Assignment 2B - Simulated Annealing

In this assignment, you will run simulations, comparing Hill Climbing and Simulated Annealing.

TODO

Enter your information below.

Name: HaoLiu
CWID: A20473685

In [1]:
```python
import time

import numpy as np

import pandas as pd

from matplotlib import pylab
import matplotlib.pyplot as plt
pylab.rcParams['figure.figsize'] = (10.0, 8.0)

from sa_utils import Node
from sa_utils import hill_climbing, simulated_annealing
```

In [2]:
```python
from tsp_utils import City, TSPNode, read_cities, subsample_cities, create_initial_node
from tsp_utils import plot_cities, plot_path, compare_sols
```

Read Data

In [3]:
```python
all_cities = read_cities('berlin52.tsp')
TSPNode._cities = all_cities
```

Simulations

You will run simulations for multiple subsets and multiple initializations, like you have done in Assignment 2a. One major difference here is that, in addition to hill climbing (HC), you will also run simulations using simulated annealing (SA).

Important: You need to pick the temperature schedule and the respective parameters to achieve the best results you can get. The temperature schedule and its parameters depend on the domain, as well as the range of the optimization value (in this case, the -1*cost of the travel plan).

The best parameters might also depend on the size of the problem. For example, the best parameters might be different for 10 cities versus 20 cities.

In [4]:
```python
# Temperature Schedules for SA

# Here, you are given one temperature schedule.
# You are free to add other schedules, or experiment with only this.

## Exponential multiplicative schedule

def exp_schedule(T_0, l):
    """Returns a function whose input is iter."""
    return lambda iter: T_0 * np.exp(-l * iter)
```

Example call to simulated annealing:

`_, sa_sol_n = simulated_annealing(initial_n, temp_schedule=exp_schedule(T_0=20, l=0.2), max_iter=100)`

Notes:

1. `simulated_annealing` returns the final state and the best state. Given large enough temperature and enough iterations, these should be the same states, but they might not be. We will work with the best state, which is saved in `sa_sol_n` in this call.
2. These parameter settings are just examples and not the best settings :)

Simulations 1 - Subsample of 10

1. Create multiple subsamples of cities, of size 10 each.
2. Create multiple initializations for each.
3. Run HC for each.
4. Run SA for each. Try different temperature schedules and parameters. Do NOT share everthing you tried; show us only the setting that achieved the best performance (on average).
5. Present the initial, the HC, and SA results as a table. Your table should include a final row that includes the average values for Initial, HC, and SA.

Use

- subsample_size = 10
- subsample_seeds of `[0, 1, 2, 3, 4]`
- initial_seeds = `[11, 12, 13, 14, int(last_three_digits_of_your_CWID)]`

In [5]:
```python
# TODO - Write code and run the simulation

CWID='A20473685' # EDIT THIS; CHANGE IT TO YOUR A#.

subsample_size = 10
subsample_seeds = range(0, 5)
initial_seeds = [11, 12, 13, 14, 15, int(CWID[6:])]

#Write code
#function to run the simulation
import pandas as pd
import multiprocessing as mp
import sys
sys.setrecursionlimit(1000000)

def run_simulations(subsample_size, subsample_seeds, initial_seeds,T, l, max_iter,hc_run=True,sa_run=True):

    """
    Run the simulations for the given parameters.
    """
    initial_states = {}
    hc_states = {}
    sa_states = {}
    for subsample_seed in subsample_seeds:
        #ssubsample the cities
        cities = subsample_cities(all_cities, number_of_cities=subsample_size, random_seed=subsample_seed)
        initial_states[subsample_seed] = {}
        hc_states[subsample_seed] = {}
        sa_states[subsample_seed] = {}
        for initial_seed in initial_seeds:
            initial_node = create_initial_node(cities, random_seed=initial_seed)
            initial_states[subsample_seed][initial_seed] = initial_node
            if hc_run:
                hc_states[subsample_seed][initial_seed] = hill_climbing(initial_node)
            if sa_run:
                sa_states[subsample_seed][initial_seed] = simulated_annealing(initial_node, temp_schedule=exp_schedule(T_0=T, l=l), max_iter=max_iter)[1]
    return initial_states, hc_states, sa_states
#function to find best parameters for SA
```

```python
def find_best_parameters(subsample_size, subsample_seeds, initial_seeds):
    """
    Find the best parameters for SA.
    """
    best_T_0 = 0
    best_l = 0
    best_max_iter = 0
    best_avg = 0
    import  time
    a=time.time()
    df_x = pd.DataFrame(columns=['T_0', 'l', 'max_iter', 'avg'])
    #切换成多进程的方式执行
    pool = mp.Pool(mp.cpu_count())
    for T_0 in range(1100, 1102):
        for l in range(10, 11):
            l=l/5000
            for max_iter in range(1700,1701):
                df_x.loc[len(df_x)] = [T_0, l, max_iter, pool.apply_async(run_simulations, args=(subsample_size, subsample_seeds, initial_seeds,T_0, l, max_iter,False,True))]

    #替换df 里面的avg为pool.apply_async的返回值
    for i in range(len(df_x)):
        print(i,len(df_x))
        initial_states, hc_states, sa_states=df_x.iloc[i,3].get()
        df_x.iloc[i,3]=np.mean([-sa_states[j][i].value() for j in subsample_seeds for i in initial_seeds])
    #计算每个参数组合的平均值

    #draw the plot
    import matplotlib.pyplot as plt
    plt.plot(df_x['avg'])
    plt.show()

    # print(df_x)
    # print(time.time()-a)
    df_x['avg']=df_x['avg'].astype(float)
    #取最小值的行
    df_x=df_x.sort_values(by='avg',ascending=True)
    #获取第一行
    #print(df_x)
    df_x=df_x.iloc[0:1,:]
    #print(df_x)

    return df_x['T_0'].values[0],df_x['l'].values[0],df_x['max_iter'].values[0],df_x['avg'].values[0]
```

Results

In [6]:

```python
# TODO: Present a table of the results.
# Note that the entries are costs (-1*value).
# Note that the last row are the mean values.
# Write code

#res=find_best_parameters(subsample_size, subsample_seeds, initial_seeds)
#T,l,max_iter,avg=res
T,l,max_iter=1049,0.002,1700
initial_states, hc_states,sa_states = run_simulations(subsample_size, subsample_seeds, initial_seeds,T,l,max_iter)
def get_df(initial_states, hc_states, sa_states, subsample_seeds, initial_seeds):
    """
    Show the table of results.
    """
    df = pd.DataFrame(columns=['Subsample Seed', 'Initial Seed', 'Initial Value', 'HC Value'])
    df['Subsample Seed'] = [ j for j in subsample_seeds for i in initial_seeds]
    df['Initial Seed'] = [ i for j in subsample_seeds for i in initial_seeds]
    df['Initial Value'] = [-initial_states[j][i].value() for j in subsample_seeds for i in initial_seeds]
    df['HC Value'] = [-hc_states[j][i].value() for j in subsample_seeds for i in initial_seeds]
    df['SA best Value'] = [-sa_states[j][i].value() for j in subsample_seeds for i in initial_seeds]
    #add avg row
    df.loc['mean'] = df.mean()
    df.loc['mean', 'Subsample Seed'] = '-'
    df.loc['mean', 'Initial Seed'] = '-'
    return df
display(get_df(initial_states, hc_states, sa_states, subsample_seeds, initial_seeds))
```

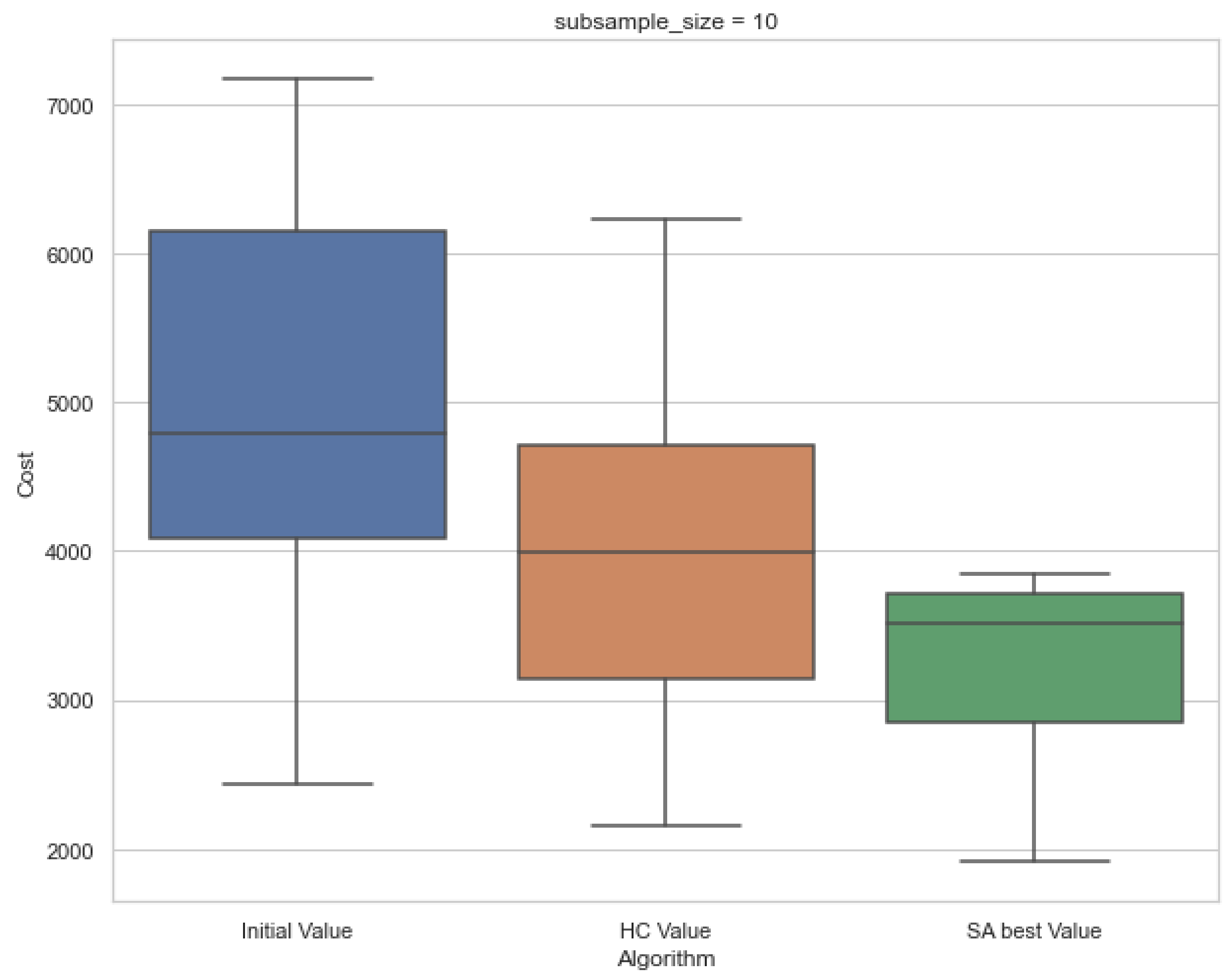
	Subsample Seed	Initial Seed	Initial Value	HC Value	SA best Value
0	0.0	11.0	6910.854964	4845.283431	3661.643228
1	0.0	12.0	4805.420205	4578.810278	3835.567764
2	0.0	13.0	6281.931261	6230.336304	3646.276239
3	0.0	14.0	6547.397559	4943.598730	3848.508855
4	0.0	15.0	6567.276372	3994.034490	3646.276239
5	0.0	685.0	4089.327327	3939.512675	3726.512489
6	1.0	11.0	3897.908590	2195.289900	1946.226847
7	1.0	12.0	3851.562313	3140.493238	1910.703722
8	1.0	13.0	3343.303102	2746.034130	1924.937867
9	1.0	14.0	2431.764939	2159.997566	1910.703722
10	1.0	15.0	2541.940049	2390.651920	1910.703722
11	1.0	685.0	3797.873196	2297.324830	1910.703722
12	2.0	11.0	4544.428908	4089.549443	2951.143619
13	2.0	12.0	4312.788187	3211.747659	2850.467881
14	2.0	13.0	4733.314832	3118.205023	2850.467881
15	2.0	14.0	3813.323874	3334.947124	2850.467881
16	2.0	15.0	4393.977833	2850.467881	2885.684409
17	2.0	685.0	4094.846276	3139.174043	2850.467881
18	3.0	11.0	4799.996881	3990.085683	3574.679504
19	3.0	12.0	5107.349706	3764.067382	3574.679504
20	3.0	13.0	4792.187279	3898.438303	3583.188993
21	3.0	14.0	4842.838365	4342.710220	3517.628642
22	3.0	15.0	4777.704743	4060.666300	3517.628642
23	3.0	685.0	5640.635557	4341.438565	3517.628642
24	4.0	11.0	6450.980927	4993.819117	3749.841195
25	4.0	12.0	7169.922143	5886.325861	3737.352948
26	4.0	13.0	6146.594024	4957.369556	3716.875884
27	4.0	14.0	4637.973404	3997.536911	3716.875884
28	4.0	15.0	6147.884236	6078.827882	3765.643947
29	4.0	685.0	7015.783332	5089.433264	3716.875884
mean	-	-	4949.636346	3953.539257	3160.212121

In [7]:

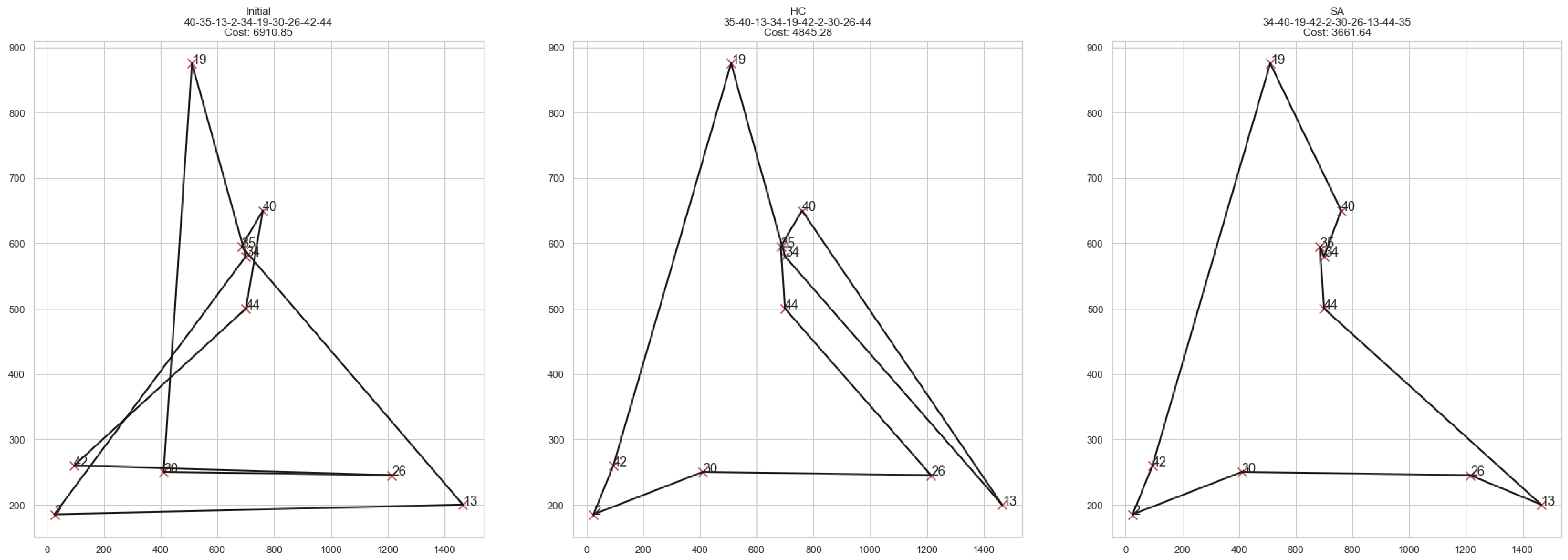
```python
# TODO: Plot a boxplot of the cost values for Initial, HC, and SA.

# Write code
def plot_boxplot(df):
    import matplotlib.pyplot as plt
    import seaborn as sns
    sns.set(style="whitegrid")
    df = df.drop(['Subsample Seed', 'Initial Seed'], axis=1)
    df = df.melt(var_name='Algorithm', value_name='Cost')
    ax = sns.boxplot(x="Algorithm", y="Cost", data=df)
```

```
    ax.set_title('subsample_size = '+str(subsample_size))
    plt.show()
plot_boxplot(get_df(initial_states, hc_states, sa_states, subsample_seeds, initial_seeds))
```



In [8]:
```
# TODO: Pick subsample seed and initial seed, and visualize Initialization, HC, and SA.
# Use the compare_sols function.
compare_sols((("Initial", initial_states[subsample_seeds[0]][initial_seeds[0]]),("HC",hc_states[subsample_seeds[0]][initial_seeds[0]]),("SA", sa_states[subsample_seeds[0]][initial_seeds[0
```



SA Parameter Settings for Subsample 10

The best parameter settings I found for subsample 20 are as follows. T=1049 l=0.002 max_iter=1700

TODO

temp_schedule=exp_schedule(T_0=1049, l=0.002), max_iter=1700

Simulations 20, 30, 40, Full Data

Repeat the above simulations, tables, and plots for

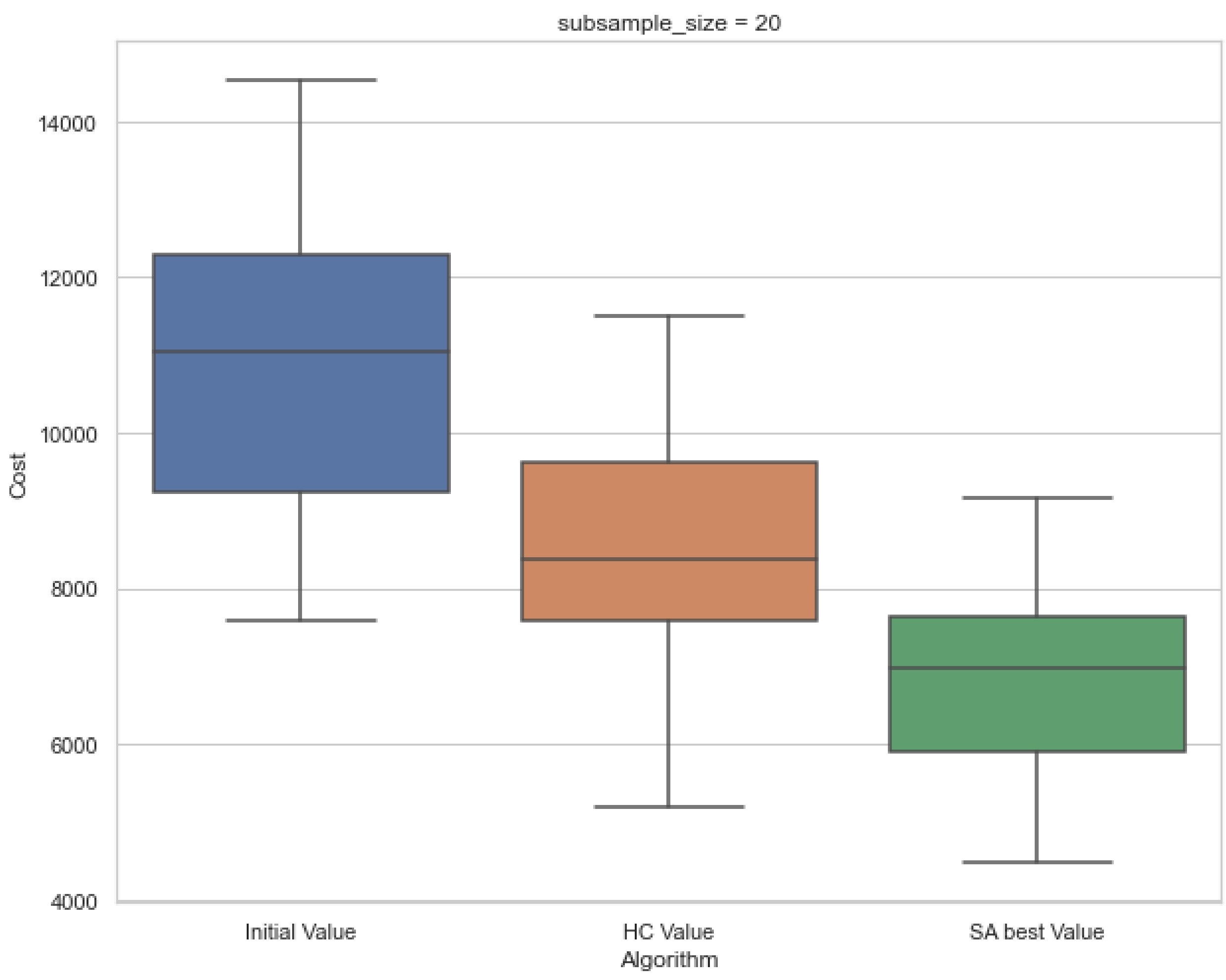
- subsample of 20
- subsample of 30
- subsample of 40
- Full data (no subsampling for full data, only random initialization).

You need to choose the best parameter settings and report them.

Simulations - Subsample 20

In [9]:
```
# Run simulations using different temperature settings and pick the best setting.
subsample_size = 20
# res=find_best_parameters(subsample_size, subsample_seeds, initial_seeds)
# print(res)
T,l,max_iter=819,0.002,1699
initial_states, hc_states,sa_states = run_simulations(subsample_size, subsample_seeds, initial_seeds,T,l,max_iter)
df=get_df(initial_states, hc_states, sa_states, subsample_seeds, initial_seeds)
display(df)
plot_boxplot(df)
```

	Subsample Seed	Initial Seed	Initial Value	HC Value	SA best Value
0	0.0	11.0	14528.512545	9409.188607	7911.075236
1	0.0	12.0	12492.176845	9553.188395	8498.185461
2	0.0	13.0	12938.237671	11515.194157	7564.438928
3	0.0	14.0	12529.839281	10628.089376	6980.742624
4	0.0	15.0	11961.551958	10324.493947	7804.553411
5	0.0	685.0	12764.576346	7868.568848	6832.545693
6	1.0	11.0	8315.996528	5971.753474	5883.465393
7	1.0	12.0	8106.832988	5710.267338	4463.806504
8	1.0	13.0	7919.323807	6222.817913	4514.532833
9	1.0	14.0	7841.527843	5757.361661	4899.048645
10	1.0	15.0	7579.257232	5198.359541	5410.630199
11	1.0	685.0	8142.940583	7096.208365	4767.706950
12	2.0	11.0	8682.089796	7607.631794	6373.573638
13	2.0	12.0	10238.872421	7579.814402	6480.719963
14	2.0	13.0	9250.016401	7040.697803	5659.663454
15	2.0	14.0	10050.787735	7726.043985	6552.151545
16	2.0	15.0	9214.227042	7682.478157	4815.211934
17	2.0	685.0	9768.657953	7975.684458	7213.228012
18	3.0	11.0	10567.370527	9742.518415	7692.512463
19	3.0	12.0	10543.538445	8856.363487	7561.932410
20	3.0	13.0	11736.349148	10009.973969	7191.339664
21	3.0	14.0	11166.550993	9536.974683	8101.661964
22	3.0	15.0	11551.965621	8076.005732	7526.498578
23	3.0	685.0	11500.495571	8592.875125	5901.119479
24	4.0	11.0	13671.503005	11329.118532	7035.082564
25	4.0	12.0	11587.825714	8361.201935	8215.619096
26	4.0	13.0	12308.573258	9682.017457	7246.303572
27	4.0	14.0	11053.665807	7622.474497	9170.428543
28	4.0	15.0	12269.771205	10862.073814	8685.057765
29	4.0	685.0	13194.954000	8917.875528	6961.791965
mean	-	-	10782.599609	8415.243847	6797.154283



Results

Table, boxplot, and path visualizations.

In [ ]:

SA Parameter Settings for Subsample 20

The best parameter settings I found for subsample 20 are as follows. T=819 l=0.002 max_iter=1699 ***TODO***

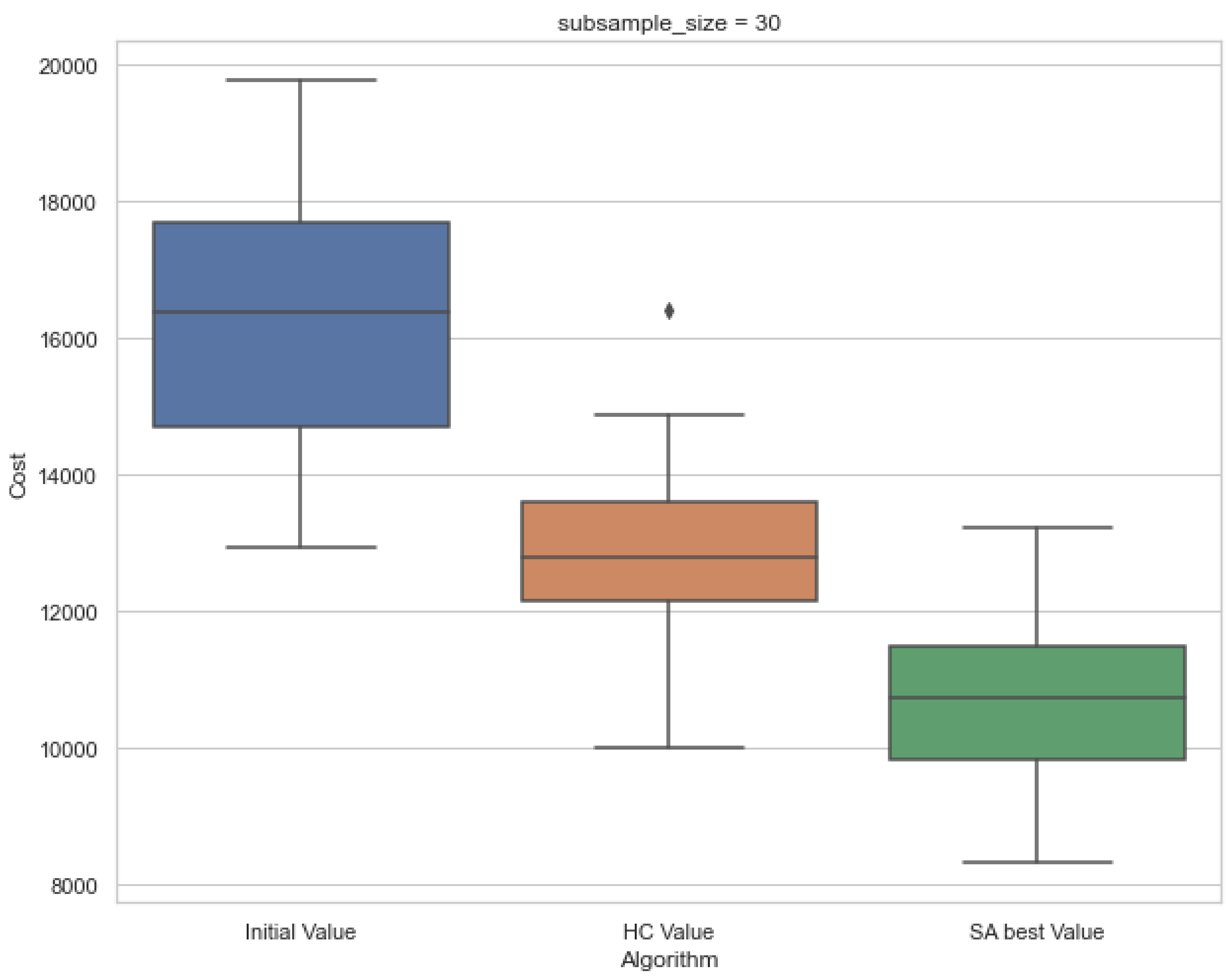
temp_schedule=exp_schedule(T_0=819, l=0.002), max_iter=1699

Simulations - Subsample 30

In [10]:

```
subsample_size = 30
#res=find_best_parameters(subsample_size, subsample_seeds, initial_seeds)
#print(res)
T,l,max_iter=1262,0.002,1700
initial_states, hc_states,sa_states = run_simulations(subsample_size, subsample_seeds, initial_seeds,T,l,max_iter)
df=get_df(initial_states, hc_states, sa_states, subsample_seeds, initial_seeds)
display(df)
plot_boxplot(df)
```

	Subsample Seed	Initial Seed	Initial Value	HC Value	SA best Value
0	0.0	11.0	18452.333046	14751.060989	11810.144179
1	0.0	12.0	16392.240025	13710.665979	10299.836713
2	0.0	13.0	19073.027869	13446.357383	11021.410272
3	0.0	14.0	18543.235765	14528.437203	12490.746856
4	0.0	15.0	18072.423051	12982.142435	12057.756919
5	0.0	685.0	19757.068889	12084.093737	12675.672209
6	1.0	11.0	14617.254235	11752.905682	8610.993907
7	1.0	12.0	12924.087636	11395.282251	9903.647900
8	1.0	13.0	13329.522781	11252.846115	10460.166082
9	1.0	14.0	13921.360320	10533.700060	8301.982590
10	1.0	15.0	14768.205467	12661.765421	9378.804986
11	1.0	685.0	14854.343435	12545.604744	9727.429278
12	2.0	11.0	12965.237731	9998.038274	8812.317713
13	2.0	12.0	14217.105152	12282.945719	9400.145036
14	2.0	13.0	14082.051073	12146.101451	8886.916127
15	2.0	14.0	16210.674008	12451.308075	11275.793659
16	2.0	15.0	14568.237519	12123.613370	9967.861506
17	2.0	685.0	16189.480659	14084.468451	9557.883455
18	3.0	11.0	16658.990034	14731.745296	11361.393306
19	3.0	12.0	16427.212697	13249.806835	13216.554124
20	3.0	13.0	16750.003217	12192.455287	10308.570415
21	3.0	14.0	17842.382778	14800.082032	12137.132401
22	3.0	15.0	16098.062045	12958.085754	11279.255579
23	3.0	685.0	16440.250739	11984.257858	9965.935606
24	4.0	11.0	17191.618369	12626.906252	11424.449219
25	4.0	12.0	16373.436395	13487.906800	10945.503818
26	4.0	13.0	18476.092408	16402.522209	13191.875468
27	4.0	14.0	17528.624119	12792.169598	10384.625953
28	4.0	15.0	15100.790955	13475.475739	11226.268186
29	4.0	685.0	18562.133710	14850.776159	11527.836179
mean	-	-	16212.916204	12942.784239	10720.296988



SA Parameter Settings for Subsample 30

The best parameter settings I found for subsample 30 are as follows.

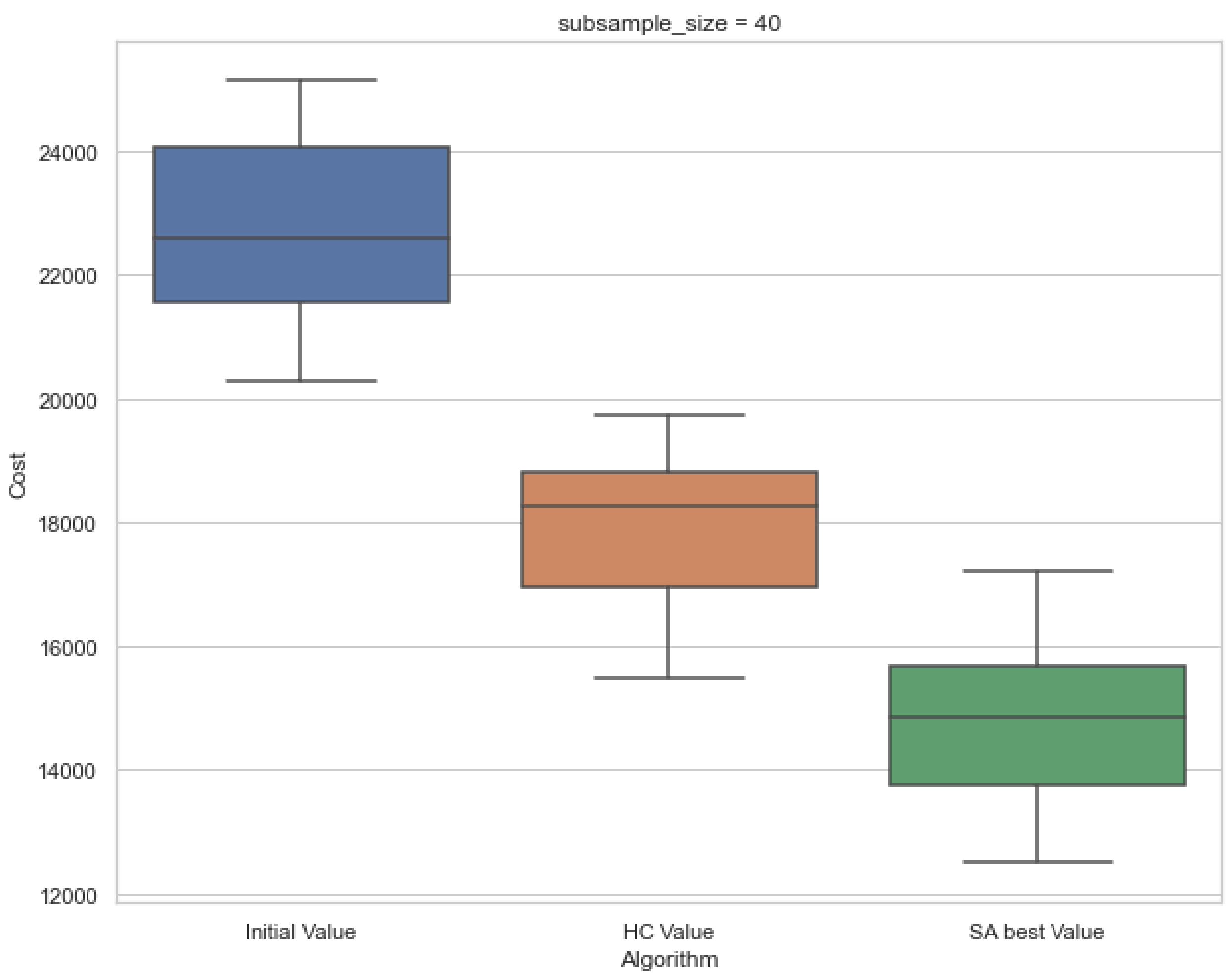
T=1262 l=0.002 max_iter=1700 ***TODO***

temp_schedule=exp_schedule(T_0=1262, l=0.002), max_iter=1700

Simulations - Subsample 40

In [11]:
```
subsample_size = 40
#res=find_best_parameters(subsample_size, subsample_seeds, initial_seeds)
#print(res)
T,l,max_iter=1048,0.002,1700
initial_states, hc_states,sa_states = run_simulations(subsample_size, subsample_seeds, initial_seeds,T,l,max_iter)
df=get_df(initial_states, hc_states, sa_states, subsample_seeds, initial_seeds)
display(df)
plot_boxplot(df)
```

	Subsample Seed	Initial Seed	Initial Value	HC Value	SA best Value
0	0.0	11.0	22422.827965	18173.154615	15064.884294
1	0.0	12.0	24004.194769	18844.451113	15204.604182
2	0.0	13.0	24314.444478	19406.699556	13804.493662
3	0.0	14.0	23950.875799	18255.824281	15886.042057
4	0.0	15.0	25058.430067	18536.135701	14860.732077
5	0.0	685.0	22871.791725	19439.177595	16115.531789
6	1.0	11.0	21039.012888	15656.884408	13628.667174
7	1.0	12.0	22582.888615	17234.947213	12909.224832
8	1.0	13.0	20314.188732	15903.115885	12496.907131
9	1.0	14.0	21356.947180	16087.632942	15833.867543
10	1.0	15.0	20338.593483	16509.662754	14906.170692
11	1.0	685.0	22128.838784	15499.226735	13590.978923
12	2.0	11.0	24160.336086	16567.714593	15286.090181
13	2.0	12.0	24050.568443	17847.127587	17220.640042
14	2.0	13.0	20854.844012	18709.864400	13718.805138
15	2.0	14.0	24817.518102	19279.484009	16141.658655
16	2.0	15.0	21517.972362	17015.181136	15456.785977
17	2.0	685.0	24082.028716	18842.906614	14516.047468
18	3.0	11.0	20334.250556	18257.623656	12724.592592
19	3.0	12.0	20291.047321	17871.852822	13008.365729
20	3.0	13.0	24315.205986	18508.736349	16229.341883
21	3.0	14.0	21786.137728	18506.239308	14746.797910
22	3.0	15.0	21698.490496	16922.600429	15622.564540
23	3.0	685.0	22193.636820	18498.234506	13797.239543
24	4.0	11.0	21728.882616	18831.781799	14596.855746
25	4.0	12.0	21626.604248	16252.476551	12811.138837
26	4.0	13.0	25140.093334	18509.374608	16468.420669
27	4.0	14.0	23924.830059	19249.368027	14493.371834
28	4.0	15.0	25000.958085	18799.549114	15067.663990
29	4.0	685.0	23818.456296	19737.394912	15729.345103
mean	-	-	22724.163192	17925.147440	14731.261006



SA Parameter Settings for Subsample 40

The best parameter settings I found for subsample 40 are as follows.

T=1048 l=0.002 max_iter=1700 ***TODO***

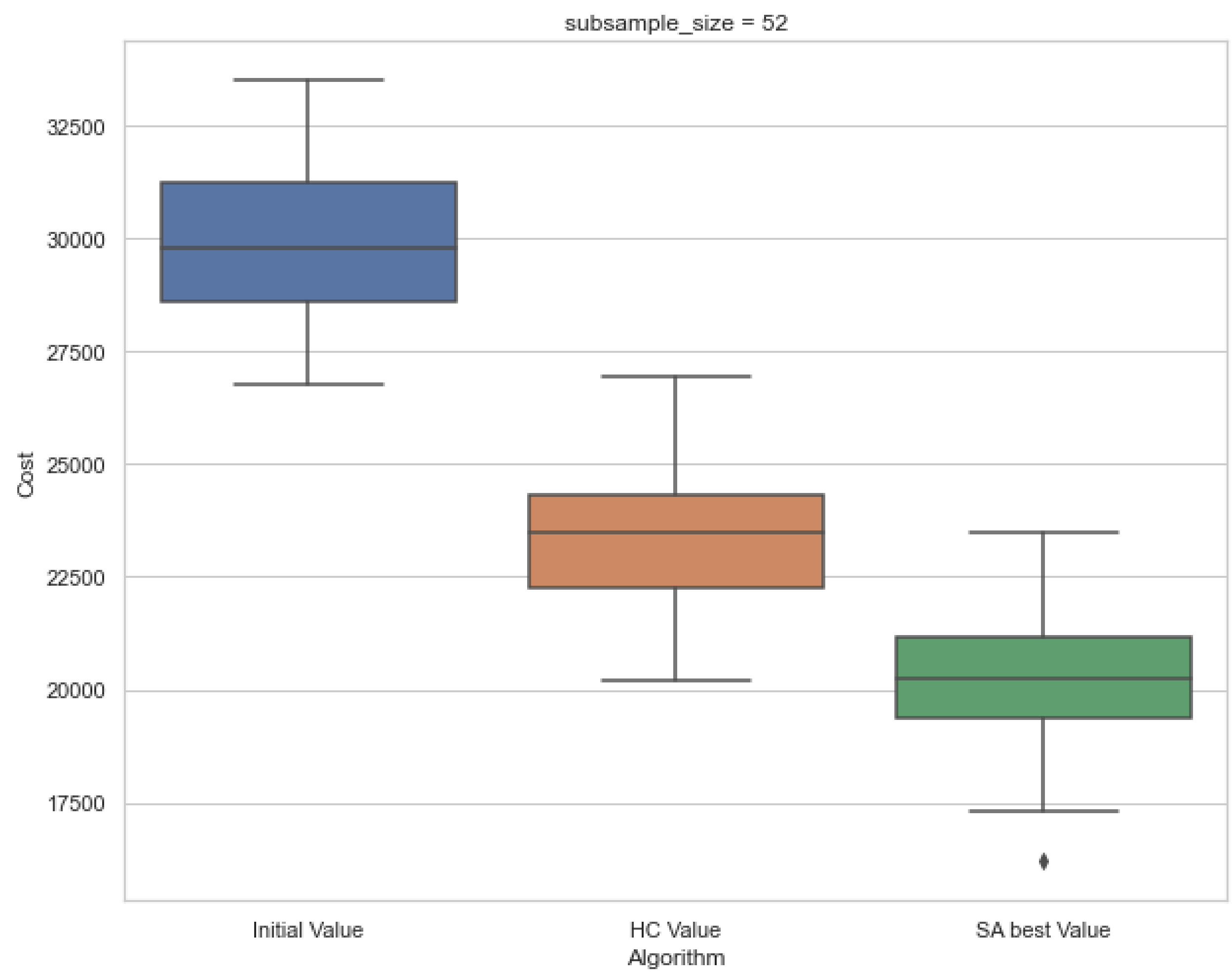
temp_schedule=exp_schedule(T_0=1048, l=0.002), max_iter=1700

Simulations - Full Data

Note: for the full data, you do not perform subsampling. Run only the random initializations.

In [12]:
```
subsample_size = len(all_cities)
#res=find_best_parameters(subsample_size, subsample_seeds, initial_seeds)
T,l,max_iter=1100,0.002,1700
initial_states, hc_states,sa_states = run_simulations(subsample_size, subsample_seeds, initial_seeds,T,l,max_iter)
df=get_df(initial_states, hc_states, sa_states, subsample_seeds, initial_seeds)
display(df)
plot_boxplot(df)
```

	Subsample Seed	Initial Seed	Initial Value	HC Value	SA best Value
0	0.0	11.0	31341.440592	24386.679891	20380.026737
1	0.0	12.0	28501.327303	22336.651571	20344.455297
2	0.0	13.0	29191.886193	22960.907423	20891.076907
3	0.0	14.0	33497.821978	24220.819770	21033.928561
4	0.0	15.0	28864.122676	23114.078512	19770.380030
5	0.0	685.0	29767.168904	23499.217536	18129.943389
6	1.0	11.0	27733.692461	22213.206925	18700.348163
7	1.0	12.0	33503.439105	26638.790908	21312.308563
8	1.0	13.0	33253.988918	25542.650339	20780.400837
9	1.0	14.0	28666.006138	24951.430933	19352.854760
10	1.0	15.0	28543.404999	21941.293088	19101.329672
11	1.0	685.0	26764.807334	20185.195234	17322.683696
12	2.0	11.0	31283.939751	23705.428838	22184.463888
13	2.0	12.0	27940.575589	21245.902813	18296.994526
14	2.0	13.0	28888.282236	23766.845769	20903.690629
15	2.0	14.0	27127.133115	24352.542707	21817.446016
16	2.0	15.0	28939.621876	21644.230853	19797.357402
17	2.0	685.0	30799.715848	23423.217027	21353.706973
18	3.0	11.0	32396.582311	26930.542723	21762.270638
19	3.0	12.0	29835.971857	23660.091484	18342.275528
20	3.0	13.0	31618.508175	26419.659615	19772.115031
21	3.0	14.0	31006.810601	22004.844266	23490.604020
22	3.0	15.0	30719.495773	22759.561740	22421.919361
23	3.0	685.0	28248.855505	23771.499303	19407.209378
24	4.0	11.0	30332.390858	23359.367994	19387.974769
25	4.0	12.0	29153.398684	21496.265113	19374.358489
26	4.0	13.0	31219.015970	24257.962331	20857.844450
27	4.0	14.0	28269.002791	23651.328536	16193.356103
28	4.0	15.0	28666.599965	21970.458833	20261.532928
29	4.0	685.0	32505.501574	24594.720852	21383.110881
mean	-	-	29952.683636	23500.179764	20137.598921



SA Parameter Settings for full data

The best parameter settings I found for full data are as follows.

T=1100 l=0.002 max_iter=1700 ***TODO***

temp_schedule=exp_schedule(T_0=1100, l=0.002), max_iter=1700

Report

Discuss your findings and your experience with these simulations. This part of the question is worth 5 points.

My main feelings throughout the process are:

1、Finding the best solution may be difficult or low cost-effective.

2、In a limited time, I first assume that each parameter is independent of each other and each has a trend:

For example, suppose that max_iter will gradually reduce the average cost as the value increases until it enters a stable period. I hope to find this stable period first.

3、Try to observe whether when several parameters are combined, whether there is a situation of breaking through various independent situations.

4、In the proximity of the optimal solution independent of each parameter, combine and then grid search to select the optimal parameter combination.

5、There is a little difference between different subsamples

In [ ]: