

```
In [1]: import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
from collections import defaultdict
```

```
In [2]: df_salesOrder = pd.read_excel('Input Data/Sales Orders.xlsx')
df_salesOrder.head()
```

```
Out[2]:
```

	Plant	MATERIAL_NUMBER	SALES_ORDER	SALES_ORDER_ITEM	SALES_ORDER_ITEM_CREATE_DATE_FISCAL_WEEK	SALES_ORDER_I
0	WH1	ITM3249	29273582	50		7
1	WH1	ITM6	29273582	30		7
2	WH1	ITM3249	29273582	20		7
3	WH1	ITM2103	29311350	440		8
4	WH1	ITM2103	29311350	310		8

```
In [3]: df_salesOrder['SALES_ORDER'] = df_salesOrder['SALES_ORDER'].astype('str')
```

```
In [4]: df_salesOrder['MATERIAL_NUMBER'].value_counts()
```

```
Out[4]:
```

ITM2103	3422
ITM5010	1069
ITM742	734
ITM5011	562
ITM1130	557
...	
ITM2924	1
ITM5353	1
ITM5116	1
ITM5257	1
ITM770	1

Name: MATERIAL_NUMBER, Length: 3180, dtype: int64

```
In [5]: df = df_salesOrder[['MATERIAL_NUMBER', 'SALES_ORDER']].drop_duplicates()
df['MATERIAL_NUMBER'].value_counts().to_frame()
```

```
Out[5]:
```

MATERIAL_NUMBER	
ITM742	674

MATERIAL_NUMBER	
ITM5010	576
ITM1130	553
ITM2103	523
ITM157	463
...	...
ITM2924	1
ITM5353	1
ITM5116	1
ITM5257	1
ITM770	1

3180 rows × 1 columns

```
In [6]: Order_freq = df_salesOrder['MATERIAL_NUMBER'].value_counts().to_frame()
Order_freq = Order_freq.reset_index()
Order_freq = Order_freq.rename(columns={"MATERIAL_NUMBER": "Order Count", "index": "MATERIAL_NUMBER"})
Order_freq.head()
```

```
Out[6]:
```

	MATERIAL_NUMBER	Order Count
0	ITM2103	3422
1	ITM5010	1069
2	ITM742	734
3	ITM5011	562
4	ITM1130	557

```
In [7]: distinctOrder_freq = df['MATERIAL_NUMBER'].value_counts().to_frame()
distinctOrder_freq = distinctOrder_freq.reset_index()
distinctOrder_freq = distinctOrder_freq.rename(columns={"MATERIAL_NUMBER": "Order Count", "index": "MATERIAL_NUMBER"})
distinctOrder_freq.head()
```

```
Out[7]:
```

	MATERIAL_NUMBER	Order Count
--	-----------------	-------------

	MATERIAL_NUMBER	Order Count
0	ITM742	674
1	ITM5010	576
2	ITM1130	553
3	ITM2103	523
4	ITM157	463

```
In [8]: df_salesOrder.shape
```

```
Out[8]: (68895, 7)
```

```
In [9]: Total_salesOrderLines = df_salesOrder.shape[0]
Total_salesOrderLines
```

```
Out[9]: 68895
```

```
In [10]: Total_distinct_salesOrders = df_salesOrder.SALES_ORDER.nunique()
Total_distinct_salesOrders
```

```
Out[10]: 18998
```

```
In [11]: Total_distinct_Products_sold = df_salesOrder.MATERIAL_NUMBER.nunique()
Total_distinct_Products_sold
```

```
Out[11]: 3180
```

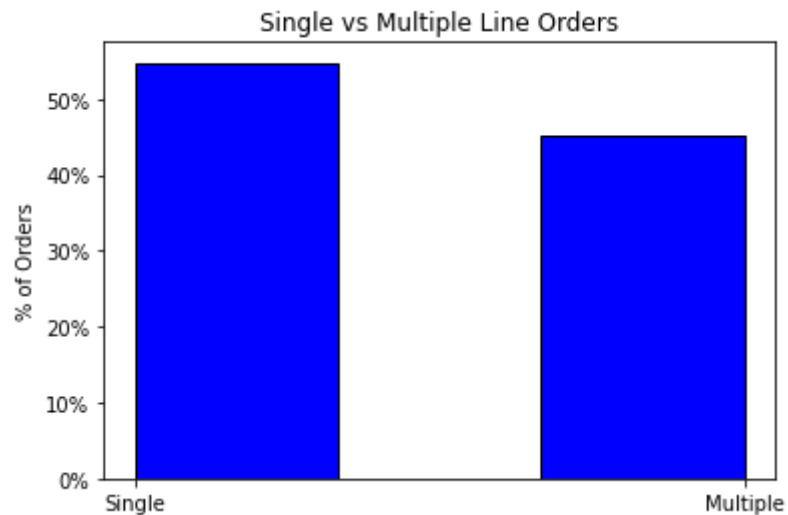
```
In [12]: df = df_salesOrder[['MATERIAL_NUMBER', 'SALES_ORDER']].drop_duplicates()
df2 = df.groupby('SALES_ORDER')['MATERIAL_NUMBER'].agg(No_of_Lines='count').reset_index()
df2.loc[df2['No_of_Lines'] == 1, 'Single or Multiple'] = 'Single'
df2.loc[df2['No_of_Lines'] > 1, 'Single or Multiple'] = 'Multiple'

data = df2['Single or Multiple']

from matplotlib.ticker import PercentFormatter
fig = plt.figure()
ax = fig.add_subplot(111)
ax.hist(data, edgecolor='black', bins=3, color = 'blue',
        weights=np.ones_like(data)*100 / len(data))
```

```
ax.yaxis.set_major_formatter(PercentFormatter())
plt.ylabel('% of Orders')
plt.title('Single vs Multiple Line Orders')
```

Out[12]: Text(0.5, 1.0, 'Single vs Multiple Line Orders')



```
In [13]: df = df_salesOrder[['MATERIAL_NUMBER', 'SALES_ORDER']].drop_duplicates()
df2 = df.groupby('SALES_ORDER')['MATERIAL_NUMBER'].agg(No_of_Lines='count').reset_index()
df2.loc[df2['No_of_Lines'] == 1, 'Single or Multiple'] = 'Single'
df2.loc[df2['No_of_Lines'] > 1, 'Single or Multiple'] = 'Multiple'

df2.loc[df2['No_of_Lines'] > 10, 'No_of_Lines'] = '>10'
df3 = df2[df2['No_of_Lines'] != 1]
df3['No_of_Lines'] = df3['No_of_Lines'].astype(str)

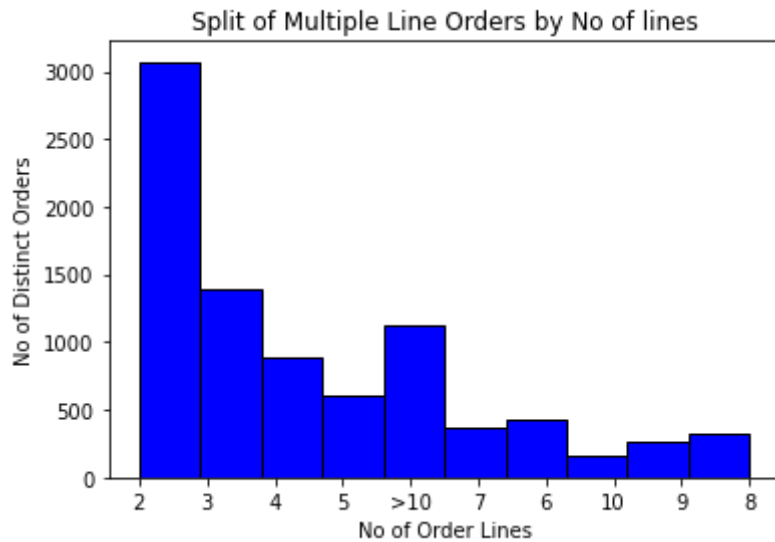
data = df3['No_of_Lines']
fig = plt.figure()
ax = fig.add_subplot(111)
ax.hist(data, edgecolor='black', color = 'blue')
plt.ylabel('No of Distinct Orders')
plt.xlabel('No of Order Lines')
plt.title('Split of Multiple Line Orders by No of lines')
```

/var/folders/19/_tyxbxcj0n57tt5s1rk8m0l40000gn/T/ipykernel_67885/2502679177.py:8: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#ret

```
urning-a-view-versus-a-copy
df3['No_of_Lines'] = df3['No_of_Lines'].astype(str)
```

Out[13]: Text(0.5, 1.0, 'Split of Multiple Line Orders by No of lines')



```
In [14]: mybasket = (df_salesOrder.groupby(['SALES_ORDER', 'MATERIAL_NUMBER'])['SCHEDULE_QUANTITY'].
              sum().unstack().reset_index().fillna(0).set_index('SALES_ORDER'))
```

```
In [15]: mybasket.head()
```

```
Out[15]: MATERIAL_NUMBER ITM1 ITM10 ITM100 ITM1000 ITM1002 ITM1004 ITM1006 ITM1007 ITM1012 ITM1017 ... ITM97 ITM98 I
          SALES_ORDER
          27034852    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0 ...    0.0    0.0
          27546143    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0 ...    0.0    0.0
          27546176    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0 ...    0.0    0.0
          27728583    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0 ...    0.0    0.0
          27997929    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0 ...    0.0    0.0
```

5 rows × 3180 columns

```
In [16]: #Fucntion
def my_encode_units(x):
```

```

    if x <= 0:
        return False
    if x > 0:
        return True

mybasket = mybasket.applymap(my_encode_units)

```

In [17]: `mybasket.head()`

Out[17]:

MATERIAL_NUMBER	ITM1	ITM10	ITM100	ITM1000	ITM1002	ITM1004	ITM1006	ITM1007	ITM1012	ITM1017	...	ITM97	ITM98	I
SALES_ORDER														
27034852	False	False	False	False	False	False	False	False	False	False	...	False	False	
27546143	False	False	False	False	False	False	False	False	False	False	...	False	False	
27546176	False	False	False	False	False	False	False	False	False	False	...	False	False	
27728583	False	False	False	False	False	False	False	False	False	False	...	False	False	
27997929	False	False	False	False	False	False	False	False	False	False	...	False	False	

5 rows × 3180 columns

In [18]:

```

from mlxtend.frequent_patterns import apriori
from mlxtend.frequent_patterns import association_rules
my_freq_items = apriori(mybasket, min_support=.001, use_colnames=True)

```

In [19]: `my_freq_items.sort_values(by=['support'], ascending=False)`

Out[19]:

	support	itemsets
691	0.035477	(ITM742)
242	0.030319	(ITM5010)
25	0.029108	(ITM1130)
159	0.027529	(ITM2103)
79	0.024371	(ITM157)
...
1934	0.001000	(ITM789, ITM6326, ITM1130)

	support	itemsets
1010	0.001000	(ITM5808, ITM157)
271	0.001000	(ITM5094)
2636	0.001000	(ITM5, ITM328, ITM677, ITM3164)
2269	0.001000	(ITM5011, ITM677, ITM5012)

2887 rows × 2 columns

```
In [20]: my_rules = association_rules(my_freq_items, metric="lift", min_threshold=1)
```

```
In [21]: my_rules.head()
```

```
Out[21]:
```

	antecedents	consequents	antecedent support	consequent support	support	confidence	lift	leverage	conviction
0	(ITM1114)	(ITM1)	0.009369	0.012107	0.001053	0.112360	9.280899	0.000939	1.112943
1	(ITM1)	(ITM1114)	0.012107	0.009369	0.001053	0.086957	9.280899	0.000939	1.084976
2	(ITM1)	(ITM2105)	0.012107	0.008580	0.001000	0.082609	9.628221	0.000896	1.080695
3	(ITM2105)	(ITM1)	0.008580	0.012107	0.001000	0.116564	9.628221	0.000896	1.118241
4	(ITM1)	(ITM2769)	0.012107	0.007053	0.002474	0.204348	28.971642	0.002389	1.247966

```
In [22]: my_rules = my_rules.sort_values(by=['antecedent support', 'consequent support', 'confidence'], ascending=False)
```

```
In [23]: my_rules.head()
```

```
Out[23]:
```

	antecedents	consequents	antecedent support	consequent support	support	confidence	lift	leverage	conviction
190	(ITM742)	(ITM1130)	0.035477	0.029108	0.008632	0.243323	8.359238	0.007600	1.283100
1329	(ITM742)	(ITM5011)	0.035477	0.023108	0.010212	0.287834	12.456189	0.009392	1.371720
2217	(ITM742)	(ITM677)	0.035477	0.021844	0.008580	0.241840	11.071016	0.007805	1.290170
1364	(ITM742)	(ITM5012)	0.035477	0.021634	0.008632	0.243323	11.247345	0.007865	1.292978
1136	(ITM742)	(ITM373)	0.035477	0.018949	0.007527	0.212166	11.196480	0.006855	1.245251

```
In [24]: my_rules.to_csv('complete_rules.csv', index=False)
```

```
In [25]: df = pd.read_csv('complete_rules.csv')
df.head()
```

```
Out[25]:
```

	antecedents	consequents	antecedent support	consequent support	support	confidence	lift	leverage	conviction
0	frozenset({'ITM742'})	frozenset({'ITM1130'})	0.035477	0.029108	0.008632	0.243323	8.359238	0.007600	1.283100
1	frozenset({'ITM742'})	frozenset({'ITM5011'})	0.035477	0.023108	0.010212	0.287834	12.456189	0.009392	1.371720
2	frozenset({'ITM742'})	frozenset({'ITM677'})	0.035477	0.021844	0.008580	0.241840	11.071016	0.007805	1.290170
3	frozenset({'ITM742'})	frozenset({'ITM5012'})	0.035477	0.021634	0.008632	0.243323	11.247345	0.007865	1.292978
4	frozenset({'ITM742'})	frozenset({'ITM373'})	0.035477	0.018949	0.007527	0.212166	11.196480	0.006855	1.245251

```
In [26]: df = df[df["antecedents"].str.contains(",") == False]
df = df[df["consequents"].str.contains(",") == False]

df['antecedents'] = df['antecedents'].str.replace('frozenset', '')
df['antecedents'] = df['antecedents'].str.replace('{', '')
df['antecedents'] = df['antecedents'].str.replace('}', '')
df['antecedents'] = df['antecedents'].str.replace('(', '')
df['antecedents'] = df['antecedents'].str.replace(')', '')
df['antecedents'] = df['antecedents'].str.replace('"', '')

df['consequents'] = df['consequents'].str.replace('frozenset', '')
df['consequents'] = df['consequents'].str.replace('{', '')
df['consequents'] = df['consequents'].str.replace('}', '')
df['consequents'] = df['consequents'].str.replace('(', '')
df['consequents'] = df['consequents'].str.replace(')', '')
df['consequents'] = df['consequents'].str.replace('"', '')

rules = df
rules
```

```
Out[26]:
```

	antecedents	consequents	antecedent support	consequent support	support	confidence	lift	leverage	conviction
0	ITM742	ITM1130	0.035477	0.029108	0.008632	0.243323	8.359238	0.007600	1.283100
1	ITM742	ITM5011	0.035477	0.023108	0.010212	0.287834	12.456189	0.009392	1.371720
2	ITM742	ITM677	0.035477	0.021844	0.008580	0.241840	11.071016	0.007805	1.290170
3	ITM742	ITM5012	0.035477	0.021634	0.008632	0.243323	11.247345	0.007865	1.292978

	antecedents	consequents	antecedent support	consequent support	support	confidence	lift	leverage	conviction
4	ITM742	ITM373	0.035477	0.018949	0.007527	0.212166	11.196480	0.006855	1.245251
...
14570	ITM6610	ITM6500	0.001158	0.004316	0.001000	0.863636	200.089800	0.000995	7.301681
14571	ITM6610	ITM1838	0.001158	0.001842	0.001000	0.863636	468.781818	0.000998	7.319823
14596	ITM6418	ITM5011	0.001105	0.023108	0.001105	1.000000	43.275626	0.001080	inf
14646	ITM5650	ITM5652	0.001105	0.003000	0.001053	0.952381	317.426901	0.001049	20.936993
14709	ITM6427	ITM6421	0.001053	0.001579	0.001000	0.950000	601.603333	0.000998	19.968418

2228 rows x 9 columns

```
In [27]: rules.to_csv('product affinity.csv', index=False)
```

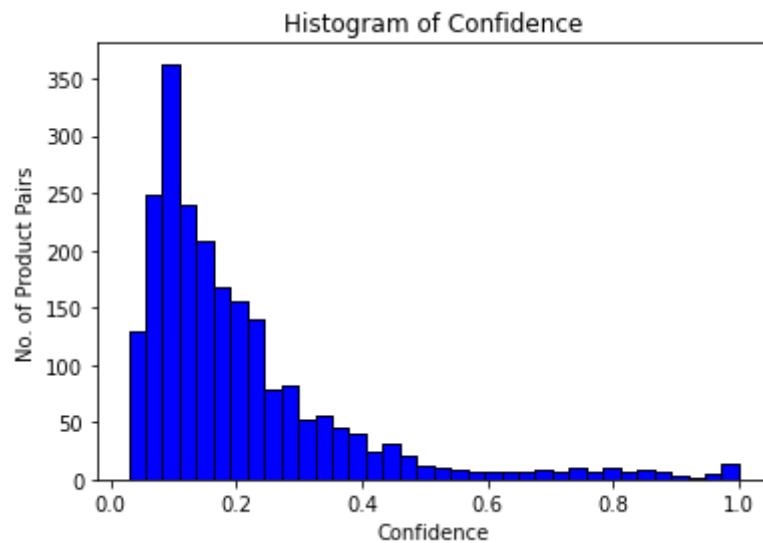
```
In [28]: plt.hist(rules['confidence'], color = 'blue', edgecolor = 'black',
               bins = int(180/5))
```

```
# seaborn histogram
sns.distplot(rules['confidence'], hist=True, kde=False,
              bins=int(180/5), color = 'blue',
              hist_kws={'edgecolor':'black'})
# Add labels
plt.title('Histogram of Confidence')
plt.xlabel('Confidence')
plt.ylabel('No. of Product Pairs')
```

/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/seaborn/distributions.py:2551: FutureWarning: `distplot` is a deprecated function and will be removed in a future version. Please adapt your code to use either `displot` (a figure-level function with similar flexibility) or `histplot` (an axes-level function for histograms).

```
warnings.warn(msg, FutureWarning)
```

```
Out[28]: Text(0, 0.5, 'No. of Product Pairs')
```

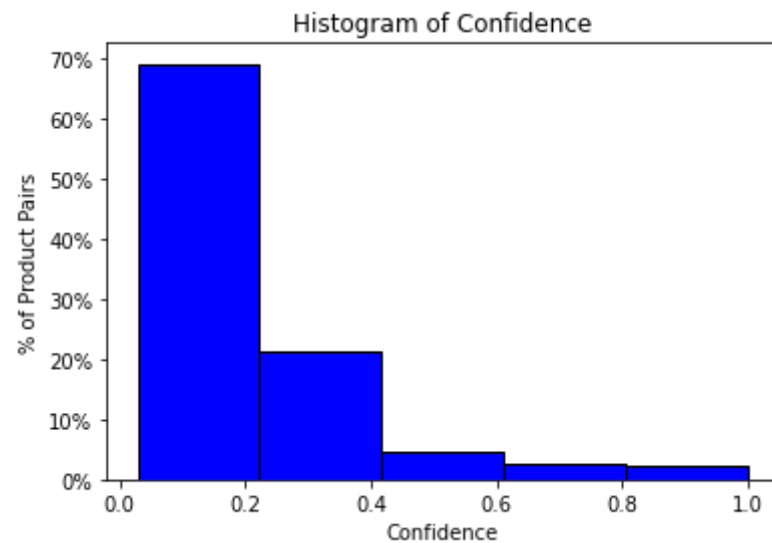


```
In [29]: from matplotlib.ticker import PercentFormatter

#define data values
data = rules['confidence']

#create relative frequency histogram with percentages on y-axis
fig = plt.figure()
ax = fig.add_subplot(111)
ax.hist(data, edgecolor='black', bins=int(100/20), color = 'blue',
        weights=np.ones_like(data)*100 / len(data))
ax.yaxis.set_major_formatter(PercentFormatter())
plt.title('Histogram of Confidence')
plt.xlabel('Confidence')
plt.ylabel('% of Product Pairs')
```

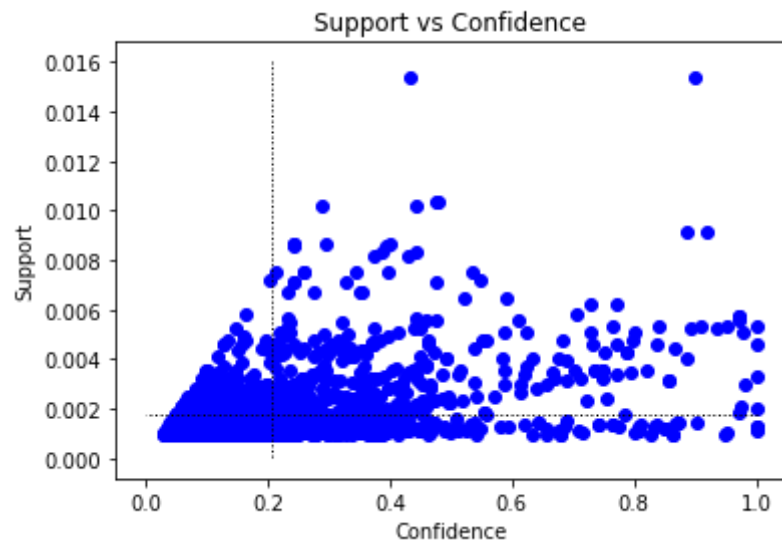
```
Out[29]: Text(0, 0.5, '% of Product Pairs')
```



```
In [30]: x = rules['confidence']
y = rules['support']

plt.scatter(x, y, c = "blue")
plt.plot([x.mean(), x.mean()], [.016, .000], 'k-', linestyle = ":", lw=1)
plt.plot([1, 0], [y.mean(), y.mean()], 'k-', linestyle = ":", lw=1)

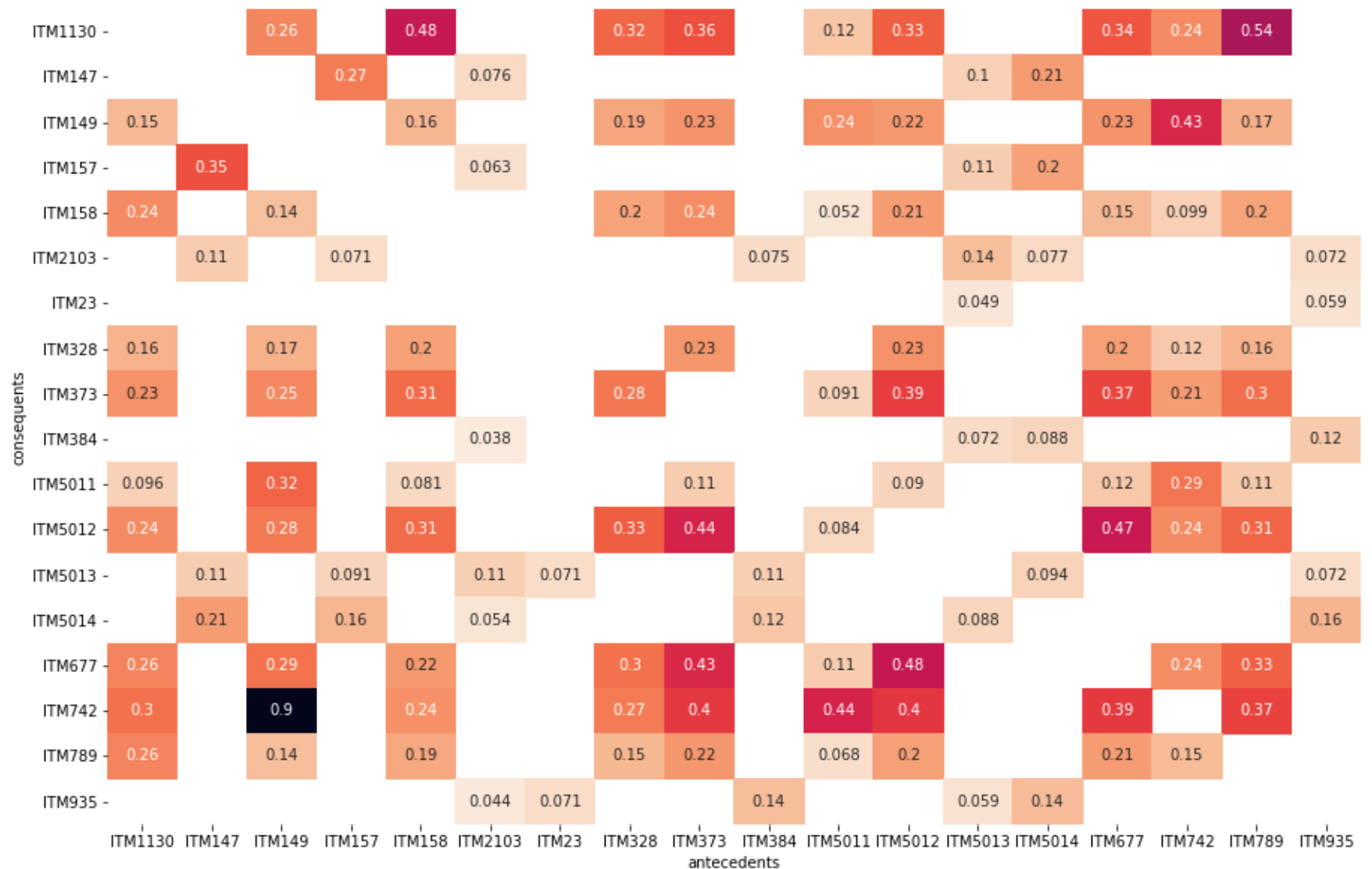
# To show the plot
plt.title('Support vs Confidence')
plt.xlabel('Confidence')
plt.ylabel('Support')
plt.show()
```



```
In [31]: top20_materials = distinctOrder_freq.head(20)['MATERIAL_NUMBER'].tolist()
df = rules[rules['antecedents'].isin(top20_materials)]
df = df[df['consequents'].isin(top20_materials)]
```

```
In [32]: # Transform antecedent, consequent, and support columns into matrix
support_table = df.pivot(index='consequents', columns='antecedents', values='confidence')

plt.figure(figsize=(15,10))
cmap = sns.cm.rocket_r
sns.heatmap(support_table, cmap = cmap, annot=True, cbar=False)
plt.show()
```

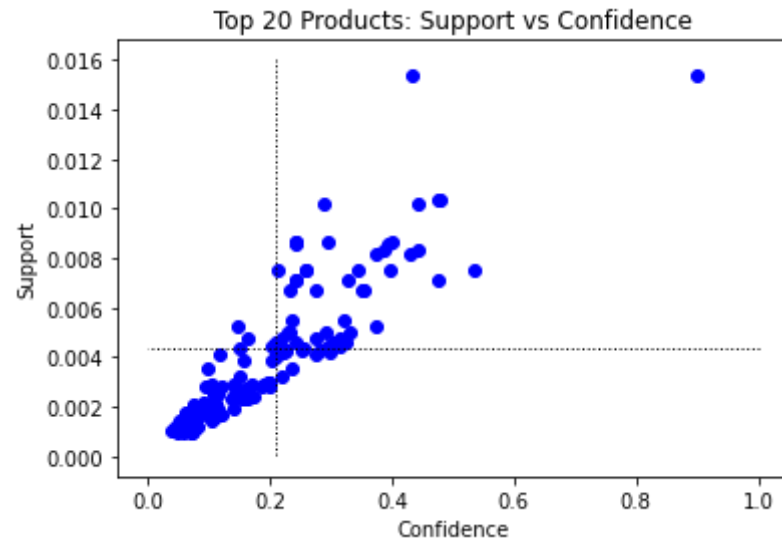


```
In [33]: x = df['confidence']
y = df['support']

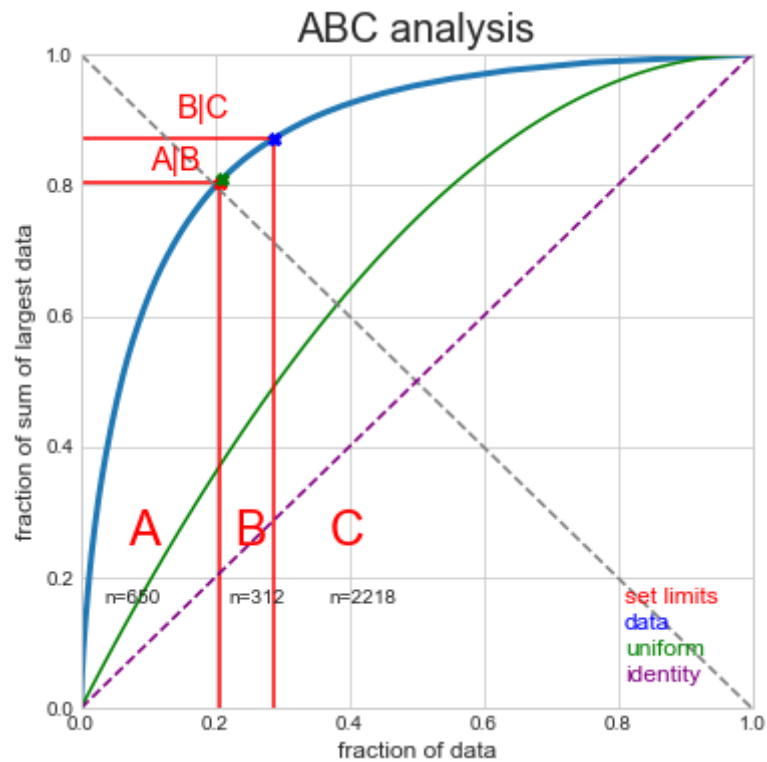
plt.scatter(x, y, c="blue")
plt.plot([x.mean(),x.mean()], [.016,.000], 'k-', linestyle=":", lw=1)
plt.plot([1,0],[y.mean(),y.mean()], 'k-', linestyle=":", lw=1)

# To show the plot
plt.title('Top 20 Products: Support vs Confidence')
```

```
plt.xlabel('Confidence')
plt.ylabel('Support')
plt.show()
```



```
In [34]: from abc_analysis import abc_analysis, abc_plot
abc = abc_analysis(distinctOrder_freq['Order Count'], True)
```



```
In [35]: # index position of A, B, and C Videos
a_index = abc['Aind']
b_index = abc['Bind']
c_index = abc['Cind']

# New Column indicating A, B, or C
cond_list = [distinctOrder_freq.index.isin(a_index),
             distinctOrder_freq.index.isin(b_index),
             distinctOrder_freq.index.isin(c_index)]

choice_list = ['A', 'B', 'C']

distinctOrder_freq['ABC'] = np.select(cond_list, choice_list)
distinctOrder_freq
```

```
Out[35]:
```

	MATERIAL_NUMBER	Order Count	ABC
0	ITM742	674	A
1	ITM5010	576	A

	MATERIAL_NUMBER	Order Count	ABC
2	ITM1130	553	A
3	ITM2103	523	A
4	ITM157	463	A
...
3175	ITM2924	1	C
3176	ITM5353	1	C
3177	ITM5116	1	C
3178	ITM5257	1	C
3179	ITM770	1	C

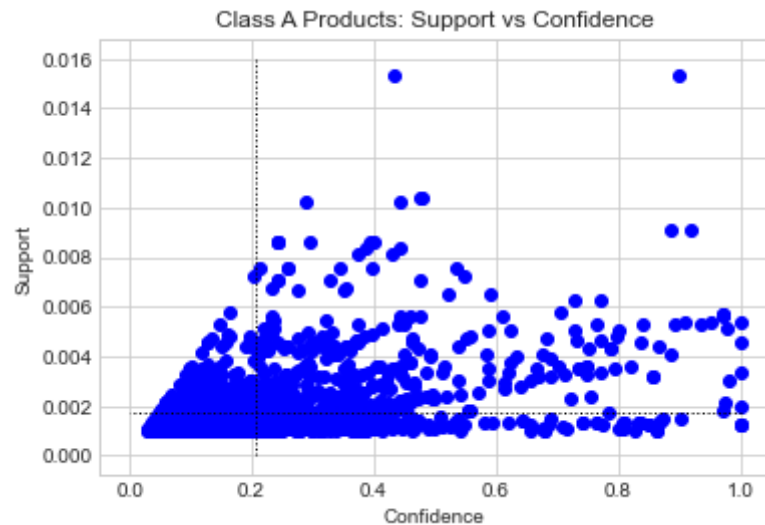
3180 rows × 3 columns

```
In [36]: cnt_A = int(distinctOrder_freq[distinctOrder_freq['ABC']=='A'].MATERIAL_NUMBER.count())
Class_A_materials = distinctOrder_freq.head(cnt_A)['MATERIAL_NUMBER'].tolist()
df = rules[rules['antecedents'].isin(Class_A_materials)]
df = df[df['consequents'].isin(Class_A_materials)]

x = df['confidence']
y = df['support']

plt.scatter(x, y, c="blue")
plt.plot([x.mean(),x.mean()], [.016,.000], 'k-', linestyle=":", lw=1)
plt.plot([1,0],[y.mean(),y.mean()], 'k-', linestyle=":", lw=1)

# To show the plot
plt.title('Class A Products: Support vs Confidence')
plt.xlabel('Confidence')
plt.ylabel('Support')
plt.show()
```

```
In [37]: Product_dims = pd.read_excel('Input Data/Product dims.xlsx')
```

```
/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/xlrd/xlsx.py:266: DeprecationWarning: This method
will be removed in future versions. Use 'tree.iter()' or 'list(tree.iter())' instead.
    for elem in self.tree.iter() if Element_has_iter else self.tree.getiterator():
/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/xlrd/xlsx.py:312: DeprecationWarning: This method
will be removed in future versions. Use 'tree.iter()' or 'list(tree.iter())' instead.
    for elem in self.tree.iter() if Element_has_iter else self.tree.getiterator():
/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/xlrd/xlsx.py:266: DeprecationWarning: This method
will be removed in future versions. Use 'tree.iter()' or 'list(tree.iter())' instead.
    for elem in self.tree.iter() if Element_has_iter else self.tree.getiterator():
```

```
In [185... import math

STD_LOC_VOL = (46 * 48 * 60) * .8
nbrOfdays = 18 * 7
DaysOfSupply = 3
df = distinctOrder_freq
product = df['MATERIAL_NUMBER'].values.tolist()

distinctOrder_freq['PICK_FACE_NO_OF_LOC'] = 1

for ind, rec in Product_dims.iterrows():
    p = rec['Material']
    vol = 0.0
    if rec['Volume Cubic Unit'] == 'IN':
        vol = rec['Volume']
    elif rec['Volume Cubic Unit'] == 'CM':
```

```

        vol = rec['Volume'] * (0.393701)**3.0
    elif rec['Volume Cubic Unit'] == 'MM':
        vol = rec['Volume'] * (0.0393701)**3
    elif rec['Volume Cubic Unit'] == 'M':
        vol = rec['Volume'] * (39.3701)**3
    if vol > 0.0:
        if p in product:
            avg_demand = df[df['MATERIAL_NUMBER'] == p]['Order Count'] / nbrOfdays * DaysOfSupply
            distinctOrder_freq.loc[distinctOrder_freq['MATERIAL_NUMBER'] == p,
                                   'PICK_FACE_NO_OF_LOC'] = int(math.ceil(avg_demand*vol/STD_LOC_VOL))

distinctOrder_freq[distinctOrder_freq['PICK_FACE_NO_OF_LOC'] > 1]

```

Out[185...

	MATERIAL_NUMBER	Order Count	ABC	PICK_FACE_NO_OF_LOC
43	ITM6182	203	A	3

In [385... `distinctOrder_freq.to_csv('Products.csv', index=False)`

In [386... `Products = pd.read_csv('Products.csv')`
`Locations = pd.read_excel('Input Data/Location Distances.xlsx')`

```

/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/xlrd/xlsx.py:266: DeprecationWarning: This method will be removed in future versions. Use 'tree.iter()' or 'list(tree.iter())' instead.
    for elem in self.tree.iter() if Element_has_iter else self.tree.getiterator():
/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/xlrd/xlsx.py:312: DeprecationWarning: This method will be removed in future versions. Use 'tree.iter()' or 'list(tree.iter())' instead.
    for elem in self.tree.iter() if Element_has_iter else self.tree.getiterator():
/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/xlrd/xlsx.py:266: DeprecationWarning: This method will be removed in future versions. Use 'tree.iter()' or 'list(tree.iter())' instead.
    for elem in self.tree.iter() if Element_has_iter else self.tree.getiterator():

```

In [387... `Locations.head()`

Out[387...

	Location	Aisle	Bin Position	Level	Oneway Pick Distance	Factored Vertical Distance	Final Pick Distance	Distance to dropoff	Final distance to drop off	Sort Field
0	50.54.A	50	54	A	0.000000	0.0	0.000000	18.000000	18.000000	1
1	50.54.B	50	54	B	0.000000	18.5	18.500000	18.000000	36.500000	2
2	50.54.C	50	54	C	0.000000	37.0	37.000000	18.000000	55.000000	3
3	50.54.D	50	54	D	0.000000	55.5	55.500000	18.000000	73.500000	4
4	50.53.A	50	53	A	4.041667	0.0	4.041667	22.041667	22.041667	9

'48.54.A': 453.45833333333394,
'49.51.A': 24.125,
'50.48.A': 24.250000000000004,
'48.53.A': 449.41666666666725,
'49.50.A': 28.16666666666668,
'50.47.A': 28.2916666666667,
'48.52.A': 445.37500000000057,
'49.49.A': 32.20833333333336,
'50.46.A': 32.33333333333336,
'47.54.A': 465.45833333333394,
'48.51.A': 441.3333333333339,
'49.48.A': 36.25,
'50.45.A': 36.375,
'47.53.A': 461.41666666666725,
'48.50.A': 437.2916666666672,
'49.47.A': 40.2916666666667,
'50.44.A': 40.41666666666664,
'47.52.A': 457.37500000000057,
'48.49.A': 433.2500000000005,
'49.46.A': 44.33333333333336,
'50.43.A': 44.45833333333333,
'47.51.A': 453.3333333333339,
'48.48.A': 429.2083333333338,
'49.45.A': 48.375,
'50.42.A': 48.49999999999999,
'47.50.A': 449.2916666666672,
'48.47.A': 425.16666666666714,
'49.44.A': 52.41666666666664,
'50.41.A': 52.54166666666666,
'47.49.A': 445.2500000000005,
'48.46.A': 421.12500000000045,
'49.43.A': 56.45833333333333,
'50.40.A': 56.58333333333332,
'47.48.A': 441.2083333333338,
'48.45.A': 417.08333333333377,
'49.42.A': 60.49999999999999,
'50.39.A': 60.624999999999986,
'47.47.A': 437.16666666666714,
'48.44.A': 413.0416666666671,
'49.41.A': 64.54166666666666,
'50.38.A': 64.66666666666666,
'47.46.A': 433.12500000000045,
'48.43.A': 409.0000000000004,
'49.40.A': 68.58333333333331,
'50.37.A': 68.70833333333333,
'47.45.A': 429.08333333333377,
'48.42.A': 404.9583333333337,
'49.39.A': 72.62499999999999,
'50.36.A': 72.75,

'47.44.A': 425.04166666666671,
'48.41.A': 400.9166666666667,
'49.38.A': 76.66666666666666,
'50.35.A': 76.79166666666667,
'47.43.A': 421.00000000000004,
'48.40.A': 396.875000000000034,
'49.37.A': 80.70833333333333,
'50.34.A': 80.83333333333334,
'47.42.A': 416.9583333333337,
'48.39.A': 392.83333333333366,
'49.36.A': 84.75,
'50.33.A': 84.87500000000001,
'47.41.A': 412.9166666666667,
'48.38.A': 388.79166666666697,
'49.35.A': 88.79166666666667,
'50.32.A': 88.91666666666669,
'47.40.A': 408.875000000000034,
'48.37.A': 384.75000000000003,
'49.34.A': 92.83333333333334,
'50.31.A': 92.95833333333336,
'47.39.A': 404.83333333333366,
'48.36.A': 380.7083333333336,
'49.33.A': 96.87500000000001,
'50.30.A': 97.00000000000003,
'47.38.A': 400.79166666666697,
'48.35.A': 376.6666666666669,
'49.32.A': 100.91666666666669,
'50.29.A': 101.0416666666667,
'47.37.A': 396.75000000000003,
'48.34.A': 372.62500000000002,
'49.31.A': 104.95833333333336,
'50.28.A': 105.08333333333337,
'47.36.A': 392.7083333333336,
'48.33.A': 368.58333333333354,
'49.30.A': 109.00000000000003,
'50.27.A': 109.12500000000004,
'47.35.A': 388.6666666666669,
'48.32.A': 364.54166666666686,
'49.29.A': 113.0416666666667,
'50.26.A': 113.16666666666671,
'47.34.A': 384.62500000000002,
'48.31.A': 360.50000000000017,
'49.28.A': 117.08333333333337,
'50.25.A': 117.20833333333339,
'47.33.A': 380.58333333333354,
'48.30.A': 356.4583333333335,
'49.27.A': 121.12500000000004,
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'48.29.A': 352.4166666666668,

'49.26.A': 125.16666666666671,
'47.31.A': 372.50000000000017,
'48.28.A': 348.37500000000001,
'49.25.A': 129.20833333333337,
'47.30.A': 368.4583333333335,
'48.27.A': 344.3333333333334,
'50.24.A': 121.25000000000006,
'47.29.A': 364.4166666666668,
'48.26.A': 340.29166666666674,
'50.23.A': 125.29166666666673,
'47.28.A': 360.37500000000001,
'48.25.A': 336.25000000000006,
'50.22.A': 129.33333333333334,
'47.27.A': 356.3333333333334,
'49.24.A': 133.25000000000006,
'50.21.A': 133.37500000000006,
'47.26.A': 352.29166666666674,
'49.23.A': 137.29166666666674,
'50.20.A': 137.4166666666667,
'47.25.A': 348.25000000000006,
'49.22.A': 141.33333333333334,
'50.19.A': 141.45833333333337,
'48.24.A': 332.20833333333337,
'49.21.A': 145.37500000000006,
'50.18.A': 145.50000000000003,
'48.23.A': 328.1666666666667,
'49.20.A': 149.4166666666667,
'50.17.A': 149.54166666666669,
'48.22.A': 324.125,
'49.19.A': 153.45833333333337,
'50.16.A': 153.58333333333334,
'47.24.A': 344.20833333333337,
'48.21.A': 320.08333333333333,
'49.18.A': 157.50000000000003,
'50.15.A': 157.625,
'47.23.A': 340.1666666666667,
'48.20.A': 316.04166666666663,
'49.17.A': 161.54166666666669,
'50.14.A': 161.66666666666666,
'47.22.A': 336.125,
'48.19.A': 311.99999999999994,
'49.16.A': 165.58333333333334,
'50.13.A': 165.70833333333331,
'47.21.A': 332.08333333333333,
'48.18.A': 307.95833333333326,
'49.15.A': 169.625,
'50.12.A': 169.74999999999997,
'47.20.A': 328.04166666666663,
'48.17.A': 303.91666666666666,

'49.14.A': 173.66666666666666,
'50.11.A': 173.79166666666663,
'47.19.A': 323.99999999999994,
'48.16.A': 299.87499999999999,
'49.13.A': 177.70833333333331,
'50.10.A': 177.83333333333333,
'47.18.A': 319.95833333333326,
'48.15.A': 295.83333333333332,
'49.12.A': 181.74999999999997,
'50.09.A': 181.87499999999994,
'47.17.A': 315.91666666666666,
'48.14.A': 291.79166666666665,
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'50.08.A': 185.91666666666666,
'47.16.A': 311.87499999999999,
'48.13.A': 287.74999999999983,
'49.10.A': 189.83333333333333,
'50.07.A': 189.95833333333326,
'47.15.A': 307.83333333333332,
'48.12.A': 283.70833333333314,
'49.09.A': 193.87499999999994,
'50.06.A': 193.99999999999991,
'47.14.A': 303.79166666666665,
'48.11.A': 279.66666666666646,
'49.08.A': 197.91666666666666,
'50.05.A': 198.04166666666657,
'47.13.A': 299.74999999999983,
'48.10.A': 275.62499999999998,
'49.07.A': 201.95833333333326,
'50.04.A': 202.08333333333323,
'47.12.A': 295.70833333333314,
'48.09.A': 271.58333333333314,
'49.06.A': 205.99999999999991,
'50.03.A': 206.12499999999999,
'47.11.A': 291.66666666666646,
'48.08.A': 267.54166666666646,
'49.05.A': 210.04166666666657,
'50.02.A': 210.16666666666654,
'47.10.A': 287.62499999999998,
'48.07.A': 263.49999999999998,
'49.04.A': 214.08333333333323,
'50.01.A': 214.20833333333332,
'47.09.A': 283.58333333333314,
'48.06.A': 259.45833333333314,
'49.03.A': 218.12499999999999,
'47.08.A': 279.54166666666646,
'48.05.A': 255.41666666666665,
'49.02.A': 222.16666666666654,
'47.07.A': 275.49999999999998,

```

'48.04.A': 251.37499999999983,
'49.01.A': 226.2083333333332,
'47.06.A': 271.45833333333314,
'48.03.A': 247.33333333333317,
'47.05.A': 267.4166666666665,
'48.02.A': 243.29166666666652,
'47.04.A': 263.37499999999983,
'48.01.A': 239.24999999999986,
'47.03.A': 259.33333333333314,
'47.02.A': 255.29166666666652,
'47.01.A': 251.24999999999986}})]

```

In [390...

```

##STAGE 1
from pyomo.environ import *

noOfPrd = len(product)
supply = dict(zip(product, [No_of_Loc_per_product]*noOfPrd))

noOfLoc = len(location)
demand = dict(zip(location, [1]*noOfLoc))

orderFreq_dict = pd.Series(Products['Order Count'].values,index=Products.MATERIAL_NUMBER).to_dict()

supply["DUMMY_PART"] = 0
diff = sum(demand.values()) - sum(supply.values()) #comparing supply and demand
if 'DUMMY_PART' not in product:
    product.append("DUMMY_PART")
supply["DUMMY_PART"] = diff
orderFreq_dict["DUMMY_PART"] = 0

# instantiate Concrete Model
model = ConcreteModel()

# define variables
model.X = Var(product, location, domain=NonNegativeReals)

# define objective function
model.total_distance = Objective(expr=sum(orderFreq_dict[p] * distance_IO[l] * model.X[p, l]
                                         for p in product
                                         for l in location),
                                sense=minimize)

# define constraints
model.supply_ct = ConstraintList()
for p in product:
    model.supply_ct.add(sum(model.X[p, l] for l in location) == supply[p])

```



```

model.demand_ct = ConstraintList()
for l in location:
    model.demand_ct.add(
        sum(model.X[p, l] for p in product) == demand[l])

```

```

In [391... # solve
solver = SolverFactory('glpk')
solver.solve(model)

```

```

Out[391... {'Problem': [{'Name': 'unknown', 'Lower bound': 3667107.625, 'Upper bound': 3667107.625, 'Number of objective
s': 1, 'Number of constraints': 433, 'Number of variables': 46657, 'Number of nonzeros': 93313, 'Sense': 'minim
ize'}], 'Solver': [{'Status': 'ok', 'Termination condition': 'optimal', 'Statistics': {'Branch and bound': {'Nu
mber of bounded subproblems': 0, 'Number of created subproblems': 0}}, 'Error rc': 0, 'Time': 1.244308948516845
7}], 'Solution': [OrderedDict([('number of solutions', 0), ('number of solutions displayed', 0)])]}

```

```

In [392... # convert model into a Pandas data frame for nicer display
import pandas as pd
assignment = pd.DataFrame(0, index=product, columns=location)
STG1_assignment = defaultdict(dict)
cols = ['Product', 'Distance']
STG1_distance_df = pd.DataFrame(columns = cols)
for p in product:
    STG1_assignment[p] = []
    for l in location:
        if model.X[p, l].value > 0:
            assignment.loc[p, l] = 'S'
            STG1_assignment[p] += [l]
            if p != 'DUMMY_PART':
                STG1_distance_df = STG1_distance_df.append({'Product': p, 'Distance IO':distance_IO[l]},
                                                            ignore_index=True)
        else:
            assignment.loc[p, l] = ''

# display
print(f"\nTotal Distance minimized to = {model.total_distance():.2f}")

```

Total Distance minimized to = 3,667,107.62

```

In [393... print("Final assignment: ")
assignment

```

Final assignment:

```

Out[393... 50.54.A 50.53.A 50.52.A 49.54.A 50.51.A 49.53.A 50.50.A 49.52.A 50.49.A 48.54.A ... 49.01.A 47.06.A 48.0

```

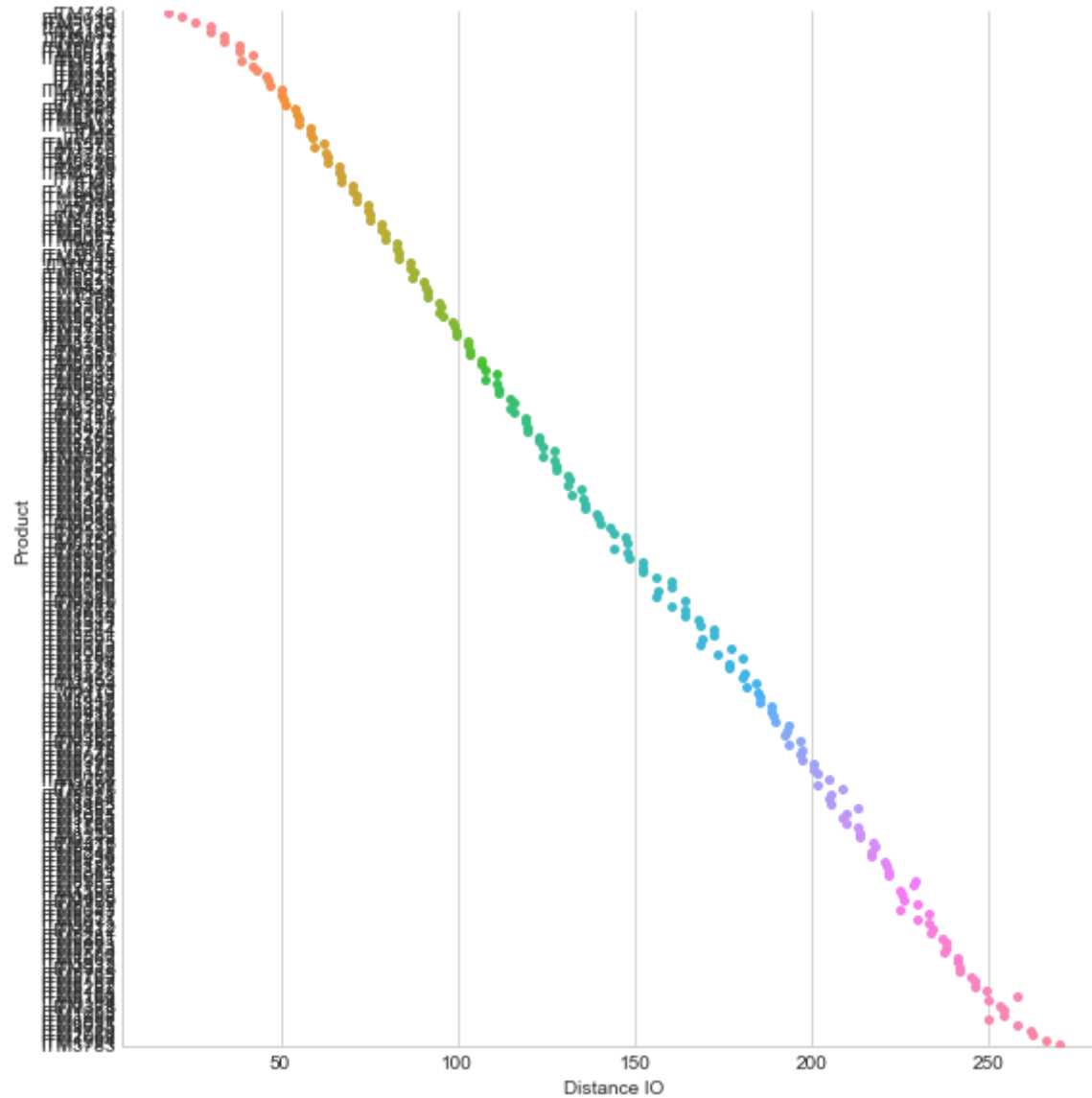
	50.54.A	50.53.A	50.52.A	49.54.A	50.51.A	49.53.A	50.50.A	49.52.A	50.49.A	48.54.A	...	49.01.A	47.06.A	48.0
ITM742	S										...			
ITM5010		S									...			
ITM1130			S								...			
ITM2103				S							...			
ITM157					S						...			
...
ITM1729											...			
ITM2066											...			
ITM1994											...			
ITM5783											...			
DUMMY_PART											...			

216 rows × 216 columns

```
In [394... assignment.to_csv('STG1_result.csv')
```

```
In [395... sns.catplot(x="Distance IO", y="Product", data=STG1_distance_df, kind='swarm', height=8, aspect=1)
```

```
Out[395... <seaborn.axisgrid.FacetGrid at 0x7fe4a93e90d0>
```



```
In [396... rules['antecedents'] = rules['antecedents'].astype(str)
rules['consequents'] = rules['consequents'].astype(str)

rules = rules[rules['antecedents'].isin(product)]
rules = rules[rules['consequents'].isin(product)]
```

```
In [397... distinctOrder_freq['MATERIAL_NUMBER'] = distinctOrder_freq['MATERIAL_NUMBER'].astype(str)
```

In [398...

```
##STAGE 2
product = Products.head(No_of_Products)['MATERIAL_NUMBER'].values.tolist() #list of products
noOfPrd = len(product)
demand = dict(zip(product, [No_of_Loc_per_product]*noOfPrd)) #number of locations needed. Time being 1 per product

confidence_list = defaultdict(dict) #confidence_list[p1][p2] will give confidence that p2 is bought for each p1
for ind, rec in rules.iterrows():
    ant = (rec['antecedents'])
    con = (rec['consequents'])
    conf = rec['confidence']
    confidence_list[ant][con] = conf

#relative order freq
order_freq = pd.Series(Products['Order Count'].values, index=Products.MATERIAL_NUMBER).to_dict()

location = locations['Location'].values.tolist() #list of all locations
noOfLoc = len(location)
supply = dict(zip(location,
                  [1]*noOfLoc)) #number of products that can be assigned to a location. Default 1 - one product

demand["DUMMY_PART"] = 0
diff = sum(supply.values()) - sum(demand.values()) #comparing supply and demand
if 'DUMMY_PART' not in product:
    product.append("DUMMY_PART") #adding dummy product as supply is more than demand
demand["DUMMY_PART"] = diff #assign these many extra locations to dummy part
order_freq["DUMMY_PART"] = 0 #no sales for dummy part

Aff_wt = 1 #to control weightage of product affinity in the optimization equation

#####
#all product pairs should have confidence. If a product pair is not in input file (Apriori output), assign ZERO
for p in product:
    for c in product:
        if c not in confidence_list[p]:
            if p==c:
                confidence_list[p][c] = 1 #confidence of 1 when product pair is itself
            else:
                confidence_list[p][c] = 0 #confidence of 0 when product pair has not been purchased together (a
#####

# instantiate Concrete Model
model = ConcreteModel()

# define variables
model.X = Var(product, location, domain=NonNegativeIntegers)
```

```

# define objective function
model.total_distance = Objective(expr=sum(order_freq[p] * distance_IO[l] * model.X[p, l]
                                         for p in product
                                         for l in location)
                                +
                                sum(order_freq[pc] * distance_IO[lc] * model.X[pc, lc]
                                    for pc in product
                                    for lc in location)
                                +
                                Aff_wt *
                                sum(confidence_list[p][pc] * order_freq[p]
                                    * abs(distance_BTW[l][lc])
                                    * model.X[p, l] * model.X[pc, lc]
                                    for p in product
                                    for l in location
                                    for pc in product
                                    for lc in location),
                                sense=minimize)

# define constraints
model.supply_ct = ConstraintList()
for l in location:
    model.supply_ct.add(
        sum(model.X[p, l] for p in product) == supply[l])

model.demand_ct = ConstraintList()
for p in product:
    model.demand_ct.add(sum(model.X[p, l] for l in location) == demand[p])

```

```

In [399... # solve
solver = SolverFactory('ipopt')
solver.solve(model)

```

```

Out[399... {'Problem': [{'Lower bound': -inf, 'Upper bound': inf, 'Number of objectives': 1, 'Number of constraints': 432,
'Number of variables': 46656, 'Sense': 'unknown'}], 'Solver': [{'Status': 'ok', 'Message': 'Ipopt 3.12.12\\x3a
Optimal Solution Found', 'Termination condition': 'optimal', 'Id': 0, 'Error rc': 0, 'Time': 7158.73561382293
7}], 'Solution': [OrderedDict([('number of solutions', 0), ('number of solutions displayed', 0)])]}

```

```

In [400... # convert model into a Pandas data frame for nicer display
assignment = pd.DataFrame(0, index=product, columns=location)
for p in product:
    for l in location:
        assignment.loc[p, l] = model.X[p, l].value

```


	50.54.A	50.53.A	50.52.A	49.54.A	50.51.A	49.53.A	50.50.A	49.52.A	50.49.A	48.54.A	...	49.01.A	47.06.A	48.0
ITM1729											...			
ITM2066											...		S	
ITM1994											...			
ITM5783											...			
DUMMY_PART											...			

216 rows x 216 columns

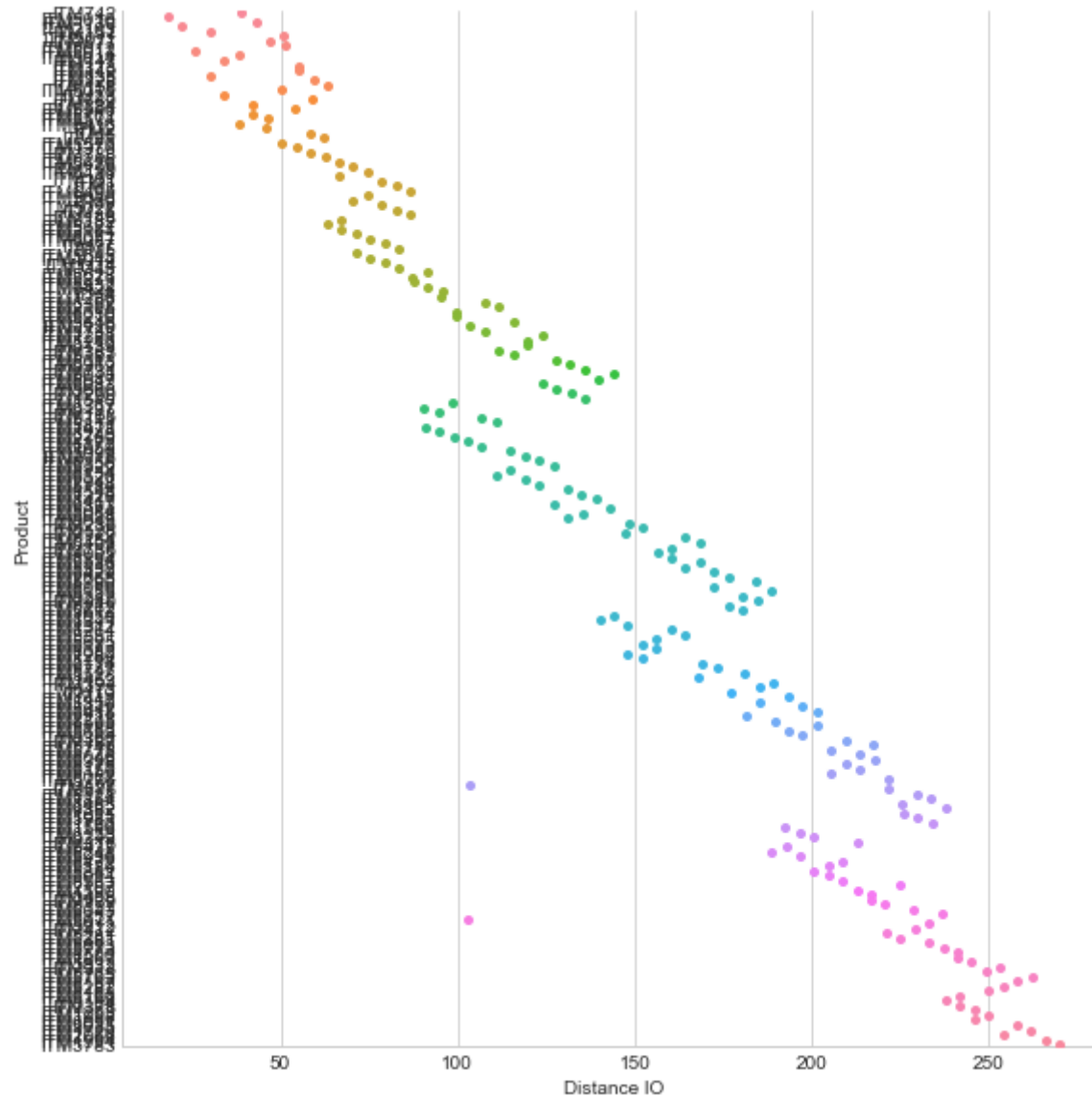
```
In [401... assignment.to_csv('STG2_result.csv')
```

```
In [402... # convert model into a Pandas data frame for nicer display
assignment = pd.DataFrame(0, index=product, columns=location)
for p in product:
    for l in location:
        assignment.loc[p, l] = model.X[p, l].value

assignment.to_csv('STG2_result_raw.csv')
```

```
In [403... sns.catplot(x="Distance IO", y="Product", data=STG2_distance_df, kind='swarm', height=8, aspect=1)
```

```
Out[403... <seaborn.axisgrid.FacetGrid at 0x7fe5a786a1f0>
```



```
In [404... pick_orders = df_salesOrder[df_salesOrder['MATERIAL_NUMBER'].isin(product)]
pick_orders.drop(['SALES_ORDER_ITEM_CREATE_DATE_FISCAL_WEEK', 'SALES_ORDER_ITEM_CREATE_DATE_FISCAL_YEAR',
                  'SALES_ORDER_ITEM', 'SCHEDULE_QUANTITY'], axis=1)
pick_orders = pick_orders[['MATERIAL_NUMBER', 'SALES_ORDER']].drop_duplicates()
pick_orders = pick_orders.sort_values(by=['SALES_ORDER'], ascending=True)
```

```
In [405... pick_orders.shape
```


Out[405... (33032, 2)

```
In [406... Total_orders_toPick = pick_orders.SALES_ORDER.nunique()  
Total_orders_toPick
```

Out[406... 12617

```
In [407... Total_picks = pick_orders.shape[0]  
Total_picks
```

Out[407... 33032

```
In [408... order_list = pick_orders.SALES_ORDER.unique().tolist()
```

```
In [409... stage = 'STG1'  
STG_Assignment = STG1_assignment  
  
pick_orders['Stage'] = [stage]*Total_picks  
pick_orders['Location'] = ['']*Total_picks  
pick_orders['Sort Field'] = [0]*Total_picks  
for ind,rec in pick_orders.iterrows():  
    p = rec['MATERIAL_NUMBER']  
    l = STG_Assignment[p][0]  
    sf = int(Locations[Locations['Location'] == l]['Sort Field'])  
    pick_orders.loc[pick_orders['MATERIAL_NUMBER'] == p, 'Location'] = l  
    pick_orders.loc[pick_orders['MATERIAL_NUMBER'] == p, 'Sort Field'] = sf  
  
pick_orders = pick_orders.sort_values(by=['SALES_ORDER', 'Sort Field'], ascending=True)  
pick_orders  
  
Pick_time = pd.DataFrame(order_list, columns=['Sales Order'])  
Pick_time['Stage'] = [stage] * Total_orders_toPick  
Pick_time['Total Distance'] = [stage] * Total_orders_toPick  
for order in order_list:  
    total_dist = 0  
    df = pick_orders[pick_orders['SALES_ORDER'] == order]  
    first_time = True  
    for ind, rec in df.iterrows():  
        if first_time:  
            first_time = False  
            l = str(rec['Location'])  
            total_dist += distance_IO[l]  
            #print("first time: ",order, total_dist)
```

```

        l1 = 1
        l2 = 1
    else:
        l2 = str(rec['Location'])
        total_dist += abs(distance_BTW[l1][l2])
        #print("next time: ",order, total_dist)
    total_dist += distance_IO[l2]
    #print("last time: ",order, total_dist)
    Pick_time.loc[Pick_time['Sales Order'] == order, 'Total Distance'] = total_dist

print(Pick_time)
tot_pick_dist = Pick_time['Total Distance'].sum()
print(f"\nTotal pick distance for {stage} = {tot_pick_dist:,.2f}")

```

	Sales Order	Stage	Total Distance
0	27997929	STG1	84.5
1	28018206	STG1	84.5
2	28025370	STG1	230
3	28057994	STG1	230
4	28100693	STG1	483.042
...
12612	55875321	STG1	449.125
12613	55875328	STG1	3327.46
12614	55875339	STG1	583.708
12615	55875348	STG1	2011.92
12616	55875362	STG1	1676.46

[12617 rows x 3 columns]

Total pick distance for STG1 = 6,733,313.33

In [410... Pick_time.to_csv('STG1_order pick times.csv')

```

In [411... stage = 'STG2'
STG_Assignment = STG2_assignment

pick_orders['Stage'] = [stage]*Total_picks
pick_orders['Location'] = ['']*Total_picks
pick_orders['Sort Field'] = [0]*Total_picks
for ind,rec in pick_orders.iterrows():
    p = rec['MATERIAL_NUMBER']
    l = STG_Assignment[p][0]
    sf = int(Locations[Locations['Location'] == l]['Sort Field'])
    pick_orders.loc[pick_orders['MATERIAL_NUMBER'] == p, 'Location'] = l
    pick_orders.loc[pick_orders['MATERIAL_NUMBER'] == p, 'Sort Field'] = sf

```

```

pick_orders = pick_orders.sort_values(by=['SALES_ORDER', 'Sort Field'], ascending=True)
pick_orders

Pick_time = pd.DataFrame(order_list, columns=['Sales Order'])
Pick_time['Stage'] = [stage] * Total_orders_toPick
Pick_time['Total Distance'] = [stage] * Total_orders_toPick
for order in order_list:
    total_dist = 0
    df = pick_orders[pick_orders['SALES_ORDER'] == order]
    first_time = True
    for ind, rec in df.iterrows():
        if first_time:
            first_time = False
            l = str(rec['Location'])
            total_dist += distance_IO[l]
            #print("first time: ",order, total_dist)
            l1 = l
            l2 = l
        else:
            l2 = str(rec['Location'])
            total_dist += abs(distance_BTW[l1][l2])
            #print("next time: ",order, total_dist)
    total_dist += distance_IO[l2]
    #print("last time: ",order, total_dist)
    Pick_time.loc[Pick_time['Sales Order'] == order, 'Total Distance'] = total_dist

print(Pick_time)
tot_pick_dist = Pick_time['Total Distance'].sum()
print(f"\nTotal pick distance for {stage} = {tot_pick_dist:,.2f}")

```

	Sales Order	Stage	Total Distance
0	27997929	STG2	110.333
1	28018206	STG2	110.333
2	28025370	STG2	181.25
3	28057994	STG2	181.25
4	28100693	STG2	499.208
...
12612	55875321	STG2	432.708
12613	55875328	STG2	3899.79
12614	55875339	STG2	448.875
12615	55875348	STG2	1407.33
12616	55875362	STG2	1173.71

[12617 rows x 3 columns]

Total pick distance for STG2 = 6,755,399.71

```
In [412... Pick_time.to_csv('STG2_order pick times.csv')
```

```
In [413... ##STAGE 3
product = Products.head(No_of_Products)['MATERIAL_NUMBER'].values.tolist() #list of products
noOfPrd = len(product)
demand = dict(zip(product, [No_of_Loc_per_product]*noOfPrd)) #number of locations needed. Time being 1 per product

confidence_list = defaultdict(dict) #confidence_list[p1][p2] will give confidence that p2 is bought for each p1
for ind, rec in rules.iterrows():
    ant = (rec['antecedents'])
    con = (rec['consequents'])
    conf = rec['confidence']
    if conf > .5:
        confidence_list[ant][con] = conf
    else:
        confidence_list[ant][con] = 0

#relative order freq
order_freq = pd.Series(Products['Order Count'].values, index=Products.MATERIAL_NUMBER).to_dict()

location = locations['Location'].values.tolist() #list of all locations
noOfLoc = len(location)
supply = dict(zip(location,
                  [1]*noOfLoc)) #number of products that can be assigned to a location. Default 1 - one product

demand["DUMMY_PART"] = 0
diff = sum(supply.values()) - sum(demand.values()) #comparing supply and demand
if 'DUMMY_PART' not in product:
    product.append("DUMMY_PART") #adding dummy product as supply is more than demand
demand["DUMMY_PART"] = diff #assign these many extra locations to dummy part
order_freq["DUMMY_PART"] = 0 #no sales for dummy part

Aff_wt = 1 #to control weightage of product affinity in the optimization equation

#####
#all product pairs should have confidence. If a product pair is not in input file (Apriori output), assign ZERO
for p in product:
    for c in product:
        if c not in confidence_list[p]:
            if p==c:
                confidence_list[p][c] = 1 #confidence of 1 when product pair is itself
            else:
                confidence_list[p][c] = 0 #confidence of 0 when product pair has not been purchased together (a
#####
```

```

# instantiate Concrete Model
model = ConcreteModel()

# define variables
model.X = Var(product, location, domain=NonNegativeIntegers)

# define objective function
model.total_distance = Objective(expr=sum(order_freq[p] * distance_IO[l] * model.X[p, l]
                                         for p in product
                                         for l in location)
                                +
                                sum(order_freq[pc] * distance_IO[lc] * model.X[pc, lc]
                                      for pc in product
                                      for lc in location)
                                +
                                Aff_wt *
                                sum(confidence_list[p][pc] * order_freq[p]
                                    * abs(distance_BTW[l][lc])
                                    * model.X[p, l] * model.X[pc, lc]
                                      for p in product
                                      for l in location
                                      for pc in product
                                      for lc in location),
                                sense=minimize)

# define constraints
model.supply_ct = ConstraintList()
for l in location:
    model.supply_ct.add(
        sum(model.X[p, l] for p in product) == supply[l])

model.demand_ct = ConstraintList()
for p in product:
    model.demand_ct.add(sum(model.X[p, l] for l in location) == demand[p])

```

```

In [414... # solve
solver = SolverFactory('ipopt')
solver.solve(model)

```

```

Out[414... {'Problem': [{'Lower bound': -inf, 'Upper bound': inf, 'Number of objectives': 1, 'Number of constraints': 432,
'Number of variables': 46656, 'Sense': 'unknown'}], 'Solver': [{'Status': 'ok', 'Message': 'Ipopt 3.12.12\\x3a
Optimal Solution Found', 'Termination condition': 'optimal', 'Id': 0, 'Error rc': 0, 'Time': 3289.16752004623
4}], 'Solution': [OrderedDict([('number of solutions', 0), ('number of solutions displayed', 0)])]}

```

```

In [415... # convert model into a Pandas data frame for nicer display

```

```

assignment = pd.DataFrame(0, index=product, columns=location)
for p in product:
    for l in location:
        assignment.loc[p, l] = model.X[p, l].value

for p in product:
    dmd = demand[p]
    for l in location:
        if assignment.loc[p, l] > 0.1:
            if dmd != 0:
                assignment.loc[:, l] = 0
                assignment.loc[p, l] = 1
                dmd -= 1
            else:
                assignment.loc[p, l] = 0

STG3_assignment = defaultdict(dict)
cols = ['Product', 'Distance']
STG3_distance_df = pd.DataFrame(columns = cols)
for p in product:
    STG3_assignment[p] = []
    for l in location:
        if assignment.loc[p, l] > 0:
            assignment.loc[p, l] = 'S'
            STG3_assignment[p] += [l]
            if p != 'DUMMY_PART':
                STG3_distance_df = STG3_distance_df.append({'Product': p, 'Distance IO':distance_IO[l]},
                                                            ignore_index=True)
        else:
            assignment.loc[p, l] = ''

# display
print(f"\nThe best distance that can be achived = {model.total_distance():,.2f}")
print("Final assignment: ")
assignment

```

The best distance that can be achived = 7,397,199.14

Final assignment:

Out[415...		50.54.A	50.53.A	50.52.A	49.54.A	50.51.A	49.53.A	50.50.A	49.52.A	50.49.A	48.54.A	...	49.01.A	47.06.A	48.0
	ITM742	S										...			
	ITM5010		S									...			
	ITM1130					S						...			

	50.54.A	50.53.A	50.52.A	49.54.A	50.51.A	49.53.A	50.50.A	49.52.A	50.49.A	48.54.A	...	49.01.A	47.06.A	48.0
ITM2103			S								...			
ITM157				S							...			
...
ITM1729											...			
ITM2066											...			
ITM1994											...			
ITM5783											...			
DUMMY_PART											...			

216 rows × 216 columns

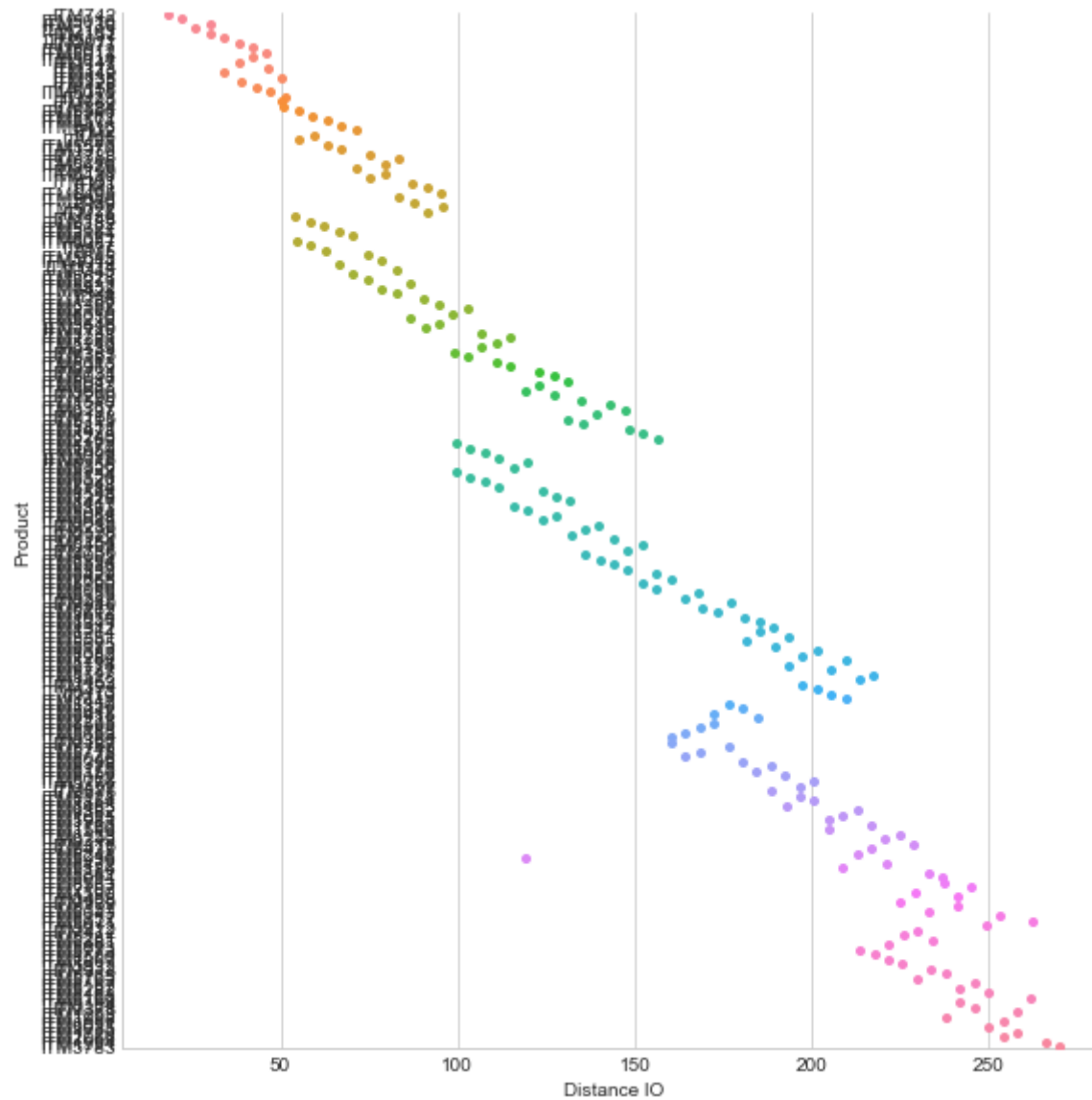
```
In [416... assignment.to_csv('STG3_result.csv')
```

```
In [417... # convert model into a Pandas data frame for nicer display
assignment = pd.DataFrame(0, index=product, columns=location)
for p in product:
    for l in location:
        assignment.loc[p, l] = model.X[p, l].value

assignment.to_csv('STG3_result_raw.csv')
```

```
In [418... sns.catplot(x="Distance IO", y="Product", data=STG3_distance_df, kind='swarm', height=8, aspect=1)
```

```
Out[418... <seaborn.axisgrid.FacetGrid at 0x7fe496cea5e0>
```



In [419...

```
stage = 'STG3'
STG_Assignment = STG3_assignment

pick_orders['Stage'] = [stage]*Total_picks
pick_orders['Location'] = ['']*Total_picks
pick_orders['Sort Field'] = [0]*Total_picks
for ind,rec in pick_orders.iterrows():
    p = rec['MATERIAL_NUMBER']
```



```

l = STG_Assignment[p][0]
sf = int(Locations[Locations['Location'] == l]['Sort Field'])
pick_orders.loc[pick_orders['MATERIAL_NUMBER'] == p, 'Location'] = l
pick_orders.loc[pick_orders['MATERIAL_NUMBER'] == p, 'Sort Field'] = sf

pick_orders = pick_orders.sort_values(by=['SALES_ORDER', 'Sort Field'], ascending=True)
pick_orders

Pick_time = pd.DataFrame(order_list, columns=['Sales Order'])
Pick_time['Stage'] = [stage] * Total_orders_toPick
Pick_time['Total Distance'] = [stage] * Total_orders_toPick
for order in order_list:
    total_dist = 0
    df = pick_orders[pick_orders['SALES_ORDER'] == order]
    first_time = True
    for ind, rec in df.iterrows():
        if first_time:
            first_time = False
            l = str(rec['Location'])
            total_dist += distance_IO[l]
            #print("first time: ",order, total_dist)
            l1 = l
            l2 = l
        else:
            l2 = str(rec['Location'])
            total_dist += abs(distance_BTW[l1][l2])
            #print("next time: ",order, total_dist)
    total_dist += distance_IO[l2]
    #print("last time: ",order, total_dist)
    Pick_time.loc[Pick_time['Sales Order'] == order, 'Total Distance'] = total_dist

print(Pick_time)
tot_pick_dist = Pick_time['Total Distance'].sum()
print(f"\nTotal pick distance for {stage} = {tot_pick_dist:,.2f}")

```

	Sales Order	Stage	Total Distance
0	27997929	STG3	92.5833
1	28018206	STG3	92.5833
2	28025370	STG3	294.417
3	28057994	STG3	294.417
4	28100693	STG3	543.417
...
12612	55875321	STG3	543.417
12613	55875328	STG3	2380.13
12614	55875339	STG3	762.458
12615	55875348	STG3	1139.88

12616 55875362 STG3 1234.08

[12617 rows x 3 columns]

Total pick distance for STG3 = 6,648,429.79

```
In [420...] Pick_time.to_csv('STG3_order pick times.csv')
```

```
In [421...] Current_WH_loc_assignment = pd.read_excel('Input Data/Current Material Location.XLSX')
```

```
/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/xlrd/xlsx.py:266: DeprecationWarning: This method will be removed in future versions. Use 'tree.iter()' or 'list(tree.iter())' instead.  
    for elem in self.tree.iter() if Element_has_iter else self.tree.getiterator():  
/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/xlrd/xlsx.py:312: DeprecationWarning: This method will be removed in future versions. Use 'tree.iter()' or 'list(tree.iter())' instead.  
    for elem in self.tree.iter() if Element_has_iter else self.tree.getiterator():  
/Users/shyamsrikumar/opt/anaconda3/lib/python3.8/site-packages/xlrd/xlsx.py:266: DeprecationWarning: This method will be removed in future versions. Use 'tree.iter()' or 'list(tree.iter())' instead.  
    for elem in self.tree.iter() if Element_has_iter else self.tree.getiterator():
```

```
In [422...] Current_WH_loc_assignment = Current_WH_loc_assignment.sort_values(by=['Storage Bin'], ascending=False)  
current_assignment = Current_WH_loc_assignment[~Current_WH_loc_assignment.isnull().any(axis=1)]  
current_assignment
```

```
Out[422...]            Storage Bin   level   Material
```

3716	50.51.D	D	ITM866
10829	50.51.C	C	ITM4591
10546	50.51.B	B	ITM4402
1377	50.51.A	A	ITM5015
3715	50.50.D	D	ITM865
...
9632	01.21.C	C	ITM3981
3194	01.05.B	B	ITM434
8515	01.01.D	D	ITM3256
8412	01.01.C	C	ITM3195
3193	01.01.B	B	ITM433

8830 rows x 3 columns

```
In [423... Unassigned_locations = Current_WH_loc_assignment[Current_WH_loc_assignment.isnull().any(axis=1)]
Unassigned_locations = Unassigned_locations[(Unassigned_locations['level'] == 'A')|(Unassigned_locations['level']
Unassigned_locations
```

```
Out[423... Storage Bin level Material
```

	Storage Bin	level	Material
1387	50.54.B	B	NaN
1386	50.54.A	A	NaN
1383	50.53.B	B	NaN
1382	50.53.A	A	NaN
1379	50.52.B	B	NaN
...
2089	01.03.B	B	NaN
2088	01.03.A	A	NaN
2085	01.02.B	B	NaN
2084	01.02.A	A	NaN
2083	01.01.A	A	NaN

1133 rows x 3 columns

```
In [424... STG0_assignment = defaultdict(dict)
for p in product:
    STG0_assignment[p] = []

for ind, rec in current_assignment.iterrows():
    p = rec['Material']
    l = rec['Storage Bin']
    if p in product:
        STG0_assignment[p] += [l]

for p in product:
    l = STG0_assignment[p]
    if len(l) == 0:
        l1 = Unassigned_locations['Storage Bin'].iat[0]
        STG0_assignment[p] = [l1]
        Current_WH_loc_assignment.loc[Current_WH_loc_assignment['Storage Bin'] == l1, 'Material'] = p
```

```
Unassigned_locations = Current_WH_loc_assignment[Current_WH_loc_assignment.isnull().any(axis=1)]
Unassigned_locations = Unassigned_locations[(Unassigned_locations['level'] == 'A')|(Unassigned_location
```

```
In [425... STG0_assignment
```

```
Out[425... defaultdict(dict,
    {'ITM742': ['43.54.A'],
     'ITM5010': ['50.01.A'],
     'ITM1130': ['49.13.A'],
     'ITM2103': ['37.32.A'],
     'ITM157': ['29.11.A'],
     'ITM5011': ['50.22.A', '50.21.A'],
     'ITM677': ['50.36.C'],
     'ITM5012': ['50.31.A'],
     'ITM5013': ['50.32.A'],
     'ITM5014': ['50.50.A', '50.35.A'],
     'ITM147': ['49.32.D',
                '49.31.D',
                '30.16.C',
                '30.14.C',
                '29.25.C',
                '27.03.A'],
     'ITM373': ['48.37.B'],
     'ITM149': ['42.51.A', '27.24.A'],
     'ITM935': ['42.44.D'],
     'ITM328': ['47.04.D'],
     'ITM158': ['40.29.B', '29.32.A'],
     'ITM5015': ['50.51.A'],
     'ITM23': ['48.19.A',
               '48.09.A',
               '47.25.A',
               '43.13.A',
               '28.05.A',
               '28.02.A',
               '28.01.A'],
     'ITM789': ['49.29.A'],
     'ITM384': ['49.31.C'],
     'ITM5546': ['50.38.A'],
     'ITM5761': ['50.39.A'],
     'ITM5574': ['49.03.A', '49.01.A'],
     'ITM6416': ['49.09.A', '49.07.A'],
     'ITM2': ['27.33.A'],
     'ITM6': ['30.09.A', '29.17.A', '29.03.A'],
     'ITM21': ['46.20.A', '42.24.A', '42.08.A', '29.01.A'],
     'ITM5579': ['48.22.A'],
     'ITM1370': ['50.37.A'],
     'ITM788': ['49.29.A', '36.19.A', '29.08.A'],
```

'ITM6246': ['50.54.B'],
'ITM5626': ['48.24.A'],
'ITM199': ['39.35.B'],
'ITM6436': ['48.28.A'],
'ITM161': ['30.31.A'],
'ITM1': ['49.28.A',
'49.02.A',
'48.21.A',
'48.08.A',
'46.20.C',
'43.14.A',
'36.17.B',
'36.13.A',
'30.50.A',
'29.08.A',
'28.34.A',
'28.19.A',
'27.25.A',
'27.05.B'],
'ITM3': ['48.42.A', '44.24.A', '28.49.A', '28.42.A', '27.37.A'],
'ITM6495': ['50.54.A'],
'ITM5640': ['50.53.B'],
'ITM9': ['31.24.A', '31.23.A', '31.19.A', '29.12.A'],
'ITM5022': ['50.53.A'],
'ITM75': ['50.24.B',
'50.09.A',
'50.06.D',
'49.19.A',
'49.18.A',
'49.05.A',
'39.50.B'],
'ITM148': ['30.34.A', '30.25.A', '27.06.A', '27.05.A', '27.04.A'],
'ITM6182': ['50.52.B'],
'ITM5627': ['50.52.A'],
'ITM3164': ['44.39.A'],
'ITM6071': ['50.49.A'],
'ITM6087': ['48.53.A', '48.52.A'],
'ITM77': ['49.29.B'],
'ITM5': ['49.38.B', '49.24.A', '29.06.A'],
'ITM5645': ['50.48.A'],
'ITM1044': ['44.07.D',
'42.17.C',
'40.38.C',
'38.54.A',
'37.27.B',
'37.23.B',
'37.06.B'],
'ITM1114': ['49.04.A', '35.21.A'],
'ITM45': ['47.26.A', '37.44.A'],

'ITM5628': ['50.43.A'],
'ITM5271': ['50.42.A'],
'ITM5932': ['50.40.A'],
'ITM6428': ['50.29.A'],
'ITM4': ['39.39.D', '28.38.A'],
'ITM1236': ['46.34.C'],
'ITM6392': ['50.24.A'],
'ITM2105': ['39.11.A'],
'ITM6050': ['50.23.A'],
'ITM5210': ['50.17.B'],
'ITM5646': ['50.17.A'],
'ITM1120': ['46.37.B', '37.32.B'],
'ITM5738': ['50.15.A'],
'ITM1281': ['36.34.D', '35.39.A'],
'ITM5249': ['50.14.A'],
'ITM6139': ['50.10.A'],
'ITM383': ['49.24.B'],
'ITM5187': ['50.08.A'],
'ITM6013': ['50.06.A'],
'ITM6369': ['50.05.A'],
'ITM731': ['42.12.C'],
'ITM6048': ['50.04.A'],
'ITM6047': ['50.03.A'],
'ITM6083': ['50.02.A'],
'ITM5660': ['49.54.B'],
'ITM260': ['49.36.A', '47.29.C', '44.33.A', '43.07.D', '30.50.A'],
'ITM1540': ['29.13.A'],
'ITM6367': ['49.54.A'],
'ITM6137': ['49.53.B'],
'ITM163': ['50.18.B',
'48.16.B',
'47.21.C',
'31.11.D',
'31.10.B',
'31.09.D',
'31.07.D'],
'ITM5715': ['49.53.A'],
'ITM5851': ['49.52.B'],
'ITM1478': ['35.17.A'],
'ITM6245': ['49.52.A'],
'ITM2769': ['30.26.D'],
'ITM6372': ['49.51.A'],
'ITM1659': ['47.11.A', '40.10.A', '37.13.C'],
'ITM5099': ['49.50.A'],
'ITM6116': ['49.49.A'],
'ITM6356': ['49.48.A'],
'ITM5529': ['49.44.A'],
'ITM6134': ['49.42.A'],
'ITM6520': ['49.41.A'],

'ITM2948': ['27.18.A'],
'ITM5184': ['49.40.A'],
'ITM6548': ['49.39.A'],
'ITM1328': ['50.45.A',
'47.25.B',
'47.20.C',
'47.20.A',
'46.25.A',
'44.30.A',
'37.21.A'],
'ITM6417': ['49.35.A'],
'ITM6393': ['49.34.A'],
'ITM5084': ['49.33.A'],
'ITM6058': ['49.30.B'],
'ITM6045': ['49.25.A'],
'ITM236': ['48.35.A', '43.22.A', '42.40.A', '42.31.A', '27.17.A'],
'ITM6128': ['49.22.A'],
'ITM929': ['38.43.C'],
'ITM6154': ['49.21.B'],
'ITM6409': ['49.21.A'],
'ITM736': ['43.15.A'],
'ITM4005': ['36.49.A'],
'ITM6394': ['49.20.B'],
'ITM5536': ['49.20.A'],
'ITM5532': ['49.19.B'],
'ITM6429': ['49.18.B'],
'ITM2665': ['27.40.A'],
'ITM5790': ['49.17.B'],
'ITM6090': ['49.16.B'],
'ITM6155': ['49.15.B'],
'ITM6242': ['49.15.A'],
'ITM940': ['50.26.C', '44.10.B'],
'ITM6262': ['49.14.A'],
'ITM5612': ['49.10.B'],
'ITM1050': ['42.44.D'],
'ITM6341': ['49.10.A'],
'ITM1312': ['43.39.B', '30.25.B'],
'ITM6264': ['48.54.B'],
'ITM5351': ['48.54.A'],
'ITM5695': ['48.53.B'],
'ITM6173': ['48.52.B'],
'ITM6082': ['48.49.A'],
'ITM1280': ['35.27.B'],
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'ITM5642': ['48.39.B'],
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'46.44.C',
'41.46.B',
'40.22.A',
'39.53.A'],
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'ITM187': ['37.40.B', '37.40.A'],
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'ITM5775': ['48.26.A'],
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'ITM6175': ['48.20.B'],
'ITM6156': ['48.18.A'],
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'37.26.B',
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'30.27.A',
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'ITM6408': ['48.01.A'],
'ITM939': ['43.46.B'],
'ITM6157': ['47.54.A'],
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'ITM5281': ['47.49.A'],
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'ITM6500': ['47.45.A'],
'ITM1867': ['43.33.B'],
'ITM5832': ['47.44.A'],
'ITM313': ['46.46.B'],
'ITM5765': ['47.43.A'],
'ITM5763': ['47.42.A'],
'ITM6167': ['47.41.B'],
'ITM5282': ['47.41.A'],
'ITM6163': ['47.40.A'],
'ITM6166': ['47.38.B'],
'ITM6164': ['47.38.A'],
'ITM378': ['49.33.C', '48.48.A', '30.37.A'],
'ITM1293': ['38.17.A'],
'ITM1998': ['49.35.C',
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 '40.11.B',
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 '30.14.B'],
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```

'ITM5035': ['47.35.A'],
'ITM1729': ['41.05.A'],
'ITM2066': ['40.15.A'],
'ITM1994': ['49.45.C', '49.45.A', '44.38.A', '36.48.A'],
'ITM5783': ['47.33.A'],
'DUMMY_PART': ['47.32.A'])

```

```

In [426... location = Locations['Location'].values.tolist()

same_aisle = [{50,49},{48,47},{46,45},{44,43},{42,41},{40,39},{38,37},{36,35},
               {34,33},{32,31},{30,29},{28,27},{26,25},{24,23},{22,21},{20,19},
               {18,17},{16,15},{14,13},{12,11},{10,9},{8,7},{6,5},{4,3},{2,1}]

distance_Pick = pd.Series(Locations['Final Pick Distance'].values,index=Locations.Location).to_dict()
distance_IO = pd.Series(Locations['Final distance to drop off'].values,index=Locations.Location).to_dict()
distance_BTW = defaultdict(dict)
for l1 in location:
    distance_BTW[l1] = defaultdict(dict)
    for l2 in location:
        a1 = int(l1[:2])
        a2 = int(l2[:2])
        if {a1,a2} in same_aisle:
            if a1 > a2:
                d1 = distance_Pick[l1]
                d2 = distance_Pick[l2] - 12
            else:
                d1 = distance_Pick[l1] - 12
                d2 = distance_Pick[l2]
            distance_BTW[l1][l2] = abs(d1-d2) + 12
        else:
            distance_BTW[l1][l2] = abs(distance_Pick[l1] - distance_Pick[l2])

#list(distance_BTW.items())[ :1]

```

```

In [427... stage = 'STG0'
STG_Assignment = STG0_assignment

pick_orders['Stage'] = [stage]*Total_picks
pick_orders['Location'] = ['']*Total_picks
pick_orders['Sort Field'] = [0]*Total_picks
for ind,rec in pick_orders.iterrows():
    p = rec['MATERIAL_NUMBER']
    l = STG_Assignment[p][0]
    sf = int(Locations[Locations['Location'] == l]['Sort Field'])
    pick_orders.loc[pick_orders['MATERIAL_NUMBER'] == p, 'Location'] = l
    pick_orders.loc[pick_orders['MATERIAL_NUMBER'] == p, 'Sort Field'] = sf

```

```

pick_orders = pick_orders.sort_values(by=['SALES_ORDER', 'Sort Field'], ascending=True)
pick_orders

Pick_time = pd.DataFrame(order_list, columns=['Sales Order'])
Pick_time['Stage'] = [stage] * Total_orders_toPick
Pick_time['Total Distance'] = [stage] * Total_orders_toPick
for order in order_list:
    total_dist = 0
    df = pick_orders[pick_orders['SALES_ORDER'] == order]
    first_time = True
    for ind, rec in df.iterrows():
        if first_time:
            first_time = False
            l = str(rec['Location'])
            total_dist += distance_IO[l]
            #print("first time: ",order, total_dist)
            l1 = l
            l2 = l
        else:
            l2 = str(rec['Location'])
            total_dist += abs(distance_BTW[l1][l2])
            #print("next time: ",order, total_dist)
    total_dist += distance_IO[l2]
    #print("last time: ",order, total_dist)
    Pick_time.loc[Pick_time['Sales Order'] == order, 'Total Distance'] = total_dist

print(Pick_time)
tot_pick_dist = Pick_time['Total Distance'].sum()
print(f"\nTotal pick distance for {stage} = {tot_pick_dist:,.2f}")

```

	Sales Order	Stage	Total Distance
0	27997929	STG0	252.417
1	28018206	STG0	252.417
2	28025370	STG0	105.083
3	28057994	STG0	105.083
4	28100693	STG0	534.458
...
12612	55875321	STG0	556.417
12613	55875328	STG0	9125.08
12614	55875339	STG0	575.125
12615	55875348	STG0	1966.04
12616	55875362	STG0	1516.25

[12617 rows x 3 columns]

Total pick distance for STG0 = 15,745,292.71

```
In [428... Pick_time.to_csv('STG0_order pick times.csv')
```

```
In [429... df0 = pd.read_csv('STG0_order pick times.csv')
df1 = pd.read_csv('STG1_order pick times.csv')
df2 = pd.read_csv('STG2_order pick times.csv')
df3 = pd.read_csv('STG3_order pick times.csv')
```

```
In [430... df = pd.concat([df0, df1, df2, df3])
df.rename(columns = {'Unnamed: 0': 'Index'}, inplace = True)
df.rename(columns = {'Sales Order': 'SALES_ORDER'}, inplace = True)
df.loc[df['Stage'] == 'STG0', 'Stage'] = 'AS-IS'
df.loc[df['Stage'] == 'STG1', 'Stage'] = 'Popularity Based'
df.loc[df['Stage'] == 'STG2', 'Stage'] = 'Affinity Based'
df.loc[df['Stage'] == 'STG3', 'Stage'] = 'Hybrid'
```

```
In [431... df1 = df_salesOrder[df_salesOrder['MATERIAL_NUMBER'].isin(product)][['MATERIAL_NUMBER', 'SALES_ORDER']].drop_duplicates()
df2 = df1.groupby('SALES_ORDER')['MATERIAL_NUMBER'].agg(No_of_Lines='count').reset_index()
df2.loc[df2['No_of_Lines'] == 1, 'Single or Multiple'] = 'Single'
df2.loc[df2['No_of_Lines'] > 1, 'Single or Multiple'] = 'Multiple'
```

```
In [432... df['SALES_ORDER'] = df['SALES_ORDER'].astype(str)
df2['SALES_ORDER'] = df2['SALES_ORDER'].astype(str)
Run_Results = pd.merge(df, df2, on="SALES_ORDER", how="left")
Run_Results.reset_index()
Run_Results
```

```
Out[432...
```

	Index	SALES_ORDER	Stage	Total Distance	No_of_Lines	Single or Multiple	
	0	0	27997929	AS-IS	252.416667	1	Single
	1	1	28018206	AS-IS	252.416667	1	Single
	2	2	28025370	AS-IS	105.083333	1	Single
	3	3	28057994	AS-IS	105.083333	1	Single
	4	4	28100693	AS-IS	534.458333	2	Multiple

	50463	12612	55875321	Hybrid	543.416667	2	Multiple
	50464	12613	55875328	Hybrid	2380.125000	14	Multiple
	50465	12614	55875339	Hybrid	762.458333	3	Multiple

	Index	SALES_ORDER	Stage	Total Distance	No_of_Lines	Single or Multiple
50466	12615	55875348	Hybrid	1139.875000	8	Multiple
50467	12616	55875362	Hybrid	1234.083333	6	Multiple

50468 rows x 6 columns

```
In [433... Run_Results.groupby('Stage').agg({'Total Distance': 'sum', 'SALES_ORDER': 'count'})
```

```
Out[433...
              Total Distance  SALES_ORDER
Stage
AS-IS      1.574529e+07      12617
Affinity Based  6.755400e+06      12617
Hybrid      6.648430e+06      12617
Popularity Based  6.733313e+06      12617
```

```
In [434... Run_Results.groupby(['Stage', 'Single or Multiple']).agg({'Total Distance': 'sum', 'SALES_ORDER': 'count'})
```

```
Out[434...
              Total Distance  SALES_ORDER
Stage Single or Multiple
AS-IS      Multiple  1.329148e+07      5340
           Single   2.453814e+06      7277
Affinity Based  Multiple  5.237929e+06      5340
           Single   1.517471e+06      7277
Hybrid      Multiple  5.136518e+06      5340
           Single   1.511912e+06      7277
Popularity Based  Multiple  5.224244e+06      5340
           Single   1.509069e+06      7277
```

```
In [435... # Python code to get the Cumulative sum of a list
def Cumulative(lists):
    cu_list = []
```

```
length = len(lists)
cu_list = [sum(lists[0:x:1]) for x in range(0, length+1)]
return cu_list[1:]
```

In [436...

```
x = Run_Results.loc[Run_Results['Stage'] == 'AS-IS']['Index']
y1 = Run_Results.loc[Run_Results['Stage'] == 'AS-IS']['Total Distance']
y1 = Cumulative(y1)

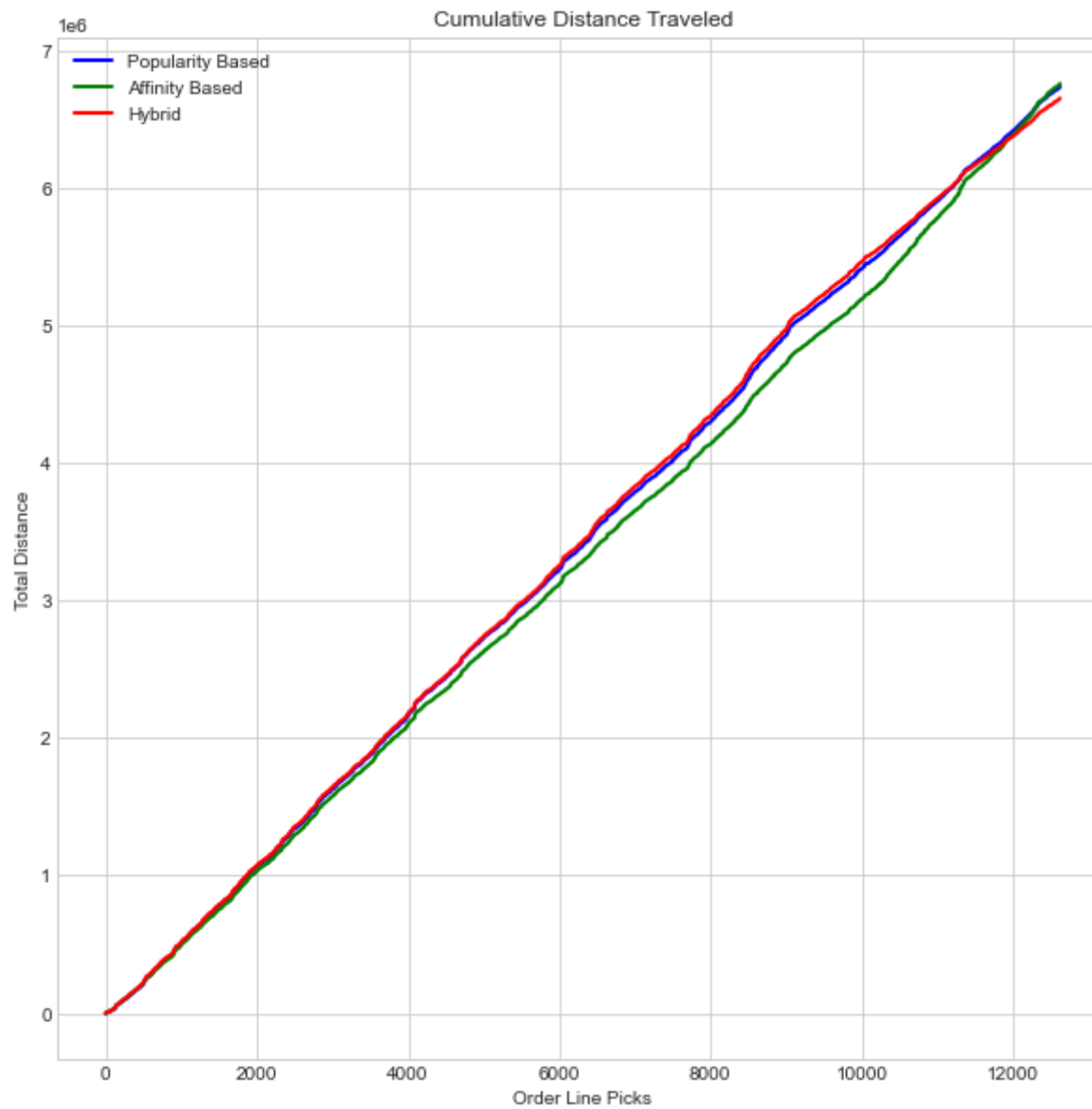
y2 = Run_Results.loc[Run_Results['Stage'] == 'Popularity Based']['Total Distance']
y2 = Cumulative(y2)

y3 = Run_Results.loc[Run_Results['Stage'] == 'Affinity Based']['Total Distance']
y3 = Cumulative(y3)

y4 = Run_Results.loc[Run_Results['Stage'] == 'Hybrid']['Total Distance']
y4 = Cumulative(y4)

plt.rcParams["figure.figsize"] = (10,10)

#plt.plot(x,y1)
plt.plot(x,y2, color = "blue", linewidth=2)
plt.plot(x,y3, color = "green", linewidth=2)
plt.plot(x,y4, color = "red", linewidth=2)
plt.title('Cumulative Distance Traveled')
plt.xlabel('Order Line Picks')
plt.ylabel('Total Distance')
plt.gca().legend(('Popularity Based', 'Affinity Based', 'Hybrid'))
plt.show()
```



In [437...

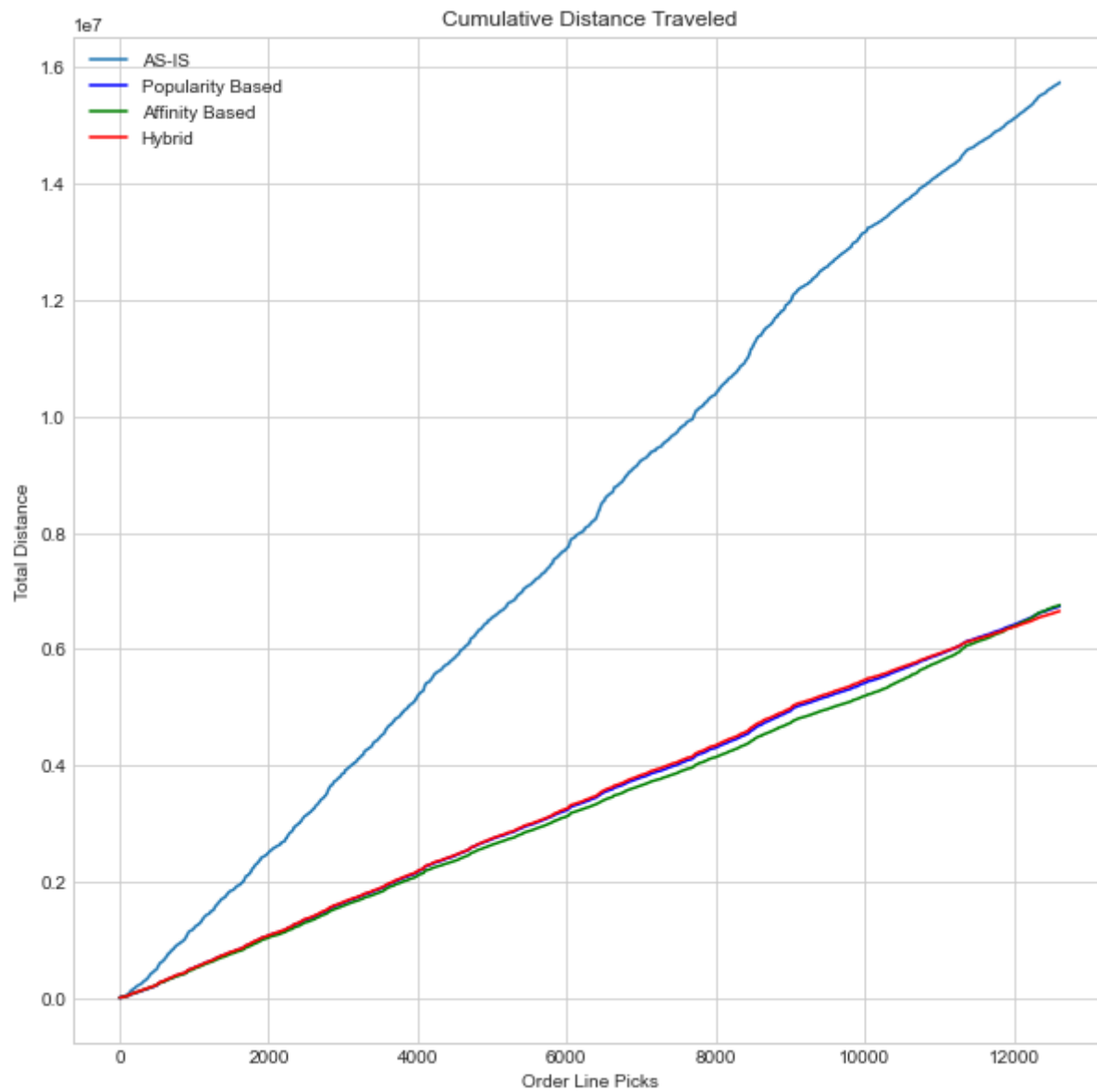
```
x = Run_Results.loc[Run_Results['Stage'] == 'AS-IS']['Index']
y1 = Run_Results.loc[Run_Results['Stage'] == 'AS-IS']['Total Distance']
y1 = Cumulative(y1)

y2 = Run_Results.loc[Run_Results['Stage'] == 'Popularity Based']['Total Distance']
y2 = Cumulative(y2)
```

```
y3 = Run_Results.loc[Run_Results['Stage'] == 'Affinity Based']['Total Distance']
y3 = Cumulative(y3)

y4 = Run_Results.loc[Run_Results['Stage'] == 'Hybrid']['Total Distance']
y4 = Cumulative(y4)

plt.plot(x,y1)
plt.plot(x,y2, color = "blue")
plt.plot(x,y3, color = "green")
plt.plot(x,y4, color = "red")
plt.title('Cumulative Distance Traveled')
plt.xlabel('Order Line Picks')
plt.ylabel('Total Distance')
plt.gca().legend(('AS-IS', 'Popularity Based', 'Affinity Based', 'Hybrid'))
plt.show()
```

In []: