FedEx: Las Vegas Deliveries

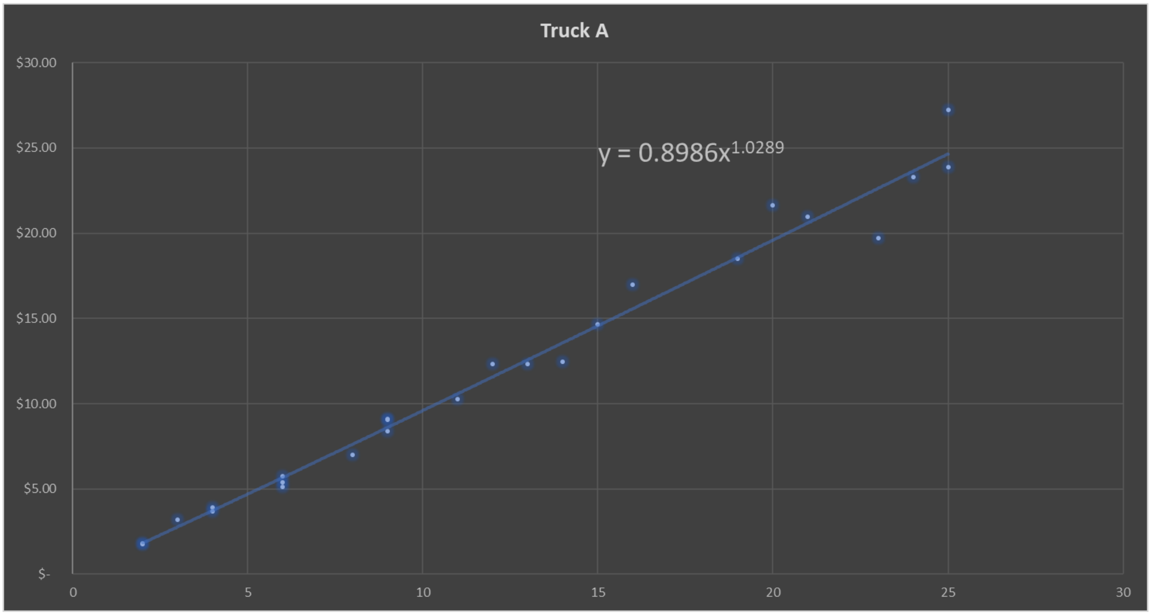
Introduction

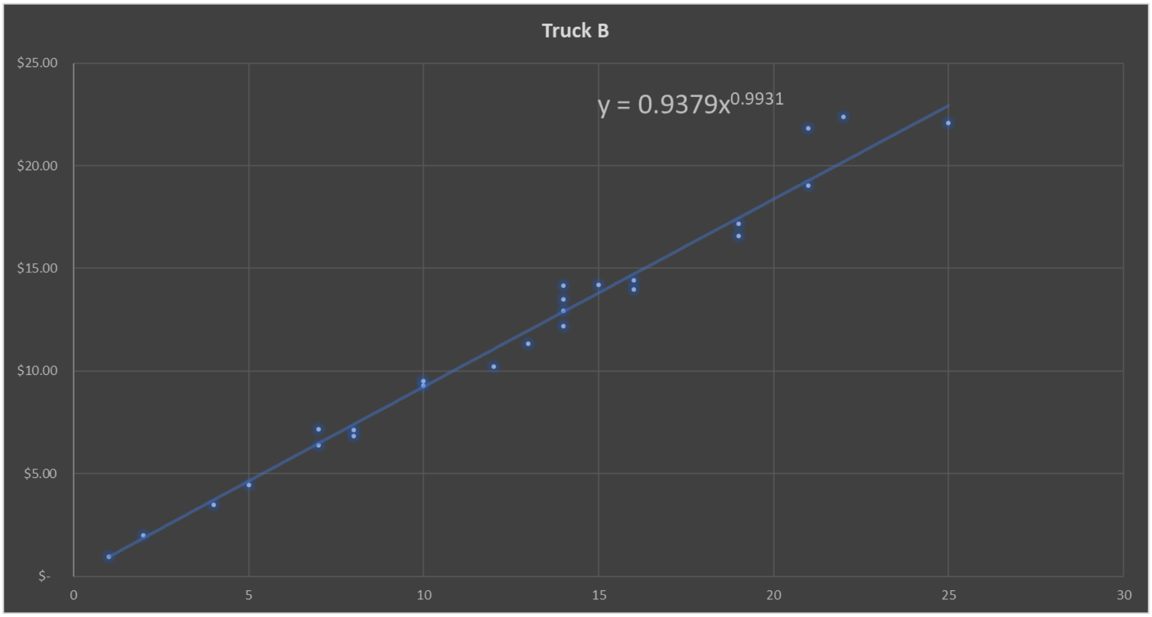
This notebook, based on several online tutorials, is meant to be a basic example of the Clark Wright savings algorithm, as applied for deliveries from a single hun to locations in the Las Vegas area. Please note I did not overlay the road system with Google API, but merely assumes direct travel from hub to nodes and back for simplicity.

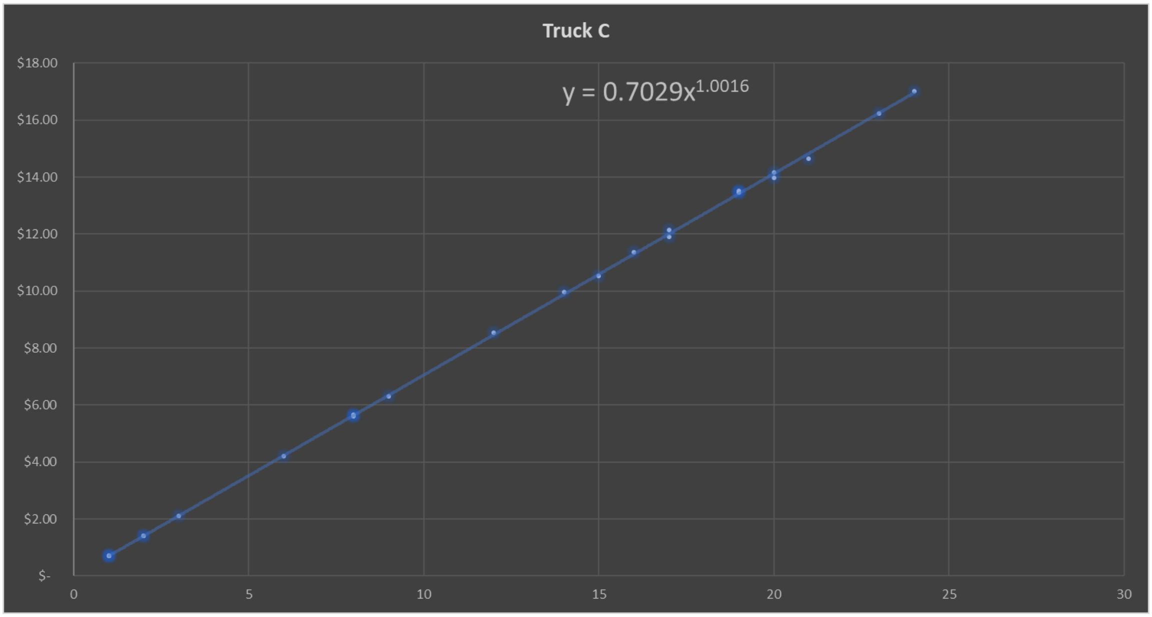
The constraints and assumptions on the underlying data can be found in the formulas of the accompanying dataset, but here are some examples:

```
-Three trucks:
    Truck A has total capacity of 10, and gets 13-18 mpg.
    Truck B has total capacity of 8, and gets 15-19 mpg.
    Truck C has total capacity of 5, and gets 3-5 kWpm (electric).
-Gas cost varies between $3-6/gallon, electricity fixed at
$0.15/kW.
-Labor cost is fixed at $20/hour
-Assumption is that drivers move at an average of 30 mph.
-15 separate locations in Las Vegas area, with the same weighted
delivery for each location.
-Two months worth of deliveries, 500 in total.
```

Here are the cost functions for each truck **(y = mx^(1-n))**:


Truck A
y = 0.8986x^1.0289
$30.00
$25.00
$20.00
$15.00
$10.00
$5.00
$-
0
5
10
15
20
25
30


Truck B
y = 0.9379x^0.9931
$25.00
$20.00
$15.00
$10.00
$5.00
$-
0
5
10
15
20
25
30


Truck C
y = 0.7029x^1.0016
$18.00
$16.00
$14.00
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$-
0
5
10
15
20
25
30

In [1]:

```
import numpy as np

Truck_list = [['A', 10, 0.8986, -0.0289],
              ['B', 8, 0.9379, 0.0069],
              ['C', 5, 0.7029, -0.0016]]

sorter_guide = []

max_truck_capacity = 0

for i in range(len(Truck_list)):
    sorter_guide.append([i, int(Truck_list[i][1])])
    if int(Truck_list[i][1]) >= max_truck_capacity:
        max_truck_capacity = int(Truck_list[i][1])
sorter_guide = np.array(sorter_guide)
sorter_guide = sorter_guide[sorter_guide[:,1].argsort()[::-1]]
sorter_temp = []

for i in range(len(sorter_guide)):
    sorter_temp.append(Truck_list[sorter_guide[i][0]])

Truck_list = np.array(sorter_temp)

print('\n',"max_truck_capacity =",max_truck_capacity,'\n')
Truck_list
```

```
max_truck_capacity = 10
```

Out[1]:

```
array([['A', '10', '0.8986', '-0.0289'],
       ['B', '8', '0.9379', '0.0069'],
       ['C', '5', '0.7029', '-0.0016']], dtype='<U32')
```

Let's look at the dataset

The csv file is included on the FedEx GitHub page.

The first tab labeled **'Deliveries'** is the full dataset on which we will run the simulation with shape (500,5), and follows the parameter outlined above.

The next three tabs calculate cost functions for each truck with their separate constraints, charts above describing the same. There is also a **'Trucks'** tab which summarizes **m & b** for each truck.

Finally there is a **'rand data'** tab which provides unique values for each of the five features, to make calling easier from this notebook.

In [2]:

```
import pandas as pd
df = pd.read_excel('trux.xlsx',sheet_name = 'Deliveries')
df
```

Out[2]:

	Date	Location	Latitude	Longitude	Weight
0	2023-06-21	Location 15	36.015227	-115.136941	12.627326
1	2023-07-21	Location 11	36.261824	-114.863869	9.415903
2	2023-07-04	Location 14	35.954698	-115.252443	11.732146
3	2023-06-20	Location 13	36.212549	-115.113713	11.172734
4	2023-07-10	Location 14	36.261824	-115.041135	8.469263
...	...	...	...	...	...
495	2023-08-05	Location 3	36.140476	-115.252443	7.440683
496	2023-07-24	Location 7	36.031776	-114.940866	6.613489
497	2023-07-09	Location 4	36.080865	-115.113713	14.889736
498	2023-08-10	Location 4	36.060911	-115.136941	12.627326
499	2023-06-25	Location 2	36.266401	-115.273677	8.469263

500 rows × 5 columns

Visualizing the Delivery Locations

In [3]:

```
df_locations = pd.read_excel('trux.xlsx', sheet_name = 'rand data', usecols = 'B:D'
df_locations
```

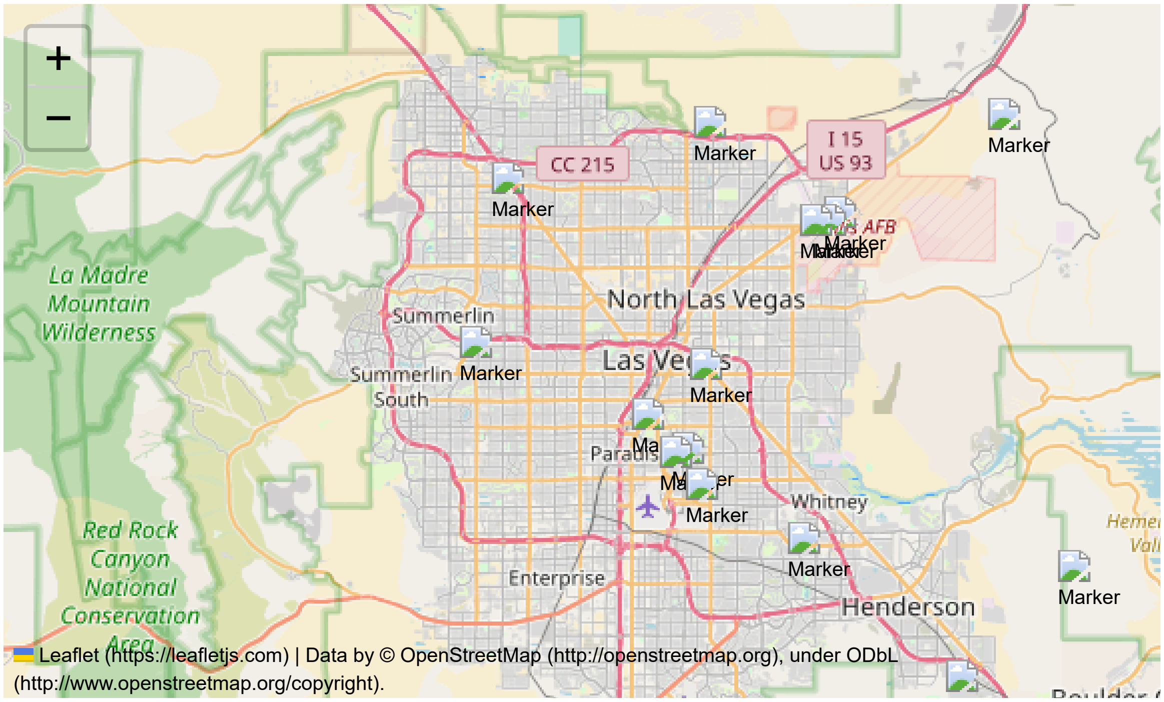
Out[3]:

	Location	lat	lon
0	Location 1	36.080865	-115.128101
1	Location 2	36.128031	-115.116429
2	Location 3	36.031776	-115.049082
3	Location 4	36.230767	-115.252443
4	Location 5	36.261824	-115.113713
5	Location 6	36.208246	-115.030617
6	Location 7	36.207871	-115.041135
7	Location 8	36.140476	-115.273677
8	Location 9	36.079104	-115.136941
9	Location 10	36.060911	-115.118218
10	Location 11	35.954698	-114.940866
11	Location 12	36.212549	-115.023806
12	Location 13	36.015227	-114.863869
13	Location 14	36.100257	-115.156120
14	Location 15	36.266401	-114.912155

In [4]:

```
import folium
import pandas as pd

df_map = pd.read_excel('trux.xlsx', sheet_name = 'rand data', usecols = 'C:D', nrow
m = folium.Map(location=[36.145283, -115.152068]) #center location
for index, row in df_map.iterrows():
    folium.Marker(location=[row['lat'], row['lon']]).add_to(m)
m
```

Out[4]:


+
−
Marker
Marker
Marker
Marker
Marker
Marker
Marker
Marker
Marker
Marker
CC 215
I 15
US 93
AFB
La Madre Mountain Wilderness
North Las Vegas
Summerlin
Summerlin South
Las Vegas
Paradise
Whitney
Enterprise
Henderson
Red Rock Canyon National Conservation Area
Leaflet (https://leafletjs.com) | Data by © OpenStreetMap (http://openstreetmap.org), under ODbL (http://www.openstreetmap.org/copyright).

Calculate Distances - Geodesic

In [5]:

```
from math import sin, cos, sqrt, atan2, radians

def distance_calc(lat_1, lon_1, lat_2, lon_2):
    R = 3958.8 #radius of Earth in miles

    lat_1 = radians(lat_1)
    lon_1 = radians(lon_1)
    lat_2 = radians(lat_2)
    lon_2 = radians(lon_2)

    dist_lon = lon_2 - lon_1
    dist_lat = lat_2 - lat_1

    a = sin(dist_lat / 2) ** 2 + cos(lat_1) * cos(lat_2) * sin(dist_lon / 2) **2
    c = 2 * atan2(sqrt(a), sqrt(1 - a))

    distance = R * c

    return distance
```

The Clark Wright Algorithm - Primer on math here:

http://web.mit.edu/urban_or_book/www/book/chapter6/6.4.12.html

In [13]:

```
def truck_assign(loc_list, weights, status):
    dist_matrix = [[distance_calc(loc_list[i][0], loc_list[i][1], loc_list[j][0], l
    dist_matrix = np.array(dist_matrix)

    savings_matrix = [[(dist_matrix[0][i + 1] + dist_matrix[0][j + 1] - min(dist_ma
    if status == True:
        savings_threshold = 0.42
    else:
        savings_threshold = 0.5

    savings_percent_matrix = [[((dist_matrix[0][i + 1] + dist_matrix[0][j + 1] - mi

    savings_matrix = np.array(savings_matrix)

    for i in range(len(savings_matrix)):
        savings_matrix[i][i] = 0

    for i in range(len(savings_percent_matrix)):
        savings_percent_matrix[i][i] = 0

    savings_list = []

    for i in range(len(savings_matrix)):
        j = 0
        while j < i:
            if savings_percent_matrix[i][j] >= savings_threshold:
                savings_list.append([i + 1, j + 1, savings_matrix[i][j]])
            j = j + 1
    savings_list = np.array(savings_list)

    if(len(savings_list) > 0):
        savings_list = savings_list[savings_list[:,2].argsort()[::-1]]

    truck_assign_savings = []

    for i in range(len(savings_list)):
        truck_assign_savings.append([savings_list[i][0],savings_list[i][1],savings_

    truck_assign_savings = np.array(truck_assign_savings)
    #print('\n',truck_assign_savings)

    truck_assign_matrix = np.zeros((len(weights), len(weights)))
    truck_assigned_weights = np.zeros((len(weights)))
    truck_assigned_savings = np.zeros((len(weights)))

    truck_count = 0

    for i in range(len(truck_assign_savings)):
        loc1 = int(truck_assign_savings[i][0])
        loc2 = int(truck_assign_savings[i][1])
        truck_no = 0

        if truck_assign_savings[i][3] == 0 and truck_assign_savings[i][4] == 0:
            if weights[int(loc1-1)] + weights[int(loc2 - 1)] <= max_truck_capacity:
                truck_no = truck_count
                truck_count = truck_count + 1
                truck_assign_matrix[int(loc1-1)][int(truck_no)] = 1
                truck_assign_matrix[int(loc2-1)][int(truck_no)] = 1
                truck_assign_savings[i][3] = 1
                truck_assign_savings[i][4] = 1
                truck_assign_savings[i][5] = truck_no + 1
                truck_assigned_savings[int(truck_no)] = truck_assigned_savings[int(

                for j in range(len(truck_assign_savings)):
                    if truck_assign_savings[j][0] == loc1 or truck_assign_savings[j
                        if truck_assign_savings[j][0] == loc1:
                            truck_assign_savings[j][3] = 1
                            truck_assign_savings[j][5] = truck_no + 1
                        else:
                            truck_assign_savings[j][4] = 1
                            truck_assign_savings[j][5] = truck_no + 1

                    if truck_assign_savings[j][0] == loc2 or truck_assign_savings[j
                        if truck_assign_savings[j][0] == loc2:
                            truck_assign_savings[j][3] = 1
                            truck_assign_savings[j][5] = truck_no + 1
                        else:
                            truck_assign_savings[j][4] = 1
                            truck_assign_savings[j][5] = truck_no + 1

        elif truck_assign_savings[i][3] == 1 and truck_assign_savings[i][4] == 1:
            null = 0
        elif truck_assign_savings[i][3] + truck_assign_savings[i][4] == 1:
            truck_no = truck_assign_savings[i][5] - 1

            if truck_assign_savings[i][3] == 0:
                loc1 = truck_assign_savings[i][0]
            else:
                loc1 = truck_assign_savings[i][1]


            if truck_assigned_weights[int(truck_no)] + weights[int(loc1-1)] <= max_
                truck_assign_matrix[int(loc1-1)][int(truck_no)] = 1
                truck_assign_savings[i][3] = 1
                truck_assign_savings[i][4] = 1
                truck_assigned_savings[int(truck_no)] = truck_assigned_savings[int(
                for j in range(len(truck_assign_savings)):
                    if truck_assign_savings[j][0] == loc1 or truck_assign_savings[j
                        if truck_assign_savings[j][0] == loc1:
                            truck_assign_savings[j][3] = 1
                            truck_assign_savings[j][5] = truck_no + 1
                        else:
                            truck_assign_savings[j][4] = 1
                            truck_assign_savings[j][5] = truck_no + 1

        for i in range(truck_count):
            current_wt = 0
            for j in range(len(weights)):
                current_wt = current_wt + truck_assign_matrix[j][i] * weights[j]
            truck_assigned_weights[i]=current_wt

    dummy_no = 0
    for i in range(len(truck_assign_matrix)):
        assigned = 0
        for j in range(len(weights)):
            assigned = assigned + truck_assign_matrix[i][j]
        if assigned == 1:
            dummy_no =+ 1
        elif assigned > 1:
            #print("Location no:",i+1,"some error has occurred")
            dummy_no =+ 1
        elif assigned == 0:
            #print("Location no:",i+1,"has not been assigned yet by CW savings")
            truck_assign_matrix[i][int(truck_count)] = 1
            truck_count = truck_count + 1

    for i in range(truck_count):
        current_wt = 0
        for j in range(len(weights)):
            current_wt = current_wt + truck_assign_matrix[j][i] * weights_list[j]
        truck_assigned_weights[i] = current_wt


    truck_assigned_distances = np.zeros((len(weights)))

    for i in range(len(truck_assigned_distances)):
        for j in range(len(truck_assign_matrix)):
            if truck_assign_matrix[j][i] == 1:
                truck_assigned_distances[i] = truck_assigned_distances[i] + dist_ma
        truck_assigned_distances[i] = truck_assigned_distances[i] - truck_assigned_

    #print(2*'\n',np.array(distance_matrix))
    #print(2*'\n',np.array(cw_savings_matrix))
    #print(2*'\n',np.array(cw_savings_list))

    #print('\n',"Assignment matrix:",'\n',truck_assignment_matrix,2*'\n',"Number of

    truck_assigned_type = np.zeros((len(weights)))

    for i in range(len(truck_assigned_distances)):
        for j in range(len(Truck_list)):
            if(truck_assigned_weights[i] > 0 and truck_assigned_weights[i] <= int(T
                truck_assigned_type[i] = j + 1

    truck_type_counter = []

    for p in range(len(Truck_list)):
        count = 0
        for j in range(len(truck_assigned_type)):
            if truck_assigned_type[j] == p + 1:
                count = count + 1
        truck_type_counter.append(count)

    truck_costs = np.zeros((len(weights)))

    for i in range(len(truck_costs)):
        if truck_assigned_type[i] > 0 and truck_assigned_distances[i] > 0:
            k = int(truck_assigned_type[i] - 1)
            truck_costs[i] = round(float(truck_assigned_distances[i]) * float(Truck

    #print('\n',"Truck costs:",truck_costs)
    #print(cw_savings_percent_matrix[0])
    return(sum(truck_costs),truck_count,truck_type_counter)
```

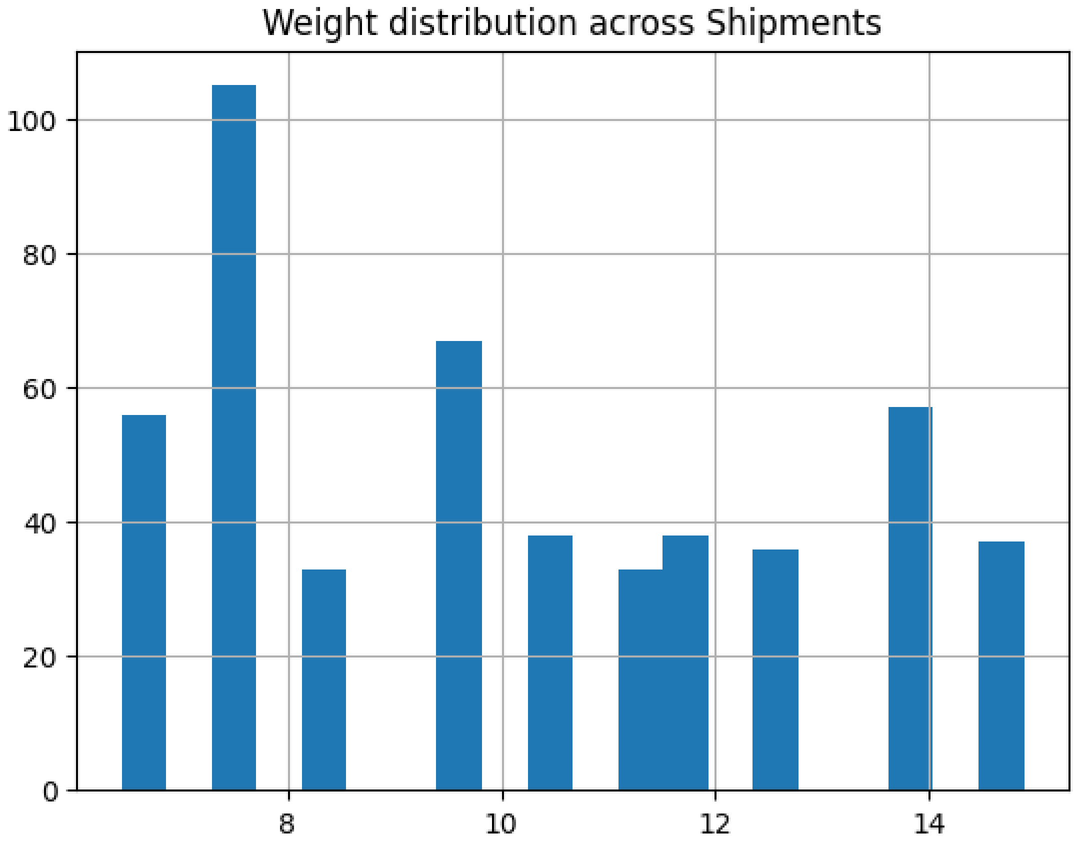
Weight Distributions

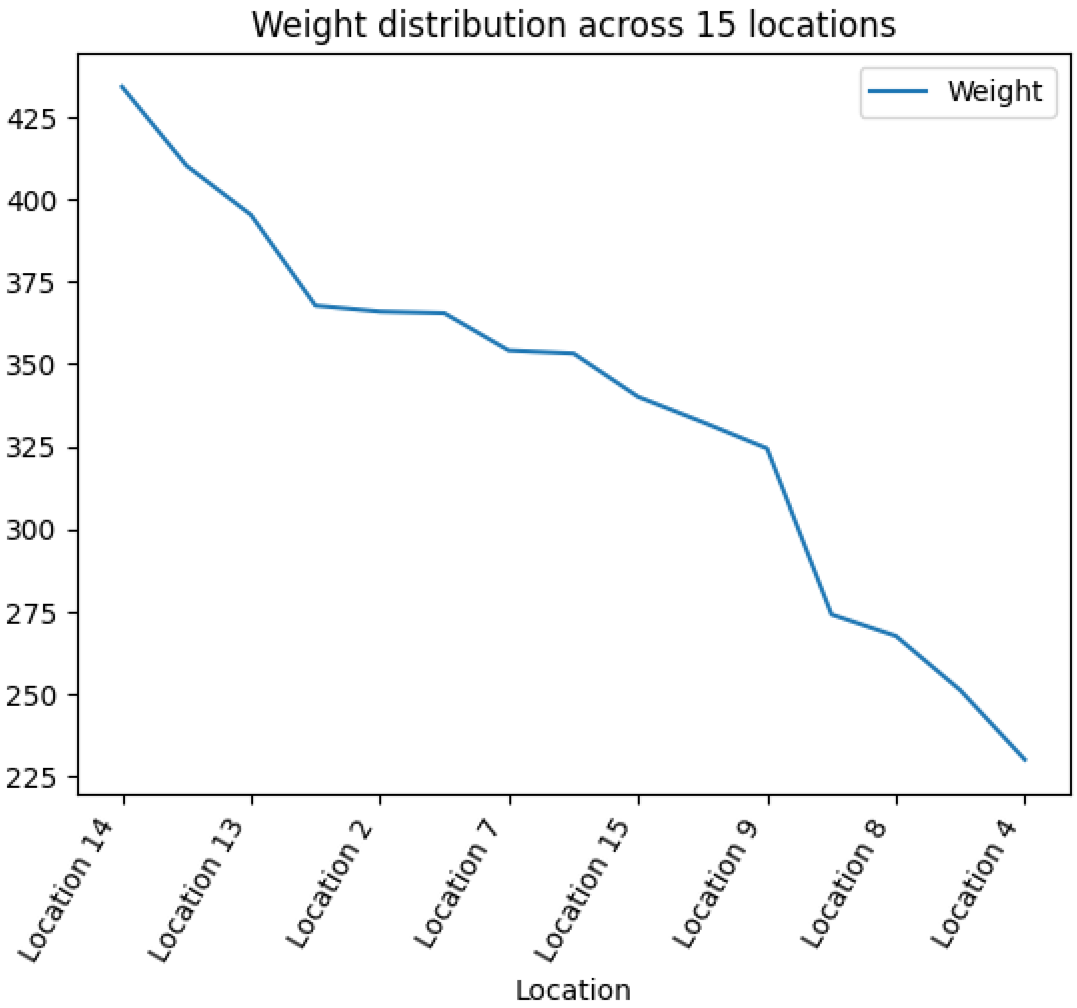
In [14]:

```
import matplotlib.pyplot as plt

df['Weight'].hist(bins = 20)
plt.title('Weight distribution across Shipments')

location_display = pd.DataFrame(df.groupby(['Location'], as_index = False)['Weight'
location_display.set_index('Location', inplace = True)

location_display = location_display.sort_values(by = 'Weight', ascending = False)
location_display.head(15).plot(title='Weight distribution across 15 locations')
plt.xticks(rotation = 60, ha = 'right')

location_display
```

Out[14]:

	Weight
Location	
Location 14	434.250032
Location 3	410.284428
Location 13	395.341540
Location 12	367.780492
Location 2	365.960393
Location 5	365.479395
Location 7	354.136450
Location 6	353.218440
Location 15	340.060466
Location 1	332.378820
Location 9	324.388047
Location 10	274.101520
Location 8	267.535029
Location 11	251.067937
Location 4	229.978052


Weight distribution across Shipments
0
20
40
60
80
100
8
10
12
14



Segregating Deliveries by Weight

In [15]:

```
import numpy as np
from datetime import datetime, timedelta, date
import warnings
warnings.filterwarnings("ignore")

dda = pd.DataFrame(df.groupby(['Date','Location','Latitude','Longitude'], as_index
df.tail(20)

job_status = 0

for i in range(len(dda)):
    if dda['Weight'][i] > max_truck_capacity:
        remainder = dda['Weight'][i] % max_truck_capacity
        no_of_splits = int(dda['Weight'][i] / max_truck_capacity - remainder / max_
        #print(dda['Weight'][i],no_of_splits,remainder)
        dda['Weight'][i] = remainder
        gg = dda[dda.index == i]
        gg['Weight'][i] = max_truck_capacity
        for j in range(no_of_splits):
            dda = dda.append(gg, ignore_index = True)
```

```
df_new = pd.DataFrame(dda)
df_new['Date'] = pd.to_datetime(df_new['Date'], format = '%d-%m-%Y')

source_Latitude_list = np.array(df['Latitude'])
source_Longitude_list = np.array(df['Longitude'])
weights_list = np.array(df['Weight'])
source_dates = np.array(df['Date'])

delta = timedelta(days = 1)

no_of_days = int((max(df_new['Date']) - min(df_new['Date'])).days + 1)

print('The number of new deliveries based on the weight distribution and truck capa
df_new
```

```
The number of new deliveries based on the weight distribution and truck capacity is:
710
```

Out[15]:

	Date	Location	Latitude	Longitude	Weight
0	2023-06-12	Location 11	36.015227	-114.863869	0.262323
1	2023-06-12	Location 2	36.079104	-115.136941	9.624671
2	2023-06-12	Location 3	36.266401	-115.136941	4.889736
3	2023-06-12	Location 6	36.140476	-115.030617	4.889736
4	2023-06-12	Location 6	36.207871	-115.128101	1.732146
...	...	...	...	...	...
705	2023-08-11	Location 5	36.031776	-115.128101	10.000000
706	2023-08-11	Location 6	36.079104	-115.252443	10.000000
707	2023-08-11	Location 7	36.140476	-114.940866	10.000000
708	2023-08-11	Location 8	36.100257	-115.156120	10.000000
709	2023-08-12	Location 6	36.128031	-114.863869	10.000000

710 rows × 5 columns

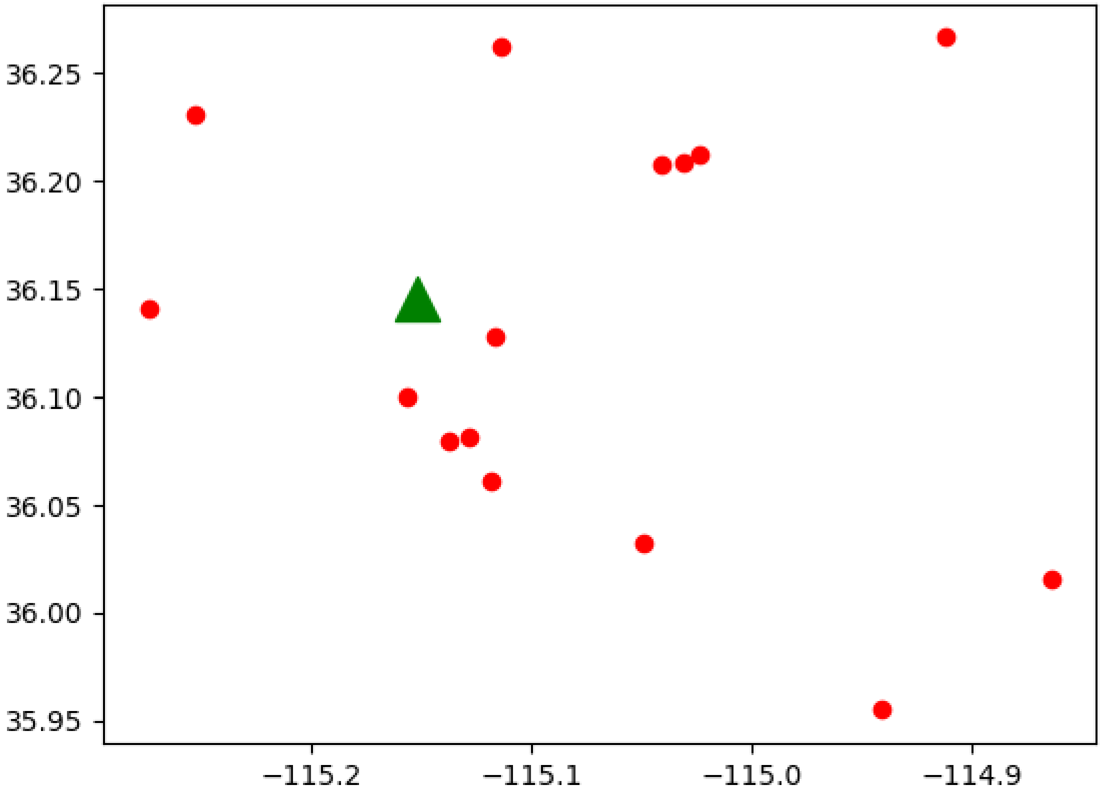
Starting Location & Timeframe

In [16]:

```
source_coordinates = [36.145283, -115.152068]
planning_horizon = 1      # Enter the no. of days you want to plan together, only i

plt.scatter(df_locations['lon'],df_locations['lat'] ,marker = 'o', s = 35, c = 'red
plt.scatter(source_coordinates[1],source_coordinates[0], marker = '^', s = 250, c =
```

Out[16]:

```
<matplotlib.collections.PathCollection at 0x1dfe1241890>
```



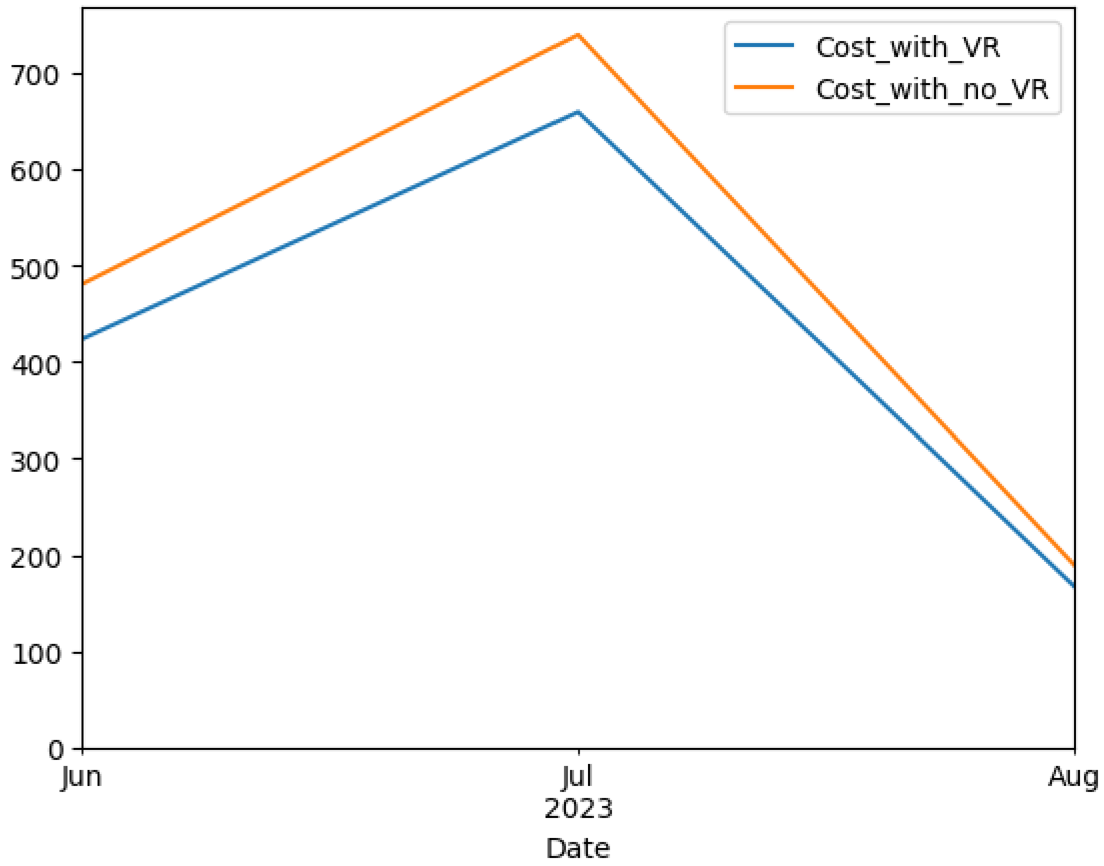
Simulating the Deliveries

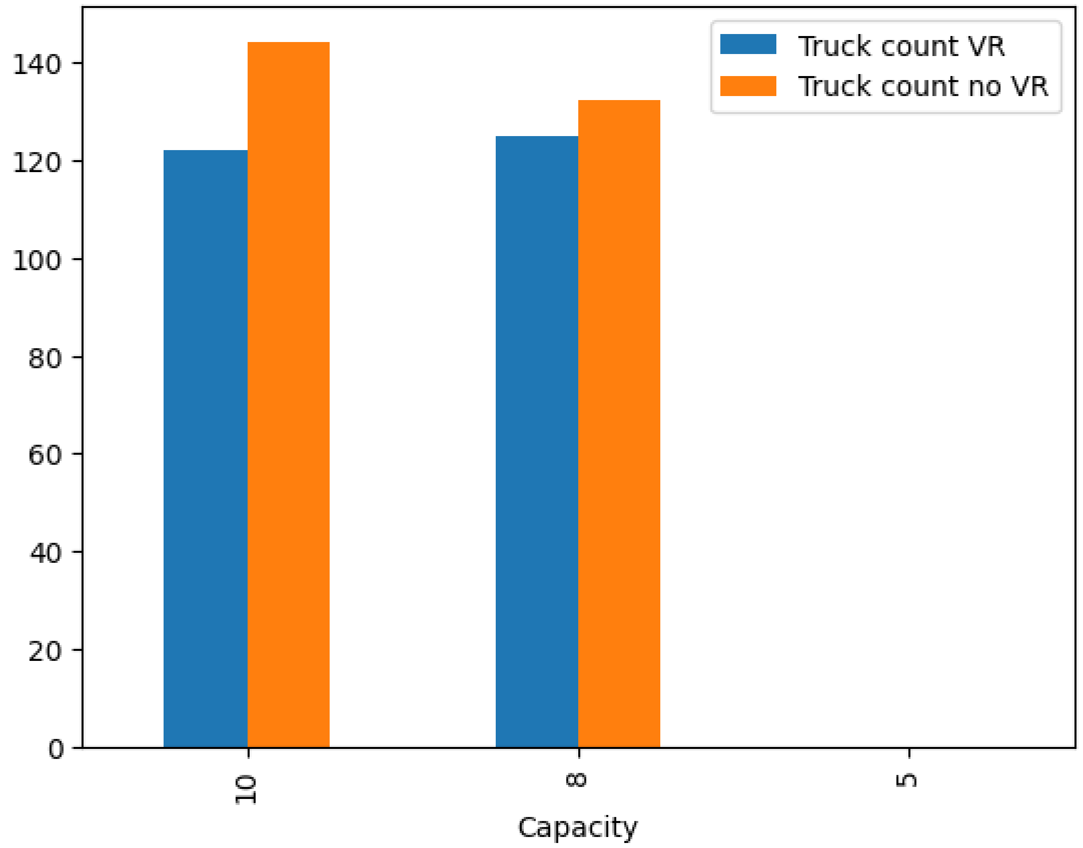
In [17]:

```
from IPython.display import clear_output

result_matrix = []
truck_type_count_VR = []
for p in range(len(Truck_list)):
    truck_type_count_VR.append(0)

truck_type_count_noVR = []
for p in range(len(Truck_list)):
    truck_type_count_noVR.append(0)

truck_type_count_VR = np.array(truck_type_count_VR)
truck_type_count_noVR = np.array(truck_type_count_noVR)


for j in range(0, no_of_days, planning_horizon):

    clear_output(wait = True)
    print("____Simulation Progress :", round(100 * j / no_of_days, 1),"%")
    weights_temp = []
    locations_temp = [[source_coordinates[0], source_coordinates[1]]]
    range_start = min(df_new['Date']) + j * delta
    range_end = min(df_new['Date']) + (j + planning_horizon) * delta

    rslt_df = df_new[df_new['Date'] >= range_start]
    rslt_df = rslt_df[rslt_df['Date'] < range_end]
    #print(rslt_df.iloc[0,'Latitude'])
    for i in range(len(rslt_df)):
        locations_temp.append([rslt_df.iloc[i]['Latitude'], rslt_df.iloc[i]['Longit
        weights_temp.append(rslt_df.iloc[i]['Weight'])
    if len(locations_temp) > 1:
        result_output_vr = truck_assign(locations_temp, weights_temp, True)
        result_output_no_vr = truck_assign(locations_temp, weights_temp, False)
        result_matrix.append([range_start,result_output_vr[0], result_output_no_vr[
        truck_type_count_VR = np.add(truck_type_count_VR, np.array(result_output_vr
        truck_type_count_noVR = np.add(truck_type_count_noVR, np.array(result_outpu

clear_output(wait = True)
result_matrix

df_final = pd.DataFrame(result_matrix, columns=['Date', 'Cost_with_VR', 'Cost_with_
df_final = df_final.set_index('Date')

Truck_list_table = pd.DataFrame(Truck_list, columns = ['Name','Capacity','m','b'])
Truck_list_table.drop(['m','b'], 1)
Truck_list_table['Truck count VR'] = pd.Series(truck_type_count_VR)
Truck_list_table['Truck count no VR'] = pd.Series(truck_type_count_noVR)


print("___Result :-",'\n')
print("Estimated Cost with no Vehicle Routing:", round(sum(df_final['Cost_with_no_V
print("Estimated Cost with Vehicle Routing:", round(sum(df_final['Cost_with_VR']),
#print('\n')
print("Estimated Cost Savings with Vehicle Routing:", round((sum(df_final['Cost_wit
print("No. of Trucks with no VR:", sum(Truck_list_table['Truck count no VR']))
print("No. of Trucks with VR:", sum(Truck_list_table['Truck count VR']))

df_final.resample('M').sum().plot().axis([None, None, 0, None])
Truck_list_table.plot.bar(x = 'Capacity')
```

```
___Result :-

Estimated Cost with no Vehicle Routing: 1410.0
Estimated Cost with Vehicle Routing: 1250.0

Estimated Cost Savings with Vehicle Routing: 11.3 %

No. of Trucks with no VR: 276
No. of Trucks with VR: 247
```

```
Out[17]: <Axes: xlabel='Capacity'>
```


Cost_with_VR
Cost_with_no_VR
700
600
500
400
300
200
100
0
Jun
Jul
2023
Aug
Date


Truck count VR
Truck count no VR
140
120
100
80
60
40
20
0
10
8
5
Capacity

In [ ]: