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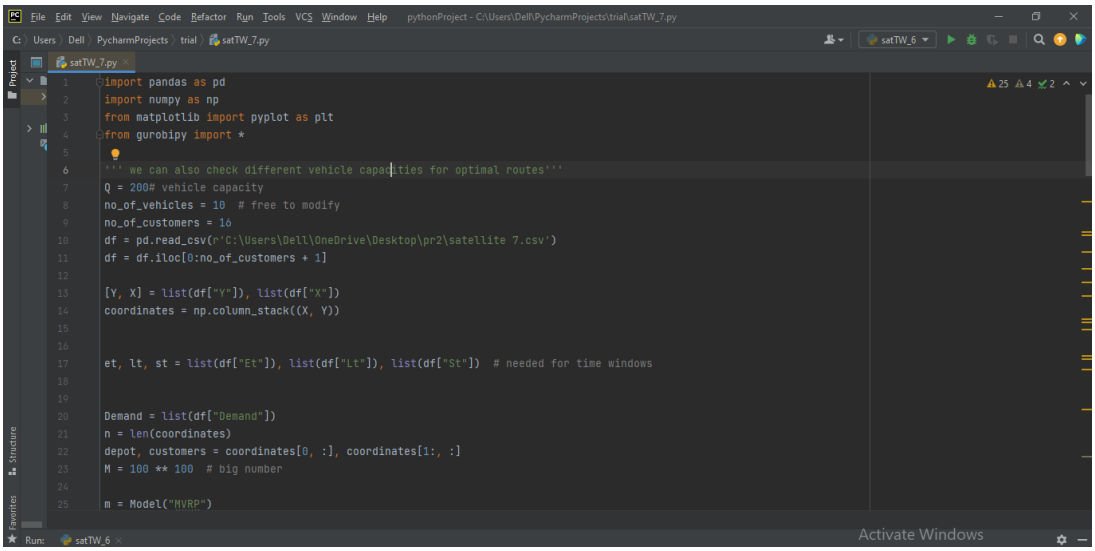
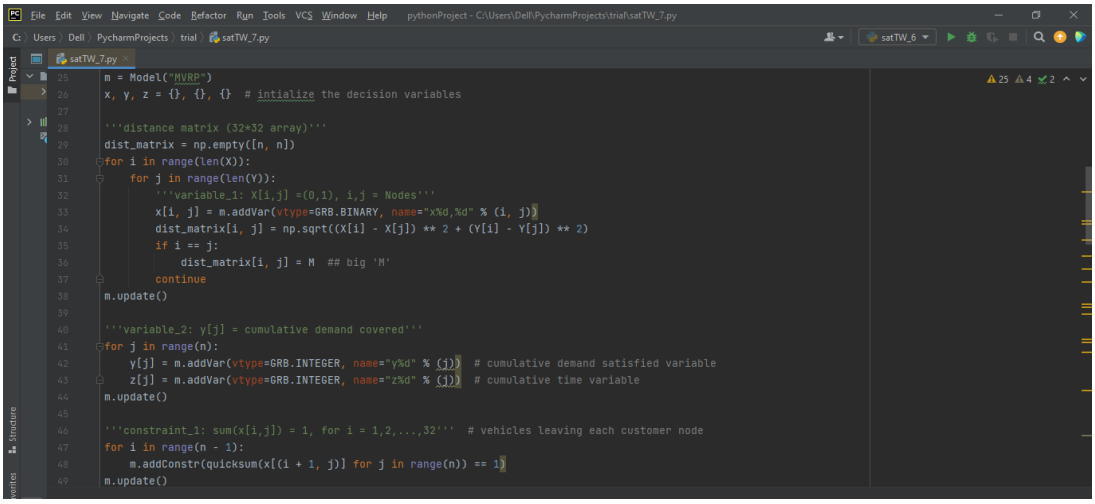
APPENDIX

Appendix A - Algorithms for VRP using Python programming language



```
import pandas as pd
import numpy as np
from matplotlib import pyplot as plt
from gurobipy import *

''' we can also check different vehicle capacities for optimal routes'''
Q = 200# vehicle capacity
no_of_vehicles = 10  # free to modify
no_of_customers = 16
df = pd.read_csv(r'C:\Users\Dell\OneDrive\Desktop\pr2\satellite 7.csv')
df = df.iloc[0:no_of_customers + 1]

[Y, X] = list(df["Y"]), list(df["X"])
coordinates = np.column_stack((X, Y))


et, lt, st = list(df["Et"]), list(df["Lt"]), list(df["St"])  # needed for time windows


Demand = list(df["Demand"])
n = len(coordinates)
depot, customers = coordinates[0, :], coordinates[1:, :]
M = 100 ** 100  # big number

m = Model("MVRP")
```



```
m = Model("MVRP")
x, y, z = {}, {}, {}  # intialize the decision variables

'''distance matrix (32*32 array)'''
dist_matrix = np.empty([n, n])
for i in range(len(X)):
    for j in range(len(Y)):
        '''variable_1: X[i,j] =(0,1), i,j = Nodes'''
        x[i, j] = m.addVar(vtype=GRB.BINARY, name="x%d,%d" % (i, j))
        dist_matrix[i, j] = np.sqrt((X[i] - X[j]) ** 2 + (Y[i] - Y[j]) ** 2)
        if i == j:
            dist_matrix[i, j] = M  ## big 'M'
        continue
m.update()

'''variable_2: y[j] = cumulative demand covered'''
for j in range(n):
    y[j] = m.addVar(vtype=GRB.INTEGER, name="y%d" % (j))  # cumulative demand satisfied variable
    z[j] = m.addVar(vtype=GRB.INTEGER, name="z%d" % (j))  # cumulative time variable
m.update()

'''constraint_1: sum(x[i,j]) = 1, for i = 1,2,...,32'''  # vehicles leaving each customer node
for i in range(n - 1):
    m.addConstr(quicksum(x[(i + 1, j)] for j in range(n)) == 1)
m.update()
```