

## **Improving Delivery Eco-Efficiency Through Multi-Drop Route Optimization to Reduce the Delivery Budget Ratio and Carbon Emissions: A Study at a Confectionery Manufacturing Company**

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| <b>Keywords:</b>                                                                                   | <b>Abstract</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
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| eco-efficiency; multi-drop routing; multimodal logistics; Delivery Budget Ratio; Scope 3 emissions | <p>Rising transportation costs and increasing pressure to reduce Scope 3 emissions require FMCG manufacturers to improve distribution eco-efficiency without compromising service performance. This study aimed to redesign multimodal road and sea distribution through multi-drop consolidation, heterogeneous fleet selection, and LCL–FCL evaluation to control the Delivery Budget Ratio (DBR) while reducing transportation-related emissions. A mixed-methods, applied research design was used, combining qualitative operational assessment with quantitative route and cost simulation. Data comprised 3,285 valid shipment records from January–June 2026, 3PL tariffs, destination access constraints, interviews, and GIS-based distance data. Candidate clusters were evaluated using capacity, access, service, cost, and GO/NO-GO criteria, while emissions were estimated using a distance-based activity approach. The simulation consolidated 852 shipments into 301 multi-drop routes, reducing estimated shipments from 2,843 to 2,292. Delivery cost decreased from IDR 14.793 billion to IDR 14.218 billion, generating savings of IDR 574.772 million (3.89%), while DBR improved from 4.84% to 4.65%. Estimated emissions fell from 126.16 to 82.93 tCO<sub>2</sub>e, a 34.27% reduction. Of 301 clusters, 148 generated savings, 147 were cost-neutral, and six increased costs, confirming need for selective implementation. The findings indicate that selective multi-drop consolidation improves distribution eco-efficiency, although complementary measures remain necessary to achieve the 4.50% DBR target.</p> |

### **INTRODUCTION**

The Fast-Moving Consumer Goods (FMCG) industry is generally resilient because it is supported by daily consumption needs. However, supply chain (Chopra, 2022) costs remain sensitive to inflation, energy cost volatility (fuel and transportation tariffs), and rising ancillary costs such as toll fees, fleet maintenance, and port charges. These conditions place logistics (Christopher, 2022) efficiency as a key factor in preserving margins, particularly for low-margin, high-volume business models such as confectionery and biscuits. Within a limited margin structure, any increase in distribution cost that is not offset by fleet productivity will directly raise the Delivery Budget Ratio (DBR)(de Bok et al., 2022; Koderia et al., 2025; Shan & Ahmad, 2025).

On the regulatory side, FMCG manufacturers must observe food-safety distribution requirements, traceability, and vehicle dimension/load compliance. In addition, the Environmental, Social, and Governance (ESG) agenda increasingly requires multinational

companies to measure and reduce supply chain (Pujawan & Mahendrawathi, 2024) emissions in line with Sustainable (Siems et al., 2023) Development Goal (SDG) 13, including vendor transportation emissions (Scope 3). Initiatives to reduce separate shipments, consolidate multi-drop routes, and select more economical transport modes are therefore relevant not only for cost control but also for supporting the parent entity's Net Zero (Zero, 2025) target (Teece, 2025).

Based on internal transportation tariff benchmarking, all distribution regions show an upward cost trend in 2026, with average increases of approximately 5% for Java, 6% for Sumatra, 7% for Kalimantan and Sulawesi, and 8% for Bali–Nusa Tenggara (Table 1). Cost pressure affects both road fleets (box trucks, medium trucks, and wing-box trucks) and sea shipments through FCL and LCL schemes. Because every shipment incurs a minimum tariff based on the vehicle type or mode used, an increase in the number of separate shipments directly raises cumulative delivery costs. Consolidating nearby destinations into multi-drop routes, selecting vehicles that match total volume and site access, and converting LCL into FCL at economical volume points therefore become important levers for controlling the DBR.

**Table 1.** Average Freight Tariff Increase by Region and Mode, 2025–2026 (%)

| Region             | Box Truck | Long Box Truck | Medium Truck | Wing-Box | FCL 20ft | FCL 40ft | LCL/CBM | Regional Average |
|--------------------|-----------|----------------|--------------|----------|----------|----------|---------|------------------|
| Java               | 5.26      | 4.76           | 5.11         | 4.94     | 5.14     | 4.91     | 4.65    | 4.97             |
| Sumatra            | 6.06      | 5.92           | 5.91         | 6.09     | 6.25     | 5.95     | 6.06    | 6.03             |
| Kalimantan         | 7.14      | 7.06           | 7.07         | 7.03     | 6.80     | 7.05     | 7.59    | 7.11             |
| Sulawesi           | 6.95      | 6.90           | 6.95         | 7.04     | 6.91     | 6.90     | 7.14    | 6.97             |
| Bali–Nusa Tenggara | 7.88      | 8.11           | 7.97         | 8.00     | 7.86     | 8.04     | 8.25    | 8.01             |

Source: PT XYZ internal data, April 2026

PT XYZ distributes finished goods from its main facility in West Java to more than 100 business-to-business distributor points serving Modern Trade and General Trade channels, relying on third-party logistics (3PL) vendors for heterogeneous road fleets and inter-island sea shipments. Because of this dependence, the delivery cost structure is heavily influenced by route design, consolidation policy, and vendor tariff schemes (LTL/FTL for road and LCL/FCL for sea).

Masked internal data show that the 2025 DBR was recorded at 4.38% (delivery cost of approximately IDR 22.4 billion against sales of approximately IDR 512 billion). To reach the 2026 sales target of approximately IDR 716.8 billion, the business-as-usual (BAU) projection indicates the DBR could rise to 4.96% (cost of approximately IDR 35.52 billion), while management (Kotler et al., 2022) has set a maximum 2026 DBR of 4.50% (budget ceiling of approximately IDR 32.256 billion). This leaves a gap of 0.46 percentage points, or an opportunity cost of approximately IDR 3.264 billion that must be closed.

Previous research available through major scholarly databases such as Google Scholar and Scopus provides a strong theoretical foundation for addressing these problems, particularly

through vehicle-routing and heterogeneous-fleet optimization. (Asghari & Mirzapour Al-e-hashem, 2021) and Mirzapour Al-e-hashem (2021) reviewed the development of the Green (Rastegardebidi & Su, 2025) Vehicle Routing Problem and demonstrated how conventional vehicle-routing objectives have progressively been expanded beyond economic optimization to incorporate environmental considerations, including different vehicle technologies and operational configurations. (Batsyn et al., 2021) examined vehicle assignment within site-dependent vehicle-routing problems involving heterogeneous fleets and demonstrated the importance of considering differences in vehicle capacities, fixed and travel costs, and customer-specific restrictions on which vehicles can physically serve particular locations. Similarly, (Huerta-Muñoz et al., 2022) developed mathematical formulations and solution approaches for a heterogeneous flexible periodic vehicle-routing problem, reinforcing the importance of simultaneously considering route scheduling and heterogeneous vehicle characteristics. These studies establish that route efficiency depends not only on minimizing distance but also on aligning vehicle characteristics, customer accessibility, capacity, scheduling, and operating costs.

A second stream of research emphasizes shipment consolidation and multimodal freight decisions. (Bertazzi et al., 2021), Moezi, and Maggioni (2021) examined the integration of Full Container Load (FCL) with Less than Container Load (LCL) and air-freight shipments within a vendor-managed inventory system. Their mixed-integer linear programming model demonstrated that integrating different shipment alternatives can generate significant transportation and inventory cost savings compared with evaluating the modes independently. (Bedoya-Maya et al., 2025) similarly investigated cargo consolidation in port-hinterland transportation and showed that low loading factors create a need for more transport services, increasing costs and travel time, while consolidation provides an economically relevant mechanism for improving freight utilization. From the sustainability (Nicoletti & Appolloni, 2024) perspective, Govindan (Govindan et al., 2024) et al. (2024) mapped the theoretical foundations of sustainable supply-chain research and emphasized the continuing need to connect sustainability (Shahin & Dulebenets, 2025) concepts with operational supply-chain decisions. Collectively, these studies support the argument that consolidation, vehicle selection, multimodal integration, and sustainability should be viewed as interconnected logistics decisions rather than as independent improvement initiatives.

Despite these advances, an important research gap remains when the existing literature is compared with the operational requirements of the case investigated in this study. The literature reviewed above has generated sophisticated models for green vehicle routing, heterogeneous fleets, site-dependent vehicle assignment, cargo consolidation, and FCL–LCL integration, but these research streams are generally examined through distinct problem formulations. Less attention has been directed toward an applied decision framework that simultaneously connects road multi-drop consolidation, heterogeneous vehicle-access restrictions, road–sea multimodal decisions, company-specific third-party logistics tariffs, a managerial cost-performance indicator such as DBR, and Scope 3 carbon-emission consequences within a single FMCG distribution network. This gap is particularly relevant in the present setting because the company's cost structure depends on actual 3PL tariffs and minimum shipment charges, while route feasibility depends on whether selected vehicles can physically access each distributor location. Thus, a mathematically attractive route does not necessarily constitute an

economically or operationally feasible solution, and a cost-saving solution cannot automatically be classified as eco-efficient unless its environmental consequences are also evaluated.

Addressing this gap is urgent because continued reliance on fragmented direct delivery exposes the company to cumulative transportation charges at a time when regional freight tariffs are increasing and the targeted DBR is already under pressure. The preliminary investigation provides practical evidence of the scale of the opportunity: consolidation of five separate shipments within the Makassar–Palopo–Bone and Padang–Bukittinggi clusters into two consolidated movements reduced the combined delivery cost from IDR 54,646,563 to IDR 46,912,320, representing a potential saving of IDR 7,734,243 or 14.15%. The underlying operational problem, however, cannot be solved by applying multi-drop routing indiscriminately because differences in route direction, shipment volume, vehicle capacity, destination accessibility, tariffs, delivery schedules, and service requirements may cause some consolidated routes to be economically beneficial while others are neutral or unfavorable. This creates a need for a selective decision mechanism in which each candidate consolidation is evaluated against explicit feasibility and economic criteria. Such an approach is also consistent with site-dependent vehicle-routing research, which demonstrates that heterogeneous fleet decisions must account for customer-specific vehicle restrictions rather than capacity and distance alone.

Accordingly, the novelty of this research lies in developing an applied eco-efficiency framework that integrates multi-drop route consolidation, heterogeneous fleet and destination-access constraints, road and sea transportation alternatives, LCL–FCL break-even assessment, DBR control, and Scope 3 emission estimation within the same managerial decision process. Rather than assuming that every possible consolidation should be implemented, the study incorporates a selective feasibility logic in which proposed delivery configurations must satisfy economic, capacity, access, schedule, and service requirements. The primary purpose is to redesign the company's multimodal road and sea distribution pattern through stronger load consolidation and feasible multi-drop route planning so that transportation expenditure can be controlled toward the 4.50% DBR ceiling while reducing the environmental footprint associated with vendor transportation. More specifically, the research seeks to identify and simulate candidate multi-drop road clusters according to regional proximity, shipment volume, tariffs, and vehicle-access limitations; reduce the DBR from the projected business-as-usual condition; evaluate opportunities to convert repeated LCL movements into FCL based on cumulative volume and economic break-even conditions; and estimate potential changes in Scope 3 emissions resulting from differences in trip frequency, route distance, and vehicle type.

The research is expected to provide theoretical, methodological, managerial, and environmental contributions. Theoretically, it extends the application of green and heterogeneous vehicle-routing concepts by positioning route consolidation as an eco-efficiency mechanism connecting financial performance and value-chain environmental outcomes. Methodologically, it contributes an integrated decision structure in which route clustering, fleet capacity, site accessibility, multimodal shipment alternatives, transportation cost, DBR, and emissions are evaluated using a common baseline-versus-improvement framework rather than through isolated analyses. Managerially, the research can provide PT XYZ and comparable FMCG manufacturers with a replicable basis for determining which shipments should remain direct, which destinations can be consolidated into multi-drop routes, which vehicle should

serve each cluster, and when accumulated LCL volume should be evaluated against an FCL alternative. Environmentally, the research supports more systematic assessment of third-party transportation within Scope 3 management, consistent with the (Protocol et al., 2013) treatment of transportation and distribution activities. Therefore, the principal benefit of the study is not merely the identification of lower-cost routes, but the development of a practical decision-support approach for achieving more economical, operationally feasible, and environmentally responsible distribution within a complex multimodal FMCG supply chain.

## **METHOD**

### **Research Approach and Design**

This study used a mixed-methods approach with a sequential exploratory–explanatory design. The qualitative phase was conducted first to map operational constraints and rules that are not always recorded in the system (for example, points that large vehicles cannot enter, customer-service policies, and tariff-negotiation practices). Findings from the qualitative phase were then used to parameterize the quantitative (operations-research) model and to interpret simulation results; the quantitative phase is the primary phase because the required output is the proposed route/fleet assignment together with a measurement of its cost and emission impact. Mixed-methods was chosen to (1) prevent a model that is 'optimal on paper' but infeasible in the field, through validation of access constraints and operational policy, and (2) ensure that recommendations are grounded in figures (DBR, cost, and emissions) while remaining explainable in managerial terms.

The research design is applied, problem-solving-oriented research comparing two conditions: (a) the baseline/business-as-usual (BAU) condition and (b) the proposed scenario derived from optimization simulation. The object of the study is the road and sea distribution operating system, 3PL fleet composition, distribution cost, and the Scope 3 carbon footprint across PT XYZ's supply chain network; the subjects are the Supply Chain Management team (particularly the Logistics Manager), dispatchers, and third-party logistics vendors. The study was conducted at PT XYZ's head office and factory in the MM2100 Industrial Estate, Bekasi, West Java, with data collection and simulation carried out from January to May 2026. The unit of analysis (Pujono & Imaroh, 2024) is the shipment transaction per trip, the distributor route, the type of logistics fleet (wing-box, medium truck, box truck), and sea containers. The population comprises all shipment transaction data and the list of 100-plus national distributor points for the current operating year; the sample was selected using purposive sampling, focused on road-route clusters with nearby destinations, recurring partial shipments, feasible combined volume, relatively high delivery cost, and vehicles that satisfy access constraints.

### **Data Sources and Collection Techniques**

Data were drawn from two main sources to ensure the accuracy of the mathematical simulation: secondary data (historical shipment records from the ERP system and monthly Logistics reports, 3PL tariff documents, the 100-point destination list with access constraints, and a Google Maps/GIS-based distance matrix) and primary data (semi-structured interviews and field verification of access constraints). Data-collection techniques comprised: (1) documentation/data mining, extracting raw ERP data on order history (volume, cubic measurement/CBM, and weight) as demand input for the routing simulation; (2) semi-

structured interviews with one Logistics Manager and two dispatchers, covering current consolidation rules, the rationale for choosing a box truck versus a wing-box, and experience with trucks being refused entry by distributors due to narrow roads; and (3) digital-mapping observation using spatial-mapping software (Google Maps/GIS) to observe actual routes and precisely measure the distance matrix among the 100 distributor points.

### Data Analysis Technique

Analysis followed a baseline → data cleaning → parameterization → cluster formation → decision formulation → scenario simulation → go/no-go → cost, DBR, and emission evaluation flow, so that every result reported in Section 4 can be traced back to its input data and decision rules. The raw January–June 2026 data set of 3,290 shipments was checked for duplication, missing values, period consistency, destination codes, CBM, mode, and cost attributes, yielding 3,285 valid rows used as the analysis base. Each vehicle type was then parameterized with CBM capacity, tonnage/GVW limits where available, base tariff, multi-drop/unloading cost, and access status per destination, so that the model could not select a vehicle that is cheap but unable to enter the customer site. Destinations were grouped into candidate clusters based on delivery period, region/direction of travel, and volume-combination opportunity; for sea shipments, accumulated LCL volume at the same port/corridor was compared against the FCL alternative based on cost break-even.

**Table 4.** Step-by-Step Multi-Drop Scenario Formation and Analysis Procedure

| Step | Activity                                                  | Output                              |
|------|-----------------------------------------------------------|-------------------------------------|
| 1    | Extract direct-delivery shipment data from source systems | Raw shipment data set               |
| 2    | Form clusters by region and delivery period               | Candidate destination clusters      |
| 3    | Calculate total CBM per cluster                           | Combined volume per cluster         |
| 4    | Select the appropriate vehicle type                       | Candidate fleet assignment          |
| 5    | Check capacity and access feasibility                     | Validated capacity/access status    |
| 6    | Calculate direct-delivery cost                            | Baseline cost per destination       |
| 7    | Calculate multi-drop consolidated cost                    | Scenario cost per route             |
| 8    | Apply the GO/NO-GO decision rule                          | Selective implementation decision   |
| 9    | Calculate the resulting cost and emission impact          | Aggregate cost and emission results |

*Source: authors' synthesis of the study's data-analysis procedure*

The decision model uses a cost-minimization objective function with a binary decision variable, in which a candidate route/vehicle combination is either selected (1) or not selected (0). The main constraints are that every destination remains served, volume does not exceed vehicle capacity, the vehicle satisfies access constraints, and the route does not violate the established service requirement. The mathematical structure of the model is summarized in

Table 5. Because the model was not solved with an exact solver proving global optimality, results are reported as feasible scenarios; the direct-versus-multi-drop comparison (Prasasti et al., 2026) used saving = direct cost – multi-drop cost, with a candidate route declared GO only when the saving is positive and both access and service constraints are satisfied, and NO-GO or requiring redesign otherwise. Total scenario cost was obtained by aggregating all regular and multi-drop shipments according to the GO/NO-GO decision, and the DBR was calculated as total delivery cost divided by sales/delivery value for the same period, then compared against the baseline and the 4.50% maximum target.

**Table 5.** Mathematical Formulation of the HFVRPAC Model

| Component           | Formulation                                 | Meaning                                                                  |
|---------------------|---------------------------------------------|--------------------------------------------------------------------------|
| Objective function  | $\text{Min } Z = \sum C(r,k) \times Y(r,k)$ | Select the route–vehicle combination with minimum total cost             |
| Destination service | $\sum a(i,r) \times Y(r,k) = 1$             | Every destination is served exactly once in the scenario                 |
| Capacity            | $\sum q(i) \times a(i,r) \leq Q(k)$         | Total route CBM does not exceed vehicle capacity                         |
| Access              | $Y(r,k) \leq A(r,k)$                        | A route may only use a vehicle if access to all destinations is feasible |
| Service guardrail   | $Y(r,k) \leq S(r,k)$                        | A route is selected only if the schedule/service requirement is feasible |

*Source: authors' formulation, adapted from HFVRP with access-constraint principles*

Land-transport emissions were estimated using an activity-based/distance-based approach: route emission (tCO<sub>2</sub>e) = route distance (km) × number of trips × vehicle emission factor (kgCO<sub>2</sub>e/km) ÷ 1,000. Baseline direct-delivery emissions were compared with multi-drop scenario emissions using the same boundary and assumptions, and the emission factor was tested for ±20% sensitivity. To ensure output quality, the credibility of the findings was strengthened through source triangulation (cross-referencing ERP tariff data, 3PL vendor invoices, and management interviews); dependability was addressed through an audit trail in which model parameters (truck capacity, base tariff, CBM ratio) were transparently recorded so that re-running the simulation would yield consistent routes; and confirmability was addressed through field verification (peer debriefing) with dispatchers to confirm that proposed multi-drop routes were geographically and infrastructurally logical.

## RESULTS AND DISCUSSION

### Existing Shipment Condition, January–June 2026

During January–June 2026, PT XYZ's delivery pattern was essentially conducted directly from the MM2100 facility to each destination city, with every destination treated as an independent delivery requirement. This direct-delivery pattern provided scheduling flexibility but caused transportation cost to accumulate on every shipment. Based on the cleaned data set, total shipments reached 3,290, comprising 53,879 CBM of volume (an average of 16.39 CBM per shipment); of 2,907 road shipments, 655 (22.53%) were partial, and of 383 sea shipments,

97 (25.33%) used the LCL scheme with a cumulative volume of 648 CBM. An initial clustering exercise identified 47 candidate destination clusters that could potentially be consolidated through a multi-drop pattern, indicating that the main efficiency opportunity lies in reducing separately handled shipments and combining volume toward the same region or port (Zhang et al., 2023).

**Table 6.** Existing (Direct-Delivery) Shipment Profile, January–June 2026

| Indicator                            | Value               | Interpretation                                                              |
|--------------------------------------|---------------------|-----------------------------------------------------------------------------|
| Sales/delivery value                 | IDR 305.767 billion | Basis for the delivery-cost ratio                                           |
| Delivery cost under direct delivery  | IDR 14.793 billion  | Baseline cost if every destination is shipped separately                    |
| Delivery cost ratio                  | 4.84%               | 0.34 percentage points above the 4.50% maximum target                       |
| Estimated direct shipments           | 2,843 shipments     | Every multi-drop candidate destination still counted as a separate shipment |
| Shipments eligible for consolidation | 852 shipments       | Destinations meeting the clustering criteria                                |
| Candidate multi-drop clusters        | 301 clusters        | Groups of destinations analyzed for one delivery route                      |

Source: PT XYZ internal data processing, January–June 2026

### Multi-Drop Consolidation Simulation Results

The improvement scenario was built by combining destinations sharing regional proximity, direction of travel, delivery period, combined volume, vehicle type, and access feasibility. Each route retained every destination that must be served, but the number of vehicles or shipments required could be reduced. The simulation shows that 852 shipments previously treated as separate could be consolidated into 301 multi-drop routes, reducing the estimated number of shipments from 2,843 to 2,292 — a decrease of 551 shipments (19.38%). Total delivery cost fell from IDR 14.793 billion to IDR 14.218 billion, yielding a potential saving of IDR 574.772 million (3.89%); the cost-to-sales ratio improved from 4.84% to 4.65% (Table 7). This result indicates that multi-drop consolidation provides a measurable improvement, although it does not fully reach the 4.50% maximum DBR target on its own.

**Table 7.** Comparison of Direct-Delivery and Multi-Drop Scenarios (Aggregate, Jan–Jun 2026)

| Indicator            | Before: Direct      | After: Multi-Drop   | Change              |
|----------------------|---------------------|---------------------|---------------------|
| Total delivery value | IDR 305.767 billion | IDR 305.767 billion | Unchanged           |
| Total delivery cost  | IDR 14.793 billion  | IDR 14.218 billion  | – IDR 0.575 billion |

| Indicator                           | Before: Direct | After: Multi-Drop | Change                      |
|-------------------------------------|----------------|-------------------|-----------------------------|
| Cost-to-delivery-value ratio (DBR)  | 4.84%          | 4.65%             | – 0.19 pp                   |
| Estimated number of shipments/trips | 2,843          | 2,292             | – 551 (– 19.38%)            |
| Destinations/sales orders served    | Unchanged      | Unchanged         | Service coverage maintained |

Source: PT XYZ internal data processing, January–June 2026

The GO/NO-GO screening applied to all 301 candidate clusters found that 148 clusters generated a positive saving, 147 were cost-neutral, and 6 increased cost. This confirms that multi-drop consolidation should not be applied uniformly across the network; it must instead be evaluated selectively at the cluster level, implemented only where cost, access, schedule, and service-level criteria are jointly satisfied.

### Scope 3 Emission Estimation: A Worked Example

Emission calculation was performed once the route and vehicle for both the direct and multi-drop conditions were determined. For each shipment code, the baseline was calculated from the distance of each direct shipment, the number of trips, and the vehicle emission factor; for the improvement scenario, distance was calculated from the resulting multi-drop route sequence and the emission factor of the selected vehicle, with the difference between the two conditions representing the avoided emission for that shipment code. As a worked example, the study uses an actual shipment code from the Padang–Bukittinggi cluster. Under the baseline, Padang (12.1173 CBM, estimated distance 1,157.649 km) was served by a box truck and Bukittinggi (30.6401 CBM, estimated distance 1,211.294 km) by a wing-box, together producing baseline emissions of 0.7145 and 1.1802 tCO<sub>2</sub>e (total 1.8947 tCO<sub>2</sub>e). Under the improvement scenario, both destinations were consolidated into a single MM2100–Padang–Bukittinggi wing-box route of 42.7574 CBM and an estimated distance of 1,243.774 km, at an emission factor of 0.9743 kg CO<sub>2</sub>e per vehicle-km, yielding a scenario emission of 1.2154 tCO<sub>2</sub>e — a reduction of 0.6793 tCO<sub>2</sub>e, or 35.85%, for this shipment code (Table 8).

**Table 8.** Worked Example: Padang–Bukittinggi Cluster — Cost and Emission Calculation

| Condition               | Destination(s) | Volume (CBM) | Distance (km) | Vehicle (EF, kg CO <sub>2</sub> e/km) | Cost (IDR) | Emission (tCO <sub>2</sub> e) |
|-------------------------|----------------|--------------|---------------|---------------------------------------|------------|-------------------------------|
| Direct 1                | Padang         | 12.1173      | 1,157.649     | Box truck (0.6172)                    | 11,440,000 | 0.7145                        |
| Direct 2                | Bukittinggi    | 30.6401      | 1,211.294     | Wing-box (0.9743)                     | 17,440,000 | 1.1802                        |
| Direct total (baseline) | –              | 42.7574      | –             | –                                     | 28,880,000 | 1.8947                        |

| Condition  | Destination(s)       | Volume (CBM) | Distance (km) | Vehicle (EF, kg CO <sub>2</sub> e/km) | Cost (IDR)         | Emission (tCO <sub>2</sub> e) |
|------------|----------------------|--------------|---------------|---------------------------------------|--------------------|-------------------------------|
| Multi-drop | Padang → Bukittinggi | 42.7574      | 1,243.774     | Wing-box (0.9743)                     | 23,312,320         | 1.2154                        |
| Reduction  | –                    | –            | –             | –                                     | 5,567,680 (19.28%) | 0.6793 (35.85%)               |

Source: PT XYZ internal data processing, January–June 2026 (emission formula: distance × trips × emission factor ÷ 1,000)

The same procedure was then applied to all 301 candidate shipment codes/clusters using the GO/NO-GO criterion. On aggregate, the multi-drop scenario is estimated to generate 82.93 tCO<sub>2</sub>e of emissions, lower than the direct-delivery condition of 126.16 tCO<sub>2</sub>e (Table 9), indicating an estimated reduction of 43.24 tCO<sub>2</sub>e (34.27%) resulting from fewer trips and shorter total distance needed to serve a broadly similar volume and set of destinations. This result should be interpreted as an estimate applicable to the analyzed clusters and routes rather than the company's total corporate (Institute & Development, 2011) carbon footprint, since the proxy emission factors used still require further validation against actual vehicle, fuel-consumption, and GPS-distance data.

**Table 9.** Aggregate Estimated Scope 3 Emission Impact

| Delivery Condition                | Estimated Emission (tCO <sub>2</sub> e) | Change |
|-----------------------------------|-----------------------------------------|--------|
| Direct delivery (baseline)        | 126.16                                  | –      |
| Multi-drop scenario (improvement) | 82.93                                   | –      |
| Emission reduction                | 43.24                                   | 34.27% |

Source: PT XYZ internal data processing, January–June 2026. Note: totals may differ slightly due to rounding.

### Problem–Root Cause–Solution–Outcome Synthesis

Linking the identified problems to their root causes and the simulation outcomes clarifies that the DBR escalation stems mainly from shipment fragmentation, the absence of a standardized multi-drop consolidation rule, and the lack of a volume-and-cost-based LCL–FCL decision rule (Table 10). The synthesis shows that the cost and DBR problem is addressed through selective multi-drop implementation, reducing direct-delivery cost from IDR 14.793 billion to IDR 14.218 billion (a saving of IDR 574.772 million, or 3.89%) and improving the cost ratio from 4.84% to 4.65% an improvement that has not yet reached the 4.50% maximum target. The high shipment-count problem is addressed by combining eligible destinations into a single shipment code and trip, reducing the estimated number of shipments from 2,843 to 2,292 (551 shipments, 19.38%). Because not every multi-drop candidate yields a saving, clusters that are cost-neutral or cost-increasing are retained as direct shipments or redesigned, while vehicle selection is based on total cluster volume, maximum vehicle capacity, and the largest vehicle able to enter every destination in the route. The LCL–FCL decision requires a standardized break-even rule based on cumulative volume, tariff, vessel schedule, and handling

cost, and the environmental-impact problem is addressed through the activity-based/distance-based method described in Section 4.3.

**Table 10.** Problem–Root Cause–Solution–Outcome Matrix

| <b>Problem Identified</b>                                                      | <b>Root Cause</b>                                                                                              | <b>Solution Applied</b>                                                                                                             | <b>Evaluation Result</b>                                                                                                                                                         |
|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Delivery cost and DBR above the corporate target                               | Most Jan–Jun 2026 shipments still handled as direct delivery, so every destination incurs its own cost         | Selective multi-drop consolidation for destinations sharing region, direction, period, volume, and access feasibility               | Direct-delivery cost of IDR 14.793 billion reduced to IDR 14.218 billion; saving of IDR 574.772 million (3.89%); ratio improved from 4.84% to 4.65%, not yet at the 4.50% target |
| High shipment count from destinations shipped separately                       | No standardized pattern existed for combining nearby destinations into one trip                                | Combining eligible destinations into a single shipment code and multi-drop trip                                                     | Estimated shipments fell from 2,843 to 2,292 (–551, 19.38%)                                                                                                                      |
| Not all multi-drop candidates generate a saving                                | Cluster formation did not always jointly consider cost, vehicle access, and service risk                       | Selective multi-drop application; neutral/cost-increasing clusters kept as direct or redesigned                                     | Of 301 candidate shipment codes, 148 generated savings, 147 were neutral, and 6 increased cost                                                                                   |
| Vehicle selection did not fully consider combined volume and route-wide access | Each destination has a different vehicle-access limit; fleet decisions relied heavily on dispatcher experience | Vehicle assignment based on total cluster volume, maximum vehicle capacity, and the largest vehicle able to reach every destination | Scenario produced feasible box-truck, long box-truck, medium-truck, wing-box, or sea-mode alternatives suited to combined volume and access constraints                          |
| Repeated LCL shipments to the same port                                        | No standardized rule existed to compare cumulative LCL cost against FCL tariff                                 | Development of a volume-, tariff-, schedule-, and handling-based LCL–FCL break-even rule                                            | Requires further per-port analysis beyond the multi-drop simulation used in this study                                                                                           |
| Environmental impact of the delivery-pattern change not directly measured      | Prior calculations did not fully use route distance, trip count, and vehicle type                              | Activity-based/distance-based method comparing direct-delivery and multi-drop emissions                                             | Estimated emissions fell from 126.16 tCO <sub>2</sub> e to 82.93 tCO <sub>2</sub> e, a reduction of approximately 43.24 tCO <sub>2</sub> e (34.27%)                              |

Source: authors' synthesis based on January–June 2026 distribution data and improvement-simulation results

## Semester II (July–December 2026) Forecast

Implementation in July–December 2026 is assumed to follow the same cluster-formation and feasibility-screening principles used in the first-semester simulation. With an

annual sales target of IDR 716.8 billion and January–June realization/estimate of IDR 305.767 billion, second-semester sales are forecast at IDR 411.033 billion. If the direct-delivery pattern were maintained, second-semester logistics cost is estimated at approximately IDR 19.886 billion; applying multi-drop at an efficiency level equivalent to the first-semester simulation is estimated to lower this to approximately IDR 19.113 billion, for a ratio of approximately 4.65%. To reach the 4.50% maximum for the second semester alone, the cost ceiling is approximately IDR 18.497 billion, implying that an additional efficiency of approximately IDR 616.486 million is still required beyond the multi-drop benefit already estimated.

The findings are consistent with the shipment-consolidation and heterogeneous-fleet-vehicle-routing literature, confirming that combining several destinations into one route together with appropriate vehicle selection can reduce the transportation services required and total cost. The importance of access constraints is also consistent with Batsyn et al. (2021), who emphasize that a routing solution is only beneficial if the vehicle type can genuinely serve every point; the six cost-negative clusters found in this study reinforce the view that optimization must be applied selectively at the cluster level rather than as a blanket policy without evaluation. From an eco-efficiency perspective, the 3.89% cost saving and the estimated 34.27% emission reduction indicate an opportunity to generate economic and environmental value simultaneously, although the two figures carry different levels of certainty: the cost result is derived directly from company data, whereas the emission result remains influenced by assumptions about distance, vehicle class, and load density, and should therefore be positioned as an initial managerial estimate requiring confirmation through actual activity data.

The results carry several managerial implications across different time horizons. In the short term, the company should prioritize implementing the 148 shipment codes with a proven positive saving after access, schedule, OTIF, and emission checks; exclude the six cost-increasing shipment codes until tariff, route sequencing, or vehicle type is corrected; and adopt a single mandatory comparison format covering direct cost, multi-drop cost, saving, shipment count, distance, emissions, and service level. In the medium term, the focus should shift toward standardization: building a destination master file with coordinates, maximum vehicle type, receiving hours, surcharges, and product risk limits; integrating the HFVRPAC rule engine and the LCL–FCL break-even rule into dispatch planning; incorporating multi-drop tariff, unloading, and cost-sharing clauses into 3PL vendor SLAs; and producing a monthly dashboard of cost, cost ratio, saving, shipment reduction, OTIF, and tCO<sub>2</sub>e. In the long term, optimization needs to become a recurring process connected to transaction data and sustainability reporting: linking order, shipment, tariff, GPS, proof-of-delivery, and fuel-consumption data so that optimization can run periodically; developing emission factors more representative of the vendor fleet actually operating in Indonesia; and using the estimated emission reduction as an input to Scope 3 and SDG 13 reporting once the method and boundary have been verified. Because PT XYZ does not own the full transportation fleet outside the Jabodetabek area, successful implementation ultimately depends on the company's ability to influence 3PL vendors through contracts, SLAs, agreed tariffs, vehicle-type selection, delivery schedules, proof-of-delivery obligations, and vendor performance evaluation, so that the feasibility of the multi-drop simulation is jointly determined by route mathematics and vendor readiness.

## CONCLUSION

Based on the January–June 2026 evaluation, the direct-delivery pattern produced a delivery cost of IDR 14.793 billion against a delivery value of IDR 305.767 billion, a cost ratio of 4.84% that exceeds the 4.50% maximum DBR target. The multi-drop simulation consolidated 852 shipments into 301 routes, reducing the estimated number of shipments from 2,843 to 2,292, lowering delivery cost to IDR 14.218 billion for a saving of IDR 574.772 million (3.89%) and improving the cost ratio to 4.65%, still short of the 4.50% target. The benefit was not uniform across clusters: 148 generated savings, 147 were cost-neutral, and 6 increased costs, confirming that implementation must follow a selective go/no-go principle based on cost, vehicle access, schedule, and service level. Estimated Scope 3 emissions in the multi-drop clusters fell from 126.16 to 82.93 tCO<sub>2</sub>e, a reduction of 34.27%, indicating that fewer separate routes can generate economic and environmental benefits simultaneously. The July–December 2026 forecast, assuming the same efficiency level, projects a cost ratio of 4.65%, meaning an additional efficiency of approximately IDR 616.486 million is still required to reach 4.50%. Multi-drop consolidation is therefore a feasible core strategy for improving distribution eco-efficiency, but reaching the DBR target requires complementary measures: eliminating cost-negative clusters, renegotiating vendor tariffs, controlling ancillary charges, improving vehicle selection, and pursuing LCL–FCL consolidation. It is recommended that PT XYZ implement multi-drop routing selectively under a strict go/no-go rule, prioritize the 148 proven-saving clusters for July–December rollout while redesigning the six cost-increasing clusters, strengthen destination master data, obtain actual vehicle and fuel-consumption data from 3PL vendors to replace proxy emission factors, integrate the routing and LCL–FCL rules into monthly dispatch planning with a cost–DBR–emission dashboard, and pursue a phased rollout beginning with an 8–12-week pilot before national expansion.

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