Artificial Intelligence Assignment 3

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Report: Ant Colony System for the TSP

The required statistics of the search for each of the runs (3 seeds for each q_0 value, 3 q_0 values for each map, 3 maps in total). The final results are as follows (raw data can be reproduced in the attached notebook following the same seeds), overall best in bold:

2-Opt with CL

Map 1: eil76 (optimal solution: 538), 3 minute run ≈ 700 tours

- Seed: 0, $q_0 = 0.5$: Best Tour 547 (gap=9, cost=0.01672), found @ tour number 388
- Seed: 1, $q_0 = 0.5$: Best Tour 546 (gap=8, cost=0.01486), found @ tour number 207
- Seed: 2, $q_0 = 0.5$: Best Tour 541 (gap=3, cost=0.00557), found @ tour number 345

- Seed: 0, $q_0 = 0.98$: Best Tour 550 (gap=12, cost=0.0223), found @ tour number 77
- Seed: 1, $q_0 = 0.98$: Best Tour 548 (gap=10, cost=0.01859), found @ tour number 197
- Seed: 2, $q_0 = 0.98$: Best Tour 548 (gap=10, cost=0.01859), found @ tour number 28

- Seed: 0, $q_0 = 1 - 13/n$: Best Tour 546 (gap=8, cost=0.01486), found @ tour number 479
- Seed: 1, $q_0 = 1 - 13/n$: Best Tour 542 (gap=4, cost=0.00743), found @ tour number 162
- **Seed: 2, $q_0 = 1 - 13/n$: Best Tour 540 (gap=2, cost=0.00371), found @ tour number 176**

Map 2: ch130 (optimal solution: 6110), 3 minute run ≈ 370 tours

- Seed: 0, $q_0 = 0.5$: Best Tour 6280 (gap=170, cost=0.02782), found @ tour number 25
- Seed: 1, $q_0 = 0.5$: Best Tour 6359 (gap=249, cost=0.04074), found @ tour number 330
- Seed: 2, $q_0 = 0.5$: Best Tour 6316 (gap=206, cost=0.0337), found @ tour number 312

- Seed: 0, $q_0 = 0.98$: Best Tour 6436 (gap=326, cost=0.05334), found @ tour number 19
- Seed: 1, $q_0 = 0.98$: Best Tour 6362 (gap=252, cost=0.04123), found @ tour number 20
- Seed: 2, $q_0 = 0.98$: Best Tour 6308 (gap=198, cost=0.0324), found @ tour number 83

- Seed: 0, $q_0 = 1 - 13/n$: Best Tour 6293 (gap=183, cost=0.02994), found @ tour number 219
- Seed: 1, $q_0 = 1 - 13/n$: Best Tour 6302 (gap=192, cost=0.03142), found @ tour number 49
- **Seed: 2, $q_0 = 1 - 13/n$: Best Tour 6234 (gap=124, cost=0.0203), found @ tour number 177**

Map 3: d198 (optimal solution: 15780), 3 minute run ≈ 220 tours

- Seed: 0, $q_0 = 0.5$: Best Tour 16652 (gap=872, cost=0.05525), found @ tour number 143
- Seed: 1, $q_0 = 0.5$: Best Tour 16318 (gap=538, cost=0.03409), found @ tour number 59
- Seed: 2, $q_0 = 0.5$: Best Tour 16438 (gap=658, cost=0.04169), found @ tour number 109

- Seed: 0, $q_0 = 0.98$: Best Tour 17039 (gap=1259, cost=0.07977), found @ tour number 146
- **Seed: 1, $q_0 = 0.98$: Best Tour 16242 (gap=462, cost=0.02927), found @ tour number 8**
- Seed: 2, $q_0 = 0.98$: Best Tour 16452 (gap=672, cost=0.04257), found @ tour number 74

- Seed: 0, $q_0 = 1 - 13/n$: Best Tour 16412 (gap=632, cost=0.04004), found @ tour number 8
- Seed: 1, $q_0 = 1 - 13/n$: Best Tour 16817 (gap=1037, cost=0.0657), found @ tour number 47
- Seed: 2, $q_0 = 1 - 13/n$: Best Tour 16553 (gap=773, cost=0.04898), found @ tour number 133

2-Opt without CL

Map 1: eil76 (optimal solution: 538), 3 minute run ≈ 1800 tours

- Seed: 0, $q_0 = 0.5$: Best Tour 548 (gap=10, cost=0.01859), found @ tour number 64
- Seed: 1, $q_0 = 0.5$: Best Tour 550 (gap=12, cost=0.0223), found @ tour number 331
- Seed: 2, $q_0 = 0.5$: Best Tour 550 (gap=12, cost=0.0223), found @ tour number 66

- Seed: 0, $q_0 = 0.98$: Best Tour 547 (gap=9, cost=0.01672), found @ tour number 14
- Seed: 1, $q_0 = 0.98$: Best Tour 556 (gap=18, cost=0.03345), found @ tour number 138
- Seed: 2, $q_0 = 0.98$: Best Tour 554 (gap=16, cost=0.02974), found @ tour number 540

- Seed: 0, $q_0 = 1 - 13/n$: Best Tour 543 (gap=5, cost=0.0093), found @ tour number 1120
- Seed: 1, $q_0 = 1 - 13/n$: Best Tour 545 (gap=7, cost=0.013), found @ tour number 192
- **Seed: 2, $q_0 = 1 - 13/n$: Best Tour 540 (gap=2, cost=0.00371), found @ tour number 577**

Map 2: ch130 (optimal solution: 6110), 3 minute run ≈ 860 tours

- Seed: 0, $q_0 = 0.5$: Best Tour 6275 (gap=165, cost=0.027), found @ tour number 314
- Seed: 1, $q_0 = 0.5$: Best Tour 6278 (gap=168, cost=0.02748), found @ tour number 227
- Seed: 2, $q_0 = 0.5$: Best Tour 6270 (gap=160, cost=0.03354), found @ tour number 171

- Seed: 0, $q_0 = 0.98$: Best Tour 6315 (gap=205, cost=0.03354), found @ tour number 19
- Seed: 1, $q_0 = 0.98$: Best Tour 6364 (gap=254, cost=0.04156), found @ tour number 36

- Seed: 2, $q_0 = 0.98$: Best Tour 6405 (gap=295, cost=0.04828), found @ tour number 472

- **Seed: 0, $q_0 = 1 - 13/n$: Best Tour 6248 (gap=138, cost=0.02258), found @ tour number 238**
- Seed: 1, $q_0 = 1 - 13/n$: Best Tour 6272 (gap=162, cost=0.0265), found @ tour number 79
- Seed: 2, $q_0 = 1 - 13/n$: Best Tour 6300 (gap=290, cost=0.0), found @ tour number 495

Map 3: d198 (optimal solution: 15780), 3 minute run ≈ 390 tours

- Seed: 0, $q_0 = 0.5$: Best Tour 16191 (gap=411, cost=0.02603), found @ tour number 170
- Seed: 1, $q_0 = 0.5$: Best Tour 16282 (gap=502, cost=0.0318), found @ tour number 200
- Seed: 2, $q_0 = 0.5$: Best Tour 16199 (gap=419, cost=0.02655), found @ tour number 232

- Seed: 0, $q_0 = 0.98$: Best Tour 16235 (gap=455, cost=0.02882), found @ tour number 263
- Seed: 1, $q_0 = 0.98$: Best Tour 16168 (gap=388, cost=0.02458), found @ tour number 22
- Seed: 2, $q_0 = 0.98$: Best Tour 16184 (gap=404, cost=0.02559), found @ tour number 76

- Seed: 0, $q_0 = 1 - 13/n$: Best Tour 16172 (gap=392, cost=0.02484), found @ tour number 254
- **Seed: 1, $q_0 = 1 - 13/n$: Best Tour 16140 (gap=360, cost=0.02281), found @ tour number 195**
- Seed: 2, $q_0 = 1 - 13/n$: Best Tour 16156 (gap=376, cost=0.02382), found @ tour number 140

1. Plotting

Below are the results for the 2-opt variants without and with candidate lists, respectively.

Aside from the evolution of the best tours of each of the exploration thresholds q_0, it's also interesting to see how the number of tours changes for each variant with respect to the q value being used, as it's more computationally demanding for an ant to perform exploration than exploitation. Below are the averaged versions across the seeds and q values

2. Comments on the results and Conclusion

In the example of heavy exploitation (q_0 value of 0.98), it was rare to find a shorter tour after a minute of running but on some of the occasions we can see the exploitative variants perform well - so with time efficiency in mind, I would in the future limit the exploitative variants to 1 minute instead of 3. This is so that there's the added benefit of the randomness introduced with the initial placement of the ants, as a way for us to better explore the search space considering that it was very rare to improve upon a result after more than a minute had passed (this can be seen from the tour number timestamps at which the best results were found for when $q_0 = 0.98$, and comparing to he average number of tours that elapsed in a 3 minute run for the respective map/variant combination).

Also, if I had more time I would have implemented a 'semi-biased' exploration by assigning a probability (e.g. 0.5) that the connection with greatest pheromone*inverse(distance) product gets discarded from the usual

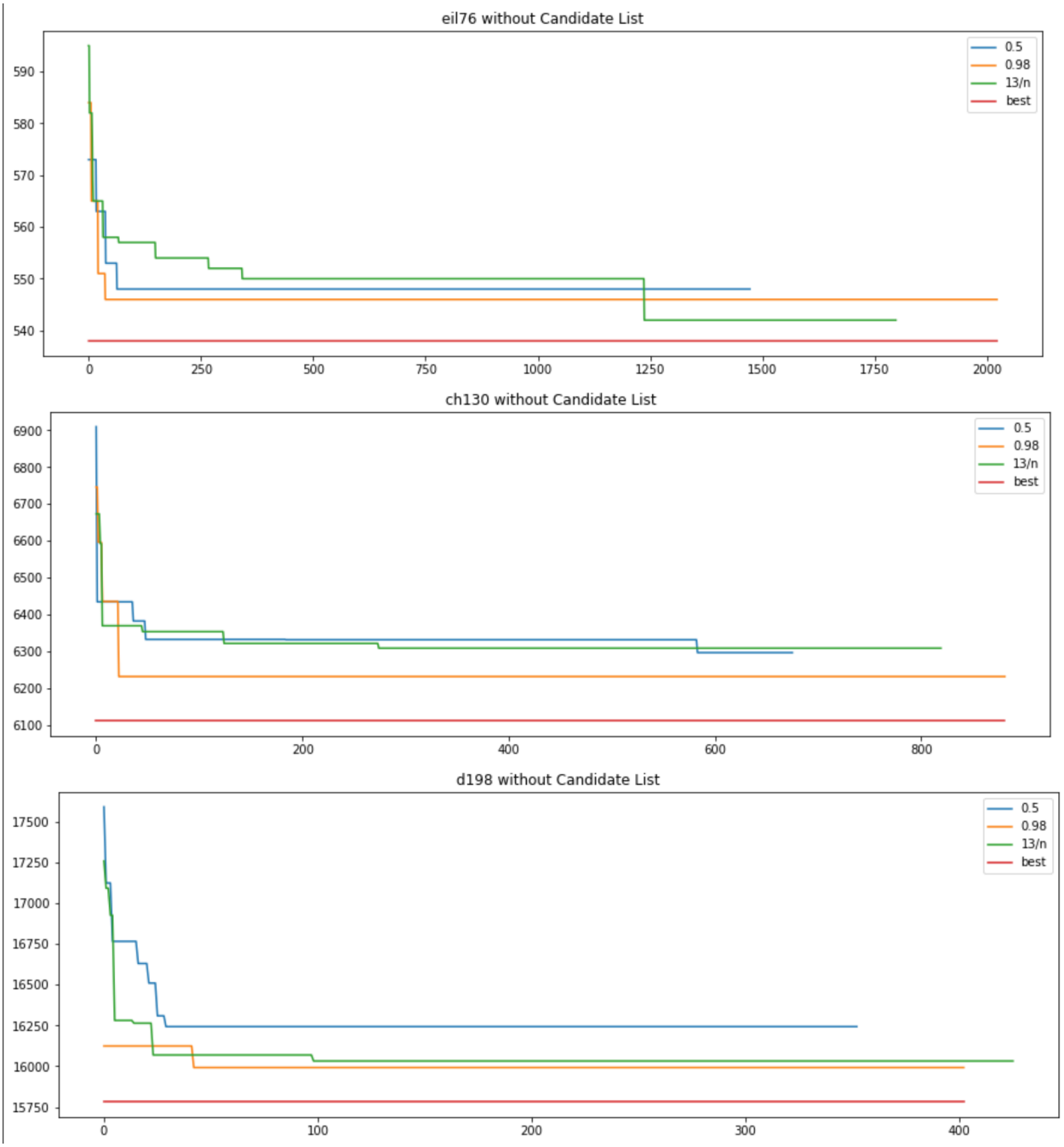

Figure 1: Rolling best tours for each map across all 3 seeds for each value of q without candidate lists

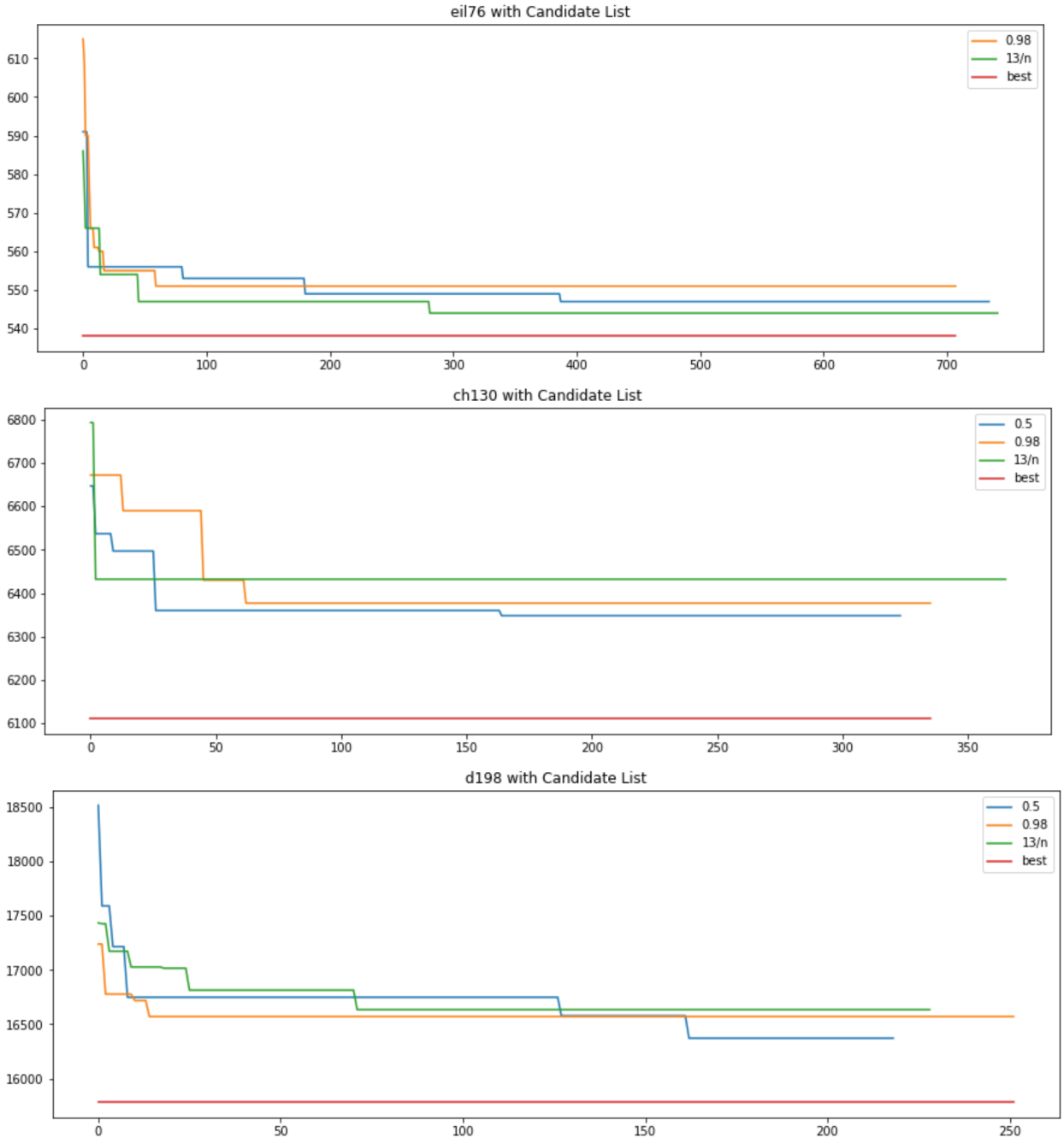

Figure 2: Rolling best tours for each map across all 3 seeds for each value of q with candidate lists

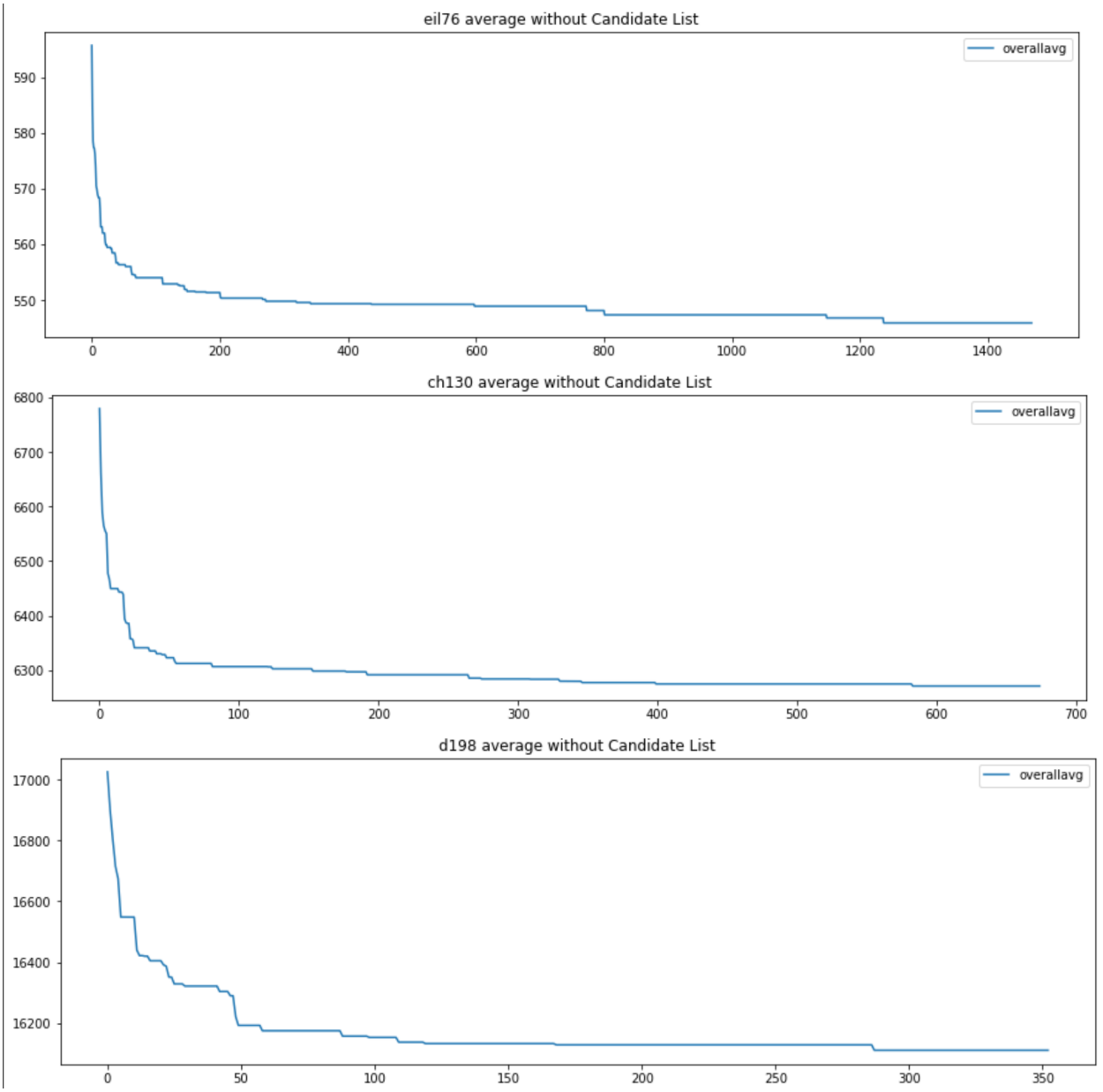

Figure 3: Average best tour length at each iteration across the 3 seeds and 3 q values for the 3 maps, no candidate lists

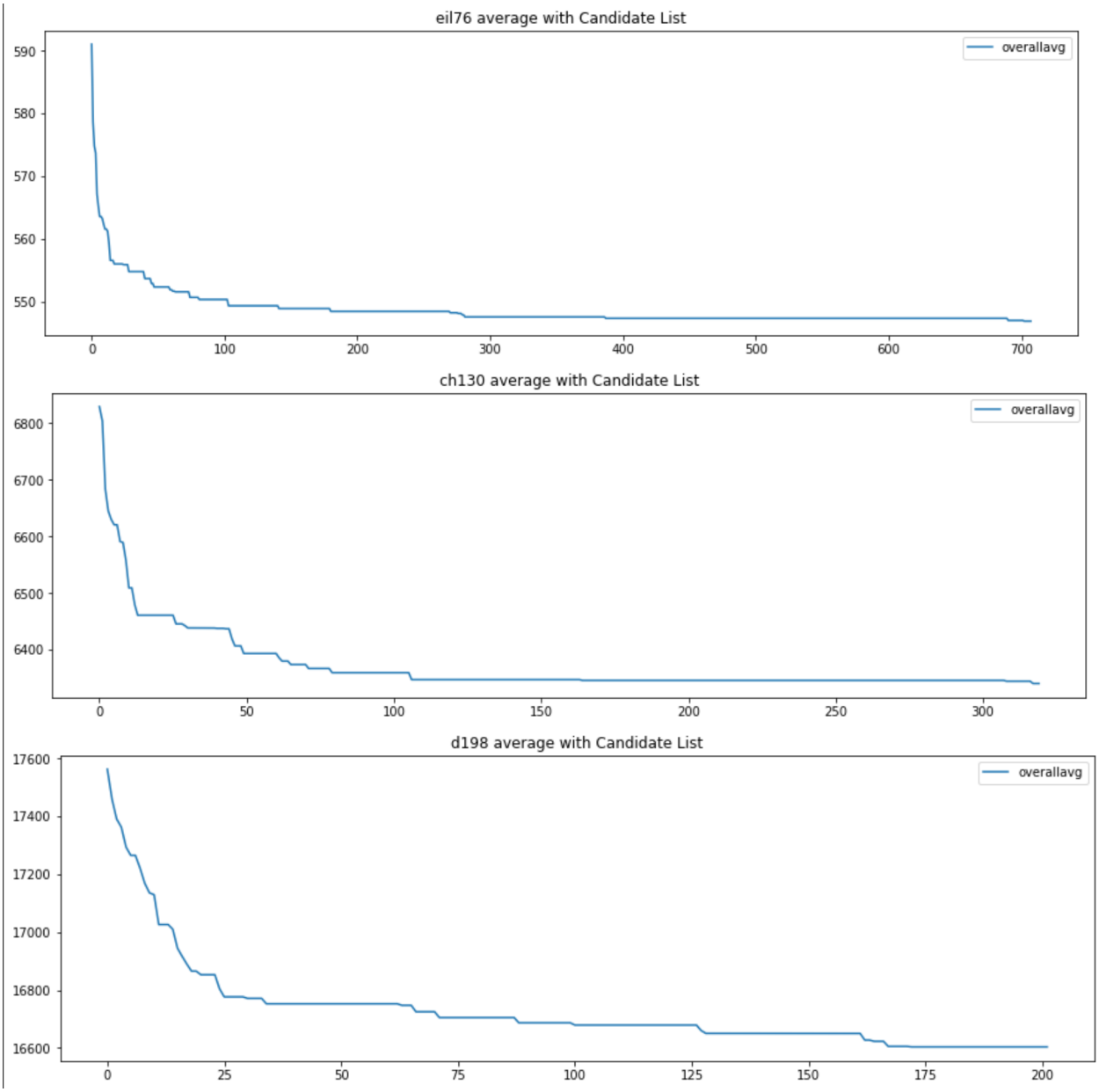

Figure 4: Average best tour length at each iteration across the 3 seeds and 3 q values for the 3 maps,with candidate lists

biased exploration sample, to allow for more exploration later on in the run, when the pheromone values are more concrete and thus a lot less likely to yield an exploration outcome that we haven't taken before (i.e. the algorithm, on average, becomes more weighted towards exploitation as more iterations elapse)

As for the variants, it is evident that the 2-opt with candidate lists works better for the smaller map (eil76), but when the problem size gets larger we find that in the 3 minute period, the 2-opt without candidate lists performs better. This makes sense considering the stronger tendency to explore the search space when we proceed with a 2-opt version that's not just limited to a candidate list.