Cost Optimization for JDID

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Course: Managerial Decision Making & Modeling	

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V1.0	28/02/2023	- Acronyms and Definitions, - Problem Statement, - System	The confirmation of a chosen problem	28/02/2023
V2.0	08/03/2023	- Mathematical Model - Data Collection	Mathematical Model, Constraints and Data Collection	08/03/2023
V3.0	11/04/2023	- Data Collection - Constraints	Modified the data and constraints	12/04/2023
V4.0	18/04/2023	- Code Outline : Scenario 1 and Scenario 2	Draft 1 of code for scenario 1 and 2	19/04/2023
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V6.0	27/04/2023	Revised code Scenario 3	Finalizing scenario 3 and template	
V7.0	01/05/2023	- All Scenario Analysis	Interpreting the resulting and finalizing template	
V8.0	02/05/2023	All Pages and Code	Revision	03/05/2023

Abstract

The report discusses a logistics problem faced by JD.ID. and evaluates three scenarios to minimize transportation costs while meeting demand and respecting capacity constraints.

In the first scenario, the company needs to find the optimal flow of the product from two main warehouses to two local warehouses and three distribution centers. In the second scenario, the company needs to decide whether to build a third local warehouse in West Java. In the third scenario, the company analyzes the flow of two products (groceries and electronics) and decides whether adding a third local warehouse would be more efficient.

During the problem analysis the following findings were derived: in scenario 1 the flow capacity from local warehouses to distribution centers should be increased, as well as the capacity of some of the main warehouses, if possible. In scenario 2, a new local warehouse is required to meet increased demand in the West, but it is unnecessary if demand remains constant. Because transportation costs from main warehouses to local warehouses are lower in scenario 3, Local Warehouse 3 should be opened as well. In the future research it is recommended to take into account the size of each product's SKUs as well as the sizes of the warehouses.

Overall, the study provides insights into how mathematical models and optimization tools can be used to address real-life problems in logistics and supply chain management.

Acronyms and definitions

JD.com	Chinese retail and e-commerce company.
JD.ID	JD.com after expansion into the Indonesian market.
Retail	Companies who purchase products in large quantities from manufacturers or wholesalers, and then sell them in smaller quantities to individual customers through various channels such as physical stores, online marketplaces or mobile applications.
Java Island	One of the islands in Indonesia that is divided into six main provinces; Banten, DKI Jakarta, West Java, Central Java, DIY Yogyakarta, and East Java.
Main Warehouse	Is a primary storage. It is responsible for receiving, storing from factories, and organizing inventory, picking and packing orders, and coordinating deliveries to local warehouses and distribution centers.
Groceries	Food and household items that are typically purchased by consumers regularly for their day-to-day needs.
Electronics	A wide range of products such as televisions, smartphones, cameras, etc.
Local Warehouse	Intermediate storage warehouse which is strategically located in areas with a high demand for products and near the distribution center to quickly fulfill customers orders and improve its overall delivery efficiency.
Distribution Center	Is the last resort in the product flow from the main and local warehouses to the customers.
Storage Capacity	Maximum amount of products that can be stored in a given storage facility.
Transportation Cost	The expenses associated with moving products or materials from one location to another.
Fixed costs	Represents rent and other costs associated with maintaining the warehouses on a long-term basis.
Flow capacity	Maximum amount of product that can be transported from one facility to another.

Summary

Problem statement

JD.com, the largest retailer in China, expanded into the Indonesian market as JD.ID. JD.ID is currently focusing on the Java Island market and operates 2 main warehouses in DKI Jakarta, which are allowed to transport goods to local warehouses and distribution centers. The main warehouse has no specific coverage area, which means they can cover all of Java Island. In addition, JD.ID has two local warehouses in Central Java and East Java to cover faster delivery in specific areas, which receive their supplies from the main warehouses. The first local warehouse will cover only Center Java, and the other local warehouse will cover only East Java. The items in the local warehouse can only be supplied from the main warehouse. JD.ID also has 3 distribution centers located in West Java, Central Java, and East Java. They receive goods from both main and local warehouses.

The logistics department is trying to determine how to minimize the total transportation cost of delivering the products while meeting the demand at each customer location and respecting the capacity constraints of the transportation network and whether opening a third local warehouse in the West region, due to increased demand, would be efficient.

System

Scenario 1

- Product is supplied from Main Warehouse 1 and Main Warehouse 2. There are also two local warehouses in Central Java and East Java. The product can be supplied to the local warehouses only from the main warehouses. The company also operates three distribution centers located in West Java, Central Java, and East Java. Distribution centers may receive products from main and local warehouses.

Scenario 2

- Product is supplied from Main Warehouse 1 and Main Warehouse 2. Now the company decides whether to build a third local warehouse in West Java in addition to two local warehouses in Central Java and East Java. The product can be supplied to the local warehouses only from the main warehouses. The company also operates three distribution centers located in West Java, Central Java, and East Java. Distribution centers may receive products from main and local warehouses.

Scenario 3

- There are 2 types of product: groceries and electronics. Main Warehouses 1 and 2 store a mix of products, which are then transported to local warehouses and 3 distribution centers. There are 2 local warehouses in Central Java, East Java and the necessity of the warehouse in West Java is to be decided. The local warehouses can store a mix of products and can only accept products from the main warehouses. The three distribution centers are located in West Java, Central Java, and East Java. Distribution centers store the mix of products as well.

Elements

Agents/DMs

DMs	Attribute/Characteristic	Objective
Logistic planning manager	Strong organizational skills, analytical thinking, attention to details, communication skills, problem-solving skills, strategic thinking	Minimize and optimize costs flow; Decide whether to open another local warehouse or not

Entities

<u>Scenario 1</u>

Entity	Notation	Attributes/ Characteristics
Products:		
Groceries	P1	Transportation cost
Warehouses:		
Main warehouse 1	MW1	Storage capacity, Fixed and Variable costs
Main warehouse 2	MW2	Storage capacity, Fixed and Variable costs
Local warehouse 1	LW1	Storage capacity, Fixed and Variable costs
Local warehouse 2	LW2	Storage capacity, Fixed and Variable costs
Distribution centers:		
Distribution center 1	D1	Demand
Distribution center 2	D2	Demand
Distribution center 3	D3	Demand

<u>Scenario 2</u>

Entity	Notation	Attributes/ Characteristics
Products:		
Groceries	P1	Transportation cost

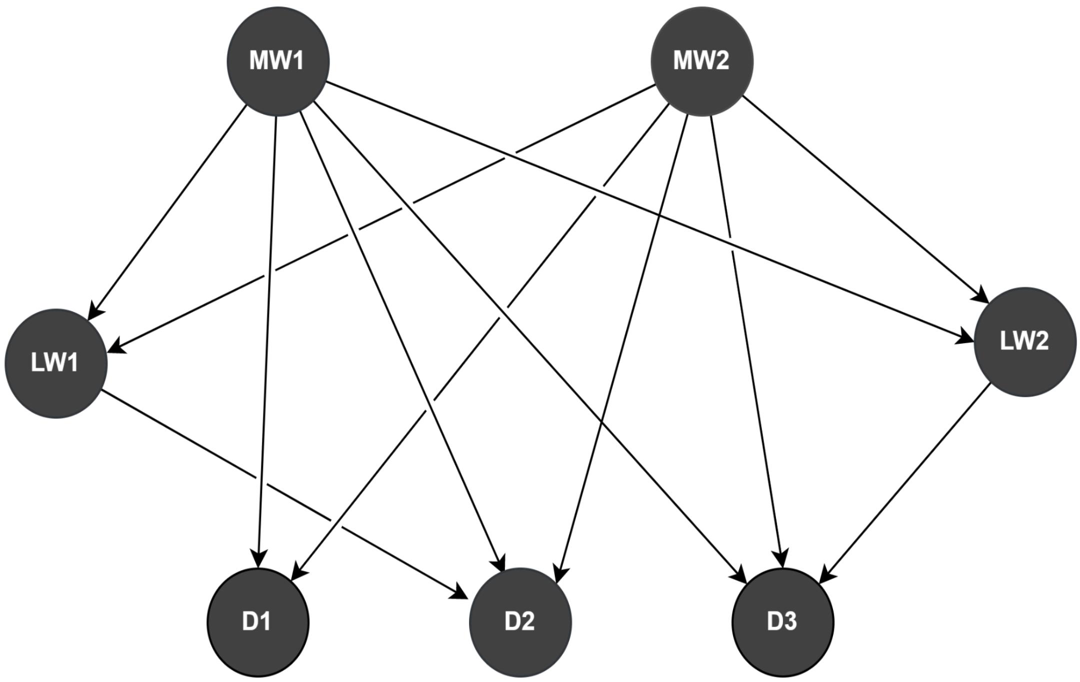
Warehouses:		
Main warehouse 1	MW1	Storage capacity, Fixed and Variable costs
Main warehouse 2	MW2	Storage capacity, Fixed and Variable costs
Local warehouse 1	LW1	Storage capacity, Fixed and Variable costs
Local warehouse 2	LW2	Storage capacity, Fixed and Variable costs
Local warehouse 3	LW3	Storage capacity, Fixed and Variable costs
Distribution centers:		
Distribution center 1	D1	Demand
Distribution center 2	D2	Demand
Distribution center 3	D3	Demand

Scenario 3

Entity	**Notation**	**Attributes/ Characteristics**
Products:		
Groceries	P1	Transportation cost
Electronics	P2	Transportation cost
Warehouses:		
Main warehouse 1	MW1	Storage capacity, Fixed and Variable costs, Stores a mix of products
Main warehouse 2	MW1	Storage capacity, Fixed and Variable costs, Stores a mix of products
Local warehouse 1	LW1	Storage capacity, Fixed and Variable costs
Local warehouse 2	LW2	Storage capacity, Fixed and Variable costs
Local warehouse 3	LW3	Storage capacity, Fixed and Variable costs
Distribution centers:		
Distribution center 1	D1	Demand
Distribution center 2	D2	Demand
Distribution center 3	D3	Demand

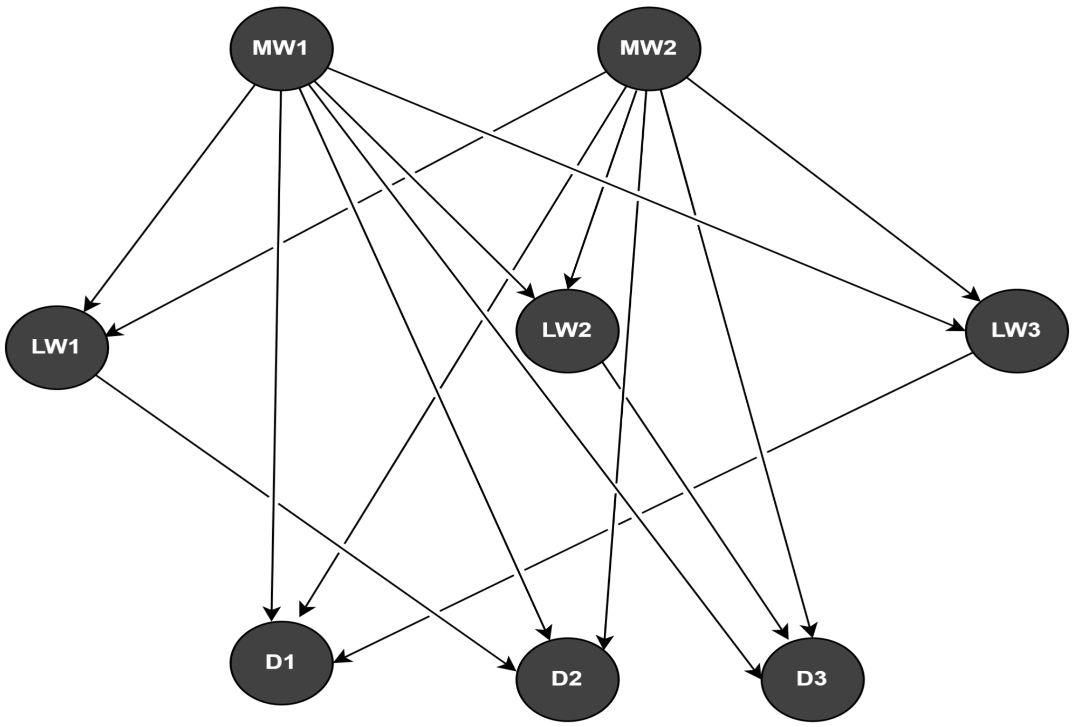
Relationships among elements

Scenario 1



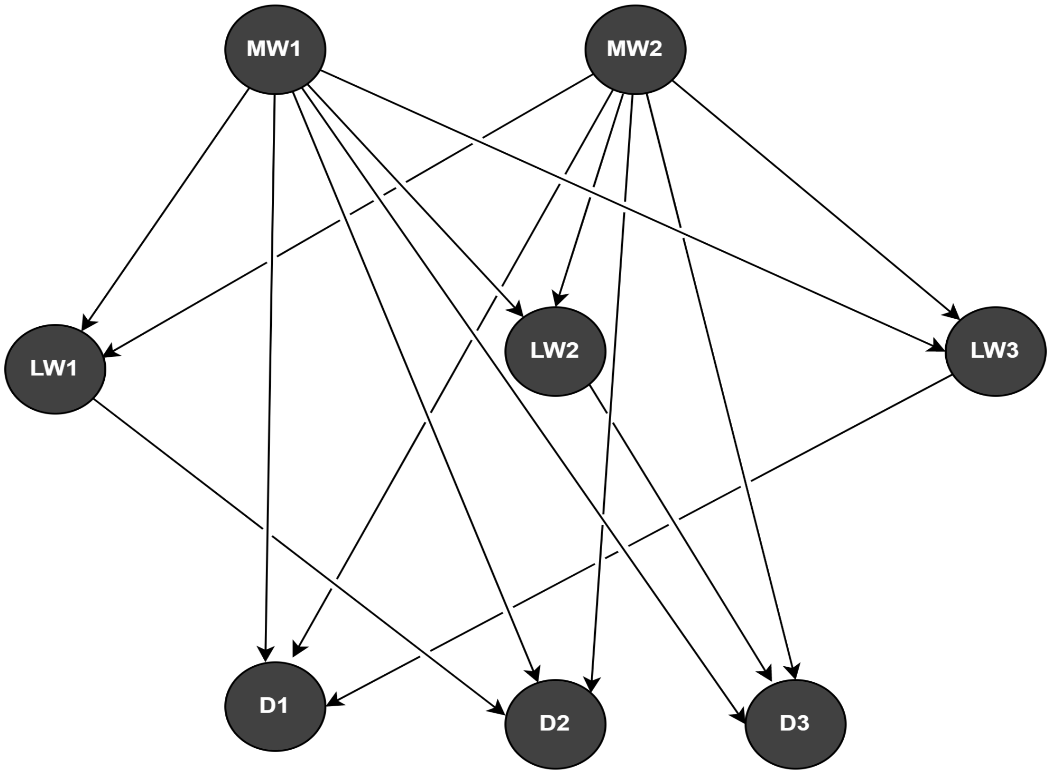
Picture 1. Relationships among elements of the problem for scenario 1

Scenario 2



Picture 2. Relationships among elements of the problem for scenario 2

Scenario 3



Picture 3. Relationships among elements of the problem for scenario 3

Other constituents of the system

1. External Disturbances:
    - Traffic or natural disasters that may disrupt transportation and logistics operations;
    - Changes in the government policies and regulations related to transportation cost such as increase gasoline and toll costs that may affect costs and profitability;
    - Changes in market trends and consumer behavior that may impact demand for products.
2. Internal Uncertainties:
    - Fluctuations in production and supply chain operation that may lead to stockouts or excess inventory;
    - Changes in operating costs that may impact overall profitability;
    - Equipment failure or breakdown that may cause delays or disruptions in the supply chain.
3. Externalities:
    - Environmental impact of the transportation and logistics operations;
    - Social and economic impacts of JD.ID's operations on local communities and stakeholders.
4. Other constituents:

- Capacity constraints in the transportation network that may impact transportation costs.

Assumptions

- The demand for products is known and constant over the planning horizon.
- The transportation costs from the main warehouses to the local warehouses/ distribution centers and from the local warehouses to the distribution centers are fixed and do not vary with the quantity of products transported.
- The transportation capacity of the network is fixed and does not change over the planning horizon.
- The transportation network is reliable and there are no delays or disruptions in the transportation process.
- Transportation costs differ with the region of the facility and the type of product.
- The prices of the products are fixed and do not vary over the planning horizon.

Mathematical model

Sets

Scenario 1:
M= Set of Main Warehouses (MW1, MW2)

L= Set of Local Warehouses (LW1(Central), LW2(East))

D= Set of Distribution Centers (D1(West), D2(Central), D3(East))

Scenario 2:
M= Set of Main Warehouses (MW1, MW2)

L= Set of Local Warehouses (LW1(Central), LW2(East), LW3(West))

D= Set of Distribution Centers (D1(West), D2(Central), D3(East))

Scenario 3:
M= Set of Main Warehouses (MW1, MW1)

L= Set of Local Warehouses (LW1(Central), LW2(East), LW3(West))

D= Set of Distribution Centers (D1(West), D2(Central), D3(East))

P= Set of 2 types of product (P1 (Groceries) and P2(Electronics))

Variables

Decision variables

1. vol : a discrete variable representing the number of units of product transported from main warehouse to local warehouse, main warehouse to distribution centers or local warehouse to distribution center.
2. x_i : a binary variable that indicates whether the third local warehouse is built or not, and it is only used in scenarios 2 and 3.

Parameters

1. Nodes: Points of product destination, supply or demand. Represented by sets M, L, D.
2. Arcs: Transportation relations between the nodes through which the flow of the product is performed.
3. Fixed costs: Costs associated with operating the warehouses, which are independent of the product transported.
4. Transportation costs: Variable cost including the transportation and packaging of one unit of product from one facility to another.:
5. Capacity of the nodes: maximum amount of products that can be stored at the nodes.
6. Flow capacity (*FlowCap*): maximum volume of product that can be transported from one node to another.
7. Demand: amount of products bought by customers

Constraints

Our problem has the following constraints:

Scenario 1

- The transportation network consists of a set of nodes and arcs representing the main warehouses, local warehouses, distribution centers, and transportation routes between them.
- Each arc has a capacity, representing the maximum amount of goods that can be transported on that route.
- Each warehouse has a certain storage capacity.
- The transportation cost for each arc is known and represents the cost per unit of goods transported.
- Volume of product transported from the main warehouse to the local warehouse cannot exceed the capacity of the local warehouse.
- Volume of product transported from the main warehouse to the local warehouse and from the main warehouse to the distribution center cannot exceed the capacity of the main warehouse.
- The volume of the product sent from the main warehouse to the local warehouse should be equal to the volume of the product sent from the local warehouse to the distribution center.

- Volume of products transported from the local warehouse should be bigger than demand.
- The volume (transportation capacity) cannot be negative.

Scenario 2

- The transportation network consists of a set of nodes and arcs representing the main warehouses, local warehouses, distribution centers, and transportation routes between them.
- Each arc has a capacity, representing the maximum amount of goods that can be transported on that route.
- Each warehouse has a certain storage capacity.
- The transportation cost for each arc is known and represents the cost per unit of goods transported.
- Volume of product transported from the main warehouse to the local warehouse cannot exceed the capacity of the local warehouse.
- Volume of product transported from the main warehouse to the local warehouse and from the main warehouse to the distribution center cannot exceed the capacity of the main warehouse.
- The volume of the product sent from the main warehouse to the local warehouse should be equal to the volume of the product sent from the local warehouse to the distribution center.
- Volume of products transported from the local warehouse should be bigger than demand.
- The volume (transportation capacity) cannot be negative.
- There can be no more than 3 local warehouses functioning.
- If the local warehouse 3 is not open, there should not be any flow coming there.

Scenario 3

- Each main warehouse stores a mix of products.
- The transportation network consists of a set of nodes and arcs representing the factories, main warehouses, local warehouses, distribution centers, and transportation routes between them.
- Each arc has a capacity, representing the maximum amount of goods that can be transported on that route.
- Each warehouse has a certain storage capacity.
- Each distribution center has a demand for multiple products, and each product has a delivery cost and a delivery capacity.
- The transportation cost for each arc is known and represents the cost per unit of goods transported.
- The volume of the product of each type sent from the main warehouse to the local warehouse and distribution center cannot exceed the capacity of the main warehouse.
- The volume of the product of each type sent from main warehouse to local warehouse cannot exceed the capacity of this product in the local warehouse.
- The volume of the product of each type sent from the main warehouse to the local warehouse should be equal to the volume of the product of each type sent from the local warehouse to the distribution center.

- The volume of the product of each type sent from the local warehouse to the distribution center cannot exceed the capacity of this product in the local warehouse.
- The volume of the product of each type sent from the local warehouse to the distribution center should be bigger than the demand of this product at the distribution center.
- The volume (transportation capacity) cannot be negative.
- Sum of the capacities of each product in the local warehouse should be more than the total capacity of the local warehouse.
- There can be no more than 3 local warehouses functioning.
- If the local warehouse 3 is not open, there should not be any flow coming there.

Objective

JD.ID wants to minimize the total transportation cost of delivering the products while meeting the demand at each customer location and respecting the capacity constraints of the transportation network.

Scenario 1

We need to account for the fixed costs of different types of warehouses separately. The first member of the equation represents the fixed costs for the main warehouse, the second member is the fixed costs for the local warehouses The last member of the equation represents the variable costs (which are transportation plus packaging costs) multiplied by the transportation capacity (volume).

Scenario 2

Considering we have a binary variable representing the presence of a third local warehouse, we need to account for the fixed costs of different types of warehouses separately. The first member of the equation represents the fixed costs for the main warehouse, the second member is the fixed costs for the local warehouses multiplied by the binary variable. As follows from the constraints it can be equal to 3 as a maximum. The last member of the equation represents the variable costs (which are transportation plus packaging costs) multiplied by the transportation capacity (volume).

Scenario 3

Considering we have a binary variable representing the presence of a third local warehouse, we need to account for the fixed costs of different types of warehouses separately. The first member of the equation represents the fixed costs for the main warehouse, the second member is the fixed costs for the local warehouses multiplied by the binary variable. As follows from the constraints it can be equal to 3 as a maximum. The last member of the equation represents the variable costs (which are transportation plus packaging costs) multiplied by the transportation capacity (volume). Moreover, all these account for 2 types of products.

Model

The full model looks as follows:

Scenario 1

$$min(\sum^{M}\sum^{L} Fixed\ Cost\ + \sum^{M}\sum^{L} (c_{ML} \bullet vol_{ML}) + \sum^{L}\sum^{D} (c_{LD} \bullet vol_{LD}) + \sum^{M}\sum^{D}(c_{MD} \bullet vol_{MD}))$$

Constraints:

1. $\sum vol_{MWnDC_j} + \sum vol_{MWnLWi} \leq Cap_{MWn}$

2. $\sum vol_{LWiDCj} + \sum vol_{MWnDCj} \geq\ demand$

3. $\sum vol_{MWnLWi} = \sum vol_{LWiDCj}$

4. $\sum vol_{MWnLWi} \leq\ Cap_{LWi}$

5. $vol_{MWnLWi} \geq\ 0,\ vol_{MWnDCj} \geq\ 0,\ vol_{LWiDCj} \geq\ 0$

6. $vol_{MWnLWi}\ \leq\ FlowCap_{MWnLWi}$

7. $vol_{MWnDCj}\ \leq\ FlowCap_{MWnDCj}$

8. $vol_{LWnDCj}\ \leq\ FlowCap_{LWnDCj}$

$n\ \subseteq \{1, 2\}$
$i\ \subseteq \{1, 2\}$
$j\ \subseteq \{1, 2, 3\}$

Scenario 2

$$min(\sum^{M} Fixed\ Cost_{m} + \sum^{L} Fixed\ Cost_{i} \bullet\ x_{i}\ + \sum^{M}\sum^{L} (c_{ML} \bullet vol_{ML}) + \sum^{L}\sum^{D} (c_{LD} \bullet vol_{LD}) + \sum^{M}\sum^{D}(c_{MD} \bullet vol_{MD}))$$

Constraints:

1. $vol_{MWnDC_j} + vol_{MWnLWi} \leq Cap_{MWn}$

2. $\sum vol_{LWiDCj} + \sum vol_{MWnDCj} \geq\ demand$

3. $\sum vol_{MWnLWi} = \sum vol_{LWiDCj}$

4. $\sum vol_{MWnLWi} \leq\ Cap_{LWi}$

5. $vol_{MWnLWi} \geq\ 0,\ vol_{MWnDCj} \geq\ 0,\ vol_{LWiDCj} \geq\ 0$

6. $vol_{MWnLWi}\ \leq\ FlowCap_{MWnLW}$

7. $vol_{MWnDCj} \leq FlowCap_{MWnDCj}$
8. $vol_{LWnDCj} \leq FlowCap_{LWnDCj}$
9. $vol_{LWiDCj} \leq c_i * x_i$
10. $\sum^{L} x_i \leq 3$

$n \subseteq \{1, 2\}$
$i \subseteq \{1, 2, 3\}$
$j \subseteq \{1, 2, 3\}$

Scenario 3

$$min(\sum^{M} Fixed\ Cost_m + \sum^{L} Fixed\ Cost_i \bullet x_i + \sum\sum\sum^{P\ M\ L} (c_{MLP} \bullet vol_{MLP}) + \sum\sum\sum^{P\ L\ D} (c_{LDP} \bullet vol_{LDP})$$
$$+ \sum\sum\sum^{P\ M\ D}(c_{MDP} \bullet vol_{MDP}))$$

Constraints:

1. $\sum vol_{MWnLWiPk} + \sum vol_{MWnDCjPk} \leq Cap_{MWn}$

2. $\sum vol_{LWiDCjPk} + \sum vol_{MWnDCjPk} \geq demand_{DCjPk}$

3. $\sum vol_{MWnLWiPk} = \sum vol_{LWiDCjPk}$

4. $\sum vol_{MWnLWiPk} \leq Cap_{LWiPk}$

5. $\sum vol_{LWiDCjPk} \leq Cap_{LWiPk}$

6. $\sum^{L} x_i \leq 3$

7. $vol_{LWiDCj} \leq c_i * x_i$
8. $vol_{MWnLWiPk} \geq 0, vol_{MWnDCjPk} \geq 0, vol_{LWiDCjPk} \geq 0$
9. $vol_{MWnLWiPk} \leq FlowCap_{MWnLWiPk}$
10. $vol_{MWnDCjPk} \leq FlowCap_{MWnDCjPk}$
11. $vol_{LWnDCjPk} \leq FlowCap_{LWnDCjPk}$

where:

$n \subseteq \{1, 2\}$ main warehouse
$i \subseteq \{1, 2, 3\}$ local warehouse
$j \subseteq \{1, 2, 3\}$ distribution center
$k \subseteq \{1, 2\}$ product

Data collection

Data was collected from the data sources of the previous working place of one of our colleagues. With the help of the ex-colleagues, it was stated right in the Colab Notebook for the convenience of processing it by the Python package pyomo.

Scenario 1

Table 1. Variable costs for scenario 1

Origin	Destination	Volume Capacity (Units)	Cost (Per unit)
MW1	LW1 (Central)	915	$0.4/unit
MW1	LW2 (East)	800	$0.5/unit
MW2	LW1 (Central)	776	$0.3/unit
MW2	LW2 (East)	780	$0.6/unit
MW1	D1 (West)	1,976	$1.7/unit
MW1	D2 (Central)	968	$2.3/unit
MW1	D3 (East)	265	$3.2/unit
MW2	D1 (West)	1,874	$2.8/unit
MW2	D2 (Central)	699	$2.5/unit
MW2	D3 (East)	780	$2.9/unit
LW1 (Central)	D2 (Central)	813	$0.6/unit
LW2 (East)	D3 (East)	768	$0.9/unit

Table 2. Fixed costs for scenario 1

Facility	Total Capacity (Units)	Fixed costs
MW1	2,500	$7,161/month
MW2	5,200	$7,157/month

LW1 (Central)	1,940	$1,125/month
LW2 (East)	1,820	$1,626/month

Table 3. Demand of the distribution centers for Scenario 1

Facility	Total Demand by Facility (Units)
D1 (West)	2,150
D2 (Central)	1,580
D3 (East)	1,400
Total	**5,130**

Scenario 2

Table 4. Variable costs for scenario 2

Origin	Destination	Volume Capacity (Units)	Cost (Per unit)
MW1	LW1 (Central)	915	$0.4/unit
MW1	LW2 (East)	800	$0.5/unit
MW1	LW3 (West)	978	$0.1/unit
MW2	LW1 (Central)	776	$0.3/unit
MW2	LW2 (East)	780	$0.6/unit
MW2	LW3 (West)	898	$0.3/unit
MW1	D1 (West)	1,976	$1.7/unit
MW1	D2 (Central)	969	$2.3/unit
MW1	D3 (East)	765	$3.2/unit
MW2	D1 (West)	1,874	$2.8/unit
MW2	D2 (Central)	699	$2.5/unit
MW2	D3 (East)	780	$2.9/unit
LW1 (Central)	D2 (Central)	1,813	$0.6/unit
LW2 (East)	D3 (East)	1,768	$0.9/unit

LW3 (West)	D1 (West)	1,798	$0.7/unit

Table 5. Fixed costs for scenario 2

Facility	Total Capacity (Units)	Fixed costs
MW1	2,500	$7,161/month
MW2	5,200	$8,157/month
LW1 (Central)	1,940	$1,125/month
LW2 (East)	1,820	$1,626/month
LW3 (West)	1,900	$1,839/month

Table 6. Demand of the distribution centers for Scenario 2

Facility	Total Demand by Facility (Units)
D1 (West)	3,350
D2 (Central)	1,580
D3 (East)	1,440
Total	**6,370**

Senario 3

Table 7.Variable costs for scenario 3

Origin	Destination	Volume (Units)		Cost/Unit	
		Groceries	Electronics	Groceries	Electronics
MW1	LW1(Central)	915	458	$0.4/unit	$0.9/unit
MW1	LW2 (East)	800	400	$0.5/unit	$1.0/unit
MW1	LW3 (West)	978	489	$0.1/unit	$0.6/unit
MW2	LW1 (Central)	776	388	$0.3/unit	$0.8/unit
MW2	LW2 (East)	780	390	$0.6/unit	$1.1/unit
MW2	LW3 (West)	898	450	$0.3/unit	$0.8/unit
MW1	D1 (West)	1,976	988	$1.7/unit	$2.2/unit
MW1	D2 (Central)	969	485	$2.3/unit	$2.8/unit

MW1	D3(East)	765	383	$3.2/unit	$3.7/unit
MW2	D1(West)	1,874	937	$2.8/unit	$3.3/unit
MW2	D2(Central)	699	350	$2.5/unit	$3.0/unit
MW2	D3(East)	780	390	$2.9/unit	$3.4/unit
LW1 (Central)	D2(Central)	1,813	907	$0.6/unit	$1.1/unit
LW2(East)	D3(East)	1,768	884	$0.9/unit	$1.4/unit
LW3(West)	D1(West)	1,798	899	$0.9/unit	$1.2/unit

Table 8. Fixed costs for scenario 3

Facility	**Total Capacity**	**Capacity Groceries**	**Capacity Electronics**	**Fixed costs**
MW1	2,500	2,200	1,000	$7,161/month
MW2	5,200	3,200	3,000	$8,157/month
LW1 (Central)	1,940	1,500	600	$1,125/month
LW2 (East)	1,820	1,400	570	$1,626/month
LW3 (West)	1,900	1,450	630	$1,839/month

Table 9. Demand of the distribution centers for Scenario 3

Facility	Demand (Units)		**Total Demand by Facility (Units)**
	Product 1 (Groceries)	Product 2 (Electronics)	
D1 (West)	1,850	1,500	**3,350**
D2 (central)	1,350	230	**1,580**
D3 (east)	1,100	340	**1,440**
Total by Product	**4,300**	**2,070**	**6,370**

Assumptions:

- The transportation costs are independent of the size of the product, they depend on the location of facilities and their distance.
- The sum of products of each type stored in the warehouse is bigger than the total capacity of the warehouse.
- Since all the transportation costs are given in dollars, it is assumed that the currency exchange rate fluctuations are not important for the model.

Scenario analysis

Scenario 1

Scenario 1 represents the initial state of our problem. One product flows from 2 main warehouses to 2 local warehouses and 3 distribution centers. According the minimization performed using pyomo package it can be seen that the most optimal way to send products is the following:

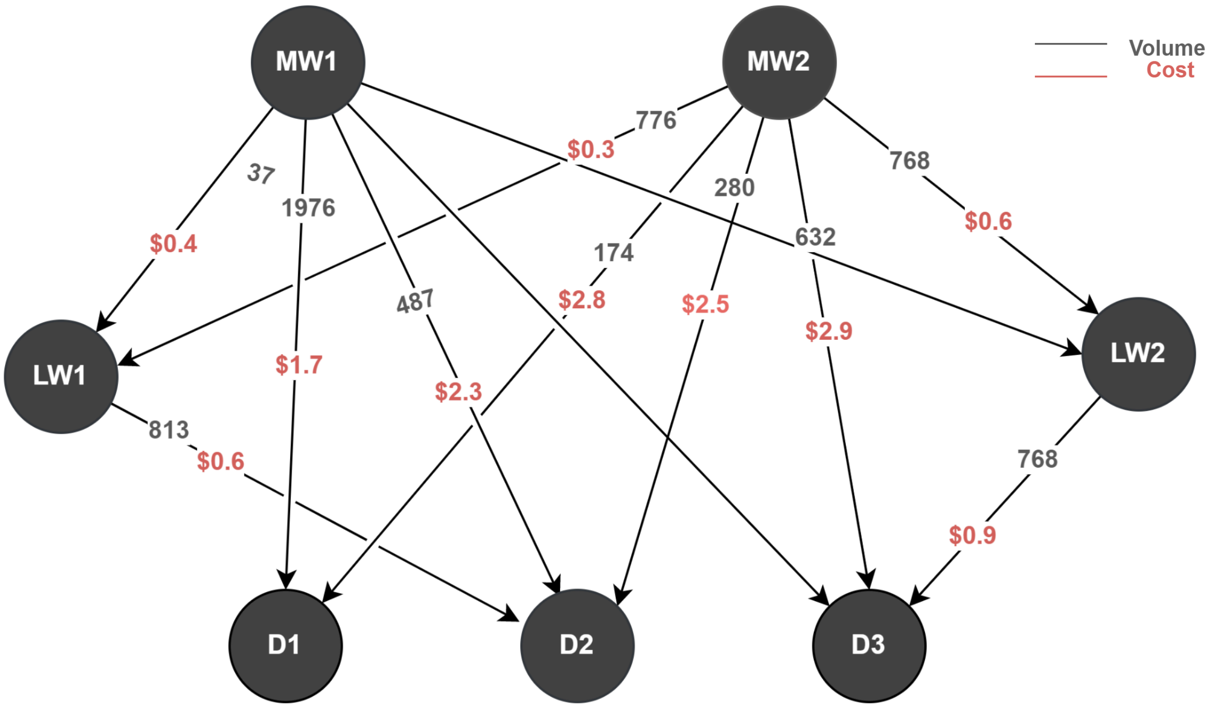
```
Optimal solution found

Object function value =  <pyomo.core.base.block._generic_component_decorator object at 0x7ff15941f940>
x : Flow from Main Warehouse to Local Warehouse
    Size=4, Index=x_index
    Key            : Lower : Value : Upper : Fixed : Stale : Domain
    ('MW1', 'LW1') :     0 :  37.0 :  None : False : False : NonNegativeReals
    ('MW1', 'LW2') :     0 :   0.0 :  None : False : False : NonNegativeReals
    ('MW2', 'LW1') :     0 : 776.0 :  None : False : False : NonNegativeReals
    ('MW2', 'LW2') :     0 : 768.0 :  None : False : False : NonNegativeReals
y : Flow from Main Warehouse to Distribution Center
    Size=6, Index=y_index
    Key            : Lower : Value  : Upper : Fixed : Stale : Domain
    ('MW1', 'DC1') :     0 : 1976.0 :  None : False : False : NonNegativeReals
    ('MW1', 'DC2') :     0 :  487.0 :  None : False : False : NonNegativeReals
    ('MW1', 'DC3') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('MW2', 'DC1') :     0 :  174.0 :  None : False : False : NonNegativeReals
    ('MW2', 'DC2') :     0 :  280.0 :  None : False : False : NonNegativeReals
    ('MW2', 'DC3') :     0 :  632.0 :  None : False : False : NonNegativeReals
z : Flow from Local Warehouse to Distribution Center
    Size=6, Index=z_index
    Key            : Lower : Value : Upper : Fixed : Stale : Domain
    ('LW1', 'DC1') :     0 :   0.0 :  None : False : False : NonNegativeReals
    ('LW1', 'DC2') :     0 : 813.0 :  None : False : False : NonNegativeReals
    ('LW1', 'DC3') :     0 :   0.0 :  None : False : False : NonNegativeReals
    ('LW2', 'DC1') :     0 :   0.0 :  None : False : False : NonNegativeReals
    ('LW2', 'DC2') :     0 :   0.0 :  None : False : False : NonNegativeReals
    ('LW2', 'DC3') :     0 : 768.0 :  None : False : False : NonNegativeReals
```

The solution is feasible so it can be applied in the real world to see how changes in demand, fixed and variable costs etc can affect the result of the model.

From the result obtained we can derive the following findings:

- It is better to increase the capacity of the flow from LW1 to D2, so the company uses a cheaper way to send the product since the capacity of the LW1 can still store a higher amount of product and the transportation cost of the straight route from MW1 to D2 is more expensive.
- Increase the capacity of the MW1 (rent more of the space). Now the capacity of storage does not allow to send anything from MW1 to D3 but in the other case sending products from there to D3 would be cheaper and it would allow to avoid the transportation to local warehouses first.



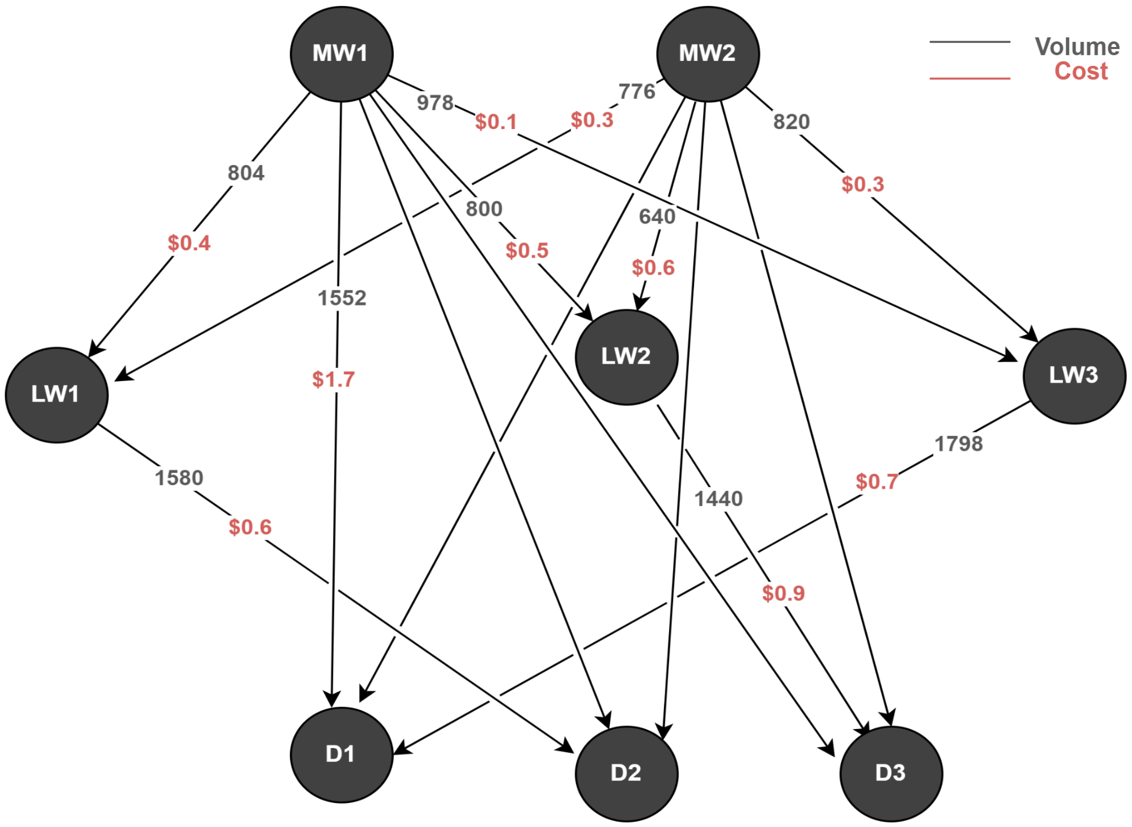
Moreover, we observe that distribution center 1 is left without any support of the local warehouse. Considering the limited capacity of the distribution centers we may need another local warehouse serving that area because it will help ease usage of some arcs in a cheaper and more efficient way.
Criticism of the result/ another strategy: a company can consider enlarging the number of distribution centers substantially and increase the capacity of its flow and operate through them directly since we see that sending product to the local warehouse first is not always cheap and effective.

Scenario 2

In scenario 2 demand for the product in the West part of the island increased, therefore there is a necessity in the new local warehouse there. So, now product flows from 2 main warehouses to 3 local warehouses and 3 distribution centers. It is needed not only to minimize the flow cost again, but to analyze whether it is worth it to have the 3rd local warehouse in the system or not.
Result: the most optimal flow of the product is the following:

```
Optimal solution found

Object function value =  <pyomo.core.base.block._generic_component_decorator object at 0x7f488e59dbb0>
x : Flow from Main Warehouse to Local Warehouse
    Size=6, Index=x_index
    Key            : Lower : Value : Upper : Fixed : Stale : Domain
    ('MW1', 'LW1') :     0 : 804.0 :  None : False : False : NonNegativeReals
    ('MW1', 'LW2') :     0 : 800.0 :  None : False : False : NonNegativeReals
    ('MW1', 'LW3') :     0 : 978.0 :  None : False : False : NonNegativeReals
    ('MW2', 'LW1') :     0 : 776.0 :  None : False : False : NonNegativeReals
    ('MW2', 'LW2') :     0 : 640.0 :  None : False : False : NonNegativeReals
    ('MW2', 'LW3') :     0 : 820.0 :  None : False : False : NonNegativeReals
y : Flow from Main Warehouse to Distribution Center
    Size=6, Index=y_index
    Key            : Lower : Value  : Upper : Fixed : Stale : Domain
    ('MW1', 'DC1') :     0 : 1552.0 :  None : False : False : NonNegativeReals
    ('MW1', 'DC2') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('MW1', 'DC3') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('MW2', 'DC1') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('MW2', 'DC2') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('MW2', 'DC3') :     0 :    0.0 :  None : False : False : NonNegativeReals
z : Flow from Local Warehouse to Distribution Center
    Size=9, Index=z_index
    Key            : Lower : Value  : Upper : Fixed : Stale : Domain
    ('LW1', 'DC1') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW1', 'DC2') :     0 : 1580.0 :  None : False : False : NonNegativeReals
    ('LW1', 'DC3') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW2', 'DC1') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW2', 'DC2') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW2', 'DC3') :     0 : 1440.0 :  None : False : False : NonNegativeReals
    ('LW3', 'DC1') :     0 : 1798.0 :  None : False : False : NonNegativeReals
    ('LW3', 'DC2') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW3', 'DC3') :     0 :    0.0 :  None : False : False : NonNegativeReals
o : Whether to open Local Warehouse 3 or not
    Size=3, Index=lw
    Key : Lower : Value : Upper : Fixed : Stale : Domain
    LW1 :     1 :   1.0 :     1 : False : False : Binary
    LW2 :     1 :   1.0 :     1 : False : False : Binary
    LW3 :     0 :   1.0 :     1 : False : False : Binary
```



As we can see from the result, in case of the substantial increase in the demand, the opening of the new local warehouse is necessary. It adds the capacity and allows the use of a cheaper route for the transportation of the product. However, if demand remains the same as in scenario 1, the opening of the local warehouse 3 is not needed. The minimum demand at D1 for opening LW3 is 2,326 units of product. In addition, increase in the transportation cost from LW3 to D1 also leads to the closure of the LW3.
Criticism of the result: the company may consider expanding the number of arcs and their capacities since it will make the full usage of node capacities possible. Nevertheless, the solution is still feasible with current data and can be used in real life.

<u>Scenario 3</u>

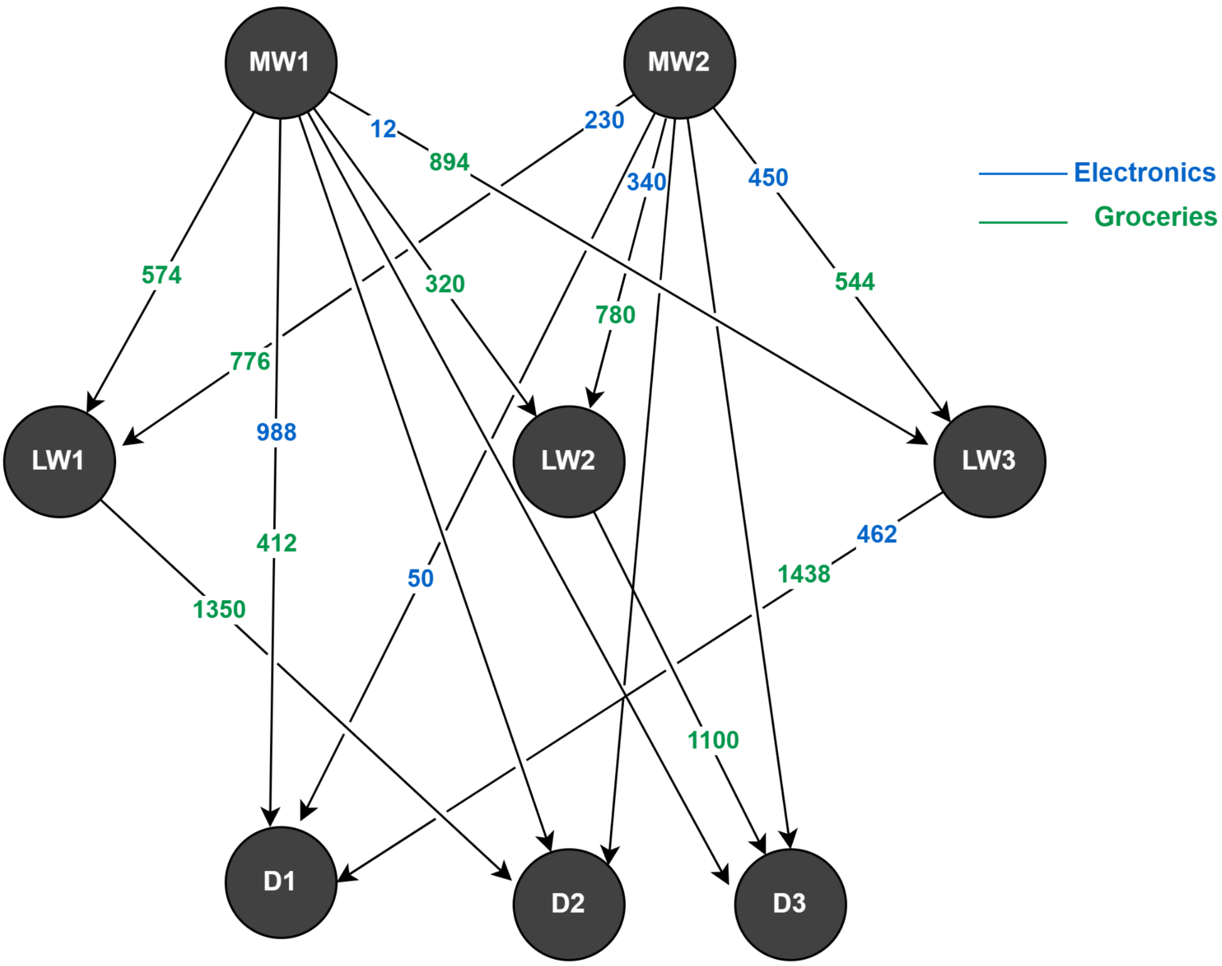
The management board of the JD.ID now faces the need to calculate and try to minimize the cost flow if we begin to supply 2 products instead of one to compete with the other players in the market. Main warehouses now supply the mix of 2 products: groceries and electronics. There are 3 distribution centers, 2 local warehouses and the existence of the 3rd local warehouse is to be decided. It is needed to optimize the cost flow to see if such change can be done and the product range can be expanded while not disrupting the supply chain that already exists.

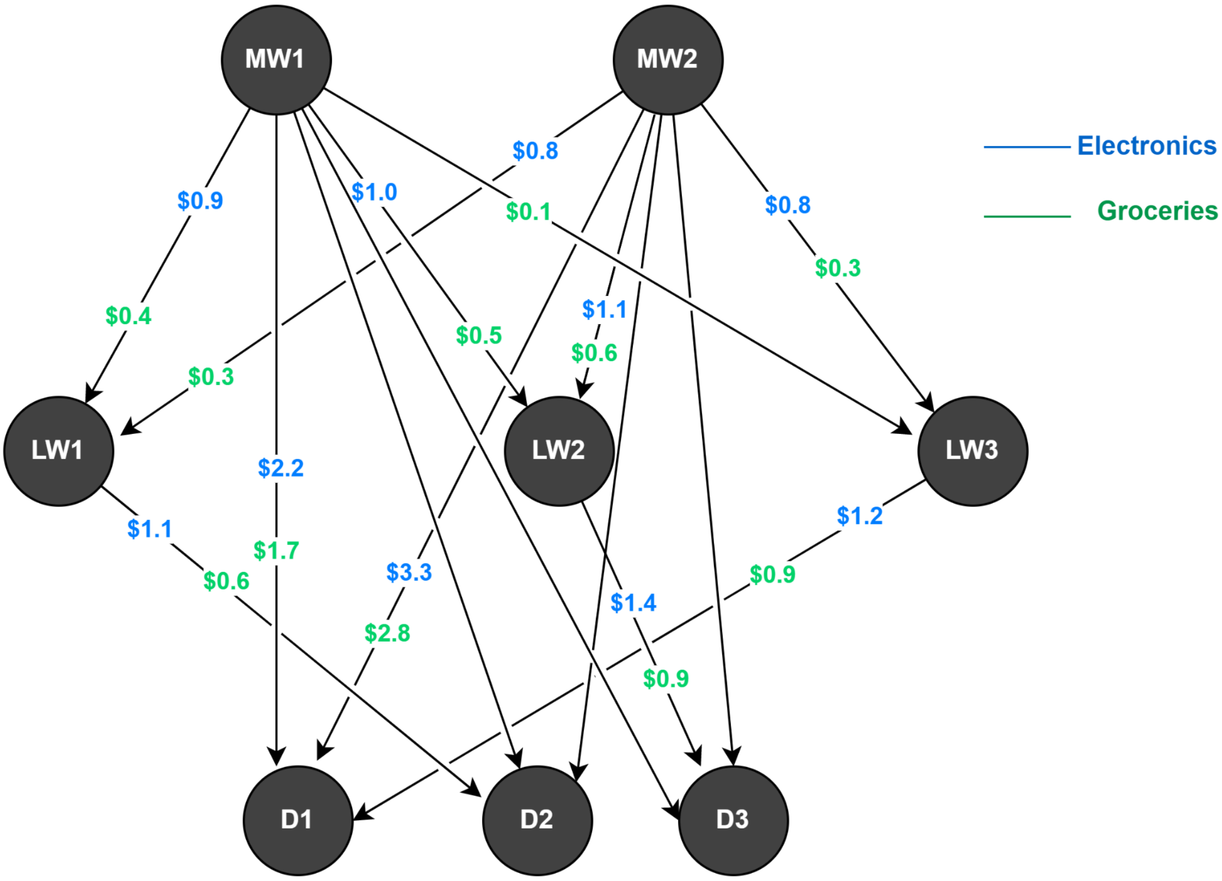
Result: According to the pyomo the most optimal products flow is the following:

```
Optimal solution found

Object function value =  <pyomo.core.base.block._generic_component_decorator object at 0x7fedb148ddb0
x : Flow from Main Warehouse to Local Warehouse
    Size=12, Index=x_index
    Key                            : Lower : Value : Upper : Fixed : Stale : Domain
    ('MW1', 'LW1', 'Electronics') :     0 :   0.0 :  None : False : False : NonNegativeReals
      ('MW1', 'LW1', 'Groceries') :     0 : 574.0 :  None : False : False : NonNegativeReals
    ('MW1', 'LW2', 'Electronics') :     0 :   0.0 :  None : False : False : NonNegativeReals
      ('MW1', 'LW2', 'Groceries') :     0 : 320.0 :  None : False : False : NonNegativeReals
    ('MW1', 'LW3', 'Electronics') :     0 :  12.0 :  None : False : False : NonNegativeReals
      ('MW1', 'LW3', 'Groceries') :     0 : 894.0 :  None : False : False : NonNegativeReals
    ('MW2', 'LW1', 'Electronics') :     0 : 230.0 :  None : False : False : NonNegativeReals
      ('MW2', 'LW1', 'Groceries') :     0 : 776.0 :  None : False : False : NonNegativeReals
    ('MW2', 'LW2', 'Electronics') :     0 : 340.0 :  None : False : False : NonNegativeReals
      ('MW2', 'LW2', 'Groceries') :     0 : 780.0 :  None : False : False : NonNegativeReals
    ('MW2', 'LW3', 'Electronics') :     0 : 450.0 :  None : False : False : NonNegativeReals
      ('MW2', 'LW3', 'Groceries') :     0 : 544.0 :  None : False : False : NonNegativeReals
y : Flow from Main Warehouse to Distribution Center
    Size=12, Index=y_index
    Key                            : Lower : Value : Upper : Fixed : Stale : Domain
    ('MW1', 'DC1', 'Electronics') :     0 : 988.0 :  None : False : False : NonNegativeReals
      ('MW1', 'DC1', 'Groceries') :     0 : 412.0 :  None : False : False : NonNegativeReals
    ('MW1', 'DC2', 'Electronics') :     0 :   0.0 :  None : False : False : NonNegativeReals
      ('MW1', 'DC2', 'Groceries') :     0 :   0.0 :  None : False : False : NonNegativeReals
    ('MW1', 'DC3', 'Electronics') :     0 :   0.0 :  None : False : False : NonNegativeReals
      ('MW1', 'DC3', 'Groceries') :     0 :   0.0 :  None : False : False : NonNegativeReals
    ('MW2', 'DC1', 'Electronics') :     0 :  50.0 :  None : False : False : NonNegativeReals
      ('MW2', 'DC1', 'Groceries') :     0 :   0.0 :  None : False : False : NonNegativeReals
    ('MW2', 'DC2', 'Electronics') :     0 :   0.0 :  None : False : False : NonNegativeReals
      ('MW2', 'DC2', 'Groceries') :     0 :   0.0 :  None : False : False : NonNegativeReals
    ('MW2', 'DC3', 'Electronics') :     0 :   0.0 :  None : False : False : NonNegativeReals
      ('MW2', 'DC3', 'Groceries') :     0 :   0.0 :  None : False : False : NonNegativeReals
```

```
z : Flow from Local Warehouse to Distribution Center
    Size=18, Index=z_index
    Key                             : Lower : Value  : Upper : Fixed : Stale : Domain
    ('LW1', 'DC1', 'Electronics') :     0 :    0.0 :  None : False : False : NonNegativeReals
      ('LW1', 'DC1', 'Groceries') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW1', 'DC2', 'Electronics') :     0 :  230.0 :  None : False : False : NonNegativeReals
      ('LW1', 'DC2', 'Groceries') :     0 : 1350.0 :  None : False : False : NonNegativeReals
    ('LW1', 'DC3', 'Electronics') :     0 :    0.0 :  None : False : False : NonNegativeReals
      ('LW1', 'DC3', 'Groceries') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW2', 'DC1', 'Electronics') :     0 :    0.0 :  None : False : False : NonNegativeReals
      ('LW2', 'DC1', 'Groceries') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW2', 'DC2', 'Electronics') :     0 :    0.0 :  None : False : False : NonNegativeReals
      ('LW2', 'DC2', 'Groceries') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW2', 'DC3', 'Electronics') :     0 :  340.0 :  None : False : False : NonNegativeReals
      ('LW2', 'DC3', 'Groceries') :     0 : 1100.0 :  None : False : False : NonNegativeReals
    ('LW3', 'DC1', 'Electronics') :     0 :  462.0 :  None : False : False : NonNegativeReals
      ('LW3', 'DC1', 'Groceries') :     0 : 1438.0 :  None : False : False : NonNegativeReals
    ('LW3', 'DC2', 'Electronics') :     0 :    0.0 :  None : False : False : NonNegativeReals
      ('LW3', 'DC2', 'Groceries') :     0 :    0.0 :  None : False : False : NonNegativeReals
    ('LW3', 'DC3', 'Electronics') :     0 :    0.0 :  None : False : False : NonNegativeReals
      ('LW3', 'DC3', 'Groceries') :     0 :    0.0 :  None : False : False : NonNegativeReals
o : Whether to open Local Warehouse 3 or not
    Size=3, Index=lw
    Key : Lower : Value : Upper : Fixed : Stale : Domain
    LW1 :     1 :   1.0 :     1 : False : False : Binary
    LW2 :     1 :   1.0 :     1 : False : False : Binary
    LW3 :     0 :   1.0 :     1 : False : False : Binary
```





Local warehouse 3 in case of scenario 3 should be opened as well (the minimum demand for its opening is 3,009 units (1,800 - groceries, 1,209 - electronics), in case of lower figures it will not be opened). We may also see that costs of transportation from the main warehouses to the local warehouse are lower, therefore these routes are used more since the logic of the solution is the following: after considering the cheapest routes and when the capacity of the local warehouse is at its limit compared to the demand, it moves to the arcs from main warehouse to the distribution center (which are more expensive but the main goal is to satisfy the demand).

Solution is feasible with current figures, it is adequate and can be used in real life. Recommendations for the solution of all the scenarios: In the future research it is recommended to take into account the size of keeping units of each product, for example, SKU of electronics is twice as big as SKU groceries, and the sizes of the warehouses in square meters. This will allow to organize the space and transportation in a more precise and real way since every sm will be counted.

Attachments

The project documentation includes the following files:

- Final_Project.jpynb: file with a code for the model and the output