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**Queen Marry**

**University of London**

**School of Business and Management**

**Individual Report**

Module: **Transportation and Logistics Analytics**

Code of Module: **BUSM227**

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**Part A - Mathematical Programming Formulation**

**Sets:**

**S**: Set of suppliers.

**W**: Set of warehouses.

**D**: Set of distribution centres.

**C**: Set of customers.

**P**: Set of products.

**Parameters:**

​: Capacity from supplier **s** to warehouse **w** in kg.

: Capacity from warehouse **w** to distribution centre **d** in kg.

: Fixed cost for using **s-w** link

 : Fixed cost for using **w-d** link

: Variable cost per kg for **s-w** link.

: Variable cost per kg for **w-d** link.

: Weight of one unit of product **p** (kg/unit).

​: Euclidean distance from distribution centre **d** to customer **c.**

: Cost per kg per km for product **p.**

: Demand (in units) of product **p** by customer **c.**

**Decision Variables:**

≥ 0: Units of product **p** transported from supplier **s** to warehouse **w.**

≥ 0: Units of product **p** transported from warehouse **w** to distribution centre **d.**

≥ 0: The number of units of product **p** delivered from distribution centre **d** to customer **c**

∈ {0,1}: Binary variable = 1 if supplier **s** uses link to warehouse **w**.

∈ {0,1}: Binary variable = 1 if warehouse **w** uses link to distribution centre **d.**

(**non-negative**, **integer)**

**Objective Function:**

Minimize total cost:

Minimize Z =

**Constraints:**

**Demand Satisfaction:**

To ensure that each customer's demand for each product is met. Each customer **c** must receive the total number of units ordered for every product **p.**

**Distribution Centre Flow Balance:**

Amount sent to customers = amount received from warehouses.

For each product **p**, the total number of units that a distribution centre **d** sends to customers must match what it receives from warehouses.

**Warehouse Flow Balance:**

Amount received from suppliers = amount sent to distribution centres

Ensures warehouses are only transshipment points:

The number of units of product **p** that a warehouse **w** receives from suppliers must equal what it sends to distribution centres.

**Link Capacity Constraints:**

Limits how much weight can be shipped per link and enforces fixed cost usage:

If a shipping link is used (y = 1), the total weight shipped must not exceed the maximum capacity of that link.

**From suppliers to warehouses:**

**From warehouses to distribution centres:**

This constraint also guarantees that fixed costs are only incurred when capacity is reserved (y = 1).

**Route Availability Constraints.**

Disables links that are not available due to physical or logistical restrictions:

These binary usage variables are manually fixed to 0 where no route exists:

W1 can't receive from S2

   D4 can't receive from W1

   D5 can't receive from W1

   D2 can't receive from W2

   D1 can't receive from W3

   D2 can't receive from W3

This prevents infeasible routes from being chosen.

**Customer-to-DC Allocation Constraint:**  
Customers are pre-assigned to a specific distribution centre. Each customer can only receive products from their designated distribution centre.

   if c ∉ d ∈ D,c ∈ C, p ∈ P

Where:

This constraint ensures that each customer only receives products from their designated distribution centre.

**Variable Type Constraints:**

Defines the allowed values for all decision variables:

Quantity variables must be non-negative integers:

Link usage variables must be binary (0 or 1):

These constraints ensure realistic logistics decisions, with indivisible units and binary routing choices.

**Part B - Supply Chain Optimization: A Pulp Implementation for Cost Minimization**

To facilitate more efficient data manipulation and ensure compatibility with Python's data processing libraries, several modifications were made to the initial dataset. In the **"Demands per product type"** sheet, the first column header was renamed from blank to **"Customers"**. Similarly, the first columns in **"Lastmilecost per product per kg"**, **"Last mile coordinates"**, and **"Product weight"** sheets were renamed to **"Product"**, **"DC\_C"**, and **"Product"** respectively. These changes enabled seamless indexing, merging, and lookups during model development.

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A table with a list of products

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**Table 1 –** Transportation flow summary

The optimization model for DeliverEase Ltd. resulted in a total logistics cost of **€824,980.94**, ensuring all customer demands were met while respecting route restrictions and transportation capacities. The optimized network flow, illustrated in **Figure 1 and Table 1**, shows how products flow efficiently from suppliers to warehouses and then to distribution centres. Specifically, supplier S1 ships 23,357 kg to W1, 60,000 kg to W2, and 9,424 kg to W3, while supplier S2 supplies 10,936 kg to W2 and 15,000 kg to W3. From the warehouses, W1 ships 23,357 kg to DC2; W2 distributes 24,945 kg to DC1, 23,334 kg to DC3, and 22,657 kg to DC5; and W3 ships 24,424 kg to DC4. These link-specific flows reflect the model's cost-effective allocation strategy, minimizing transport expenses while adhering to the company's operational constraints.

# **Part C - Network Flow Visualization: Mapping Optimal Supply Chain Pathways**

A diagram of a customer relationship

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**Figure 2 -** Last-Mile Delivery Network Optimization: DC to Customer Assignments.

**Figure 2** illustrates the optimized last-mile delivery network, showing Customers (blue dots) and their assigned Distribution Centres (red stars). Orange lines represent DC-to-customer delivery assignments. Each customer location is labelled with a green text indicating the total volume of goods (kg) they receive, effectively showcasing DC service areas and demand variations. The total volume for each customer is calculated step-by-step by multiplying the number of units of each product type by its corresponding weight and then summing these values for all products assigned to that customer.

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**Figure 3** - Multi-Echelon Supply Chain Flow: Supplier, Warehouse, and DC Network.

**Figure 3** illustrates the optimized product flow across a multi-tiered supply chain. It visually maps geographical locations of Suppliers (orange triangles), Warehouses (green stars), and Distribution Centres (red stars). Connections denote pathways: orange lines for supplier-to-warehouse shipments, and green lines for warehouse-to-DC movements. Each line is clearly labelled with the exact product volume (kg), providing a comprehensive view of the logistical plan.

**Part D – Strategic supply chain recommendations:**

**Recommendation (1) : Strategic Network Optimization with Route Expansion**

Our primary recommendation involves the strategic opening of previously unused transportation routes: (W1,DC4), (W2,DC2), (W3,DC2), (W1,DC5), and (W3,DC1).

The specific data regarding the fixed costs, variable costs, and capacity for these newly considered routes were unavailable. To ensure the accuracy of our model, we estimated these by calculating the average variable cost of existing outbound routes from Warehouses W1, W2, and W3 to various Distribution Centres (as detailed in **Table 2**).

**A close up of numbers

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**Table 2 -** Assumed Parameters for Newly Opened Transportation Routes

Recognizing that the prior unavailability of these links might stem from higher associated costs, we conservatively increased this calculated average variable cost by **€2**. This increment, representing approximately half of the average variable cost, is intended to account for factors such as longer distances or other increased operational expenses for these newly opened routes.

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A key outcome of the optimization is the strategic integration of the W2-DC2 route into the operational network, **which was previously unavailable**. Complementing this, a notable change in traffic involves Warehouse W1: while the Initial Model directed goods from W1 to DC2, the Adjusted Model now reroutes W1's traffic to DC3 as shown in **Figure 4**.

**A screenshot of a list of goods

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By implementing these adjustments, the total transportation cost decreased from €824,980.94 to €802,060.27, representing a saving of approximately **€22,920.67**. This demonstrates that the proposed changes lead to a more efficient and cost-effective distribution strategy as shown in **Table 3**.

**A pie chart with text and numbers

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The pie chart effectively illustrates that the **Route Expansion Model** accounts for a smaller proportion (49%) of the combined costs compared to the Initial Model (51%). This directly demonstrates the successful cost reduction and improved efficiency achieved through the model adjustments.

**Recommendation (2): Strategic Relocation Proposal – Northeast Site (33×60)**

In large-scale distribution networks, even modest changes in facility location can yield substantial efficiency gains. This section explores a targeted relocation of Distribution Centre 1 (DC1) from its existing coordinates at (45, 45) to a proposed site at (33, 60). The motivation for this adjustment stems from spatial inefficiencies observed in last-mile delivery to nearby customers, particularly those in the C1–C10 group.

**A chart with green and blue dots

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**Figure 6** presents a visual comparison of customer locations relative to both the existing and proposed DC sites. Customers are color-coded to indicate which of the two DCs they are closer to, making it clear that the proposed site better aligns with the majority of nearby demand points.

A close-up of a number

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According to **Table 4**, 8 out of the 10 customers in this cluster would be geographically closer to the proposed DC, some by a substantial margin such as Customer C9, whose distance drops from 22.8 to just 3.61 units.

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A pie chart of a cost comparison

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Operational implications of this shift are further highlighted in **Figure 7 and Figure 8**, which compares total network costs under the current and proposed configurations. The optimized solution with the new DC location results in a reduced total cost of **€811,587.08**, compared to **€824,980.94** in the initial setup. This cost improvement of over **€13,000** validates the effectiveness of the relocation strategy.

**Part E - Limitations and possible improvements of initial mode and TWO recommendations:**

**Limitations and possible improvements uniquely associated with Strategic Network Optimization with Route Expansion:**

**Assumed Cost Parameters:**

New route parameters such as costs, capacity was estimated using averages of existing routes due to unavailable specific data, potentially affecting optimality.

**Possible improvement:** Replace estimated costs with actual transport data.

**Unverified Feasibility:**

Operational, regulatory, or infrastructural feasibility of the new links is not validated.

**Possible improvement:** Assess regulatory, geographic, or infrastructure viability of new routes.

**Uniform Cost Uplift:**  
Adding €2 to average variable cost for all new links may oversimplify real cost differences.

**Possible improvement:** Replace estimated costs with actual transport data.

**Limitations and possible improvements uniquely associated with Strategic Relocation Proposal – Northeast Site (33×60):**

**No Transition or Capital Costs:**

While the objective function includes detailed fixed and variable logistics costs, it excludes one-time transition costs associated with opening a new facility and decommissioning the old one.

**Possible improvement:** Account for relocation expenses and capital investment.

**Omitted Operational Details in Last-Mile Delivery:**

Although the model accurately captures per-kilogram-per-kilometre cost structure, it does not include routing complexity, traffic considerations, which are critical in last-mile performance.

**Possible improvement:** Include routing complexity and urban delivery challenges.

**Static Customer Segmentation:**  
The relocation analysis assumes that customer assignments to distribution centres remain fixed, even after moving the facility.

**Possible improvement:** More flexible, dynamic assignment could further improve cost-efficiency post-relocation.

**Limitations inherent to the initial model and both strategic recommendations:**

**Deterministic Demand:**

The model assumes exact customer demand, which rarely holds true in real operations.

**Possible improvement:** Incorporate demand uncertainty to reflect real-world variability.

**Fixed Customer-to-DC Assignment:**

Customers are restricted to receiving products from one assigned distribution centre. This limits flexibility and may prevent lower-cost options.

**Possible improvement:** Allow customers to be served by the most optimal DC, not fixed ones.

**No Inventory Consideration:**

Warehouses are treated as pass-through points with no inventory limits or holding costs. This oversimplifies logistics and ignores potential bottlenecks.

**Possible improvement:** Introduce inventory levels and holding costs at warehouses/DCs.

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