

Assignment 6 - Multiple Start Local Search and Iterated Local Search

Authors

- Michał Kamiński 151969
- Jan Indrzejczak 152059

Description of the problem

The travelling salesman problem (TSP) is a classic optimization problem. Given a list of cities and the distances between them, the task is to find the shortest possible route that visits each city exactly once and returns to the origin city. In this version of the problem, each city also has a cost of being visited, and we only need to select half of the cities.

As an input we received a list of coordinates of cities, along with the cost. To calculate the distance between cities we used Euclidean distance, and each city is represented as a number from 0 to $n-1$ (n -number of cities). The objective function is to find the route that minimizes the sum of distances between cities and the cost of visiting them.

Pseudocode of all implemented algorithms

Multiple Start Local Search

```
1. Initialize Variables
Best solution = empty
Best score = infinity

2. Repeat 200 times:
    Generate starting solution
    Run local search (either steepest or steepest with the use of deltas)
    Evaluate the solution
    Store the best solution and scores if it is better

3. Return the best solution
```

Iterated Local Search

```
1. Generate initial solution
2. Apply local search (steepest with the use of deltas)
3. Repeat until time limit has been reached:
    Perturb the solution
    Apply local search (steepest with the use of deltas)
```

If the new solution is better than the current one, replace it

4. Retrun the solution

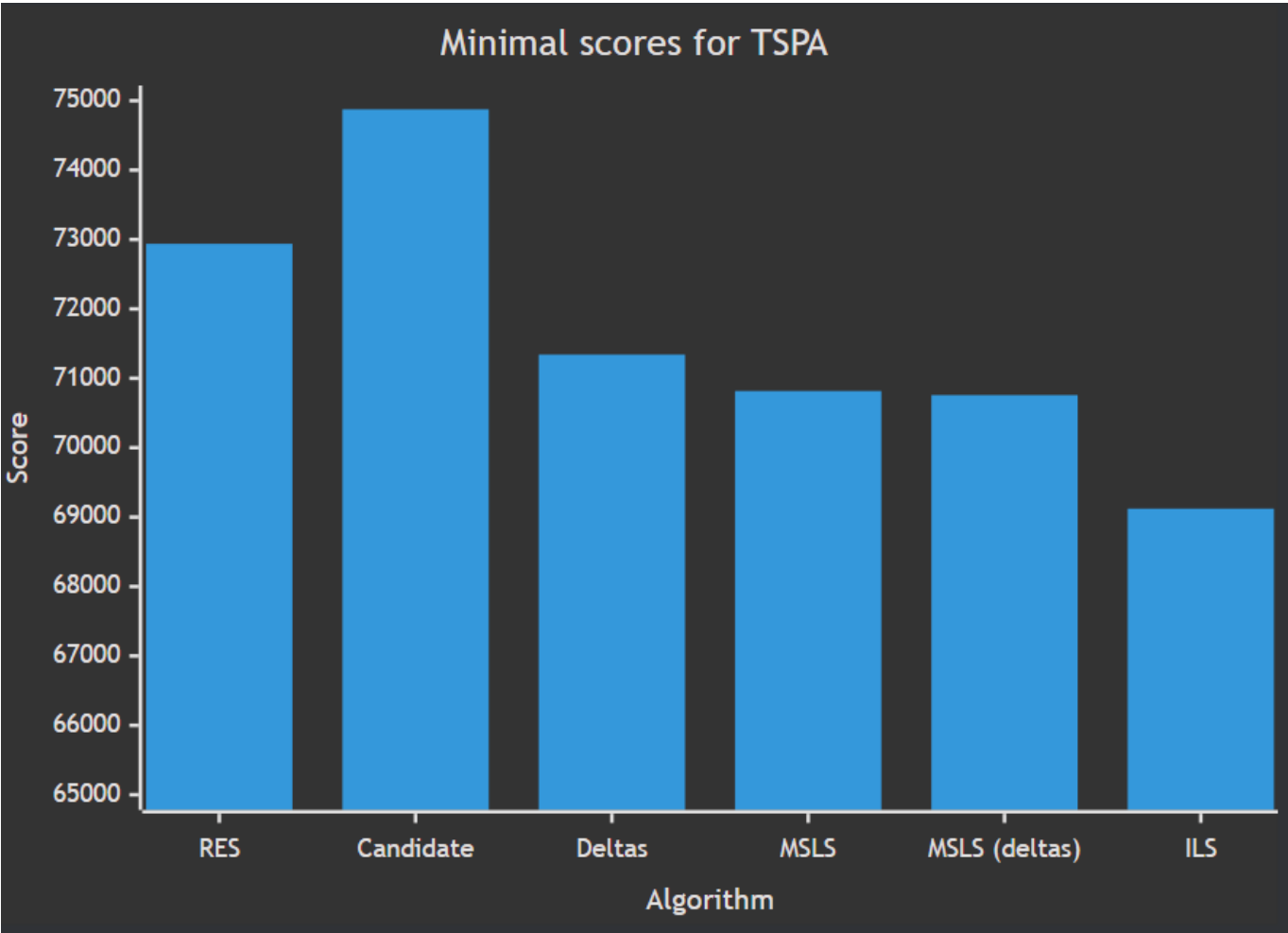
Perturbation:

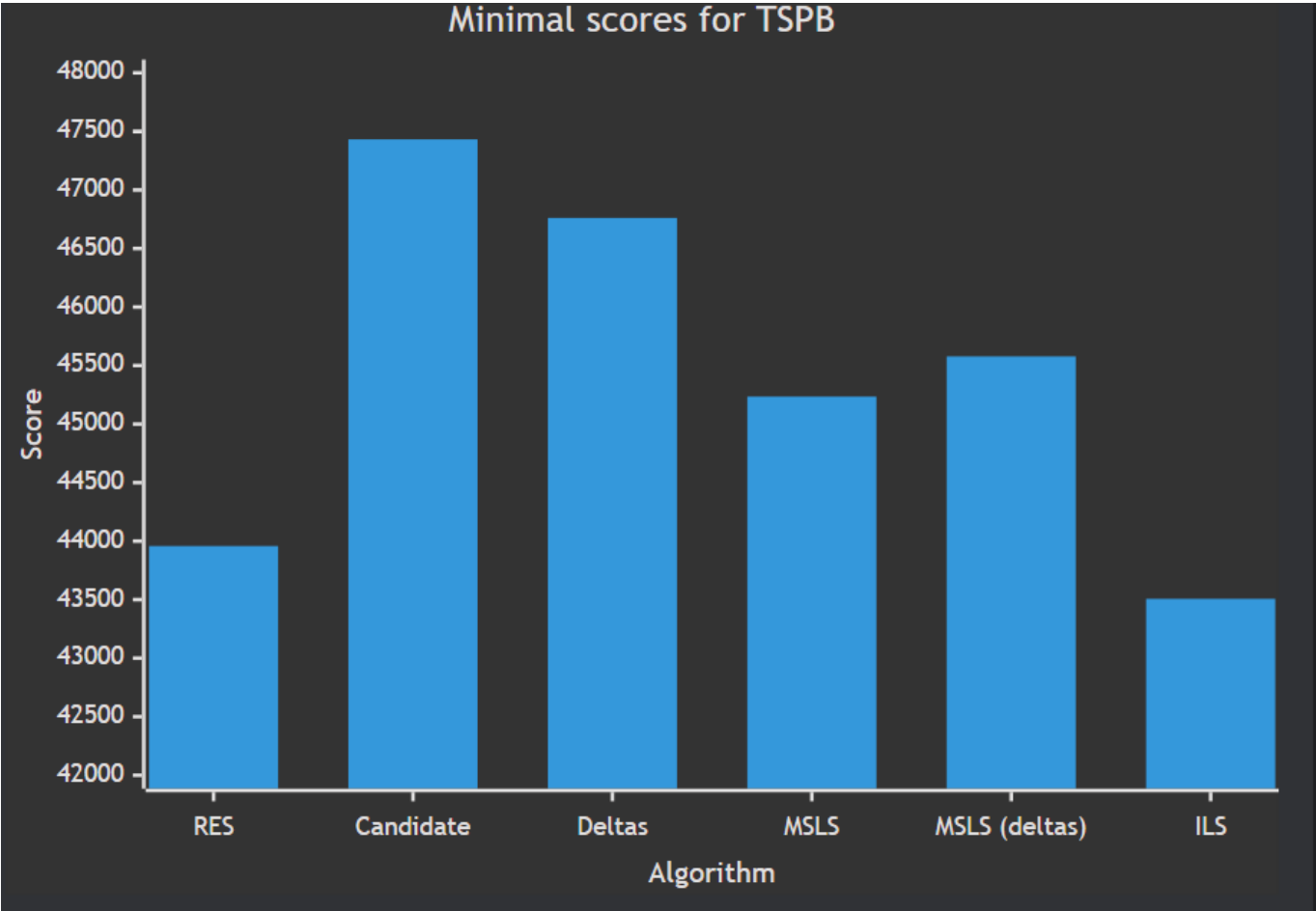
1. Repeat 20 times:
 - Randomly select move type (Intra or Inter)
 - Radomly select move parameters
 - Apply the move
2. Return the perturbed solution

Table of the results

Algorithm	TSPA	TSPB
Random Start Two Nodes Intra Greedy	86727 (82039-95867)	61477 (53396-67230)
Random Start Two Edges Intra Greedy	74035 (77907-82039)	48390 (45665-51760)
Greedy Start Two Nodes Intra Greedy	71599 (70602-72778)	45331 (43826-51911)
Greedy Start Two Edges Intra Greedy	71335 (70004-72452)	44898 (43790-50892)
Random Start Two Nodes Intra Steepest	88618 (81178-98102)	63387 (56112-73195)
Greedy Start Two Nodes Intra Steepest	71936 (71041-73353)	45355 (43862-51147)
Greedy Start Two Edges Intra Steepest	71677 (70397-72984)	45008 (43958-50901)
Random Start Two Edges Intra Steepest Candidate	79763 (74876-84144)	51500 (47433-58226)
Random Start Two Edges Intra Steepest	75326 (72938-80126)	49725 (46957-52832)
Random Start Two Edges Intra Steepest Deltas	74207 (71342-78723)	49160 (46761-52674)
Random Start Two Edges Intra Steepest Multiple Start Local Search	71299 (70817-71812)	45970 (45235-46595)
Random Start Two Edges Intra Steepest Deltas Multiple Start Local Search	71700 (70758-72325)	46101 (45578-46676)

Algorithm	TSPA	TSPB
Random Start Two Edges Intra Steepest Deltas Iterated Local Search	69340 (69122-69531)	43647 (43507-43877)





Results of previous algorithms

Algorithm	TSPA	TSPB
Random Algorithm	225467	193417
Nearest Neighbor (Add at End)	83182	52319
Nearest Neighbor (Insert Anywhere)	71179	44417
Greedy Cycle	72636 (71488-74410)	51401 (49001-57324)
Greedy Regret Heuristic with 2-Regret	116681 (108804-123447)	70265 (65043-76325)
Greedy Regret Heuristic with Weighted 2-Regret	72148 (71108-73718)	50997 (47144-56747)
Random Start Two Edges Intra Steepest Candidate	79763 (74876-84144)	51500 (47433-58226)
Random Start Two Edges Intra Steepest	75172 (72784-80372)	49635 (47325-52654)

Table of execution times in microseconds (μs)

Algorithm	TSPA	TSPB
Random Start Two Nodes Intra Greedy	7634	7254
Random Start Two Edges Intra Greedy	5436	5166

Algorithm	TSPA	TSPB
Greedy Start Two Nodes Intra Greedy	13122	12566
Greedy Start Two Edges Intra Greedy	13836	12623
Random Start Two Nodes Intra Steepest	27127	28967
Greedy Start Two Nodes Intra Steepest	12350	12597
Greedy Start Two Edges Intra Steepest	12498	12690
Random Start Two Edges Intra Steepest Candidate	9225	9826
Random Start Two Edges Intra Steepest	18214	18860
Random Start Two Edges Intra Steepest Deltas	8818	9259
Random Start Two Edges Intra Steepest Multiple Start Local Search	6573463	6539911
Random Start Two Edges Intra Steepest Deltas Multiple Start Local Search	2182366	2067664
Random Start Two Edges Intra Steepest Deltas Iterated Local Search	2001405	2001686

Table of number of local search iterations

Algorithm	Iterations
Random Start Two Edges Intra Steepest Multiple Start Local Search	200
Random Start Two Edges Intra Steepest Deltas Multiple Start Local Search	200
Random Start Two Edges Intra Steepest Deltas Iterated Local Search	382

Raw results

TSPA

Results for Random Start Two Edges Intra Steepest Multiple Start Local Search

Min cost: 70817

Max cost: 71812

Average cost: 71299

Time took for 20 runs: 131.46927050s, time per run: 6573463μs

Best solution:

[151, 162, 133, 180, 53, 154, 135, 70, 127, 123, 149, 65, 116, 59, 115, 46, 68, 139, 41, 193, 159, 42, 43, 184, 35, 84, 112, 4, 190, 10, 177, 30, 54, 48, 160, 34, 22, 18, 108, 93, 117, 0, 143, 183, 89, 23, 137, 186, 15, 148, 9, 62, 102, 49, 14, 144, 21, 7, 164, 27, 90, 81, 196, 40, 119, 165, 185, 106, 178, 52, 55, 57, 92, 145, 78, 31, 113, 175, 171, 16, 25, 44,

120, 129, 2, 152, 97, 1, 101, 75, 86, 100, 26, 124, 94, 63, 79, 80, 176, 51]

Results for Random Start Two Edges Intra Steepest Deltas Multiple Start Local Search

Min cost: 70758

Max cost: 72325

Average cost: 71700

Time took for 20 runs: 43.64732230s, time per run: 2182366 μ s

Best solution:

[22, 18, 159, 193, 41, 139, 115, 46, 68, 117, 0, 143, 183, 89, 186, 23, 137, 176, 80, 133, 79, 122, 63, 94, 124, 148, 9, 62, 102, 49, 144, 14, 138, 3, 178, 106, 185, 40, 119, 165, 39, 27, 90, 81, 196, 179, 52, 55, 57, 92, 129, 82, 78, 145, 31, 56, 113, 175, 171, 16, 25, 44, 120, 2, 152, 97, 1, 101, 75, 86, 26, 100, 121, 53, 158, 180, 154, 135, 70, 127, 123, 162, 151, 51, 118, 59, 65, 116, 43, 42, 184, 84, 112, 4, 177, 54, 48, 160, 34, 146]

Results for Random Start Two Edges Intra Steepest Deltas Iterated Local Search

Min cost: 69122

Max cost: 69531

Average cost: 69340

Time took for 20 runs: 40.02811420s, time per run: 2001405 μ s

Best solution:

[151, 51, 118, 59, 115, 46, 68, 139, 41, 193, 159, 181, 42, 43, 116, 65, 149, 131, 184, 84, 112, 4, 190, 10, 177, 54, 48, 160, 34, 146, 22, 18, 108, 140, 93, 117, 0, 143, 183, 89, 186, 23, 137, 176, 80, 79, 63, 94, 124, 148, 9, 62, 102, 144, 14, 49, 178, 106, 52, 55, 57, 129, 92, 78, 145, 179, 185, 40, 119, 165, 90, 81, 196, 31, 56, 113, 175, 171, 16, 25, 44, 120, 2, 152, 97, 1, 101, 75, 86, 26, 100, 53, 180, 154, 135, 70, 127, 123, 162, 133]

TSPB

Results for Random Start Two Edges Intra Steepest Multiple Start Local Search

Min cost: 45235

Max cost: 46595

Average cost: 45970

Time took for 20 runs: 130.79823430s, time per run: 6539911 μ s

Best solution:

[124, 106, 143, 111, 82, 87, 21, 8, 56, 104, 138, 139, 11, 33, 160, 144, 0, 35, 109, 29, 168, 195, 13, 145, 15, 3, 70, 132, 169, 188, 6, 147, 191, 90, 125, 51, 121, 131, 135, 122, 133, 107, 40, 100, 63, 38, 27, 1, 156, 198, 117, 54, 73, 31, 193, 190, 80, 175, 78, 5, 177, 36, 61, 91, 141, 97, 77, 81, 153, 163, 89, 165, 127, 103, 113, 180, 176, 194, 166, 86, 95, 130, 99, 185, 179, 94, 47, 148, 20, 28, 149, 4, 199, 140, 183, 152, 34, 55, 18,

62]

Results for Random Start Two Edges Intra Steepest Deltas Multiple Start Local Search

Min cost: 45578

Max cost: 46676

Average cost: 46101

Time took for 20 runs: 41.35328490s, time per run: 2067664μs

Best solution:

[11, 138, 33, 160, 144, 56, 104, 8, 21, 82, 111, 29, 0, 109, 35, 143, 106, 124, 62, 18, 55, 34, 170, 152, 183, 140, 4, 149, 28, 20, 60, 148, 47, 94, 66, 179, 185, 130, 95, 86, 166, 194, 176, 180, 113, 103, 89, 127, 163, 153, 77, 97, 141, 61, 36, 177, 5, 175, 45, 190, 80, 73, 54, 31, 193, 117, 198, 156, 1, 16, 27, 38, 102, 63, 135, 122, 100, 40, 107, 133, 10, 147, 90, 121, 51, 134, 6, 188, 65, 169, 132, 70, 3, 15, 145, 13, 195, 168, 43, 139]

Results for Random Start Two Edges Intra Steepest Deltas Iterated Local Search

Min cost: 43507

Max cost: 43877

Average cost: 43647

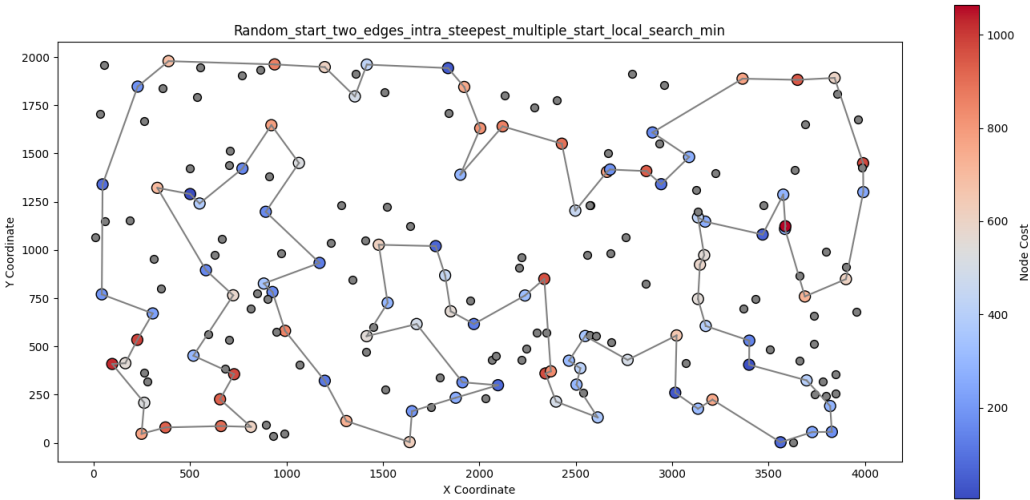
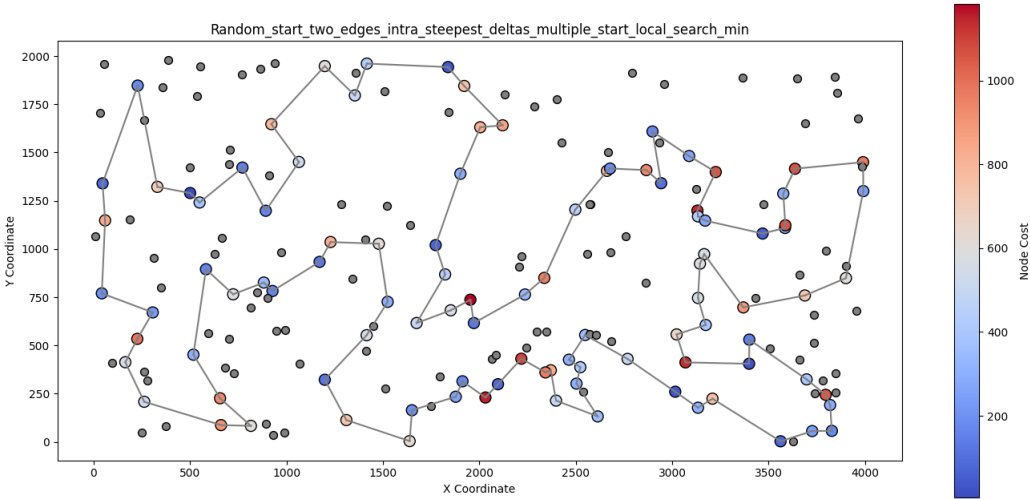
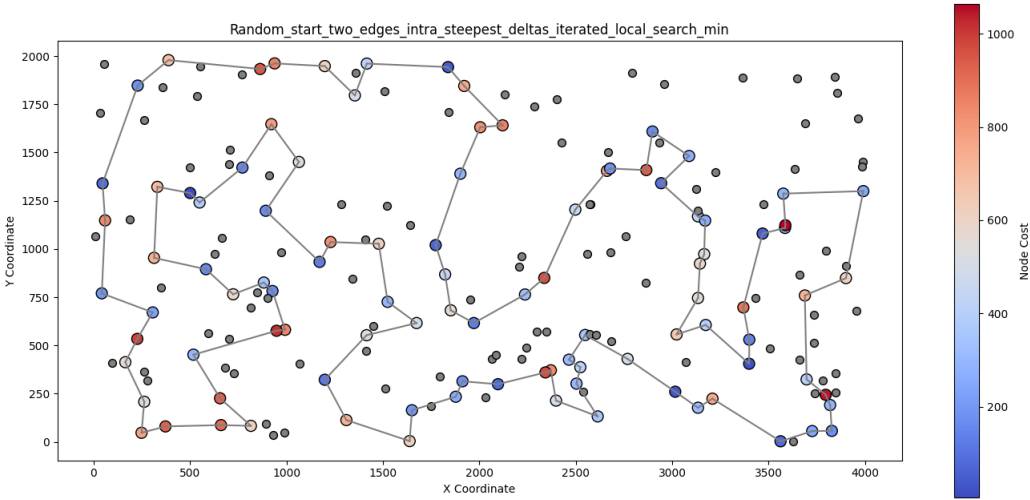
Time took for 20 runs: 40.03373060s, time per run: 2001686μs

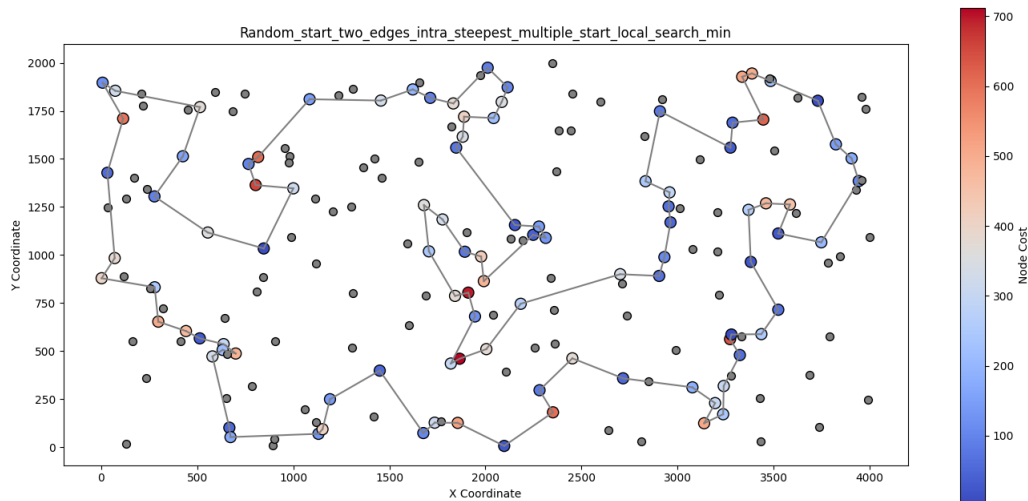
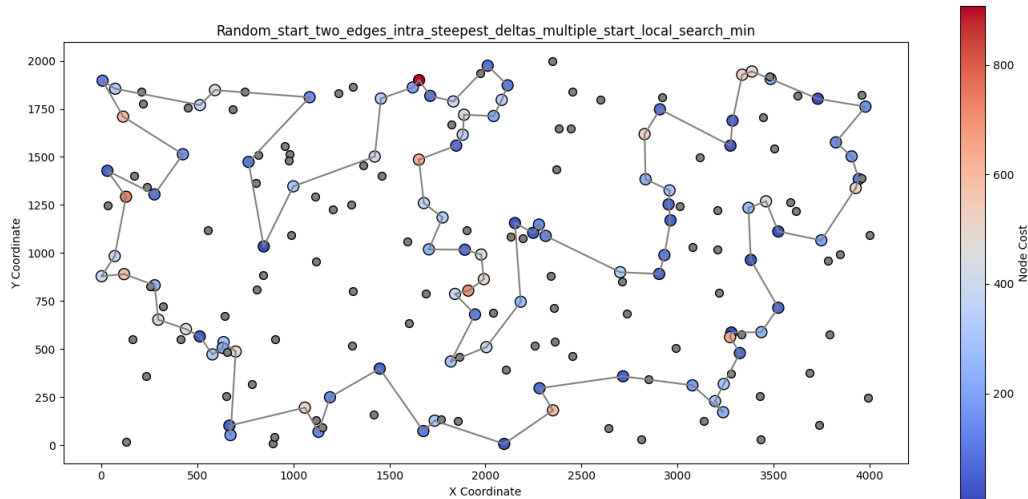
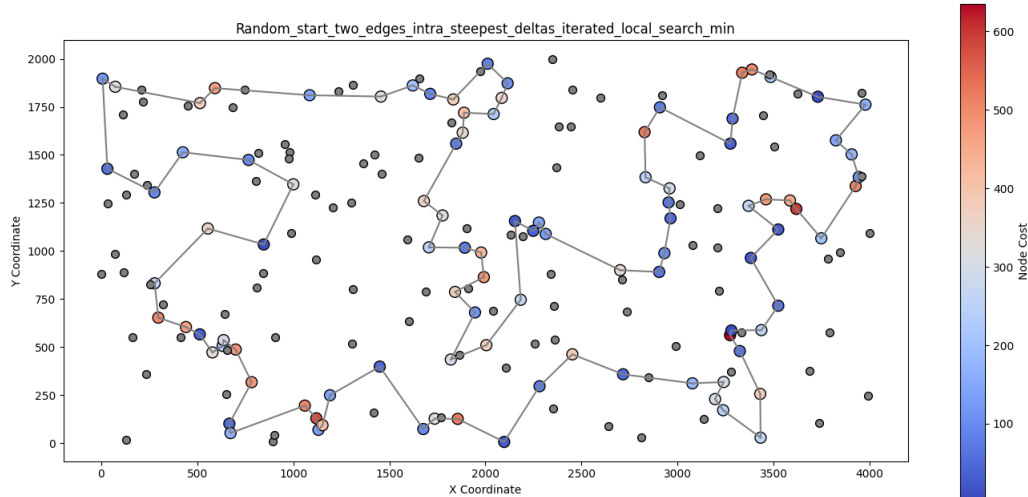
Best solution:

[55, 18, 62, 124, 106, 143, 35, 109, 0, 29, 111, 82, 21, 8, 104, 144, 160, 33, 138, 11, 139, 168, 195, 13, 145, 15, 3, 70, 132, 169, 188, 6, 147, 10, 133, 107, 40, 63, 135, 122, 90, 51, 121, 131, 1, 15 6, 198, 117, 193, 31, 54, 73, 136, 190, 80, 45, 142, 175, 78, 5, 177, 36, 61, 91, 141, 77, 81, 153, 163, 103, 89, 127, 137, 114, 113, 180, 176, 194, 166, 86, 185, 95, 130, 99, 22, 179, 66, 94, 47, 148, 60, 20, 28, 149, 4, 140, 183, 152, 170, 34]

Plots of the results

TSPA





Source code

- [Github repository](#)

Conclusions

All implemented methods performed better than the previous ones. Multiple Start Local search with the use of Local Search with deltas always improved the solution and time execution. Time per run was around 2 seconds, thus this was also the limit for Iterated Local Search. ILS consistently outperformed MSLS. As the perturbation function we used simple stacking of 20 random moves. The number of moves was tested experimentally and this gave the best results.