In [80]:

```
import numpy as np
import pandas as pd
import networkx as nx
import matplotlib.pyplot as plt
import plotly.graph_objects as go
import seaborn as sns

!pip install openpyxl
!pip install pulp

import pulp

from google.colab import drive
drive.mount('/content/drive')
```

```
Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels
/public/simple/
Requirement already satisfied: openpyxl in /usr/local/lib/python3.7/dist-packages (
3.0.10)
Requirement already satisfied: et-xmlfile in /usr/local/lib/python3.7/dist-packages
(from openpyxl) (1.1.0)
Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels
/public/simple/
Requirement already satisfied: pulp in /usr/local/lib/python3.7/dist-packages (2.6.
0)
Drive already mounted at /content/drive; to attempt to forcibly remount, call drive
.mount("/content/drive", force_remount=True).
```

In [81]:

```
# reading in all the csv files
file = pd.ExcelFile("/content/drive/MyDrive/ACO/KAGGLE/Supply chain logisitcs probl
em.xlsx")
plant_ports = file.parse("PlantPorts")
order_list = file.parse("OrderList")
products_plants = file.parse("ProductsPerPlant")
vmi_plants = file.parse("VmiCustomers")
freight_rates = file.parse("FreightRates")
wh_cost = file.parse("WhCosts")
wh_capacities = file.parse("WhCapacities")
```

In [82]:

```
# Data cleaning for order_list

# order_list format conversion
order_list['TPT'] = order_list['TPT'].astype(int)
order_list['Ship ahead day count'] = order_list['Ship ahead day count'].astype(int)
order_list['Ship Late Day count'] = order_list['Ship Late Day count'].astype(int)
order_list['Unit quantity'] = order_list['Unit quantity'].astype(int)
order_list['Weight'] = order_list['Weight'].astype(float)
# drop nulls form order_list
order_list.dropna(inplace=True)
# drop duplicates from order_list
order_list.drop_duplicates(inplace=True)

# Data cleaning for freight_rates

# freight_rates format conversion
```

```
freight_rates['minm_wgh_qty'] = freight_rates['minm_wgh_qty'].astype(int)
freight_rates['max_wgh_qty'] = freight_rates['max_wgh_qty'].astype(float)
freight_rates['minimum cost'] = freight_rates['minimum cost'].astype(float)
freight_rates['rate'] = freight_rates['rate'].astype(float)
freight_rates['tpt_day_cnt'] = freight_rates['tpt_day_cnt'].astype(int)
# drop nulls form freight_rates
freight_rates.dropna(inplace=True)
# drop duplicates from freight_rates
freight_rates.drop_duplicates(inplace=True)

# Data cleaning for wh_cost

# wh_cost format conversion
wh_cost['Cost/unit'] = wh_cost['Cost/unit'].astype(float)
# drop nulls form wh_cost
wh_cost.dropna(inplace=True)
# drop duplicates from wh_cost
wh_cost.drop_duplicates(inplace=True)

# Data cleaning for wh_capacities

# wh_cost format conversion
wh_capacities['Daily Capacity '] = wh_capacities['Daily Capacity '].astype(int)
# drop nulls form wh_capacities
wh_capacities.dropna(inplace=True)
# drop duplicates from wh_capacities
wh_capacities.drop_duplicates(inplace=True)

# Data cleaning for products_plants

# drop nulls form products_plants
products_plants.dropna(inplace=True)
# drop duplicates from products_plants
products_plants.drop_duplicates(inplace=True)

# Data cleaning for vmi_plants

# drop nulls form vmi_plants
vmi_plants.dropna(inplace=True)
# drop duplicates from vmi_plants
vmi_plants.drop_duplicates(inplace=True)

# Data cleaning for

# drop nulls form plant_ports
plant_ports.dropna(inplace=True)
# drop duplicates from plant_ports
plant_ports.drop_duplicates(inplace=True)
```

In [83]:

```
print(order_list.info())
```

```
<class 'pandas.core.frame.DataFrame'>
Int64Index: 9215 entries, 0 to 9214
Data columns (total 14 columns):
 #   Column                Non-Null Count  Dtype
---  ------                --------------  -----
 0   Order ID              9215 non-null   float64
 1   Order Date            9215 non-null   datetime64[ns]
 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: datetime64[ns](1), float64(2), int64(5), object(6)
memory usage: 1.1+ MB
None
```

In [84]:

```
print(freight_rates.info())
```

```
<class 'pandas.core.frame.DataFrame'>
Int64Index: 1537 entries, 0 to 1539
Data columns (total 11 columns):
 #   Column         Non-Null Count  Dtype
---  ------         --------------  -----
 0   Carrier        1537 non-null   object
 1   orig_port_cd   1537 non-null   object
 2   dest_port_cd   1537 non-null   object
 3   minm_wgh_qty   1537 non-null   int64
 4   max_wgh_qty    1537 non-null   float64
 5   svc_cd         1537 non-null   object
 6   minimum cost   1537 non-null   float64
 7   rate           1537 non-null   float64
 8   mode_dsc       1537 non-null   object
 9   tpt_day_cnt    1537 non-null   int64
 10  Carrier type   1537 non-null   object
dtypes: float64(3), int64(2), object(6)
memory usage: 144.1+ KB
None
```

In [85]:

```
print(wh_cost.info())
```

```
<class 'pandas.core.frame.DataFrame'>
Int64Index: 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: 456.0+ bytes
None
```

In [86]:

```
print(wh_cost.info())
```

```
<class 'pandas.core.frame.DataFrame'>
Int64Index: 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: 456.0+ bytes
None
```

In [87]:

```
print(products_plants.info())
```

```
<class 'pandas.core.frame.DataFrame'>
Int64Index: 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: 47.7+ KB
None
```

In [88]:

```
print(vmi_plants.info())
```

```
<class 'pandas.core.frame.DataFrame'>
Int64Index: 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: 336.0+ bytes
None
```

In [89]:

```
print(plant_ports.info())
```

```
<class 'pandas.core.frame.DataFrame'>
Int64Index: 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: 528.0+ bytes
None
```

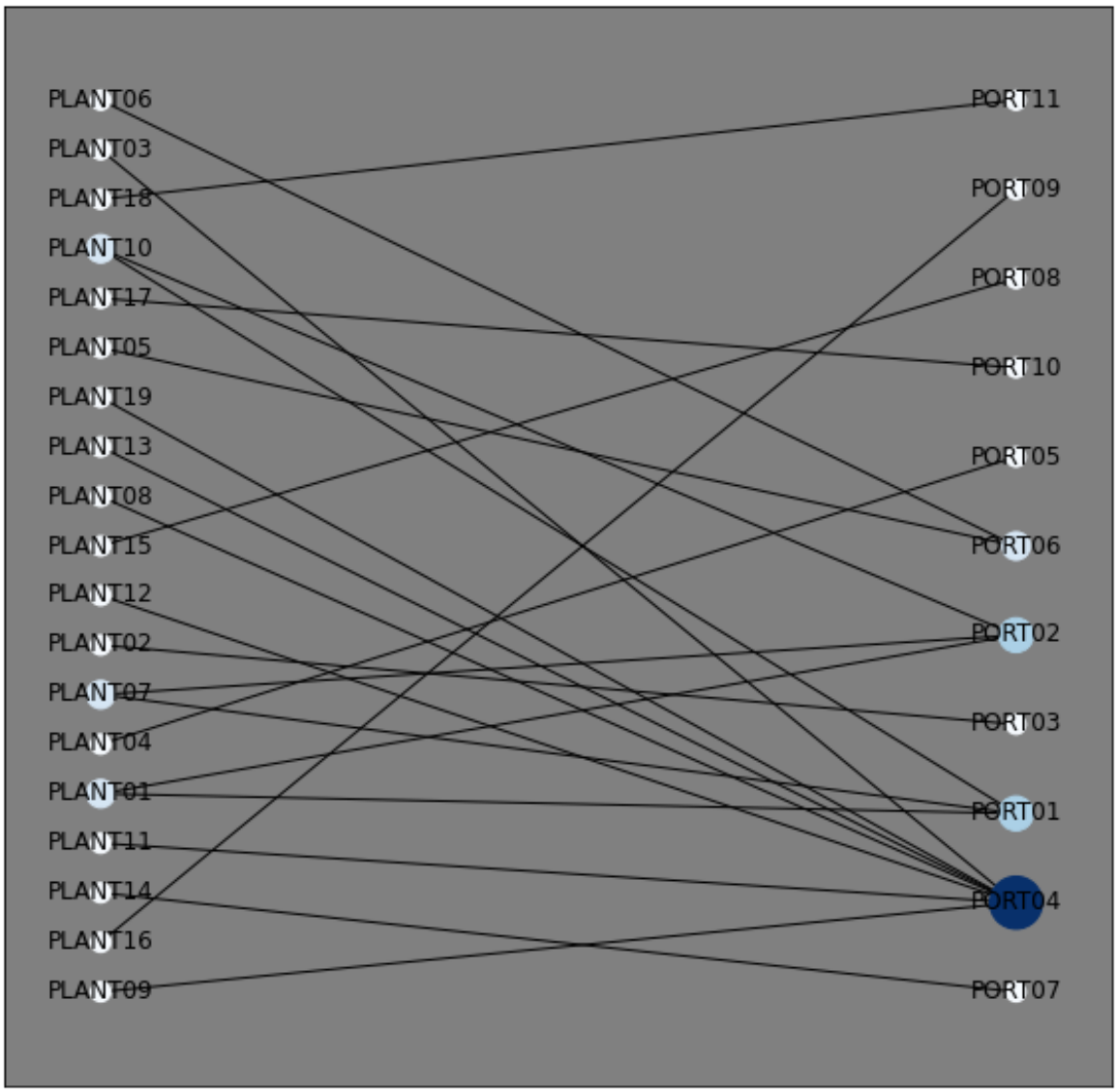
In [90]:

```
# changing column names
order_list.columns = [i.replace(" ", "_") for i in order_list.columns]
products_plants.columns = [i.replace(" ", "_") for i in products_plants.columns]
plant_ports.columns = [i.replace(" ", "_") for i in plant_ports.columns]
vmi_plants.columns = [i.replace(" ", "_") for i in vmi_plants.columns]
wh_cost.set_index("WH", inplace=True)

plant_ports_graph = nx.from_pandas_edgelist(plant_ports, source="Plant_Code", targe
t="Port")
```

In [91]:

```
fig, ax = plt.subplots(figsize=(10,10))
ax.set_facecolor("Grey")

# specify layout for the graph
```

```
# layout = nx.bipartite_layout(plant_ports_graph, plant_ports["Plant Code"])

layout = nx.bipartite_layout(plant_ports_graph, plant_ports["Plant_Code"])

for i in layout:
    if i.startswith("PLANT"):
        layout[i][0] -= 0.1
    else:
        layout[i][0] += 0.1

# we want to map the degree of the node to a color/size
degrees = dict(plant_ports_graph.degree)
maps = [v*100 for v in degrees.values()]

# specify the color map
cmap = plt.cm.Blues

# keyword args that are the same for both functions
kwargs = {"pos":layout, "ax":ax}

nx.draw_networkx_nodes(plant_ports_graph, node_size=maps, node_color=maps, cmap=cma
p, **kwargs)
nx.draw_networkx_edges(plant_ports_graph, **kwargs)
nx.draw_networkx_labels(plant_ports_graph, pos=layout)
plt.show()
```



In [92]:

```
# get starting and ending points of the edges and add them to the graph
layout = nx.bipartite_layout(plant_ports_graph, plant_ports["Plant_Code"])
```

```
edge_x = []
edge_y = []

for edge in plant_ports_graph.edges():
    x0, y0 = layout[edge[0]]
    x1, y1 = layout[edge[1]]

    edge_x.append(x0)
    edge_x.append(x1)
    edge_x.append(None)
    edge_y.append(y0)
    edge_y.append(y1)
    edge_y.append(None)

edge_trace = go.Scatter(
    x=edge_x, y=edge_y,
    line=dict(width=0.5, color='#25488e'),
    hoverinfo='none',
    mode='lines')

# get coordinated of nodes and add them to the graph

node_x = []
node_y = []
for node in plant_ports_graph.nodes():
    x, y = layout[node]
    node_x.append(x)
    node_y.append(y)

maps = [v for v in degrees.values()]

node_trace = go.Scatter(
    x=node_x, y=node_y,
    mode='markers',
    hoverinfo='text',
    marker=dict(
        showscale=True,
        colorscale='YlGnBu',
        reversescale=True,
        color=maps,
        size=10,
        colorbar=dict(
            thickness=15,
            title='Node Connections',
            xanchor='left',
            titleside='right'
        ),
        line_width=2))

node_trace.text = [i + " Number of Links: " + str(degrees[i]) for i in degrees]

fig = go.Figure(data=[edge_trace, node_trace],
             layout=go.Layout(
                title='<br>Supply Chain',
                titlefont_size=16,
                showlegend=False,
                hovermode='closest',
                margin=dict(b=20,l=5,r=5,t=40),
                annotations=[dict(text="Factories",
                     showarrow=False,
                     xref="paper", yref="paper",
                     x=0.005, y=-0.002 ),
                             dict(text="Ports",
```

```
                    showarrow=False,
                    xref="paper", yref="paper",
                    x=0.95, y=-0.002 )],
                  xaxis=dict(showgrid=True, zeroline=False, showticklabels=True),
                  yaxis=dict(showgrid=True, zeroline=False, showticklabels=True))
                  )
fig
```

Most facilities have only one connection to a port. Port 4 is potentially the most important one as it has the most connections to the warehouses.

Preparing the Order Table The existing order table already contains a solution. We will delete those columns.

In [93]:

```
order_new = order_list.drop(columns=["Order_Date", "Origin_Port", "Carrier", "Plant
_Code", "TPT", "Service_Level", "Ship_ahead_day_count", "Ship_Late_Day_count"])
order_new.set_index("Order_ID", inplace=True)
order_new.to_csv("order_new.csv")
```

Preparing Freight Table

In [94]:

```
freight_rates.drop(columns=["dest_port_cd", "Carrier type", "svc_cd"], inplace=True
)
freight_rates.to_csv("FreightRates_mod.csv")
```

Problem Restrictions

In [95]:

```
# given a product id, return the plants that can produce this product.
def product_restriction(index):
    data = order_new.loc[index]
    product_id = data["Product_ID"]
    possible_plants = products_plants.loc[products_plants["Product_ID"] == product_
id]
    return np.array(possible_plants["Plant_Code"])

# vmi restriction: check if a given customer has to be serviced by a specific
facility, else return all facilities as possibilities.
def customer_restriction(index):
    data = order_new.loc[index]
    Customer_id = data["Customer"]
    possible_plants = vmi_plants.loc[vmi_plants["Customers"] == Customer_id]
    if list(possible_plants["Plant_Code"]) == []:
        return plant_ports["Plant_Code"].unique()
    else:
        return np.array(possible_plants["Plant_Code"])

# combine both the product and vmi restriction. There will be orders for which
only one, or possibly even 0, facilities can fullfil it.
def check_order(Order_Id, length=True):
    if length:
        return len(np.intersect1d(customer_restriction(Order_Id),
product_restriction(Order_Id)))
    else:
        return np.intersect1d(customer_restriction(Order_Id), product_restriction(O
rder_Id))

# under the restrictions above, we can calculate the number of facilities that can
process a given order.
order_new["decision_space_size"] = np.array(list(map(check_order, order_new.index))
)
```

In [96]:

```
order_new["decision_space_size"].value_counts()
```

Out[96]:

```
1    6275
0    1045
4     982
2     785
3     127
5       1
Name: decision_space_size, dtype: int64
```

We can see that for most orders, there is only one facility that can handle the order. For ~1,000 there is no possible facility that can handle the order given our problem restrictions, we will exclude these orders from our further optimization problem.

Assigning orders

Instead of using the specific rate for a carrier we will aggregate the rates for a given port. The main problem is that rates range from 0.03 to 128 which makes it hard to know the unit of measurement (e.g. €/kg or €/unit). Therefore I will average the rates for each port and use those as the costs.

In [97]:

```
freight_rates["rate"].describe()
```

Out[97]:

```
count    1537.000000
mean        2.875135
std         4.590475
min         0.033200
25%         0.451200
50%         1.656800
75%         3.916800
max       128.027200
Name: rate, dtype: float64
```

In [98]:

```
ports_agg = freight_rates.groupby(["orig_port_cd"]).agg(avg_rate=("rate", np.mean))
# we will exclude orders that cannot be processed by any facility (i.e. where the
decision space size == 0)
order_new = order_new.loc[order_new.decision_space_size != 0]
# return the possible plants that can process the order.
order_new["decision_space_plants"] = np.array((map(lambda x: check_order(x, length=
False), order_new.index)))

def min_cost(dec_space):

    plant_port_cost = {}

    wh = wh_cost.copy()
    min_cost = np.inf

    for plant in dec_space:
        plant_port_cost[plant] = wh.loc[plant].iloc[0]
        port_price, port = find_best_port(plant)
        plant_port_cost[plant] += port_price

        if plant_port_cost[plant] < min_cost:
            min_cost = plant_port_cost[plant]
            best_plant = plant
            best_port = port
            best_port_price = port_price

    return min_cost, best_plant, best_port_price, best_port

# given a port and the order specifications return the carrier that can handle the
product at the best price.
def find_best_port(plant_id):
    # choose the ports that have a connection to the given plant and then find the
port with the lowest freight rate
    possible_ports = plant_ports.loc[(plant_ports.Plant_Code == plant_id) &
(plant_ports.Port != "PORT01"), "Port"]
    possible_ports = ports_agg.loc[possible_ports]
    return possible_ports.loc[possible_ports["avg_rate"] ==
min(possible_ports["avg_rate"])].iloc[0]["avg_rate"],
possible_ports.loc[possible_ports["avg_rate"] == min(possible_ports["avg_rate"])].i
loc[0].name

order_new["decision"] = order_new["decision_space_plants"].apply(min_cost)
```

In [99]:

```
order_new["decision"]
```

Out[99]:

```
Order_ID
1.447296e+09    (4.7563741745191, PLANT16, 2.8365666666666662,...
1.447158e+09    (4.7563741745191, PLANT16, 2.8365666666666662,...
1.447139e+09    (4.7563741745191, PLANT16, 2.8365666666666662,...
1.447364e+09    (4.7563741745191, PLANT16, 2.8365666666666662,...
1.447364e+09    (4.7563741745191, PLANT16, 2.8365666666666662,...
                                      ...
1.447372e+09        (10.321903518927222, PLANT02, 9.8444, PORT03)
1.447372e+09        (10.321903518927222, PLANT02, 9.8444, PORT03)
1.447328e+09        (10.321903518927222, PLANT02, 9.8444, PORT03)
1.447358e+09        (10.321903518927222, PLANT02, 9.8444, PORT03)
1.447287e+09        (10.321903518927222, PLANT02, 9.8444, PORT03)
Name: decision, Length: 8170, dtype: object
```

In [100]:

```
decision = order_new["decision"].tolist()
lenn = len(decision)
min_cost_list = []
for i in range(lenn):
  min_cost_list.append(decision[i][0])
best_plant_list = []
for i in range(lenn):
  best_plant_list.append(decision[i][1])
best_port_price_list = []
for i in range(lenn):
  best_port_price_list.append(decision[i][2])
best_port_list = []
for i in range(lenn):
  best_port_list.append(decision[i][3])

decision_dataframe = pd.DataFrame(
    {'min_cost': min_cost_list,
     'best_plant': best_plant_list,
     'best_port_price': best_port_price_list,
     'best_port': best_port_list,
    })
```

In [101]:

```
decision_dataframe
```

Out[101]:

	min_cost	best_plant	best_port_price	best_port
0	4.756374	PLANT16	2.836567	PORT09
1	4.756374	PLANT16	2.836567	PORT09
2	4.756374	PLANT16	2.836567	PORT09
3	4.756374	PLANT16	2.836567	PORT09
4	4.756374	PLANT16	2.836567	PORT09
...	...	...	...	...
8165	10.321904	PLANT02	9.844400	PORT03
8166	10.321904	PLANT02	9.844400	PORT03
8167	10.321904	PLANT02	9.844400	PORT03
8168	10.321904	PLANT02	9.844400	PORT03

	min_cost	best_plant	best_port_price	best_port
8169	10.321904	PLANT02	9.844400	PORT03

8170 rows × 4 columns

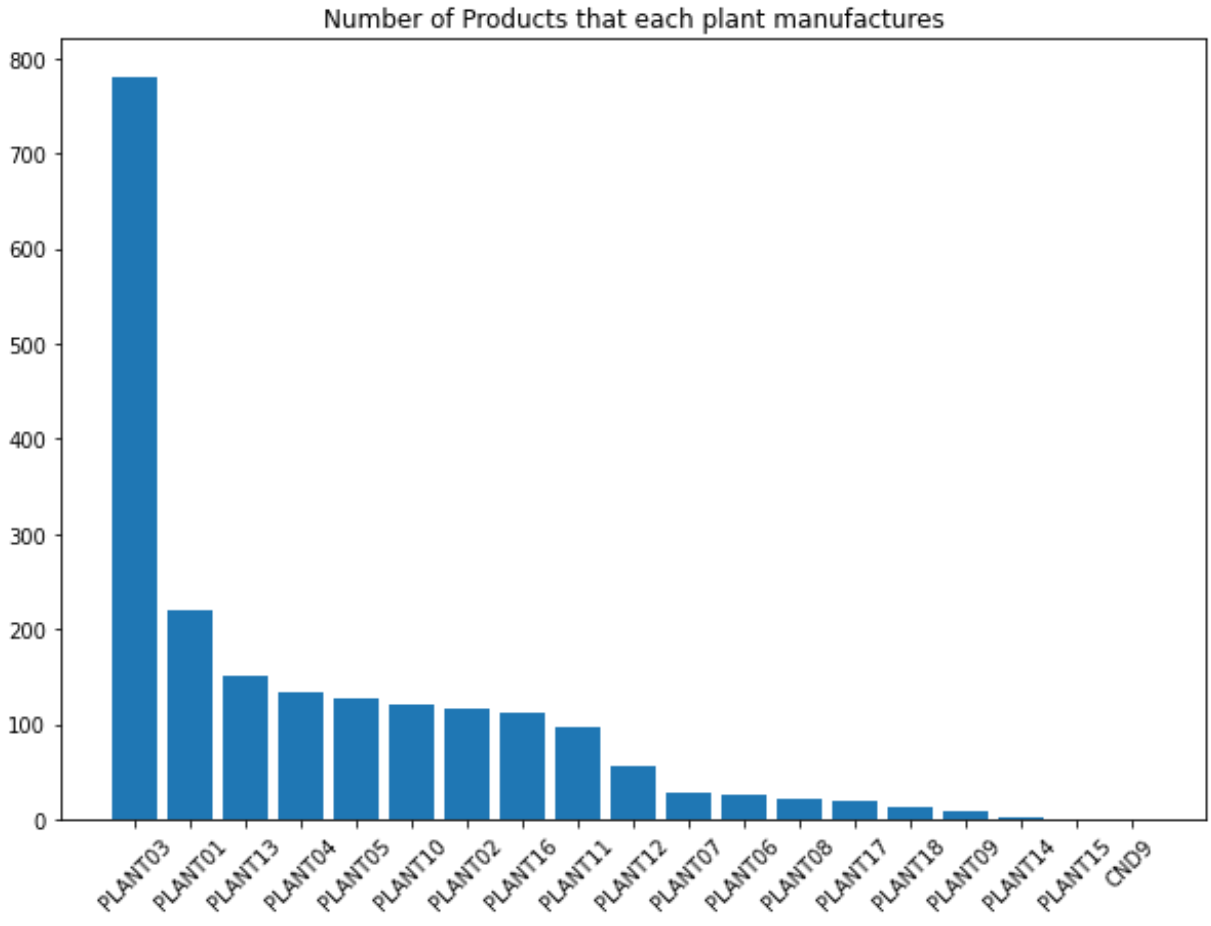
In [102]:

```
from google.colab import drive

drive.mount('/content/drive')
path = '/content/drive/MyDrive/ACO/KAGGLE/decision.csv'

with open(path, 'w', encoding = 'utf-8-sig') as f:
  decision_dataframe.to_csv('decision.csv', sep='\t', encoding='utf-8')
```

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call drive
.mount("/content/drive", force_remount=True).
```

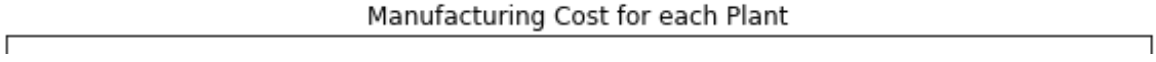
In [103]:

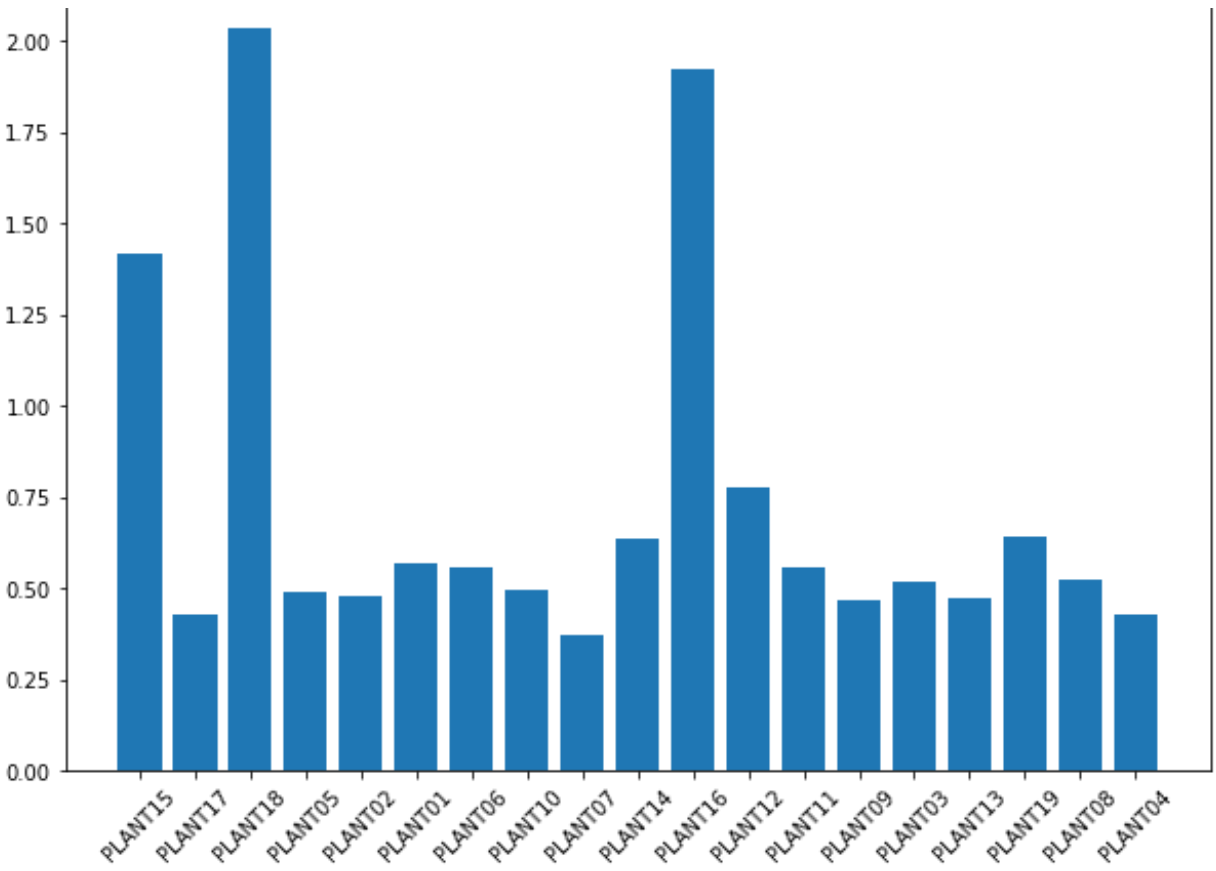
```
fig, ax = plt.subplots(1,1, figsize=(10,7))
plt.xticks(rotation=45)
plant_counts = pd.DataFrame(products_plants["Plant_Code"].value_counts())
ax.bar(plant_counts.index, plant_counts["Plant_Code"])
plt.title("Number of Products that each plant manufactures")
plt.show()
```



In [104]:

```
fig, ax = plt.subplots(1,1, figsize=(10,7))
plt.xticks(rotation=45)
ax.bar(wh_cost.index, wh_cost["Cost/unit"])
plt.title("Manufacturing Cost for each Plant")
plt.show()
```




2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
PLANT15
PLANT17
PLANT18
PLANT05
PLANT02
PLANT01
PLANT06
PLANT10
PLANT07
PLANT14
PLANT16
PLANT12
PLANT11
PLANT09
PLANT03
PLANT13
PLANT19
PLANT08
PLANT04