Supply_Chain_Optimization

July 27, 2024

[1]:
```
import pandas as pd
```

1 OrderList

Contains historical records of orders, their respective routing, and costs.

[74]:
```
df_OrderList= pd.read_csv("OrderList.csv")
df_OrderList.head()
```

[74]:

	Order ID	Order Date	Origin Port	Carrier	TPT	Service Level	Ship ahead day count	Ship Late Day count	Customer	Product ID	Plant Code	Destination Port	Unit quantity	Weight
0	1447296447	5/26/2013	PORT09	V44_3	1	CRF	3	0	V55555_53	1700106	PLANT16	PORT09	808	14.30
1	1447158015	5/26/2013	PORT09	V44_3	1	CRF	3	0	V55555_53	1700106	PLANT16	PORT09	3188	87.94
2	1447138899	5/26/2013	PORT09	V44_3	1	CRF	3	0	V55555_53	1700106	PLANT16	PORT09	2331	61.20
3	1447363528	5/26/2013	PORT09	V44_3	1	CRF	3	0	V55555_53	1700106	PLANT16	PORT09	847	16.16
4	1447363981	5/26/2013	PORT09	V44_3	1	CRF	3	0	V55555_53	1700106	PLANT16	PORT09	2163	52.34

[75]:
```
df_OrderList.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 9215 entries, 0 to 9214
Data columns (total 14 columns):
 #   Column                Non-Null Count  Dtype
---  ------                --------------  -----
 0   Order ID              9215 non-null   int64
```

```
 1   Order Date            9215 non-null   object
 2   Origin Port           9215 non-null   object
 3   Carrier               9215 non-null   object
 4   TPT                   9215 non-null   int64
 5   Service Level         9215 non-null   object
 6   Ship ahead day count  9215 non-null   int64
 7   Ship Late Day count   9215 non-null   int64
 8   Customer              9215 non-null   object
 9   Product ID            9215 non-null   int64
 10  Plant Code            9215 non-null   object
 11  Destination Port      9215 non-null   object
 12  Unit quantity         9215 non-null   int64
 13  Weight                9215 non-null   float64
dtypes: float64(1), int64(6), object(7)
memory usage: 1008.0+ KB
```

[76]:
```
df_OrderList.describe()
```

[76]:

	Order ID	TPT	Ship ahead day count	Ship Late Day count	\
count	9.215000e+03	9215.000000	9215.000000	9215.000000	
mean	1.447274e+09	1.717743	1.852306	0.039935	
std	8.381629e+04	0.630500	1.922302	0.319625	
min	1.447126e+09	0.000000	0.000000	0.000000	
25%	1.447197e+09	1.000000	0.000000	0.000000	
50%	1.447276e+09	2.000000	3.000000	0.000000	
75%	1.447346e+09	2.000000	3.000000	0.000000	
max	1.447425e+09	4.000000	6.000000	6.000000	

	Product ID	Unit quantity	Weight
count	9.215000e+03	9215.000000	9215.000000
mean	1.680536e+06	3202.747151	19.871688
std	1.526593e+04	15965.622260	66.569064
min	1.613321e+06	235.000000	0.000000
25%	1.669702e+06	330.000000	1.407430
50%	1.683636e+06	477.000000	4.440000
75%	1.689554e+06	1275.500000	13.325673
max	1.702654e+06	561847.000000	2338.405126

[77]:
```
df_OrderList.isnull().sum()
```

[77]:
```
Order ID               0
Order Date             0
Origin Port            0
Carrier                0
TPT                    0
Service Level          0
Ship ahead day count   0
Ship Late Day count    0
```

```
Customer                0
Product ID              0
Plant Code              0
Destination Port        0
Unit quantity           0
Weight                  0
dtype: int64
```

[78]:
```
df_OrderList.columns
```

[78]:
```
Index(['Order ID', 'Order Date', 'Origin Port', 'Carrier', 'TPT',
       'Service Level', 'Ship ahead day count', 'Ship Late Day count',
       'Customer', 'Product ID', 'Plant Code', 'Destination Port',
       'Unit quantity', 'Weight'],
      dtype='object')
```

[79]:
```
df_OrderList.dtypes
```

[79]:
```
Order ID                 int64
Order Date              object
Origin Port             object
Carrier                 object
TPT                      int64
Service Level           object
Ship ahead day count     int64
Ship Late Day count      int64
Customer                object
Product ID               int64
Plant Code              object
Destination Port        object
Unit quantity            int64
Weight                 float64
dtype: object
```

'Order date' should be converted to date time format

[84]:
```
df_OrderList['Order Date'] = pd.to_datetime(df_OrderList['Order Date'])
df_OrderList['Plant Code'] = df_OrderList['Plant Code'].astype(str)
df_OrderList['Product ID'] = df_OrderList['Product ID'].astype(str)
```

[81]:
```
df_OrderList.dtypes
```

[81]:
```
Order ID                       int64
Order Date            datetime64[ns]
Origin Port                   object
Carrier                       object
TPT                            int64
Service Level                 object
```

```
Ship ahead day count             int64
Ship Late Day count              int64
Customer                        object
Product ID                       int64
Plant Code                      object
Destination Port                object
Unit quantity                    int64
Weight                         float64
dtype: object
```

[82]:
```
# Get unique values for each column in df_OrderList individually
unique_values_df_OrderList = {col: df_OrderList[col].unique() for col in␣
 ↪['Origin Port', 'Carrier', 'Plant Code', 'Destination Port']}
print(unique_values_df_OrderList)
```

```
{'Origin Port': array(['PORT09', 'PORT04', 'PORT05'], dtype=object), 'Carrier':
array(['V44_3', 'V444_0', 'V444_1'], dtype=object), 'Plant Code':
array(['PLANT16', 'PLANT03', 'PLANT08', 'PLANT04', 'PLANT12', 'PLANT09',
       'PLANT13'], dtype=object), 'Destination Port': array(['PORT09'],
dtype=object)}
```

OrderList Deatials are avaialble for Only 'PLANT16', 'PLANT03', 'PLANT08', 'PLANT04', 'PLANT12', 'PLANT09' and Carriers 'V44_3', 'V444_0', 'V444_1'

2 FreightRates

Lists available couriers, their rates based on weight gaps for specific lanes, and estimated shipping times.

[108]:
```
df_FreightRates= pd.read_csv("FreightRates.csv")
df_FreightRates.head()
```

[108]:

	Carrier	orig_port_cd	dest_port_cd	minm_wgh_qty	max_wgh_qty	svc_cd	\
0	V444_6	PORT08	PORT09	250.0	499.99	DTD	
1	V444_6	PORT08	PORT09	65.0	69.99	DTD	
2	V444_6	PORT08	PORT09	60.0	64.99	DTD	
3	V444_6	PORT08	PORT09	50.0	54.99	DTD	
4	V444_6	PORT08	PORT09	35.0	39.99	DTD	

	minimum cost	rate	mode_dsc	tpt_day_cnt	Carrier type
0	$ 43.23	$ 0.71	AIR	2	V88888888_0
1	$ 43.23	$ 0.75	AIR	2	V88888888_0
2	$ 43.23	$ 0.79	AIR	2	V88888888_0
3	$ 43.23	$ 0.83	AIR	2	V88888888_0
4	$ 43.23	$ 1.06	AIR	2	V88888888_0

[12]:
```
df_FreightRates.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 1540 entries, 0 to 1539
Data columns (total 11 columns):
 #   Column        Non-Null Count  Dtype
---  ------        --------------  -----
 0   Carrier       1540 non-null   object
 1   orig_port_cd  1540 non-null   object
 2   dest_port_cd  1540 non-null   object
 3   minm_wgh_qty  1540 non-null   float64
 4   max_wgh_qty   1540 non-null   object
 5   svc_cd        1540 non-null   object
 6   minimum cost  1540 non-null   object
 7   rate          1540 non-null   object
 8   mode_dsc      1540 non-null   object
 9   tpt_day_cnt   1540 non-null   int64
 10  Carrier type  1540 non-null   object
dtypes: float64(1), int64(1), object(9)
memory usage: 132.5+ KB
```

[13]:
```
df_FreightRates.describe()
```

[13]:
```
       minm_wgh_qty  tpt_day_cnt
count   1540.000000  1540.000000
mean     155.886637     2.186364
std      475.952049     2.000895
min        0.000000     0.000000
25%       15.010000     1.000000
50%       41.010000     2.000000
75%       67.229614     2.000000
max    10000.000000    14.000000
```

[14]:
```
df_FreightRates.isnull().sum()
```

[14]:
```
Carrier         0
orig_port_cd    0
dest_port_cd    0
minm_wgh_qty    0
max_wgh_qty     0
svc_cd          0
minimum cost    0
rate            0
mode_dsc        0
tpt_day_cnt     0
Carrier type    0
dtype: int64
```

[15]:
```
df_FreightRates.dtypes
```

[15]:
```
Carrier          object
orig_port_cd     object
dest_port_cd     object
minm_wgh_qty    float64
max_wgh_qty      object
svc_cd           object
minimum cost     object
rate             object
mode_dsc         object
tpt_day_cnt       int64
Carrier type     object
dtype: object
```

As we can see the “minimum cost” and ” rat” are in object datatype and we will convert it to an integer

[109]:
```
df_FreightRates['minimum cost'] = df_FreightRates['minimum cost'].str.
 ↪replace('$', '', regex=False).str.strip().astype(float)
# Convert to int
df_FreightRates['minimum cost'] = df_FreightRates['minimum cost'].astype(int)
df_FreightRates['rate'] = df_FreightRates['rate'].str.replace('$', '',␣
 ↪regex=False).str.strip().astype(float)
df_FreightRates['minm_wgh_qty'] = pd.
 ↪to_numeric(df_FreightRates['minm_wgh_qty'], errors='coerce')
df_FreightRates['max_wgh_qty'] = pd.to_numeric(df_FreightRates['max_wgh_qty'],␣
 ↪errors='coerce')
```

[110]:
```
df_FreightRates.head(2)
```

[110]:

	Carrier	orig_port_cd	dest_port_cd	minm_wgh_qty	max_wgh_qty	svc_cd	minimum cost	rate	mode_dsc	tpt_day_cnt	Carrier type
0	V444_6	PORT08	PORT09	250.0	499.99	DTD	43	0.71	AIR	2	V88888888_0
1	V444_6	PORT08	PORT09	65.0	69.99	DTD	43	0.75	AIR	2	V88888888_0

[19]:
```
# Get unique values for each column individually
unique_values = {col: df_FreightRates[col].unique() for col in ['Carrier',␣
 ↪'orig_port_cd', 'dest_port_cd', 'svc_cd', 'mode_dsc', 'Carrier type']}
print(unique_values)
```

```
{'Carrier': array(['V444_6', 'V444_8', 'V444_9', 'V444_2', 'V444_1', 'V444_0',
       'V444_5', 'V444_4', 'V444_7'], dtype=object), 'orig_port_cd':
array(['PORT08', 'PORT10', 'PORT09', 'PORT11', 'PORT04', 'PORT02',
       'PORT03', 'PORT07', 'PORT05', 'PORT06'], dtype=object), 'dest_port_cd':
array(['PORT09'], dtype=object), 'svc_cd': array(['DTD', 'DTP'], dtype=object),
'mode_dsc': array(['AIR   ', 'GROUND'], dtype=object), 'Carrier type':
```

```
array(['V88888888_0', 'V888888883_1'], dtype=object)}
```

3 PlantPorts

Specifies allowed links between warehouses and shipping ports.

[20]:
```
df_PlantPorts= pd.read_csv("PlantPorts.csv")
df_PlantPorts.head()
```

[20]:

	Plant Code	Port
0	PLANT01	PORT01
1	PLANT01	PORT02
2	PLANT02	PORT03
3	PLANT03	PORT04
4	PLANT04	PORT05

[21]:
```
df_PlantPorts.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 22 entries, 0 to 21
Data columns (total 2 columns):
 #   Column      Non-Null Count  Dtype
---  ------      --------------  -----
 0   Plant Code  22 non-null     object
 1   Port        22 non-null     object
dtypes: object(2)
memory usage: 484.0+ bytes
```

[22]:
```
df_PlantPorts.describe()
```

[22]:

	Plant Code	Port
count	22	22
unique	19	11
top	PLANT01	PORT04
freq	2	7

[23]:
```
df_PlantPorts.isnull().sum()
```

[23]:
```
Plant Code    0
Port          0
dtype: int64
```

[24]:
```
df_PlantPorts.dtypes
```

[24]:
```
Plant Code    object
Port          object
dtype: object
```

4 ProductsPerPlant

Lists supported warehouse-product combinations.

[25]:
```
df_ProductsPerPlant= pd.read_csv("ProductsPerPlant.csv")
df_ProductsPerPlant.head()
```

[25]:

	Plant Code	Product ID
0	PLANT15	1698815
1	PLANT17	1664419
2	PLANT17	1664426
3	PLANT17	1672826
4	PLANT17	1674916

[26]:
```
df_ProductsPerPlant.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 2036 entries, 0 to 2035
Data columns (total 2 columns):
 #   Column      Non-Null Count  Dtype 
---  ------      --------------  ----- 
 0   Plant Code  2036 non-null   object
 1   Product ID  2036 non-null   int64 
dtypes: int64(1), object(1)
memory usage: 31.9+ KB
```

[27]:
```
df_ProductsPerPlant.isnull().sum()
```

[27]:
```
Plant Code    0
Product ID    0
dtype: int64
```

[28]:
```
print(df_ProductsPerPlant['Plant Code'].nunique())
print(df_ProductsPerPlant['Plant Code'].unique())
```

```
19
['PLANT15' 'PLANT17' 'PLANT18' 'PLANT05' 'PLANT02' 'PLANT01' 'PLANT06'
 'PLANT10' 'PLANT07' 'CND9' 'PLANT14' 'PLANT16' 'PLANT12' 'PLANT11'
 'PLANT09' 'PLANT03' 'PLANT13' 'PLANT08' 'PLANT04']
```

[29]:
```
df_ProductsPerPlant['Product ID'].nunique()
```

[29]:
```
1540
```

5 VmiCustomers

Lists special cases where a warehouse is only allowed to support specific customers.

[30]:
```
df_VmiCustomers= pd.read_csv("VmiCustomers.csv")
df_VmiCustomers.head()
```

[30]:

	Plant Code	Customers
0	PLANT02	V5555555555555_16
1	PLANT02	V555555555555555_29
2	PLANT02	V555555555_3
3	PLANT02	V55555555555555_8
4	PLANT02	V55555555_9

[123]:
```
df_VmiCustomers.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 14 entries, 0 to 13
Data columns (total 2 columns):
 #   Column      Non-Null Count  Dtype
---  ------      --------------  -----
 0   Plant Code  14 non-null     object
 1   Customers   14 non-null     object
dtypes: object(2)
memory usage: 356.0+ bytes
```

[32]:
```
df_VmiCustomers.describe()
```

[32]:

	Plant Code	Customers
count	14	14
unique	4	10
top	PLANT02	V55555_10
freq	7	3

6 WhCapacities

Specifies the maximum number of orders that can be processed by each warehouse per day.

[125]:
```
df_WhCapacities= pd.read_csv("WhCapacities.csv")
df_WhCapacities.head()
```

[125]:

	Plant ID	Daily Capacity
0	PLANT15	11
1	PLANT17	8
2	PLANT18	111
3	PLANT05	385
4	PLANT02	138

[37]:
```
# Strip trailing spaces from column names
df_WhCapacities.columns = df_WhCapacities.columns.str.strip()
```

[38]:
```
df_WhCapacities.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 19 entries, 0 to 18
Data columns (total 2 columns):
 #   Column          Non-Null Count  Dtype
---  ------          --------------  -----
 0   Plant ID        19 non-null     object
 1   Daily Capacity  19 non-null     int64
dtypes: int64(1), object(1)
memory usage: 436.0+ bytes
```

[39]:
```
df_WhCapacities.describe()
```

[39]:

	Daily Capacity
count	19.000000
mean	304.789474
std	323.513280
min	7.000000
25%	31.500000
50%	209.000000
75%	473.500000
max	1070.000000

7 WhCosts

Lists the cost associated with storing products in each warehouse.

[131]:
```
df_WhCosts= pd.read_csv("WhCosts.csv")
df_WhCosts.head()
```

[131]:

	WH	Cost/unit
0	PLANT15	1.42
1	PLANT17	0.43
2	PLANT18	2.04
3	PLANT05	0.49
4	PLANT02	0.48

[44]:
```
df_WhCosts.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 19 entries, 0 to 18
Data columns (total 2 columns):
 #   Column     Non-Null Count  Dtype
---  ------     --------------  -----
 0   WH         19 non-null     object
 1   Cost/unit  19 non-null     float64
dtypes: float64(1), object(1)
memory usage: 436.0+ bytes
```

[45]:
```
df_WhCosts.describe()
```

[45]:

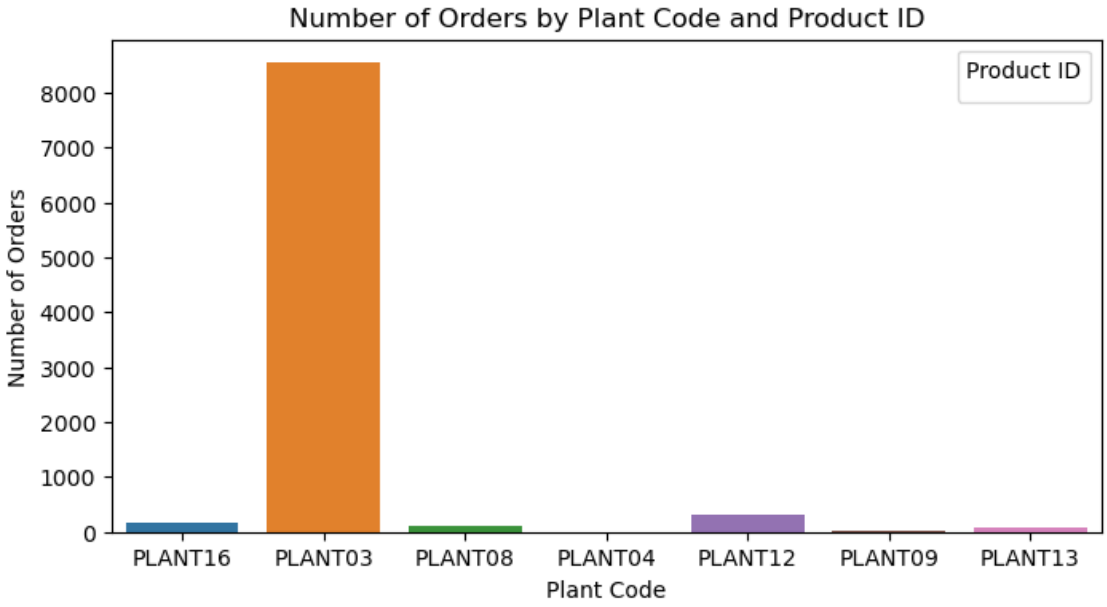
	Cost/unit
count	19.000000
mean	0.724737
std	0.495820
min	0.370000
25%	0.475000
50%	0.520000
75%	0.635000
max	2.040000

8 Exploratory Data Analysis(EDA)

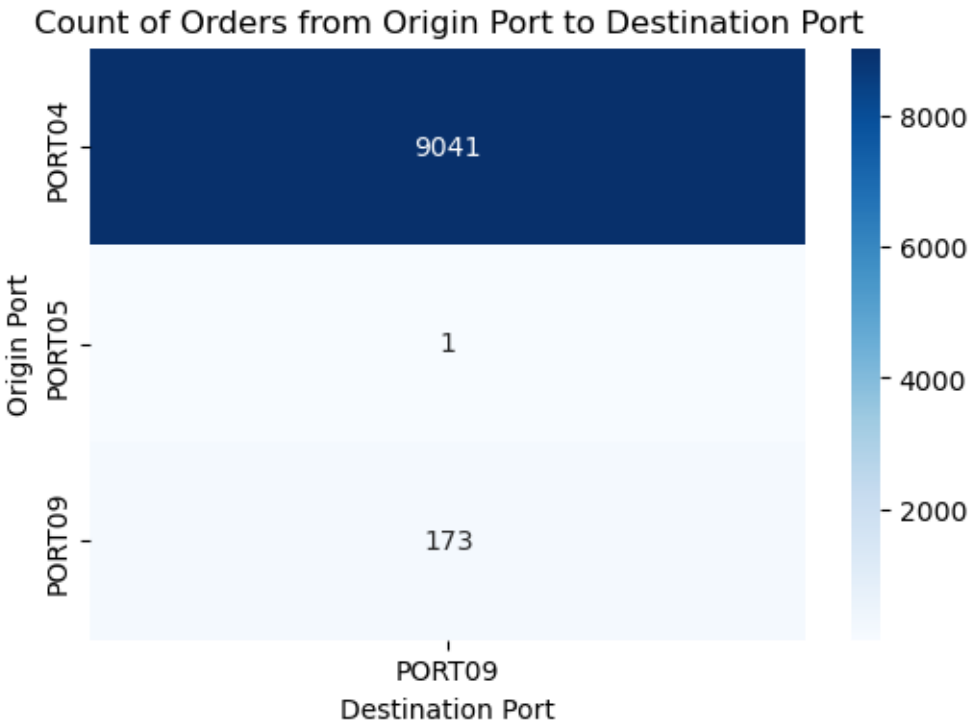
[71]:
```
import matplotlib.pyplot as plt
import seaborn as sns
```

[87]:
```
# Bar plot: Count of orders per Plant Code
plt.figure(figsize=(8, 4))
sns.countplot(x='Plant Code', data=df_OrderList)
plt.title('Number of Orders by Plant Code and Product ID')
plt.xlabel('Plant Code')
plt.ylabel('Number of Orders')
plt.legend(title='Product ID')
plt.show()
```

```
No artists with labels found to put in legend.  Note that artists whose label
start with an underscore are ignored when legend() is called with no argument.
```

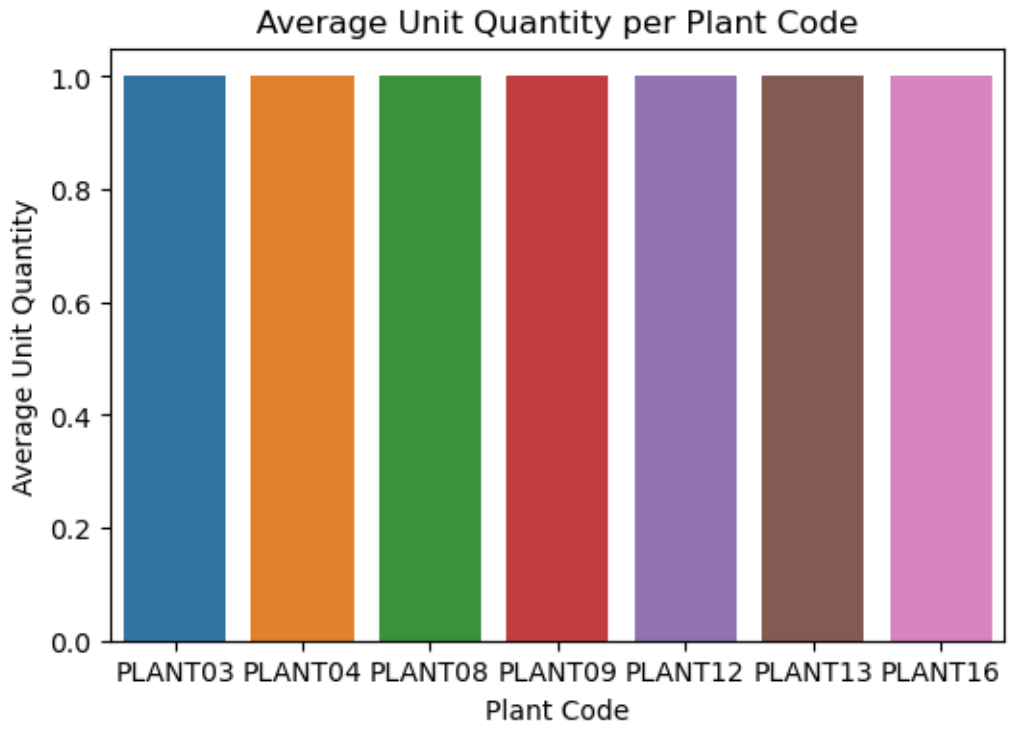


[94]:
```
pivot_table = df_OrderList.pivot_table(index='Origin Port',␣
↪columns='Destination Port', aggfunc='size', fill_value=0)

# Plot heatmap
plt.figure(figsize=(6, 4))
sns.heatmap(pivot_table, annot=True, cmap='Blues', cbar=True, fmt='d')
plt.title('Count of Orders from Origin Port to Destination Port')
plt.xlabel('Destination Port')
plt.ylabel('Origin Port')
plt.show()
```



[97]:
```
# Calculate the average of Unit quantity per Plant Code
average_unit_quantity = df_OrderList.groupby('Plant Code')['Unit quantity'].
↪mean().reset_index()

# Rename columns for clarity
average_unit_quantity.columns = ['Plant Code', 'Average Unit Quantity']

# Plot heatmap
plt.figure(figsize=(6, 4))
```

```
sns.countplot(x='Plant Code', data=average_unit_quantity)
plt.title('Average Unit Quantity per Plant Code')
plt.xlabel('Plant Code')
plt.ylabel('Average Unit Quantity')
plt.show()
```



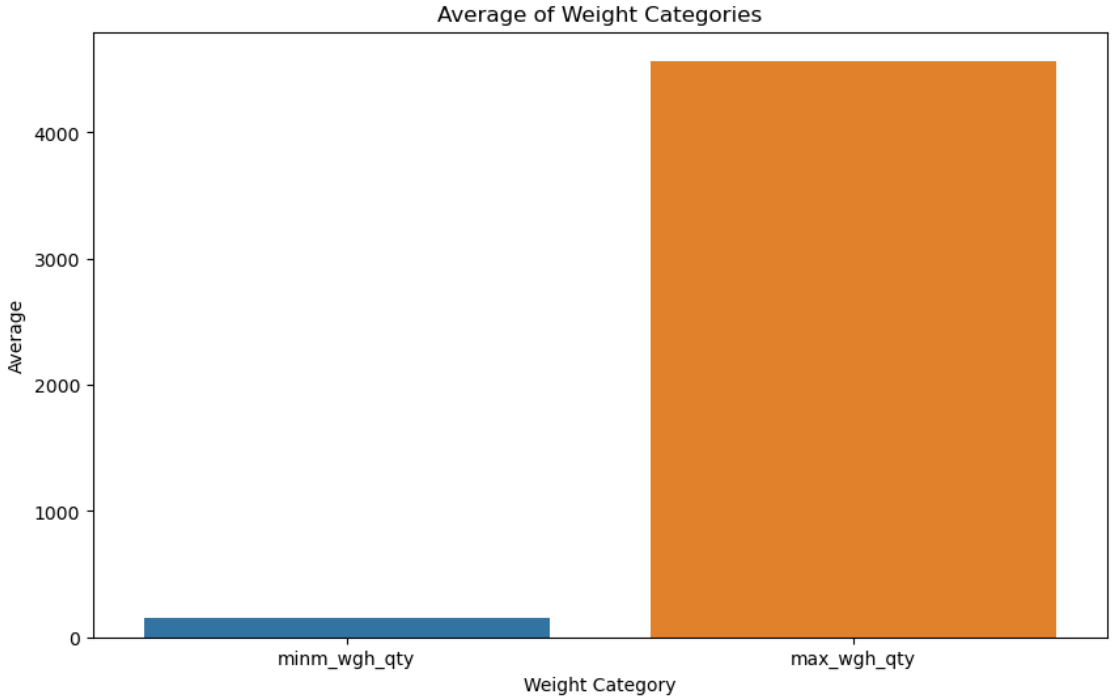
[112]:
```
# Calculate the average of minm_wgh_qty and max_wgh_qty
averages = df_FreightRates[['minm_wgh_qty', 'max_wgh_qty']].mean().reset_index()
averages
```

[112]:

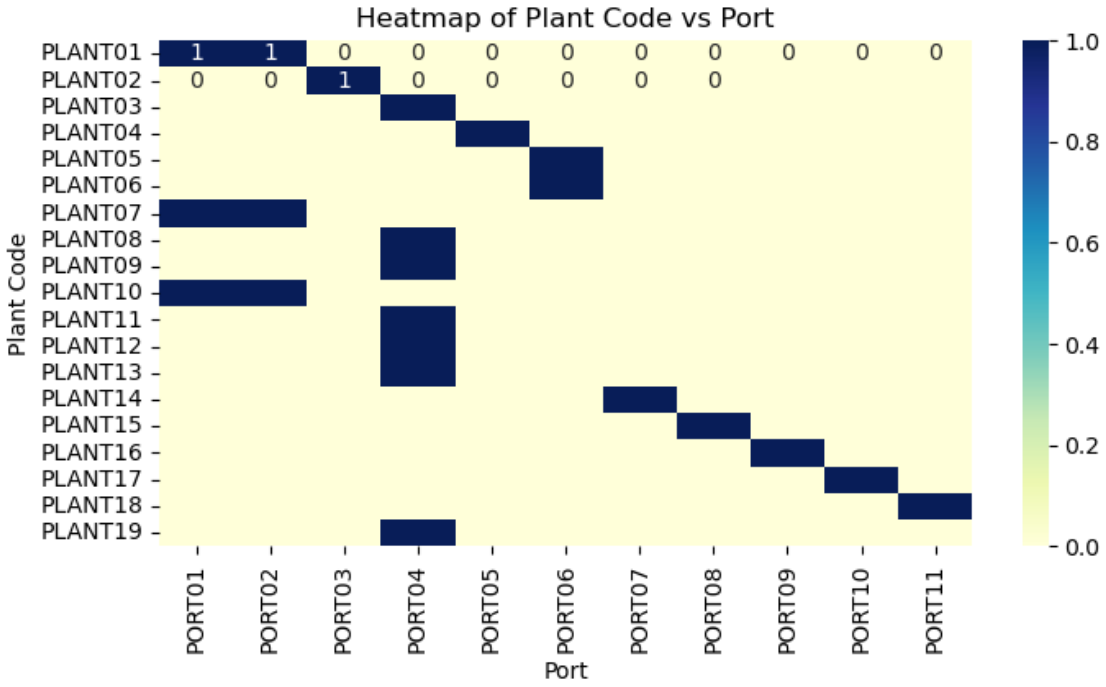
	index	0
0	minm_wgh_qty	155.886637
1	max_wgh_qty	4570.091943

[114]:
```
# Rename columns for clarity
averages.columns = ['Weight Category', 'Average']

# Prepare data for plotting
plot_data = averages.melt(id_vars='Weight Category', var_name='Category',␣
 ↪value_name='Avg_Value')

# Plot
plt.figure(figsize=(10, 6))
```

```
sns.barplot(x='Weight Category', y='Avg_Value', data=plot_data)
plt.title('Average of Weight Categories')
plt.xlabel('Weight Category')
plt.ylabel('Average')
plt.show()
```

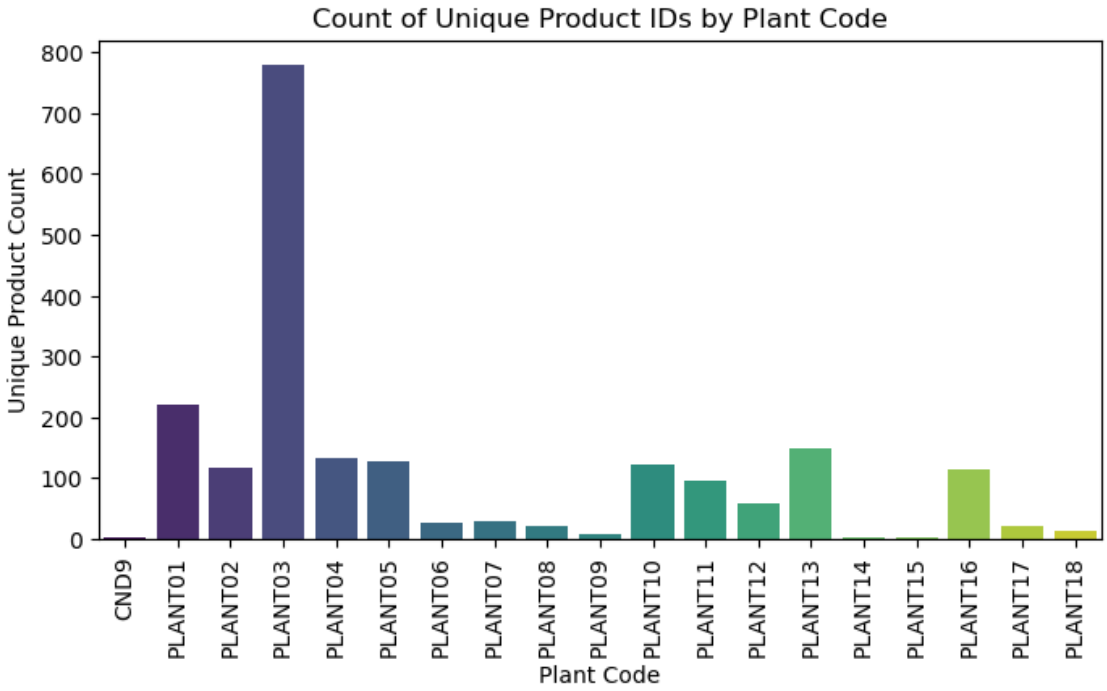


[117]:
```
# Aggregate data by count
heatmap_data = pd.crosstab(df_PlantPorts['Plant Code'], df_PlantPorts['Port'])

plt.figure(figsize=(8, 4))
sns.heatmap(heatmap_data, annot=True, cmap='YlGnBu', fmt='d')
plt.title('Heatmap of Plant Code vs Port')
plt.xlabel('Port')
plt.ylabel('Plant Code')
plt.show()
```

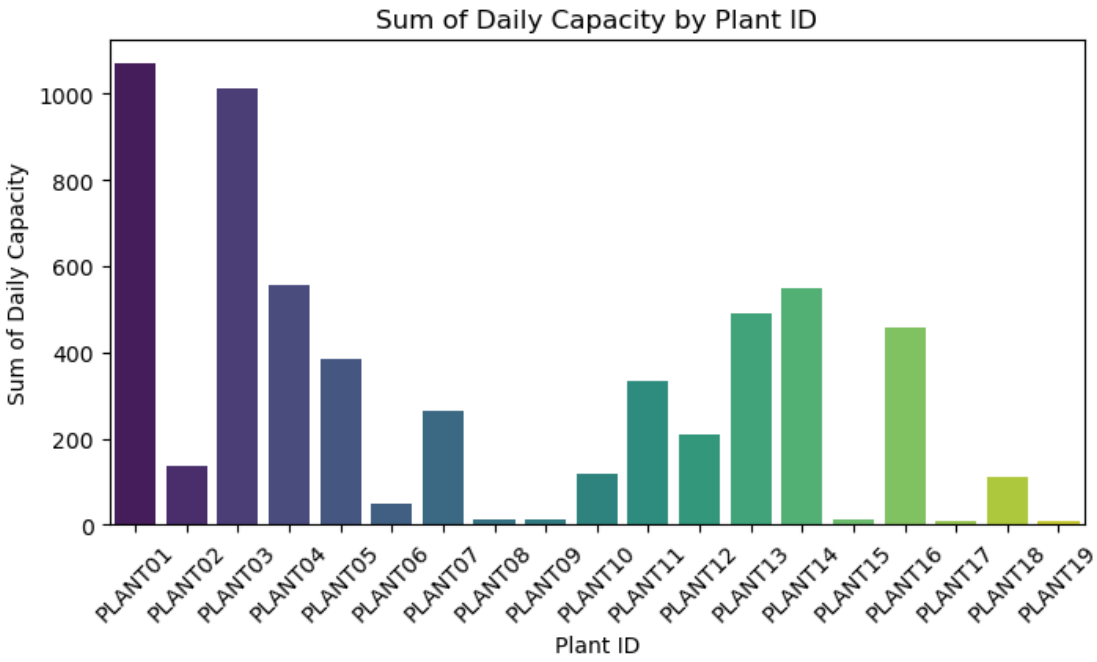


[118]:
```
# Count unique Product IDs for each Plant Code
unique_product_counts = df_ProductsPerPlant.groupby('Plant Code')['Product ID'].
 ↪nunique().reset_index()
unique_product_counts.columns = ['Plant Code', 'Unique Product Count']
```

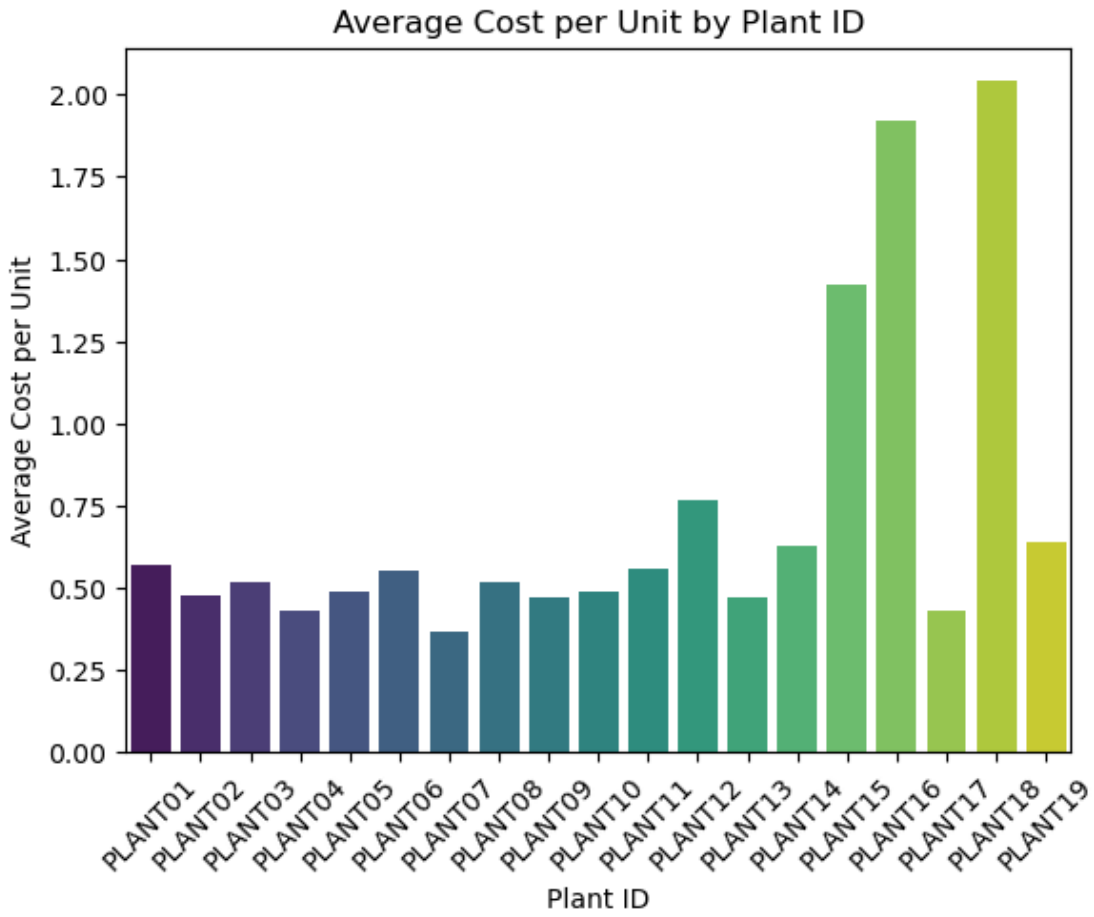
[120]:
```
plt.figure(figsize=(8, 4))
sns.barplot(x='Plant Code', y='Unique Product Count',␣
 ↪data=unique_product_counts, palette='viridis')
plt.title('Count of Unique Product IDs by Plant Code')
plt.xlabel('Plant Code')
plt.ylabel('Unique Product Count')
plt.xticks(rotation=90)

plt.show()
```



[128]:
```
# Aggregate the data
capacity_sum = df_WhCapacities.groupby('Plant ID')['Daily Capacity '].sum().
 ↪reset_index()

# Plot
plt.figure(figsize=(8, 4))
sns.barplot(x='Plant ID', y='Daily Capacity ', data=capacity_sum,␣
 ↪palette='viridis')
plt.title('Sum of Daily Capacity by Plant ID')
plt.xlabel('Plant ID')
plt.ylabel('Sum of Daily Capacity')

# Rotate x-axis
plt.xticks(rotation=45)

plt.show()
```



[135]:
```
# Calculate the average cost per unit by Plant ID
average_cost_per_unit = df_WhCosts.groupby('Plant ID')['Cost/unit'].mean().
 ↪reset_index()
average_cost_per_unit.columns = ['Plant ID', 'Average Cost per Unit']

# Plot
sns.barplot(x='Plant ID', y='Average Cost per Unit',␣
 ↪data=average_cost_per_unit, palette='viridis')
plt.title('Average Cost per Unit by Plant ID')
plt.xlabel('Plant ID')
plt.ylabel('Average Cost per Unit')
plt.xticks(rotation=45)
plt.show()
```



[ ]:

9 1.Historical Cost Calculation:

[140]:
```
# Rename column 'Plant Code' from df_OrderList  for consistency
df_OrderList = df_OrderList.rename(columns={'Plant Code': 'Plant ID'})
df_WhCosts = df_WhCosts.rename(columns ={'WH':'Plant ID' })
```

[141]:
```
# Merge the dataframes on 'WH' and 'Product ID'
merged_df = pd.merge(df_OrderList, df_WhCosts, on='Plant ID')
```

[142]:
```
# Calculate the total historical cost
merged_df['Total Cost'] = merged_df['Unit quantity'] * merged_df['Cost/unit']

# Sum up the total costs to get the overall historical cost of order fulfillment
total_historical_cost = merged_df['Total Cost'].sum()
```

```
print(f"Total Historical Cost of Order Fulfillment: {total_historical_cost}")
```

```
Total Historical Cost of Order Fulfillment: 15704718.23
```

10 2.Capacity Utilization:

[143]:
```
# Group the orders by warehouse and date, and count the number of orders per day
daily_order_counts = df_OrderList.groupby(['Plant ID', 'Order Date']).size().
 ↪reset_index(name='Daily Orders')
daily_order_counts
```

[143]:

	Plant ID	Order Date	Daily Orders
0	PLANT03	2013-05-26	8541
1	PLANT04	2013-05-26	1
2	PLANT08	2013-05-26	102
3	PLANT09	2013-05-26	12
4	PLANT12	2013-05-26	300
5	PLANT13	2013-05-26	86
6	PLANT16	2013-05-26	173

[144]:
```
# Merge the daily order counts with warehouse capacities
merged_df = pd.merge(daily_order_counts, df_WhCapacities, on='Plant ID')
merged_df
```

[144]:

	Plant ID	Order Date	Daily Orders	Daily Capacity
0	PLANT03	2013-05-26	8541	1013
1	PLANT04	2013-05-26	1	554
2	PLANT08	2013-05-26	102	14
3	PLANT09	2013-05-26	12	11
4	PLANT12	2013-05-26	300	209
5	PLANT13	2013-05-26	86	490
6	PLANT16	2013-05-26	173	457

[147]:
```
# Calculate capacity utilization
merged_df['Capacity Utilization'] = (merged_df['Daily Orders'] /␣
 ↪merged_df['Daily Capacity ']) * 100

# Group by Plant ID to get average capacity utilization for each plant
capacity_utilization_summary = merged_df.groupby('Plant ID')['Capacity␣
 ↪Utilization'].mean().reset_index()

print(capacity_utilization_summary)
```

	Plant ID	Capacity Utilization
0	PLANT03	843.139191
1	PLANT04	0.180505
2	PLANT08	728.571429

```
3  PLANT09            109.090909
4  PLANT12            143.540670
5  PLANT13             17.551020
6  PLANT16             37.855580
```

11 3.Freight Cost Analysis:

[149]:
```
# Ensuring columns match for merge
df_OrderList.rename(columns={'Origin Port': 'orig_port_cd', 'Destination Port':␣
 ↪'dest_port_cd'}, inplace=True)

# Merge the DataFrames
df_merged = pd.merge(df_OrderList, df_FreightRates, how='left', on=['Carrier',␣
 ↪'orig_port_cd', 'dest_port_cd'])
df_merged.head(2)
```

[149]:
```
     Order ID Order Date orig_port_cd Carrier  TPT Service Level  \
0  1447296447 2013-05-26       PORT09   V44_3    1           CRF
1  1447158015 2013-05-26       PORT09   V44_3    1           CRF

   Ship ahead day count  Ship Late Day count   Customer Product ID  …  \
0                     3                    0  V55555_53    1700106  …
1                     3                    0  V55555_53    1700106  …

  Unit quantity Weight  minm_wgh_qty  max_wgh_qty  svc_cd  minimum cost rate  \
0           808  14.30           NaN          NaN     NaN            NaN  NaN
1          3188  87.94           NaN          NaN     NaN            NaN  NaN

   mode_dsc  tpt_day_cnt Carrier type
0       NaN          NaN          NaN
1       NaN          NaN          NaN

[2 rows x 22 columns]
```

[153]:
```
# Calculate the freight cost for each order
df_merged['Freight Cost'] = df_merged['minimum cost'] + (df_merged['Weight'] *␣
 ↪df_merged['rate'])
df_merged.head(2)
```

[153]:
```
     Order ID Order Date orig_port_cd Carrier  TPT Service Level  \
0  1447296447 2013-05-26       PORT09   V44_3    1           CRF
1  1447158015 2013-05-26       PORT09   V44_3    1           CRF

   Ship ahead day count  Ship Late Day count   Customer Product ID  …  \
0                     3                    0  V55555_53    1700106  …
1                     3                    0  V55555_53    1700106  …
```

```
   Weight minm_wgh_qty  max_wgh_qty  svc_cd  minimum cost  rate mode_dsc  \
0   14.30          NaN          NaN     NaN           NaN   NaN      NaN
1   87.94          NaN          NaN     NaN           NaN   NaN      NaN

    tpt_day_cnt  Carrier type Freight Cost
0           NaN           NaN          NaN
1           NaN           NaN          NaN

[2 rows x 23 columns]
```

[164]:
```
# Summarize the total freight costs
total_freight_cost = df_merged['Freight Cost'].sum()
print(f"The total Freight Cost is:${total_freight_cost}")
```

```
The total Freight Cost is:$2461358.2234439584
```

12 4. Optimization Model:

Before building Optimization model, Lets take a look at the constraints of the given data:

Problem Constraints: Warehouse Capacities: Each warehouse has a maximum capacity of orders it can handle per day (WhCapacities).

Product-Warehouse Compatibility: Only specific products can be stored in specific warehouses (ProductsPerPlant).

Customer-Warehouse Restrictions: Some customers can only be served by specific warehouses (VmiCustomers).

Freight Costs: Transportation costs depend on the weight of the shipment and the distance between source and destination (FreightRates).

Transportation Time: Estimated shipping time is considered for optimal route planning (tpt_day_cnt in FreightRates).

Storage Costs: Costs associated with storing products in warehouses (WhCosts).

[165]:
```
from pulp import LpMinimize, LpProblem, LpVariable, lpSum, LpStatus
```

[183]:
```
def run_optimization(wh_capacities, wh_costs, df_FreightRates, df_OrderList,␣
↪products_per_warehouse, customer_warehouse_restrictions):
    # Initialize the LP problem
    prob = LpProblem("OrderRoutingOptimization", LpMinimize)

    # Create list of orders with needed details
    orders = df_OrderList[['Customer', 'Product ID', 'Unit quantity', 'Weight',␣
↪'orig_port_cd', 'dest_port_cd', 'Carrier']].values.tolist()

    # Create the decision variables
```

```
    x = LpVariable.dicts("ship", [(order[0], order[1], warehouse) for order in orders for warehouse in wh_capacities.keys()], 0, None, cat='Continuous')

    # Objective function: Minimize total cost (storage + freight)
    objective_terms = []

    HIGH_DEFAULT_COST = 1e6  # High but finite default cost

    for order in orders:
        for warehouse in wh_capacities.keys():
            wh_cost = wh_costs.get(warehouse, HIGH_DEFAULT_COST)  # Use HIGH_DEFAULT_COST if no cost found

            rate_query = df_FreightRates[
                (df_FreightRates['orig_port_cd'] == order[4]) &
                (df_FreightRates['dest_port_cd'] == order[5]) &
                (df_FreightRates['Carrier'] == order[6])
            ]

            if not rate_query.empty:
                rate = rate_query['rate'].values[0]
            else:
                rate = HIGH_DEFAULT_COST

            if not pd.isna(wh_cost) and not pd.isna(rate):
                objective_terms.append(x[(order[0], order[1], warehouse)] * (wh_cost + rate))

    prob += lpSum(objective_terms)

    # Constraints
    # 1. Warehouse Capacities
    for warehouse in wh_capacities.keys():
        prob += lpSum([x[(order[0], order[1], warehouse)] for order in orders]) <= wh_capacities[warehouse]

    # 2. Product-Warehouse Compatibility
    for order in orders:
        for warehouse in wh_capacities.keys():
            if (warehouse, order[1]) not in products_per_warehouse:
                prob += x[(order[0], order[1], warehouse)] == 0

    # 3. Customer-Warehouse Restrictions
    for order in orders:
        for warehouse in wh_capacities.keys():
            if (warehouse, order[0]) not in customer_warehouse_restrictions:
                prob += x[(order[0], order[1], warehouse)] == 0
```

```
    # 4. Demand fulfillment
    for order in orders:
        prob += lpSum([x[(order[0], order[1], warehouse)] for warehouse in␣
↪wh_capacities.keys()]) == order[2]

    # Solve the problem
    prob.solve()


    # Collect results
    results = {
        'status': LpStatus[prob.status],
        'total_cost': prob.objective.value(),
        'shipment_plan': [(order[0], order[1], warehouse, x[(order[0],␣
↪order[1], warehouse)].varValue)
                          for order in orders for warehouse in wh_capacities.
↪keys()
                          if x[(order[0], order[1], warehouse)].varValue > 0]
    }

    return results
```

[184]:
```
result = run_optimization(wh_capacities, wh_costs, df_FreightRates,␣
↪df_OrderList, products_per_warehouse, customer_warehouse_restrictions)
print(result)
```

```
{'status': 'Infeasible', 'total_cost': 1396895732949.3647, 'shipment_plan':
[('V55555555_32', '1699574', 'PLANT17', 139689.0), ('V55555555_32', '1699574',
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```

```
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469247.0), ('V55555555_5', '1684862', 'PLANT04', 469247.0), ('V55555555_5',
'1684862', 'PLANT04', 469247.0)]}
```

13 5.Scenario Analysis:

[185]:
```
import copy

# Define base parameters
base_wh_capacities = df_WhCapacities.set_index('Plant ID')['Daily Capacity '].
 ↪to_dict()
base_wh_costs = df_WhCosts.set_index('Plant ID')['Cost/unit'].to_dict()
base_products_per_warehouse = {(row['Plant Code'], row['Product ID']): True for␣
 ↪index, row in df_ProductsPerPlant.iterrows()}
base_customer_warehouse_restrictions = {(row['Plant Code'], row['Customers']):␣
 ↪True for index, row in df_VmiCustomers.iterrows()}
```

[186]:
```
# Scenario 1: Increase warehouse capacities by 20%
scenario_1_wh_capacities = {k: v * 1.2 for k, v in base_wh_capacities.items()}
scenario_1_results = run_optimization(scenario_1_wh_capacities, base_wh_costs,␣
 ↪df_FreightRates, df_OrderList, base_products_per_warehouse,␣
 ↪base_customer_warehouse_restrictions)

# Scenario 2: Decrease freight rates by 10%
scenario_2_FreightRates = df_FreightRates.copy()
scenario_2_FreightRates['rate'] *= 0.9
scenario_2_results = run_optimization(base_wh_capacities, base_wh_costs,␣
 ↪scenario_2_FreightRates, df_OrderList, base_products_per_warehouse,␣
 ↪base_customer_warehouse_restrictions)

# Scenario 3: Change product compatibility (add one more compatible␣
 ↪product-warehouse pair)
scenario_3_products_per_warehouse = copy.deepcopy(base_products_per_warehouse)
scenario_3_products_per_warehouse[('PLANT18', 'ProductC')] = True
scenario_3_results = run_optimization(base_wh_capacities, base_wh_costs,␣
 ↪df_FreightRates, df_OrderList, scenario_3_products_per_warehouse,␣
 ↪base_customer_warehouse_restrictions)

# Print results for comparison
print("Base Scenario Total Cost:", run_optimization(base_wh_capacities,␣
 ↪base_wh_costs, df_FreightRates, df_OrderList, base_products_per_warehouse,␣
 ↪base_customer_warehouse_restrictions)['total_cost'])
print("Scenario 1 Total Cost (20% increase in warehouse capacities):",␣
 ↪scenario_1_results['total_cost'])
print("Scenario 2 Total Cost (10% decrease in freight rates):",␣
 ↪scenario_2_results['total_cost'])
print("Scenario 3 Total Cost (additional product compatibility):",␣
 ↪scenario_3_results['total_cost'])
```

```
Base Scenario Total Cost: 1396895732949.3647
Scenario 1 Total Cost (20% increase in warehouse capacities): 1396895732946.175
Scenario 2 Total Cost (10% decrease in freight rates): 1396895679487.88
Scenario 3 Total Cost (additional product compatibility): 1396895732949.3647
```

[190]:
```
# save the dataframes to csv for creating dashboard

df_OrderList.to_csv('OrderList.csv', index=False)
df_FreightRates.to_csv('FreightRates.csv',index=False)
df_PlantPorts.to_csv('PlantPorts.csv',index=False)
df_ProductsPerPlant.to_csv('ProductsPerPlant.csv',index=False)
df_VmiCustomers.to_csv('VmiCustomers.csv',index=False)
df_WhCapacities.to_csv('WhCapacities.csv',index=False)
df_WhCosts.to_csv('WhCosts.csv',index=False)
```

[ ]: