Traveling Salesman Problem Solutions with Ant Colony Optimization and Genetic Algorithms.

In [1]:
```
import numpy as np

class AntColony:
    def __init__(self, distances, n_ants, decay, alpha, beta):
        self.distances  = distances
        self.pheromone = np.ones(self.distances.shape) / len(distances)
        self.all_inds = range(len(distances))
        self.n_ants = n_ants
        self.decay = decay
        self.alpha = alpha
        self.beta = beta

    def run(self, n):
        self.all_inds = range(len(distances))
        self.shortest_path_ = None
        all_time_shortest_path = ("placeholder", np.inf)
        for i in range(n):
            all_paths = self.gen_all_paths()
            self.spread_pheronome(all_paths, self.pheromone, self.all_inds, self.distanc

            self.pheromone *= self.decay

            self.shortest_path_ = min(all_paths, key=lambda x: x[1])
            if self.shortest_path_[1] < all_time_shortest_path[1]:
                all_time_shortest_path = self.shortest_path_
        return all_time_shortest_path

    def spread_pheronome(self, all_paths, pheromone, all_inds, distances):
        pheromone *= self.decay
        for path, dist in all_paths:
            for move in path:
                pheromone[move] += 1.0 / distances[move]

    def gen_path_dist(self, path):
        total_dist = 0
        for ele in path:
            total_dist += self.distances[ele]
        return total_dist

    def gen_all_paths(self):
        all_paths = []
        for i in range(self.n_ants):
            path_dist = 0
            path = []
            visited_inds = set()
            visited_inds.add(self.all_inds[i])
            prev = self.all_inds[i]
            for j in range(len(self.distances) - 1):
                move = self.pick_move(self.pheromone[prev], self.distances[prev], visite
                path_dist += self.distances[prev][move]
                path.append((prev, move))
                prev = move
                visited_inds.add(move)
            all_paths.append((path, path_dist))
        return all_paths

    def pick_move(self, pheromone, dist, visited_inds):
        pheromone = np.copy(pheromone)
        pheromone[list(visited_inds)] = 0
```

```
        row = pheromone ** self.alpha * ((1.0 / dist) ** self.beta)

        # Normalize row only if it's not empty
        if row.sum() > 0:
            norm_row = row / row.sum()
            move = np.random.choice(self.all_inds, 1, p=norm_row)[0]
        else:
            # If the row is empty, choose a random move
            move = np.random.choice(list(set(self.all_inds) - visited_inds), 1)[0]

        return move

class GeneticAlgorithm:
    def __init__(self, population_size, elite_size, mutation_rate, crossover_prob):
        self.population_size = population_size
        self.elite_size = elite_size
        self.mutation_rate = mutation_rate
        self.crossover_prob = crossover_prob  # Add crossover probability

    def crossover(self, parent1, parent2):
        # Order Crossover (OX1) - a common crossover method for TSP
        if np.random.rand() < self.crossover_prob:
            start, end = sorted(np.random.choice(len(parent1), 2, replace=False))
            child = [-1] * len(parent1)
            child[start:end] = parent1[start:end]
            remaining = [item for item in parent2 if item not in child]
            index = 0
            for i in range(len(child)):
                if child[i] == -1:
                    child[i] = remaining[index]
                    index += 1
            return child
        else:
            return parent1  # If no crossover, return the first parent as the child

    def mutate(self, individual):
        # Swap Mutation - swap two cities in the individual
        mutate_index1, mutate_index2 = np.random.choice(len(individual), 2, replace=Fals
        individual[mutate_index1], individual[mutate_index2] = individual[mutate_index2]
        return individual

    def evolve(self, population):
        elite_size = int(self.elite_size * len(population))
        elites = sorted(population, key=lambda x: x[1])[:elite_size]

        # Crossover
        children = []
        while len(children) < (len(population) - elite_size):
            parent1, parent2 = np.random.choice(elites, 2, replace=False)
            child = self.crossover(parent1[0], parent2[0])
            children.append((child, -1))

        # Mutation
        for i in range(len(children)):
            if np.random.rand() < self.mutation_rate:
                children[i] = (self.mutate(children[i][0]), -1)

        # Combine elites and children
        population = elites + children
        return population

class ACOGA:
    def __init__(self, distances, n_ants, decay, alpha, beta, ga_population_size, ga_eli
        self.aco = AntColony(distances, n_ants, decay, alpha, beta)
        self.ga = GeneticAlgorithm(ga_population_size, ga_elite_size, ga_mutation_rate,
```

```
        self.generations = generations

    def run(self):
        for gen in range(self.generations):
            aco_shortest_path = self.aco.run(10)
            ga_population = self.generate_ga_population(aco_shortest_path)
            ga_population = self.ga.evolve(ga_population)
            best_ga_solution = min(ga_population, key=lambda x: x[1])
            self.aco.pheromone *= self.aco.decay
            self.aco.spread_pheronome([best_ga_solution], self.aco.pheromone, self.aco.a

        return aco_shortest_path

    def generate_ga_population(self, aco_solution):
        # Generate GA population from ACO solution
        ga_population = [(aco_solution[0], -1) for _ in range(self.ga.population_size)]
        return ga_population

# Example usage:
if __name__ == "__main__":
    distances = np.array([[np.inf, 2, 2, 5, 7],
                          [2, np.inf, 4, 8, 2],
                          [2, 4, np.inf, 1, 3],
                          [5, 8, 1, np.inf, 2],
                          [7, 2, 3, 2, np.inf]])

    aco_ga = ACOGA(distances, n_ants=5, decay=0.95, alpha=1, beta=2, ga_population_size=
    result = aco_ga.run()

    print("ACO-GA Combined Solution:", result)
```

```
ACO-GA Combined Solution: ([(0, 2), (2, 3), (3, 4), (4, 1)], 7.0)
```

In [2]:

```
import numpy as np
import re

def euclidean_distance(coord1, coord2):
    return np.sqrt((coord2[0] - coord1[0])**2 + (coord2[1] - coord1[1])**2)

def read_coordinates_from_file(file_path):
    coordinates = []
    with open(file_path, 'r') as file:
        for line in file:
            new_line = re.split(r'\s+', line.strip())
            if new_line[0].isdigit():
                id, x, y = new_line[0], float(new_line[1]), float(new_line[2])
                coordinates.append((x, y))
    return coordinates

# Specify the path to the file containing coordinates
#file_path = "burma14.tsp"
#file_path = "eil51.tsp"
#file_path = "berlin52.tsp"
file_path = "eil76.tsp"
#file_path = "lin105.tsp"
#file_path = "bier127.tsp"
#file_path = "gr137.tsp"
#file_path = "rat195.tsp"
#file_path = "lin318.tsp"
#file_path = "rat575.tsp"

# Read coordinates from the file
coordinates = read_coordinates_from_file(file_path)

# Create a distance matrix using NumPy array
num_points = len(coordinates)
```

```python
distance_matrix = np.zeros((num_points, num_points))

for i in range(num_points):
    for j in range(num_points):
        if i != j:
            distance_matrix[i, j] = euclidean_distance(coordinates[i], coordinates[j])
        else:
            distance_matrix[i, j] = np.inf

# Replace inf values with np.inf
distance_matrix = np.where(np.isinf(distance_matrix), np.inf, distance_matrix)

# Round the values in the distance array to 2 decimal places
distances = np.round(distance_matrix, 2)

print("Distance Matrix:")

# Print column indices
print("      ", end="")
for i in range(num_points):
    print(f"  {i:<6}", end="")
print()

# Print the matrix with row indices
for i in range(num_points):
    print(f"{i:2} |", end="")
    for value in distances[i]:
        print(f"{value:7.2f}", end=" ")
    print()

# ACOGA implementation using the read coordinates.
aco_ga = ACOGA(distances, n_ants=5, decay=0.95, alpha=1, beta=2, ga_population_size=400,
result = aco_ga.run()

best_path_indices = result[0]

print("Best Path Indices:", best_path_indices)
print("Best Path length:", np.round(result[1], 2))
```

```
Distance Matrix:
        0       1       2       3       4       5       6       7       8       9
10      11      12      13      14      15      16      17      18      19      20
21      22      23      24      25      26      27      28      29      30      31
32      33      34      35      36      37      38      39      40      41      42
43      44      45      46      47      48      49      50      51      52      53
54      55      56      57      58      59      60      61      62      63      64
65      66      67      68      69      70      71      72      73      74      75
 0 |    inf   14.56   23.02   26.42   33.06   16.28   39.60   40.22   37.22   47.54    5
4.20   31.78   42.06   53.15   40.05   14.04   24.60   36.40   47.71   44.72   23.77
9.85   12.53   25.81   42.30   30.61   35.11   14.32   30.27   21.38   54.74   31.00
8.06   33.29   43.28   34.18   38.64   50.61   38.83   29.12   11.18   10.63    6.71    2
6.02   29.12   35.23   28.86   26.02   18.87   34.71   18.38   35.78   48.10   48.85    4
9.48   16.28   43.29   42.05   63.78   45.69   21.26    8.25    8.25   18.38   55.57    6
1.03   30.48   19.42   33.29   46.17   40.72   40.16    5.39   18.11   23.43   25.46
 1 |  14.56     inf   24.21   12.73   19.92    8.54   27.78   26.87   34.48   40.20    4
3.38   25.02   27.51   40.46   26.08   18.03   18.25   40.36   34.06   32.31   15.26    1
6.40   25.08   33.62   42.49   20.62   20.62   10.05   16.00    7.00   50.25   30.41    1
0.44   19.80   30.61   24.08   26.40   41.48   34.53   24.74   25.63   24.19   21.19    2
6.63   14.56   21.93   17.80   13.00   26.83   36.62   14.76   21.63   36.36   34.44    5
1.11   30.02   29.02   34.23   50.99   35.61   20.00    8.49   16.49   29.70   46.17    5
0.57   18.36    7.28   26.08   34.99   31.14   34.01    9.22    7.21   11.70   14.56
 2 |  23.02   24.21     inf   26.00   42.20   16.28   29.43   34.00   14.87   28.32    3
9.45   15.23   42.20   42.72   46.07    9.00   12.04   16.28   41.11   54.64   39.41    3
2.39   19.72   14.14   19.42   20.02   35.74   32.20   36.36   29.07   32.57    8.06    1
6.76   29.43   34.37   48.10   49.20   33.42   17.49   10.30   29.41   31.58   26.48
3.00   32.65   30.15   41.73   36.12   11.40   12.53   10.00   33.73   36.06   46.17    2
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2.70 52.70 50.00 38.64 17.80 23.00 45.62 31.14 33.24 30.61 33.24 4
0.31 17.72 7.00 47.01 42.30 12.04 25.18 25.96 58.73 58.73 54.45 3
5.17 27.46 15.52 42.30 36.67 47.01 40.01 31.62 19.03 inf 20.00 4
6.84 58.52 31.62 15.30 16.55 53.76 54.42 44.65 44.20 65.60 13.93 1
5.13 18.03 29.41 53.24 50.22 52.15 20.22 43.28 39.92 25.00 22.67
53 | 48.85 34.44 46.17 22.80 24.19 34.71 19.24 12.65 44.78 36.80 2
6.83 33.53 7.81 16.76 17.72 46.27 34.13 59.91 8.60 27.02 36.24 4
9.65 57.49 60.03 55.04 26.48 13.89 40.61 21.21 28.30 50.21 46.57 4
2.72 17.03 15.00 33.62 26.93 32.02 41.59 38.08 60.01 58.59 55.54 4
6.53 20.25 16.03 31.06 27.59 55.08 54.12 38.05 13.34 20.00 inf 6
3.95 63.06 14.14 33.02 23.19 37.12 46.75 42.54 48.27 63.25 33.62 3
2.57 22.02 30.08 40.72 33.02 36.88 37.22 43.46 34.21 27.29 27.02
54 | 49.48 51.11 27.31 49.50 67.27 42.72 44.72 51.48 19.42 30.27 4
5.28 31.40 62.68 53.60 69.43 35.74 34.71 14.04 56.46 79.20 66.37 5
9.20 42.01 27.17 9.22 39.20 57.63 59.51 60.83 55.00 21.84 20.81 4
4.01 50.00 49.24 74.40 74.33 37.22 22.36 28.28 53.04 56.22 51.35 2
4.60 56.57 49.65 68.01 62.01 32.06 14.87 36.36 54.41 46.84 63.95
inf 45.18 69.81 31.62 60.30 85.28 69.08 53.85 41.23 65.19 40.00 4
7.04 44.82 46.40 77.18 83.55 81.40 26.93 49.04 58.31 44.60 42.43
55 | 16.28 30.02 25.00 40.26 49.25 28.46 50.61 52.92 39.45 53.26 6
3.25 38.95 56.89 64.50 56.01 18.60 33.02 31.14 60.54 61.00 39.85 2
3.32 5.83 18.03 40.52 40.82 49.82 30.36 46.01 37.01 56.80 32.25 2
0.40 46.49 55.01 50.29 54.92 57.98 42.44 34.66 10.00 14.21 11.66 2
7.46 44.28 48.10 45.12 42.19 14.32 32.28 26.93 49.73 58.52 63.06 4
5.18 inf 59.03 48.80 74.95 61.68 35.51 24.52 14.87 21.93 62.94 6
9.35 42.54 32.98 48.75 62.36 56.65 45.45 21.02 34.37 36.06 37.16
56 | 43.29 29.02 47.54 21.54 12.21 32.76 27.46 20.59 50.45 46.32 3
9.29 38.42 8.54 30.15 4.24 44.91 36.24 63.06 21.21 13.04 25.24 4
1.44 54.01 60.17 60.61 30.61 12.21 31.95 13.04 22.02 59.64 50.25 3
9.05 19.85 25.08 20.25 13.00 42.95 48.10 41.88 53.94 51.66 49.65 4
8.75 15.30 20.52 19.21 18.03 54.13 57.80 37.95 15.56 31.62 14.14 6
9.81 59.03 inf 41.40 37.34 23.02 35.81 35.69 45.10 54.63 45.54 4
5.71 25.00 27.66 27.46 19.03 22.80 44.60 38.12 25.96 26.93 28.18
57 | 42.05 34.23 24.21 25.50 42.72 26.93 14.14 21.21 14.04 6.00 1
5.81 10.30 33.30 22.20 42.19 30.61 17.46 31.26 25.06 52.84 47.17 4
9.04 43.19 37.12 23.35 14.04 30.02 44.28 36.06 34.13 18.36 19.31 3
4.01 22.36 18.03 51.92 49.24 9.22 10.00 14.14 51.31 52.35 47.51 2
2.47 31.62 21.10 46.10 39.81 35.61 25.32 23.71 26.08 15.30 33.02 3
1.62 48.80 41.40 inf 30.27 60.93 54.15 41.23 36.06 60.42 14.14 2
0.81 18.68 27.07 56.89 58.14 58.19 5.00 38.28 40.00 23.00 20.00
58 | 63.78 50.99 52.55 38.29 46.49 47.63 24.41 24.21 44.28 30.07 1
5.03 37.34 30.08 10.63 40.79 56.44 42.06 61.52 17.89 50.16 57.25 6
7.36 69.12 66.41 53.00 34.13 33.54 59.41 42.05 46.62 40.80 49.24 5
6.22 31.24 20.52 56.32 50.01 23.09 40.20 42.38 74.65 74.33 70.29 5
1.55 39.45 29.07 52.92 48.30 63.56 55.58 48.02 30.53 16.55 23.19 6
0.30 74.95 37.34 30.27 inf 60.30 67.23 59.46 60.46 80.66 20.88 1
5.26 33.30 44.55 63.25 56.14 60.02 35.23 58.73 53.25 40.36 38.42
59 | 45.69 35.61 59.41 36.36 18.36 43.14 48.08 41.98 66.85 66.48 6
1.66 55.23 31.06 53.04 20.10 53.60 50.61 75.69 44.05 10.20 21.93 3

9.05 58.18 69.07 76.22 47.89 31.32 31.38 25.06 30.41 79.20 64.54 4
5.49 38.63 46.87 11.66 11.70 64.29 65.51 57.20 53.60 50.01 50.29 6
1.52 29.53 40.16 17.80 23.35 62.13 71.45 49.50 35.44 53.76 37.12 8
5.28 61.68 23.02 60.93 60.30 inf 28.07 37.58 51.11 49.01 67.47 6
8.36 42.49 38.95 14.00 4.47 5.10 63.06 42.06 28.84 40.80 43.27
60 | 21.26 20.00 41.79 30.36 23.60 28.16 46.17 43.38 53.94 60.13 6
1.98 45.01 38.95 57.25 31.62 33.54 38.12 56.82 49.40 31.05 10.63 1
2.21 33.30 47.01 61.03 40.31 33.84 10.05 25.61 21.19 70.18 49.04 2
5.08 36.77 47.93 18.44 25.63 61.00 54.33 44.41 26.40 22.47 23.85 4
4.60 27.78 39.00 16.64 19.21 40.00 54.23 33.73 36.72 54.42 46.75 6
9.08 35.51 35.81 54.15 67.23 28.07 inf 15.23 28.84 21.02 65.51 6
9.26 37.11 27.07 14.14 30.07 23.02 54.01 20.12 14.56 31.26 34.23
61 | 8.25 8.49 26.57 21.21 25.00 14.32 36.06 35.36 39.20 47.07 5
1.48 31.40 35.34 48.92 32.25 18.36 24.19 41.68 42.52 36.50 15.65
8.06 20.62 32.53 45.88 28.23 28.65 6.40 22.80 14.32 56.01 33.96
9.85 28.28 39.05 26.00 30.41 49.04 40.00 30.00 18.25 16.16 14.04 2
9.41 22.36 30.41 20.62 18.03 25.46 39.00 19.03 30.00 44.65 42.54 5
3.85 24.52 35.69 41.23 59.46 37.58 15.23 inf 14.14 21.21 53.85 5
8.59 26.63 15.26 25.61 37.95 32.65 40.31 5.00 10.00 19.72 22.36
62 | 8.25 16.49 15.03 25.50 36.40 13.60 36.06 38.08 29.61 41.18 4
9.50 25.81 42.30 49.93 42.43 6.08 19.10 28.23 45.69 48.70 29.41 1
8.03 9.22 18.38 34.13 26.40 35.23 20.52 32.25 23.35 47.30 23.09
6.08 31.62 40.31 39.45 42.72 45.00 31.62 22.36 15.26 16.76 11.70 1
8.03 30.00 33.24 33.54 29.41 11.31 26.48 12.73 34.93 44.20 48.27 4
1.23 14.87 45.10 36.06 60.46 51.11 28.84 14.14 inf 25.50 50.00 5
5.97 27.73 18.25 39.70 50.99 46.32 33.54 9.22 22.36 21.19 22.36
63 | 18.38 29.70 40.45 42.43 42.72 34.13 57.01 56.57 55.11 65.92 7
2.11 50.16 55.76 70.09 50.70 31.58 42.95 51.35 63.70 51.79 30.08 1
3.60 23.35 38.83 59.03 48.55 49.41 22.83 42.54 35.00 72.78 48.51 2
6.40 49.50 60.21 39.32 46.10 68.88 57.01 47.43 12.37 9.00 14.04 4
3.42 43.01 51.62 36.40 36.67 33.14 51.00 36.77 51.09 65.60 63.25 6
5.19 21.93 54.63 60.42 80.66 49.01 21.02 21.21 25.50 inf 73.82 7
9.08 47.63 36.24 35.01 51.09 44.00 58.52 22.47 29.15 40.61 43.01
64 | 55.57 46.17 38.29 35.36 50.25 39.81 20.00 25.50 26.40 10.77
7.07 24.21 37.00 17.69 47.54 44.69 31.06 43.32 25.06 58.24 57.31 6
1.85 57.31 50.77 33.54 25.63 36.35 56.04 44.05 44.55 19.92 32.76 4
7.51 30.00 20.62 60.13 55.90 5.00 22.36 28.28 65.22 66.04 61.29 3
6.40 40.00 28.02 55.00 49.04 49.68 37.70 37.44 32.25 13.93 33.62 4
0.00 62.94 45.54 14.14 20.88 67.47 65.51 53.85 50.00 73.82 inf
7.28 28.44 38.90 66.00 64.03 65.62 18.03 51.43 50.99 34.48 31.62
65 | 61.03 50.57 45.00 38.90 52.04 44.94 23.09 27.07 33.62 18.03
7.28 30.41 37.34 15.81 48.26 50.91 36.88 50.60 24.52 58.69 60.42 6
6.65 63.66 57.80 40.79 30.53 38.05 60.17 46.27 48.08 26.31 39.82 5
3.01 32.76 22.09 62.07 57.08 11.66 29.55 34.83 71.06 71.61 67.01 4
3.27 42.58 30.59 57.43 51.79 56.40 44.94 43.28 34.13 15.13 32.57 4
7.04 69.35 45.71 20.81 15.26 68.36 69.26 58.59 55.97 79.08 7.28
inf 32.31 43.38 68.36 64.63 67.03 25.06 56.60 54.71 38.91 36.24
66 | 30.48 18.36 24.19 7.00 24.17 14.42 9.43 10.44 25.50 24.52 2
5.08 13.45 18.38 22.67 24.76 24.74 12.17 38.63 18.03 35.00 29.02 3
4.67 36.77 38.01 35.61 5.66 12.81 27.86 17.46 16.12 36.77 25.50 2
3.02 5.39 12.81 33.24 30.89 24.08 23.43 17.00 41.40 41.04 37.01 2
4.74 13.00 6.00 27.46 21.21 33.24 33.11 16.28 9.85 18.03 22.02 4
4.82 42.54 25.00 18.68 33.30 42.49 37.11 26.63 27.73 47.63 28.44 3
2.31 inf 11.40 38.33 39.96 39.56 20.59 25.46 22.56 7.07 5.39
67 | 19.42 7.28 20.81 7.28 21.40 5.10 20.81 20.81 28.64 33.06 3
6.24 18.25 24.08 33.94 25.63 17.26 12.08 37.01 28.30 33.84 20.88 2
3.32 27.46 32.57 37.44 13.34 17.03 17.26 15.65 8.60 43.57 25.61 1
2.65 13.89 24.04 28.02 28.43 34.21 28.16 18.79 30.53 29.83 26.08 2
2.67 12.37 15.81 21.63 15.62 26.48 32.53 10.82 16.76 29.41 30.08 4
6.40 32.98 27.66 27.07 44.55 38.95 27.07 15.26 18.25 36.24 38.90 4
3.38 11.40 inf 31.38 37.54 35.00 27.17 14.21 13.15 4.47 7.28
68 | 33.29 26.08 50.22 31.40 16.76 34.48 46.00 41.30 60.01 62.80 6
1.20 49.34 33.24 54.34 23.32 43.19 43.46 66.22 45.61 18.87 10.82 2
5.63 45.79 58.05 68.48 42.95 30.41 19.21 22.09 23.09 74.46 56.44 3
4.66 36.00 46.27 7.21 14.87 62.07 59.46 50.16 40.16 36.40 37.16 5
2.70 26.00 38.01 11.00 17.12 50.99 62.68 40.82 34.23 53.24 40.72 7

```
7.18   48.75   27.46   56.89   63.25   14.00   14.14   25.61   39.70   35.01   66.00   6
8.36   38.33   31.38     inf   16.49    9.06   57.97   30.48   18.87   34.48   37.36
69 |  46.17   34.99   58.26   34.21   16.28   42.01   44.94   38.60   64.82   63.56   5
8.05   53.01   27.29   49.16   16.49   53.00   48.84   74.52   40.20    6.00   22.56   4
0.31   58.52   68.60   74.41   45.49   28.23   32.02   22.80   29.21   76.48   62.94   4
5.18   35.78   43.42   12.17    9.22   61.03   63.25   55.32   54.74   51.35   51.20   6
0.21   27.20   37.16   17.46   22.20   61.77   70.04   48.27   32.31   50.22   33.02   8
3.55   62.36   19.03   58.14   56.14    4.47   30.07   37.95   50.99   51.09   64.03   6
4.63   39.96   37.54   16.49     inf    7.62   60.54   42.15   28.64   38.95   41.23
70 |  40.72   31.14   55.17   33.11   15.52   38.95   45.89   40.20   63.29   63.89   6
0.13   51.88   30.15   52.09   19.24   49.04   46.87   71.42   43.10   11.40   17.00   3
3.96   53.23   64.40   72.42   44.78   29.27   26.40   22.14   26.40   76.32   60.61   4
0.80   36.14   45.18    7.07   10.05   62.17   62.18   53.54   48.51   44.91   45.22   5
7.38   26.57   37.85   13.45   19.42   57.43   67.36   45.34   33.38   52.15   36.88   8
1.40   56.65   22.80   58.19   60.02    5.10   23.02   32.65   46.32   44.00   65.62   6
7.03   39.56   35.00    9.06    7.62     inf   60.01   37.22   24.21   37.22   39.82
71 |  40.16   34.01   20.52   26.93   44.72   26.08   18.03   25.00    9.06    7.81   2
0.62    9.00   36.80   27.17   45.00   27.78   16.12   26.31   29.55   55.47   47.85   4
7.85   40.00   32.76   18.44   15.23   32.80   44.00   38.01   34.93   16.49   14.76   3
2.28   25.00   22.36   53.49   51.48   13.42    5.00   11.18   48.76   50.16   45.19   1
8.44   33.54   24.08   47.43   41.11   31.83   20.40   21.84   29.07   20.22   37.22   2
6.93   45.45   44.60    5.00   35.23   63.06   54.01   40.31   33.54   58.52   18.03   2
5.06   20.59   27.17   57.97   60.54   60.01     inf   36.88   40.31   23.54   20.62
72 |   5.39    9.22   21.84   21.10   28.28   11.66   34.71   35.00   35.01   43.97   4
9.65   28.16   36.69   48.10   35.00   13.42   20.88   36.72   42.44   40.26   20.25   1
1.05   16.49   27.59   41.23   26.08   29.73   11.31   25.08   16.12   52.15   29.43
5.10   28.02   38.21   30.41   34.21   46.52   36.12   26.17   16.55   15.62   12.08   2
4.74   23.77   30.00   24.70   21.21   20.52   34.18   15.13   30.41   43.28   43.46   4
9.04   21.02   38.12   38.28   58.73   42.06   20.12    5.00    9.22   22.47   51.43   5
6.60   25.46   14.21   30.48   42.15   37.22   36.88     inf   13.60   18.38   20.62
73 |  18.11    7.21   31.40   15.81   15.00   15.65   31.62   29.15   41.44   46.00   4
7.43   31.40   26.63   43.05   22.36   24.84   25.00   47.51   35.61   26.68    8.06   1
5.65   30.08   40.22   49.65   26.02   20.52    6.40   13.42    6.71   56.72   37.59   1
6.64   22.36   33.54   17.20   20.62   46.53   41.23   31.62   28.16   25.71   24.02   3
3.84   14.14   24.60   11.18    8.06   33.29   43.83   21.95   22.80   39.92   34.21   5
8.31   34.37   25.96   40.00   53.25   28.84   14.56   10.00   22.36   29.15   50.99   5
4.71   22.56   13.15   18.87   28.64   24.21   40.31   13.60     inf   17.00   20.00
74 |  23.43   11.70   20.62    5.39   22.67    7.62   16.40   17.00   26.08   29.00   3
1.76   14.87   22.09   29.73   25.55   19.03    9.90   36.36   24.60   34.71   24.33   2
7.78   30.36   33.54   35.47    9.06   15.30   21.59   16.28   11.40   40.02   24.08   1
6.12   10.44   19.85   30.41   29.73   29.83   25.08   16.40   34.41   33.97   30.00   2
1.95   12.21   12.08   24.17   17.89   28.02   31.40   11.18   14.04   25.00   27.29   4
4.60   36.06   26.93   23.00   40.36   40.80   31.26   19.72   21.19   40.61   34.48   3
8.91    7.07    4.47   34.48   38.95   37.22   23.54   18.38   17.00     inf    3.00
75 |  25.46   14.56   19.65    7.07   25.00    9.22   14.14   15.81   23.60   26.00   2
9.15   12.08   22.56   27.80   27.20   19.42    8.06   34.89   23.41   36.77   27.29   3
0.41   31.38   33.14   33.24    6.08   16.16   24.52   18.44   14.32   37.11   22.20   1
7.80   10.00   18.03   33.11   32.02   26.93   22.36   14.14   36.24   36.07   31.89   2
0.62   14.14   11.18   26.93   20.62   28.07   29.68   11.05   14.14   22.67   27.02   4
2.43   37.16   28.18   20.00   38.42   43.27   34.23   22.36   22.36   43.01   31.62   3
6.24    5.39    7.28   37.36   41.23   39.82   20.62   20.62   20.00    3.00     inf
Best Path Indices: [(1, 73), (73, 29), (29, 47), (47, 28), (28, 44), (44, 26), (26, 51),
(51, 33), (33, 45), (45, 7), (7, 34), (34, 6), (6, 52), (52, 66), (66, 3), (3, 74), (74,
67), (67, 5), (5, 0), (0, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 16), (16, 3
9), (39, 11), (11, 25), (25, 75), (75, 2), (2, 43), (43, 31), (31, 8), (8, 38), (38, 7
1), (71, 57), (57, 9), (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 1
8), (18, 53), (53, 12), (12, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 5
9), (59, 70), (70, 35), (35, 46), (46, 20), (20, 68), (68, 60), (60, 27), (27, 61), (61,
21), (21, 42), (42, 40), (40, 41), (41, 63), (63, 55), (55, 22), (22, 48), (48, 23), (2
3, 17), (17, 49), (49, 24), (24, 54), (54, 30)]
Best Path length: 576.51
```

In [3]:

```
import numpy as np
import re
```

```python
def euclidean_distance(coord1, coord2):
    return np.sqrt((coord2[0] - coord1[0])**2 + (coord2[1] - coord1[1])**2)

def read_coordinates_from_file(file_path):
    coordinates = []
    with open(file_path, 'r') as file:
        for line in file:
            new_line = re.split(r'\s+', line.strip())
            if new_line[0].isdigit():
                id, x, y = new_line[0], float(new_line[1]), float(new_line[2])
                coordinates.append((x, y))
    return coordinates

# Specify the path to the file containing coordinates
#file_path = "burma14.tsp"
#file_path = "eil51.tsp"
#file_path = "berlin52.tsp"
file_path = "eil76.tsp"
#file_path = "lin105.tsp"
#file_path = "bier127.tsp"
#file_path = "gr137.tsp"
#file_path = "rat195.tsp"
#file_path = "lin318.tsp"
#file_path = "rat575.tsp"

# Read coordinates from the file
coordinates = read_coordinates_from_file(file_path)

# Create a distance matrix using NumPy array
num_points = len(coordinates)
distance_matrix = np.zeros((num_points, num_points))

for i in range(num_points):
    for j in range(num_points):
        if i != j:
            distance_matrix[i, j] = euclidean_distance(coordinates[i], coordinates[j])
        else:
            distance_matrix[i, j] = np.inf

# Replace inf values with np.inf
distance_matrix = np.where(np.isinf(distance_matrix), np.inf, distance_matrix)

# Round the values in the distance array to 2 decimal places
distances = np.round(distance_matrix, 2)

print("Distance Matrix:")

# Print column indices
print("      ", end="")
for i in range(num_points):
    print(f"  {i:<6}", end="")
print()

# Print the matrix with row indices
for i in range(num_points):
    print(f"{i:2} |", end="")
    for value in distances[i]:
        print(f"{value:7.2f}", end=" ")
    print()

# Run ACOGA with 30 different random seeds
for run in range(30):
    # Set a different random seed for each run
    random_seed = run + 1
    np.random.seed(random_seed)
```

```python
    # ACOGA implementation using the read coordinates.
    aco_ga = ACOGA(distances, n_ants=5, decay=0.95, alpha=1, beta=2, ga_population_size=
    result = aco_ga.run()

    best_path_indices = result[0]

    print(f"\nRun {run + 1} - Best Path Indices: {best_path_indices}")
    print(f"Run {run + 1} - Best Path Length: {np.round(result[1], 2)}")
```

```
Distance Matrix:
        0       1       2       3       4       5       6       7       8       9
10      11      12      13      14      15      16      17      18      19      20
21      22      23      24      25      26      27      28      29      30      31
32      33      34      35      36      37      38      39      40      41      42
43      44      45      46      47      48      49      50      51      52      53
54      55      56      57      58      59      60      61      62      63      64
65      66      67      68      69      70      71      72      73      74      75
 0 |    inf   14.56   23.02   26.42   33.06   16.28   39.60   40.22   37.22   47.54   5
4.20   31.78   42.06   53.15   40.05   14.04   24.60   36.40   47.71   44.72   23.77
9.85   12.53   25.81   42.30   30.61   35.11   14.32   30.27   21.38   54.74   31.00
8.06   33.29   43.28   34.18   38.64   50.61   38.83   29.12   11.18   10.63    6.71   2
6.02   29.12   35.23   28.86   26.02   18.87   34.71   18.38   35.78   48.10   48.85   4
9.48   16.28   43.29   42.05   63.78   45.69   21.26    8.25    8.25   18.38   55.57   6
1.03   30.48   19.42   33.29   46.17   40.72   40.16    5.39   18.11   23.43   25.46
 1 |  14.56     inf   24.21   12.73   19.92    8.54   27.78   26.87   34.48   40.20   4
3.38   25.02   27.51   40.46   26.08   18.03   18.25   40.36   34.06   32.31   15.26   1
6.40   25.08   33.62   42.49   20.62   20.62   10.05   16.00    7.00   50.25   30.41   1
0.44   19.80   30.61   24.08   26.40   41.48   34.53   24.74   25.63   24.19   21.19   2
6.63   14.56   21.93   17.80   13.00   26.83   36.62   14.76   21.63   36.36   34.44   5
1.11   30.02   29.02   34.23   50.99   35.61   20.00    8.49   16.49   29.70   46.17   5
0.57   18.36    7.28   26.08   34.99   31.14   34.01    9.22    7.21   11.70   14.56
 2 |  23.02   24.21     inf   26.00   42.20   16.28   29.43   34.00   14.87   28.32   3
9.45   15.23   42.20   42.72   46.07    9.00   12.04   16.28   41.11   54.64   39.41   3
2.39   19.72   14.14   19.42   20.02   35.74   32.20   36.36   29.07   32.57    8.06   1
6.76   29.43   34.37   48.10   49.20   33.42   17.49   10.30   29.41   31.58   26.48
3.00   32.65   30.15   41.73   36.12   11.40   12.53   10.00   33.73   36.06   46.17   2
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5.00   24.19   20.81   50.22   58.26   55.17   20.52   21.84   31.40   20.62   19.65
 3 |  26.42   12.73   26.00     inf   18.03   12.04   15.81   14.14   30.61   31.40   3
1.62   18.87   17.00   27.80   20.25   24.02   15.00   41.68   21.40   29.70   22.02   2
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8.90    7.00    7.28   31.40   34.21   33.11   26.93   21.10   15.81    5.39    7.07
 4 |  33.06   19.92   42.20   18.03     inf   26.08   30.41   25.00   48.60   48.38   4
5.00   36.89   16.55   37.66    8.06   37.58   32.56   58.41   28.86   12.53   13.04   2
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4.05   11.18   22.36    7.07    7.07   46.62   53.81   32.20   18.03   37.00   24.19   6
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2.04   24.17   21.40   16.76   16.28   15.52   44.72   28.28   15.00   22.67   25.00
 5 |  16.28    8.54   16.28   12.04   26.08     inf   23.35   24.60   25.96   32.76   3
8.01   17.12   29.02   37.01   30.68   12.17   10.00   32.56   32.20   38.59   23.71   2
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 6 |  39.60   27.78   29.43   15.81   30.41   23.35     inf    7.07   25.63   18.87   1
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3.09    9.43   20.81   46.00   44.94   45.89   18.03   34.71   31.62   16.40   14.14
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64 | 55.57 46.17 38.29 35.36 50.25 39.81 20.00 25.50 26.40 10.77
7.07 24.21 37.00 17.69 47.54 44.69 31.06 43.32 25.06 58.24 57.31
61.85 57.31 50.77 33.54 25.63 36.35 56.04 44.05 44.55 19.92 32.76
47.51 30.00 20.62 60.13 55.90 5.00 22.36 28.28 65.22 66.04 61.29
36.40 40.00 28.02 55.00 49.04 49.68 37.70 37.44 32.25 13.93 33.62
40.00 62.94 45.54 14.14 20.88 67.47 65.51 53.85 50.00 73.82 inf
7.28 28.44 38.90 66.00 64.03 65.62 18.03 51.43 50.99 34.48 31.62
65 | 61.03 50.57 45.00 38.90 52.04 44.94 23.09 27.07 33.62 18.03
7.28 30.41 37.34 15.81 48.26 50.91 36.88 50.60 24.52 58.69 60.42
66.65 63.66 57.80 40.79 30.53 38.05 60.17 46.27 48.08 26.31 39.82
53.01 32.76 22.09 62.07 57.08 11.66 29.55 34.83 71.06 71.61 67.01
43.27 42.58 30.59 57.43 51.79 56.40 44.94 43.28 34.13 15.13 32.57
47.04 69.35 45.71 20.81 15.26 68.36 69.26 58.59 55.97 79.08 7.28
inf 32.31 43.38 68.36 64.63 67.03 25.06 56.60 54.71 38.91 36.24
66 | 30.48 18.36 24.19 7.00 24.17 14.42 9.43 10.44 25.50 24.52 2
5.08 13.45 18.38 22.67 24.76 24.74 12.17 38.63 18.03 35.00 29.02 3
4.67 36.77 38.01 35.61 5.66 12.81 27.86 17.46 16.12 36.77 25.50 2
3.02 5.39 12.81 33.24 30.89 24.08 23.43 17.00 41.40 41.04 37.01 2
4.74 13.00 6.00 27.46 21.21 33.24 33.11 16.28 9.85 18.03 22.02 4
4.82 42.54 25.00 18.68 33.30 42.49 37.11 26.63 27.73 47.63 28.44 3
2.31 inf 11.40 38.33 39.96 39.56 20.59 25.46 22.56 7.07 5.39
67 | 19.42 7.28 20.81 7.28 21.40 5.10 20.81 20.81 28.64 33.06 3
6.24 18.25 24.08 33.94 25.63 17.26 12.08 37.01 28.30 33.84 20.88 2
3.32 27.46 32.57 37.44 13.34 17.03 17.26 15.65 8.60 43.57 25.61 1
2.65 13.89 24.04 28.02 28.43 34.21 28.16 18.79 30.53 29.83 26.08 2
2.67 12.37 15.81 21.63 15.62 26.48 32.53 10.82 16.76 29.41 30.08 4
6.40 32.98 27.66 27.07 44.55 38.95 27.07 15.26 18.25 36.24 38.90 4
3.38 11.40 inf 31.38 37.54 35.00 27.17 14.21 13.15 4.47 7.28
68 | 33.29 26.08 50.22 31.40 16.76 34.48 46.00 41.30 60.01 62.80 6
1.20 49.34 33.24 54.34 23.32 43.19 43.46 66.22 45.61 18.87 10.82 2
5.63 45.79 58.05 68.48 42.95 30.41 19.21 22.09 23.09 74.46 56.44 3
4.66 36.00 46.27 7.21 14.87 62.07 59.46 50.16 40.16 36.40 37.16 5
2.70 26.00 38.01 11.00 17.12 50.99 62.68 40.82 34.23 53.24 40.72 7
7.18 48.75 27.46 56.89 63.25 14.00 14.14 25.61 39.70 35.01 66.00 6
8.36 38.33 31.38 inf 16.49 9.06 57.97 30.48 18.87 34.48 37.36
69 | 46.17 34.99 58.26 34.21 16.28 42.01 44.94 38.60 64.82 63.56 5
8.05 53.01 27.29 49.16 16.49 53.00 48.84 74.52 40.20 6.00 22.56 4
0.31 58.52 68.60 74.41 45.49 28.23 32.02 22.80 29.21 76.48 62.94 4
5.18 35.78 43.42 12.17 9.22 61.03 63.25 55.32 54.74 51.35 51.20 6
0.21 27.20 37.16 17.46 22.20 61.77 70.04 48.27 32.31 50.22 33.02 8
3.55 62.36 19.03 58.14 56.14 4.47 30.07 37.95 50.99 51.09 64.03 6
4.63 39.96 37.54 16.49 inf 7.62 60.54 42.15 28.64 38.95 41.23
70 | 40.72 31.14 55.17 33.11 15.52 38.95 45.89 40.20 63.29 63.89 6
0.13 51.88 30.15 52.09 19.24 49.04 46.87 71.42 43.10 11.40 17.00 3
3.96 53.23 64.40 72.42 44.78 29.27 26.40 22.14 26.40 76.32 60.61 4
0.80 36.14 45.18 7.07 10.05 62.17 62.18 53.54 48.51 44.91 45.22 5
7.38 26.57 37.85 13.45 19.42 57.43 67.36 45.34 33.38 52.15 36.88 8
1.40 56.65 22.80 58.19 60.02 5.10 23.02 32.65 46.32 44.00 65.62 6
7.03 39.56 35.00 9.06 7.62 inf 60.01 37.22 24.21 37.22 39.82
71 | 40.16 34.01 20.52 26.93 44.72 26.08 18.03 25.00 9.06 7.81 2
0.62 9.00 36.80 27.17 45.00 27.78 16.12 26.31 29.55 55.47 47.85 4
7.85 40.00 32.76 18.44 15.23 32.80 44.00 38.01 34.93 16.49 14.76 3
2.28 25.00 22.36 53.49 51.48 13.42 5.00 11.18 48.76 50.16 45.19 1
8.44 33.54 24.08 47.43 41.11 31.83 20.40 21.84 29.07 20.22 37.22 2
6.93 45.45 44.60 5.00 35.23 63.06 54.01 40.31 33.54 58.52 18.03 2
5.06 20.59 27.17 57.97 60.54 60.01 inf 36.88 40.31 23.54 20.62
72 | 5.39 9.22 21.84 21.10 28.28 11.66 34.71 35.00 35.01 43.97 4
9.65 28.16 36.69 48.10 35.00 13.42 20.88 36.72 42.44 40.26 20.25 1
1.05 16.49 27.59 41.23 26.08 29.73 11.31 25.08 16.12 52.15 29.43
5.10 28.02 38.21 30.41 34.21 46.52 36.12 26.17 16.55 15.62 12.08
24.74 23.77 30.00 24.70 21.21 20.52 34.18 15.13 30.41 43.28 43.46
49.04 21.02 38.12 38.28 58.73 42.06 20.12 5.00 9.22 22.47 51.43
56.60 25.46 14.21 30.48 42.15 37.22 36.88 inf 13.60 18.38 20.62

```
73 |  18.11    7.21   31.40   15.81   15.00   15.65   31.62   29.15   41.44   46.00   4
7.43   31.40   26.63   43.05   22.36   24.84   25.00   47.51   35.61   26.68    8.06   1
5.65   30.08   40.22   49.65   26.02   20.52    6.40   13.42    6.71   56.72   37.59   1
6.64   22.36   33.54   17.20   20.62   46.53   41.23   31.62   28.16   25.71   24.02   3
3.84   14.14   24.60   11.18    8.06   33.29   43.83   21.95   22.80   39.92   34.21   5
8.31   34.37   25.96   40.00   53.25   28.84   14.56   10.00   22.36   29.15   50.99   5
4.71   22.56   13.15   18.87   28.64   24.21   40.31   13.60     inf   17.00   20.00
74 |  23.43   11.70   20.62    5.39   22.67    7.62   16.40   17.00   26.08   29.00   3
1.76   14.87   22.09   29.73   25.55   19.03    9.90   36.36   24.60   34.71   24.33   2
7.78   30.36   33.54   35.47    9.06   15.30   21.59   16.28   11.40   40.02   24.08   1
6.12   10.44   19.85   30.41   29.73   29.83   25.08   16.40   34.41   33.97   30.00   2
1.95   12.21   12.08   24.17   17.89   28.02   31.40   11.18   14.04   25.00   27.29   4
4.60   36.06   26.93   23.00   40.36   40.80   31.26   19.72   21.19   40.61   34.48   3
8.91    7.07    4.47   34.48   38.95   37.22   23.54   18.38   17.00     inf    3.00
75 |  25.46   14.56   19.65    7.07   25.00    9.22   14.14   15.81   23.60   26.00   2
9.15   12.08   22.56   27.80   27.20   19.42    8.06   34.89   23.41   36.77   27.29   3
0.41   31.38   33.14   33.24    6.08   16.16   24.52   18.44   14.32   37.11   22.20   1
7.80   10.00   18.03   33.11   32.02   26.93   22.36   14.14   36.24   36.07   31.89   2
0.62   14.14   11.18   26.93   20.62   28.07   29.68   11.05   14.14   22.67   27.02   4
2.43   37.16   28.18   20.00   38.42   43.27   34.23   22.36   22.36   43.01   31.62   3
6.24    5.39    7.28   37.36   41.23   39.82   20.62   20.62   20.00    3.00     inf
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Run 1 - Best Path Indices: [(2, 43), (43, 31), (31, 8), (8, 38), (38, 30), (30, 24), (2
4, 54), (54, 17), (17, 49), (49, 23), (23, 48), (48, 22), (22, 55), (55, 40), (40, 41),
 (41, 42), (42, 0), (0, 21), (21, 63), (63, 60), (60, 68), (68, 35), (35, 70), (70, 59),
 (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 12), (12, 53), (53, 18),
 (18, 34), (34, 6), (6, 7), (7, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28),
 (28, 47), (47, 46), (46, 20), (20, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 6
2), (62, 15), (15, 50), (50, 5), (5, 67), (67, 1), (1, 29), (29, 3), (3, 74), (74, 75),
 (75, 66), (66, 25), (25, 16), (16, 39), (39, 11), (11, 71), (71, 57), (57, 9), (9, 37),
 (37, 64), (64, 65), (65, 10), (10, 52), (52, 13), (13, 58)]
Run 1 - Best Path Length: 549.72

Run 2 - Best Path Indices: [(4, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 35),
 (35, 46), (46, 47), (47, 28), (28, 44), (44, 3), (3, 29), (29, 73), (73, 27), (27, 60),
 (60, 21), (21, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 5), (5, 67),
 (67, 74), (74, 75), (75, 66), (66, 25), (25, 11), (11, 39), (39, 16), (16, 43), (43,
 2), (2, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 9), (9, 37), (37, 64), (64, 1
0), (10, 65), (65, 58), (58, 13), (13, 52), (52, 6), (6, 34), (34, 7), (7, 45), (45, 3
3), (33, 51), (51, 26), (26, 12), (12, 53), (53, 18), (18, 14), (14, 56), (56, 68), (68,
 20), (20, 1), (1, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 22), (22, 55), (55, 4
8), (48, 23), (23, 49), (49, 17), (17, 24), (24, 54), (54, 30)]
Run 2 - Best Path Length: 602.69

Run 3 - Best Path Indices: [(2, 43), (43, 39), (39, 11), (11, 25), (25, 16), (16, 50),
 (50, 5), (5, 1), (1, 67), (67, 75), (75, 74), (74, 3), (3, 44), (44, 28), (28, 4), (4,
 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 68), (68, 35), (35, 46), (46, 20), (2
0, 47), (47, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15),
 (15, 48), (48, 23), (23, 17), (17, 49), (49, 31), (31, 8), (8, 38), (38, 71), (71, 57),
 (57, 9), (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 52), (52, 6),
 (6, 34), (34, 7), (7, 18), (18, 53), (53, 12), (12, 26), (26, 51), (51, 33), (33, 45),
 (45, 66), (66, 56), (56, 14), (14, 60), (60, 21), (21, 0), (0, 42), (42, 40), (40, 41),
 (41, 63), (63, 55), (55, 22), (22, 24), (24, 54), (54, 30)]
Run 3 - Best Path Length: 610.23

Run 4 - Best Path Indices: [(0, 42), (42, 41), (41, 40), (40, 22), (22, 55), (55, 48),
 (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71),
 (71, 38), (38, 8), (8, 31), (31, 43), (43, 2), (2, 15), (15, 62), (62, 32), (32, 72),
 (72, 61), (61, 27), (27, 73), (73, 29), (29, 1), (1, 67), (67, 5), (5, 50), (50, 16),
 (16, 39), (39, 11), (11, 25), (25, 75), (75, 74), (74, 3), (3, 44), (44, 28), (28, 47),
 (47, 46), (46, 20), (20, 60), (60, 21), (21, 63), (63, 68), (68, 35), (35, 70), (70, 5
9), (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 12), (12, 53), (53, 1
8), (18, 34), (34, 7), (7, 45), (45, 33), (33, 66), (66, 6), (6, 52), (52, 13), (13, 5
8), (58, 65), (65, 10), (10, 37), (37, 64), (64, 51), (51, 26)]
Run 4 - Best Path Length: 593.52
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Run 5 - Best Path Indices: [(4, 56), (56, 14), (14, 53), (53, 18), (18, 12), (12, 3),
 (3, 74), (74, 75), (75, 66), (66, 25), (25, 11), (11, 39), (39, 16), (16, 50), (50, 5),
 (5, 67), (67, 1), (1, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62),
 (62, 15), (15, 2), (2, 43), (43, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 9),
 (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 52), (52, 34), (34, 6),
 (6, 7), (7, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 20),
 (20, 46), (46, 35), (35, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 68), (68, 6
0), (60, 21), (21, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 55), (55, 22), (22, 4
8), (48, 23), (23, 49), (49, 17), (17, 24), (24, 54), (54, 30)]
Run 5 - Best Path Length: 576.0

Run 6 - Best Path Indices: [(0, 42), (42, 40), (40, 41), (41, 63), (63, 21), (21, 61),
 (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 23), (23, 17), (17, 49), (49, 2
4), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 31), (31, 4
3), (43, 2), (2, 39), (39, 11), (11, 25), (25, 66), (66, 33), (33, 45), (45, 7), (7, 3
4), (34, 6), (6, 52), (52, 13), (13, 58), (58, 65), (65, 10), (10, 64), (64, 37), (37, 1
8), (18, 53), (53, 12), (12, 26), (26, 51), (51, 44), (44, 28), (28, 47), (47, 46), (46,
 20), (20, 73), (73, 29), (29, 1), (1, 67), (67, 5), (5, 50), (50, 16), (16, 75), (75, 7
4), (74, 3), (3, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 59), (59, 7
0), (70, 35), (35, 68), (68, 60), (60, 27), (27, 55), (55, 22)]
Run 6 - Best Path Length: 588.41

Run 7 - Best Path Indices: [(3, 74), (74, 75), (75, 66), (66, 33), (33, 45), (45, 51),
 (51, 26), (26, 12), (12, 53), (53, 18), (18, 34), (34, 7), (7, 6), (6, 52), (52, 13),
 (13, 58), (58, 65), (65, 10), (10, 64), (64, 37), (37, 9), (9, 71), (71, 38), (38, 8),
 (8, 31), (31, 43), (43, 2), (2, 39), (39, 11), (11, 25), (25, 16), (16, 50), (50, 5),
 (5, 67), (67, 1), (1, 29), (29, 47), (47, 28), (28, 44), (44, 14), (14, 56), (56, 4),
 (4, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 68), (68, 35), (35, 46), (46, 2
0), (20, 73), (73, 27), (27, 60), (60, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 2
1), (21, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 22), (22, 55), (55,
 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 57)]
Run 7 - Best Path Length: 576.66

Run 8 - Best Path Indices: [(1, 20), (20, 46), (46, 35), (35, 68), (68, 70), (70, 59),
 (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 12), (12, 53), (53, 18),
 (18, 34), (34, 7), (7, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47),
 (47, 60), (60, 21), (21, 61), (61, 27), (27, 73), (73, 29), (29, 3), (3, 66), (66, 25),
 (25, 75), (75, 74), (74, 67), (67, 5), (5, 50), (50, 16), (16, 11), (11, 39), (39, 31),
 (31, 43), (43, 2), (2, 15), (15, 62), (62, 32), (32, 72), (72, 0), (0, 42), (42, 40),
 (40, 41), (41, 63), (63, 22), (22, 55), (55, 48), (48, 23), (23, 17), (17, 49), (49, 2
4), (24, 54), (54, 30), (30, 9), (9, 37), (37, 64), (64, 65), (65, 10), (10, 52), (52, 1
3), (13, 58), (58, 6), (6, 57), (57, 71), (71, 38), (38, 8)]
Run 8 - Best Path Length: 580.35

Run 9 - Best Path Indices: [(2, 43), (43, 31), (31, 8), (8, 38), (38, 71), (71, 57), (5
7, 9), (9, 37), (37, 64), (64, 65), (65, 10), (10, 13), (13, 52), (52, 34), (34, 6), (6,
 7), (7, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 29), (29,
 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 16), (1
6, 11), (11, 39), (39, 25), (25, 66), (66, 75), (75, 74), (74, 67), (67, 5), (5, 3), (3,
 1), (1, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 21), (21, 60), (60, 20), (20, 4
6), (46, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 1
4), (14, 56), (56, 12), (12, 53), (53, 18), (18, 58), (58, 30), (30, 54), (54, 24), (24,
 49), (49, 17), (17, 23), (23, 48), (48, 22), (22, 55)]
Run 9 - Best Path Length: 578.52

Run 10 - Best Path Indices: [(3, 74), (74, 75), (75, 66), (66, 33), (33, 45), (45, 51),
 (51, 7), (7, 6), (6, 34), (34, 52), (52, 13), (13, 58), (58, 65), (65, 64), (64, 37),
 (37, 10), (10, 18), (18, 53), (53, 12), (12, 26), (26, 44), (44, 28), (28, 47), (47, 4
6), (46, 20), (20, 60), (60, 21), (21, 61), (61, 72), (72, 0), (0, 42), (42, 40), (40, 4
1), (41, 63), (63, 55), (55, 22), (22, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24,
 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 31), (31, 43), (43,
 2), (2, 15), (15, 62), (62, 32), (32, 1), (1, 67), (67, 5), (5, 50), (50, 16), (16, 3
9), (39, 11), (11, 25), (25, 29), (29, 73), (73, 27), (27, 68), (68, 35), (35, 70), (70,
 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56)]
Run 10 - Best Path Length: 579.6
```

Run 11 - Best Path Indices: [(4, 47), (47, 46), (46, 35), (35, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 68), (68, 20), (20, 60), (60, 21), (21, 0), (0, 22), (22, 55), (55, 40), (40, 41), (41, 42), (42, 63), (63, 1), (1, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 31), (31, 43), (43, 2), (2, 39), (39, 11), (11, 25), (25, 66), (66, 75), (75, 74), (74, 67), (67, 5), (5, 50), (50, 16), (16, 3), (3, 44), (44, 28), (28, 56), (56, 14), (14, 12), (12, 26), (26, 51), (51, 33), (33, 45), (45, 7), (7, 34), (34, 6), (6, 52), (52, 13), (13, 58), (58, 65), (65, 10), (10, 64), (64, 37), (37, 18), (18, 53)]
Run 11 - Best Path Length: 600.95

Run 12 - Best Path Indices: [(0, 42), (42, 40), (40, 41), (41, 63), (63, 55), (55, 22), (22, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 38), (38, 71), (71, 57), (57, 9), (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 18), (18, 53), (53, 12), (12, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 29), (29, 1), (1, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 2), (2, 43), (43, 31), (31, 8), (8, 39), (39, 16), (16, 50), (50, 5), (5, 67), (67, 74), (74, 75), (75, 66), (66, 25), (25, 11), (11, 3), (3, 33), (33, 45), (45, 7), (7, 34), (34, 6), (6, 52), (52, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 35), (35, 68), (68, 20), (20, 46), (46, 60), (60, 21)]
Run 12 - Best Path Length: 593.5

Run 13 - Best Path Indices: [(0, 42), (42, 41), (41, 40), (40, 55), (55, 22), (22, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 31), (31, 43), (43, 2), (2, 39), (39, 11), (11, 16), (16, 50), (50, 5), (5, 67), (67, 1), (1, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 63), (63, 21), (21, 60), (60, 20), (20, 68), (68, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 7), (7, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 46), (46, 35), (35, 3), (3, 74), (74, 75), (75, 66), (66, 25), (25, 6), (6, 34), (34, 52), (52, 13), (13, 58), (58, 65), (65, 10), (10, 37), (37, 64)]
Run 13 - Best Path Length: 581.37

Run 14 - Best Path Indices: [(4, 47), (47, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 31), (31, 2), (2, 43), (43, 16), (16, 50), (50, 5), (5, 67), (67, 1), (1, 0), (0, 42), (42, 41), (41, 40), (40, 55), (55, 22), (22, 63), (63, 21), (21, 60), (60, 20), (20, 46), (46, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 34), (34, 6), (6, 52), (52, 10), (10, 37), (37, 64), (64, 65), (65, 58), (58, 13), (13, 51), (51, 26), (26, 28), (28, 44), (44, 3), (3, 74), (74, 75), (75, 66), (66, 33), (33, 45), (45, 7), (7, 25), (25, 11), (11, 39)]
Run 14 - Best Path Length: 588.9

Run 15 - Best Path Indices: [(1, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 52), (52, 34), (34, 6), (6, 7), (7, 18), (18, 53), (53, 12), (12, 56), (56, 14), (14, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 35), (35, 68), (68, 20), (20, 46), (46, 47), (47, 28), (28, 44), (44, 3), (3, 75), (75, 74), (74, 67), (67, 5), (5, 50), (50, 2), (2, 43), (43, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 11), (11, 39), (39, 16), (16, 25), (25, 66), (66, 33), (33, 45), (45, 51), (51, 26), (26, 4), (4, 60), (60, 21), (21, 63), (63, 41), (41, 40), (40, 22), (22, 55), (55, 42), (42, 0)]
Run 15 - Best Path Length: 568.78

Run 16 - Best Path Indices: [(3, 7), (7, 34), (34, 6), (6, 52), (52, 13), (13, 58), (58, 10), (10, 64), (64, 37), (37, 65), (65, 18), (18, 53), (53, 12), (12, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 70), (70, 59), (59, 68), (68, 35), (35, 46), (46, 20), (20, 60), (60, 21), (21, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 55), (55, 22), (22, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 31), (31, 43), (43, 2), (2, 39), (39, 11), (11, 25), (25, 16), (16, 50), (50, 5), (5, 67), (67, 74), (74, 75), (75, 66), (66, 33), (33, 45), (45, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 29), (29, 1), (1, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15)]
Run 16 - Best Path Length: 578.61

```
Run 17 - Best Path Indices: [(0, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 23),
 (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 38),
 (38, 8), (8, 31), (31, 43), (43, 2), (2, 22), (22, 55), (55, 42), (42, 41), (41, 40),
 (40, 63), (63, 21), (21, 60), (60, 20), (20, 73), (73, 27), (27, 61), (61, 1), (1, 3),
 (3, 74), (74, 75), (75, 66), (66, 33), (33, 45), (45, 51), (51, 26), (26, 44), (44, 2
8), (28, 29), (29, 47), (47, 46), (46, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69,
 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 7), (7, 3
4), (34, 6), (6, 25), (25, 11), (11, 39), (39, 16), (16, 50), (50, 5), (5, 67), (67, 3
7), (37, 64), (64, 65), (65, 10), (10, 52), (52, 13), (13, 58)]
Run 17 - Best Path Length: 580.54

Run 18 - Best Path Indices: [(3, 44), (44, 28), (28, 47), (47, 46), (46, 35), (35, 70),
 (70, 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 26), (26, 51),
 (51, 33), (33, 45), (45, 7), (7, 18), (18, 53), (53, 12), (12, 52), (52, 13), (13, 58),
 (58, 65), (65, 64), (64, 37), (37, 10), (10, 6), (6, 34), (34, 66), (66, 25), (25, 16),
 (16, 39), (39, 11), (11, 50), (50, 5), (5, 67), (67, 74), (74, 75), (75, 1), (1, 29),
 (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 2
3), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 3
8), (38, 8), (8, 31), (31, 43), (43, 2), (2, 22), (22, 55), (55, 40), (40, 41), (41, 6
3), (63, 21), (21, 0), (0, 42), (42, 60), (60, 20), (20, 68)]
Run 18 - Best Path Length: 610.08

Run 19 - Best Path Indices: [(2, 43), (43, 31), (31, 49), (49, 17), (17, 24), (24, 54),
 (54, 30), (30, 71), (71, 38), (38, 8), (8, 39), (39, 11), (11, 16), (16, 50), (50, 5),
 (5, 67), (67, 74), (74, 75), (75, 25), (25, 66), (66, 33), (33, 45), (45, 51), (51, 2
6), (26, 12), (12, 53), (53, 18), (18, 34), (34, 6), (6, 7), (7, 10), (10, 65), (65, 6
4), (64, 37), (37, 9), (9, 57), (57, 52), (52, 13), (13, 58), (58, 56), (56, 14), (14,
 4), (4, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 35), (35, 46), (46, 20), (20,
 47), (47, 28), (28, 44), (44, 3), (3, 29), (29, 1), (1, 73), (73, 27), (27, 61), (61, 7
2), (72, 32), (32, 62), (62, 15), (15, 48), (48, 23), (23, 22), (22, 55), (55, 40), (40,
 41), (41, 42), (42, 0), (0, 21), (21, 60), (60, 68), (68, 63)]
Run 19 - Best Path Length: 612.53

Run 20 - Best Path Indices: [(0, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 16),
 (16, 39), (39, 11), (11, 25), (25, 66), (66, 45), (45, 33), (33, 51), (51, 26), (26, 4
4), (44, 28), (28, 47), (47, 4), (4, 46), (46, 35), (35, 68), (68, 70), (70, 59), (59, 6
9), (69, 19), (19, 36), (36, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 13), (13,
 52), (52, 6), (6, 34), (34, 7), (7, 3), (3, 74), (74, 75), (75, 67), (67, 5), (5, 1),
 (1, 29), (29, 73), (73, 27), (27, 61), (61, 21), (21, 60), (60, 20), (20, 63), (63, 4
1), (41, 42), (42, 40), (40, 55), (55, 22), (22, 48), (48, 23), (23, 17), (17, 49), (49,
 24), (24, 54), (54, 30), (30, 9), (9, 37), (37, 64), (64, 65), (65, 10), (10, 58), (58,
 57), (57, 71), (71, 38), (38, 8), (8, 31), (31, 43), (43, 2)]
Run 20 - Best Path Length: 584.1

Run 21 - Best Path Indices: [(2, 43), (43, 31), (31, 8), (8, 38), (38, 71), (71, 57), (5
7, 9), (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 52), (52, 18), (1
8, 53), (53, 12), (12, 26), (26, 51), (51, 33), (33, 45), (45, 7), (7, 34), (34, 6), (6,
 66), (66, 75), (75, 74), (74, 67), (67, 5), (5, 50), (50, 16), (16, 11), (11, 39), (39,
 25), (25, 3), (3, 44), (44, 28), (28, 47), (47, 46), (46, 35), (35, 68), (68, 70), (70,
 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 20), (20, 60), (60,
 21), (21, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 55), (55, 22), (22, 1), (1, 2
9), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48,
 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30)]
Run 21 - Best Path Length: 578.01

Run 22 - Best Path Indices: [(0, 42), (42, 72), (72, 32), (32, 62), (62, 15), (15, 48),
 (48, 23), (23, 22), (22, 55), (55, 40), (40, 41), (41, 63), (63, 21), (21, 61), (61, 2
7), (27, 73), (73, 29), (29, 1), (1, 67), (67, 5), (5, 50), (50, 2), (2, 43), (43, 31),
 (31, 49), (49, 17), (17, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 38),
 (38, 8), (8, 39), (39, 11), (11, 16), (16, 25), (25, 6), (6, 34), (34, 7), (7, 45), (4
5, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 46), (46, 20), (20, 60),
 (60, 68), (68, 35), (35, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 14),
 (14, 56), (56, 12), (12, 53), (53, 18), (18, 13), (13, 58), (58, 65), (65, 64), (64, 3
7), (37, 10), (10, 52), (52, 3), (3, 74), (74, 75), (75, 66)]
Run 22 - Best Path Length: 573.81
```

Run 23 - Best Path Indices: [(4, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 34), (34, 7), (7, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 46), (46, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 20), (20, 60), (60, 21), (21, 61), (61, 27), (27, 73), (73, 29), (29, 1), (1, 67), (67, 5), (5, 50), (50, 16), (16, 11), (11, 39), (39, 25), (25, 66), (66, 75), (75, 74), (74, 3), (3, 6), (6, 52), (52, 13), (13, 58), (58, 65), (65, 10), (10, 64), (64, 37), (37, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 31), (31, 43), (43, 2), (2, 15), (15, 62), (62, 32), (32, 72), (72, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 55), (55, 22), (22, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30)]
Run 23 - Best Path Length: 553.99

Run 24 - Best Path Indices: [(1, 29), (29, 47), (47, 46), (46, 20), (20, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 15), (15, 62), (62, 22), (22, 55), (55, 40), (40, 41), (41, 42), (42, 0), (0, 21), (21, 60), (60, 68), (68, 35), (35, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 28), (28, 44), (44, 26), (26, 51), (51, 33), (33, 45), (45, 7), (7, 34), (34, 6), (6, 52), (52, 13), (13, 58), (58, 10), (10, 37), (37, 64), (64, 65), (65, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 31), (31, 43), (43, 2), (2, 39), (39, 11), (11, 25), (25, 16), (16, 50), (50, 5), (5, 67), (67, 74), (74, 75), (75, 66), (66, 3), (3, 18), (18, 53), (53, 12), (12, 56), (56, 14), (14, 63), (63, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30)]
Run 24 - Best Path Length: 620.3

Run 25 - Best Path Indices: [(3, 74), (74, 75), (75, 66), (66, 25), (25, 11), (11, 39), (39, 16), (16, 50), (50, 5), (5, 67), (67, 1), (1, 29), (29, 73), (73, 27), (27, 61), (61, 0), (0, 72), (72, 32), (32, 62), (62, 15), (15, 2), (2, 43), (43, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 9), (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 18), (18, 53), (53, 12), (12, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 35), (35, 68), (68, 20), (20, 46), (46, 47), (47, 28), (28, 44), (44, 26), (26, 51), (51, 45), (45, 33), (33, 7), (7, 34), (34, 6), (6, 52), (52, 30), (30, 54), (54, 24), (24, 49), (49, 17), (17, 23), (23, 48), (48, 55), (55, 22), (22, 42), (42, 40), (40, 41), (41, 63), (63, 21), (21, 60)]
Run 25 - Best Path Length: 555.44

Run 26 - Best Path Indices: [(2, 43), (43, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 9), (9, 37), (37, 64), (64, 65), (65, 10), (10, 52), (52, 18), (18, 13), (13, 58), (58, 53), (53, 12), (12, 26), (26, 51), (51, 33), (33, 45), (45, 7), (7, 34), (34, 6), (6, 66), (66, 75), (75, 74), (74, 67), (67, 5), (5, 1), (1, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 16), (16, 39), (39, 11), (11, 25), (25, 3), (3, 44), (44, 28), (28, 47), (47, 46), (46, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 56), (56, 14), (14, 20), (20, 60), (60, 21), (21, 0), (0, 63), (63, 41), (41, 42), (42, 40), (40, 55), (55, 22), (22, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30)]
Run 26 - Best Path Length: 570.13

Run 27 - Best Path Indices: [(3, 74), (74, 75), (75, 66), (66, 25), (25, 6), (6, 34), (34, 7), (7, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 16), (16, 11), (11, 39), (39, 43), (43, 2), (2, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 9), (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 52), (52, 18), (18, 53), (53, 12), (12, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 68), (68, 35), (35, 46), (46, 20), (20, 60), (60, 21), (21, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 55), (55, 22), (22, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 5), (5, 67), (67, 1)]
Run 27 - Best Path Length: 576.64

Run 28 - Best Path Indices: [(3, 44), (44, 28), (28, 4), (4, 47), (47, 46), (46, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 14), (14, 56), (56, 12), (12, 26), (26, 51), (51, 45), (45, 33), (33, 7), (7, 34), (34, 6), (6, 52), (52, 13), (13, 18), (18, 53), (53, 58), (58, 65), (65, 10), (10, 64), (64, 37), (37, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 39), (39, 11), (11, 16), (16, 50), (50, 5), (5, 74), (74, 75), (75, 66), (66, 25), (25, 67), (67, 1), (1, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 2), (2, 43), (43, 31), (31, 49), (49, 17), (17, 24), (24, 54), (54, 30), (30, 23), (23, 48), (48, 22), (22, 55), (55, 42), (42, 41), (41, 40), (40, 63), (63, 21), (21, 60), (60, 20), (20, 0)]
Run 28 - Best Path Length: 608.09

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Run 29 - Best Path Indices: [(0, 42), (42, 41), (41, 40), (40, 55), (55, 22), (22, 23),
 (23, 48), (48, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 11), (11, 39), (39,
 2), (2, 43), (43, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 9), (9, 37), (37, 6
4), (64, 10), (10, 65), (65, 58), (58, 13), (13, 52), (52, 6), (6, 34), (34, 7), (7, 4
5), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 4), (4, 46), (46, 2
0), (20, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69, 36), (36, 19), (19, 56), (56,
 14), (14, 12), (12, 53), (53, 18), (18, 3), (3, 74), (74, 75), (75, 66), (66, 25), (25,
 16), (16, 50), (50, 5), (5, 67), (67, 1), (1, 29), (29, 73), (73, 27), (27, 61), (61, 7
2), (72, 32), (32, 15), (15, 62), (62, 63), (63, 21), (21, 60)]
Run 29 - Best Path Length: 598.72

Run 30 - Best Path Indices: [(1, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 21), (2
1, 60), (60, 20), (20, 46), (46, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69, 19),
 (19, 36), (36, 4), (4, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 34), (34, 6),
 (6, 7), (7, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 29),
 (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 2
3), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 3
8), (38, 8), (8, 31), (31, 43), (43, 2), (2, 39), (39, 11), (11, 25), (25, 66), (66, 7
5), (75, 74), (74, 67), (67, 5), (5, 50), (50, 16), (16, 37), (37, 64), (64, 10), (10, 6
5), (65, 58), (58, 13), (13, 52), (52, 3), (3, 55), (55, 22)]
Run 30 - Best Path Length: 603.51
```
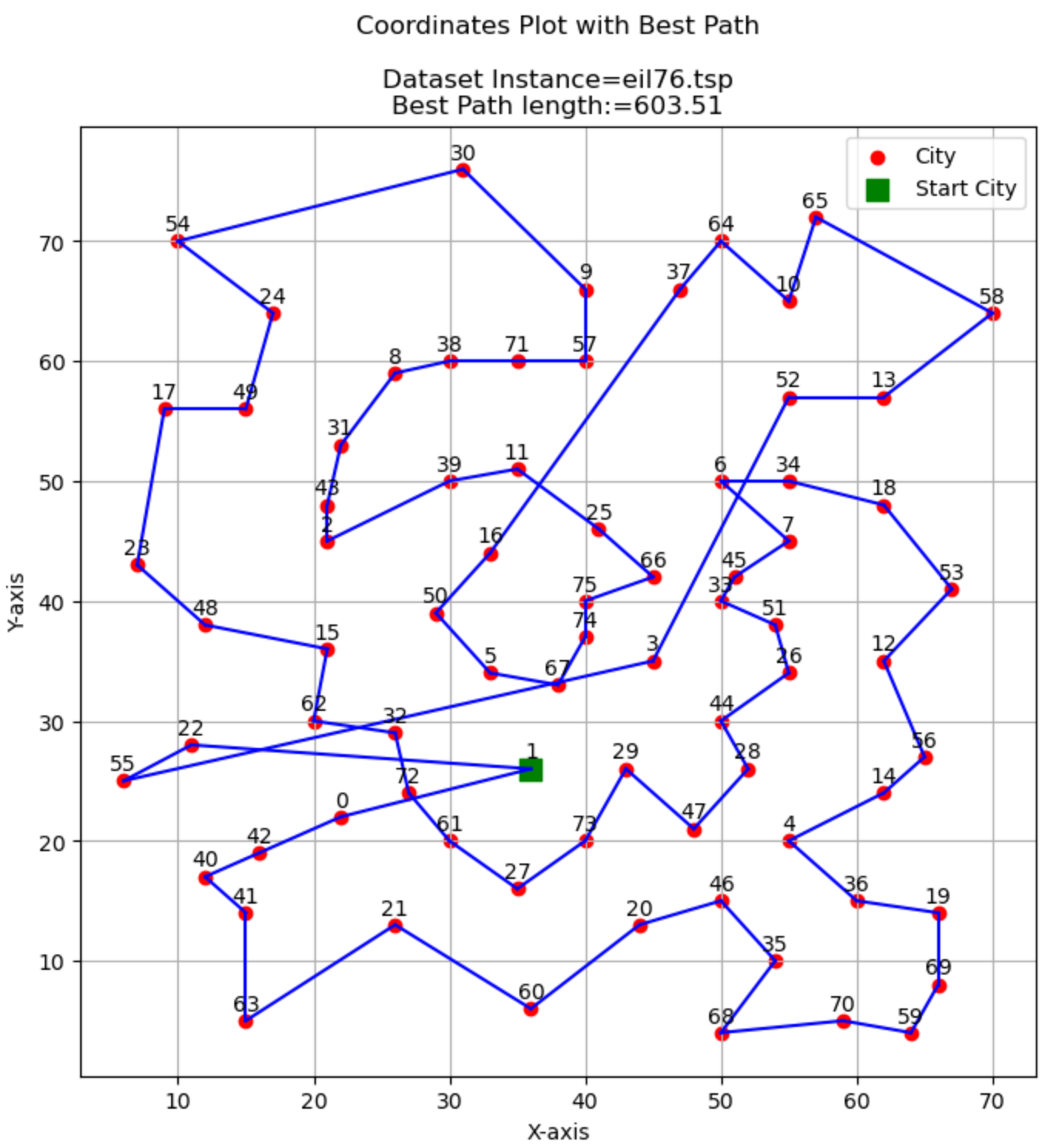

Calculating Best Path and Plot

In [4]:

```python
import matplotlib.pyplot as plt

# Extract x and y coordinates from the list of coordinates
x_coords, y_coords = zip(*coordinates)

# Plot the coordinates
plt.figure(figsize=(8, 8))
plt.scatter(x_coords, y_coords, c='red', marker='o', label='City')

# Annotate each point with its index
for i, (x, y) in enumerate(coordinates):
    plt.annotate(str(i), (x, y), textcoords="offset points", xytext=(0, 5), ha='center')

# Connect the points in the order of the best path indices
for start, end in best_path_indices:
    x_start, y_start = coordinates[start]
    x_end, y_end = coordinates[end]
    plt.plot([x_start, x_end], [y_start, y_end], linestyle='-', color='blue')

# Connect back to the starting point
x_start, y_start = coordinates[best_path_indices[-1][1]]
x_end, y_end = coordinates[best_path_indices[0][0]]
plt.plot([x_start, x_end], [y_start, y_end], linestyle='-', color='blue')

# Mark the starting point with a different marker or color
start_index = best_path_indices[0][0]
x_start, y_start = coordinates[start_index]
plt.scatter(x_start, y_start, c='green', marker='s', s=100, label='Start City')

# Show the legend
plt.legend()

# Show the plot
plt.title(f'Coordinates Plot with Best Path\n\nDataset Instance={file_path}\nBest Path l

plt.xlabel('X-axis')
plt.ylabel('Y-axis')
plt.grid(True)
plt.show()
```



Plotting Generation vs Execution time and Generation vs Best Path Length

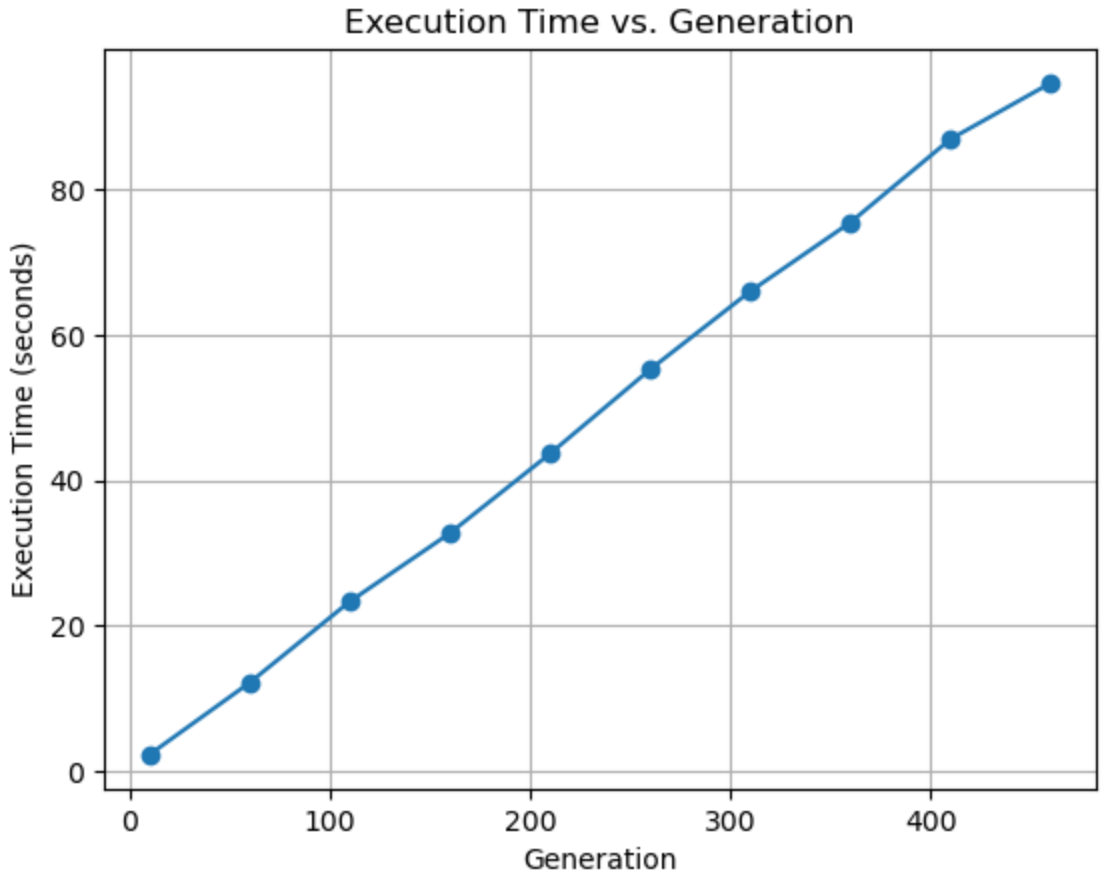
In [5]:
```
import time

# Lists to store data for plotting
generations_list = []
execution_times_list = []
best_path_lengths_list = []

# Run ACOGA for multiple generations
for generations in range(10, 500, 50):
    # Initialize ACOGA instance
    aco_ga = ACOGA(distances, n_ants=5, decay=0.95, alpha=1, beta=2, ga_population_size=
```

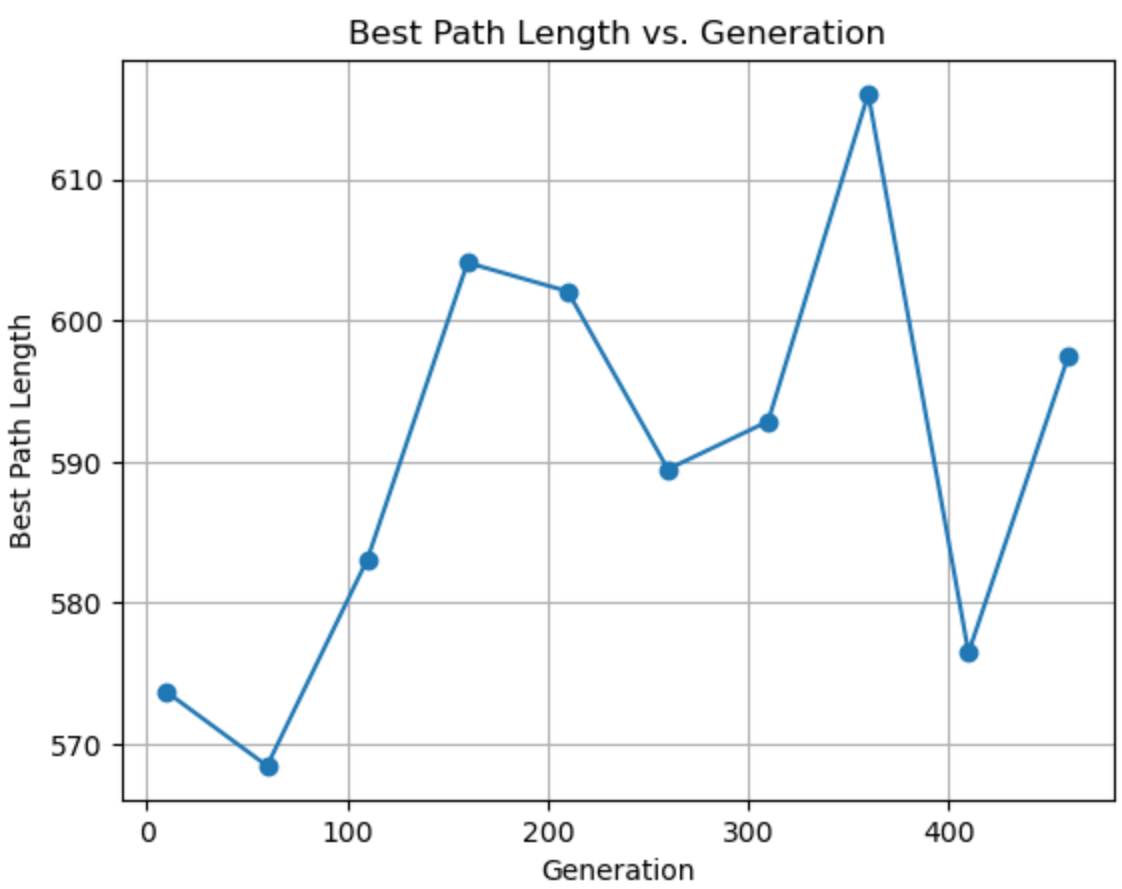
```
    # Measure execution time
    start_time = time.time()

    # Run ACOGA
    result = aco_ga.run()

    # Measure execution time
    execution_time = time.time() - start_time
    print(f"Generations: {generations}, Execution Time: {execution_time:.4f} seconds")

    # Store data for plotting
    generations_list.append(generations)
    execution_times_list.append(execution_time)
    best_path_lengths_list.append(result[1])  # Appending the best path length

    # Extract result data
    best_path_indices = result[0]
    best_path_length = np.round(result[1], 2)

    # Print results
    print("Best Path Indices:", best_path_indices)
    print("Best Path Length:", best_path_length)


# Plot time vs. generation
plt.plot(generations_list, execution_times_list, marker='o')
plt.title('Execution Time vs. Generation')
plt.xlabel('Generation')
plt.ylabel('Execution Time (seconds)')
plt.grid(True)
plt.show()

# Plot best path length vs. generation
plt.plot(generations_list, best_path_lengths_list, marker='o')
plt.title('Best Path Length vs. Generation')
plt.xlabel('Generation')
plt.ylabel('Best Path Length')
plt.grid(True)
plt.show()
```

```
Generations: 10, Execution Time: 2.1861 seconds
Best Path Indices: [(2, 43), (43, 31), (31, 49), (49, 17), (17, 24), (24, 54), (54, 30),
(30, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 39), (39, 11), (11, 16), (16, 50), (5
0, 5), (5, 67), (67, 1), (1, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32,
62), (62, 15), (15, 48), (48, 23), (23, 55), (55, 22), (22, 0), (0, 42), (42, 40), (40,
41), (41, 63), (63, 21), (21, 60), (60, 20), (20, 46), (46, 47), (47, 28), (28, 44), (4
4, 3), (3, 74), (74, 75), (75, 25), (25, 66), (66, 33), (33, 45), (45, 7), (7, 34), (34,
6), (6, 52), (52, 10), (10, 64), (64, 37), (37, 65), (65, 58), (58, 13), (13, 18), (18,
53), (53, 56), (56, 14), (14, 36), (36, 4), (4, 35), (35, 68), (68, 70), (70, 59), (59,
69), (69, 19), (19, 12), (12, 26), (26, 51)]
Best Path Length: 573.67
Generations: 60, Execution Time: 12.0900 seconds
Best Path Indices: [(0, 42), (42, 40), (40, 41), (41, 63), (63, 21), (21, 61), (61, 72),
(72, 32), (32, 62), (62, 15), (15, 50), (50, 16), (16, 11), (11, 39), (39, 43), (43, 2),
(2, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 9), (9, 30), (30, 37), (37, 64), (6
4, 10), (10, 65), (65, 58), (58, 13), (13, 52), (52, 34), (34, 6), (6, 7), (7, 18), (18,
53), (53, 12), (12, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 59), (59,
70), (70, 35), (35, 68), (68, 60), (60, 20), (20, 46), (46, 47), (47, 28), (28, 44), (4
4, 3), (3, 74), (74, 75), (75, 25), (25, 66), (66, 33), (33, 45), (45, 51), (51, 26), (2
6, 67), (67, 5), (5, 1), (1, 29), (29, 73), (73, 27), (27, 22), (22, 55), (55, 48), (48,
23), (23, 17), (17, 49), (49, 24), (24, 54)]
Best Path Length: 568.45
Generations: 110, Execution Time: 23.2635 seconds
Best Path Indices: [(3, 66), (66, 33), (33, 45), (45, 51), (51, 26), (26, 12), (12, 53),
(53, 18), (18, 34), (34, 6), (6, 7), (7, 44), (44, 28), (28, 47), (47, 29), (29, 1), (1,
73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 16), (1
```

6, 39), (39, 11), (11, 25), (25, 75), (75, 74), (74, 67), (67, 5), (5, 2), (2, 43), (43, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 9), (9, 37), (37, 64), (64, 65), (65, 10), (10, 13), (13, 52), (52, 58), (58, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 68), (68, 35), (35, 46), (46, 20), (20, 60), (60, 21), (21, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 55), (55, 22), (22, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30)]
Best Path Length: 583.06
Generations: 160, Execution Time: 32.6805 seconds
Best Path Indices: [(0, 42), (42, 40), (40, 41), (41, 63), (63, 21), (21, 60), (60, 68), (68, 47), (47, 28), (28, 44), (44, 3), (3, 74), (74, 75), (75, 66), (66, 33), (33, 45), (45, 7), (7, 6), (6, 34), (34, 52), (52, 13), (13, 18), (18, 53), (53, 12), (12, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 35), (35, 46), (46, 20), (20, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 71), (71, 57), (57, 9), (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 26), (26, 51), (51, 67), (67, 1), (1, 29), (29, 5), (5, 50), (50, 16), (16, 25), (25, 11), (11, 39), (39, 38), (38, 8), (8, 31), (31, 43), (43, 2), (2, 22), (22, 55)]
Best Path Length: 604.09
Generations: 210, Execution Time: 43.6257 seconds
Best Path Indices: [(0, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 5), (5, 67), (67, 74), (74, 75), (75, 66), (66, 25), (25, 11), (11, 39), (39, 16), (16, 2), (2, 43), (43, 31), (31, 49), (49, 17), (17, 23), (23, 48), (48, 55), (55, 22), (22, 40), (40, 41), (41, 42), (42, 63), (63, 21), (21, 61), (61, 1), (1, 29), (29, 73), (73, 27), (27, 60), (60, 20), (20, 46), (46, 35), (35, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 7), (7, 34), (34, 6), (6, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 68), (68, 3), (3, 57), (57, 71), (71, 38), (38, 8), (8, 24), (24, 54), (54, 30), (30, 9), (9, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 52)]
Best Path Length: 602.06
Generations: 260, Execution Time: 55.2325 seconds
Best Path Indices: [(0, 72), (72, 61), (61, 27), (27, 73), (73, 29), (29, 1), (1, 67), (67, 5), (5, 50), (50, 16), (16, 39), (39, 11), (11, 25), (25, 66), (66, 75), (75, 74), (74, 3), (3, 44), (44, 28), (28, 47), (47, 46), (46, 20), (20, 60), (60, 21), (21, 63), (63, 41), (41, 40), (40, 42), (42, 22), (22, 55), (55, 48), (48, 23), (23, 15), (15, 62), (62, 32), (32, 2), (2, 43), (43, 31), (31, 49), (49, 17), (17, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 37), (37, 64), (64, 65), (65, 10), (10, 52), (52, 13), (13, 58), (58, 7), (7, 34), (34, 6), (6, 18), (18, 53), (53, 12), (12, 26), (26, 51), (51, 33), (33, 45), (45, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 59), (59, 70), (70, 35), (35, 68)]
Best Path Length: 589.46
Generations: 310, Execution Time: 65.9934 seconds
Best Path Indices: [(1, 0), (0, 42), (42, 40), (40, 41), (41, 63), (63, 21), (21, 60), (60, 20), (20, 46), (46, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 34), (34, 6), (6, 7), (7, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 29), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 16), (16, 39), (39, 11), (11, 25), (25, 66), (66, 75), (75, 74), (74, 3), (3, 67), (67, 5), (5, 30), (30, 10), (10, 52), (52, 13), (13, 58), (58, 65), (65, 64), (64, 37), (37, 9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 2), (2, 43), (43, 31), (31, 49), (49, 17), (17, 54), (54, 24), (24, 23), (23, 48), (48, 22), (22, 55)]
Best Path Length: 592.85
Generations: 360, Execution Time: 75.4846 seconds
Best Path Indices: [(3, 44), (44, 28), (28, 47), (47, 46), (46, 20), (20, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 71), (71, 57), (57, 9), (9, 37), (37, 64), (64, 65), (65, 10), (10, 52), (52, 13), (13, 18), (18, 53), (53, 12), (12, 26), (26, 51), (51, 33), (33, 45), (45, 7), (7, 34), (34, 6), (6, 66), (66, 75), (75, 74), (74, 67), (67, 5), (5, 50), (50, 16), (16, 39), (39, 11), (11, 25), (25, 38), (38, 8), (8, 31), (31, 43), (43, 2), (2, 55), (55, 22), (22, 42), (42, 40), (40, 41), (41, 63), (63, 21), (21, 60), (60, 0), (0, 1), (1, 29), (29, 68), (68, 35), (35, 70), (70, 59), (59, 69), (69, 19), (19, 36), (36, 4), (4, 14), (14, 56), (56, 58)]
Best Path Length: 616.05
Generations: 410, Execution Time: 86.9588 seconds
Best Path Indices: [(0, 42), (42, 40), (40, 41), (41, 63), (63, 55), (55, 22), (22, 2), (2, 43), (43, 39), (39, 11), (11, 16), (16, 50), (50, 5), (5, 67), (67, 74), (74, 75), (75, 25), (25, 66), (66, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 4

```
7), (47, 46), (46, 20), (20, 27), (27, 73), (73, 1), (1, 29), (29, 3), (3, 7), (7, 34),
(34, 6), (6, 52), (52, 13), (13, 58), (58, 65), (65, 64), (64, 37), (37, 10), (10, 18),
(18, 53), (53, 12), (12, 56), (56, 14), (14, 4), (4, 36), (36, 19), (19, 69), (69, 59),
(59, 70), (70, 35), (35, 68), (68, 60), (60, 21), (21, 61), (61, 72), (72, 32), (32, 6
2), (62, 15), (15, 48), (48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30,
9), (9, 57), (57, 71), (71, 38), (38, 8), (8, 31)]
Best Path Length: 576.47
Generations: 460, Execution Time: 94.6785 seconds
Best Path Indices: [(1, 67), (67, 5), (5, 50), (50, 32), (32, 62), (62, 15), (15, 48),
(48, 23), (23, 17), (17, 49), (49, 24), (24, 54), (54, 30), (30, 9), (9, 57), (57, 71),
(71, 38), (38, 8), (8, 37), (37, 64), (64, 10), (10, 65), (65, 58), (58, 13), (13, 18),
(18, 53), (53, 12), (12, 56), (56, 14), (14, 4), (4, 28), (28, 47), (47, 29), (29, 0),
(0, 42), (42, 40), (40, 41), (41, 63), (63, 21), (21, 60), (60, 68), (68, 70), (70, 59),
(59, 69), (69, 19), (19, 36), (36, 35), (35, 46), (46, 20), (20, 73), (73, 27), (27, 6
1), (61, 72), (72, 55), (55, 22), (22, 2), (2, 43), (43, 31), (31, 39), (39, 11), (11, 1
6), (16, 25), (25, 66), (66, 75), (75, 74), (74, 3), (3, 44), (44, 26), (26, 51), (51, 3
3), (33, 45), (45, 7), (7, 34), (34, 6), (6, 52)]
Best Path Length: 597.54
```





Plotting Best Path on different Parameters

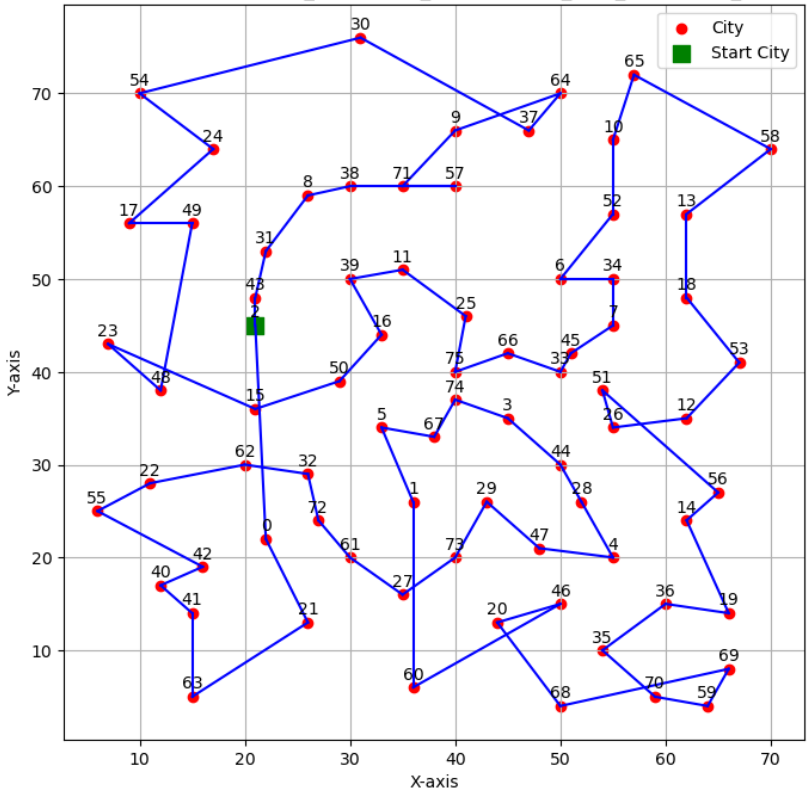
In [6]:
```
# Lists to store data for plotting
generations_list = []
execution_times_list = []
best_path_lengths_list = []

# Various Parameter combination to achieve best solution
parameter_combinations = [
    (5, 0.9, 1, 1, 100, 2, 0.7, 0.8, 500),
    (7, 0.95, 2, 2, 200, 2, 0.8, 0.7, 600),
    (10, 0.99, 3, 3, 300, 2, 0.9, 0.9, 700),
]

for params in parameter_combinations:
    n_ants, decay, alpha, beta, ga_population_size, ga_elite_size, ga_mutation_rate, ga_
    aco_ga = ACOGA(distances, n_ants=n_ants, decay=decay, alpha=alpha, beta=beta,
                   ga_population_size=ga_population_size, ga_elite_size=ga_elite_size,
                   ga_mutation_rate=ga_mutation_rate, ga_crossover_prob = ga_crossover_p

    # Measure execution time
    start_time = time.time()

    # Run ACOGA
    result = aco_ga.run()

    # Measure execution time
    execution_time = time.time() - start_time
    print(f"Generations: {generations}, Execution Time: {execution_time:.4f} seconds")

    # Store data for plotting
    generations_list.append(generations)
    execution_times_list.append(execution_time)
    best_path_lengths_list.append(result[1])  # Appending the best path length
```

```
    # Extract result data
    best_path_indices = result[0]
    best_path_length = np.round(result[1], 2)

    # Print results
    print("Best Path Indices:", best_path_indices)
    print("Best Path Length:", best_path_length)

    # Extract x and y coordinates from the list of coordinates
    x_coords, y_coords = zip(*coordinates)

    # Plot the coordinates
    plt.figure(figsize=(8, 8))
    plt.scatter(x_coords, y_coords, c='red', marker='o', label='City')

    # Annotate each point with its index
    for i, (x, y) in enumerate(coordinates):
        plt.annotate(str(i), (x, y), textcoords="offset points", xytext=(0, 5), ha='cent

    # Connect the points in the order of the best path indices
    for start, end in best_path_indices:
        x_start, y_start = coordinates[start]
        x_end, y_end = coordinates[end]
        plt.plot([x_start, x_end], [y_start, y_end], linestyle='-', color='blue')

    # Connect back to the starting point
    x_start, y_start = coordinates[best_path_indices[-1][1]]
    x_end, y_end = coordinates[best_path_indices[0][0]]
    plt.plot([x_start, x_end], [y_start, y_end], linestyle='-', color='blue')

    # Mark the starting point with a different marker or color
    start_index = best_path_indices[0][0]
    x_start, y_start = coordinates[start_index]
    plt.scatter(x_start, y_start, c='green', marker='s', s=100, label='Start City')

    # Show the legend
    plt.legend()

    # Show the plot
    #plt.title('Coordinates Plot with Best Path')
    plt.title(f'Coordinates Plot with Best Path\n\nParameters:n_ants={n_ants},decay={dec

    plt.xlabel('X-axis')
    plt.ylabel('Y-axis')
    plt.grid(True)
    plt.show()
```

```
Generations: 500, Execution Time: 103.7992 seconds
Best Path Indices: [(2, 43), (43, 31), (31, 8), (8, 38), (38, 57), (57, 71), (71, 9),
(9, 64), (64, 37), (37, 30), (30, 54), (54, 24), (24, 17), (17, 49), (49, 48), (48, 23),
(23, 15), (15, 50), (50, 16), (16, 39), (39, 11), (11, 25), (25, 75), (75, 66), (66, 3
3), (33, 45), (45, 7), (7, 34), (34, 6), (6, 52), (52, 10), (10, 65), (65, 58), (58, 1
3), (13, 18), (18, 53), (53, 12), (12, 26), (26, 51), (51, 56), (56, 14), (14, 19), (19,
36), (36, 35), (35, 70), (70, 59), (59, 69), (69, 68), (68, 20), (20, 46), (46, 60), (6
0, 1), (1, 5), (5, 67), (67, 74), (74, 3), (3, 44), (44, 28), (28, 4), (4, 47), (47, 2
9), (29, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 22), (22, 55), (55,
42), (42, 40), (40, 41), (41, 63), (63, 21), (21, 0)]
Best Path Length: 612.07
```

Coordinates Plot with Best Path

Parameters:n_ants=5,decay=0.9, alpha=1, beta=1, ga_population_size=100, ga_elite_size=2, ga_mutation_rate=0.7, generations=500



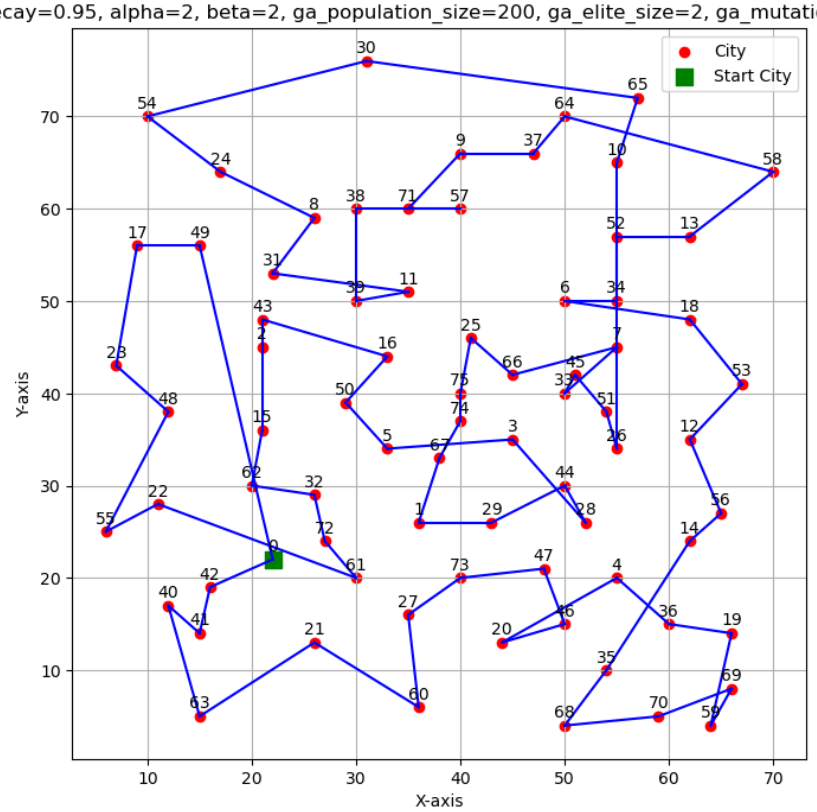
Generations: 600, Execution Time: 173.3319 seconds

Best Path Indices: [(0, 42), (42, 41), (41, 40), (40, 63), (63, 21), (21, 60), (60, 27), (27, 73), (73, 47), (47, 46), (46, 20), (20, 4), (4, 36), (36, 19), (19, 59), (59, 69), (69, 70), (70, 68), (68, 35), (35, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 6), (6, 34), (34, 52), (52, 13), (13, 58), (58, 64), (64, 37), (37, 9), (9, 71), (71, 57), (57, 38), (38, 39), (39, 11), (11, 31), (31, 8), (8, 24), (24, 54), (54, 30), (30, 65), (65, 10), (10, 26), (26, 51), (51, 45), (45, 33), (33, 7), (7, 66), (66, 25), (25, 75), (75, 74), (74, 67), (67, 1), (1, 29), (29, 44), (44, 28), (28, 3), (3, 5), (5, 50), (50, 16), (16, 43), (43, 2), (2, 15), (15, 62), (62, 32), (32, 72), (72, 61), (61, 22), (22, 55), (55, 48), (48, 23), (23, 17), (17, 49)]

Best Path Length: 665.37

Coordinates Plot with Best Path

Parameters:n_ants=7,decay=0.95, alpha=2, beta=2, ga_population_size=200, ga_elite_size=2, ga_mutation_rate=0.8, generations=600



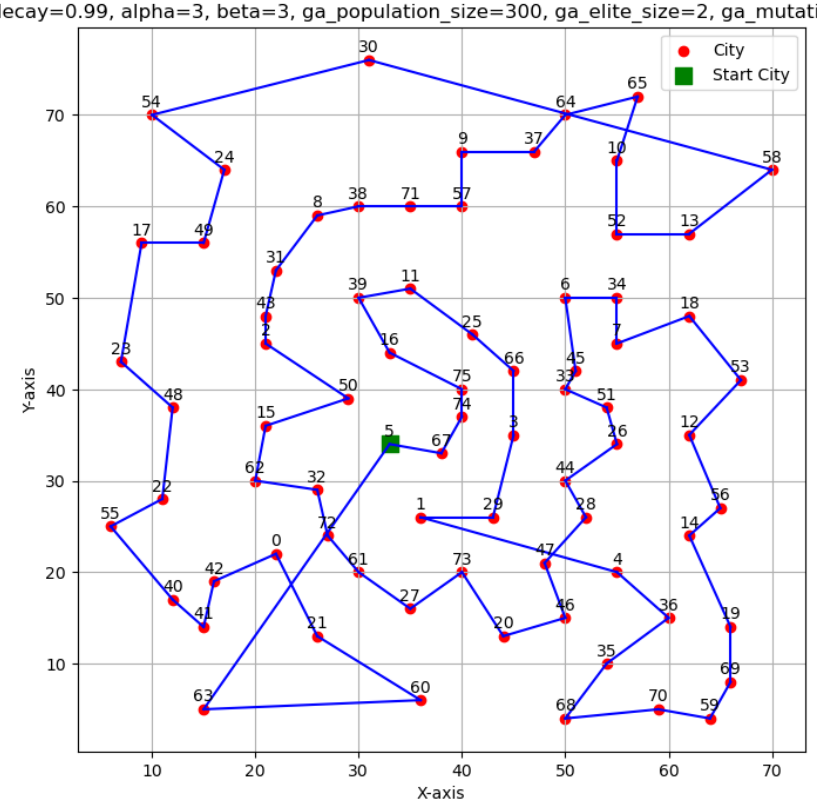
Generations: 700, Execution Time: 306.5323 seconds

Best Path Indices: [(5, 67), (67, 74), (74, 75), (75, 16), (16, 39), (39, 11), (11, 25), (25, 66), (66, 3), (3, 29), (29, 1), (1, 4), (4, 36), (36, 35), (35, 68), (68, 70), (70, 59), (59, 69), (69, 19), (19, 14), (14, 56), (56, 12), (12, 53), (53, 18), (18, 7), (7, 34), (34, 6), (6, 45), (45, 33), (33, 51), (51, 26), (26, 44), (44, 28), (28, 47), (47, 46), (46, 20), (20, 73), (73, 27), (27, 61), (61, 72), (72, 32), (32, 62), (62, 15), (15, 50), (50, 2), (2, 43), (43, 31), (31, 8), (8, 38), (38, 71), (71, 57), (57, 9), (9, 37), (37, 64), (64, 65), (65, 10), (10, 52), (52, 13), (13, 58), (58, 30), (30, 54), (54, 24), (24, 49), (49, 17), (17, 23), (23, 48), (48, 22), (22, 55), (55, 40), (40, 41), (41, 42), (42, 0), (0, 21), (21, 60), (60, 63)]

Best Path Length: 582.77

Coordinates Plot with Best Path

Parameters:n_ants=10,decay=0.99, alpha=3, beta=3, ga_population_size=300, ga_elite_size=2, ga_mutation_rate=0.9, generations=700

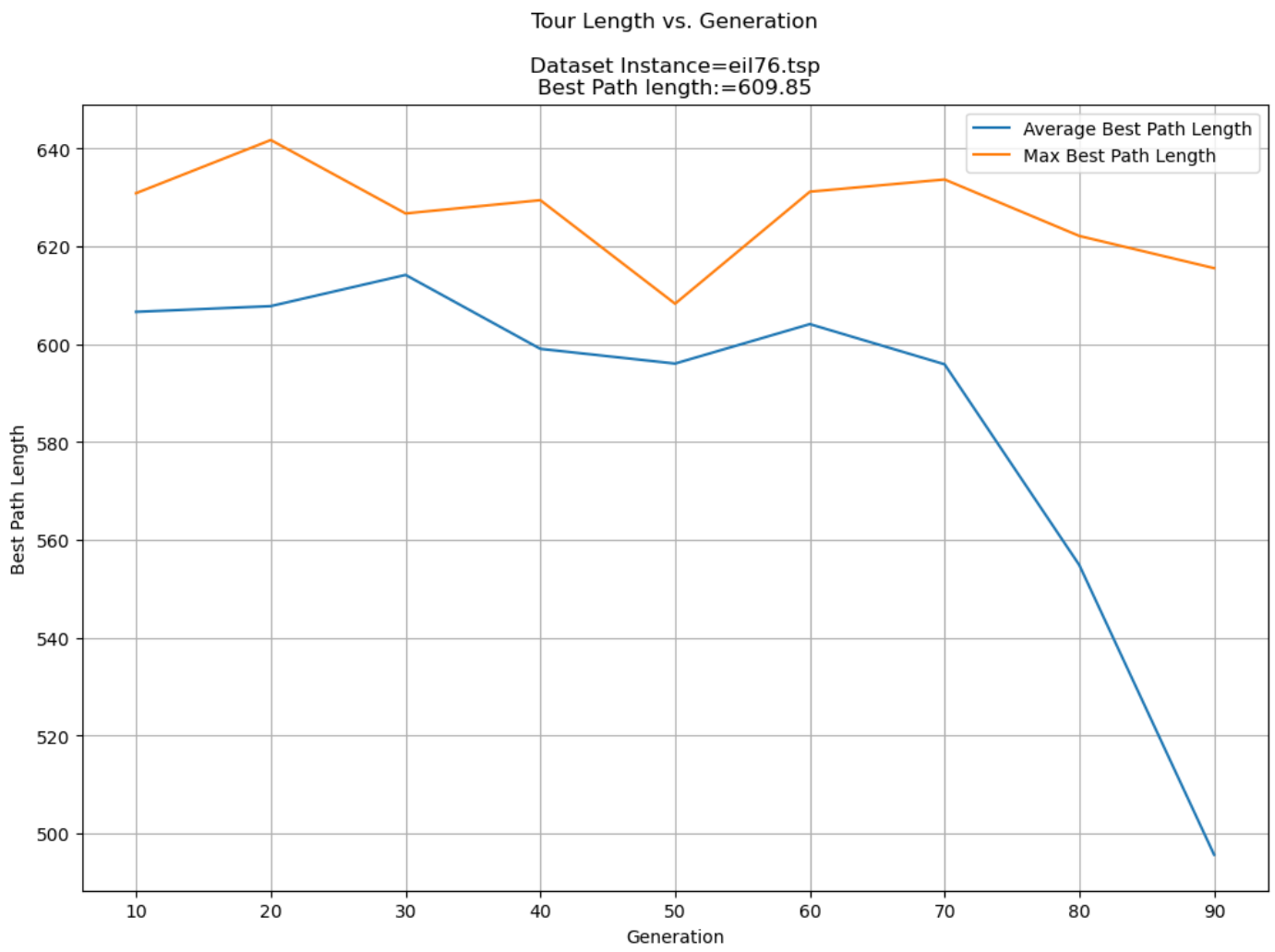


Plotting avg-avg and max-avg versus number of generations

In [7]:
```
import numpy as np
import matplotlib.pyplot as plt
import time

# Lists to store data for plotting
generations_list = []
execution_times_list = []
overall_avg_best_path_lengths_list = []
overall_max_best_path_lengths_list = []

# Define the parameter combinations for ACOGA
parameter_combinations = [(10, 5, 0.95, 1, 2, 400, 2, 0.8, 0.9)]

# Run ACOGA for multiple generations
for generations in range(10, 100, 10):
    # Initialize arrays to store path length values
    num_generations_acoga = generations
    avg_best_path_length = np.zeros((num_generations_acoga,))
    max_best_path_length = np.zeros((num_generations_acoga,))

    num_runs = 5
    for params_idx, params in enumerate(parameter_combinations):
        num_of_generations, n_ants, decay, alpha, beta, ga_population_size, ga_elite_siz

        for run in range(num_runs):
            # Initialize ACOGA instance
            aco_ga = ACOGA(distances, n_ants=n_ants, decay=decay, alpha=alpha, beta=beta
                           ga_elite_size=ga_elite_size, ga_mutation_rate=ga_mutation_rat
                           generations=num_of_generations)

            # Measure execution time
            start_time = time.time()

            # Run ACOGA
            result = aco_ga.run()

            # Measure execution time
            execution_time = time.time() - start_time

            # Store data for plotting

            execution_times_list.append(execution_time)

            # Extract result data
            best_path_indices = result[0]

            # Calculate best path length
            best_path_length = np.sum([distances[i, j] for i, j in best_path_indices])

            # Update best path length arrays
            avg_best_path_length[:len(best_path_indices)] += np.array([best_path_length]
            max_best_path_length[:len(best_path_indices)] = np.maximum(max_best_path_len

            # Print results
            #print("Best Path Indices:", best_path_indices)
           # print("Best Path Length:", best_path_length)

    # Print average and maximum best path lengths after all runs for each generation
```

```
    overall_avg_best_path_length = np.mean(avg_best_path_length[:num_generations_acoga])
    overall_max_best_path_length = np.max(max_best_path_length[:num_generations_acoga])

    print("generations:", generations)
    print("overall_avg_best_path_length:", overall_avg_best_path_length)
    print("overall_max_best_path_length:", overall_max_best_path_length)

    generations_list.append(generations)
    overall_avg_best_path_lengths_list.append(overall_avg_best_path_length)
    overall_max_best_path_lengths_list.append(overall_max_best_path_length)

# Plotting with magnified figure size
plt.figure(figsize=(12, 8))

# Plotting
plt.plot(generations_list, overall_avg_best_path_lengths_list, label='Average Best Path
plt.plot(generations_list, overall_max_best_path_lengths_list, label='Max Best Path Leng

# Customize plot appearance
plt.xlabel('Generation')
plt.ylabel('Best Path Length')
plt.title('Overall Best Path Lengths vs. Generation')
plt.title(f'Tour Length vs. Generation\n\nDataset Instance={file_path}\nBest Path length

plt.legend()
plt.grid(True)
plt.show()
```

```
generations: 10
overall_avg_best_path_length: 606.5820000000001
overall_max_best_path_length: 630.83
generations: 20
overall_avg_best_path_length: 607.7600000000001
overall_max_best_path_length: 641.69
generations: 30
overall_avg_best_path_length: 614.1320000000002
overall_max_best_path_length: 626.69
generations: 40
overall_avg_best_path_length: 599.0280000000001
overall_max_best_path_length: 629.4000000000002
generations: 50
overall_avg_best_path_length: 596.0200000000001
overall_max_best_path_length: 608.25
generations: 60
overall_avg_best_path_length: 604.0800000000002
overall_max_best_path_length: 631.13
generations: 70
overall_avg_best_path_length: 595.8720000000002
overall_max_best_path_length: 633.6300000000001
generations: 80
overall_avg_best_path_length: 554.840625
overall_max_best_path_length: 622.09
generations: 90
overall_avg_best_path_length: 495.6733333333333
overall_max_best_path_length: 615.5099999999999
```



In [8]:

```python
import numpy as np
import matplotlib.pyplot as plt
import time

# Lists to store data for plotting
generations_list = []
execution_times_list = []
overall_avg_best_path_lengths_list = []
overall_max_best_path_lengths_list = []

# Define the parameter combinations for ACOGA

# Define the parameter combinations for ACOGA
parameter_combinations = [(10, 5, 0.95, 1, 2, 400, 2, 0.8, 0.9)]

# Run ACOGA for multiple generations
for generations in range(10, 500, 10):
    # Initialize arrays to store path length values
    num_generations_acoga = generations
    avg_best_path_length = np.zeros((num_generations_acoga,))
    max_best_path_length = np.zeros((num_generations_acoga,))

    for params_idx, params in enumerate(parameter_combinations):
        num_of_generations, n_ants, decay, alpha, beta, ga_population_size, ga_elite_siz

        num_runs = 30
        for run in range(num_runs):
            # Initialize ACOGA instance
            aco_ga = ACOGA(distances, n_ants=n_ants, decay=decay, alpha=alpha, beta=beta
                           ga_elite_size=ga_elite_size, ga_mutation_rate=ga_mutation_rat
                           generations=num_of_generations)
```

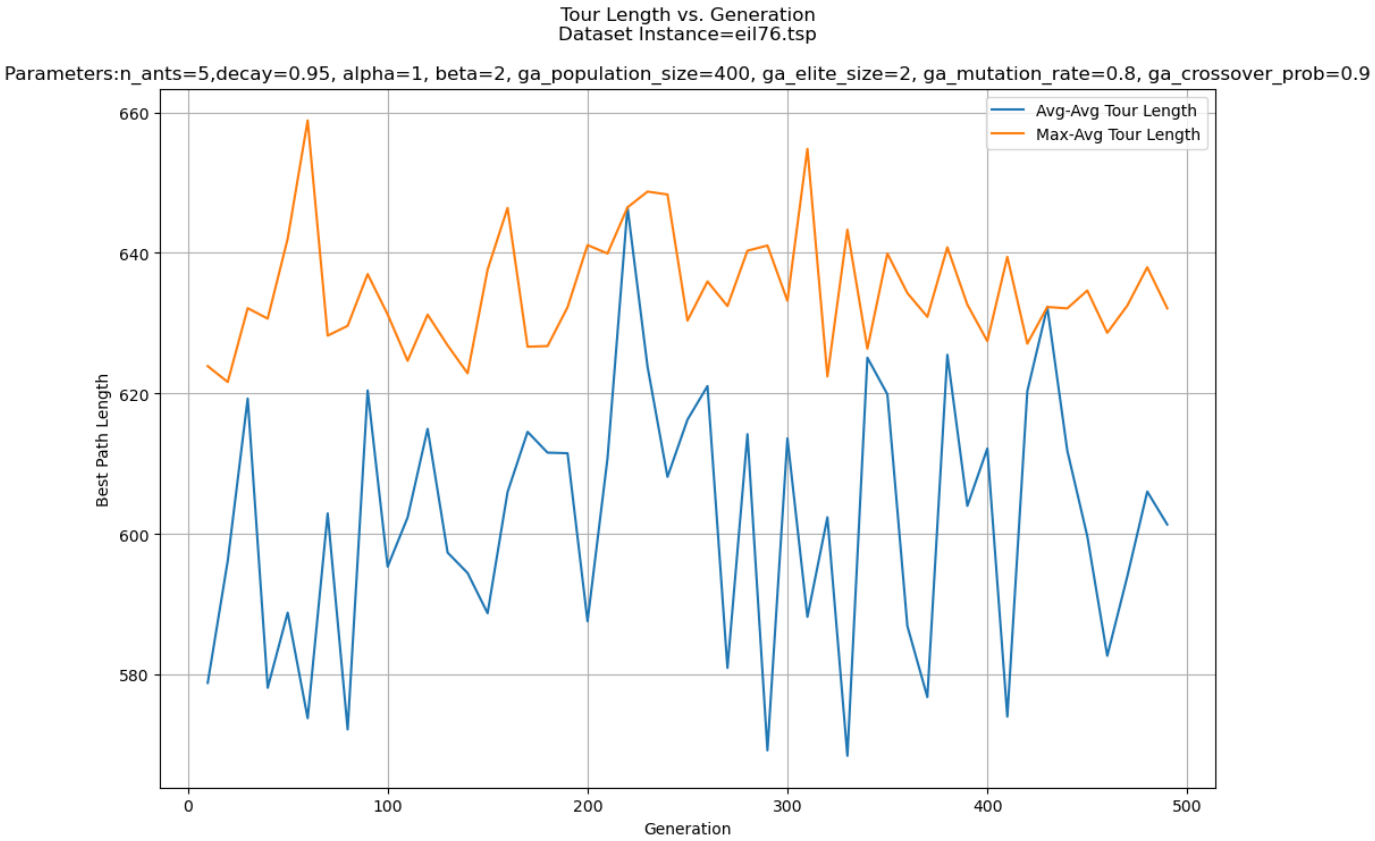
```
            # Measure execution time
            start_time = time.time()

            # Run ACOGA
            result = aco_ga.run()

            # Measure execution time
            execution_time = time.time() - start_time

            # Store data for plotting

            execution_times_list.append(execution_time)

            # Extract result data
            best_path_indices = result[0]

            # Calculate best path length
            best_path_length = np.sum([distances[i, j] for i, j in best_path_indices])

            # Update best path length arrays
            avg_best_path_length[:len(best_path_indices)] = np.array([best_path_length])
            max_best_path_length[:len(best_path_indices)] = np.maximum(max_best_path_len

            # Print results
            #print("Best Path Indices:", best_path_indices)
            #print("Best Path Length:", best_path_length)


    # Print average and maximum best path lengths after all runs for each generation


    #overall_avg_best_path_length = np.mean(avg_best_path_length[:num_generations_acoga]
    #overall_max_best_path_length = np.max(max_best_path_length[:num_generations_acoga])

    overall_avg_best_path_length = np.mean(avg_best_path_length[:num_runs])
    overall_max_best_path_length = np.max(max_best_path_length[:num_runs])

    print("generations:", generations)
    print("overall_avg_best_path_length:", overall_avg_best_path_length)
    print("overall_max_best_path_length:", overall_max_best_path_length)

    generations_list.append(generations)
    overall_avg_best_path_lengths_list.append(overall_avg_best_path_length)
    overall_max_best_path_lengths_list.append(overall_max_best_path_length)

# Plotting with magnified figure size
plt.figure(figsize=(12, 8))

# Plotting
plt.plot(generations_list, overall_avg_best_path_lengths_list, label='Avg-Avg Tour Lengt
plt.plot(generations_list, overall_max_best_path_lengths_list, label='Max-Avg Tour Lengt

# Customize plot appearance
plt.xlabel('Generation')
plt.ylabel('Best Path Length')
plt.title('Overall Best Path Lengths vs. Generation')
plt.title(f'Tour Length vs. Generation\nDataset Instance={file_path}\n\nParameters:n_ant


plt.legend()
plt.grid(True)
plt.show()
```

```
generations: 10
overall_avg_best_path_length: 578.82
overall_max_best_path_length: 623.89
```

```
generations: 20
overall_avg_best_path_length: 596.1700000000001
overall_max_best_path_length: 621.6299999999999
generations: 30
overall_avg_best_path_length: 619.28
overall_max_best_path_length: 632.1400000000001
generations: 40
overall_avg_best_path_length: 578.1200000000001
overall_max_best_path_length: 630.6500000000001
generations: 50
overall_avg_best_path_length: 588.8100000000001
overall_max_best_path_length: 642.03
generations: 60
overall_avg_best_path_length: 573.7900000000003
overall_max_best_path_length: 658.85
generations: 70
overall_avg_best_path_length: 602.9300000000001
overall_max_best_path_length: 628.23
generations: 80
overall_avg_best_path_length: 572.19
overall_max_best_path_length: 629.6300000000001
generations: 90
overall_avg_best_path_length: 620.4300000000001
overall_max_best_path_length: 636.99
generations: 100
overall_avg_best_path_length: 595.3600000000001
overall_max_best_path_length: 631.2499999999999
generations: 110
overall_avg_best_path_length: 602.3600000000001
overall_max_best_path_length: 624.65
generations: 120
overall_avg_best_path_length: 614.97
overall_max_best_path_length: 631.22
generations: 130
overall_avg_best_path_length: 597.3600000000001
overall_max_best_path_length: 626.85
generations: 140
overall_avg_best_path_length: 594.45
overall_max_best_path_length: 622.87
generations: 150
overall_avg_best_path_length: 588.7299999999998
overall_max_best_path_length: 637.6200000000001
generations: 160
overall_avg_best_path_length: 605.9799999999999
overall_max_best_path_length: 646.41
generations: 170
overall_avg_best_path_length: 614.5400000000003
overall_max_best_path_length: 626.6499999999999
generations: 180
overall_avg_best_path_length: 611.5800000000003
overall_max_best_path_length: 626.75
generations: 190
overall_avg_best_path_length: 611.5000000000001
overall_max_best_path_length: 632.2700000000001
generations: 200
overall_avg_best_path_length: 587.5899999999999
overall_max_best_path_length: 641.1199999999999
generations: 210
overall_avg_best_path_length: 610.78
overall_max_best_path_length: 639.92
generations: 220
overall_avg_best_path_length: 646.4799999999999
overall_max_best_path_length: 646.48
generations: 230
overall_avg_best_path_length: 623.84
overall_max_best_path_length: 648.7300000000001
```

generations: 240
overall_avg_best_path_length: 608.1300000000003
overall_max_best_path_length: 648.3199999999999
generations: 250
overall_avg_best_path_length: 616.28
overall_max_best_path_length: 630.3700000000001
generations: 260
overall_avg_best_path_length: 621.0499999999998
overall_max_best_path_length: 635.9400000000002
generations: 270
overall_avg_best_path_length: 580.9500000000002
overall_max_best_path_length: 632.44
generations: 280
overall_avg_best_path_length: 614.2099999999998
overall_max_best_path_length: 640.32
generations: 290
overall_avg_best_path_length: 569.2099999999998
overall_max_best_path_length: 641.05
generations: 300
overall_avg_best_path_length: 613.6100000000002
overall_max_best_path_length: 633.1999999999999
generations: 310
overall_avg_best_path_length: 588.2099999999998
overall_max_best_path_length: 654.8199999999999
generations: 320
overall_avg_best_path_length: 602.3799999999999
overall_max_best_path_length: 622.43
generations: 330
overall_avg_best_path_length: 568.4400000000002
overall_max_best_path_length: 643.3100000000001
generations: 340
overall_avg_best_path_length: 625.0899999999999
overall_max_best_path_length: 626.37
generations: 350
overall_avg_best_path_length: 619.88
overall_max_best_path_length: 639.9200000000001
generations: 360
overall_avg_best_path_length: 586.9000000000001
overall_max_best_path_length: 634.29
generations: 370
overall_avg_best_path_length: 576.7999999999998
overall_max_best_path_length: 630.9100000000001
generations: 380
overall_avg_best_path_length: 625.5099999999998
overall_max_best_path_length: 640.8
generations: 390
overall_avg_best_path_length: 604.0099999999999
overall_max_best_path_length: 632.64
generations: 400
overall_avg_best_path_length: 612.1699999999997
overall_max_best_path_length: 627.45
generations: 410
overall_avg_best_path_length: 574.01
overall_max_best_path_length: 639.4399999999998
generations: 420
overall_avg_best_path_length: 620.3100000000002
overall_max_best_path_length: 627.0899999999999
generations: 430
overall_avg_best_path_length: 632.31
overall_max_best_path_length: 632.3099999999998
generations: 440
overall_avg_best_path_length: 611.8600000000001
overall_max_best_path_length: 632.1100000000001
generations: 450
overall_avg_best_path_length: 599.7000000000002
overall_max_best_path_length: 634.6500000000001

```
generations: 460
overall_avg_best_path_length: 582.6699999999998
overall_max_best_path_length: 628.63
generations: 470
overall_avg_best_path_length: 593.9500000000002
overall_max_best_path_length: 632.5000000000001
generations: 480
overall_avg_best_path_length: 606.0400000000002
overall_max_best_path_length: 637.9600000000002
generations: 490
overall_avg_best_path_length: 601.3499999999999
overall_max_best_path_length: 632.1199999999999
```



In [ ]: