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Enhanced ABC Algorithm for Optimization of Multiple Traveling Salesman Problem

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Abstract: The Multiple Traveling Salesman Problem (MTSP) is similar to famous Traveling Salesperson Problem(TSP) except the fact that there are more than one salesperson to visit the cities, though each city must be visited exactly once by only one salesperson. MTSP is NP-Hard in nature and finding a tour with minimum cost for each salesman is fairly complex. As there are many possibilities of solutions, MTSP requires optimization to find the best set of solutions that are available. Swarm Intelligent algorithms serve as very effective tools for optimization and Artificial Bee Colony (ABC) is one such algorithm. In this paper, we have proposed ABC algorithm enhanced with local search for finding solutions to MTSP. The local search is performed by using two special operators namely Exchange and Relocation, separately to each of the bee solutions. The results obtained are promising and are comparable to the optimal travel routes of the salesmen which exist in the literature. The proposed method is evaluated using Bektas problem instance, a benchmarked MTSP dataset.

Keywords: Artificial Bee Colony algorithm, Multiple Traveling Salesperson Problem, Swarm Intelligence and Meta heuristics

1. INTRODUCTION

The Multiple Traveling Salesman Problem (MTSP) is a generalization of the Traveling Salesman Problem (TSP) in which, there are $n > 1$ salesmen and m ($m > n$) cities. More than one salesman is allowed to cover the given cities. Given a set of cities, one depot (where m salesmen are located), and a cost metric, the objective of the MTSP is to determine a route for each of the m salesmen so as to minimize the total cost of the m routes. The cost metric can represent cost, distance, or time [1].

The problem MTSP is very important as it is used to model the situation of many real world problems like Vehicle Scheduling for Schools and Colleges, Job Scheduling in Production Units, Crew Scheduling, Logistics and Newspaper distribution. Apart from these, it has been used to model situations like minimizing the length of universal string in DNA sequence, in semiconductor manufacturing to optimize chain in integrated circuits, in space craft to minimize the fuel usage.

MTSP is NP-hard and hence the solution time grows exponentially with the increase in distribution points. In literature, solutions to MTSP have been obtained using exact and approximate algorithms, but they are not capable of solving problems of large dimensions. On the other hand, heuristics are thought to be more efficient for complex MTSP. Although heuristic methods solve

NP-hard problems, they become trapped in local optima and could not yield optimal solution. Meta-heuristics emerged which basically tries to combine basic heuristic methods into higher level frameworks aimed at efficiently and effectively exploring a search space [3]. Swarm Intelligent (SI) algorithms are

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metaheuristic algorithms, inspired by the foraging behavior of the living organisms. These algorithms exhibit some sort of decentralized control, self organization, collective individual behavior and hence capable of providing optimal solutions to complex problems [4]. Because of the combinatorial complexity of MTSP, optimization and SI algorithms are the best fit. In literature, evolutionary algorithms like Genetic Algorithm (GA) and SI algorithms like Ant Colony Optimization, Artificial Bee Colony (ABC) algorithm, Invasive Weed Colony Optimization have been effectively applied for finding solutions to MTSP [3, 5-8].

Though MTSP is an extension of TSP, the literature of MTSP is not huge compared to TSP. From Liu et al.'s work, it has been proved that special operators are capable of minimizing the travel cost of MTSP further when used with ACO algorithm [6]. Having inspired by the effect of these special operators on MTSP, we have used the two most promising special operators to enhance the performance of ABC algorithm on MTSP. The two operators used are the inter-tour operators Exchange and Relocation.

This paper is organized in seven sections. Section 2 provides a brief description about ABC algorithm. The basic concept of MTSP is given in section 3. The works related to optimization of MTSP by SI algorithms is presented in section 4. Section 5 explains the proposed method. Computational results are discussed in section 6. Section 7 concludes the paper.

2. ARTIFICIAL BEE COLONY ALGORITHM

ABC algorithm is inspired by the foraging behavior of honey bees and it was proposed by Karaboga in 2005 [9]. Since then it has been a powerful optimizer for many real world applications. Three types of bees are considered in ABC algorithm: employed bees, onlooker bees and scout bees. The bee hive consists of equal number of employed and onlooker bees and is equal to the number of food sources. Employed bees are responsible for exploration of food sources and so, they go in search of them. On return to the hive, employed bees perform waggle dance (a pattern of figure eight) for conveying the information about the food sources to the onlooker bees. Onlookers then select the food sources for exploitation based on the nectar content of the food sources. Food sources represent the solutions and nectar content represents the quality of the solutions. When a particular food source becomes exhausted, the associated employed bee becomes a scout. Scouts now go in search of new food sources. The entire process is repeated to find the optimal solution to the problem considered [10] and [11].

3. MULTIPLE TRAVELING SALESMAN PROBLEM

MTSP is an extension of the famous TSP with more than one salesman to visit the cities. It is required to find the travel routes of $m(m>1)$ salesmen for $n(n>m)$ cities such that the total travel cost of all the salesmen is minimum. In addition, the individual routes of the salesmen should also be of minimum cost [3]. The cities should be visited only once and be present only in one tour of any of the salesmen. There are two variants of MTSP-one is of Open Tour, where the salesperson need not have to return back to depot after the completion of tour and the other is Closed Tour where the tour is said to be complete only if each of the salesperson tour starts and ends with the depot. At this point there may be two instances, a single depot is considered for all the salesperson or multiple depots can also be considered in which, each salesperson tour starts from different depots. In this paper, we have considered the single depot case, i.e., all salespersons have to start and end their tour in the same city (depot), and followed by the constraint that every salesperson must have to visit at least one city in addition to the depot (every tour should be of non-zero tour length) [2] and [3].

4. RELATED LITERATURE

The problem MTSP is quite significant as it is a modeling of important real world problems like Job Scheduling in Production Units, Vehicle Scheduling, Logistics and Newspaper distribution. Hence finding optimal solutions to MTSP will provide a better path for the solutions to real world applications [1-3]. In literature, the problem of optimizing MTSP has been previously addressed by optimization algorithms like Genetic Algorithm, Ant Colony Optimization Algorithm and Artificial Bee Colony algorithm. These algorithms in their original as well as modified forms have been applied to solve MTSP [3, 5-8]. GA with a single crossover approach [5], GA with a specific operator for the crossover of two-part chromosome (TCX) [3], ACO with inter and intra tour operators [6], ABC with a local search [8], IWCO with a local search [8] are some of the significant works found in literature for evolutionary and swarm intelligence based optimization. Another approach of ACO algorithm for solving multi depot case of MTSP with upper and lower limits imposed on the number of cities of a salesman has also been attempted in literature [7].

In this paper ABC algorithm for optimizing the single depot MTSP [8] has been adopted and the results obtained are further improved with a local search consisting of two inter tour operators-Exchange and Relocation [6].

5. ABC ALGORITHM ENHANCED WITH LOCAL SEARCH FOR OPTIMIZING MTSP

ABC algorithm has given promising results for a voluminous number of problems that require optimal solutions [12]. Venkatesh P and Singh A have employed ABC algorithm along with Neighborhood search for finding the minimum cost routes of the MTSP [8]. They have applied neighborhood search procedure both to the employed and the onlooker bee phase so that, the best possible solution is not missed out. This methodology has resulted in reasonably good optimal solutions. But, there might be possibilities for both the employed and onlooker bees to miss out some best solutions during the search procedure. To fill out this gap, we have enhanced the ABC algorithm for MTSP with two inter-tour operators namely Exchange and Relocation. So in our proposed method, we have adopted the ABC approach for MTSP by Venkatesh P and Singh A, followed by a local search with the two inter-tour operators. This additional local search with two operators has been performed with the expectations to obtain optimal solutions with cost reduced further.

In literature, Liu et al [7] has made use of three inter-tour operators and one intra-tour operator to improve the solutions obtained from ACO algorithm [6]. It has been proved that the usage of these operators has further minimized the travel distances of the salespersons. Having inspired by the results

1. Generating initial solutions for each of the employed bees

   The initial solutions are obtained by randomly assigning cities to each of the salesman. The next assignment of cities are such that, they have not been previously assigned to any bee and it results only in minimum increase of the travel cost

2. Apply neighborhood search to the employed bees
3. Generate solutions for onlooker bees from the employed bees using binary tournament selection
4. Apply neighborhood search to the onlooker bees
5. Find the scout bees

   The bees whose solution does not improve after pre-determined number of iterations are coined as scouts

6. Abandon the solution of the scouts and turn them as employed beed.
7. Generate new solutions to the employed bees as specified in step 1
8. Repeat steps 1-7 for a fixed number of iterations

Figure 1: Steps for Optimization of MTSP using ABC Algorithm

of these operators and successful optimization of ABC algorithm for MTSP, we have considered only the two most promising inter-tour operators and have applied them to the optimization results from ABC algorithm.

The proposed method is explained as follows:

Initially, optimal solutions to MTSP are obtained using ABC algorithm following the methodology of Venkatesh P and Singh A [8]. The same search procedure for employed bees, onlooker bees, scout bees and neighborhood search has been followed and the results are obtained. The steps are briefed up in Fig. 1.

The steps of ABC algorithm for MTSP in Fig.1 are executed and the optimal routes (minimum cost routes) for the salesmen are obtained. Now that, each bee holds a solution–travel routes for all the salesmen. The solutions are now enhanced by applying exchange and relocation operators separately to each of the bee solutions. This is repeated in all the solutions for a fixed number of iterations. The relocation heuristic removes a city from one of the routes and reinserts it in another route, while the exchange operator swaps simultaneously the position of two cities in two different routes and the solution is updated if it is better

I. IMPORTANCE OF INDEXING

```
exchange operator()
{
for (each employed bee)
    {
select two random Salesperson tour T1 and T2;
select two random cities C1 from T1 and C2 from T2;
swap(c1, c2);
        }
            }
```

Figure 2: Pseudocode of Local search with Exchange Operator

```
relocation()
{
for (each employed bee)
    {
        while (T1 → assigned with maximum number of cities)
            {
                select a random Salesperson tour T1;
                    }
    select a random city c1 from T1;
    while (T2 → assigned with less than the Maximum no. of cities)
            {
                select a random Salesperson tour T2;
                    }
    Best_position = The best position where c1 from T1 can be inserted into T2;
    insert c1 to T2's tour at Best_position;
                            }
                                    }
```

Figure 3: Pseudocode of Local Search with Relocation Operator

than original one, else, the old solution remains as such. These two operators are attempted for all possible combinations to evaluate the results empirically produced by the two operators individually.

After producing a defined number of employee bees as a part of employee bee phase, the Exchange operator is applied for each bee solution and the same numbers of bees are produced as a result. The next step is to generate neighboring solutions for each bee and now local best among the bees produced is calculated, followed by the Onlooker bee phase, application of Exchange operator for onlooker bees and producing neighboring solutions. After completion of each phase, the Global best is updated periodically in comparison with the local best. The same steps are followed in the application of Relocation operator. The pseudo code of Exchange operator is presented in Fig. 2 and that of Relocation is presented in Fig. 3.

6. EXPERIMENTAL RESULTS AND DISCUSSION

Preliminary experiments have been conducted to prove the effectiveness of the proposed method. Both ABC algorithm and then the local search with special operators for ABC, have been implemented Java JDK 1.5 and executed on a Windows10 based 4 GHz Core 2 Quad system with 8 GB RAM. The objective is to find the travel routes for the salesmen such that the individual and the total travel cost (distance) is minimum. Computations were done using the benchmarked problem instance, Bektas MTSP problem instance [13]. This MTSP problem has 29 cities, 5 salesmen and city 13 is considered as the depot. The proposed method is implemented for a single depot MTSP with closed tour. A limit of 6 cities is imposed on the tour of every salesman. The details of Bektas problem instance is presented in Fig. 4.

We have considered the following parameter settings of ABC algorithm for MTSP:

Population of 100 employed bees (n_e),

100onlooker bees (n_o),

P_{copy} – 0.5,

P_{method} – 0.5 and

P_{onlook} – 0.5.

```
$set startcity i13

scalar
   m 'number of salesman' /5/
   p 'number of cities to visit' /6/
;

sets
   i /i1*i29/
;
alias (i,j);

table c(i,j) 'distance matrix (KM)'
```

	i1	i2	i3	i4	i5	i6	i7	i8	i9	i10	i11	i12	i13	i14	i15	i16	i17	i18	i19	i20	i21	i22	i23	i24	i25	i26	i27	i28	i29
i1		97	205	139	86	60	220	65	111	115	227	95	82	225	168	103	266	205	149	120	58	257	152	52	180	136	82	34	145
i2			129	103	71	105	258	154	112	65	204	150	87	176	137	142	204	148	148	49	41	211	226	116	197	89	153	124	74
i3				219	125	175	386	269	134	184	313	201	215	267	248	271	274	236	272	160	151	300	350	239	322	78	276	220	60
i4					167	182	180	162	208	39	102	227	60	86	34	96	129	69	58	60	120	119	192	114	110	192	136	173	173
i5						51	296	150	42	131	268	88	131	245	201	175	275	218	202	119	50	281	238	131	244	51	166	95	69
i6							279	114	56	150	278	46	133	266	214	162	302	242	203	146	67	300	205	111	238	98	139	52	120
i7								178	328	206	147	308	172	203	165	121	251	216	122	231	249	209	111	169	72	338	144	237	331
i8									169	151	227	133	104	242	182	84	290	230	146	165	121	270	91	48	158	200	39	64	210
i9										172	309	68	169	286	242	208	315	259	240	160	90	322	260	160	281	57	192	107	90
i10											140	195	51	117	72	104	153	93	88	25	85	152	200	104	139	154	134	149	135
i11												320	146	64	68	143	106	88	81	159	219	63	216	187	88	293	191	258	272
i12													174	311	258	196	347	288	243	192	113	345	222	144	274	124	165	71	153
i13														144	86	57	189	128	71	71	82	176	150	56	114	168	83	115	160
i14															61	165	51	32	105	127	201	36	254	196	136	260	212	258	234
i15																106	110	56	49	91	153	91	197	136	94	225	151	201	205
i16																	215	159	64	126	128	190	98	53	78	218	48	127	214
i17																		61	155	157	235	47	305	243	186	282	261	300	252
i18																			105	100	176	66	253	183	146	231	203	239	204
i19																				113	152	127	150	106	52	235	112	179	221
i20																					79	163	220	119	164	135	152	153	114
i21																						236	201	90	195	90	127	84	91
i22																							273	226	148	296	238	291	269
i23																								112	130	286	74	155	291
i24																									130	178	38	75	180
i25																										281	120	205	270
i26																											213	145	36
i27																												94	217
i28																													162
i29																													

Figure 4: Bektas Problem Instance-Details of Travel Costs between cities

Table 1
Experimental Results For Mtsp Using ABC Algorithm with Special Operators

Iterations	*ABC Algorithm*		*ABC with Exchange Operator*		*ABC with Relocation Operator*	
	Best Cost	*Global Cost*	*Best Cost*	*Global Cost*	*Best Cost*	*Global Cost*
1	3445	3445	3471	3471	3327	3327
2	3320	3320	3375	3375	3216	3216
3	3215	3215	3393	3375	3178	3178
4	3483	3215	3211	3375	3277	3178
5	3257	3215	3125	3125	3210	3178
6	3209	3209	3234	3125	3335	3178
7	3302	3209	3085	3085	3359	3178
8	3169	3209	3113	3085	3250	3178
9	3177	3209	3217	3085	3168	3168
10	3407	3209	3043	3085	3266	3168
11	3238	3209	3017	3017	3263	3168
12	3211	3209	3345	3017	3277	3168
13	3157	3157	3115	3017	3151	3151
14	3193	3157	3111	3017	3229	3151
15	3091	3091	3333	3017	3208	3151
16	3332	3091	3232	3017	3242	3151
17	3240	3091	3255	3017	3127	3127
18	3225	3091	3245	3017	3080	3080
19	3120	3091	3217	3017	3148	3080
20	3172	3091	3107	3017	3285	3080

The algorithm is executed for 20 iterations. With these parameter settings, the steps of ABC algorithm as given in Fig. 1 are executed for the MTSP problem instance given in Fig 4. Then the steps of exchange operator listed in Fig. 2 have been applied to the results of employed and onlooker bee phases. Again, to the results from ABC algorithm, the steps of relocation operator specified in Fig. 3 have been executed for the bee phases. The results obtained from ABC algorithm, ABC with Exchange operator, ABC with Relocation operator are all presented in Table 1. In Table 1, we have presented the both the global best and the current best cost solutions, after every iteration for all the three methodologies.

From the results presented in Table 1, it could be inferred that the total travel cost (distance) is minimized in all the three methods. It could also be seen that, the optimal solution obtained in ABC approach has been minimized further in both Exchange and Relocation methods. The best optimal result is obtained from ABC with Exchange operator.

Thus the usage of special operators has definitely enhanced the performance of ABC algorithm for solving MTSP.

The execution results have also shown that, longest tour of some salesmen from ABC algorithm has also been reduced to tours of shorter lengths with the usage of special operators.

The results for Computing Time (CT) and Maximum Fitness Evaluation (MFE) are obtained for ABC algorithm, ABC with Exchange operator, ABC with Relocation operator which is presented in Table 2. The We have observed the Performance of ABC algorithm over various iterations and have presented their behaviour.

Tour 1 **Tour 2**

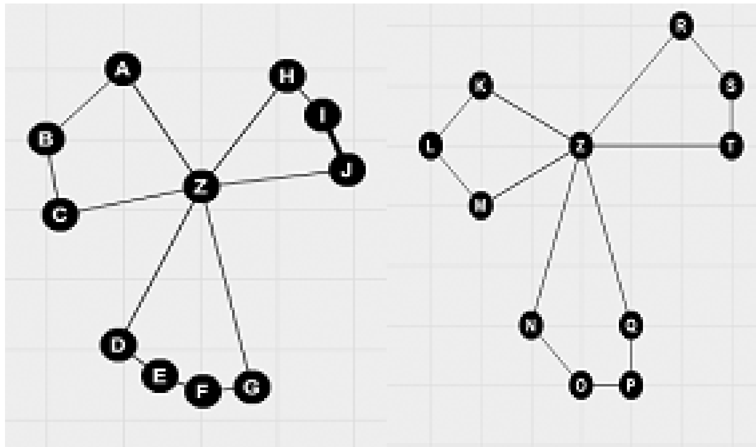

Figure 5: Solution Encoding of two tours:

Tour 1 **Tour 2**

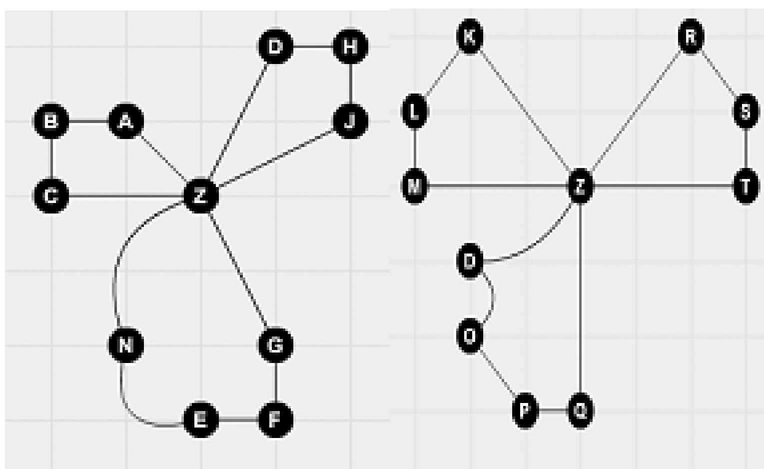

Figure 6: Results obtained after applying Exchange operator

From the results presented in Table 2 which is given below, it could be inferred that the computing time is little higher for both operators because they are additionally added after the implementation of ABC algorithm and the optimality is assured in this case. Computing time is evaluated with the metric milliseconds and hence little higher time doesn't not yield much loss. Maximum Fitness Evaluation (MFE) is the total number of various possible solutions produced in one single iteration. [The sum of Employed Bees, Neighbouring Solution of Employed Bees, Neighbouring Solution of Onlooker Bees and the Scout bee]

A Graphical representation is demonstrated below showing the variations in performance of the ABC algorithm, ABC algorithm with Exchange Operator and ABC algorithm with Relocation Operator respectively.

Pure ABC which is a metaheuristic algorithm possess the characteristics to satisfy both the exploration and exploitation property. But in the absence of special operators as a part of local search there is a possibility of attainment of local minima in earlier iterations. Also optimal result isn't obtained in the earlier iterations.

We observe sudden transitions over successive iterations here which is the sign to denote its degree of randomness.

Table 2
Performance Evaluation for Mtsp Using ABC Algorithm With MFE and Computing Time

Iterations	*ABC Algorithm*		*ABC with Exchange Operator*		*ABC with Relocation Operator*	
	*MFE**	*CT*(ms)*	*MFE**	*CT*(ms)*	*MFE**	*CT*(ms)*
1	301	25.0	301	51.6	301	29.7
2	502	39.0	502	59.4	502	46.4
3	703	40.1	703	63.1	703	63.8
4	904	43.8	904	63.4	904	64.8
5	1105	42.2	1105	75.0	1105	83.5
6	1306	46.9	1306	75.3	1306	112.0
7	1507	62.5	1507	81.0	1507	114.0
8	1708	70.4	1708	87.5	1708	117.2
9	1909	70.6	1909	106.9	1909	118.3
10	2110	71.7	2110	109.7	2110	142.8
11	2311	71.9	2311	112.7	2311	147.5
12	2512	75.0	2512	130.0	2512	171.0
13	2713	84.3	2713	137.8	2713	172.8
14	2914	84.4	2914	139.2	2914	202.0
15	3115	103.3	3115	154.8	3115	202.1
16	3316	103.6	3316	168.8	3316	228.2
17	3517	105.6	3517	172.4	3517	288.5
18	3718	119.0	3718	198.1	3718	289.8
19	3919	122.1	3919	200.5	3919	291.4
20	4120	125.1	4120	209.7	4120	284.1

*CT – Computing Time
*MFE – Maximum Fitness Evaluation

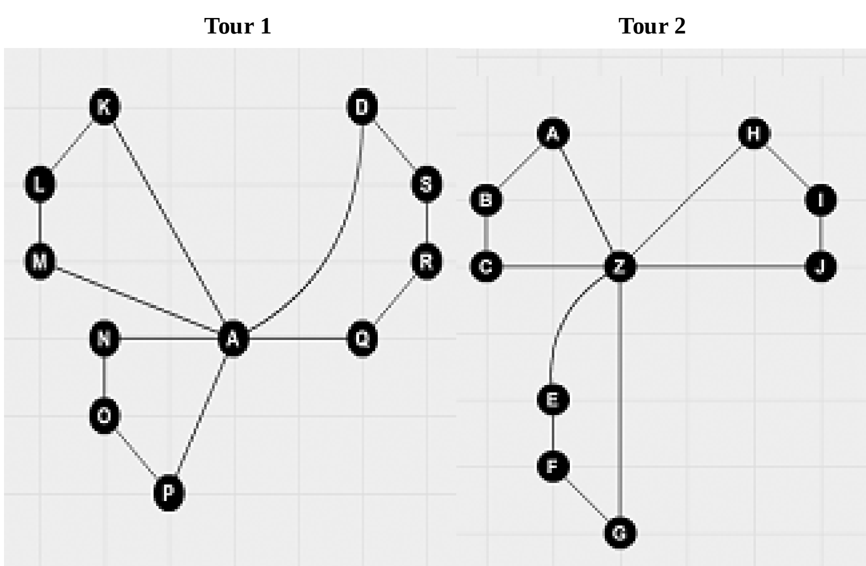

Figure 7: Results obtained after applying Relocation operator

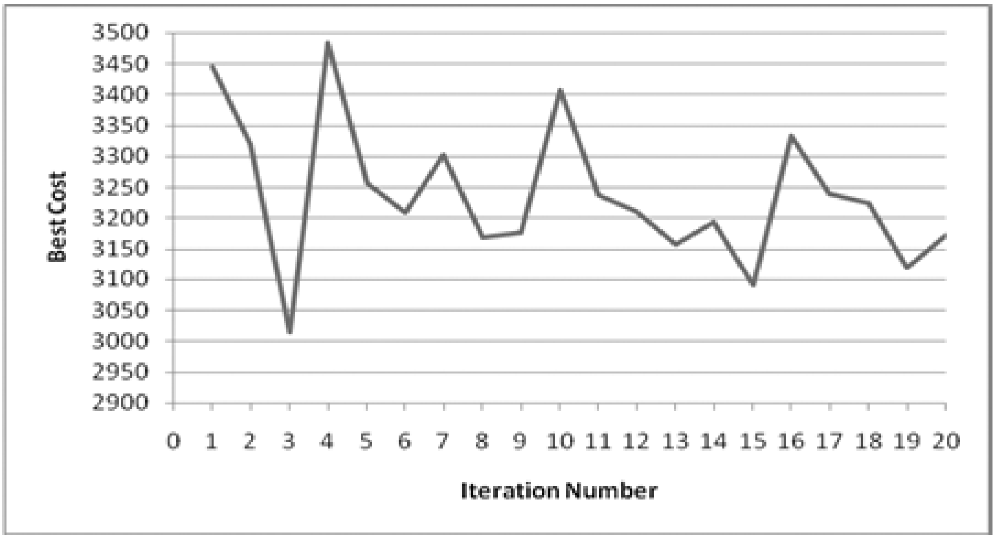

Figure 8:

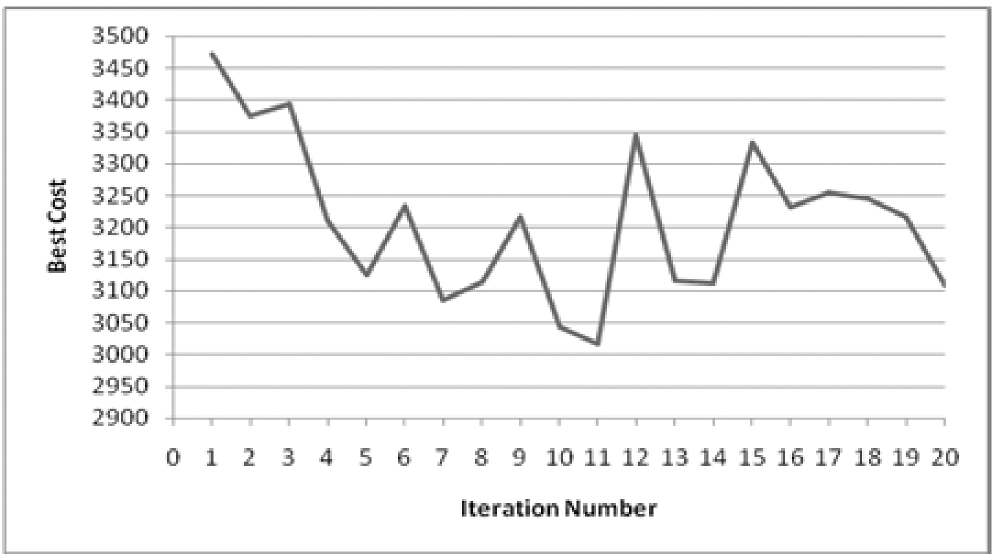

Figure 9:Variations observed with Exchange Operator

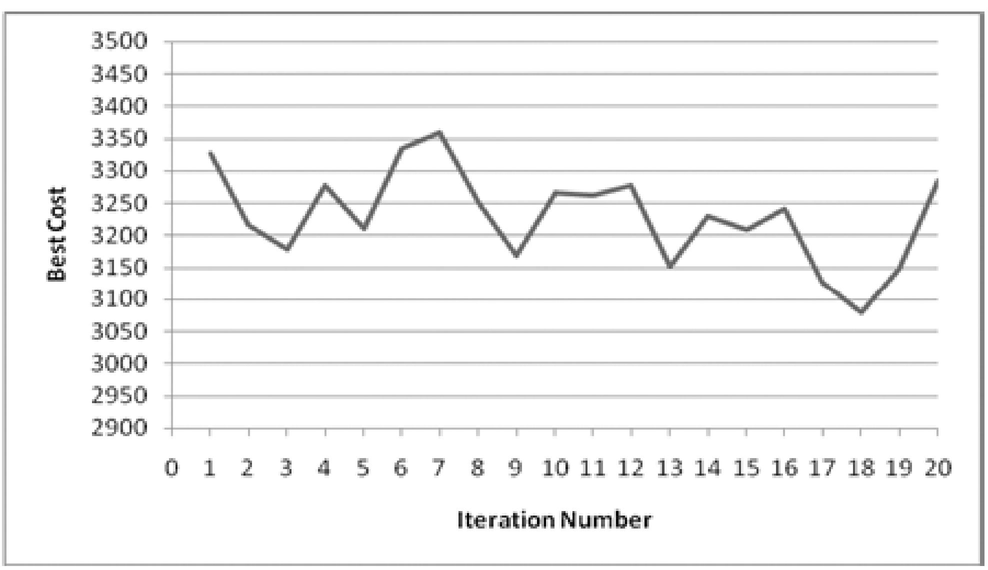

Figure 10:Variations observed with Relocation Operator

Higher the randomness, higher the exploration.

Optimal result is obtained in later iterations.

But the solution space is confined to a range of area where the exploration property is satisfied.

8. CONCLUSION AND FUTURE WORK

We have proposed two inter-tour operators for additional local search to improve the search procedure of ABC algorithm for MTSP optimization. There are three sets of results obtained, one each for ABC algorithm, ABC with Exchange operator and ABC with Relocation operator. Both operators have enhanced the results of ABC algorithm for MTSP and hence increased optimization results. Though both operators have increased the optimization, exchange operator takes the lead. The operators have also reduced the travel distance of some salesmen with tours of longest lengths. Hence the proposed method has resulted in better optimization of MTSP. In future, we have planned to experiment the performance of ABC algorithm with intra-tour operators.

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