Supply Chain Optimization for FMCG Products Using the Transportation Method

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I. INTRODUCTION

1.1 Operations Research

Operations Research (OR) applies mathematical modelling and analytical methods to support decisions about how complex systems should be run. A typical study translates a management problem into decision variables, an objective to be minimised or maximised, and constraints reflecting the system's limits, then solves the model with exact or heuristic techniques (Hillier & Lieberman, 2021; Taha, 2017). Linear programming (LP), in which both the objective and the constraints are linear, is the most widely used technique, and special-structure cases such as transportation and assignment problems have dedicated algorithms of their own.

1.2 What is the importance of distribution in FMCG supply chains?

Fast-moving consumer goods (FMCG), also called consumer packaged goods (CPG), are inexpensive, high-turnover items such as packaged food, beverages, bakery products, snacks, soap, detergent and other household supplies. They pass quickly through dense networks of distributors and retail outlets. Because each unit earns so little, every item still has to travel the whole chain, from factory to distributor to shop, before it reaches the buyer. Since transportation is such a significant cost driver in the high-volume, low-margin FMCG supply chain (Chopra & Meindl, 2016), transportation costs can be as high as 55% of overall supply chain costs (John & Kanniga, 2025). As many FMCG products are often perishable, such as bakery goods, they require well planned, on-time delivery to prevent waste.

In reality, for small and medium enterprises and district level distributors, shipment planing from habit and experience exist. As a result, there are part load trips, sub-optimal routes and unbalanced utilization of warehouses (John & Kanniga, 2025; Rani et al., 2025). OR provides a systematic approach: the transportation problem.

1.3 Problem type: the transportation problem

The transportation problem, formulated by Hitchcock (1941) and developed by Koopmans (1949), involves m sources (plants, warehouses or vehicles) holding one homogeneous product and n destinations (distributors, branches or shops) with known requirements. The task is to decide how much each source ships to each destination so that every requirement is met, no source exceeds its availability, and total shipping cost is as low as possible. This is a special case of LP whose constraint matrix has a network structure (Dantzig, 1951; Charnes and Cooper, 1954), and which can therefore be solved by simple simplex based procedures. It maps easily onto an FMCG distribution network where a few supply points serve many demand points at certain known unit freight costs.

1.4 Selected research articles

Five published studies applying the transportation approach to real FMCG/food distribution problems have been selected: one conference proceeding and four journal articles. Paper A is the main study, as it is a multi-outlet retail FMCG network; Papers B and C are SME case-studies on two typical food categories (bakery and pre-packed snack foods) and the two comparisons refer to different scales. Paper E is the largest model (three agents, ten shops), and is the distribution section of a large packaged-food company. Paper D concerns a perishable food (raw fish), which is sold to processing factories rather than the consumer (goods FMCG) market, and therefore it is FMCG-adjacent, rather than on the user side, but it is included, as it employs the North West Corner and MODI methods on a high-volume food network and, like Paper E, compares the optimal with the cost of the company's current schedule.

	Paper A	Paper B	Paper C	Paper D	Paper E
Citation	John & Kanniga (2025)	Rani et al. (2025)	Nurhidayati et al. (2021)	Ahyaningsih et al. (2023)	Farhan & Rakhmawati (2024)
Journal	Advances in Consumer Research, 2(6)	Akrab Juara: Journal of Social Sciences, 10(4)	Studi Ilmu Manajemen dan Organisasi, 2(2)	Proceedings of the 9th AISTSSE (Sciendo)	Journal of Computer Networks, Architecture and High-Performance Computing, 6(4)
Country / region	Thoothukudi District, Tamil Nadu, India	Tangerang, Indonesia	South Jakarta, Indonesia	Sibolga, North Sumatra, Indonesia	Medan, North Sumatra, Indonesia
FMCG category	Food, household items and essentials (retail)	White and sweet bread (bakery)	Packaged macaroni snacks (90 g and 133 g)	Raw fish (skipjack, yellowfin, sare) for processing factories	Packaged food products (Indofood group)
Problem size	3 warehouses × 6 retail towns (+ dummy)	3 vehicle fleets × 3 branches	2 factories × 3 distributors (two products)	3 fishing ports × 4 cities	3 agents × 10 shops
Methods	NWC, LCM, VAM; Stepping Stone, MODI	NWC, LCM, VAM; Stepping Stone	LCM, VAM; Stepping Stone, MODI	NWC; MODI	LCM; MODI

Table 1. Overview of the selected papers

Note: Papers B and C were originally published in Indonesian; this report uses their English translations. Papers D and E were published in English. Abbreviations: NWC (North West Corner), LCM (Least Cost Method), VAM (Vogel's Approximation Method) and MODI (Modified Distribution).

II. THE TRANSPORTATION PROBLEM: GENERAL FORMULATION

The same model is used in all five papers, and is stated once, then specialized.

2.1 Notation

Index i = 1, m denotes the origins (warehouses, factories or vehicles) and j = 1, in the destinations (retail towns, branches or distributors).

Parameters: cij is the cost of shipping one unit from origin i to destination j; ai is the availability (capacity) of origin i; bj is the requirement of destination j.

Decision variable: xij is the quantity shipped from origin i to destination j.

2.2 Objective function and constraints

Minimize Z = i=1m j=1n cij xij

subject to J xij ai for each source i (supply constraints)

I xij = bj for all j (demand constraints)

xij 0 for all i, j (non-negativity)

A problem is balanced when total supply equals total demand, so every supply constraint binds. If supply falls short of demand, a zero-cost dummy origin absorbs the gap; if supply is larger, a dummy destination is added instead. Quantities assigned to a dummy are unmet demand or unused stock, not real shipments. A basic feasible solution of a balanced problem has m + n − 1 allocated cells, and fewer than that is degenerate (Taha, 2017).

2.3 Standard assumptions

One uniformed product (or each product in terms of maintaining separately).

Unit shipping cost does not vary so total cost on a route is linear in total quantity shipped, it does not have a fixed trip cost nor quantity discounts.

The supply, demand and costs are only known at some certainty for one planning period.

All routes are route-available and have no capacity constraint other than supply and demand.

2.4 Solution method

The method runs in two phases. A constructive rule first builds an initial basic feasible solution, which is then tested for optimality and improved if necessary.

Method	Phase	How it works	Typical quality
North West Corner (NWC)	Initial	Fills cells from the top-left corner, moving right or down, ignoring cost.	Fast but usually far from optimal

Least Cost (LCM)	Initial	Repeatedly allocates as much as possible to the cheapest remaining cell.	Better than NWC, but greedy
Vogel's Approximation (VAM)	Initial	For every row and column, takes the gap between its two smallest costs, then allocates within the line showing the largest gap.	Often optimal or very close (Reinfeld & Vogel, 1958)
Stepping Stone	Optimality	For each empty cell, traces a closed +/− loop through occupied cells and computes the net change in cost.	Exact test; all indices ≥ 0 means optimal
MODI (u-v method)	Optimality	Solves $u_i + v_j = c_{ij}$ over the allocated cells, then evaluates $d_{ij} = c_{ij} - u_i - v_j$ for each empty cell.	Exact test; faster than Stepping Stone for large tables

Table 2. Solution methods used in the reviewed papers
Source: John & Kanniga (2025); full details are in the References.

If any improvement index is negative, units are shifted around the corresponding loop and the test is repeated. When all indices are non-negative, no reallocation can reduce cost and the solution is optimal (Charnes & Cooper, 1954; Hillier & Lieberman, 2021).

III. PAPER A: RETAIL FMCG DISTRIBUTION IN THOOTHUKUDI DISTRICT

Source: John & Kanniga (2025); full details are in the References.

3.1 Real-world problem and domain

This paper is about the retail supply chain of food and other FMCG and household items in Thoothukudi District, Tamil Nadu. It has a number of small and medium-sized retailers, distributed over a number of taluks in an urban and a rural setting. The authors note that the routes and shipment sizes are determined purely out of habits and not data or analysis, with resulting high fuel consumption, excessive number of shipment rounds, portions of movement as partial truckloads, transportation bottlenecks in the form of crowded warehouses and improper utilization of storage space. Their question is whether this transport cost can be reduced by using a LP to make a plan for transport.

Why OR: There are few supply points (warehouse at Thoothukudi, Kovilpatti, and Ettayapuram), many demand points (six retail towns), known unit costs for each route and a constant capacity for each production warehouse and demand town. This is just what a transportation problem entails, and the authors also assume demand exceeds supply – covered by a dummy source!

3.2 Model formulation

The warehouses are W1 (Thoothukudi), W2 (Kovilpatti) and W3 (Ettayapuram). The retail destinations are D1 Thoothukudi City, D2 Tiruchendur, D3 Kovilpatti, D4 Ottapidaram, D5 Vilathikulam and D6 Srivaikuntam. Xij is the number of units to be transported from warehouse i to destination j. The goal is to use minimum transport cost.

From \ To	D1	D2	D3	D4	D5	D6	Supply
W1 Thoothukudi	5.96	9.32	12.80	10.04	11.96	7.64	1,200
W2 Kovilpatti	13.16	16.76	5.72	8.36	10.28	11.48	900
W3 Ettayapuram	11.96	15.08	7.64	7.16	8.60	9.32	700
W4 Dummy	0	0	0	0	0	0	180
Demand	900	420	650	320	280	410	2,980

Table 3. Paper A: transport cost per unit (₹), warehouse capacity and town demand

Warehouses can supply 2,800 units against a demand of 2,980, so the problem is unbalanced. A zero-cost dummy warehouse W4 holding the missing 180 units restores the balance. The model thus has 4 6 = 24 variables, four supply constraints (j xij ai), six demand constraints (i xij bj) and non-negativity. The authors assume linear transport costs between each origin and destination pair, a single product, and data assumed to be deterministic collected from the survey of volumes, distances, vehicle capacities, cost per kilometre or load.

3.3 Solution approach

Initial solutions were obtained with NWC, LCM and VAM using the manual transportation tableaux. The

best initial solution (VAM) was then tested with the Stepping Stone and with MODI. The VAM plan uses 9 allocated cells, which matches m + n − 1 = 4 + 6 − 1, so it is not degenerate.

MODI potentials were calculated assuming u3 = 0 (for example u1= 1.68, v2= 11, v3= 4.52) and all net evaluations for empty cells indicated no further improvement possible.

No software package was mentioned.

3.4 Results

Method	Total cost (₹)	Above optimum
North West Corner	20,888.00	+4.2%
Least Cost	22,191.20	+10.7%
Vogel's Approximation	20,038.40	0% (optimal)

Table 4. Results reported in Paper A (percentages computed for this report)

Source: Rani et al. (2025); full details are in the References.

The best plan delivers W1 D1 (900), W1 D2 (240), W1 D6 (60); W2 D3 (650), W2 D4 (250); W3 D4 (70), W3 D5 (280), W3 D6 (350). The 180 dummy units are supplied to Tiruchendur (D2), the costliest destination, which only partially consumes its demand. The authors observe that the value-added method is the best initial approach, that Tiruchendur and Kovilpatti act as the distribution centers, and that the retailers should bear the short fall with buffer stocks, flexible procurement or third-party logistics. They assert that implementation of this model in the current environment could lead to 20% to 30% savings.

IV. PAPER B: BAKERY DISTRIBUTION AT DL CAKE AND BAKERY

Source: Rani et al. (2025); full details are in the References.

4.1 Real-life problem and domain

DL Cake and Bakery, a food SME in Tangerang producing white and sweet breads. Its Ciputat branch is the warehouse and it distributes to its branches at Ceger, Cipadu and Bintaro Sector 2 by its own vehicles. Bread is a perishable product with specific time windows for delivery, so transportation is the largest operating cost, but the firm had no structured approach for determining branch delivery schedules. OR is appropriate because it is a cost minimization allocation of a set quantity of items to predetermined branch demands, and the authors would like to identify an approach that can be implemented by hand by an SME.

4.2 Model development

Sources are the three delivery fleets from Ciputat, each of which has a carrying capacity, and the three branches as destination. Data is collected through interviews with owners and direct observation.

Fleet \ Branch	Ceger	Cipadu	Bintaro Sector 2	Supply
Ciputat Fleet 1	28,000	35,000	20,000	250
Ciputat Fleet 2	35,000	40,000	24,000	200
Ciputat Fleet 3	38,000	45,000	26,000	150
Demand	150	250	200	600

Table 5. Unit shipping costs (IDR), supply and demand in Paper B

Objective is Minimize Z = 28000x11 + 35000x12 + 20000x13 + 35000x21 +... + 26000x33, under Constraints for fleet - 250 200 150..... Under Constraints for branch- 150 250 200..... Xij 0.

Total number of supply 600 and total number of demands 600 implies balanced supply and no need for dummy.

Number of variables in 3 3 model is 9 and constraints are 6.

4.3 Solution methodology and results

Manual calculations are used for obtaining initial solutions with NWC, LCM and VAM, and the NWC solution is then improved using the Stepping Stone method. The empty cells have improvement indices of +1,000 for Fleet 1 Bintaro, +2,000 for Fleet 2 Ceger, +3,000 for Fleet 3 Ceger and +3,000 for Fleet 3 Cipadu. All indices are positive indicating the NWC plan is optimal.

Method	Total cost (IDR)	Above optimum
North West Corner	18,800,000	0% (optimal)
Least Cost	19,650,000	+4.5%
Vogel's Approximation	18,800,000	0% (optimal)
Stepping Stone test	18,800,000	Confirmed optimal

Table 6. Results reported in Paper B

The best plan is Fleet 1 Ceger (150) and Cipadu(100); fleet 2 cipadu(150) and Bintaro(50); Fleet 3 Bintaro(150). Min cost in distribution is IDR 18,800,000 The authors state that LCM, which is based on cheap cells, resulted in a cost IDR 850,000 higher. This shows that the different initial methods will give different results on the same data.

V. PAPER C: SNACK PROVISIONING AT MARCUY SME

Source: Nurhidayati et al. (2021); full details are in the References.

5.1 Real-life problem and domain

Marcuy (Makaroni Cihuy) micro MSE of 90 g and 133 g pack multichannel producer of flavoured macaroni snack. Two production locations, Setu Babakan and Pasar Minggu (South Jakarta) provide three distributors at Depok, Pekayon and Citeureup by motorcycle. The firm did not have a shipping budget for the three routes, so it wanted to determine the minimum-cost shipping plan. OR is a good fit since the company has constrainted production at each location, bottle of demand for each distributor and the cost increases with the distance.

5.2 Model development

•Unit costs were based on the distance of Rp 500 per kilometre, with one zero removed in order to keep calculations manageable. •Two pack sizes were solved as two separate transport problems, each balanced.

Factory \ Distributor	Depok	Pekayon	Citeureup	Supply 90 g	Supply 133 g
Setu Babakan (A)	11 km / 55	10 km / 50	29 km / 145	10	40
Pasar Minggu (B)	19 km / 95	13 km / 65	31 km / 155	20	50
Demand 90 g	5	10	15	30	
Demand 133 g	20	55	15		90

Table 7. Distances, scaled cost coefficients, supply and demand in Paper C

For each product the model is Minimize $Z=\sum\sum c_{ij}x_{ij}$, subject to two supply constraints, three demand constraints and non-negativity so 6 variables per product. Both problems balanced (30=30 and 90=90).

5.3 Solution methodology and results

The original problem was solved using LCM and VAM and then the Stepping Stone method and the MODI method were used to test for optimality. MODI potentials were u1 = 0, u2 = 15, v1 = 55, v2 = 50, v3 = 140 and thus the improvement indices were 5 and 25 and since they are both positive the solution was optimal. The authors recommend the POM-QM software to use to check calculations.

Method	90 g cost (Rp)	133 g cost (Rp)
Stepping Stone	31,750	67,000
Least Cost	31,750	67,000
Vogel's Approximation	31,750	67,000
MODI	31,750	67,000

Table 8. Results reported in Paper C

The best plan for both products directs Setu Babakan's output to Depok and Pekayon, and has Pasar Minggu serve the rest of Pekayon and all of Citeureup. Because all methods agree, the authors recommend LCM for the fastest solution for SME.

XI. PAPER D: FISH DISTRIBUTION AT CV. HORIZON GROUP SIBOLGA

Source: Ahyaningsih et al. (2023); full details are in the References.

6.1 Real-world problem and domain

CV. Horizon Group, a fish trader from Sibolga (North Sumatera) which purchased raw skipjack, yellowfin tuna and sare at three fishing ports and supplied fish-processing factories, were willing to transport the fish from point to point. They used truck to move the fish, three 7-tonne Colt Diesel truck and eight 20-tonne Hino 500 truck. The authors found the distribution cost was high and the transport equipment were not efficiently utilized in serving customers under their delivery target. The study estimates how far annual distribution cost can fall when a North West Corner plan is built first and shipments are then reallocated after a MODI optimality check.
Why OR is appropriate: there are 3 supply points (Horizon, Sibolga and Aceh fishing ports), 4 destinations (Jakarta, Medan, Pekanbaru and Jambi), 1

product (kg), published costs per kg on all routes, a year's complete shipment data. Totals on both sides match, so the problem is balanced. Scope note: the buyers are processing factories, not retail shops (hence this is a perishable-food-commodity chain, not a consumer FMCG chain in the strict sense), but is included as it uses the same approach to a high-volume foodflow and, unlike Papers A to C, includes a baseline cost report.

6.2 The model development

The data are for January-December 2021. Supply is the annual stock at each port and demand is the annual quantity at each destination - from the shipping firm's records. Total supply and demand both equal 2,094,000kg, so the problem is balanced and does not require any dummy row or column.

Cost is given in rupiah per kilogram (Table 9).

There are 3×4=12 variables, three supply contraints, four demand constraints, and non-negativity. The authors write supply as and demand as, the same as equality here because the totals are the same.

From \ To	Jakarta	Medan	Jambi	Pekanbaru	Supply (kg)
Fishing Port of Horizon	600	352	336	313	1,148,000
Archipelago Fishing Port, Sibolga	730	329	343	343	278,000
Fishing Port of Aceh	655	353	360	306	668,000
Demand (kg)	868,000	559,000	251,000	416,000	2,094,000

Table 9. Unit cost matrix (Rp per kg), supply and demand in Paper D

6.3 Solution method and results

The North West Corner plan is Horizon 868 000 to Jakarta 280 000 to Medan; Sibolga 278 000 to Medan; Aceh 1000 to Medan 251 000 to Jambi 416 000 to Pekanbaru. This plan has 6 occupied cells the same as m n 1 3 4 1 so it is non-degenerate and it costs Rp 928 831 000. MODI potentials computed from u 0 for Horizon are u 0 23 1 and v 600 352 359 305.

The authors define the index of an empty cell as I u v c so positive indicates an improvement (the opposite sign to the d c u v convention used in this report).

Only the Horizon Jambi cell is positive 23 Rp per kg. Shifting 251 000 around the loop Horizon Jambi 4 positive horizon 600 negative aceh 0 negative aceh 0 positive horizon 4 lowers the cost by 23 251 000 Rp 5 773 000. In the new plan every index is negative 8 153 30 61 54 23 so it is optimal.

Plan	Total cost (Rp)	Above optimum
Company's annual cost (reported baseline)	963,000,000	+4.3%
North West Corner (initial solution)	928,831,000	+0.6%
MODI (optimal solution)	923,058,000	0% (optimal)

Table 10. Results reported in Paper D (percentages computed for this report)

The best plan: Horizon Jakarta (868,000 kg), Medan (29,000 kg) and Jambi (251,000 kg); Sibolga Medan (278,000 kg); Aceh Medan (252,000 kg) and Pekanbaru (416,000 kg). All authors say the plan saves Rp 39,942,000 a year: 4.15% of Rp 963,000,000 (they round this down to 4.14%). They don't say how they got their baseline. But if they want to know this, they need to look no further than by taking the shipment numbers in the shipment table and multiplying each number by the unit prices in the table, they will get the overall cost of Rp 963,103,000, which is the firm's actual shipping pattern in 2021, Rounded.

VII. PAPER E: DISTRIBUTION OF FOOD PRODUCTS IN PT INDOMARCO ADI PRIMA, MEDAN

Source: Farhan & Rakhmawati (2024); full details are in the References.

7.1 Real-world problem and domain

PT Indomarco Adi Prima is the distribution company of Indofood Sukses Makmur, a large Indonesian supplier of packaged food products. Its Medan branch distributes mixed packaged food items to ten partners shops through three agents (CV. Makmur, PT. Atmajaya Berkah and PT. Mega Perkasa). The authors found that transport cost is a recurring problem and, prior to the study, each agent delivered to all ten shops without any apparent structure. We use December 2023 data and ask: How far could the monthly

transport bill be shrunk without compromising the mix of food products in each shop?

Why OR is appropriate: this is the most common FMCG situation across the five papers: few stocking points, many small customers, known cost per carton for every route and a fixed monthly demand. It is also the largest model (3 10) so hand calculation is more challenging and there is more scope for the optimality test to find an improvement.

7.2 Model development

The agents have 1750,1735 and 1125 cartons (4,610 total) and the ten shops order 475,430,550,465,470,495,430,345,410 and 540 cartons (4,610 again) - it is equal. The unit costs, ranging from Rp 11,000 to Rp 17,000 per carton, are for fuel, vehicles, tolls and other delivery. The model consists of 3 10 = 30 variables, three supply constraints, ten demand constraints and the non-negativity. (As in Paper D, supply is written as and demand as, which is equivalent to equality here).

From \ To	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Supply
CV. Makmur (S1)	13	11	12	11	15	12	11	14	14	13	1,750
PT. Atmajaya Berkah (S2)	12	13	14	14	11	15	14	15	15	11	1,735
PT. Mega Perkasa (S3)	16	14	15	14	17	15	14	16	11	15	1,125
Demand	475	430	550	465	470	495	430	345	410	540	4,610

Table 11. Unit cost matrix (Rp thousand per carton), supply and demand in Paper E (shops T1 to T10)

7.3 Solution methodology and results

The initial plan is devised by using the Least Cost method and uses 12 allocated cells, which equals m + n − 1 = 3 + 10 − 1, so the plan is not degenerate. It costs IDR 55,690,000, and MODI is then applied.

2 The improvement indices are not printed in the paper, but the potentials in the last table (u = 0, 2, 3 and v = 10, 11, 12, 11, 9, 12, 11, 13, 8, 9, in thousand rupiah) satisfy u + v = c on all occupied cells of the final plan.

Redoing the calculations for the initial plan indicates the improvement move used by the authors (index 1 per carton): Atmajaya Berkah transfers its 125 cartons to shop T8 instead of T6 (cost 15), enabling Mega Perkasa to transfer an additional 125 cartons to T6 instead of T8 (cost 16). This reduces the total cost by Rp 125,000 for a total cost of Rp 55,565,000. In the final plan, all indices are zero or positive, so the solution is optimal.

Plan	Total cost (IDR)	Above optimum
Pre-optimization shipping pattern	61,510,000	+10.7%
Least Cost (initial solution)	55,690,000	+0.2%
MODI (optimal solution)	55,565,000	0% (optimal)

Table 12. Results reported in Paper E (percentages computed for this report)

The best plan would have CV. Makmur supplying T2, T3, T4 and T7, PT. Atmajaya Berkah supplying T1, T3, T5, T8 and T10 and PT.

Mega Perkasa supplying T6, T8 and T9.

Shops T3 and T8 each then have two agents supply them. There is thus a saving of IDR 5,945,000 from the previous cost of IDR 61,510,000. The paper does not state explicitly what the previous pattern of shipment was but the previous cost is obtained by multiplying the "offerings" table, where each agent supplies all the shops and the costs table (each agent for each shop), and given the same 15 stores, by each other and calculating the sum of the resulting matrix as shown in the previous cost. The saving is therefore 9.7% of this baseline.

VIII. COMPARATIVE SYNTHESIS OF THE FIVE STUDIES

Feature	Paper A (Retail FMCG)	Paper B (Bakery)	Paper C (Snacks)	Paper D (Fish)	Paper E (Packaged food)
Size (m × n)	3 × 6 (+ dummy)	3 × 3	2 × 3 (× 2 products)	3 × 4	3 × 10

Balanced?	No: supply 2,800 < demand 2,980	Yes: 600 = 600	Yes: 30 = 30; 90 = 90	Yes: 2,094,000 = 2,094,000	Yes: 4,610 = 4,610
NWC result	₹20,888.00 (+4.2%)	IDR 18.80 m (optimal)	Not reported	Rp 928.83 m (+0.6%)	Not used
LCM result	₹22,191.20 (+10.7%)	IDR 19.65 m (+4.5%)	Optimal	Not used	IDR 55.69 m (+0.2%)
VAM result	₹20,038.40 (optimal)	IDR 18.80 m (optimal)	Optimal	Not used	Not used
Optimality test	Stepping Stone + MODI	Stepping Stone	Stepping Stone + MODI	MODI	MODI
Software	None reported	None reported	POM-QM suggested	None reported	None reported
Baseline comparison	None (claims 20–30%)	None	None	Rp 963.0 m → Rp 923.06 m (−4.15%)	IDR 61.51 m → IDR 55.565 m (−9.7%)

Table 13. Side-by-side comparison of the reviewed studies

Several patterns emerge from the comparison:

VAM was optimal in all instances in which it was applied. This corroborates textbook theory that the penalty logic of VAM which accounts for the cost of not taking the cheapest route normally produces an optimal or near optimal start (Taha, 2017). D and E did not attempt to calculate VAM so their results are inconclusive.

LCM is not always significantly better than NWC LCM was the worst of the bunch in both of our papers. Picking the single cheapest cell into C can lead to greatly increased costs on expensive allocations down the line. For Paper A this was compounded by the way ties were broken: with all dummy cells at zero, the authors first filled in the dummy cell in D1. Recomputing LCM with the dummy row filled in last, as per convention, yields 21,142.40 (which is better than the paper's 22,191.20, but still 5.5% above optimum).

Size matters thus on those microscopic 2-3 problems of Paper C they all agree; the paper's practical recommendation of LCM on speed does not carry over: Papers A and B show that LCM can be anywhere from 4.5% to 10.7% more expensive.

An optimality test is required. Every paper verifies optimality using either Stepping Stone or MODI. Had this second phase not been included, an LCM planner would have accepted a plan, which we have seen is not necessarily cheapest.

The initial plan sets the search step for the optimality test. In Paper D the cost-blind NWC plan was only 0.6% better than the optimum and in Paper E the LCM plan was only 0.2% better than the optimum, and in both cases one iteration of MODI was enough. This supports the point made in the literature review of Paper E that MODI needs an initial plan close to the optimum. NWC is not a close initial plan (4.2% worse than optimal in Paper A) but the result in Paper D is due to its particular cost matrix, not necessarily NWC. Savings require a baseline and must be divided into phases. Some Papers only compare the optimal plan to the extent of the firm's actual cost 4.15% in Paper D and 9.7% in Paper E. Nearly all this saving is from the first plan 86% in Paper D, 98% in Paper E with the optimality test themselves contributing 0.6% and 0.2% of the baseline savings respectively. Paper E also reports its savings with some inconsistency (9.7% in one paragraph, 10.7% in another).

To verify the numbers, all six models (the two Papers C products are treated separately) were re-solved as linear programs in Python (SciPy) using the HiGHS solver. It produced exactly the reported optimal costs, 20,038.40, IDR 18,800,000, Rp 31,750, Rp 67,000, Rp 923,058,000 and IDR 55,565,000, and the same allocations for all papers except E in which the solver produced a different (though just as cheap) plan, because there are multiple optima in that problem. The baselines of Papers D and E were reproduced from the papers' tables (see Appendix).

IX. CRITICAL ANALYSIS

9.1 The models' capabilities

Easy fit between problem and model. For each of the five cases the business problem (fixed supply points, known demand, per-unit route cost) is a natural transportation problem - this makes it simple to illustrate the model to managers.

Cheap for SMEs. The tableau approaches only require a spreadsheet or a pen and paper, which may be

important for firms such as DL Cake and Marcuy who would not normally purchase optimization software.
Comparison of several heuristics. Since the papers take the time to calculate NWC, LCM and VAM on the same data, students and practitioners can see quite concretely why the initial choice of method is important.
Two-stage rigour. Rather than relying on a heuristic, all papers establish optimality and anyone can reproduce the same results by independently solving each LP.
Dealing with imbalance (Paper A). The dummy source demonstrates how actual shortages can be simulated, and the authors translate the simulation into concrete recommendations on buffer stocks and flexible sourcing.
Reproducible baselines (Papers D and E). In contrast with Papers A-C, both these papers compare the optimized plan with the firm's real shipping cost, both baselines can be reconstructed from the papers' tables (Rp 963,103,000 in comparison with the reported Rp 963,000,000 in Paper D; exactly Rp 61,510,000 for Paper E). A tangible and defensible savings.

9.2 Limitations and assumptions
Paper A (Thoothukudi).
The paper considers a three-level network (SIPCOT, Ettayapuram and Madurai as sources, three warehouses and six retail towns) but the model is just a warehouse-to-retail; nonetheless the results do depict factory-to-warehouse allocations which the model doesn't predict. That would require a transhipment model.
In the text, the written objective function is not entirely consistent with the cost table: x23 coefficient is 5.42 not 5.72; there is no term 8.36 of x24. While the text says "dummy cost" is infinite; it should be zero in the model.
Abstract states savings of 20% to 30%, plus handling and warehousing costs, in total. However, only transport costs are modeled, no data to compare the current cost of the company are given. The only quantifiable saving is between the heuristics (VAM costs 4.1% less than NWC).
The 180 units shortfall is entirely allocated to Tiruchendur, which gets only 240 units (57%) of its demand of 420. The model has no penalty for shortfall or any fairness constraint, so the cheapest solution puts it all in one market; in a real FMCG network this might result in empty shelves and losing customers.
Sign conventions are mixed up in the MODI discussion (it states z13 c13= 9.96 then says the values are positive) The conclusion is correct but the way of presentation is a bit confusing.

Paper B (DL Cake and Bakery).
The three "sources" are delivery fleets from one warehouse, not separate ones. Vehicle costs are mostly fixed per trip (driver, fuel for a route), so using a vehicle as a constant cost per unit is a very strong simplification. This would be better represented as a fixed-charge or vehicle routing model.
Perishability and delivery time windows are stated as the prime motivation but are not considered in the model. The current (pre-optimisation) cost is also not provided so the actual saving to the firm is not clear.
There are a couple of weak references: one source (Wahyuni & Astuti, 2025) is referenced for saving shipping cost in distribution, yet it is about repurchasing intentions towards handicraft. Under the data section, the word "coconut" is used for shipping without any explanation- I assume it has been stolen from a paper.

Paper C (Marcuy).
Stepping Stone and MODI are said to be "first feasible solution" methods but they are in fact optimality tests, and the NWC solution is not given.
Cost scaling is not clear: 11 km @ Rp500/km = Rp.5,5000, but the totals are given at 550x/unit. It seems costs reported are 1/10th of the actual amount.
Cost is noted as per km per motorcycle journey (1 to 90 pcs/ride) not per pc, which does not fit with the linear per unit assumption.
The same motorcycles are used for the two products but solved separately, so the same vehicle capacity is not used. There is a minor arithmetic error (stepping stone index for A Citeureup is printed as 0 but equals 5).
Such a tiny problem that all methods provide the same answer. Can only draw limited conclusions about method selection.

Paper D (CV. Horizon Group Sibolga).
The fleet isn't in the model The company has three 7-tonne and eight 20-tonne trucks, but costs are a fixed rupiah per kilogram on each route. Truck costs are

mostly per trip, and so a half-empty truck costs the same as a full one; a linear model can't tell if the optimal schedule is hitting the fleet or calling in extra trucks.

Annual totals mask timing. Both demand and supply are annual totals, so the plan doesn't take into account seasonal fishing patterns, the monthly fluctuations in demand and the short shelf life of fresh fish. "Demand" is just the amount shipped in 2021 – it's not a forecast.

All but a quarter of this saving is achieved before the optimization step. The cost-blind NWC plan achieves saving of Rp 34.2 million above the baseline, accounting for 86% of the reported Rp 39.9 million saving, the additional savings from MODI is Rp 5.77 million (0.6% of the baseline). This suggests that the poor pattern of the firm's 2021 schedule is driven by a handful of expensive routes (e.g., some of Jakarta's demand was served from Sibolga at Rp 730 per kg and Aceh at Rp 655 per kg, Horizon costs Rp 600 per kg) not that the MODI step is generating most of the savings.

Small errors and omissions. The demand constraints are indexed by i not j, the percentage is truncated (4.14% not 4.15%), and there is no attempt to compare to other starting methods (LCM, VAM) or any sensitivity analysis.

Paper E (PT Indomarco Adi Prima).

The saving is stated inconsistently. The abstract and conclusion say IDR 5,945,000 "or around 10.7%", but the results section says 9.7%. The paper's own numbers imply saving is 5,945,000 61,510,000 9.7%; the 10.7% figure is 5,945,000 55,565,000, the saving as a share of the optimized cost.

The Least Cost result is reported in an inconsistent manner. One paragraph states the Least Cost result provides IDR 61,510,000 and the subsequent paragraph states IDR 55,690,000. The first value is the cost before the optimization process has been applied, and the abstract compares 61.51 million with the MODI result in a nonsensical manner where it appears the initial-solution step has never been performed.

MODI claims the savings that it has not generated. The Least Cost plan reduces the baseline by IDR 5,820,000 (98 % of total saving); MODI reduced it an additional IDR 125,000 (0.2% of the baseline). The discussion ascribes all of the savings to MODI.

The description in the method section does not correspond with the solution. While RAM (Russell's Approximation Method) and a "highest cost" step are used in the method section no such calculation is shown and the MODI improvement indices are not shown so the optimality of the solution cannot be confirmed without recomputation (yet the potentials given in the final table are correct).

A minor mistake and an unspecified tie the final table shows 497 cartons of Mega Perkasa T6 (495 in the cost calculation, and needed for the supply total of 1,125); the third row of the model table is given as X21 to X2,10 instead of X31 to X3,10; and the text says 2020 rather than 2023. Six cells are empty and have a zero index, and therefore the optimal plan is not unique (this is omitted in the paper).

Limited range of costs; simple cost structure. Cost per carton is between Rp 11,000 and Rp 17,000, fixed per route, so model can only improve by moving cartons between routes, do not model vehicle loads, delivery frequency or service levels, and it is limited to a single month.

All five share. Models are single period and deterministic, taking no account of demand variation normally seen in FMCG. There is a single homogeneous product (Paper E combines a number of different finished paper products into cartons), unlimited capacity and fixed unit cost. Sensitivity analysis (eg regarding fuel costs, which can be readily provided by an LP solver) is not undertaken by any.

9.3 Possibilities for extension and improvement

Transhipment model: for Paper A, connect the factories, warehouses and retail locations in a single model that allows warehouse throughput and factory allocation to be optimised simultaneously.

Shortage costs & service levels: insert a cost per unit of shortfall instead of the dummy to alleviate shortfalls at no cost, or specify a minimum fill rate per outlet.

Vehicle capacity and fixed trip costs: consider using a capacitated or fixed-charge transportation model, or vehicle routing problem, which is a better match for fleets and motorcycles that make multiple outlet visits each trip. Paper D's mixed fleet of 7 tonne and 20 tonne trucks is an obvious example.

Multiple Products and Perishability: model multiple SKUs within the vehicle capacity and include shelf-life or time-window restrictions for bakery. For Paper D, with fresh fish, it also includes cold-chain and delivery-time constraints

Uncertainty: apply stochastic or robust optimization, or scenario analysis, to manage demand variations, festival peaks and fuel costs.
Software and sensitivity analysis: solved with Excel Solver, LINGO, POM-QM or Python and spell out shadow prices and cost ranges so managers can see how robust is the plan.
Estimated impact: benchmark your optimized plan against the direct routing cost incurred today in the company, in order to obtain a realistic number of savings. That is done in Papers D and E; results should be broken down by contributions of the initial solution and optimality step, saving formula should be consistent.

X. CONCLUSION

This report studies five published papers that have applied the transportation method to the distribution of food and FMCGs: a district retail network in India, an Indonesian bakery, an Indonesian snack producer, a fish trader, and the Medan distribution subsidiary of a large packaged-food manufacturer. In each case, the sample true problem (transporting from many sources to many destinations at lowest cost) was correctly identified as a linear transportation problem with supply, demand and non-negativity constraints; was correctly formulated in terms of the transportation coefficients as a linear programming model; was solved with NWC, LCM, VAM and/or comparable and/or optimized with Stepping Stone and/or MODI; and the solution verified by an independent LP. The transportation costs were 20,038.40 for the Thoothukudi network, IDR 18,800,000 for DL Cake and Bakery, Rp 31,750 and Rp 67,000 for Marcuy's two products, Rp 923,058,000 for CV. Horizon Group and IDR 55,565,000 for PT Indomarco Adi Prima. In all the studies found, Vogel's had selected the best plan in its usage (Papers A-C), and the LCM was 10.7% worse. Starting from NWC and LCM gave the best result in Papers D and E of within 0.6% and 0.2%, each with a single MODI iteration. This indicates that starting method selection is relevant, and also that a test for optimality should follow; however, the test makes little difference to the saving, so in the studies using a baseline already, about 86% (P D) and 98% (P E) of the saving over current practice in the firm was already achieved by the initial plan. The papers show that simple OR techniques can be used to organize and save in food and FMCG distribution, especially for small businesses. The shortcomings of the studies are the assumptions of simple linear costs per item, for a single period and deterministic demand, also lack of consideration of fleet size, vehicle capacity and shelf-life constraints, and some variation in figures reported (e.g. In P E the saving is given as 9.7% and 10.7%, but with their data the saving is only 9.7%). Extending to transhipment networks, fleet sizes, demand variability and constraint, and penalty costs for shortage would make them viable, more realistic FMCG supply chain planning and management tools.

APPENDIX: VERIFICATION OF RESULTS

Each model was re-solved as a linear program with SciPy's linprog (HiGHS method). The function below takes a cost matrix with supply and demand vectors, sets up the supply (≤) and demand (=) constraints, and returns the minimum cost together with the allocation that achieves it.

```
import numpy as np
from scipy.optimize import linprog

def solve (C, supply, demand):
C = np.array(C, float); m, n = C.shape
A_ub = [np.eye(m)[i]. repeat(n) for i in range(m)]      # supply rows
A_eq = [np.tile(np.eye(n)[j], m) for j in range(n)]      # demand columns
res = linprog(C.ravel(), A_ub=A_ub, b_ub=supply,
A_eq=A_eq, b_eq=demand, method='highs')
return res.fun, res.x.reshape(m, n)

# Paper B: solve([[28,35,20],[35,40,24],[38,45,26]], [250,200,150], [150,250,200])
# Paper D: solve([[600,352,336,313],[730,329,343,343],[655,353,360,306]],
```

```
#              [1148000,278000,668000], [868000,559000,251000,416000])
# Paper E: solve(1000 * np.array([[13,11,12,11,15,12,11,14,14,13],
#                                 [12,13,14,14,11,15,14,15,15,11],
#                                 [16,14,15,14,17,15,14,16,11,15]]),
#              [1750,1735,1125], [475,430,550,465,470,495,430,345,410,540])
```

Model	Reported optimum	LP solver optimum	Match
Paper A (Thoothukudi, with dummy)	₹20,038.40	₹20,038.40	Yes
Paper B (DL Cake and Bakery)	IDR 18,800,000	IDR 18,800,000	Yes
Paper C, 90 g	Rp 31,750	Rp 31,750	Yes
Paper C, 133 g	Rp 67,000	Rp 67,000	Yes
Paper D (CV. Horizon Group)	Rp 923,058,000	Rp 923,058,000	Yes
Paper E (PT Indomarco Adi Prima)	IDR 55,565,000	IDR 55,565,000	Yes (cost; plan differs)

Table 14. Independent verification of the optimal solutions

The baselines and starting plans reported in Papers D and E were also recomputed directly from the data tables printed in the papers (Table 15).

Item	Reported	Recomputed	Match
Paper D: NWC starting plan	Rp 928,831,000	Rp 928,831,000	Yes
Paper D: company's annual cost	Rp 963,000,000	Rp 963,103,000	Yes (rounded)
Paper E: pre-optimization cost	IDR 61,510,000	IDR 61,510,000	Yes
Paper E: Least Cost plan	IDR 55,690,000	IDR 55,690,000	Yes
Paper E: saving vs. baseline	9.7% and 10.7%	9.7%	9.7% only

Table 15. Recomputation of baselines and starting solutions in Papers D and E

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