Raport 3 - Local search GITHUB

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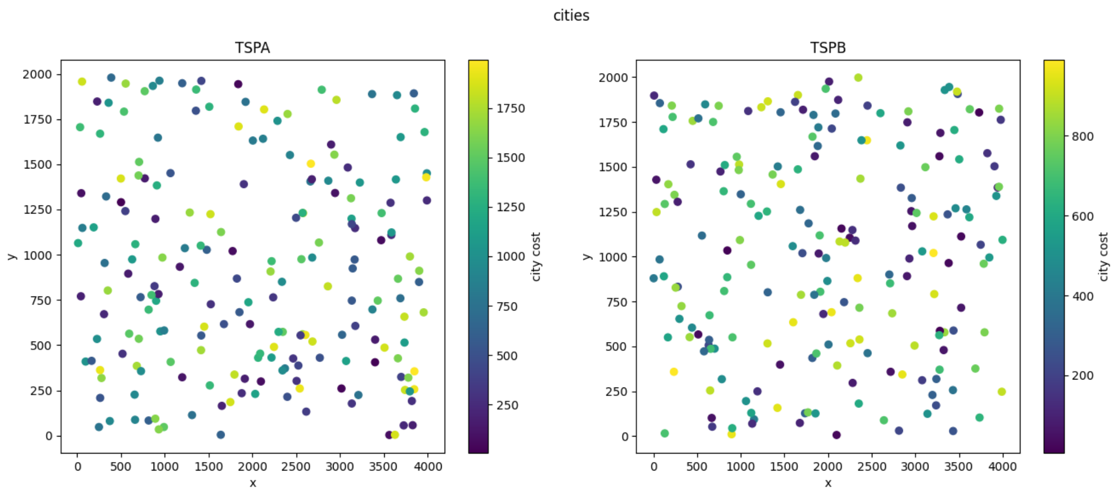
The **Traveling Salesman Problem (TSP)** is an optimization problem where the objective is to find the shortest possible route that visits a set of cities exactly once and returns to the starting city. In its traditional form, the TSP assumes that the cost of traveling between any two cities is known and fixed, and the salesman must visit all cities.

Modified TSP Problem with Additional Constraints

1. **Additional City Cost**:
   In this modified version, each city has an associated **fixed cost** (besides the cost of travel). This city cost represents an additional expense incurred for visiting the city. Therefore, the total cost of the route is the sum of the travel costs between cities and the individual costs for each visited city. The objective becomes minimizing the total of both travel costs and city costs.

2. **Selection of Only 50% of Cities**:
   Another key modification is that the salesman is not required to visit **all** cities. Instead, the objective is to visit **exactly 50% of the available cities**. This creates a **sub-selection** problem where the salesman must decide which subset of cities to visit while minimizing the total cost (**travel + city cost**).

This visual representation provides an intuitive way to interpret the spatial relationships between cities, their associated fixed costs, and potential travel paths.



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Combined TSPA and TSPB results table:

Instance TSPA results table:

Method	Min	Mean	Max	Time* (s)
`random`	233148	263540	284518	0.1673
`greedy_tail`	83182	85107	89433	0.1566
`greedy_any_position`	71263	73202	76156	0.9481
`greedy_cycle`	71488	72609	74410	0.4627
`greedy_cycle_regret`	108935	116548	126990	2.5311
`greedy_cycle_weighted_regret`	71108	72135	73395	2.3133

Method	Min	Mean	Max	Time* (s)
`local_search_with_edges_swaps_greedy_random`	71492	73710	76560	63.7732
`local_search_with_edges_swaps_greedy_heuristic`	69620	71167	73909	3.1254
`local_search_with_edges_swaps_steepest_random`	71646	73914	78738	15.9961
`local_search_with_edges_swaps_steepest_heuristic`	69864	70963	73030	2.1335
`local_search_with_nodes_swaps_greedy_random`	77870	86045	93708	81.1029
`local_search_with_nodes_swaps_greedy_heuristic`	70917	72792	75353	1.1359
`local_search_with_nodes_swaps_steepest_random`	79894	88098	96234	16.0166
`local_search_with_nodes_swaps_steepest_heuristic`	70844	72810	75353	1.1488

Instance TSPB results table:

Method	Min	Mean	Max	Time* (s)
`random`	185339	213695	239113	0.0071
`greedy_tail`	52319	54390	59030	0.0280
`greedy_any_position`	44446	46131	53438	0.6900
`greedy_cycle`	48765	51301	57324	0.4619
`greedy_cycle_regret`	67175	73164	79784	2.1903
`greedy_cycle_weighted_regret`	47144	50985	55700	2.3359

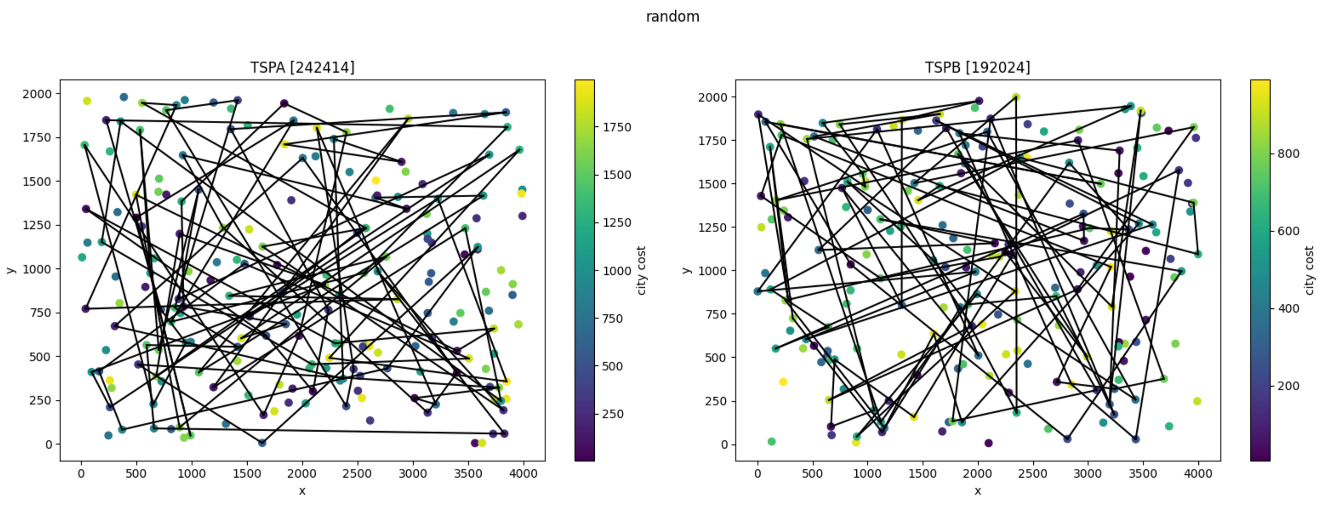
Method	Min	Mean	Max	Time* (s)
`local_search_with_edges_swaps_greedy_random`	46029	48352	51147	66.4630
`local_search_with_edges_swaps_greedy_heuristic`	43758	45089	51466	2.0703

Method	Min	Mean	Max	Time* (s)
`local_search_with_edges_swaps_steepest_random`	46021	48303	50845	16.3699
`local_search_with_edges_swaps_steepest_heuristic`	43921	45024	50766	1.9482
`local_search_with_nodes_swaps_greedy_random`	54949	61246	68531	95.5620
`local_search_with_nodes_swaps_greedy_heuristic`	43826	45667	51789	1.4737
`local_search_with_nodes_swaps_steepest_random`	57028	63071	73731	15.8347
`local_search_with_nodes_swaps_steepest_heuristic`	43826	45619	51789	1.3292

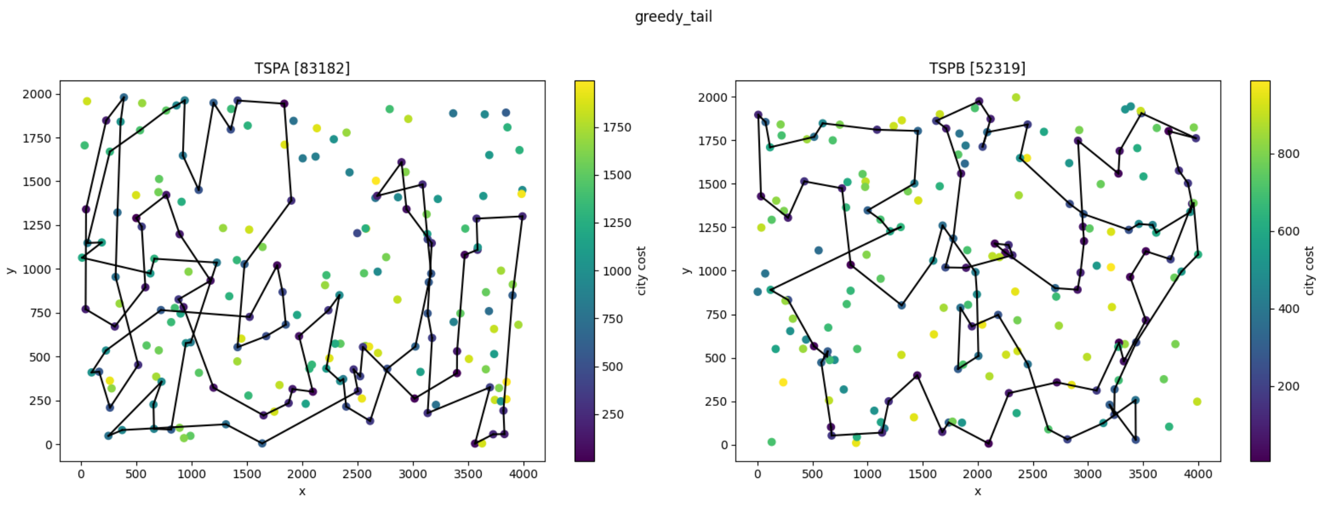
Time* - to solve all 200 instances

Solutions

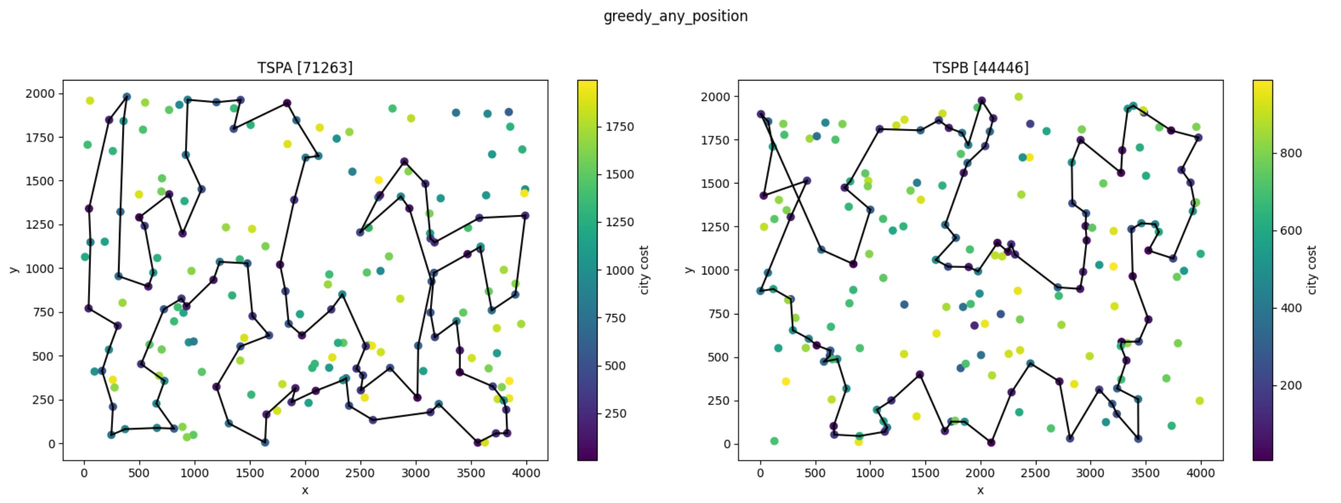
Random



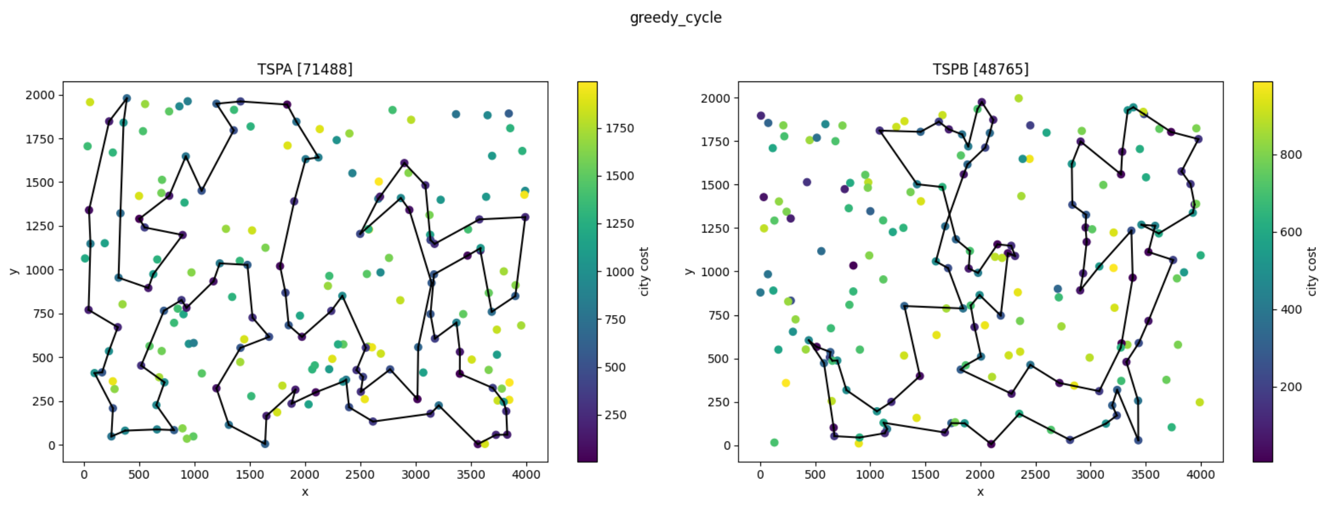
Greedy tail



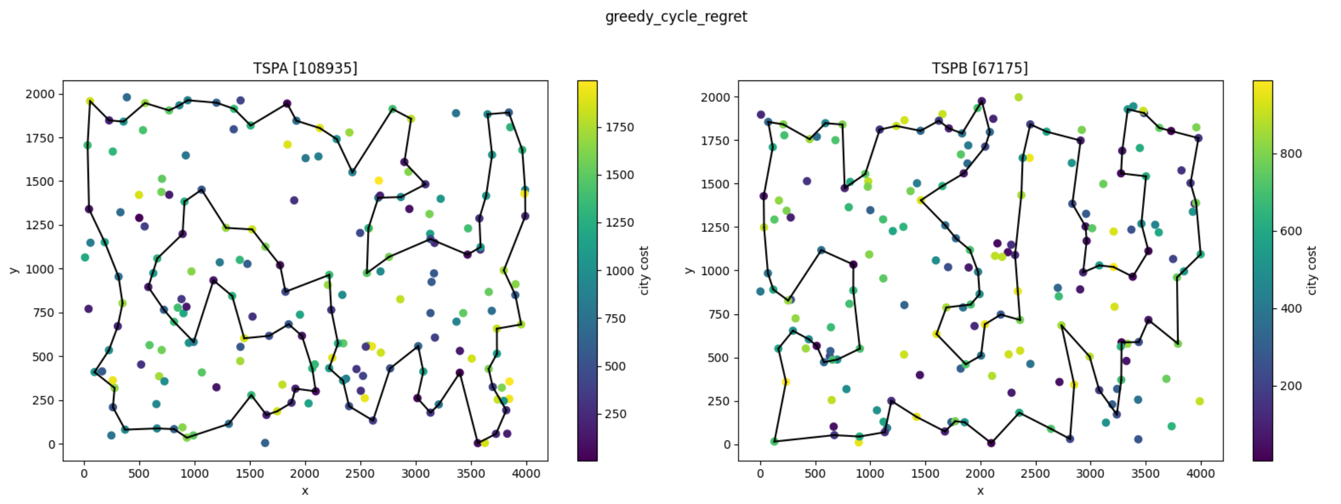
Greedy any position



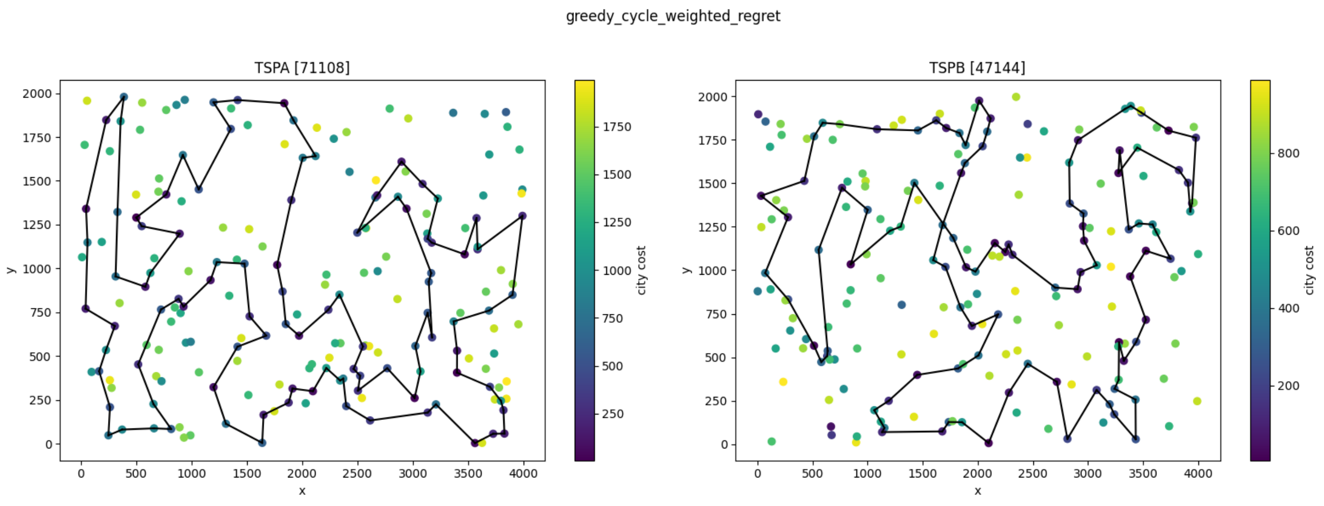
Greedy cycle



Greedy cycle regret



Greedy cycle weighted regret



Local search pseudo code:

we have three possible moves in our implementation:

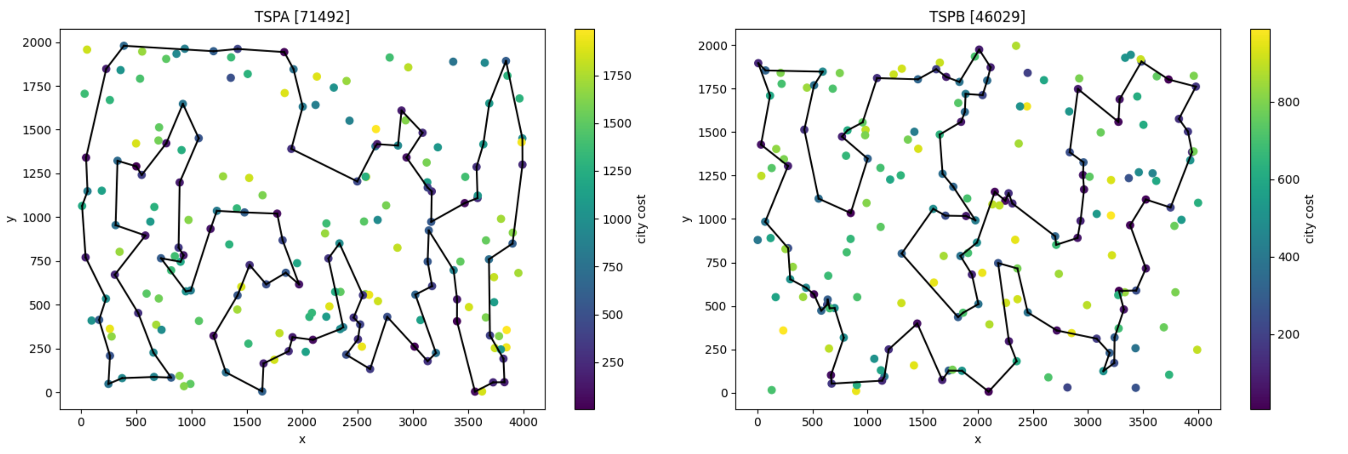
```
EdgeSwap(edge1: (Int, Int), edge2: (Int, Int))
NodeSwapOut(triplet: (Int, Int, Int), city: Int)
NodeSwapIn(triplet1: (Int, Int, Int), triplet2: (Int, Int, Int))
```

```
    def getNeighbourhoodWithEdgesSwapsIn() {
        pairs = all consecutive city pairs in the current cycle
        triplets = all consecutive city triplets in the current cycle
        edgeSwapsIn = all combinations of pairs with itself (without repetition)
        nodeSwapsOut = all combinations of triplets and all available cities not yet
included in the solution
        edgeSwapsIn ++ nodeSwapsOut
    }

    def getNeighbourhoodWithNodesSwapsIn() {
        triplets = all consecutive city triplets in the current cycle
        nodesSwapsIn = all combinations of pairs with itself (without repetition)
        nodeSwapsOut = all combinations of triplets and all available cities not yet
included in the solution
        nodesSwapsIn ++ nodeSwapsOut
    }
```

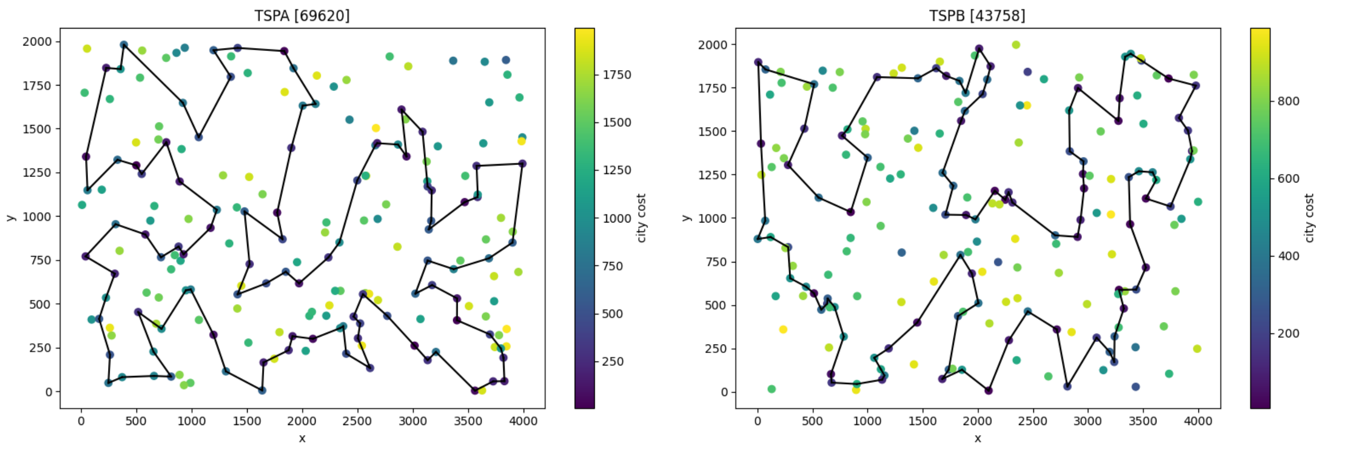
```
    def getGreedyImpovementMove() {
        firstImprovingMove = shuffle randomly all possible moves and take the first
for which delta_cost < 0
    }

    def getSteepestImprovementMove() {
        bestImprovingMoves = map each move to the tuple (move, deltaCost), and take
the one with minimal delta_cost
    }
```

Local search with edges swaps greedy

local_search_with_edges_swaps_greedy_random

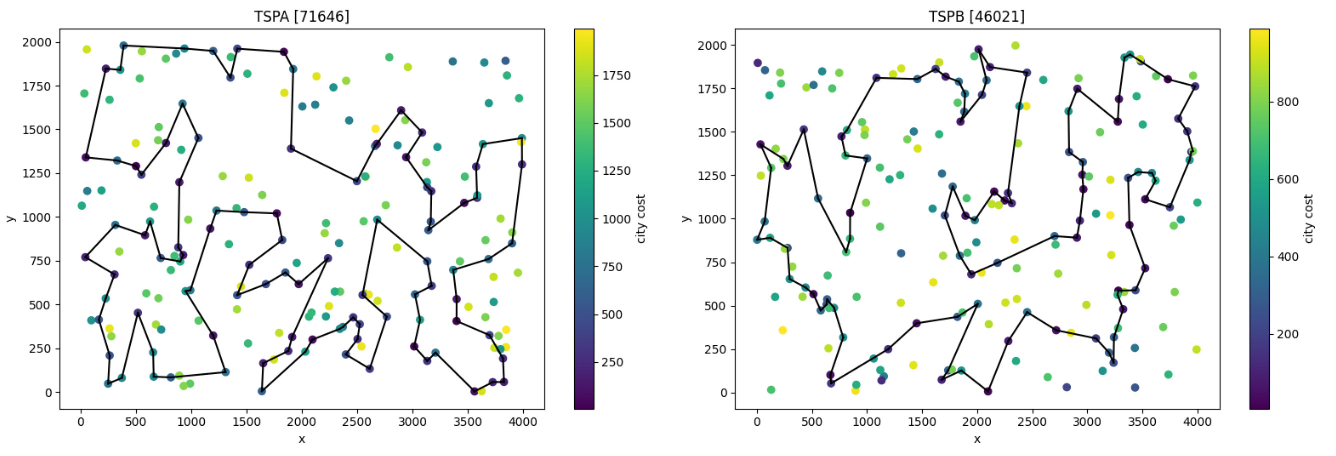


local_search_with_edges_swaps_greedy_heuristic

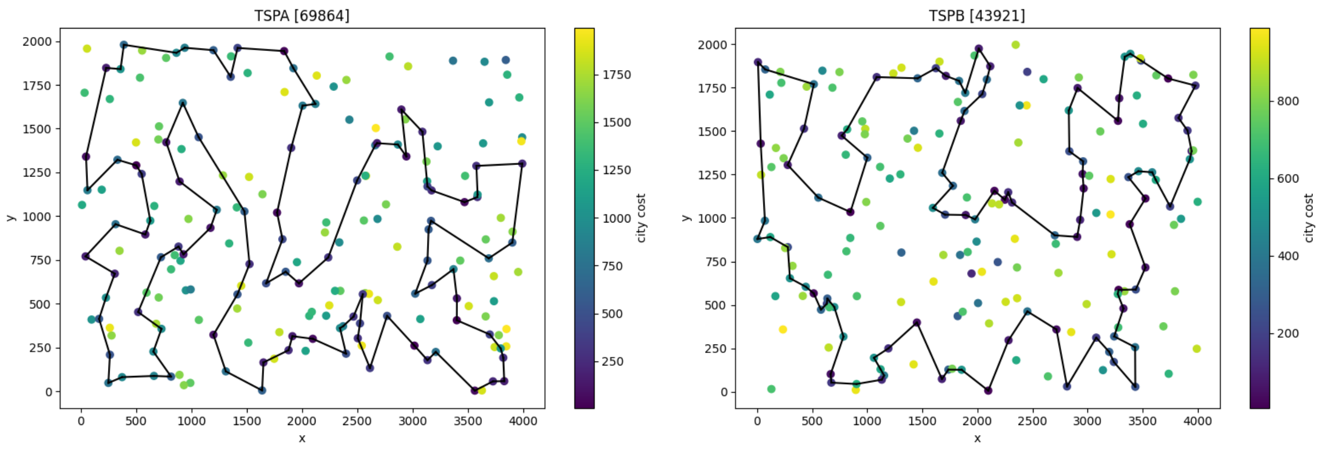


Local serach with edges swaps steepet

local_search_with_edges_swaps_steepest_random

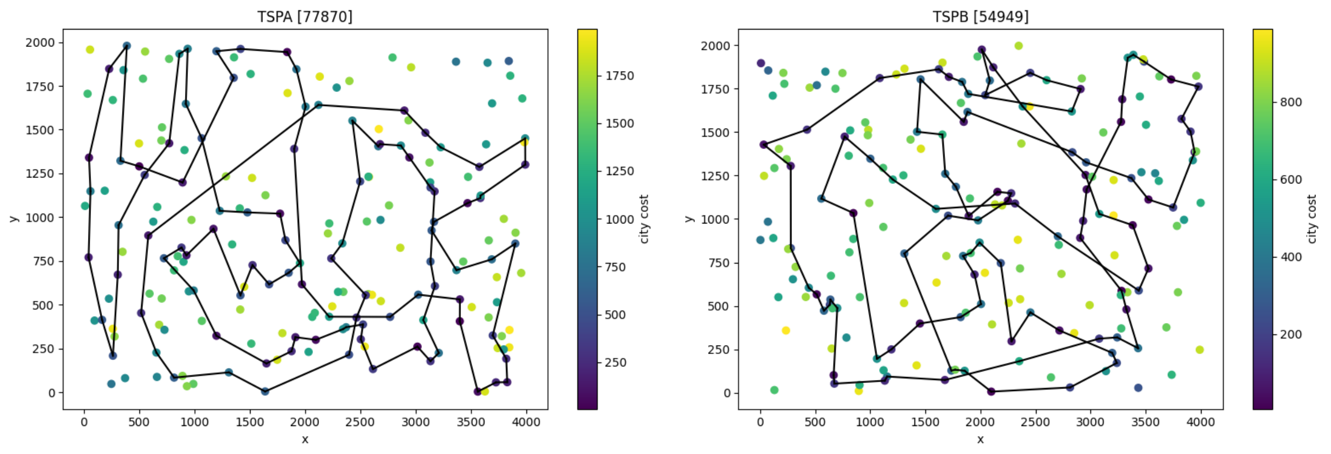


local_search_with_edges_swaps_steepest_heuristic

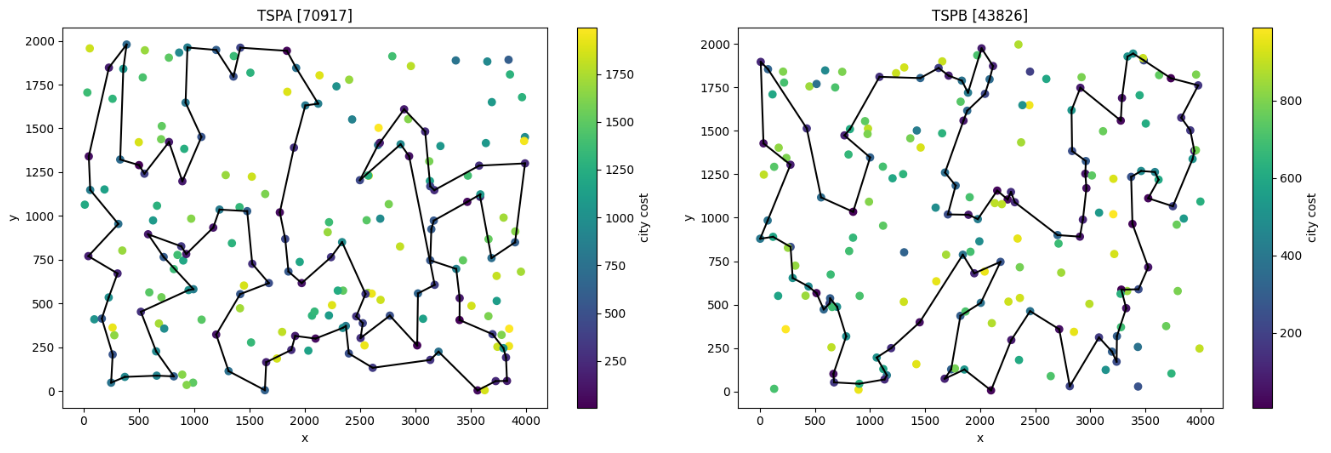


Local search with nodes swaps greedy

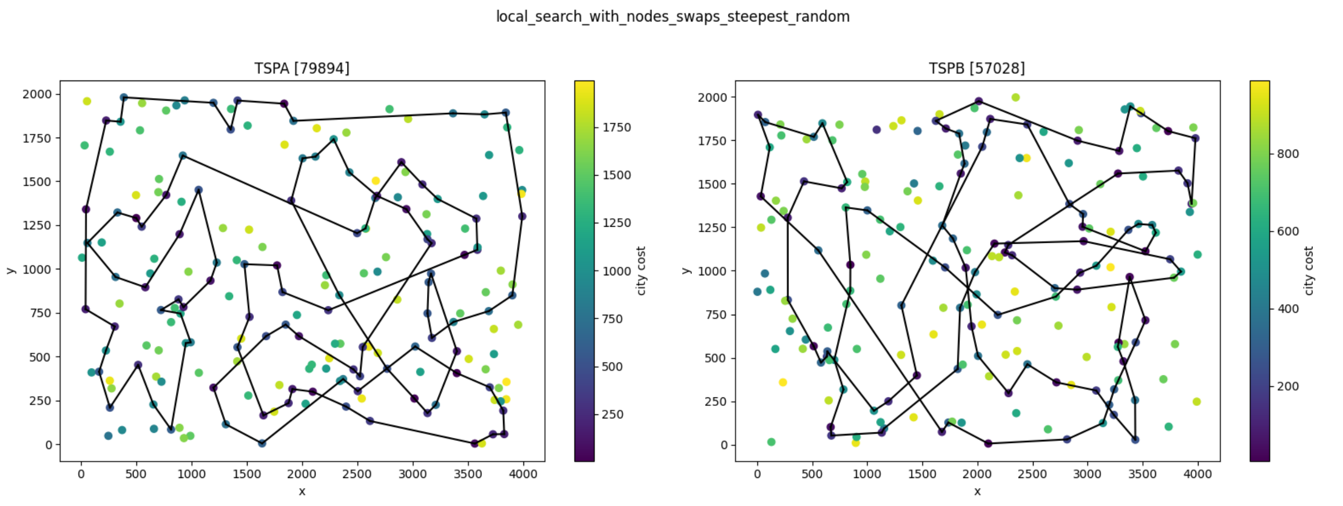
local_search_with_nodes_swaps_greedy_random

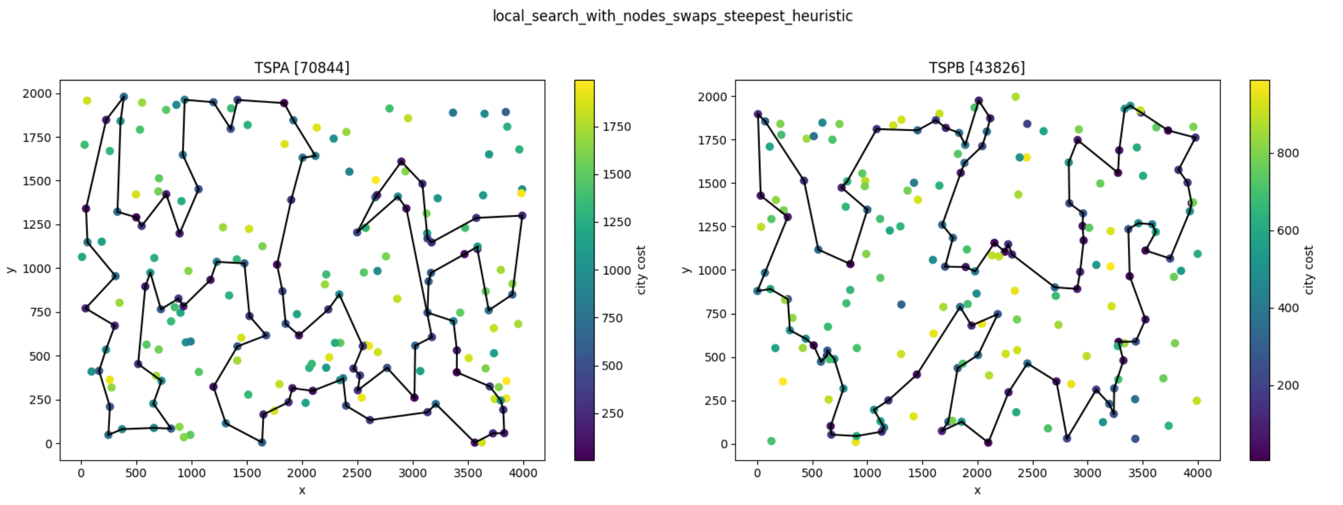


local_search_with_nodes_swaps_greedy_heuristic



Local search with nodes swaps steepest





Conclusions

In conclusion, the results for instances TSPA and TSPB demonstrate that local search methods, particularly those guided by heuristic configurations, achieve superior solution quality for the TSP with efficient computation times. Methods like local_search_with_edges_swaps_greedy_heuristic and local_search_with_nodes_swaps_steepest_heuristic outperformed simpler approaches, yielding lower mean and minimum solution lengths without excessive time costs.

The analysis shows that integrating heuristic-driven local searches with edge and node swaps, especially in steepest descent and greedy settings, significantly improves solution efficiency. These hybrid approaches offer a practical balance of solution quality and computational feasibility, making them highly effective for complex TSP instances and large-scale optimization challenges.

The analysis further reveals that edge swaps generally outperform node swaps across both TSPA and TSPB instances in terms of solution quality and computational efficiency. Specifically, edge swap methods such as local_search_with_edges_swaps_greedy_heuristic and local_search_with_edges_swaps_steepest_heuristic consistently achieved lower mean and minimum solution lengths compared to their node swap counterparts, with comparable or shorter computation times. This advantage likely stems from edge swaps' ability to make more targeted adjustments to the tour structure, effectively reducing total path length with fewer modifications, thereby enhancing both solution quality and efficiency in the search process.

```
Instance: tspa
Method: local_search_with_edges_swaps_greedy_random
Best Solution: Solution(List(101, 86, 75, 2, 120, 44, 25, 129, 92, 57, 55, 179,
145, 78, 16, 171, 175, 113, 31, 196, 81, 90, 27, 164, 95, 39, 165, 40, 185, 52,
106, 178, 49, 14, 144, 102, 62, 9, 148, 137, 23, 89, 183, 143, 117, 108, 18, 22,
146, 103, 34, 48, 54, 177, 10, 190, 4, 112, 84, 184, 160, 42, 181, 159, 193, 41,
139, 68, 46, 115, 116, 65, 47, 43, 131, 149, 59, 118, 51, 176, 80, 63, 79, 133,
151, 162, 123, 127, 70, 135, 154, 180, 53, 100, 26, 94, 124, 152, 97, 1),71492)

Instance: tspa
Method: local_search_with_edges_swaps_greedy_heuristic
Best Solution: Solution(List(196, 81, 90, 165, 119, 40, 185, 55, 52, 106, 178, 14,
144, 49, 102, 62, 9, 148, 124, 94, 63, 79, 133, 162, 151, 51, 80, 176, 137, 23,
186, 89, 183, 143, 117, 0, 46, 68, 108, 69, 18, 22, 146, 159, 193, 41, 139, 115,
118, 59, 65, 116, 43, 42, 181, 34, 160, 48, 54, 177, 10, 190, 4, 112, 84, 184, 35,
131, 149, 123, 127, 70, 135, 154, 180, 53, 100, 26, 86, 75, 101, 1, 97, 152, 2,
120, 44, 25, 16, 171, 175, 113, 56, 31, 78, 145, 92, 129, 57, 179),69620)

Instance: tspa
Method: local_search_with_edges_swaps_steepest_random
Best Solution: Solution(List(5, 42, 181, 34, 160, 48, 54, 177, 10, 190, 184, 84,
4, 112, 127, 123, 131, 149, 59, 118, 51, 176, 80, 151, 162, 133, 79, 63, 94, 180,
154, 135, 70, 158, 53, 100, 26, 97, 1, 101, 86, 75, 2, 152, 167, 57, 92, 129, 82,
120, 44, 25, 16, 171, 175, 113, 31, 78, 145, 179, 196, 81, 90, 27, 39, 165, 40,
185, 55, 52, 106, 178, 49, 14, 144, 62, 9, 148, 137, 89, 183, 143, 0, 117, 93,
108, 69, 18, 22, 159, 193, 41, 139, 68, 46, 115, 116, 65, 47, 43),71646)

Instance: tspa
Method: local_search_with_edges_swaps_steepest_heuristic
Best Solution: Solution(List(196, 81, 90, 165, 119, 40, 185, 106, 178, 14, 144,
49, 102, 62, 9, 148, 94, 63, 79, 133, 80, 176, 137, 23, 186, 89, 183, 143, 0, 117,
93, 140, 108, 69, 18, 22, 146, 159, 193, 41, 5, 42, 181, 34, 160, 48, 54, 177, 10,
190, 4, 112, 84, 35, 184, 43, 116, 65, 59, 118, 115, 139, 68, 46, 51, 151, 162,
123, 127, 70, 135, 154, 180, 53, 86, 100, 26, 97, 152, 1, 101, 75, 2, 120, 44, 25,
16, 171, 175, 113, 56, 31, 78, 145, 179, 92, 129, 57, 55, 52),69864)

Instance: tspa
Method: local_search_with_nodes_swaps_greedy_random
Best Solution: Solution(List(139, 140, 93, 68, 46, 118, 51, 176, 80, 122, 79, 133,
151, 162, 59, 65, 116, 43, 149, 123, 135, 154, 180, 53, 100, 26, 1, 101, 75, 120,
44, 25, 82, 92, 57, 106, 178, 49, 102, 62, 9, 15, 148, 124, 94, 152, 97, 86, 70,
127, 112, 84, 184, 42, 186, 144, 14, 138, 165, 27, 90, 119, 40, 185, 52, 55, 179,
196, 81, 31, 113, 175, 171, 16, 78, 145, 129, 2, 121, 63, 137, 23, 89, 183, 143,
117, 0, 115, 193, 159, 108, 18, 22, 146, 34, 54, 177, 160, 181, 41),77870)

Instance: tspa
Method: local_search_with_nodes_swaps_greedy_heuristic
Best Solution: Solution(List(68, 46, 115, 139, 41, 193, 159, 69, 108, 18, 22, 146,
181, 34, 160, 48, 54, 177, 10, 190, 4, 112, 84, 184, 131, 149, 43, 42, 116, 65,
59, 118, 51, 151, 133, 162, 123, 127, 70, 135, 154, 180, 53, 100, 26, 86, 75, 44,
25, 16, 171, 175, 113, 56, 31, 78, 145, 179, 57, 55, 52, 185, 119, 40, 196, 81,
90, 165, 106, 178, 14, 144, 62, 9, 148, 102, 49, 92, 129, 120, 2, 101, 1, 97, 152,
124, 94, 63, 79, 80, 176, 137, 23, 186, 89, 183, 143, 0, 117, 93),70917)

Instance: tspa
Method: local_search_with_nodes_swaps_steepest_random
Best Solution: Solution(List(75, 16, 171, 175, 113, 31, 78, 129, 101, 26, 70, 127,
123, 133, 79, 63, 97, 1, 152, 106, 178, 49, 62, 15, 114, 186, 23, 137, 124, 2,
120, 44, 25, 145, 52, 55, 57, 92, 179, 196, 81, 90, 164, 7, 21, 89, 183, 143, 0,
117, 108, 69, 18, 22, 34, 160, 48, 54, 177, 184, 84, 112, 131, 149, 47, 43, 116,
65, 59, 118, 46, 115, 42, 181, 146, 159, 193, 41, 139, 68, 148, 37, 9, 144, 14,
138, 165, 40, 185, 94, 80, 176, 51, 151, 162, 135, 154, 180, 53, 86),79894)

Instance: tspa
Method: local_search_with_nodes_swaps_steepest_heuristic
Best Solution: Solution(List(68, 46, 115, 139, 41, 193, 159, 69, 108, 18, 22, 146,
181, 34, 160, 48, 54, 177, 10, 190, 4, 112, 84, 35, 184, 42, 5, 43, 116, 65, 59,
118, 51, 151, 133, 162, 123, 127, 70, 135, 154, 180, 53, 100, 26, 86, 75, 44, 25,
16, 171, 175, 113, 56, 31, 78, 145, 179, 57, 55, 52, 185, 119, 40, 196, 81, 90,
165, 106, 178, 14, 144, 62, 9, 148, 102, 49, 92, 129, 120, 2, 101, 1, 97, 152,
124, 94, 63, 79, 80, 176, 137, 23, 186, 89, 183, 143, 0, 117, 93),70844)


Instance: tspb
Method: local_search_with_edges_swaps_greedy_random
Best Solution: Solution(List(164, 73, 136, 190, 80, 175, 78, 5, 177, 36, 61, 91,
141, 97, 77, 111, 41, 81, 153, 163, 89, 165, 127, 103, 113, 176, 194, 166, 86,
185, 179, 94, 47, 148, 60, 20, 28, 140, 183, 152, 34, 55, 18, 62, 124, 106, 159,
143, 35, 109, 0, 29, 144, 104, 8, 82, 87, 21, 25, 182, 138, 33, 160, 11, 139, 43,
168, 195, 13, 145, 15, 3, 70, 132, 169, 188, 6, 147, 71, 191, 90, 51, 121, 131,
122, 133, 10, 107, 40, 100, 63, 135, 38, 1, 156, 198, 117, 193, 31, 54),46029)

Instance: tspb
Method: local_search_with_edges_swaps_greedy_heuristic
Best Solution: Solution(List(40, 107, 133, 122, 135, 131, 121, 51, 90, 191, 147,
6, 188, 169, 132, 13, 70, 3, 15, 145, 195, 168, 139, 11, 138, 33, 160, 29, 0, 109,
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47, 94, 66, 179, 185, 22, 99, 130, 95, 86, 166, 194, 176, 113, 103, 127, 89, 163,
187, 153, 81, 77, 141, 91, 36, 61, 21, 82, 8, 104, 177, 5, 45, 142, 78, 175, 162,
80, 190, 136, 73, 54, 31, 193, 117, 198, 156, 1, 16, 27, 38, 63),43758)

Instance: tspb
Method: local_search_with_edges_swaps_steepest_random
Best Solution: Solution(List(54, 73, 136, 190, 80, 5, 177, 21, 82, 61, 36, 91,
141, 77, 81, 153, 163, 89, 127, 103, 113, 180, 176, 194, 166, 86, 95, 130, 99, 22,
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131, 122, 135, 32, 63, 102, 38, 27, 16, 1, 156, 198, 117, 193, 31),46021)

Instance: tspb
Method: local_search_with_edges_swaps_steepest_heuristic
Best Solution: Solution(List(40, 107, 133, 122, 135, 131, 121, 51, 90, 191, 147,
6, 188, 169, 132, 13, 70, 3, 15, 145, 195, 168, 139, 11, 182, 138, 33, 160, 29, 0,
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162, 80, 190, 136, 73, 54, 31, 193, 117, 198, 156, 1, 16, 27, 38, 63),43921)

Instance: tspb
Method: local_search_with_nodes_swaps_greedy_random
Best Solution: Solution(List(138, 160, 0, 109, 29, 33, 11, 139, 43, 134, 6, 168,
195, 34, 55, 95, 185, 179, 94, 47, 148, 60, 20, 28, 149, 4, 140, 183, 62, 124,
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18, 128, 86, 166, 194, 143, 35, 182, 118, 51, 90, 131, 121, 45, 5, 177, 21, 82, 8,
104, 56, 144, 111, 77, 81, 153, 89, 127, 187, 141, 91, 79, 61, 25),54949)

Instance: tspb
Method: local_search_with_nodes_swaps_greedy_heuristic
Best Solution: Solution(List(131, 122, 107, 40, 63, 135, 38, 27, 16, 1, 156, 198,
117, 193, 31, 54, 73, 136, 190, 80, 162, 175, 78, 142, 45, 5, 177, 104, 8, 111,
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86, 95, 130, 99, 22, 185, 179, 66, 94, 47, 148, 60, 20, 28, 149, 4, 140, 183, 152,
170, 34, 55, 18, 62, 124, 106, 143, 35, 109, 0, 29, 160, 33, 138, 11, 139, 168,
195, 145, 15, 3, 70, 13, 132, 169, 188, 6, 147, 191, 90, 51, 121),43826)

Instance: tspb
Method: local_search_with_nodes_swaps_steepest_random
Best Solution: Solution(List(165, 89, 103, 194, 166, 86, 176, 180, 113, 114, 137,
127, 163, 153, 81, 77, 82, 8, 33, 11, 139, 168, 195, 132, 169, 188, 70, 152, 140,
149, 28, 20, 60, 94, 47, 148, 183, 109, 0, 35, 143, 106, 52, 172, 179, 62, 29,
160, 104, 21, 78, 175, 80, 190, 136, 73, 112, 121, 125, 51, 138, 111, 159, 124,
128, 95, 130, 99, 22, 185, 18, 55, 34, 155, 3, 145, 25, 177, 5, 45, 54, 31, 193,
117, 1, 135, 122, 90, 191, 10, 133, 107, 40, 100, 63, 131, 36, 61, 141,
187),57028)

Instance: tspb
Method: local_search_with_nodes_swaps_steepest_heuristic
Best Solution: Solution(List(131, 122, 107, 40, 63, 135, 38, 27, 16, 1, 156, 198,
117, 193, 31, 54, 73, 136, 190, 80, 162, 175, 78, 142, 45, 5, 177, 104, 8, 111,
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195, 145, 15, 3, 70, 13, 132, 169, 188, 6, 147, 191, 90, 51, 121),43826)
```