UECS2153 Artificial Intelligence

May 2021 Trimester

Lab 2 Assignment- Genetic Algorithms

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Results Presentation

Model	MaxIt	nPop	pc	Nc	Nm	Beta	Iterations	Best Cost	Elapsed Times (sec)
1	50	100	40	4000	4000	0.00001	4	852.169	29.93
2	50	80	40	3200	3200	0.00001	10	1093.853	25.14
3	50	150	40	6000	6000	0.0001	24	2950.415	40.51
4	50	80	20	1600	1600	0.01	20	59.254	18.21
5	50	85	45	3824	3824	0.00001	15	59.617	31.14

The Result Summary

The table above summaries the best parameters for 5 models. These parameters are determined to be the best because they are the most stable. They are able to consistently produce the same best cost solutions.

Genetic Algorithm (GA) Parameters Analysis

GA is a stochastic searching algorithm based on the *Theory of Natural Selection* developed by Charles Darwin. Basically, GA is a competition of "*Survival of the Fittest*", where competition occurs between individuals, and the winner will get to spread their genes by reproducing their offspring. Hence, the population will be populated by the generation of the best individuals, thereby achieving the optimum of objective functions. With that said, we can conclude that the parameters of GA include: *number of population (**nPop**), percentage of crossover (**PC**), number of offspring (**Nc**), number of mutations (**nm**) and selection pressure (**β**).*

1. **nPop**

The population should be large enough to produce sufficient stochasticity of selecting parents for generating their next generation, but not too large as there's a threshold where an increase in population will be detrimental rather than helpful, resulting in more randomness, which does not lead to an optimal solution or may consume more time to reach if there is any. On the other hand, population size cannot be too small, because if the population size is too small, it's possible to reach a premature solution instead of the optimal solution as the parents to be selected are very limited.

2. **PC**

The crossover is a process in which the selected members/parents were mated in the mating pool. This will result in the combination of information of the offspring, which will lead to

better offspring with better fitness value down the road. Hence the percentage of crossover should be high enough to provide sufficient exchange of information between parents, which is roughly around 40~60% but should not be too high as this will result in information exchange in chunks, which is equivalent to producing offspring with random information from their parents.

3. **Nc**

The number of offspring depends on the crossover percentage because if the crossover percentage is low, the number of offspring produced is also equally low. Likewise, the higher the percentage of crossover, the higher the number of offspring produced, but too high of the number of offspring produced is detrimental to the GA algorithm because it will consume more resources to reach an optimal solution, it's important to note that an optimal solution may not be the fastest, but we should thrive to optimise the speed of GA.

4. **nm**

Mutation is the random alteration of the value of an allele, in the case of GA, it's the alteration of data of a string/array/object that stores a sequence of data, similar to that of mutation that occurs in humans. Hence mutation should be kept to a minimum because its purpose is to maintain diversity.

5. **β**

The selection pressure is defined as the filtration of better individuals from the population as individuals with higher fitness scores will stand against the pressure of selection. Hence, it stands to reason that selection should be high enough to filter individuals with higher fitness scores. However, given that the number of offspring is large, the selection pressure should be lowered by a little because more individuals with high fitness scores can be utilised to reach an optimal algorithm. Hence, all the mentioned parameters will be decisive in producing an optimal solution. All 5 models are run at an average of 3~5 trials to determine the value of the best parameters to generate an algorithm. The method we used to mutate the genes is scramble mutation, whereby a subset or a part of a gene is randomly shuffled to scramble their genes. According to Soni and Kumar (2016), the subset may not be contiguous. The parent selection method chosen is Roulette Wheel Selection (RWS). RWS is a method used to increase the probability of selection of the parents with high fitness. Hence it has the advantages of reaching an optimal solution very quickly with sufficient stochasticity by allowing parents with lower fitness to participate in mating as well, albeit with lower

probability, as opposed to Tournament Selection (TS), where N number of parents are chosen from the population pool and 2 of the best out of the N parents are chosen. Hence TS never allows parents with lower scores to participate in the mating pool.

Genetic Algorithm (GA) Models Analysis

1.0 Model 1

No	MaxIt	nPop	pc	Nc	Nm	Beta	Iterations	Best Cost	Elapsed Times (sec)
1	50	100	10	1000	1000	0.0001	4	852.169	13.48
2	50	100	25	2500	2500	0.001	3	852.169	18.23
3	50	100	30	3000	3000	0.001	4	852.169	21.37
4	50	90	40	3600	3600	0.00001	4	852.169	24.63
5	50	100	40	4000	4000	0.00001	4	852.169	29.93

Table 1.1: Variation of GA Parameters of Model 1

```
{'position': [6, 4, 3, 1, 0, 2, 7, 5, 8, 9, 10, 11], 'cost': 852.1688232127713}

{'position': [11, 10, 9, 8, 5, 7, 2, 0, 1, 3, 4, 6], 'cost': 852.1688232127713}
```

Diagram 1.1 The route generate by the best cost

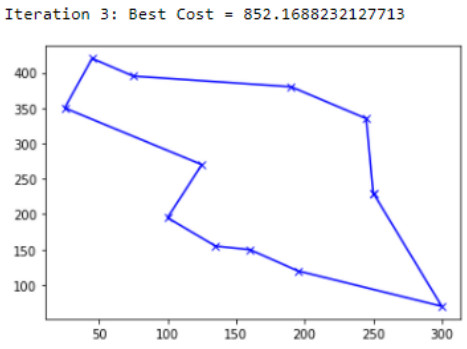

Diagram 1.2 Best Iteration with Cost

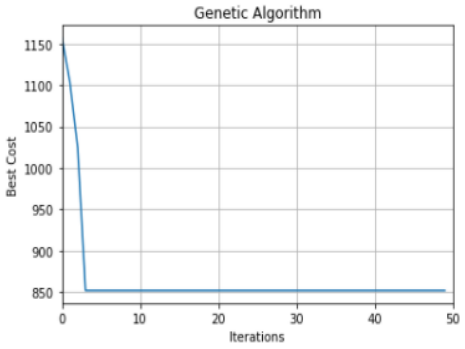

Diagram 1.3 Graph for Best Result

Analysis:

The value of parameters used for Model 1 is shown in table above. The GA algorithm is set to run for 5 separate times with constant maximum iteration of 50. In conclusion, it is observed that the value GA algorithm returns for this particular model is 852.169 as the best cost with varying elapsed time. This is done after searching for the best parameter to obtain the best cost. Based on the trial run, the least cost used is 15.03s with an average time of 24.64s based on all 5 trial runs. The best cost or the shortest solution for Model 1 is 852.169. All 5 trials provide solutions that lead to 59.254. It can be seen that the higher the number of

mutations, the longer the elapsed time. Despite the huge difference in the number of mutations, the difference in the elapsed time between the first trial and second trial is only about 5 seconds. This is because the second trial has a higher value of beta, thus only parents with higher fitness are selected, significantly reducing the elapsed time. In **diagram 1.1**, we can observe that the starting point will be started at 6 and end with 11 or by reversing it to generate the lowest cost.

Distance matrix:

	0	1	2	3	4	5	6	7	8	9	10	11
0	0.000000	39.051248	72.801099	150.416090	217.313138	231.624696	279.508497	170.000000	279.866039	293.470612	335.410197	433.041568
1	39.051248	0.000000	67.268120	115.974135	180.277564	201.556444	240.520269	134.629120	247.386338	259.326050	300.041664	395.284708
2	72.801099	67.268120	0.000000	167.705098	220.510771	172.191754	255.000000	128.062485	223.886132	241.298570	286.006993	392.460189
3	150.416090	115.974135	167.705098	0.000000	71.063352	205.730406	161.554944	127.769323	231.624696	231.948270	260.048072	328.937684
4	217.313138	180.277564	220.510771	71.063352	0.000000	201.556444	105.118980	136.473441	210.950231	203.592731	220.737401	270.647372
5	231.624696	201.556444	172.191754	205.730406	201.556444	0.000000	154.029218	79.056942	53.150729	75.000000	121.037184	235.849528
6	279.508497	240.520269	255.000000	161.554944	105.118980	154.029218	0.000000	131.244047	137.295302	120.415946	122.983739	167.630546
7	170.000000	134.629120	128.062485	127.769323	136.473441	79.056942	131.244047	0.000000	115.433964	125.000000	165.529454	265.753645
8	279.866039	247.386338	223.886132	231.624696	210.950231	53.150729	137.295302	115.433964	0.000000	25.495098	69.462220	185.607112
9	293.470612	259.326050	241.298570	231.948270	203.592731	75.000000	120.415946	125.000000	25.495098	0.000000	46.097722	161.245155
10	335.410197	300.041664	286.006993	260.048072	220.737401	121.037184	122.983739	165.529454	69.462220	46.097722	0.000000	116.297033
11	433.041568	395.284708	392.460189	328.937684	270.647372	235.849528	167.630546	265.753645	185.607112	161.245155	116.297033	0.000000

2.0 Model 2

No	MaxIt	nPop	pc	Nc	Nm	Beta	Iterations	Best Cost	Elapsed Times (sec)
1	50	100	10	1000	1000	0.0001	24	1093.853	14.33
2	50	120	10	1200	1200	0.0001	19	1093.853	15.54
3	50	100	25	2500	2500	0.001	13	1093.853	19.95
4	50	80	40	3200	3200	0.00001	10	1093.853	25.14
5	50	100	40	4000	4000	0.00001	10	1093.853	26.61

Table 2.1: Variation of GA Parameters of Model 2

```
{'position': [0, 1, 6, 5, 7, 2, 4, 3, 8, 9, 10, 11, 12, 13, 14, 16, 18, 15, 17], 'cost': 1093.8528250
416523}

{'position': [17, 15, 18, 16, 14, 13, 12, 11, 10, 9, 8, 3, 4, 2, 7, 5, 6, 1, 0], 'cost': 1093.8528250
416523}
```

Diagram 2.1 The route generate by the best cost

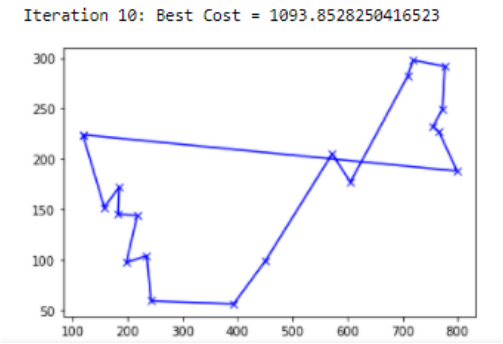

Diagram 2.2 Best Iteration with Cost

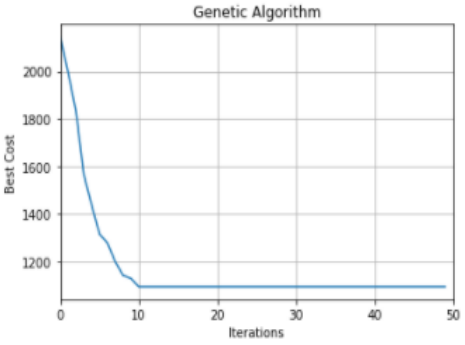

Diagram 2.3 Graph for Best Result

Distance matrix:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	0.000000	81.884064	149.566039	206.400097	166.901168	101.671038	84.023806	127.283149	321.403174	354.752026	453.398280	488.267345	592.843993	604.546111	661.504346	647.006955	653.478385	680.952274	636.050312
1	81.884064	0.000000	68.007353	125.992063	90.735880	25.961510	33.600595	60.530984	253.852319	297.754933	417.378725	447.698559	566.128077	579.686985	634.634541	612.608358	621.614833	642.010125	602.336285
2	149.566039	68.007353	0.000000	58.898217	37.656341	50.289164	76.118329	51.078371	199.263644	253.007905	389.281389	414.787898	543.457450	558.428151	610.954990	582.686880	593.784473	607.850311	573.126513
3	206.400097	125.992063	58.898217	0.000000	45.705580	104.861814	127.015747	88.600226	150.029997	211.811237	359.940273	380.746635	516.609137	532.632143	582.619087	549.320489	562.086292	570.768780	540.437786
4	166.901168	90.735880	37.656341	45.705580	0.000000	66.219333	84.403791	43.462628	165.130252	216.057863	351.809608	377.132603	506.320057	521.432642	573.679353	545.059630	556.231966	570.221010	535.522175
5	101.671038	25.961510	50.289164	104.861814	66.219333	0.000000	27.073973	35.014283	228.081126	271.919106	393.600051	423.211531	543.548526	557.409185	611.919112	588.738482	598.111194	617.498968	578.578430
6	84.023806	33.600595	76.118329	127.015747	84.403791	27.073973	0.000000	43.278170	238.159610	275.835096	388.404428	420.029761	535.421329	548.663832	604.039734	583.597464	592.028716	614.208434	573.149195
7	127.283149	60.530984	51.078371	88.600226	43.462628	35.014283	43.278170	0.000000	195.880065	237.305710	359.217204	388.404428	510.024509	524.134525	578.260322	554.249944	563.862572	582.663711	544.162660
8	321.403174	253.852319	199.263644	150.029997	165.130252	228.081126	238.159610	195.880065	0.000000	72.201108	232.899120	244.100389	388.499678	406.004926	450.723862	410.329136	425.311650	426.919196	402.517080
9	354.752026	297.754933	253.007905	211.811237	216.057863	271.919106	275.835096	237.305710	72.201108	0.000000	160.863296	172.626765	316.311555	333.803835	378.846935	340.013235	354.317654	359.200501	331.820735
10	453.398280	417.378725	389.281389	359.940273	351.809608	393.600051	388.404428	359.217204	232.899120	160.863296	0.000000	43.278170	157.155973	173.948268	222.697104	195.243438	204.782812	227.635674	184.981080
11	488.267345	447.698559	414.787898	380.746635	377.132603	423.211531	420.029761	388.404428	244.100389	172.626765	43.278170	0.000000	147.787009	166.243797	206.903359	168.585290	181.859836	194.311605	159.765453
12	592.843993	566.128077	543.457450	516.609137	506.320057	543.548526	535.421329	510.024509	388.499678	316.311555	157.155973	147.787009	0.000000	18.867962	68.731361	79.208585	71.119618	130.138388	67.941151
13	604.546111	579.686985	558.428151	532.632143	521.432642	557.409185	548.663832	524.134525	406.004926	333.803835	173.948268	166.243797	18.867962	0.000000	58.309519	85.146932	72.180330	136.014705	75.179785
14	661.504346	634.634541	610.954990	582.619087	573.679353	611.919112	604.039734	578.260322	450.723862	378.846935	222.697104	206.903359	68.731361	58.309519	0.000000	65.924199	43.289722	106.301458	63.906181
15	647.006955	612.608358	582.686880	549.320489	545.059630	588.738482	583.597464	554.249944	410.329136	340.013235	195.243438	168.585290	79.208585	85.146932	65.924199	0.000000	22.803509	51.088159	12.083046
16	653.478385	621.614833	593.784473	562.086292	556.231966	598.111194	592.028716	563.862572	425.311650	354.317654	204.782812	181.859836	71.119618	72.180330	43.289722	22.803509	0.000000	66.708320	24.041631
17	680.952274	642.010125	607.850311	570.768780	570.221010	617.498968	614.208434	582.663711	426.919196	359.200501	227.635674	194.311605	130.138388	136.014705	106.301458	51.088159	66.708320	0.000000	62.225397
18	636.050312	602.336285	573.126513	540.437786	535.522175	578.578430	573.149195	544.162660	402.517080	331.820735	184.981080	159.765453	67.941151	75.179785	63.906181	12.083046	24.041631	62.225397	0.000000

Analysis:

The value of parameters used for Model 2 is shown in table above. The GA algorithm is set to run for 5 separate times with constant maximum iterations of 50. In conclusion, it is observed that the value GA algorithm returns is 1093.853 as the best cost with the varying elapsed time because different parameters were used. This is because different parameters can affect another parameter and hence different results were obtained. It can be seen that trial 4 and 5 have a longer elapsed time because the number of mutations is higher. The number of mutations in the 3rd trial is also relatively higher than the first 2 trials, but because the beta used is relatively higher, only parents with higher fitness are selected, significantly reducing the time elapsed. On the other hand, the 2nd trial and 3rd trial have small differences in elapsed times despite the huge difference in number of mutations because of the huge difference in beta. Based on the trial run, the least cost used is 14.33s with an average time of 20.314s based on all 5 trial runs. The best cost or the shortest solution for Model 2 is 1093.853. All 5 trials provide solutions that lead to 1093.853. In **diagram 2.1**, we can

observe that the starting point will be started at 0 and end with 17 or by reversing it to generate the lowest cost.

3.0 Model 3

No	MaxIt	nPop	pc	Nc	Nm	Beta	Iterations	Best Cost	Elapsed Times (sec)
1	50	150	40	6000	6000	0.0001	24	2950.415	40.51
2	50	100	50	5000	5000	0.00001	19	2950.415	36.4
3	50	100	30	3000	3000	0.000001	27	2950.415	24.89
4	30	100	50	5000	5000	0.00001	18	2950.415	21.96
5	30	100	60	6000	6000	0.00001	20	2950.415	26.36

Table 3.1: Variation of GA Parameters of Model 3

```
{'position': [10, 11, 12, 13, 14, 15, 16, 22, 21, 18, 19, 3, 4, 20, 5, 6, 7, 8, 9, 0, 1, 17, 2], 'cos
t': 2950.4147175309167}

{'position': [2, 17, 1, 0, 9, 8, 7, 6, 5, 20, 4, 3, 19, 18, 21, 22, 16, 15, 14, 13, 12, 11, 10], 'cos
t': 2950.4147175309167}
```

Diagram 3.1 The route generate by the best cost

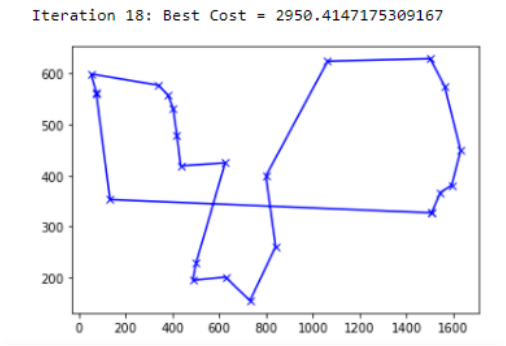

Diagram 3.2 Best Iteration with Cost

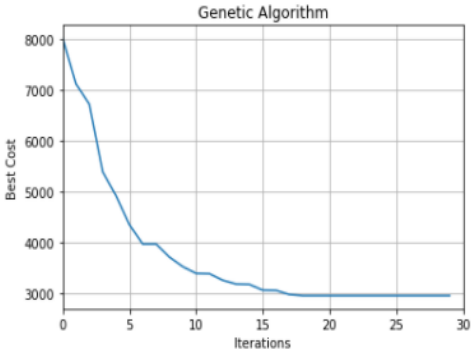

Diagram 3.3 Graph for Best Result

Analysis:

The value of parameters used for Model 3 is shown in table above. In conclusion, the GA algorithm is set to run for 5 separate times and it is observed that the value GA algorithm return is 2950.415 as the best cost with the varying elapsed time because different parameters were used. For Model 3, there is no constant variable; however, we can observe that even if the max iteration of 5th trial is lower than that of the 3rd trial, the elapsed time taken to run is longer. This is largely due to high mutation rate/offspring and high crossover percentage which resulted in producing more 'random' offspring instead of offspring with higher fitness value. Hence for this aspect, we can conclude that lower maximum iteration does not produce the optimal solution quickly. Similarly, if we observer 4th and 3rd trial, it should make sense

that 3rd trial take less time to complete when compared to that of 4th due to lower mutation rate and lower crossover percentage, but that is not the case because the β value for 3rd trial is lower than that of 4th by 10%, which means that the selection pressure is low, hence allowing individual with lower fitness value to be selected as well which explain the longer time elapsed. Lastly, we can observe the 1st trial and conclude that the larger the mutation rate and crossover percentage, the longer the elapsed time. In **diagram 3.1**, we can observe that the starting point will be started at 10 and end with 2 or by reversing it to generate the lowest cost.

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
0	0.000000	43.266615	259.306768	594.400538	582.580467	424.094329	387.071053	358.508019	332.661991	290.833286	1481.186712	1511.906082	1557.333619	1587.104281	1512.190464	1450.310312	1012.308747	46.647615	812.118218	700.128560	599.793298	859.269457	774.276436
1	43.266615	0.000000	217.862342	552.420130	541.324302	387.731866	354.107328	329.557279	306.058818	266.368166	1451.316644	1483.009103	1528.871479	1560.170504	1488.048386	1427.526532	989.881306	4.000000	772.528317	660.112112	567.048499	823.383264	742.342239
2	259.306768	217.862342	0.000000	387.659645	388.329757	309.127805	312.525199	323.394496	321.123029	305.679571	1374.245975	1412.069403	1460.268468	1501.072950	1447.129573	1395.564402	968.680030	214.009346	629.926980	516.855879	497.240385	713.952379	667.586698
3	594.400538	552.420130	387.659645	0.000000	36.769553	229.956518	292.027396	346.340873	377.200212	408.949875	1028.505712	1071.889920	1121.531096	1171.858353	1141.129265	1102.974161	718.204010	549.763586	247.256951	140.128512	268.223787	360.099986	372.773390
4	582.580467	541.324302	388.329757	36.769553	0.000000	201.136769	263.104542	317.502756	349.262079	383.019582	1010.762089	1053.081193	1102.528004	1151.216748	1116.942255	1077.032961	686.927216	538.865475	241.611258	129.073622	231.931024	341.502562	343.080166
5	424.094329	387.731866	309.127805	229.956518	201.136769	0.000000	62.096699	116.481758	148.189068	183.847763	1075.940519	1111.217350	1158.623321	1196.376195	1138.736142	1086.487920	660.612594	386.264158	396.625768	290.496127	190.094713	435.660418	364.549036
6	387.071053	354.107328	312.525199	292.027396	263.104542	62.096699	0.000000	54.405882	86.764048	125.251746	1098.566338	1131.556450	1178.083189	1212.371230	1148.020906	1092.347930	660.121958	353.179841	449.799956	347.200230	212.960090	474.982105	388.329757
7	358.508019	329.557279	323.394496	346.340873	317.502756	116.481758	54.405882	0.000000	34.058773	77.201036	1122.689628	1153.715736	1199.416525	1230.734740	1160.834183	1102.364731	666.520067	329.192953	498.958916	398.843328	246.008130	514.532798	417.420651
8	332.661991	306.058818	321.123029	377.200212	349.262079	148.189068	86.764048	34.058773	0.000000	44.721360	1149.250190	1179.404935	1224.712211	1254.656925	1182.137048	1122.311900	685.283153	306.006536	533.014071	432.726241	277.416654	547.006399	446.864633
9	290.833286	266.368166	305.679571	408.949875	383.019582	183.847763	125.251746	77.201036	44.721360	0.000000	1192.499895	1222.176747	1267.248989	1296.334833	1222.001637	1161.164932	723.528161	266.608327	574.616394	472.410838	322.117991	591.486264	491.373585
10	1481.188712	1451.316644	1374.245975	1028.505712	1010.762089	1075.940519	1098.566338	1122.689628	1149.250190	1192.499895	0.000000	55.172457	101.548018	173.954017	254.243977	302.059597	534.176937	1450.671569	794.833316	888.974690	887.427744	669.262280	711.651600
11	1511.906082	1483.009103	1412.069403	1071.889920	1053.081193	1111.217350	1131.556450	1153.715736	1179.404935	1222.176747	55.172457	0.000000	50.000000	118.827606	208.777393	265.668967	546.235297	1482.485750	841.153969	932.887989	921.826448	711.935390	746.686012
12	1557.333619	1528.871479	1460.268468	1121.531096	1102.528004	1158.623321	1178.083189	1199.416525	1224.712211	1267.248989	101.548018	50.000000	0.000000	77.897368	196.305884	264.514650	583.051456	1528.400471	891.134109	982.627091	968.999484	761.514281	794.204004
13	1587.104281	1560.170504	1501.072950	1171.858353	1151.216748	1196.376195	1212.371230	1230.734740	1254.656925	1296.334833	173.954017	118.827606	77.897368	0.000000	143.178211	222.036033	594.347541	1559.883329	946.803042	1034.176000	1006.286242	812.061574	833.501050
14	1512.190464	1488.048386	1447.129573	1141.129265	1116.942255	1138.736142	1148.020906	1160.834183	1182.137048	1222.001637	254.243977	208.777393	196.305884	143.178211	0.000000	82.219219	502.395263	1488.086019	932.000000	1007.954364	949.917891	787.324584	784.010204
15	1450.310312	1427.526532	1395.564402	1102.974161	1077.032961	1086.487920	1092.347930	1102.364731	1122.311900	1161.164932	302.059597	265.668967	264.514650	222.036033	82.219219	0.000000	438.028538	1427.717059	904.199093	973.170078	899.439826	755.661300	738.717808
16	1012.308747	989.881306	968.680030	718.204010	686.927216	660.612594	660.121958	666.520067	685.283153	723.528161	534.176937	546.235297	583.051456	594.347541	502.395263	438.028538	0.000000	990.135849	574.617264	607.474279	481.087310	425.503231	346.873176
17	46.647615	4.000000	214.009346	549.763586	538.865475	386.264158	353.179841	329.192953	306.006536	266.608327	1450.671569	1482.485750	1528.400471	1559.883329	1488.086019	1427.717059	990.135849	0.000000	770.423260	657.927048	566.088332	821.924571	741.468813
18	812.118218	772.528317	629.926980	247.256951	241.611258	396.625768	449.799956	498.958916	533.014071	574.616394	794.833316	841.153969	891.134109	946.803042	932.000000	904.199093	574.617264	770.423260	0.000000	113.718952	290.062062	152.761252	253.298243
19	700.128560	660.112112	516.855879	140.128512	129.073622	290.496127	347.200230	398.843328	432.726241	472.410838	888.974690	932.887989	982.627091	1034.176000	1007.954364	973.170078	607.474279	657.927048	113.718952	0.000000	224.008928	222.252109	262.274665
20	599.793298	567.048499	497.240385	268.223787	231.931024	190.094713	212.960090	246.008130	277.416654	322.117991	887.427744	921.826448	968.999484	1006.286242	949.917891	899.439826	481.087310	566.088332	290.062062	224.008928	0.000000	271.204720	175.931805
21	859.269457	823.383264	713.952379	360.099986	341.502562	435.660418	474.982105	514.532798	547.006399	591.486264	669.262280	711.935390	761.514281	812.061574	787.324584	755.661300	425.503231	821.924571	152.761252	222.252109	271.204720	0.000000	144.249783
22	774.276436	742.342239	667.586698	372.773390	343.080166	364.549036	388.329757	417.420651	446.864633	491.373585	711.651600	746.686012	794.204004	833.501050	784.010204	738.717808	346.873176	741.468813	253.298243	262.274665	175.931805	144.249783	0.000000

4.0 Model 4

No	MaxIt	nPop	pc	Nc	Nm	Beta	Iterations	Best Cost	Elapsed Times (sec)
1	50	100	50	5000	5000	0.00001	14	59.254	35.26
2	50	100	40	4000	4000	0.00001	15	59.254	30.37
3	50	80	50	4000	4000	0.00001	12	59.254	29.36
4	50	50	40	2000	2000	0.00001	16	59.254	19.61
5	50	80	20	1600	1600	0.01	20	59.254	18.21

Table 4.1 Variation of GA Parameters of Model 4

```
{'position': [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 0, 1, 2, 3, 4, 5, 6], 'cost': 59.25405
2501064194}
```

```
{'position': [4, 3, 2, 1, 0, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5], 'cost': 59.25405
250106419}
```

Diagram 4.1 The route generate by the best cost

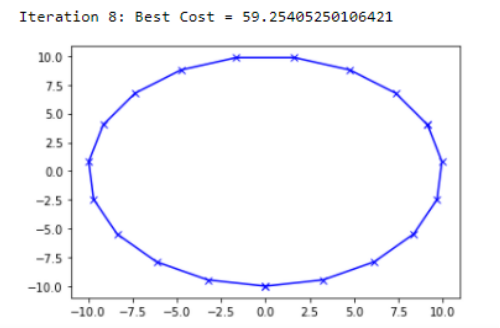

Diagram 4.2 Best Iteration with Cost

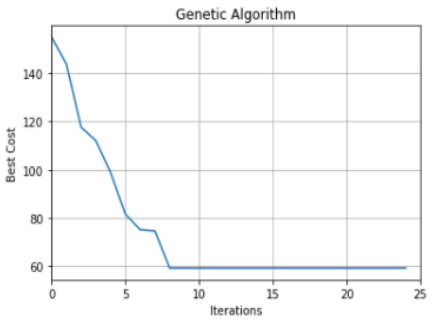

Diagram 4.3 Graph for Best Result

Analysis:

The value of parameters used for Model 4 is shown in table above. In conclusion, the GA algorithm is setted to run for 5 separate times and it is observable that the value GA algorithm return is 59.254 as the best cost with the varying elapsed time because different parameters were used. This is because different parameters can affect another parameter and hence different results were obtained. The number of iterations is set to 50 as a constant variable, it's observable that the higher the number of population or the number of mutation/offspring, the longer the elapsed time. To further strengthen the point, it's clear that the 5th result is the best result because it kept the β (0.01) and number of mutation/offspring (1600) low and obtained the best solution in the shortest time (18.21). Hence we can conclude that for Model 4, the best solution can be obtained via keeping β and number of mutation/offspring relatively low while keeping the number of population reasonably high. In **diagram 4.1**, we can observe that the starting point can be started at any point but the index must follow the previous or next index increasingly to get the best cost as the **Distance matrix** below shows the previous or next has the lowest cost.

Distance matrix:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0.000000e+00	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	2.449294e-15
1	3.291892e+00	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892e+00
2	6.493989e+00	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989e+00
3	9.518948e+00	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948e+00
4	1.228425e+01	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	1.228425e+01
5	1.471448e+01	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	1.471448e+01
6	1.674333e+01	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	1.674333e+01
7	1.831547e+01	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	1.831547e+01
8	1.938801e+01	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	1.938801e+01
9	1.993169e+01	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	1.993169e+01
10	1.993169e+01	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	1.993169e+01
11	1.938801e+01	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	1.938801e+01
12	1.831547e+01	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	1.831547e+01
13	1.674333e+01	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	14.714478	1.674333e+01
14	1.471448e+01	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	12.284254	1.471448e+01
15	1.228425e+01	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948	1.228425e+01
16	9.518948e+00	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989	9.518948e+00
17	6.493989e+00	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892	6.493989e+00
18	3.291892e+00	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000	3.291892e+00
19	2.449294e-15	3.291892	6.493989	9.518948	12.284254	14.714478	16.743330	18.315467	19.388005	19.931690	19.931690	19.388005	18.315467	16.743330	14.714478	12.284254	9.518948	6.493989	3.291892	0.000000e+00

5.0 Model 5

No	MaxIt	nPop	pc	Nc	Nm	Beta	Iterations	Best Cost	Elapsed Times (sec)
1	50	80	50	4000	4000	0.00001	15	59.617	31.33
2	50	50	50	2500	2500	0.00001	17	59.617	23.98
3	50	85	45	3824	3824	0.00001	15	59.617	31.14
4	50	80	40	3200	3200	0.00001	16	59.617	27.75
5	50	70	40	2800	2800	0.00001	19	59.617	26.78

Table 5.1 Variation of GA Parameters of Model 5

```
{'position': [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 0, 1, 2, 3], 'cost': 59.61690647046977}
{'position': [16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0, 21, 20, 19, 18, 17], 'cost': 59.61690647046977}
```

Diagram 5.1 The route generate by the best cost

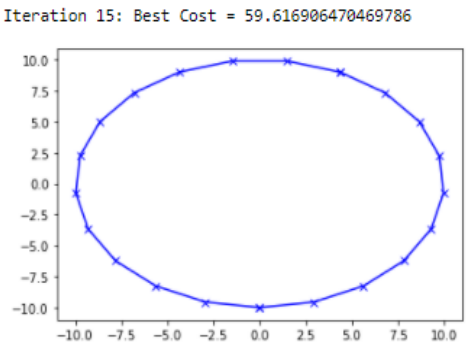

Diagram 5.2 Best Iteration with Cost

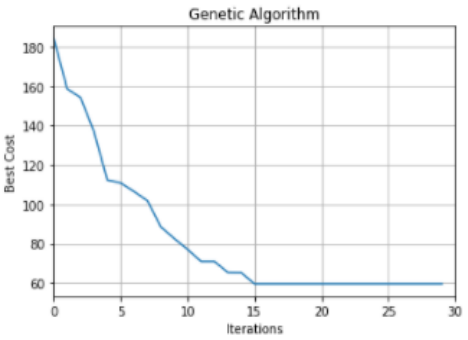

Diagram 5.3 Graph for Best Result

Analysis:

The value of parameters used for Model 5 is shown in table above. In conclusion, the GA algorithm is setted to run for 5 separate times and it is observable that the value GA algorithm return is 59.617 as the best cost with the varying elapsed time because different parameters were used. For Model 5, β was set to 0.00001 and max as a constant factor to observe how other variables would have an impact on GA. We can consider that the number of mutations/offspring impacted the most as the lower the value, the shorter the time elapsed. To further strengthen the point, we can compare 2nd and 5th trial which took the least elapsed time to complete, we can see that even if 5th trial has higher number of population and lower crossover percentage than that of 2nd trial, 2nd trial took the least elapsed time to finish because it has lower mutation rate/number of offspring than that of 5th trial. Furthermore, there is a trend of reduction in elapsed time when the number of mutations/offspring reduces

as well. Hence, we can conclude that the number of mutations/offspring plays an important role in producing optimal solutions quickly. In **diagram 5.1**, we can observe that the starting point can be started at any point but the index must follow the previous or next index increasingly to get the best cost as the **Distance matrix** below shows the previous or next has the lowest cost.

Distance matrix:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0	0.000000e+00	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	2.449294e-15
1	2.980845e+00	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845e+00
2	5.895103e+00	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103e+00
3	8.677675e+00	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675e+00
4	1.126640e+01	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	1.126640e+01
5	1.360345e+01	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	1.360345e+01
6	1.563663e+01	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	1.563663e+01
7	1.732051e+01	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	1.732051e+01
8	1.861747e+01	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	1.861747e+01
9	1.949856e+01	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	1.949856e+01
10	1.994408e+01	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	1.994408e+01
11	1.994408e+01	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	1.994408e+01
12	1.949856e+01	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	1.949856e+01
13	1.861747e+01	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	1.861747e+01
14	1.732051e+01	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	1.732051e+01
15	1.563663e+01	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	13.603455	1.563663e+01
16	1.360345e+01	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	11.266401	1.360345e+01
17	1.126640e+01	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675	1.126640e+01
18	8.677675e+00	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103	8.677675e+00
19	5.895103e+00	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845	5.895103e+00
20	2.980845e+00	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000	2.980845e+00
21	2.449294e-15	2.980845	5.895103	8.677675	11.266401	13.603455	15.636630	17.320508	18.617475	19.498558	19.944076	19.944076	19.498558	18.617475	17.320508	15.636630	13.603455	11.266401	8.677675	5.895103	2.980845	0.000000e+00

Conclusion

In conclusion, GA is very suitable to solve the Travelling Salesman Problem (TSP) because GA is very suitable to solve Nondeterministic-Polynomial Problem (NP), where NP in complexity theory simply means that a set of problems whose solutions can be verified in polynomial time, which would take exponential time to solve (De Jeong and Spears, 1989). In other words, it's hard to come up with a "quick" solution because it takes too long to solve. Hence TSP and Vehicle Route Problem (VRP) are two NP problems. Furthermore, every GA is effective when used with the best operations/function and values of parameters (Vasconcelos et al., 2001). Hence we should choose our parameters wisely because a small difference in values of parameters can lead to a very different result because parameters are not independent from each other and thus will in some way have effects on others, which can be seen by model 1 to model 5 above(Sarmady, 2007). Lastly, based on each trial run of each model, we can conclude that number of mutations/number of offspring played the most important role in obtaining, next is crossover percentage, and the third is number of population.

References

De Jong, K.A. and Spears, W.M., 1989, June. Using genetic algorithms to solve NP-complete problems. In ICGA (pp. 124-132).

Sarmady, S., 2007. An investigation on genetic algorithm parameters. *School of Computer Science, Universiti Sains Malaysia*, *126*.

Soni, N. and Kumar, T., 2014. Study of various mutation operators in genetic algorithms. International Journal of Computer Science and Information Technologies, 5(3), pp.4519-4521.

Vasconcelos, J.A., Ramirez, J.A., Takahashi, R.H.C. and Saldanha, R.R., 2001. Improvements in genetic algorithms. *IEEE Transactions on magnetics*, *37*(5), pp.3414-3417.