

# TSP\_Anealing\_Personal\_extra

February 27, 2023

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[ ]: '''
Resources:
https://towardsdatascience.com/
    ↪how-to-solve-the-traveling-salesman-problem-a-comparative-analysis-39056a916c9f
https://github.com/syakoo/simulated-annealing
https://towardsdatascience.com/
    ↪how-to-solve-travelling-salesman-problem-with-simulated-annealing-c248447a8bcd
https://towardsdatascience.com/simulated-annealing-with-restart-a19a53d914c8
https://github.com/jedrazb/python-tsp-simulated-annealing
https://en.wikipedia.org/wiki/2-opt

'''

import math
import random
import numpy as np
import pandas as pd
import plotly.express as px
from plotly.subplots import make_subplots
import plotly.graph_objects as go
import os
import matplotlib.pyplot as plt
class tsp_utils:
    #Convert coordant information into distance matrix commonly used in TSP
    ↪Problems
    def vectorToDistMatrix(coords):
        '''
        Create the distance matrix
        '''
        return np.sqrt((np.square(coords[:, np.newaxis] - coords).sum(axis=2)))

    def nearestNeighbourSolution(DM):
        '''
        Computes the initial solution (nearest neighbour strategy)
        '''
        #grabs random node in the size of the matrix
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node = random.randrange(len(DM))
#stores node in result list
result = [node]
#sets nodes to visit equal to the size of the distance matrix
NtV = list(range(len(DM)))
#removes first node
NtV.remove(node)
#goes through and tries to find the nearest neighbour for every node
while NtV:
    nearest_node = min([(DM[node][j], j) for j in NtV], key=lambda x:
↳x[0])
    node = nearest_node[1]
    NtV.remove(node)
    result.append(node)

return result

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[ ]: #Class to store the data generated by the annealing algorithm
class solution:
    def __init__(self, coords):
        #converts data form coordants into distmatrix
        self.DM = tsp_utils.vectorToDistMatrix(coords)
        #uses distance matrix to find solution
        self.saved_solution = tsp_utils.nearestNeighbourSolution(self.DM)

    def __iter__(self):
        return self

    def get_matrix(self):
        return self.DM
    def get_solution(self):
        return self.saved_solution

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[ ]: class MSA:
    def __init__(self, coords, iterations, temp, gamma, ST):

        #intial coordant points
        self.coords = coords
        #size of array
        self.sample_size = len(coords)
        #initialize iteration counter
        self.iteration = 1
        #check point to stop iterations
        self.SI = iterations

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#tempature
self.temp = temp
#tempature to stop program
self.ST = ST
#self.df = df
#gamma value to multiply tempature by
self.gamma = gamma
#tmp variable to store the data in the solution object
self.tmp_obj = solution(coords)
#current solution based on the return value fo the object
self.current = self.tmp_obj.get_solution()
#gets the distance matrix from the object
self.matrix = self.tmp_obj.get_matrix()
#saves all the solutions in a list
self.SH = [self.current]
#saves the current solution as the best solution
self.best = self.current
#saves the weight as the current weight
self.cweight = self.weight(self.current)
#saves the current weight as the immediate weight weight of current_
↪solution
self.iweight = self.cweight
#saves the current weight as the minimum weight
self.mweight = self.cweight
#saves the weights into a list
self.WL = [self.cweight]
#prints the immediate weight
print('Intial weight: ', self.iweight)

#unused function to calcuate distance
@staticmethod
def total_distance(df):

    def euclidean_distance(x1, x2, y1, y2):
        return np.sqrt((x1-x2)**2+(y1-y2)**2)

    distance = 0
    for idx in range(0, len(df)):
        if idx + 1 >= len(df):
            break
        distance += euclidean_distance(df['x'].loc[idx], df['x'].loc[idx+1],
                                       df['y'].loc[idx], df['y'].loc[idx+1])
    return distance

def weight(self, sol):

    #Calcuate weight

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        return sum([self.matrix[i, j] for i, j in zip(sol, sol[1:] + [sol[0]])])

    def probability(self, candidate_weight):
        """
        Acceptance probability as described in:
        https://stackoverflow.com/questions/19757551/
        ↪basics-of-simulated-annealing-in-python
        """
        probability = math.exp(-abs(candidate_weight - self.cweight) / self.
        ↪temp)
        if random.random() < probability:
            return True
        else:
            return False

    def accept(self, candidate):
        """
        Accept with probability 1 if candidate solution is better than
        current solution, else accept with probability equal to the
        acceptance_probability()
        """
        #sets the candiate_weight as the weight of the current solution being
        ↪tested
        candidate_weight = self.weight(candidate)
        #if the candiate weight is better than the current weight then the
        ↪current solution is updated with the candiate infromation as well as the
        ↪miniumm weight is checked and updated based on the candiate information
        if candidate_weight < self.cweight:
            self.cweight = candidate_weight
            self.current = candidate
            if candidate_weight < self.mweight:
                self.mweight = candidate_weight
                self.best_solution = candidate
            #if the candiate_weight is not better than than the current weight it
            ↪is run through the probabiltiy function and if that probibility is less than
            ↪the random that candidate is saved as the current weight
            elif self.probability(candidate_weight):
                self.cweight = candidate_weight
                self.current = candidate

    def anneal(self):
        """
        Annealing process with 2-opt
        described here: https://en.wikipedia.org/wiki/2-opt
        """

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        #if the tempt threshold or the iteration threshold is not reached then
        ↪ it continues through the while loop
        while self.temp >= self.ST and self.iteration < self.SI:
            #candidate is set to the current solution value
            candidate = list(self.current)
            #l and I are randomly generated based on the sample size defined
            ↪ above
            l = random.randint(2, self.sample_size - 1)
            i = random.randint(0, self.sample_size - 1)
            #goes through each element of the candiate based on the randomly
            ↪ generated values and reverses them
            candidate[i: (i + 1)] = reversed(candidate[i: (i + 1)])
            #the reversed canidate is passed through the acceptance check if it
            ↪ passes the current information will be updated for the next look
            self.accept(candidate)
            #the tempiture is decreased based on the predefined gamma value
            self.temp *= self.gamma
            #an itteration is added
            self.iteration += 1
            #the weight list is appened wit the current weight
            self.WL.append(self.cweight)
            #the solution history is appended with the current solution
            self.SH.append(self.current)

        #once the loop finishes the minimum weight is printed
        print('Minimum weight: ', self.mweight)
        #improvement calculation based on the starting weight and the minimum
        ↪ weight
        print('Improvement: ',
              round((self.iweight - self.mweight) / (self.iweight), 4) * 100,
              ↪ '%')

        #plot the output of the solutions
        def plotLearning(self):
            #plot the weight graph
            plt.plot([i for i in range(len(self.WL))], self.WL)
            line_init = plt.axhline(y=self.iweight, color='r', linestyle='--')
            line_min = plt.axhline(y=self.mweight, color='g', linestyle='--')
            plt.legend([line_init, line_min], ['Initial weight', 'Optimized
            ↪ weight'])
            plt.ylabel('Weight')
            plt.xlabel('Iteration')
            #plt.show()

        def plotResults(self, name):
            #set up figure

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fig, ax = plt.subplots()
#set line weight
line, = plt.plot([], [], lw=2)
''' initialize node dots on graph '''
x = [self.coords[i][0] for i in self.SH[0]]
y = [self.coords[i][1] for i in self.SH[0]]
plt.plot(x, y, 'co')

''' draw axes slightly bigger '''
extra_x = (max(x) - min(x)) * 0.05
extra_y = (max(y) - min(y)) * 0.05
ax.set_xlim(min(x) - extra_x, max(x) + extra_x)
ax.set_ylim(min(y) - extra_y, max(y) + extra_y)
#draw last solution on the graph using the starting solutions points
↳and the last solutions lines
x = [self.coords[i, 0] for i in self.SH[len(self.SH)-1] + [self.
↳SH[len(self.SH)-1][0]]]
y = [self.coords[i, 1] for i in self.SH[len(self.SH)-1] + [self.
↳SH[len(self.SH)-1][0]]]
#set lines
line.set_data(x, y)
#add lable to print the final weight
plt.xlabel('Weight:'+str(self.mweight))
plt.title(name)
#create path to images
if not os.path.exists("./images"):
    os.mkdir("./images")
#save the plot for the graph based on the input name with the default
↳being city_final
plt.savefig("./images/"+name)
#plt.show
def get_mweight(self):
    #get minimum weight
    return self.mweight

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[ ]: #run funtion with all the data needed
def run(nodes,SI, temp, gamma, ST,name="cities_final.png", weight= np.Inf,show
↳= True ):
    '''run simulated annealing algorithm with 2-opt'''
    #run simulating
    sa = MSA(nodes,SI, temp, gamma, ST)

    sa.anneal()
    #set base weight first itteration is infinity
    current_weight = weight
    # get min_weight from the simulated annealing instance

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min_wieght = sa.get_mweight()
'''animate'''

#sa.animateSolutions()
'''show the improvement over time'''
if(min_wieght<current_weight):
    #if the min_weight is less than the current weight then the plot for
    ↳that annealing is generated and the new minweight is returend
    if(show):
        sa.plotLearning()

    sa.plotResults(name)
    return min_wieght
else:
    #else the current weight is returned
    return current_weight

```

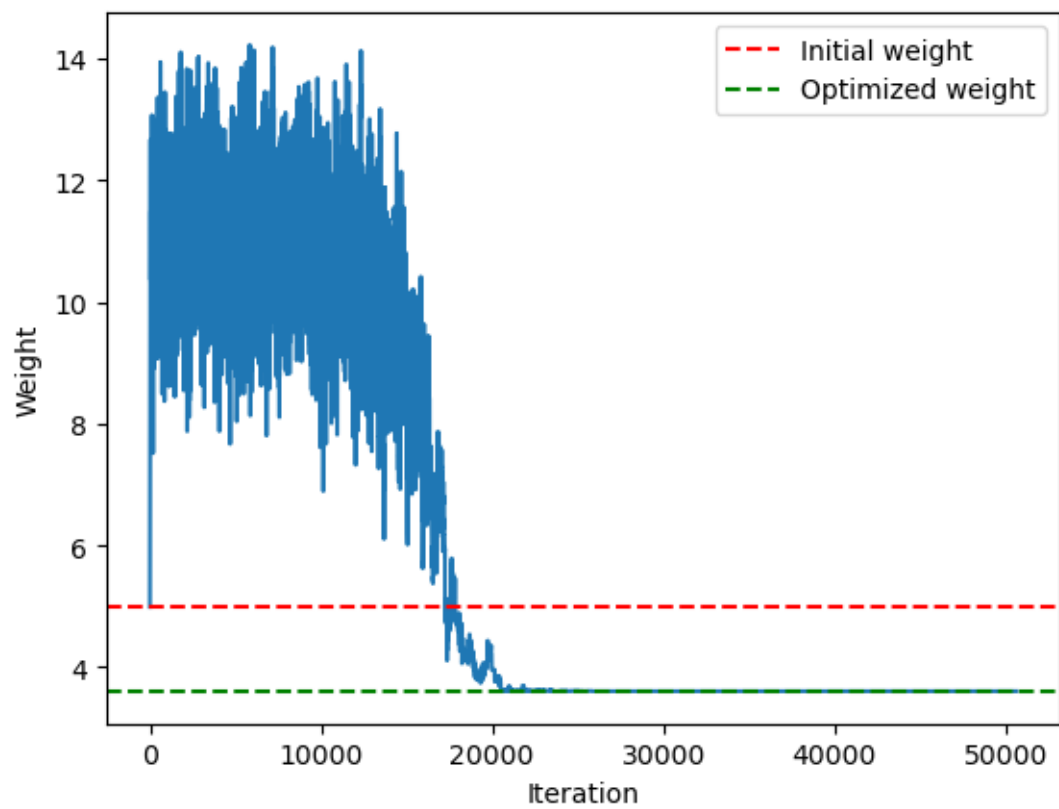
```

[ ]: '''set the simulated annealing algorithm params'''
    #test run based on wrong points
temp = 1000
ST = 0.00000001
gamma = 0.9995
SI = 10000000
xs = [0.6606,0.9695,0.5906, 0.2124, 0.0398, 0.1367,0.9536,0.6091,0.8767,0.
    ↳8148,0.9500,0.6740,0.5029,0.8274,0.9697,0.5979,0.2184,0.7148,0.2395,0.2867]
ys = [0.3876,0.7041,0.0213,0.3429,0.7471,0.5449,0.9464,0.1247,0.1636,0.8668,0.
    ↳8200,0.3296,0.1649,0.3025,0.8192,0.9392,0.8191,0.4351,0.8646,0.6768]
#print(f"X: {d} && Y:{s}",len(xs),len(ys))
nodes = np.column_stack((xs, ys))
run(nodes,SI, temp, gamma, ST)

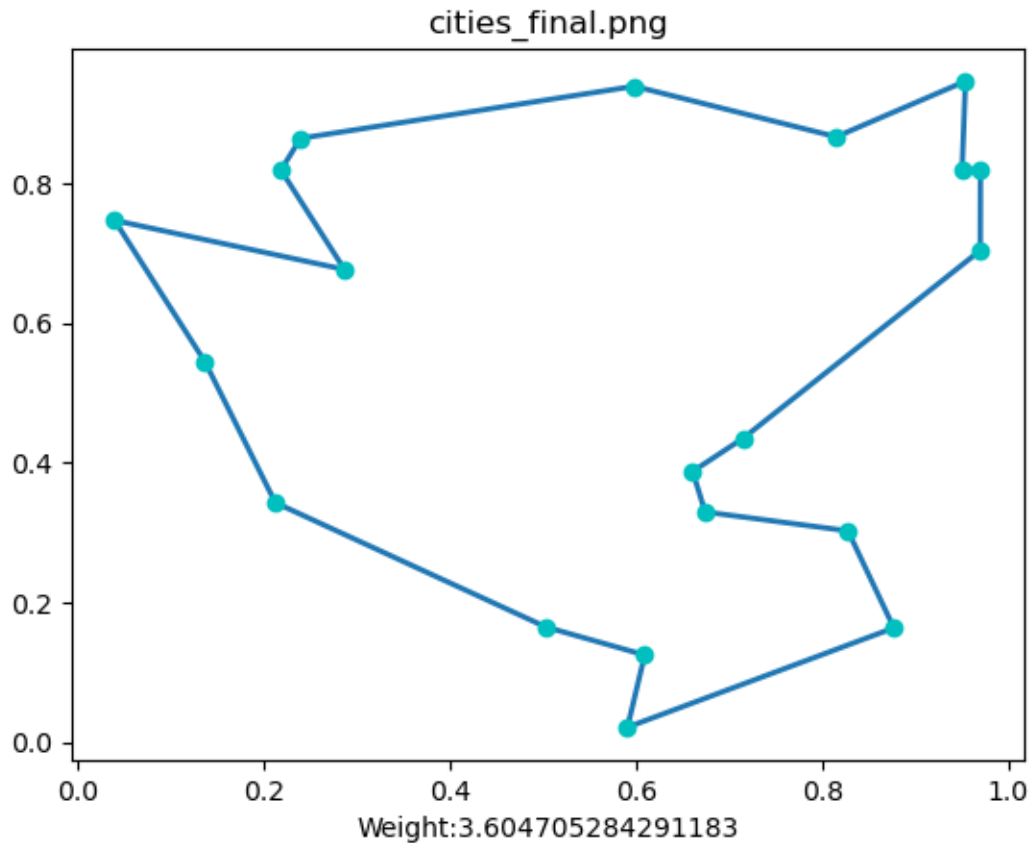
```

Intial weight: 4.991111358414833  
 Minimum weight: 3.604705284291183  
 Improvement: 27.779999999999998 %

```
[ ]: 3.604705284291183
```





[illegible]

```
plt.show
```

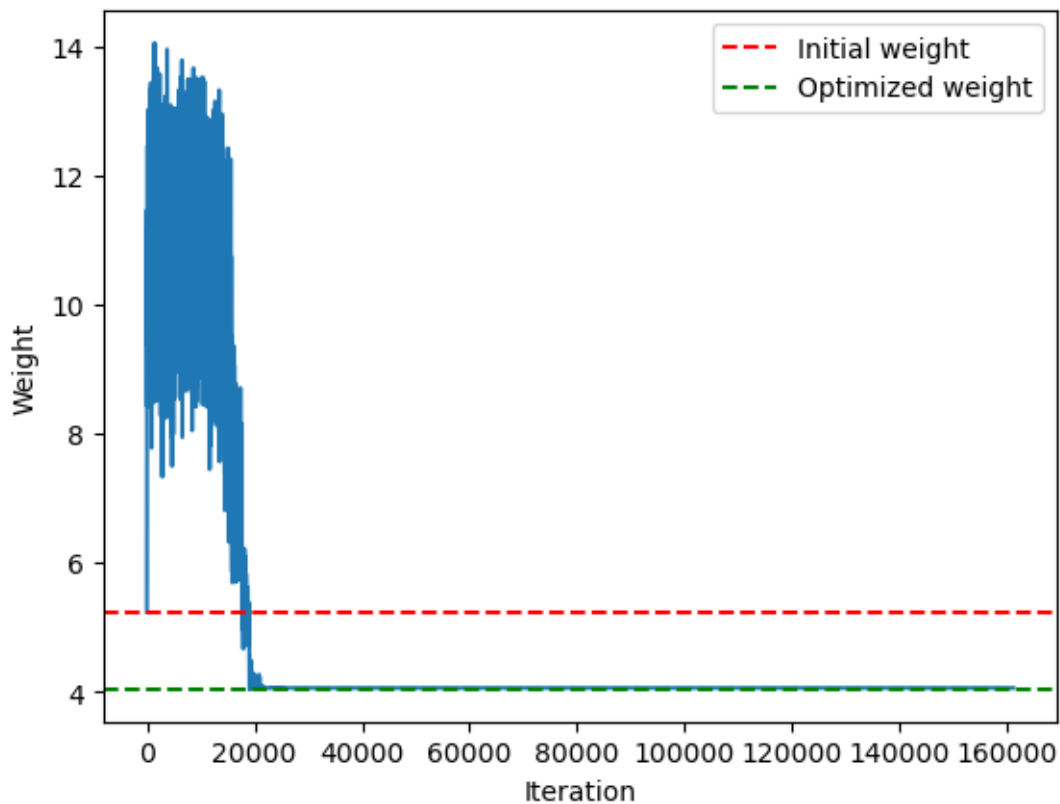
```
Intial weight: 5.22894797811956
Minimum weight: 4.03611113354273
Improvement: 22.81 %
Intial weight: 5.452254618497038
Minimum weight: 4.030656182592688
Improvement: 26.07 %
Intial weight: 4.887909931685917
Minimum weight: 4.03065618259269
Improvement: 17.54 %
Intial weight: 5.3312003295476975
Minimum weight: 4.054910629557462
Improvement: 23.94 %
Intial weight: 4.908185133302875
Minimum weight: 4.03611113354273
Improvement: 17.77 %
Intial weight: 4.444147300922404
Minimum weight: 4.036111133542731
Improvement: 9.180000000000001 %
Intial weight: 5.4142170956833695
Minimum weight: 4.076046089443103
Improvement: 24.72 %
Intial weight: 5.320873149675946
Minimum weight: 4.030656182592688
Improvement: 24.25 %
Intial weight: 4.502090428504454
Minimum weight: 4.076046089443103
Improvement: 9.46 %
Intial weight: 4.887909931685917
Minimum weight: 4.030656182592688
Improvement: 17.54 %
Intial weight: 5.014274936724524
Minimum weight: 4.076046089443103
Improvement: 18.709999999999997 %
Intial weight: 4.444147300922404
Minimum weight: 4.030656182592688
Improvement: 9.3 %
Intial weight: 5.050834563973035
Minimum weight: 4.030656182592689
Improvement: 20.200000000000003 %
Intial weight: 4.730098242141309
Minimum weight: 4.030656182592688
Improvement: 14.790000000000001 %
Intial weight: 5.452254618497038
Minimum weight: 4.076046089443103
Improvement: 25.240000000000002 %
```

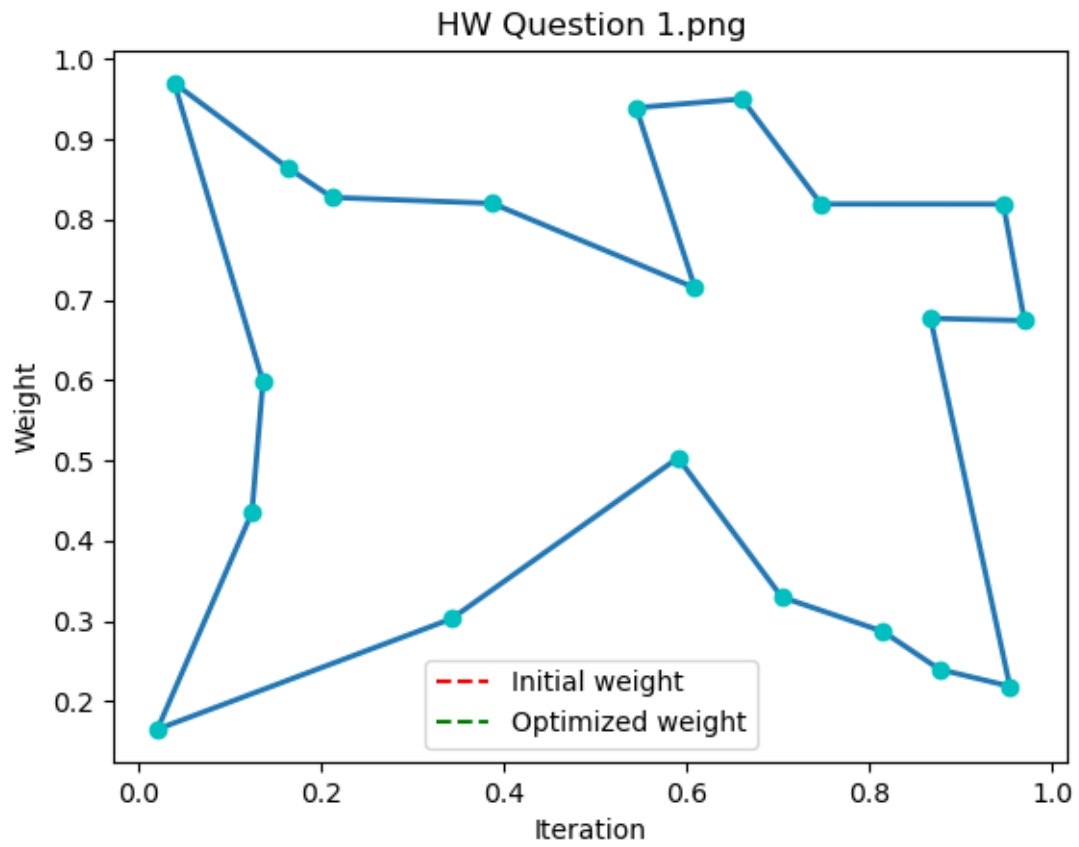
```

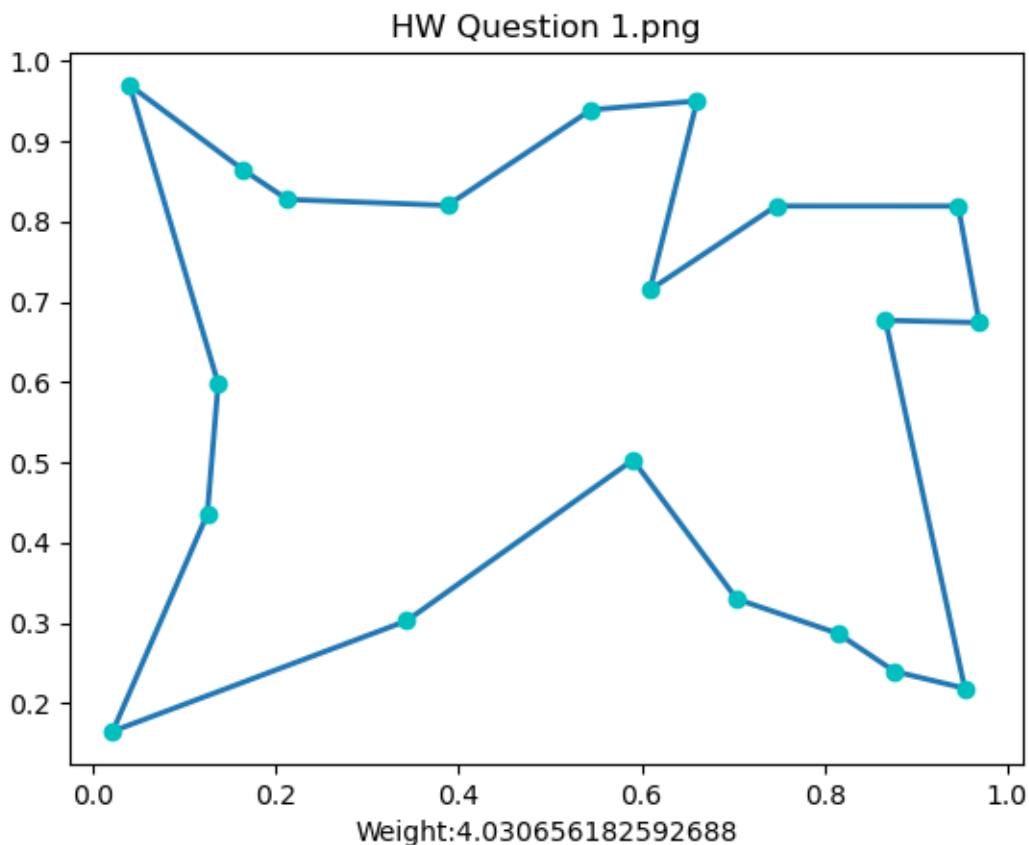
Intial weight: 4.8067459348638515
Minimum weight: 4.076046089443103
Improvement: 15.2 %
Intial weight: 4.8322153627319455
Minimum weight: 4.030656182592688
Improvement: 16.59 %
Intial weight: 4.502090428504454
Minimum weight: 4.030656182592688
Improvement: 10.47 %
Intial weight: 4.444147300922404
Minimum weight: 4.030656182592689
Improvement: 9.3 %
Intial weight: 5.014274936724524
Minimum weight: 4.076046089443103
Improvement: 18.709999999999997 %

```

```
[ ]: <function matplotlib.pyplot.show(close=None, block=None)>
```







```
[ ]: #data for the 101 cities
data = [1, 41, 49, 2, 35, 17, 3, 55, 45, 4, 55, 20, 5, 15, 30, 6, 25, 30, 7,
↪20, 50, 8, 10, 43, 9, 55, 60, 10, 30, 60, 11, 20, 65, 12, 50, 35, 13, 30,
↪25, 14, 15, 10, 15, 30, 5, 16, 10, 20, 17, 5, 30, 18, 20, 40, 19, 15, 60,
↪20, 45, 65, 21, 45, 20, 22, 45, 10, 23, 55, 5, 24, 65, 35, 25, 65, 20, 26,
↪45, 30, 27, 35, 40, 28, 41, 37, 29, 64, 42, 30, 40, 60, 31, 31, 52, 32, 35,
↪69, 33, 53, 52, 34, 65, 55, 35, 63, 65, 36, 2, 60, 37, 20, 20, 38, 5, 5, 39,
↪60, 12, 40, 40, 25, 41, 42, 7, 42, 24, 12, 43, 23, 3, 44, 11, 14, 45, 6, 38,
↪46, 2, 48, 47, 8, 56, 48, 13, 52, 49, 6, 68, 50, 47, 47, 51, 49, 58, 52, 27,
↪43, 53, 37, 31, 54, 57, 29, 55, 63, 23, 56, 53, 12, 57, 32, 12, 58, 36, 26,
↪59, 21, 24, 60, 17, 34, 61, 12, 24, 62, 24, 58, 63, 27, 69, 64, 15, 77, 65,
↪62, 77, 66, 49, 73, 67, 67, 5, 68, 56, 39, 69, 37, 47, 70, 37, 56, 71, 57,
↪68, 72, 47, 16, 73, 44, 17, 74, 46, 13, 75, 49, 11, 76, 49, 42, 77, 53, 43,
↪78, 61, 52, 79, 57, 48, 80, 56, 37, 81, 55, 54, 82, 15, 47, 83, 14, 37, 84,
↪11, 31, 85, 16, 22, 86, 4, 18, 87, 28, 18, 88, 26, 52, 89, 26, 35, 90, 31,
↪67, 91, 15, 19, 92, 22, 22, 93, 18, 24, 94, 26, 27, 95, 25, 24, 96, 22, 27,
↪97, 25, 21, 98, 19, 21, 99, 20, 26, 100, 18, 18, 101, 35, 35]
```

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[ ]:
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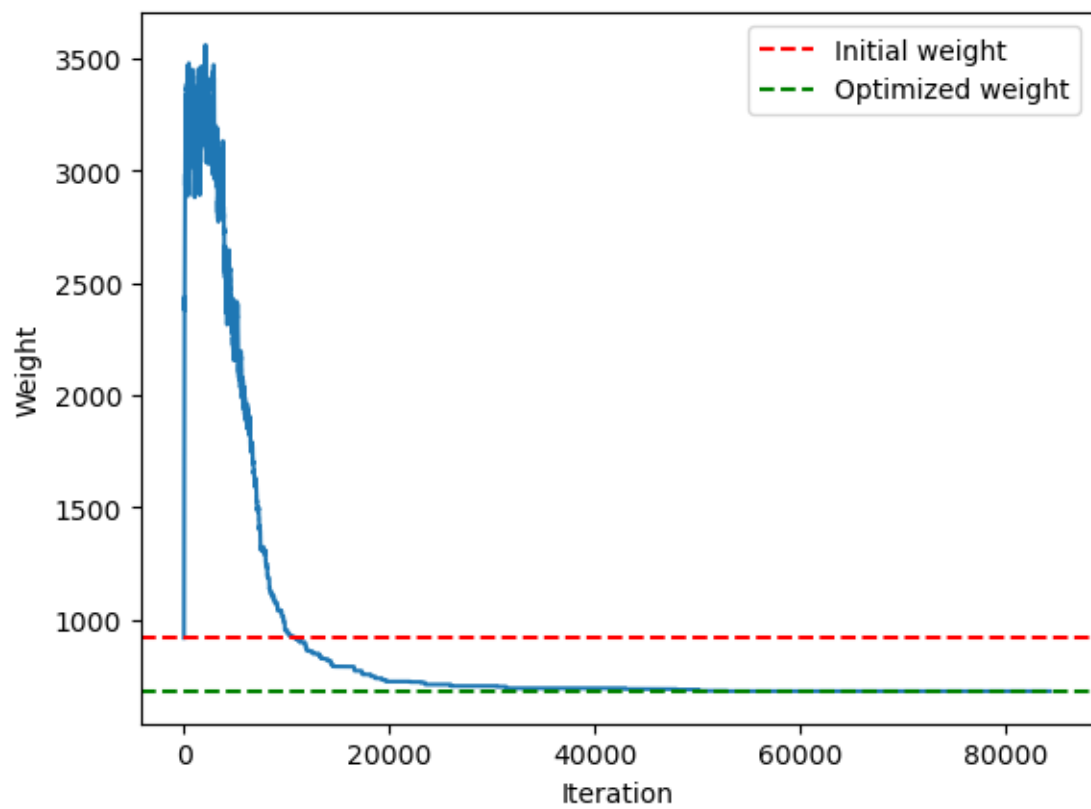


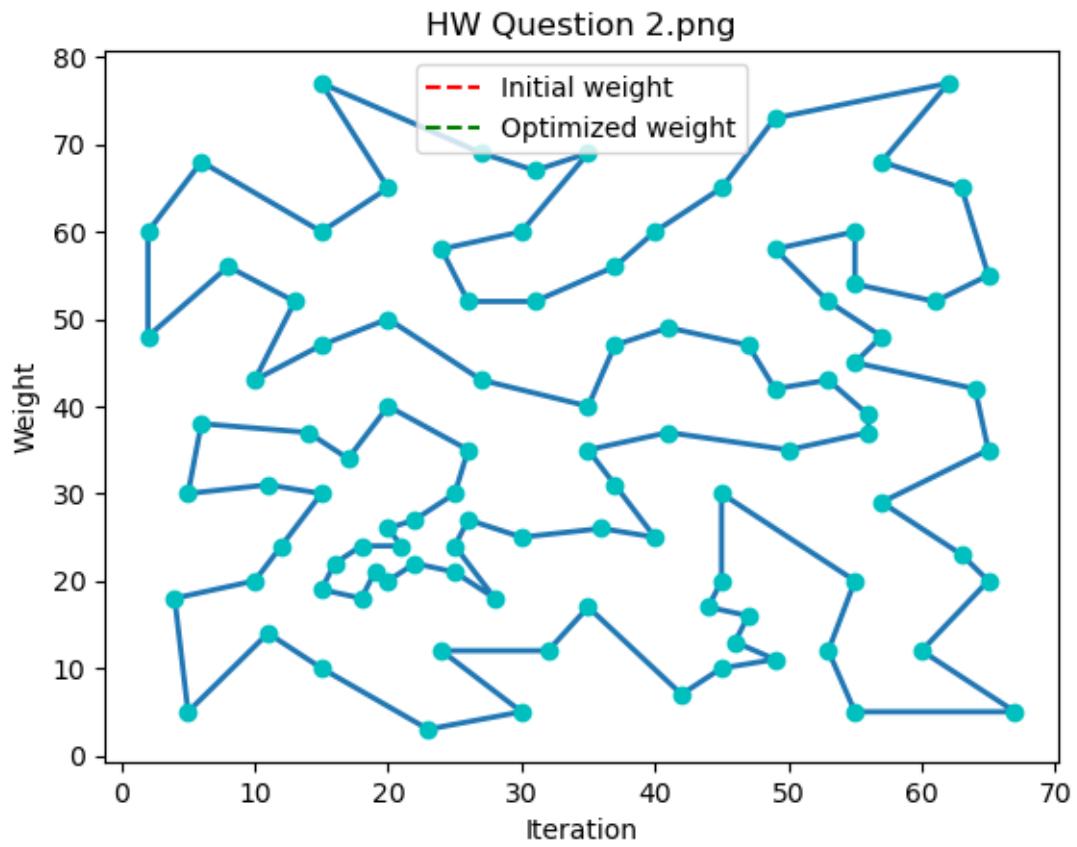
Intial weight: 822.3436318636275  
 Minimum weight: 709.6246474592393  
 Improvement: 13.71 %  
 Intial weight: 802.316665764872  
 Minimum weight: 677.0768670646064  
 Improvement: 15.61 %  
 Intial weight: 815.4958442450514  
 Minimum weight: 707.7225228445939  
 Improvement: 13.22 %  
 Intial weight: 804.4300190183241  
 Minimum weight: 693.8663707478393  
 Improvement: 13.74 %  
 Intial weight: 784.4082875651105  
 Minimum weight: 696.3422224380356  
 Improvement: 11.23 %  
 Intial weight: 762.0344161580787  
 Minimum weight: 702.0183927956032  
 Improvement: 7.88 %  
 Intial weight: 825.2423227277445  
 Minimum weight: 711.5065589505963  
 Improvement: 13.780000000000001 %  
 Intial weight: 756.2276308690998  
 Minimum weight: 679.9402744670343  
 Improvement: 10.09 %  
 Intial weight: 917.3607787145356  
 Minimum weight: 704.3545026398157  
 Improvement: 23.22 %  
 Intial weight: 818.6232461854107  
 Minimum weight: 679.4869911486863  
 Improvement: 17.0 %  
 Intial weight: 748.8847705214857  
 Minimum weight: 689.8647971749159  
 Improvement: 7.88 %  
 Intial weight: 819.5979989877326  
 Minimum weight: 674.1034966220661  
 Improvement: 17.75 %  
 Intial weight: 769.0392369904995  
 Minimum weight: 685.9780842025492  
 Improvement: 10.8 %  
 Intial weight: 746.3851974073968  
 Minimum weight: 713.1725801121111  
 Improvement: 4.45 %  
 Intial weight: 736.368439098317  
 Minimum weight: 701.1517968959085  
 Improvement: 4.78 %  
 Intial weight: 780.4585227819068  
 Minimum weight: 690.3744246654929  
 Improvement: 11.540000000000001 %

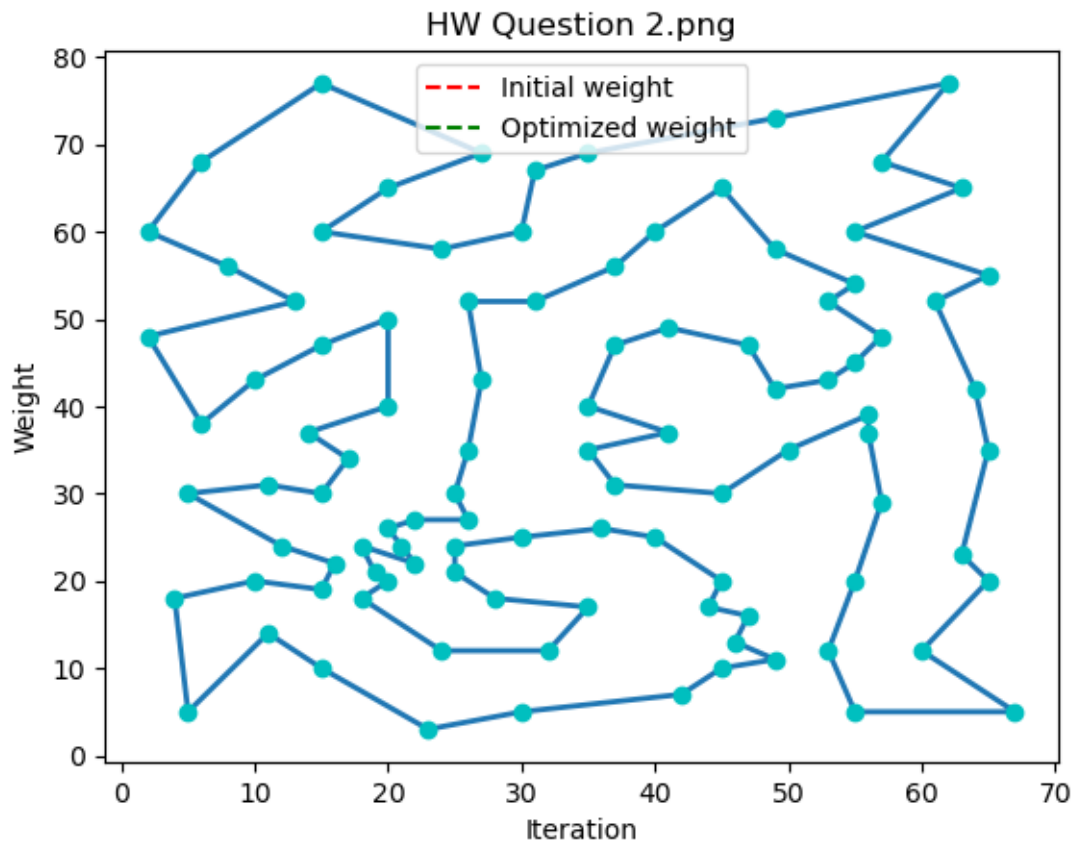
Intial weight: 779.9733767534977  
Minimum weight: 711.1014574318602  
Improvement: 8.83 %  
Intial weight: 921.7954694110074  
Minimum weight: 680.2556763719349  
Improvement: 26.200000000000003 %  
Intial weight: 763.5301390827296  
Minimum weight: 697.8848045273419  
Improvement: 8.6 %  
Intial weight: 776.5184013198424  
Minimum weight: 710.6220596915693  
Improvement: 8.49 %  
Intial weight: 764.0519266948331  
Minimum weight: 705.5658063801595  
Improvement: 7.649999999999995 %  
Intial weight: 736.368439098317  
Minimum weight: 706.8758034115385  
Improvement: 4.01 %  
Intial weight: 800.7084055666616  
Minimum weight: 695.729790258986  
Improvement: 13.11 %  
Intial weight: 917.3607787145356  
Minimum weight: 698.8565225977363  
Improvement: 23.82 %  
Intial weight: 804.4300190183241  
Minimum weight: 720.5084578967451  
Improvement: 10.43 %  
Intial weight: 756.2276308690998  
Minimum weight: 705.9668227696308  
Improvement: 6.65 %

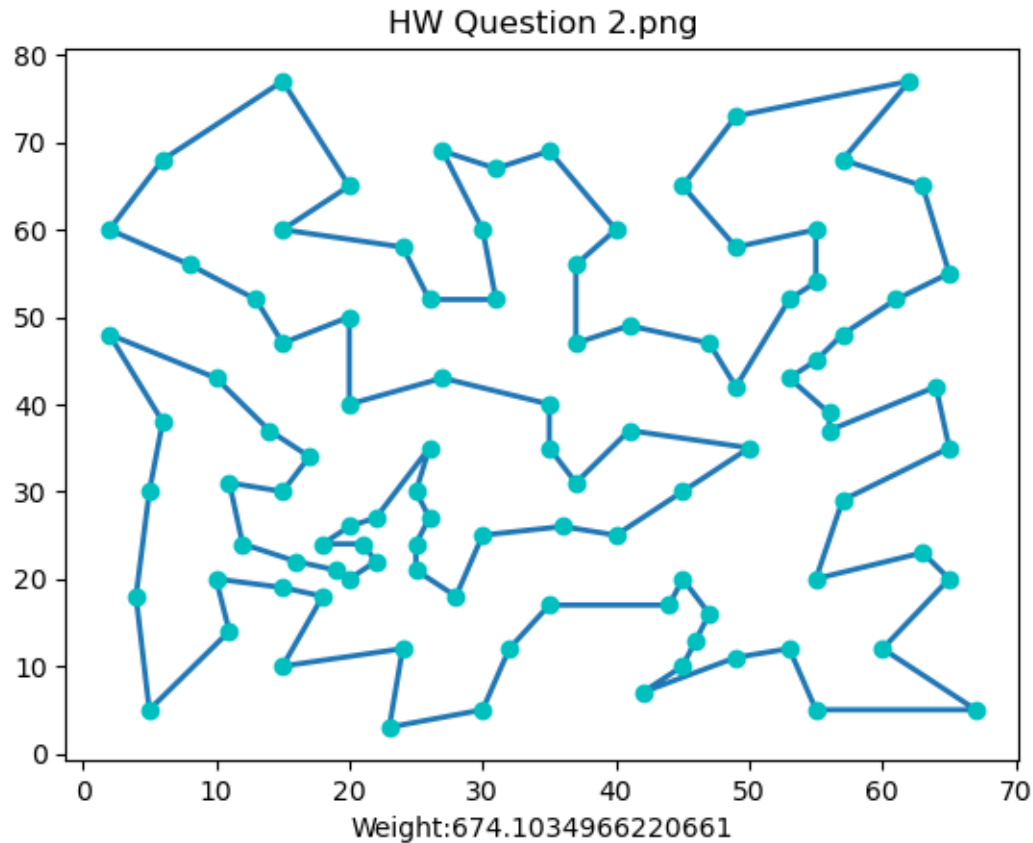
```
[ ]: <function matplotlib.pyplot.show(close=None, block=None)>
```











```
[ ]: name="HW Question 2_20.png"
temp = 20
weight = np.inf
for i in range(0,30):
    #feedback the returned weight
    weight = run(nodes,SI, temp, gamma, ST,name, weight,False)

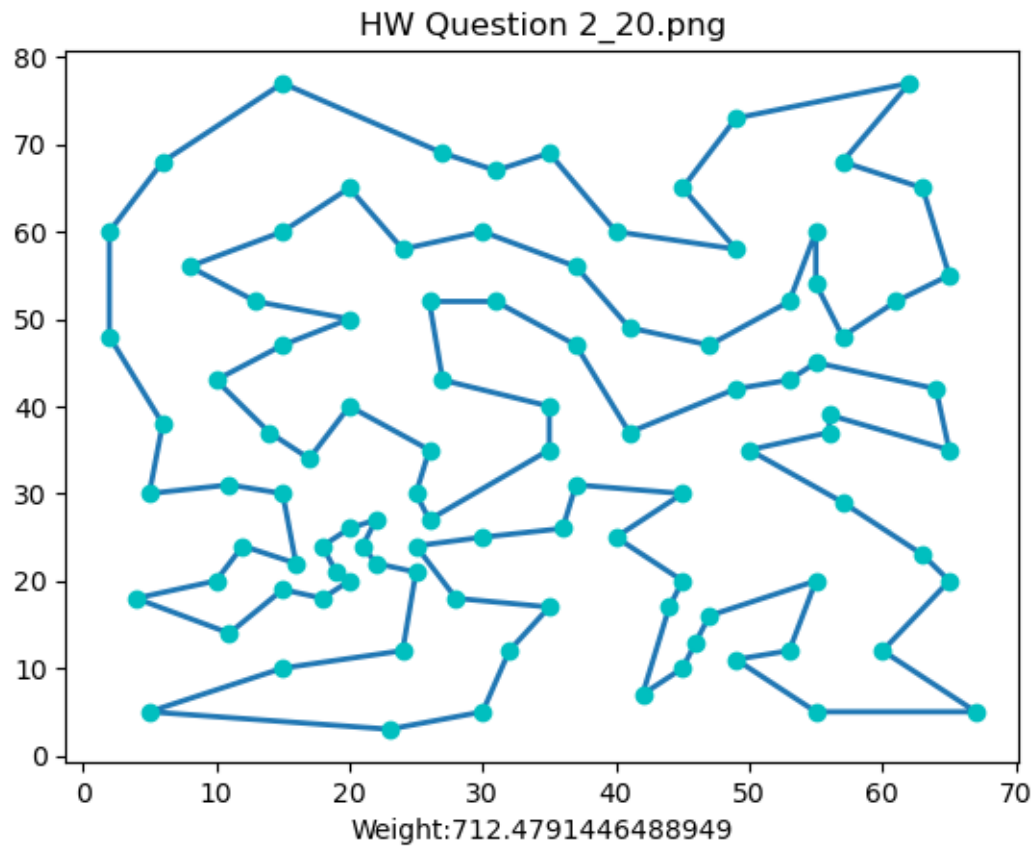
plt.show
```

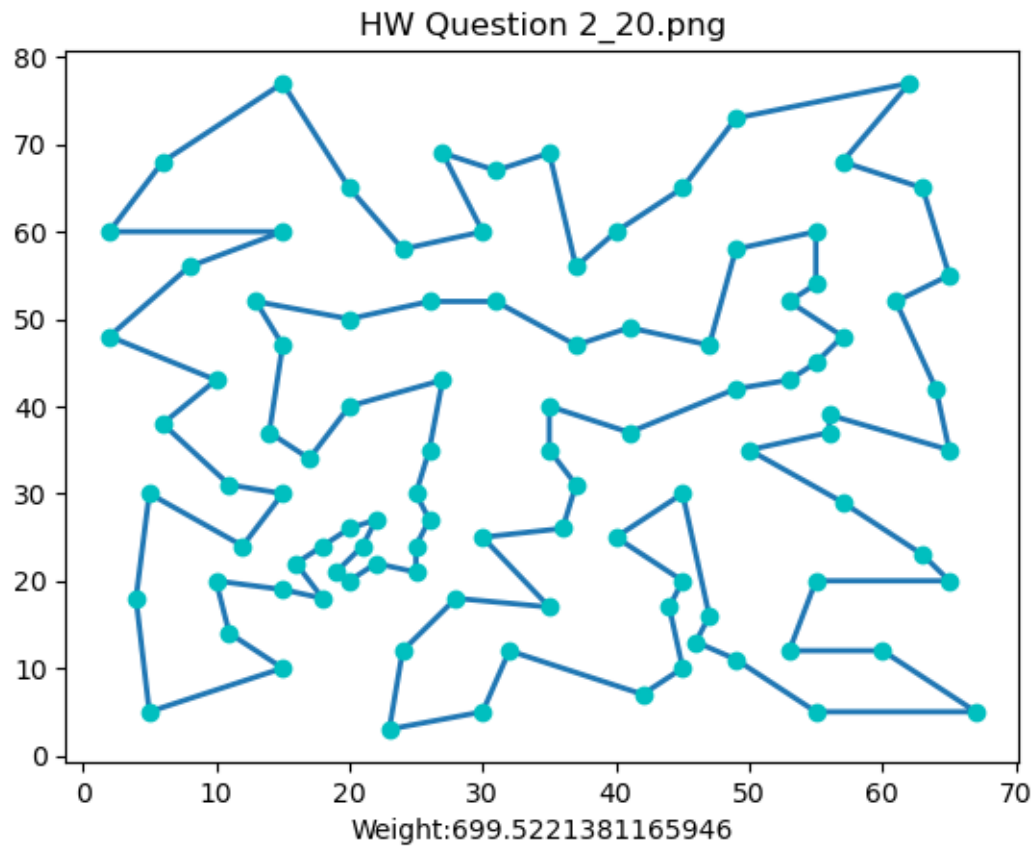
```
Intial weight: 777.5354236923063
Minimum weight: 712.4791446488949
Improvement: 8.37 %
Intial weight: 746.3851974073968
Minimum weight: 727.6808279834778
Improvement: 2.5100000000000002 %
Intial weight: 782.4834394011774
Minimum weight: 716.8910132161026
Improvement: 8.38 %
Intial weight: 794.4966192979791
```

Minimum weight: 699.5221381165946  
 Improvement: 11.95 %  
 Intial weight: 822.3436318636275  
 Minimum weight: 699.5609279020398  
 Improvement: 14.93 %  
 Intial weight: 808.4168515667888  
 Minimum weight: 706.3483043962442  
 Improvement: 12.629999999999999 %  
 Intial weight: 816.4511558169809  
 Minimum weight: 699.1898238329974  
 Improvement: 14.360000000000001 %  
 Intial weight: 764.0519266948331  
 Minimum weight: 697.9528604595779  
 Improvement: 8.649999999999999 %  
 Intial weight: 819.8967849681342  
 Minimum weight: 690.8287824374969  
 Improvement: 15.740000000000002 %  
 Intial weight: 828.3152127854873  
 Minimum weight: 709.9918226652239  
 Improvement: 14.280000000000001 %  
 Intial weight: 917.7420754760384  
 Minimum weight: 701.6833540871161  
 Improvement: 23.54 %  
 Intial weight: 773.424193263365  
 Minimum weight: 692.6470993028458  
 Improvement: 10.440000000000001 %  
 Intial weight: 736.368439098317  
 Minimum weight: 711.6493545441994  
 Improvement: 3.36 %  
 Intial weight: 763.8605117015061  
 Minimum weight: 691.5450969569335  
 Improvement: 9.47 %  
 Intial weight: 746.36064315413  
 Minimum weight: 693.6629184990655  
 Improvement: 7.06 %  
 Intial weight: 793.0403905464244  
 Minimum weight: 692.7204581125274  
 Improvement: 12.65 %  
 Intial weight: 788.5719021555468  
 Minimum weight: 695.240979795796  
 Improvement: 11.84 %  
 Intial weight: 754.5225757818118  
 Minimum weight: 709.434628952207  
 Improvement: 5.9799999999999995 %  
 Intial weight: 828.3152127854873  
 Minimum weight: 703.520179369676  
 Improvement: 15.07 %  
 Intial weight: 766.7906131204761

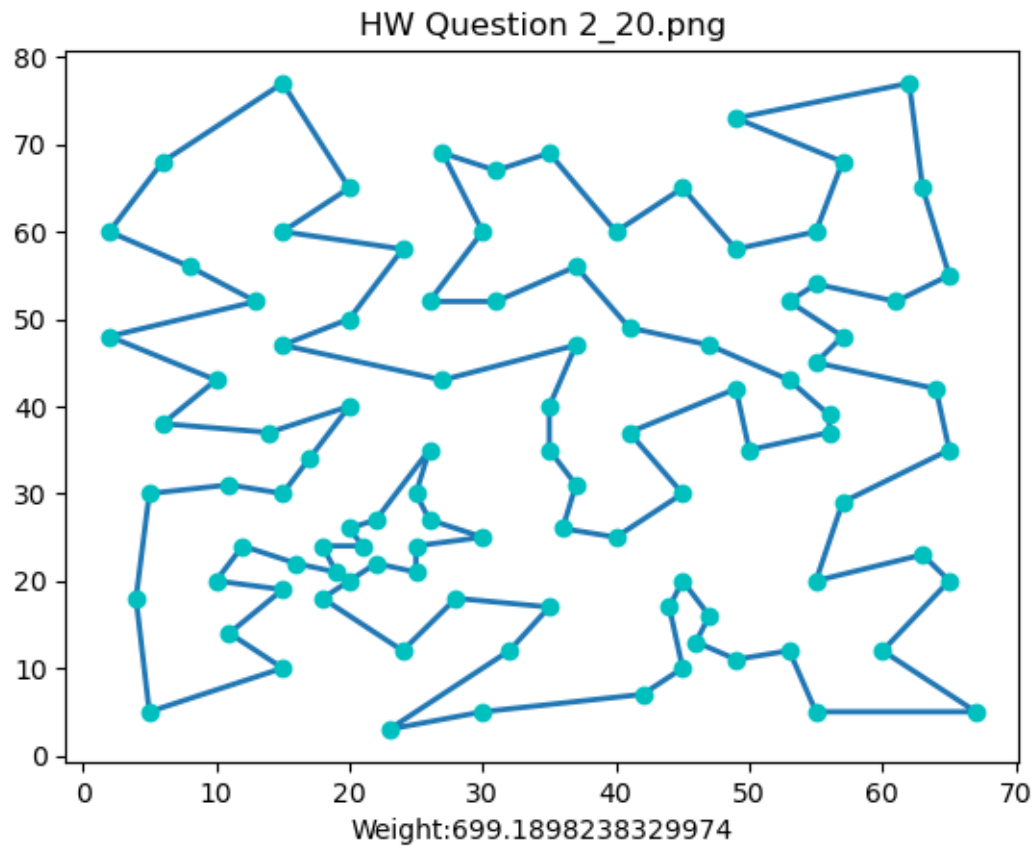
Minimum weight: 694.4587799723805  
Improvement: 9.43 %  
Intial weight: 818.6232461854107  
Minimum weight: 691.4307619947828  
Improvement: 15.540000000000001 %  
Intial weight: 816.4511558169809  
Minimum weight: 684.0198338066729  
Improvement: 16.220000000000002 %  
Intial weight: 803.2533985604902  
Minimum weight: 699.7248518611582  
Improvement: 12.889999999999999 %  
Intial weight: 788.5719021555468  
Minimum weight: 689.7918559933881  
Improvement: 12.53 %  
Intial weight: 800.1415656713435  
Minimum weight: 699.2343597192321  
Improvement: 12.61 %  
Intial weight: 769.4926738233092  
Minimum weight: 703.6142742428159  
Improvement: 8.559999999999999 %  
Intial weight: 769.0484257388638  
Minimum weight: 686.1766152556186  
Improvement: 10.780000000000001 %  
Intial weight: 917.7420754760384  
Minimum weight: 694.2822764894638  
Improvement: 24.349999999999998 %  
Intial weight: 832.0030304731138  
Minimum weight: 690.1763567155767  
Improvement: 17.05 %  
Intial weight: 808.5721371046094  
Minimum weight: 722.8540238276446  
Improvement: 10.6 %

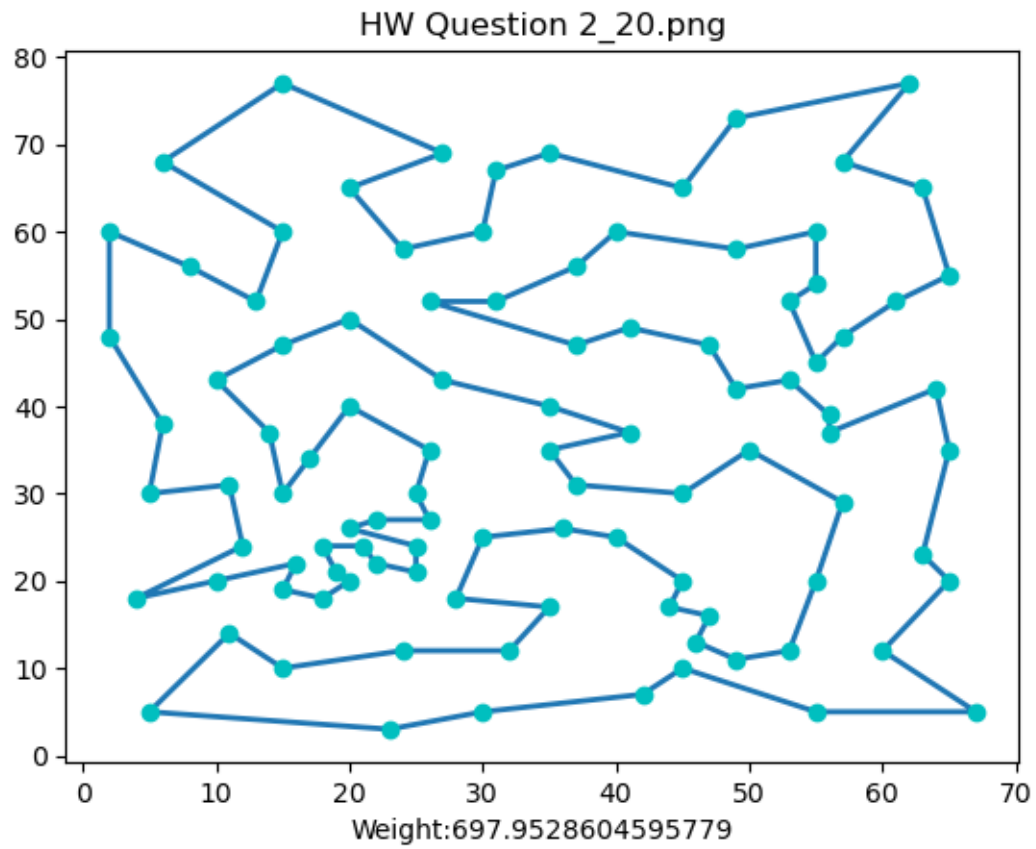
```
[ ]: <function matplotlib.pyplot.show(close=None, block=None)>
```

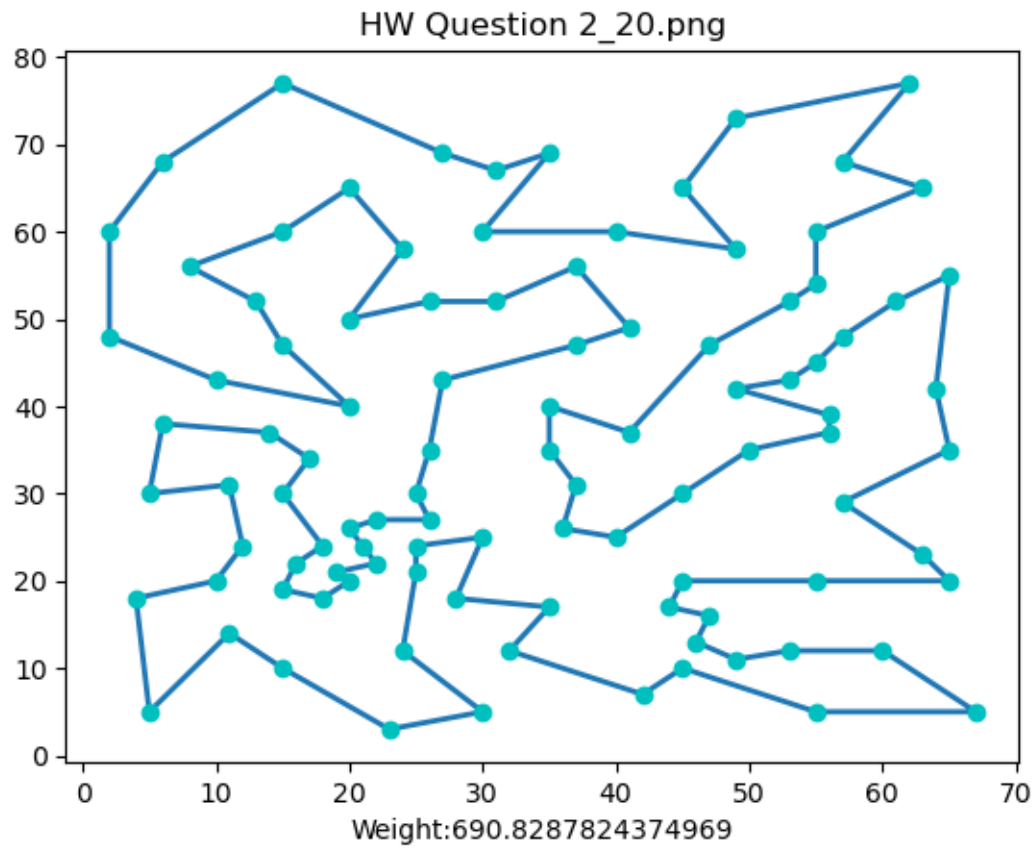


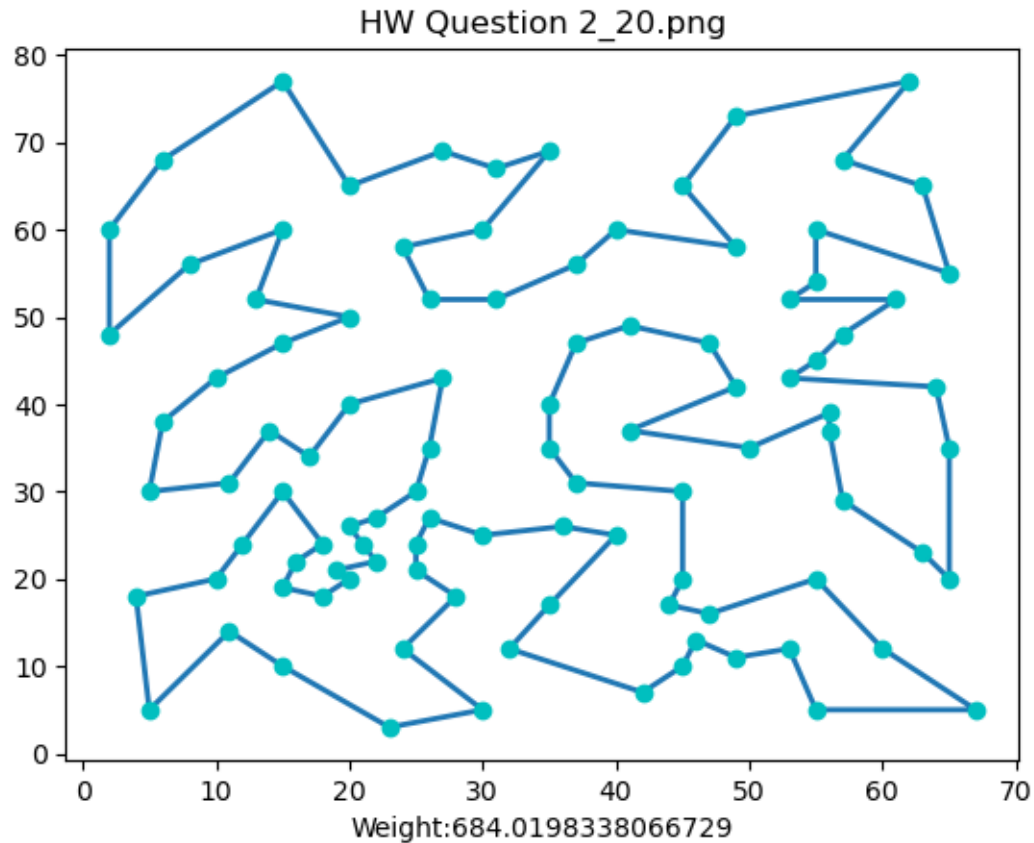












```
[ ]: name="HW Question 2_2.png"
temp = 2
weight = np.inf
for i in range(0,30):
    #feedback the returned weight
    weight = run(nodes,SI, temp, gamma, ST,name, weight,False)

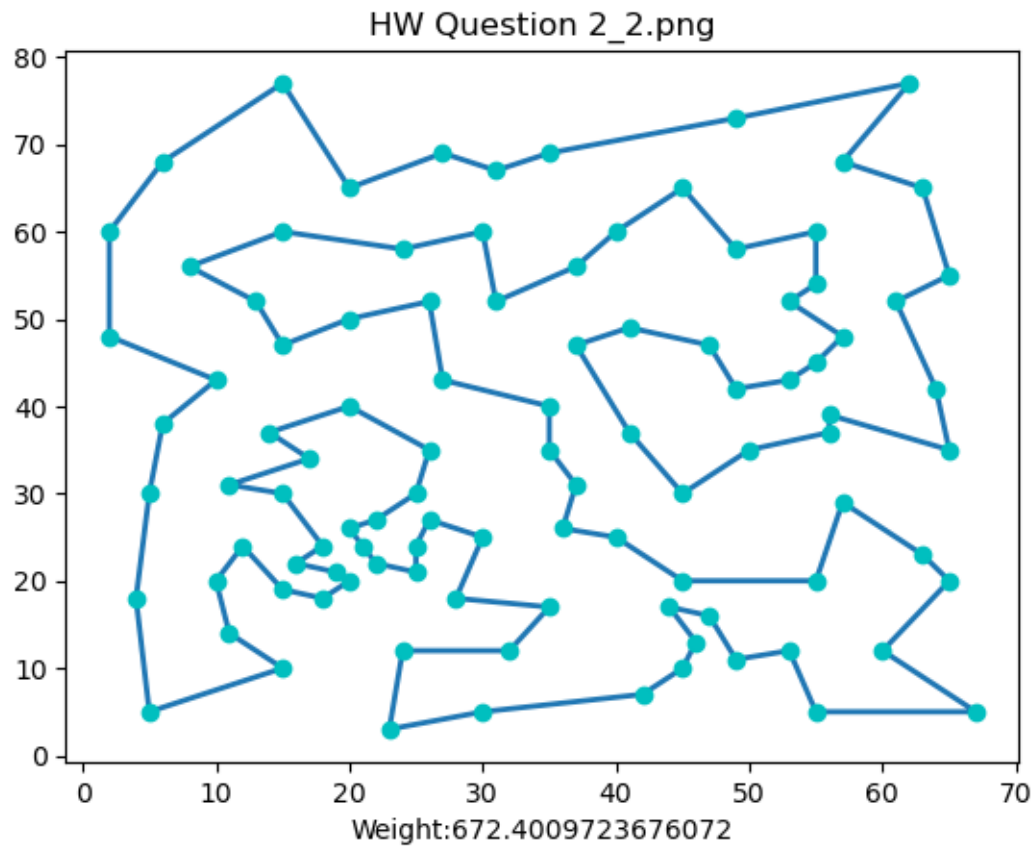
plt.show
```

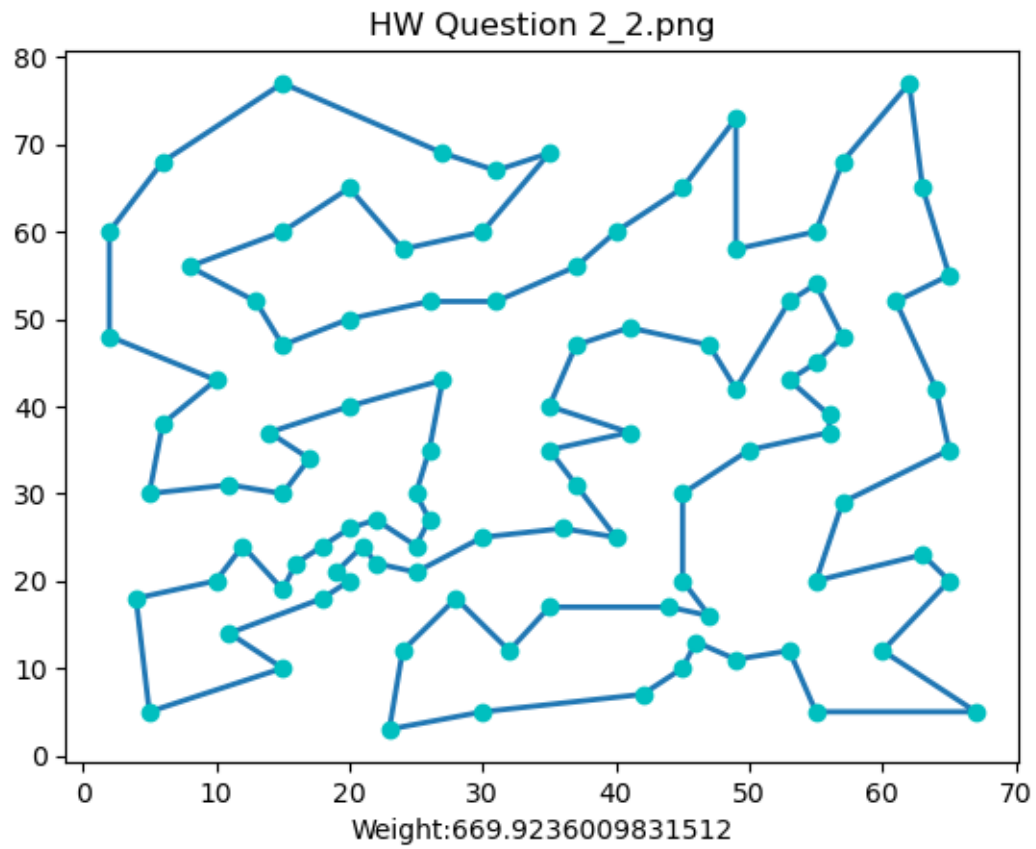
```
Intial weight: 748.8847705214857
Minimum weight: 672.4009723676072
Improvement: 10.209999999999999 %
Intial weight: 792.4349408780516
Minimum weight: 694.1883224534712
Improvement: 12.4 %
Intial weight: 794.4966192979794
Minimum weight: 679.4805347754763
Improvement: 14.48 %
Intial weight: 746.36064315413
```

Minimum weight: 702.7892688293738  
 Improvement: 5.84 %  
 Intial weight: 769.0484257388638  
 Minimum weight: 674.9962612762156  
 Improvement: 12.23 %  
 Intial weight: 784.4082875651105  
 Minimum weight: 689.3846630629761  
 Improvement: 12.11 %  
 Intial weight: 748.8847705214857  
 Minimum weight: 675.676823668322  
 Improvement: 9.78 %  
 Intial weight: 763.9059427825997  
 Minimum weight: 674.0395624564501  
 Improvement: 11.76 %  
 Intial weight: 799.5805279304747  
 Minimum weight: 677.5740681072199  
 Improvement: 15.260000000000002 %  
 Intial weight: 746.3851974073968  
 Minimum weight: 682.2726567053154  
 Improvement: 8.59 %  
 Intial weight: 800.1415656713435  
 Minimum weight: 684.2962033803723  
 Improvement: 14.48 %  
 Intial weight: 756.8253738356333  
 Minimum weight: 687.0473042782373  
 Improvement: 9.22 %  
 Intial weight: 799.5805279304747  
 Minimum weight: 693.7045671513267  
 Improvement: 13.239999999999998 %  
 Intial weight: 780.4502458301872  
 Minimum weight: 669.9236009831512  
 Improvement: 14.16 %  
 Intial weight: 757.8675656265668  
 Minimum weight: 654.8803905985111  
 Improvement: 13.59 %  
 Intial weight: 795.0548138549633  
 Minimum weight: 676.174104017954  
 Improvement: 14.95 %  
 Intial weight: 894.6314404293532  
 Minimum weight: 677.7284317542626  
 Improvement: 24.240000000000002 %  
 Intial weight: 780.4585227819068  
 Minimum weight: 672.5473138412933  
 Improvement: 13.83 %  
 Intial weight: 803.3486963224497  
 Minimum weight: 673.0120593658431  
 Improvement: 16.220000000000002 %  
 Intial weight: 762.0344161580787

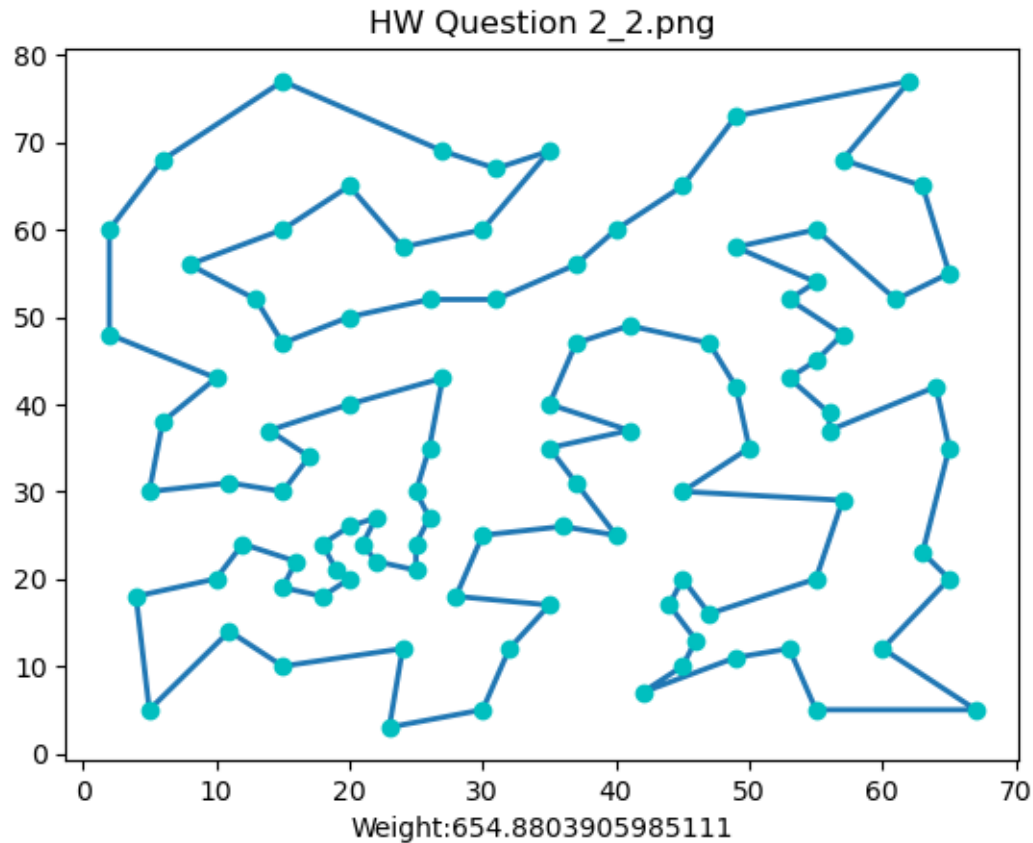
Minimum weight: 676.8873433059451  
Improvement: 11.17 %  
Intial weight: 746.36064315413  
Minimum weight: 683.8052345885131  
Improvement: 8.38 %  
Intial weight: 760.4925294157683  
Minimum weight: 679.6013901782812  
Improvement: 10.639999999999999 %  
Intial weight: 788.5719021555468  
Minimum weight: 685.5940224920489  
Improvement: 13.059999999999999 %  
Intial weight: 802.316665764872  
Minimum weight: 665.6556258119072  
Improvement: 17.03 %  
Intial weight: 754.3938641269903  
Minimum weight: 663.0663844840161  
Improvement: 12.11 %  
Intial weight: 783.591257102423  
Minimum weight: 668.7915904269566  
Improvement: 14.649999999999999 %  
Intial weight: 769.4926738233092  
Minimum weight: 673.0161773819664  
Improvement: 12.540000000000001 %  
Intial weight: 776.4330508448363  
Minimum weight: 673.619559513245  
Improvement: 13.239999999999998 %  
Intial weight: 819.8967849681342  
Minimum weight: 681.5572323611786  
Improvement: 16.869999999999997 %  
Intial weight: 773.7195943614001  
Minimum weight: 686.7132098855529  
Improvement: 11.25 %

```
[ ]: <function matplotlib.pyplot.show(close=None, block=None)>
```









```
[ ]: name="HW Question 2_100.png"
      temp = 100
      weight = np.inf
      for i in range(0,30):
          #feedback the returned weight
          weight = run(nodes,SI, temp, gamma, ST,name, weight,False)

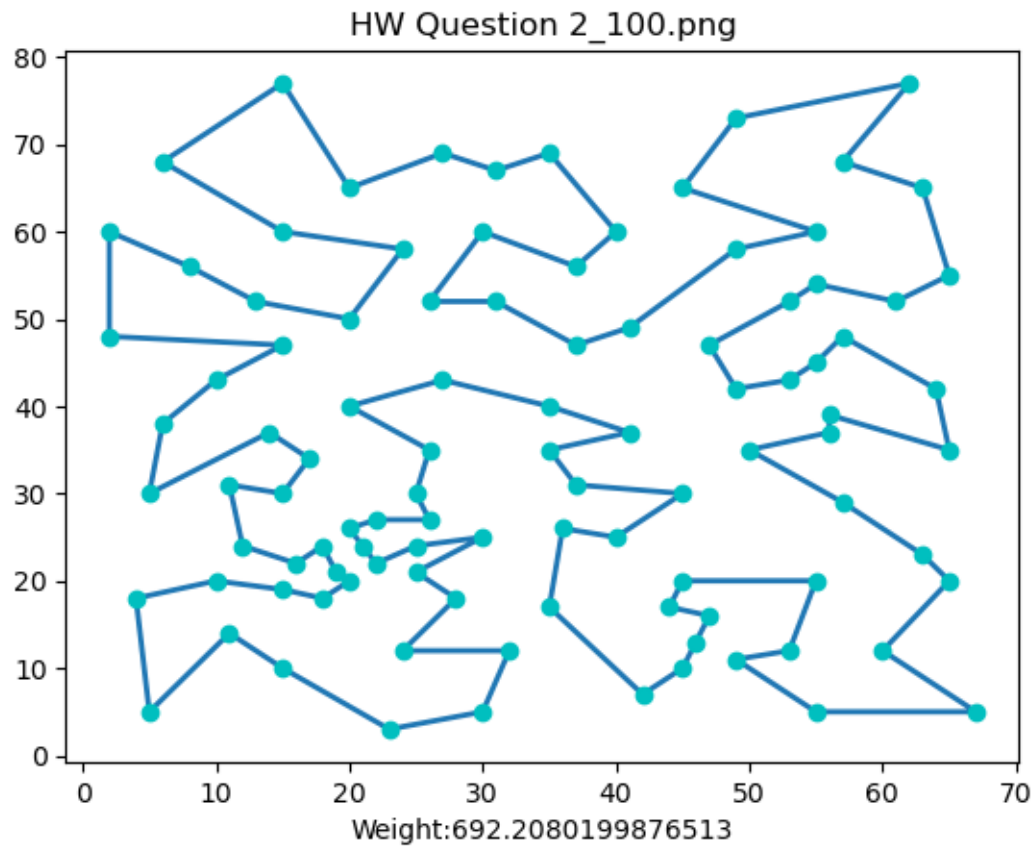
      plt.show
```

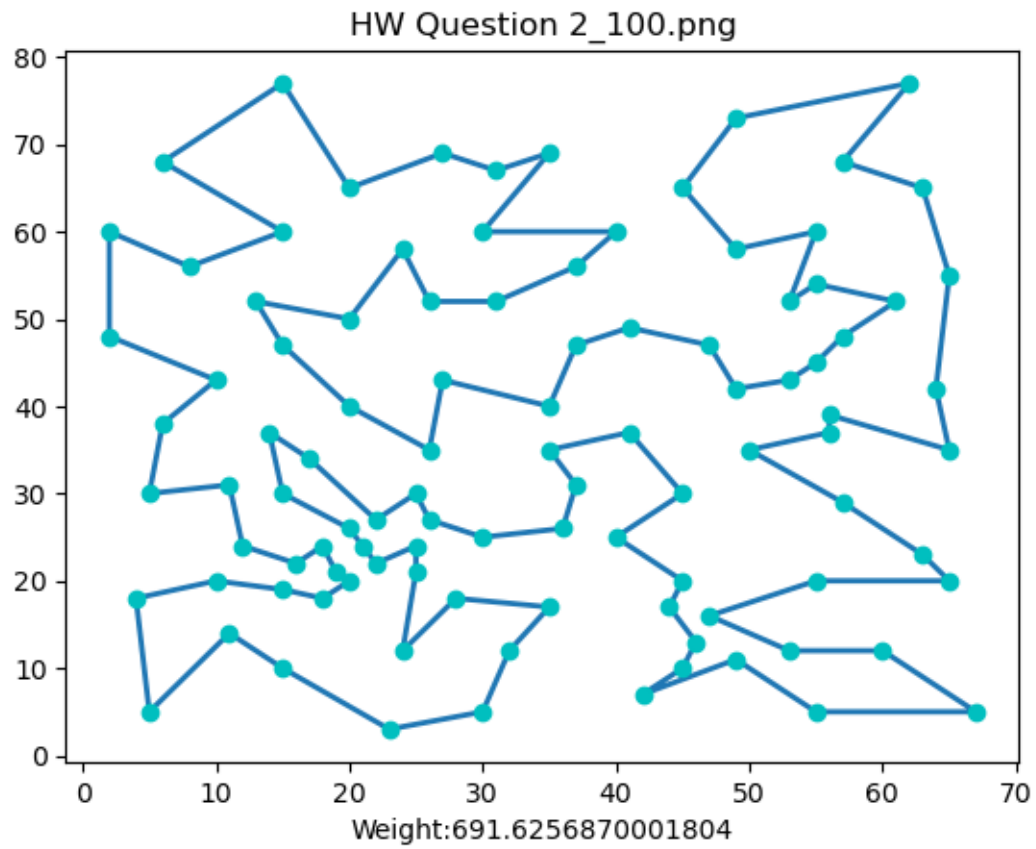
```
Initial weight: 778.8159377103368
Minimum weight: 692.2080199876513
Improvement: 11.12 %
Initial weight: 763.9059427825997
Minimum weight: 694.674130958978
Improvement: 9.06 %
Initial weight: 780.4502458301872
Minimum weight: 704.7007243644259
Improvement: 9.71 %
Initial weight: 819.5979989877326
```

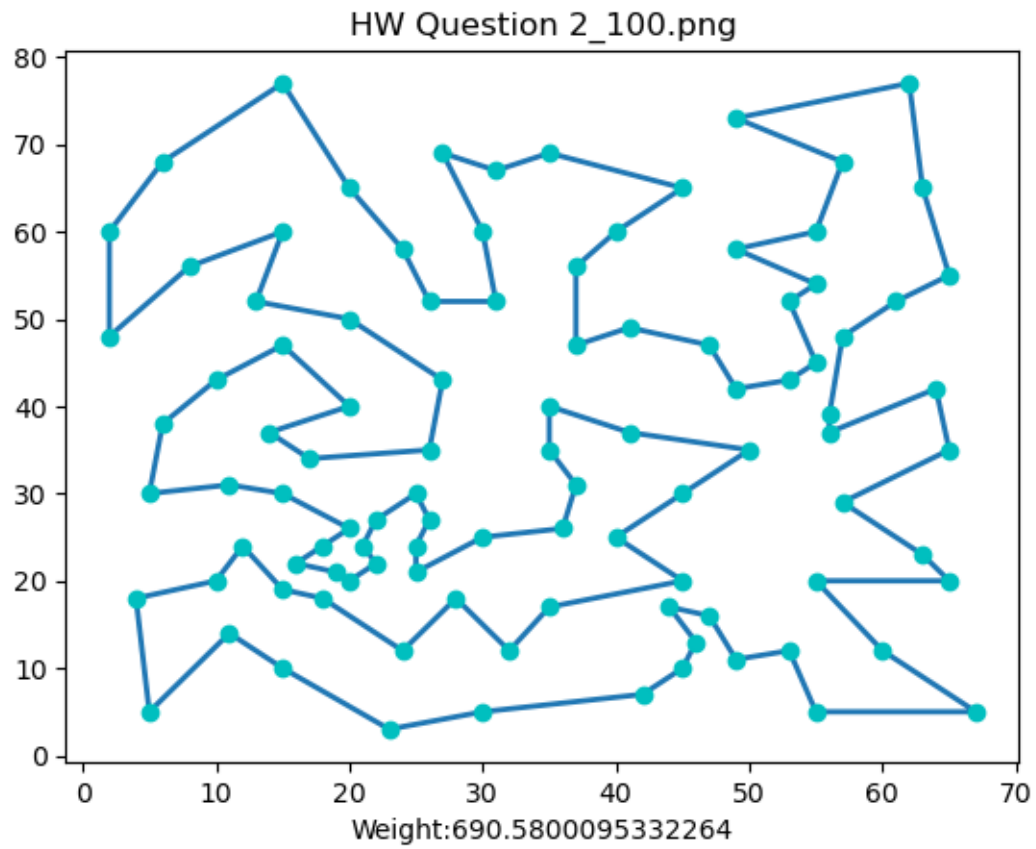
Minimum weight: 703.5841574616651  
 Improvement: 14.149999999999999 %  
 Intial weight: 777.5354236923063  
 Minimum weight: 694.9991164396889  
 Improvement: 10.620000000000001 %  
 Intial weight: 821.6661310838604  
 Minimum weight: 691.6256870001804  
 Improvement: 15.83 %  
 Intial weight: 746.3851974073968  
 Minimum weight: 705.6985956008679  
 Improvement: 5.45 %  
 Intial weight: 794.8608537531998  
 Minimum weight: 696.5104585039677  
 Improvement: 12.370000000000001 %  
 Intial weight: 746.36064315413  
 Minimum weight: 695.5013888619316  
 Improvement: 6.81 %  
 Intial weight: 819.8967849681342  
 Minimum weight: 690.5800095332264  
 Improvement: 15.770000000000001 %  
 Intial weight: 763.9059427825997  
 Minimum weight: 677.6163000350667  
 Improvement: 11.3 %  
 Intial weight: 819.8967849681342  
 Minimum weight: 707.1916531060701  
 Improvement: 13.750000000000002 %  
 Intial weight: 894.6314404293532  
 Minimum weight: 699.3453009388004  
 Improvement: 21.83 %  
 Intial weight: 784.4082875651105  
 Minimum weight: 713.0566584942719  
 Improvement: 9.1 %  
 Intial weight: 756.2276308690998  
 Minimum weight: 696.7014432172078  
 Improvement: 7.870000000000001 %  
 Intial weight: 783.591257102423  
 Minimum weight: 687.723305666142  
 Improvement: 12.23 %  
 Intial weight: 763.6858933836011  
 Minimum weight: 681.9061630816674  
 Improvement: 10.71 %  
 Intial weight: 762.0344161580787  
 Minimum weight: 695.2595482294465  
 Improvement: 8.76 %  
 Intial weight: 781.6740490839514  
 Minimum weight: 699.6729546141247  
 Improvement: 10.489999999999998 %  
 Intial weight: 782.6269886669787

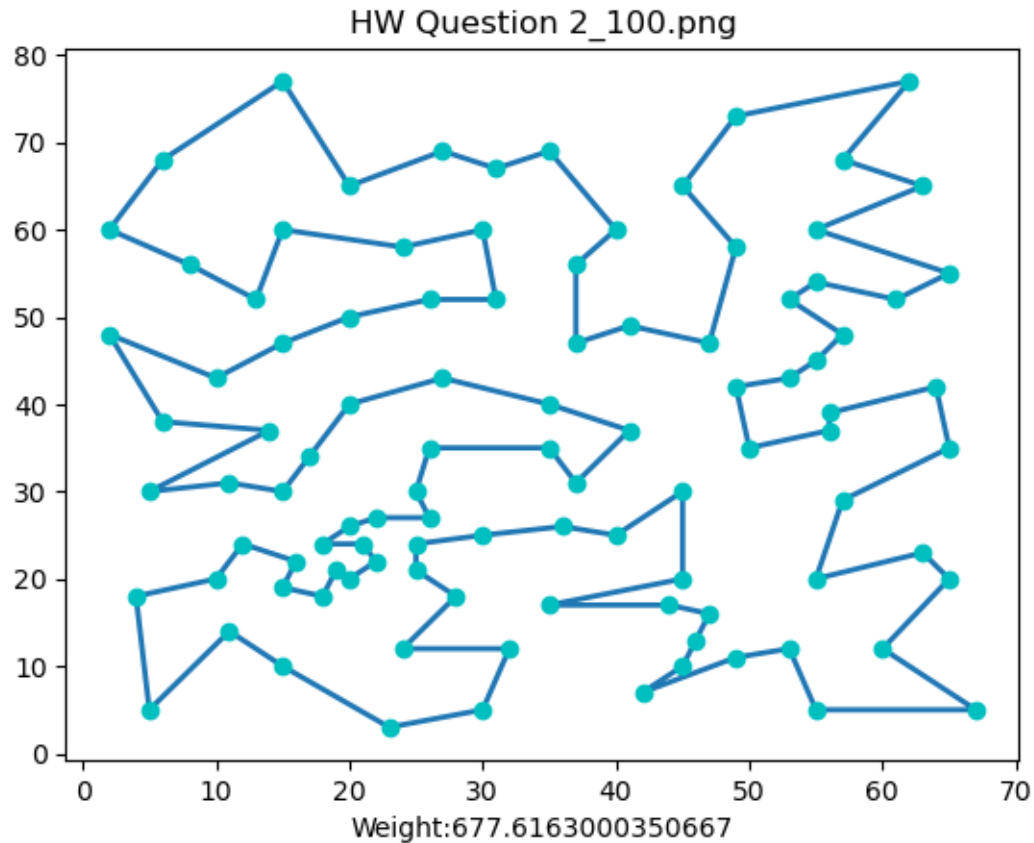
Minimum weight: 691.9450256884586  
Improvement: 11.59 %  
Intial weight: 778.8159377103368  
Minimum weight: 703.212348906462  
Improvement: 9.71 %  
Intial weight: 754.3938641269903  
Minimum weight: 711.9490554740015  
Improvement: 5.63 %  
Intial weight: 763.9629128232875  
Minimum weight: 682.2593667973318  
Improvement: 10.69 %  
Intial weight: 754.3938641269903  
Minimum weight: 712.1746587541414  
Improvement: 5.6000000000000005 %  
Intial weight: 791.4743607546113  
Minimum weight: 716.1559869029977  
Improvement: 9.520000000000001 %  
Intial weight: 914.2757793851822  
Minimum weight: 714.0116558607787  
Improvement: 21.9 %  
Intial weight: 815.1175464950453  
Minimum weight: 680.8613470241643  
Improvement: 16.470000000000002 %  
Intial weight: 803.2533985604902  
Minimum weight: 706.248892088351  
Improvement: 12.08 %  
Intial weight: 842.2017805374559  
Minimum weight: 697.1797889235088  
Improvement: 17.22 %  
Intial weight: 760.4925294157683  
Minimum weight: 697.9989855802521  
Improvement: 8.219999999999999 %

```
[ ]: <function matplotlib.pyplot.show(close=None, block=None)>
```









```
[ ]: temp = 100

while temp <= 1100:
    name="HW Question 2L_"+str(temp)+".png"
    weight = np.inf
    for i in range(0,30):
        #feedback the returned weight
        weight = run(nodes,SI, temp, gamma, ST,name, weight,False)
    temp = temp+100
    plt.show
```

```
Intial weight: 780.4502458301872
Minimum weight: 691.3798179405138
Improvement: 11.41 %
Intial weight: 750.4765472446395
Minimum weight: 690.7789958250762
Improvement: 7.95 %
Intial weight: 746.36064315413
Minimum weight: 687.5261223920373
Improvement: 7.88 %
```

Intial weight: 782.6269886669787  
 Minimum weight: 710.4223026044519  
 Improvement: 9.229999999999999 %  
 Intial weight: 769.0392369904995  
 Minimum weight: 688.5745045437131  
 Improvement: 10.459999999999999 %  
 Intial weight: 803.2533985604902  
 Minimum weight: 707.7915945457762  
 Improvement: 11.88 %  
 Intial weight: 819.5979989877326  
 Minimum weight: 706.8279334015226  
 Improvement: 13.76 %  
 Intial weight: 799.5805279304747  
 Minimum weight: 700.8608574984421  
 Improvement: 12.35 %  
 Intial weight: 746.3851974073968  
 Minimum weight: 674.1804661671636  
 Improvement: 9.67 %  
 Intial weight: 788.5719021555468  
 Minimum weight: 715.0000265683624  
 Improvement: 9.33 %  
 Intial weight: 804.3602132786455  
 Minimum weight: 686.4757530656741  
 Improvement: 14.66 %  
 Intial weight: 815.9371363720835  
 Minimum weight: 698.6020017552426  
 Improvement: 14.38 %  
 Intial weight: 814.4720562576554  
 Minimum weight: 728.8865089546404  
 Improvement: 10.51 %  
 Intial weight: 763.8605117015061  
 Minimum weight: 693.6722072135137  
 Improvement: 9.19 %  
 Intial weight: 763.5301390827296  
 Minimum weight: 699.1861275350543  
 Improvement: 8.43 %  
 Intial weight: 821.9491906621075  
 Minimum weight: 675.4023684507416  
 Improvement: 17.83 %  
 Intial weight: 811.5593135612681  
 Minimum weight: 696.3842411533238  
 Improvement: 14.19 %  
 Intial weight: 764.0519266948331  
 Minimum weight: 708.264207424059  
 Improvement: 7.3 %  
 Intial weight: 814.6496273670185  
 Minimum weight: 686.1076621882789  
 Improvement: 15.78 %



Intial weight: 822.3436318636275  
Minimum weight: 701.3219107767383  
Improvement: 14.719999999999999 %  
Intial weight: 769.4926738233092  
Minimum weight: 714.2713271091084  
Improvement: 7.180000000000001 %  
Intial weight: 758.6924852894255  
Minimum weight: 711.6909018083487  
Improvement: 6.2 %  
Intial weight: 773.424193263365  
Minimum weight: 700.7859146763864  
Improvement: 9.39 %  
Intial weight: 757.375929296319  
Minimum weight: 706.039959719087  
Improvement: 6.78 %  
Intial weight: 794.8608537531998  
Minimum weight: 709.8508460923284  
Improvement: 10.69 %  
Intial weight: 794.4966192979791  
Minimum weight: 700.4749883357837  
Improvement: 11.83 %  
Intial weight: 842.2017805374559  
Minimum weight: 705.3048737799483  
Improvement: 16.25 %  
Intial weight: 785.122088317017  
Minimum weight: 698.6700237029395  
Improvement: 11.01 %  
Intial weight: 763.6858933836011  
Minimum weight: 694.484716703086  
Improvement: 9.06 %  
Intial weight: 780.4502458301872  
Minimum weight: 693.0879576115689  
Improvement: 11.19 %  
Intial weight: 794.4966192979794  
Minimum weight: 698.7619236397708  
Improvement: 12.049999999999999 %  
Intial weight: 773.7195943614001  
Minimum weight: 693.6465108037884  
Improvement: 10.35 %  
Intial weight: 800.1415656713435  
Minimum weight: 718.332683043547  
Improvement: 10.22 %  
Intial weight: 756.2276308690998  
Minimum weight: 681.566990122528  
Improvement: 9.87 %  
Intial weight: 800.7084055666616  
Minimum weight: 733.207097123839  
Improvement: 8.43 %

Intial weight: 757.8675656265668  
 Minimum weight: 717.3834104634536  
 Improvement: 5.34 %  
 Intial weight: 764.9303268540112  
 Minimum weight: 710.526045098857  
 Improvement: 7.109999999999999 %  
 Intial weight: 763.5301390827296  
 Minimum weight: 692.5146433896845  
 Improvement: 9.3 %  
 Intial weight: 763.6858933836011  
 Minimum weight: 720.0408082948625  
 Improvement: 5.72 %  
 Intial weight: 763.9629128232875  
 Minimum weight: 669.914826491906  
 Improvement: 12.31 %  
 Intial weight: 792.4349408780516  
 Minimum weight: 702.9133103736458  
 Improvement: 11.3 %  
 Intial weight: 921.7954694110074  
 Minimum weight: 703.0913137594956  
 Improvement: 23.73 %  
 Intial weight: 815.9371363720835  
 Minimum weight: 699.0350706251721  
 Improvement: 14.330000000000002 %  
 Intial weight: 780.4585227819068  
 Minimum weight: 736.0251180485595  
 Improvement: 5.6899999999999995 %  
 Intial weight: 769.5904158703592  
 Minimum weight: 712.9702729037343  
 Improvement: 7.359999999999999 %  
 Intial weight: 821.6661310838604  
 Minimum weight: 699.5417949712903  
 Improvement: 14.860000000000001 %  
 Intial weight: 779.6686487978828  
 Minimum weight: 695.6200464570777  
 Improvement: 10.780000000000001 %  
 Intial weight: 746.3851974073968  
 Minimum weight: 708.1087104323689  
 Improvement: 5.13 %  
 Intial weight: 757.375929296319  
 Minimum weight: 683.2594667037092  
 Improvement: 9.790000000000001 %  
 Intial weight: 818.4622688211258  
 Minimum weight: 706.2910347423908  
 Improvement: 13.71 %  
 Intial weight: 811.5593135612681  
 Minimum weight: 695.7073440099208  
 Improvement: 14.280000000000001 %

Intial weight: 799.5805279304747  
 Minimum weight: 704.4794213032244  
 Improvement: 11.89 %  
 Intial weight: 746.36064315413  
 Minimum weight: 703.7222383576822  
 Improvement: 5.71 %  
 Intial weight: 899.5703548119341  
 Minimum weight: 683.9290882483384  
 Improvement: 23.97 %  
 Intial weight: 756.2276308690998  
 Minimum weight: 710.0469008473931  
 Improvement: 6.11 %  
 Intial weight: 781.6740490839514  
 Minimum weight: 696.5366324689854  
 Improvement: 10.89 %  
 Intial weight: 815.4958442450514  
 Minimum weight: 704.2546559881599  
 Improvement: 13.639999999999999 %  
 Intial weight: 788.5719021555468  
 Minimum weight: 701.4054347042404  
 Improvement: 11.05 %  
 Intial weight: 779.9733767534977  
 Minimum weight: 683.6029780703832  
 Improvement: 12.36 %  
 Intial weight: 800.7084055666616  
 Minimum weight: 713.8469270333861  
 Improvement: 10.85 %  
 Intial weight: 750.8359513590083  
 Minimum weight: 686.6832644878003  
 Improvement: 8.540000000000001 %  
 Intial weight: 754.5225757818118  
 Minimum weight: 690.9810299490168  
 Improvement: 8.42 %  
 Intial weight: 756.8253738356333  
 Minimum weight: 690.9063926736992  
 Improvement: 8.709999999999999 %  
 Intial weight: 914.2757793851822  
 Minimum weight: 701.1702793724394  
 Improvement: 23.31 %  
 Intial weight: 785.9871442319646  
 Minimum weight: 688.3922040789721  
 Improvement: 12.42 %  
 Intial weight: 800.1415656713435  
 Minimum weight: 691.9510108523651  
 Improvement: 13.52 %  
 Intial weight: 792.4349408780516  
 Minimum weight: 705.9996045692095  
 Improvement: 10.91 %

Intial weight: 779.6686487978828  
 Minimum weight: 694.5495057126691  
 Improvement: 10.92 %  
 Intial weight: 791.4743607546113  
 Minimum weight: 691.9354119581637  
 Improvement: 12.58 %  
 Intial weight: 776.5184013198424  
 Minimum weight: 702.7904887915971  
 Improvement: 9.49 %  
 Intial weight: 808.4168515667888  
 Minimum weight: 702.8888862119945  
 Improvement: 13.05 %  
 Intial weight: 794.4966192979794  
 Minimum weight: 688.5106236564385  
 Improvement: 13.34 %  
 Intial weight: 757.8675656265668  
 Minimum weight: 707.6033521601482  
 Improvement: 6.63 %  
 Intial weight: 769.0392369904995  
 Minimum weight: 695.5376755396007  
 Improvement: 9.56 %  
 Intial weight: 815.4958442450514  
 Minimum weight: 679.6793435246443  
 Improvement: 16.650000000000002 %  
 Intial weight: 818.4622688211258  
 Minimum weight: 693.2348596742047  
 Improvement: 15.299999999999999 %  
 Intial weight: 842.2017805374559  
 Minimum weight: 676.369176780782  
 Improvement: 19.689999999999998 %  
 Intial weight: 808.5721371046094  
 Minimum weight: 692.2467774865959  
 Improvement: 14.39 %  
 Intial weight: 746.36064315413  
 Minimum weight: 692.6771406720692  
 Improvement: 7.19 %  
 Intial weight: 797.5384960420745  
 Minimum weight: 687.6226419696708  
 Improvement: 13.780000000000001 %  
 Intial weight: 760.4925294157683  
 Minimum weight: 710.0374402772125  
 Improvement: 6.63 %  
 Intial weight: 788.5719021555468  
 Minimum weight: 699.6656212523171  
 Improvement: 11.27 %  
 Intial weight: 785.122088317017  
 Minimum weight: 706.9746469671732  
 Improvement: 9.950000000000001 %

Intial weight: 784.2494442357216  
Minimum weight: 704.5636302135327  
Improvement: 10.16 %  
Intial weight: 819.5979989877326  
Minimum weight: 722.5660426893626  
Improvement: 11.84 %  
Intial weight: 819.8967849681342  
Minimum weight: 692.2198058442177  
Improvement: 15.57 %  
Intial weight: 763.5301390827296  
Minimum weight: 715.8986515437492  
Improvement: 6.239999999999999 %  
Intial weight: 763.8605117015061  
Minimum weight: 696.3116066853611  
Improvement: 8.84 %  
Intial weight: 736.368439098317  
Minimum weight: 689.9823101023184  
Improvement: 6.3 %  
Intial weight: 776.4330508448363  
Minimum weight: 688.3424048271111  
Improvement: 11.35 %  
Intial weight: 784.2494442357216  
Minimum weight: 705.0429571968311  
Improvement: 10.100000000000001 %  
Intial weight: 780.4585227819068  
Minimum weight: 691.2339365236685  
Improvement: 11.43 %  
Intial weight: 776.5184013198424  
Minimum weight: 704.9547623434736  
Improvement: 9.22 %  
Intial weight: 757.8675656265668  
Minimum weight: 700.0276318012098  
Improvement: 7.630000000000001 %  
Intial weight: 764.0519266948331  
Minimum weight: 705.4160462652223  
Improvement: 7.670000000000001 %  
Intial weight: 756.8253738356333  
Minimum weight: 682.8735417949503  
Improvement: 9.77 %  
Intial weight: 784.2943069411428  
Minimum weight: 730.247339852275  
Improvement: 6.890000000000001 %  
Intial weight: 842.2017805374559  
Minimum weight: 699.8148918602249  
Improvement: 16.91 %  
Intial weight: 894.6314404293532  
Minimum weight: 689.4150615175715  
Improvement: 22.939999999999998 %

Intial weight: 793.0403905464244  
Minimum weight: 696.5454852728386  
Improvement: 12.17 %  
Intial weight: 794.4966192979794  
Minimum weight: 684.7858168005746  
Improvement: 13.81 %  
Intial weight: 783.591257102423  
Minimum weight: 695.3735563270795  
Improvement: 11.26 %  
Intial weight: 816.4511558169809  
Minimum weight: 692.9376908411201  
Improvement: 15.129999999999999 %  
Intial weight: 791.4743607546113  
Minimum weight: 700.0439214005129  
Improvement: 11.55 %  
Intial weight: 795.0548138549633  
Minimum weight: 694.8179953674176  
Improvement: 12.61 %  
Intial weight: 760.4925294157683  
Minimum weight: 694.4605382507724  
Improvement: 8.68 %  
Intial weight: 754.3938641269903  
Minimum weight: 680.524399056872  
Improvement: 9.790000000000001 %  
Intial weight: 808.5721371046094  
Minimum weight: 710.883430352451  
Improvement: 12.08 %  
Intial weight: 819.5979989877326  
Minimum weight: 698.2645688853542  
Improvement: 14.799999999999999 %  
Intial weight: 828.3152127854873  
Minimum weight: 689.7057989472094  
Improvement: 16.73 %  
Intial weight: 822.3436318636275  
Minimum weight: 707.3385759716156  
Improvement: 13.99 %  
Intial weight: 757.8675656265668  
Minimum weight: 695.2155868923519  
Improvement: 8.27 %  
Intial weight: 785.9871442319646  
Minimum weight: 690.3619004675554  
Improvement: 12.17 %  
Intial weight: 777.5354236923063  
Minimum weight: 700.2014609075077  
Improvement: 9.950000000000001 %  
Intial weight: 796.0413972056176  
Minimum weight: 689.3299522166351  
Improvement: 13.41 %

Intial weight: 797.5384960420745  
 Minimum weight: 707.5446284072441  
 Improvement: 11.28 %  
 Intial weight: 918.5468208411437  
 Minimum weight: 710.2112609327304  
 Improvement: 22.68 %  
 Intial weight: 803.3486963224497  
 Minimum weight: 710.196691133309  
 Improvement: 11.600000000000001 %  
 Intial weight: 803.2533985604902  
 Minimum weight: 697.8046382826063  
 Improvement: 13.13 %  
 Intial weight: 814.6496273670185  
 Minimum weight: 690.2726746048197  
 Improvement: 15.27 %  
 Intial weight: 758.6924852894255  
 Minimum weight: 698.7673666556208  
 Improvement: 7.9 %  
 Intial weight: 746.3851974073968  
 Minimum weight: 704.9722893767978  
 Improvement: 5.55 %  
 Intial weight: 766.7906131204761  
 Minimum weight: 692.9168382647858  
 Improvement: 9.629999999999999 %  
 Intial weight: 748.8847705214857  
 Minimum weight: 709.8765470347369  
 Improvement: 5.21 %  
 Intial weight: 781.6740490839514  
 Minimum weight: 689.2748478052148  
 Improvement: 11.82 %  
 Intial weight: 792.4349408780516  
 Minimum weight: 700.8131533850037  
 Improvement: 11.559999999999999 %  
 Intial weight: 828.3152127854873  
 Minimum weight: 692.3420524882532  
 Improvement: 16.42 %  
 Intial weight: 776.5184013198424  
 Minimum weight: 706.8294741714008  
 Improvement: 8.97 %  
 Intial weight: 804.3602132786455  
 Minimum weight: 715.7763091627421  
 Improvement: 11.01 %  
 Intial weight: 917.3607787145356  
 Minimum weight: 696.8542505746375  
 Improvement: 24.04 %  
 Intial weight: 782.4834394011774  
 Minimum weight: 692.358653643165  
 Improvement: 11.52 %

Intial weight: 763.9059427825997  
 Minimum weight: 689.6924809475345  
 Improvement: 9.71 %  
 Intial weight: 764.4920020424389  
 Minimum weight: 683.3113035684565  
 Improvement: 10.620000000000001 %  
 Intial weight: 918.5468208411437  
 Minimum weight: 703.5436347760859  
 Improvement: 23.41 %  
 Intial weight: 766.7906131204761  
 Minimum weight: 700.2624113940852  
 Improvement: 8.68 %  
 Intial weight: 802.316665764872  
 Minimum weight: 695.5205614910063  
 Improvement: 13.309999999999999 %  
 Intial weight: 763.5301390827296  
 Minimum weight: 725.4083037057037  
 Improvement: 4.99 %  
 Intial weight: 776.5184013198424  
 Minimum weight: 698.826073073517  
 Improvement: 10.01 %  
 Intial weight: 814.6496273670185  
 Minimum weight: 709.0242488005899  
 Improvement: 12.97 %  
 Intial weight: 757.8675656265668  
 Minimum weight: 693.5856721383569  
 Improvement: 8.48 %  
 Intial weight: 808.4630144950138  
 Minimum weight: 705.2213942765429  
 Improvement: 12.770000000000001 %  
 Intial weight: 756.8253738356333  
 Minimum weight: 714.3171696292366  
 Improvement: 5.62 %  
 Intial weight: 780.16798411462  
 Minimum weight: 698.3933035427049  
 Improvement: 10.48 %  
 Intial weight: 763.5301390827296  
 Minimum weight: 689.0082043695585  
 Improvement: 9.76 %  
 Intial weight: 754.3938641269903  
 Minimum weight: 695.853191337427  
 Improvement: 7.76 %  
 Intial weight: 777.5354236923063  
 Minimum weight: 679.8069403110294  
 Improvement: 12.57 %  
 Intial weight: 794.4966192979794  
 Minimum weight: 701.6808098940478  
 Improvement: 11.68 %



Intial weight: 773.7195943614001  
Minimum weight: 704.0283970119118  
Improvement: 9.01 %  
Intial weight: 766.7906131204761  
Minimum weight: 702.8580868284015  
Improvement: 8.34 %  
Intial weight: 782.4834394011774  
Minimum weight: 702.5372638898738  
Improvement: 10.22 %  
Intial weight: 749.3190731895195  
Minimum weight: 703.3189660413819  
Improvement: 6.140000000000001 %  
Intial weight: 797.5384960420745

/tmp/ipykernel\_390799/898946657.py:138: RuntimeWarning: More than 20 figures  
have been opened. Figures created through the pyplot interface  
(`matplotlib.pyplot.figure`) are retained until explicitly closed and may  
consume too much memory. (To control this warning, see the rcParam  
`figure.max_open_warning`). Consider using `matplotlib.pyplot.close``.   
fig, ax = plt.subplots()

Minimum weight: 687.7105606672876  
Improvement: 13.77 %  
Intial weight: 800.1415656713435  
Minimum weight: 694.6236795983029  
Improvement: 13.19 %  
Intial weight: 806.2540485820623  
Minimum weight: 691.3953315167463  
Improvement: 14.249999999999998 %  
Intial weight: 917.3607787145356  
Minimum weight: 710.5010841696077  
Improvement: 22.55 %  
Intial weight: 796.0413972056176  
Minimum weight: 710.3027790270692  
Improvement: 10.77 %  
Intial weight: 894.6314404293532  
Minimum weight: 688.38376600549  
Improvement: 23.05 %  
Intial weight: 811.5593135612681  
Minimum weight: 688.286426414291  
Improvement: 15.190000000000001 %  
Intial weight: 918.5468208411437  
Minimum weight: 723.0967794992324  
Improvement: 21.279999999999998 %  
Intial weight: 917.3607787145356  
Minimum weight: 681.3783537514802  
Improvement: 25.72 %  
Intial weight: 806.2540485820623  
Minimum weight: 700.229345654109

Improvement: 13.15 %  
Intial weight: 785.9871442319646  
Minimum weight: 697.8562173495131  
Improvement: 11.21 %  
Intial weight: 917.7420754760384  
Minimum weight: 727.3754528861566  
Improvement: 20.74 %  
Intial weight: 778.8159377103368  
Minimum weight: 697.8067478578961  
Improvement: 10.4 %  
Intial weight: 794.4966192979791  
Minimum weight: 687.7575171100486  
Improvement: 13.43 %  
Intial weight: 777.5354236923063  
Minimum weight: 726.2854411662623  
Improvement: 6.59 %  
Intial weight: 769.4926738233092  
Minimum weight: 689.4773898221134  
Improvement: 10.4 %  
Intial weight: 784.2943069411428  
Minimum weight: 697.7963300078609  
Improvement: 11.03 %  
Intial weight: 800.1415656713435  
Minimum weight: 675.093425920312  
Improvement: 15.629999999999999 %  
Intial weight: 756.8253738356333  
Minimum weight: 695.9547698169193  
Improvement: 8.04 %  
Intial weight: 773.424193263365  
Minimum weight: 705.2808507444228  
Improvement: 8.81 %  
Intial weight: 818.6232461854107  
Minimum weight: 722.9191763375657  
Improvement: 11.690000000000001 %  
Intial weight: 808.4630144950138  
Minimum weight: 701.0109565476286  
Improvement: 13.29 %  
Intial weight: 748.8847705214857  
Minimum weight: 705.1242276593056  
Improvement: 5.84 %  
Intial weight: 816.4511558169809  
Minimum weight: 693.2253141239307  
Improvement: 15.09 %  
Intial weight: 825.2423227277445  
Minimum weight: 684.4969634258396  
Improvement: 17.06 %  
Intial weight: 821.6661310838604  
Minimum weight: 688.6492238002036

Improvement: 16.189999999999998 %  
Intial weight: 815.1175464950453  
Minimum weight: 710.0524375865963  
Improvement: 12.889999999999999 %  
Intial weight: 769.0392369904995  
Minimum weight: 697.1627816386595  
Improvement: 9.35 %  
Intial weight: 921.7954694110074  
Minimum weight: 724.4611329832919  
Improvement: 21.41 %  
Intial weight: 772.1828681805781  
Minimum weight: 709.9819305344038  
Improvement: 8.06 %  
Intial weight: 764.4920020424389  
Minimum weight: 695.3501065038996  
Improvement: 9.04 %  
Intial weight: 756.2276308690998  
Minimum weight: 698.2122901366398  
Improvement: 7.670000000000001 %  
Intial weight: 818.4622688211258  
Minimum weight: 711.6705452055364  
Improvement: 13.05 %  
Intial weight: 814.6496273670185  
Minimum weight: 678.7301720937238  
Improvement: 16.68 %  
Intial weight: 778.8159377103368  
Minimum weight: 700.0531721190538  
Improvement: 10.11 %  
Intial weight: 800.7084055666616  
Minimum weight: 712.2482929804152  
Improvement: 11.05 %  
Intial weight: 780.4585227819068  
Minimum weight: 695.1687913634353  
Improvement: 10.93 %  
Intial weight: 749.3190731895195  
Minimum weight: 700.9173328851944  
Improvement: 6.460000000000001 %  
Intial weight: 899.5703548119341  
Minimum weight: 693.5524901519489  
Improvement: 22.900000000000002 %  
Intial weight: 792.4349408780516  
Minimum weight: 692.8108760350569  
Improvement: 12.57 %  
Intial weight: 894.6314404293532  
Minimum weight: 685.34311701699  
Improvement: 23.39 %  
Intial weight: 803.2533985604902  
Minimum weight: 680.2605483901818

Improvement: 15.310000000000002 %  
Intial weight: 780.16798411462  
Minimum weight: 719.3990226278139  
Improvement: 7.79 %  
Intial weight: 794.4966192979791  
Minimum weight: 711.7679030741755  
Improvement: 10.41 %  
Intial weight: 822.3436318636275  
Minimum weight: 695.4518080729719  
Improvement: 15.43 %  
Intial weight: 785.9871442319646  
Minimum weight: 701.1494845008519  
Improvement: 10.79 %  
Intial weight: 815.4958442450514  
Minimum weight: 707.2939412303771  
Improvement: 13.270000000000001 %  
Intial weight: 811.5593135612681  
Minimum weight: 671.8747084354792  
Improvement: 17.21 %  
Intial weight: 811.5593135612681  
Minimum weight: 723.7716351871252  
Improvement: 10.82 %  
Intial weight: 764.9303268540112  
Minimum weight: 699.739579468184  
Improvement: 8.52 %  
Intial weight: 794.4966192979794  
Minimum weight: 716.4249207592594  
Improvement: 9.83 %  
Intial weight: 785.9871442319646  
Minimum weight: 702.1464662439082  
Improvement: 10.67 %  
Intial weight: 791.4743607546113  
Minimum weight: 667.92818281114  
Improvement: 15.61 %  
Intial weight: 808.5721371046094  
Minimum weight: 693.2627744056258  
Improvement: 14.26 %  
Intial weight: 763.8605117015061  
Minimum weight: 687.9219250480688  
Improvement: 9.94 %  
Intial weight: 800.1415656713435  
Minimum weight: 713.1679074771611  
Improvement: 10.870000000000001 %  
Intial weight: 814.4720562576554  
Minimum weight: 684.2572724158362  
Improvement: 15.989999999999998 %  
Intial weight: 821.9491906621075  
Minimum weight: 703.2668059275163

Improvement: 14.44 %  
 Intial weight: 815.4958442450514  
 Minimum weight: 717.5793215313879  
 Improvement: 12.01 %  
 Intial weight: 785.9871442319646  
 Minimum weight: 698.5154251633612  
 Improvement: 11.12999999999999 %  
 Intial weight: 796.0413972056176  
 Minimum weight: 688.5749950741027  
 Improvement: 13.5 %  
 Intial weight: 769.0392369904995  
 Minimum weight: 723.2823469163831  
 Improvement: 5.94999999999999 %  
 Intial weight: 750.4765472446395  
 Minimum weight: 718.7726670284419  
 Improvement: 4.22 %  
 Intial weight: 808.4630144950138  
 Minimum weight: 690.7975790113063  
 Improvement: 14.54999999999999 %  
 Intial weight: 750.8359513590083  
 Minimum weight: 705.3800033392588  
 Improvement: 6.05 %  
 Intial weight: 899.5703548119341  
 Minimum weight: 682.5303002013447  
 Improvement: 24.13 %  
 Intial weight: 776.5184013198424  
 Minimum weight: 696.4930958494656  
 Improvement: 10.31 %  
 Intial weight: 818.6232461854107  
 Minimum weight: 694.9531048458624  
 Improvement: 15.110000000000001 %  
 Intial weight: 815.9371363720835  
 Minimum weight: 670.7107360660688  
 Improvement: 17.8 %  
 Intial weight: 822.3436318636275  
 Minimum weight: 672.4875233560266  
 Improvement: 18.22 %  
 Intial weight: 814.6496273670185  
 Minimum weight: 698.6410308965696  
 Improvement: 14.24 %  
 Intial weight: 894.6314404293532  
 Minimum weight: 712.7115039990824  
 Improvement: 20.330000000000002 %  
 Intial weight: 780.4502458301872  
 Minimum weight: 685.5361795717665  
 Improvement: 12.16 %  
 Intial weight: 773.424193263365  
 Minimum weight: 693.5966958954182

Improvement: 10.32 %  
Intial weight: 762.0344161580787  
Minimum weight: 680.2129754486829  
Improvement: 10.74 %  
Intial weight: 828.3152127854873  
Minimum weight: 701.9696767443845  
Improvement: 15.25 %  
Intial weight: 769.0392369904995  
Minimum weight: 684.3411363401184  
Improvement: 11.01 %  
Intial weight: 788.5719021555468  
Minimum weight: 696.2705121485186  
Improvement: 11.700000000000001 %  
Intial weight: 806.2540485820623  
Minimum weight: 689.5386608961571  
Improvement: 14.48 %  
Intial weight: 758.6924852894255  
Minimum weight: 684.5869039207022  
Improvement: 9.77 %  
Intial weight: 756.8253738356333  
Minimum weight: 683.6813601664373  
Improvement: 9.66 %  
Intial weight: 780.4502458301872  
Minimum weight: 679.8246976685775  
Improvement: 12.889999999999999 %  
Intial weight: 782.4834394011774  
Minimum weight: 706.5820332480263  
Improvement: 9.700000000000001 %  
Intial weight: 762.0344161580787  
Minimum weight: 698.6659670705852  
Improvement: 8.32 %  
Intial weight: 917.7420754760384  
Minimum weight: 688.6890888272408  
Improvement: 24.959999999999997 %  
Intial weight: 782.4834394011774  
Minimum weight: 715.1531934858574  
Improvement: 8.6 %  
Intial weight: 803.2533985604902  
Minimum weight: 679.4384124231599  
Improvement: 15.409999999999998 %  
Intial weight: 764.9303268540112  
Minimum weight: 693.4405831489375  
Improvement: 9.35 %  
Intial weight: 763.9059427825997  
Minimum weight: 694.5011699794544  
Improvement: 9.09 %  
Intial weight: 777.5354236923063  
Minimum weight: 694.8006891048673

Improvement: 10.639999999999999 %  
Intial weight: 825.2423227277445  
Minimum weight: 693.4076340492296  
Improvement: 15.98 %  
Intial weight: 776.4330508448363  
Minimum weight: 711.1991303827302  
Improvement: 8.4 %  
Intial weight: 800.1415656713435  
Minimum weight: 711.7229894468511  
Improvement: 11.05 %  
Intial weight: 795.0548138549633  
Minimum weight: 707.6179602393526  
Improvement: 11.0 %  
Intial weight: 779.9733767534977  
Minimum weight: 692.0716266605345  
Improvement: 11.27 %  
Intial weight: 819.8967849681342  
Minimum weight: 722.863305974801  
Improvement: 11.83 %  
Intial weight: 808.4630144950138  
Minimum weight: 681.5063912611953  
Improvement: 15.7 %  
Intial weight: 785.122088317017  
Minimum weight: 711.679202574138  
Improvement: 9.35 %  
Intial weight: 815.1175464950453  
Minimum weight: 684.7882807086709  
Improvement: 15.989999999999998 %  
Intial weight: 763.6858933836011  
Minimum weight: 686.1432598451603  
Improvement: 10.15 %  
Intial weight: 792.4349408780516  
Minimum weight: 707.9867301351735  
Improvement: 10.66 %  
Intial weight: 756.8253738356333  
Minimum weight: 696.5121285904539  
Improvement: 7.969999999999999 %  
Intial weight: 778.8159377103368  
Minimum weight: 714.6180596575538  
Improvement: 8.24 %  
Intial weight: 769.0392369904995  
Minimum weight: 695.4795156344184  
Improvement: 9.569999999999999 %  
Intial weight: 760.4925294157683  
Minimum weight: 695.1058872204623  
Improvement: 8.6 %  
Intial weight: 762.0344161580787  
Minimum weight: 701.8501193995288

Improvement: 7.9 %  
 Intial weight: 760.4925294157683  
 Minimum weight: 690.6920768330757  
 Improvement: 9.180000000000001 %  
 Intial weight: 769.4926738233092  
 Minimum weight: 694.2206075735038  
 Improvement: 9.78 %  
 Intial weight: 803.2533985604902  
 Minimum weight: 708.2604315074834  
 Improvement: 11.83 %  
 Intial weight: 757.8675656265668  
 Minimum weight: 732.187631436994  
 Improvement: 3.39 %  
 Intial weight: 757.375929296319  
 Minimum weight: 677.8638416871208  
 Improvement: 10.5 %  
 Intial weight: 756.8253738356333  
 Minimum weight: 696.7272033255767  
 Improvement: 7.939999999999995 %  
 Intial weight: 777.5354236923063  
 Minimum weight: 700.8026844019862  
 Improvement: 9.87 %  
 Intial weight: 769.0392369904995  
 Minimum weight: 682.0138790408189  
 Improvement: 11.32 %  
 Intial weight: 815.9371363720835  
 Minimum weight: 710.4522464750902  
 Improvement: 12.93 %  
 Intial weight: 803.2533985604902  
 Minimum weight: 708.0685700464451  
 Improvement: 11.85 %  
 Intial weight: 791.4743607546113  
 Minimum weight: 686.2895060256305  
 Improvement: 13.29 %  
 Intial weight: 819.8967849681342  
 Minimum weight: 685.2472660758657  
 Improvement: 16.42 %  
 Intial weight: 842.2017805374559  
 Minimum weight: 704.2318429220053  
 Improvement: 16.38 %  
 Intial weight: 764.0519266948331  
 Minimum weight: 680.7093278331079  
 Improvement: 10.91 %  
 Intial weight: 921.7954694110074  
 Minimum weight: 722.7153758802932  
 Improvement: 21.6 %  
 Intial weight: 764.9303268540112  
 Minimum weight: 697.4064414765274



Improvement: 8.83 %  
Intial weight: 818.6232461854107  
Minimum weight: 691.5673750337594  
Improvement: 15.52 %  
Intial weight: 780.16798411462  
Minimum weight: 703.2184977854154  
Improvement: 9.86 %  
Intial weight: 758.6924852894255  
Minimum weight: 693.2326979106138  
Improvement: 8.63 %  
Intial weight: 757.8675656265668  
Minimum weight: 705.1510622397718  
Improvement: 6.959999999999999 %  
Intial weight: 796.0413972056176  
Minimum weight: 714.0967592887772  
Improvement: 10.290000000000001 %  
Intial weight: 917.3607787145356  
Minimum weight: 676.8036282746119  
Improvement: 26.22 %  
Intial weight: 819.5979989877326  
Minimum weight: 702.9382451628791  
Improvement: 14.23 %  
Intial weight: 763.8605117015061  
Minimum weight: 701.9600171132789  
Improvement: 8.1 %  
Intial weight: 921.7954694110074  
Minimum weight: 692.1704206620188  
Improvement: 24.91 %  
Intial weight: 785.122088317017  
Minimum weight: 699.6341826218835  
Improvement: 10.89 %  
Intial weight: 816.2340584563308  
Minimum weight: 690.2832477285582  
Improvement: 15.43 %  
Intial weight: 821.6661310838604  
Minimum weight: 721.3788065866988  
Improvement: 12.21 %  
Intial weight: 736.368439098317  
Minimum weight: 693.796528658625  
Improvement: 5.779999999999999 %  
Intial weight: 793.2445274029868  
Minimum weight: 690.1524408561318  
Improvement: 13.0 %  
Intial weight: 795.0548138549633  
Minimum weight: 691.6063019637284  
Improvement: 13.01 %  
Intial weight: 791.4743607546113  
Minimum weight: 698.3787064811768

Improvement: 11.76 %  
Intial weight: 794.8608537531998  
Minimum weight: 686.7055321232741  
Improvement: 13.61 %  
Intial weight: 815.9371363720835  
Minimum weight: 710.8007633149873  
Improvement: 12.88999999999999 %  
Intial weight: 818.4622688211258  
Minimum weight: 685.3901092047107  
Improvement: 16.259999999999998 %  
Intial weight: 819.8967849681342  
Minimum weight: 706.0037839846685  
Improvement: 13.889999999999999 %  
Intial weight: 756.2276308690998  
Minimum weight: 719.2207142312793  
Improvement: 4.89 %  
Intial weight: 780.4502458301872  
Minimum weight: 712.2002069891165  
Improvement: 8.74 %  
Intial weight: 773.7195943614001  
Minimum weight: 706.2862853988347  
Improvement: 8.72 %  
Intial weight: 814.6496273670185  
Minimum weight: 714.8193309558685  
Improvement: 12.25 %  
Intial weight: 784.2943069411428  
Minimum weight: 703.5604383498588  
Improvement: 10.290000000000001 %  
Intial weight: 764.4920020424389  
Minimum weight: 701.3783871242304  
Improvement: 8.260000000000002 %  
Intial weight: 772.1828681805781  
Minimum weight: 704.845666034424  
Improvement: 8.72 %  
Intial weight: 818.6232461854107  
Minimum weight: 715.3778828123076  
Improvement: 12.61 %  
Intial weight: 784.2494442357216  
Minimum weight: 724.8405898191755  
Improvement: 7.580000000000001 %  
Intial weight: 746.36064315413  
Minimum weight: 697.5350118119094  
Improvement: 6.54 %  
Intial weight: 746.36064315413  
Minimum weight: 689.2419486699804  
Improvement: 7.649999999999995 %  
Intial weight: 772.1828681805781  
Minimum weight: 698.2309199521453

Improvement: 9.58 %  
 Intial weight: 819.5979989877326  
 Minimum weight: 687.3214361204545  
 Improvement: 16.14 %  
 Intial weight: 794.4966192979794  
 Minimum weight: 714.6597051357205  
 Improvement: 10.05 %  
 Intial weight: 804.3602132786455  
 Minimum weight: 687.7005386529987  
 Improvement: 14.499999999999998 %  
 Intial weight: 780.16798411462  
 Minimum weight: 696.685849254618  
 Improvement: 10.7 %  
 Intial weight: 796.0413972056176  
 Minimum weight: 689.7343412644719  
 Improvement: 13.350000000000001 %  
 Intial weight: 763.9629128232875  
 Minimum weight: 703.8167114481234  
 Improvement: 7.870000000000001 %  
 Intial weight: 917.7420754760384  
 Minimum weight: 712.9865029231696  
 Improvement: 22.31 %  
 Intial weight: 754.5225757818118  
 Minimum weight: 727.3671620457113  
 Improvement: 3.5999999999999996 %  
 Intial weight: 917.3607787145356  
 Minimum weight: 705.1552435458793  
 Improvement: 23.13 %  
 Intial weight: 814.4720562576554  
 Minimum weight: 720.5894356255079  
 Improvement: 11.53 %  
 Intial weight: 746.36064315413  
 Minimum weight: 693.4508207465606  
 Improvement: 7.090000000000001 %  
 Intial weight: 781.6740490839514  
 Minimum weight: 708.708378185526  
 Improvement: 9.33 %  
 Intial weight: 780.16798411462  
 Minimum weight: 718.6935942927007  
 Improvement: 7.88 %  
 Intial weight: 793.2445274029868  
 Minimum weight: 700.6051398997915  
 Improvement: 11.68 %  
 Intial weight: 818.4622688211258  
 Minimum weight: 696.7766630225613  
 Improvement: 14.87 %  
 Intial weight: 763.8605117015061  
 Minimum weight: 707.741837869055

Improvement: 7.35 %  
Intial weight: 762.0344161580787  
Minimum weight: 689.9605209450784  
Improvement: 9.46 %  
Intial weight: 802.316665764872  
Minimum weight: 688.2572641983355  
Improvement: 14.219999999999999 %  
Intial weight: 781.6740490839514  
Minimum weight: 691.5195844803293  
Improvement: 11.53 %  
Intial weight: 778.8159377103368  
Minimum weight: 700.3843873448901  
Improvement: 10.07 %  
Intial weight: 763.8605117015061  
Minimum weight: 686.2263097377217  
Improvement: 10.16 %  
Intial weight: 785.9871442319646  
Minimum weight: 696.3391565562722  
Improvement: 11.41 %  
Intial weight: 815.9371363720835  
Minimum weight: 686.818198012607  
Improvement: 15.82 %  
Intial weight: 758.6924852894255  
Minimum weight: 702.4647443483386  
Improvement: 7.41 %  
Intial weight: 815.4958442450514  
Minimum weight: 704.2013429019031  
Improvement: 13.65 %

