COMBINATORIAL OPTIMIZATION USING ARTIFICIAL BEE COLONY ALGORITHM AND PARTICLE SWARM OPTIMIZATION SUPPORTED GENETIC ALGORITHM*

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Emrah ÖNDER
Res. Assist. Dr.,
Istanbul University, School of Business, Department of Quantitative Methods
emrah@istanbul.edu.tr

Muhlis ÖZDEMİR
Res. Assist.,
Istanbul University, School of Business, Department of Quantitative Methods
muhlisozdemir@istanbul.edu.tr

Bahadır Fatih YILDIRIM
Res. Assist.,
Istanbul University, School of Business, Department of Quantitative Methods
bahadirf.yildirim@istanbul.edu.tr

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ABSTRACT| Combinatorial optimization problems are usually NP-hard and the solution space of them is very large. Therefore the set of feasible solutions cannot be evaluated one by one. Artificial Bee Colony (ABC), Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) are meta-heuristic techniques for combinatorial optimization problems. ABC and PSO are swarm intelligence based approaches and they are nature-inspired optimization algorithms. In this study ABC and PSO supported GA techniques were used for finding the shortest route in condition of to visit every city one time but the starting city twice. The problem is a well-known Symmetric Travelling Salesman Problem. Our travelling salesman problem (TSP) consists of 81 cities of Turkey. ABC and PSO-based GA algorithms are applied to solve the travelling salesman problem and results are compared with ant colony optimization (ACO) solution. Our research mainly focused on the application of ABC and PSO based GA algorithms in combinatorial optimization problem. Numerical experiments show that ABC and PSO supported GA are very competitive and have good results compared with the ACO, when it is applied to the regarding problem.

Keywords: *Artificial Bee Colony Algorithm, Particle Swarm Optimization, Clustering, Genetic Algorithm, Traveling Salesman Problem, Shortest Path, Meta-Heuristics, Combinatorial Problems*

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YAPAY ARI KOLONİ ALGORİTMASI ve PARÇACIK SÜRÜ OPTİMİZASYONU DESTEKLİ GENETİK ALGORİTMA İLE KOMBİNATORYAL OPTİMİZASYON

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Emrah ÖNDER
Arş. Gör. Dr.,
İstanbul Üniversitesi, İşletme Fakültesi, Sayısal Yöntemler Anabilim Dalı
emrah@istanbul.edu.tr

Muhlis ÖZDEMİR
Arş. Gör.,
İstanbul Üniversitesi, İşletme Fakültesi, Sayısal Yöntemler Anabilim Dalı
muhlisozdemir@istanbul.edu.tr

Bahadır Fatih YILDIRIM
Arş. Gör.,
İstanbul Üniversitesi, İşletme Fakültesi, Sayısal Yöntemler Anabilim Dalı
bahadirf.yildirim@istanbul.edu.tr

ÖZET | Kombinatoryal optimizasyon problemleri genellikle NP-zor sınıfında yer alan ve çözüm uzayları çok büyük olan problemlerdir. Bu nedenle çözüm uzayında yer alan bütün çözümlerin tek tek denenmesi mümkün değildir. Yapay Arı Kolonisi (YAK), Parçacık Sürü Optimizasyonu (PSO) ve Genetik Algoritma (GA) kombinatoryal optimizasyon problemlerinin çözümü için geliştirilmiş olan meta-sezgisel tekniklerdir. YAK ve PSO doğadan esinlenilmiş sürü zekâsı temelli algoritmalardır. Bu çalışmada YAK ve PSO ile desteklenmiş GA tekniği bütün şehirlerin dolaşılması ve başlangıç şehrine dönmek koşuluyla en kısa rotanın bulunmasında kullanılacaktır.Problem herkesçe bilinen Simetrik Gezen Satıcı Problemi (SGSP)'dir. Bu çalışmada yer alan Gezen Satıcı Problemi (GSP) Türkiye'deki 81 şehirden oluşmaktadır. YAK ve PSO ile desteklenmiş GA tekniği GSP'nin çözümü için kullanılmış ve elde edilen sonuçlar Karınca Kolonisi Algoritması (KKA) ile elde edilen sonuçlar ile karşılaştırılmıştır. Araştırmamız YAK ve PSO ile desteklenmiş GA tekniği ile kombinatoryal optimizasyon probleminin çözümüne dayanmaktadır. Elde edilen sonuçlar göstermektedir ki YAK ve PSO ile desteklenmiş GA tekniği ile elde edilmiş olan sonuçlar KKO ile karşılaştırıldığında oldukça etkili ve iyi sonuçlardır.

Anahtar Kelimeler: *Yapay Arı Kolonisi Algoritması, Parçacık Sürü Optimizasyonu, Sınıflandırma, Genetik Algoritma, Gezen Satıcı Problemi, En Kısa Yol, Meta-Sezgiseller, Kombinatoryel Problemler*

Jel Kodu: *C61*

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1. INTRODUCTION

Many inherent circumstances are leading to forming the research area. During the last decade swarm intelligence has become very popular. The most popular swarm intelligence approaches are Ant Colony Optimization, Particle Swarm Optimization and Artificial Bee Colony (ABC) Algorithm. These days ABC Algorithm has attracted the researchers' interest. Travelling Salesman Problems are very interesting problems and have the attraction of the researchers for the decades. Traveling Salesman Problem (TSP) is a well-known and extensively studied NP-hard combinatorial optimization problem and the aim of TSP is to find shortest tour that visits every city once for a given list of cities and back to the starting city (Liao et al, 2012). Another TSP definition is defined by Zhong et al. as follows; that there is one salesman who wants to visit *n* cities, and his object is finding the shortest Hamilton cycle through which he can visit all the cities only once and return to the starting point (Zhong et al, 2007). PSO and ABC are population based swarm intelligence algorithms. PSO was proposed by Kennedy and Eberhart in 1995. ABC was proposed by Karaboğa for numerical function optimization in 2005. PSO and ABC are well-known techniques for solving the continuous problems and these techniques can be applied discrete problems such as TSP. The TSP is an important optimization problem for many areas such as engineering, manufacturing, transportation, logistics, etc. (Kıran et al, 2012). In recent years, many kind of swarm intelligence algorithms based on bees have been developed. These approaches are Artificial Bee Colony (ABC), Virtual Bee Colony, Bee Colony Optimization Algorithm, BeeHive Algorithm, Bee Swarm Optimization Algorithm and Bees Algorithm (Marinakis et al, 2011). ABC has three essential components while the honey bees exhibiting the behaviour of foraging. These components are food sources, employed bees and unemployed bees. There are two types of unemployed bees, onlooker bees and scout bees. Employed bees are responsible for carrying the nectar to the hive and making the dance in the dancing area. Onlooker bees are responsible for watching the dances in the dancing area and make a decision of the selecting the food sources by the information from employed bees. Scout bees are in charge of searching the area for new food sources randomly when a food source is depleted. When scout bee finds a food source it becomes an employed bee. The nourishment behaviour of honey bees used for searching the solution area and the behaviour of their dance in the dancing area used for sharing the information between bees (Karaboğa, 2005). Several heuristic techniques have been developed for solving combinatorial optimization problems. This paper introduces three methods for solving combinatorial optimization problems. The one with the ACO was solved by Söyler and Keskintürk in 2007. The other two methods will be take part in this study. The results will be compared at the end of the paper. The rest of the paper is organized as follows; in section two problem definition will be given, in section three PSO based GA for TSP will be introduced, in section four ABC Algorithm for TSP will be introduced, and finally the comparative results will be presented.

2. PROBLEM DEFINITION

There are 81 cities in Turkey. While developing our algorithm we used the plate numbers to represent the cities. In this study our aim is to find shortest route in Turkey in condition of to visit every city one time but the starting city two times. The problem is a well-known symmetric travelling salesman problem. In the symmetric travelling salesman problem the distance between two cities is the same in each opposite direction. The data set of the city distances provided by Republic of Turkey General Directorate of Highways web site. The link can be found at the references section. The traveling salesman problem consists of a salesman and a set of cities. The salesman has to visit each one of the cities starting from the beginning city and returning to the same city at the end of the tour. The aim of the traveling salesman is to minimize the total length of the trip. The traveling salesman problem can be described as follows: TSP is a graph and is shown as G=(V,E). V={0,...,n} are the nodes and A={(i,j):i,j ϵ V, i ≠j} is the arc set. G=(V,A) is a graph c_{ij}: is the cost of each arc (non negative value). The unit of cost can be distance or transportation duration. G is a graph that contains a traveling salesman tour with cost that should be minimized Hamilton tour. When all the (i,j)ϵA and $c_{ij}=c_{ji}$ than the problem is symmetric and E={(i, j) : i, j ϵ V ,i < j} is a arc set and the graph without direction described in G=(V,E).

3. PARTICLE SWARM OPTIMIZATION AND GENETIC ALGORITHM FOR TSP

In this part of the study PSO was used for clustering and GA was used for solving the optimum route. Clustering made the initial solutions better. GA algorithm starts iterations with clustered solutions for reducing the complexity. The main objective of clustering is to obtain quality initial solution.

3.1. Clustering Using Particle Swarm Optimization

Particle swarm optimization is one of the new techniques for solving clustering problems. PSO based clustering is an effective algorithm for multi-dimensional clustering problems. In n dimensional Euclidian space R^n, N data points separate into K clusters and assign to cluster centers. Each particle's value is coding with real numbers strings. K is the number of cluster centers for n dimensional space the length of the particle is K*n. The initializing of population is done randomly and each particle of the population shows all cluster centers (Chen&Ye, 2004). A coded particle string example is shown in the table below. In this particle the number of dimension is 2 and the number of cluster is 5. The string of this particle represents 5 cluster centers.

Table 1. A coded particle string

Center of cluster 1		**Center of cluster 2**		**Center of cluster 3**		**Center of cluster 4**		**Center of cluster 5**	
X_1	Y_1	X_2	Y_2	X_3	Y_3	X_4	Y_4	X_5	Y_5
39.76596	27.56894	40.17901	30.21879	38.93444	34.44647	38.362728	38.094931	38.730906	41.689388

PSO based clustering algorithm can be shown as below:

INPUT: GPS coordinates number of clusters, number of iteration, inertia weight, cognitive and social coefficients
Initialize locations of particles
FOR iteration number
    FOR number of particles
        Update locations
        Find nearest cluster center to each city
        Calculate total distance from each city to its nearest cluster center
            IF total distance < particle's best distance THEN
                Update best distance of particle
            ENDIF
    ENDFOR
    Update global best of the population
    Update velocities
ENDFOR
Assign each city to its nearest cluster center
Calculate the total distance from each city to its nearest cluster center.
OUTPUTS: Coordinates of cluster centers, Each city's cluster ID, Total Distance

Table 2. Selected control parameters in PSO algorithm

Parameters	The value of parameters
Number of particles	30
Number of iterations	1000
Inertia Weight	0.7
Cognitive coefficient	1.47
Social coefficient	1.47
Stopping criteria	Number of iteration

Clustering analysis in two dimensions with PSO starts with initializing all particles in the population. 30 particles in the population take initial values randomly. But the upper and lower limits of the initial solutions are determined using GPS coordinates of the cities. Then, numbers of iteration, inertia weights, cognitive coefficients, social coefficient are determined. The GPS coordinates of the cities are put into the system in matrix form. During the iteration the locations of the X and Y dimensions of the particles are updated. Then, the distances between city and cluster centers are calculated. The sum of these distances is identified. If the calculated value is less than the global best value, it is saved. Then, the velocity vectors of particles are updated. Particles are assigned to the nearest cluster centers and again the total distances from cities to cluster centers are calculated. After all the iterations have finished the results become coordinates of cluster centers, each city's cluster ID and total distance (fitness value). Solving TSP via Genetic Algorithm with PSO based Initial Solutions

The code was developed with MATLAB programming language for solving TSP. The inputs and outputs are shown below:

∗Inputs:

∗The number of cities.

∗The size of population

∗Number of iteration

∗City coordinates or distance matrix.

∗Outputs:

∗Total traveling distance for best solution

∗Best route

The aim of the MATLAB code is to minimize the total traveling distance. The control parameters used in the GA are shown below:

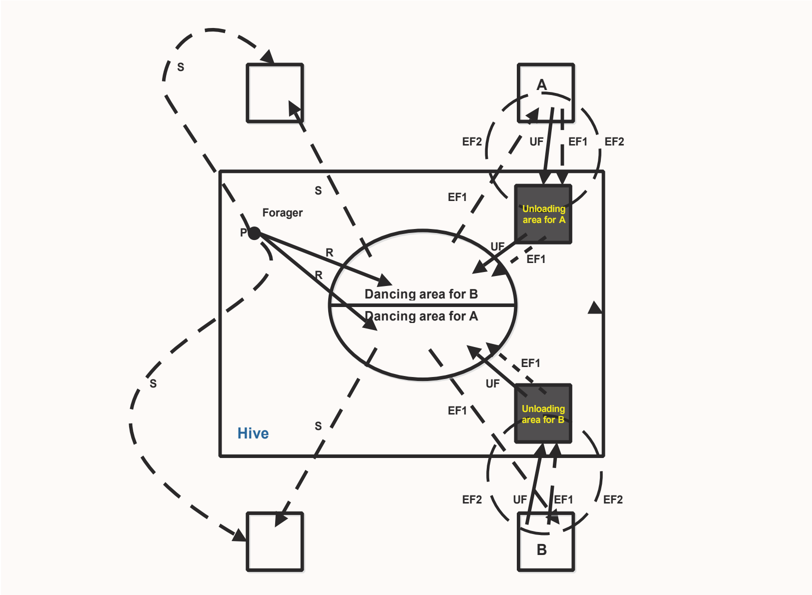
Table 3. Control Parameters of Genetic Algorithm

Control Parameter	The Value of Control Parameter
Size of the population	80
Number of iteration	1000
Types of mutation	Insertion mutation Swap mutation Reversion mutation
Stopping criteria	Number of Iteration
Selection strategy	Tournament Selection

4. ARTIFICIAL BEE COLONY ALGORITHM FOR THE TSP

In literature studies about TSP is divided two classes. Exact algorithms and heuristic algorithms have been developed for solving the TSP problems. In this paper we are going to use heuristic algorithm for solving the TSP. The heuristic one based on tour improvement method which starts an initial tour and try to change it to the shortest route. Artificial Bee Colony (ABC) algorithm is a meta-heuristic method that was developed by Derviş Karaboğa in 2005. The method was inspired by honey bee colonies and based on observing the nourishment behaviour of honey bees. Although it was developed in 2005 the ABC algorithm became a very popular method and attracted the interest of many researchers. The artificial bee colony optimization is a population-based algorithm for combinatorial optimization that is inspired by the foraging behavior of bees. The population consists of two types of artificial bees: employed bees which scout for new, good solutions and onlooker bees that search in the neighborhood of solutions found by the employed bees (Diwold et al, 2011). To summarize the foraging behaviour of bees; at first the scout bee starts to search the environment randomly in order to find a food source. After finding a food source the scout bee becomes an employed bee of the source. The employed bee is responsible for carrying the nectar to the hive. When the employed bee arrives to the hive there is two options; after carrying the nectar the employed bee can go back to the source or can go to the dancing area for sharing the information about the food source. If the source is depleted the employed bee becomes a scout bee again. Onlooker bees are responsible for watching the dances in the dancing area and have to make a decision of the selecting the food sources by the information from employed bees. These selections are depends on the quality of the source. There will be much more dances about the qualified nectar then the others. In ABC algorithm it is assumed that there is only one scout bee. Employed bee numbers and the onlooker bee numbers are equal (Akay and Karaboğa, 2012). The behaviour of honey bee foraging for food source can be seen in *Figure 1*.

Figure 1: The behavior of honey bee foraging for food source



Source: *Karaboğa Derviş, An Idea Based on Based on Honey Bee Swarm for Numerical Optimization, Technical Report, 2005*

Artificial bee colony algorithm is simple, easy, very fast, and it can be effectively applied to the combinatorial optimization problems. The procedure of ABC can be described as follows (Karaboğa and Akay, 2009); Equation [1] represents the initial solution. In this study random routes between 1 and 81 generated by using this equation. When a source is abandoned then a scout bee searches the new foods by the equation below at the same time;

$$x_{ij} = x_j^{\min} + rand(0,1)(x_j^{\max} - x_j^{\min}) \qquad [1]$$

Equation [2] represents the employed bee phase. Each employed bee represents a solution in the solution space. The employed bee performs random modifications on adjacent to a solution which belongs to it.

$$\upsilon_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}) \qquad [2]$$

Equation [3] represents the onlooker bee phase. Onlooker bees choose a food source with probability proportional to the quality of the food source. The fitness of a solution can be evaluated by the equation below;

$$fitness_i = \begin{cases} \dfrac{1}{1+f_i} & if \quad f_i \geq 0 \\ 1+abs(f_i) & if \quad f_i < 0 \end{cases} \qquad [3]$$

4.1. Parameter Tuning

The number of ABC control parameters is fewer than the other heuristic techniques. The proposed ABC algorithm can be tunable because there are only a few parameters. These parameters are food number, employed bee number, onlooker bee number, limit and iteration number. To determine appropriate parameter settings, we used trial and error method. Three levels for each parameter were selected and we run the ABC algorithm three times to select the proper values from the parameter levels. Parameter tuning table and selected values as follows;

Table 4: Parameter levels and selected values for ABC algorithm

Parameters	Considered Values	Selected Value
Food number	10, 15, 30	30
Employed bee number	10, 15, 30	15
Onlooker bee number	10, 15, 30	15
Limit	100, 200, 300	100
Iteration number	1000, 3000, 5000	3000

We used three manipulating operators. These operators are swap, insertion and reversion operators. If a solution consists ten cities then randomly two numbers produces in range between cities. The swap operator changes two points randomly by the selected random two numbers formerly. For instance if the selected two numbers are 2 and 7 then the permutation will be below;

Figure 2: The swap operator

Before Swap Operator	8	**6**	5	3	2	4	**1**	7	10	9
After Swap Operator	8	**1**	5	3	2	4	**6**	7	10	9

The insertion operator changes the placement of the permutation. The changing of the permutation can be seen in Figure 3;

Figure 3: The insertion operator

Before Insertion Operator	8	**6**	5	3	2	4	**1**	7	10	9
After Insertion Operator	8	**5**	**3**	**2**	**4**	**1**	**6**	7	10	9

The reversion operator reverses the placement of the permutation. The changing of the permutation can be seen in Figure 4;

Figure 4: The reversion operator

Before Reversion Operator	8	**6**	5	3	2	4	**1**	7	10	9
After Reversion Operator	8	**1**	**4**	**2**	**3**	**5**	**6**	7	10	9

A flowchart depicting the proposed ABC Algorithm is given in Figure 5.

Figure 5: A flowchart of ABC

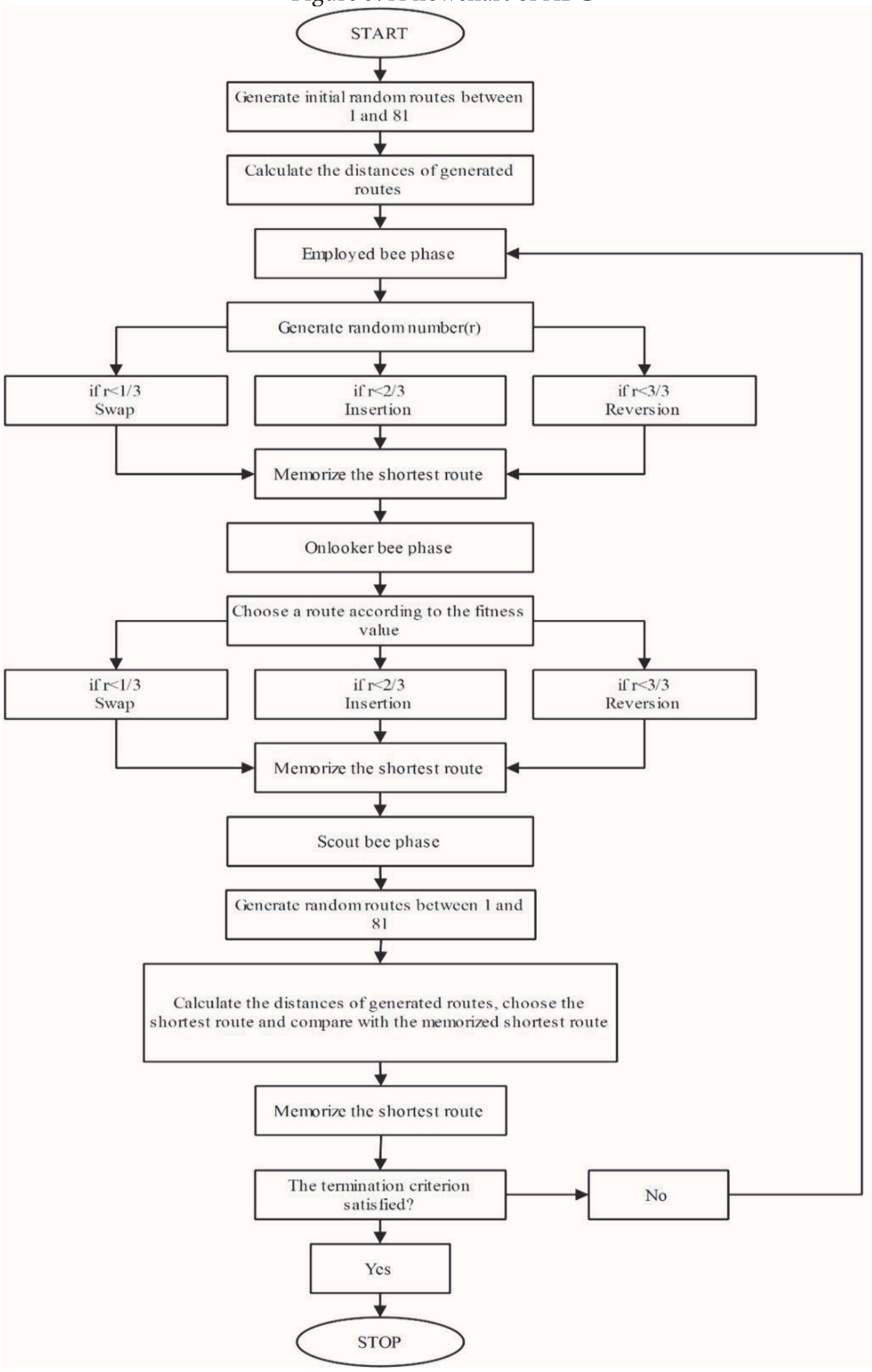


Table 5. The route proposed by PSO based GA and ABC algorithm

Plate Numbers	Departure	Arrival	Plate Numbers	Departure	Arrival	Plate Numbers	Departure	Arrival	Plate Numbers	Departure	Arrival
19--66	Çorum	Yozgat	22--39	Edirne	Kırklareli	53--8	Rize	Artvin	72--21	Batman	Diyarbakır
66--40	Yozgat	Kırşehir	39--59	Kırklareli	Tekirdağ	8--75	Artvin	Ardahan	21--47	Diyarbakır	Mardin
40--71	Kırşehir	Kırıkkale	59--34	Tekirdağ	İstanbul	75--36	Ardahan	Kars	47--63	Mardin	Şanlıurfa
71--18	Kırıkkale	Çankırı	34--41	İstanbul	Kocaeli	36--76	Kars	Iğdır	63--2	Şanlıurfa	Adıyaman
18--6	Çankırı	Ankara	41--77	Kocaeli	Yalova	76--4	Iğdır	Ağrı	2--46	Adıyaman	Kahramanmaraş
6--26	Ankara	Eskişehir	77--16	Yalova	Bursa	4--25	Ağrı	Erzurum	46--27	Kahramanmaraş	Gaziantep
26--43	Eskişehir	Kütahya	16--11	Bursa	Bilecik	25--69	Erzurum	Bayburt	27--79	Gaziantep	Kilis
43--3	Kütahya	Afyon	11--54	Bilecik	Sakarya	69--29	Bayburt	Gümüşhane	79--31	Kilis	Hatay
3--64	Afyon	Uşak	54--14	Sakarya	Bolu	29--24	Gümüşhane	Erzincan	31--80	Hatay	Osmaniye
64--32	Uşak	Isparta	14--81	Bolu	Düzce	24--62	Erzincan	Tunceli	80--1	Osmaniye	Adana
32--15	Isparta	Burdur	81--67	Düzce	Zonguldak	62--44	Tunceli	Malatya	1--33	Adana	Mersin
15--7	Burdur	Antalya	67--74	Zonguldak	Bartın	44--23	Malatya	Elazığ	33--70	Mersin	Karaman
7--20	Antalya	Denizli	74--78	Bartın	Karabük	23--12	Elazığ	Bingöl	70--42	Karaman	Konya
20--48	Denizli	Muğla	78--37	Karabük	Kastamonu	12--49	Bingöl	Muş	42--68	Konya	Aksaray
48--9	Muğla	Aydın	37--57	Kastamonu	Sinop	49--13	Muş	Bitlis	68--51	Aksaray	Nevşehir
9--35	Aydın	İzmir	57--55	Sinop	Samsun	13--65	Bitlis	Van	51--50	Nevşehir	Niğde
35--45	İzmir	Manisa	55--52	Samsun	Ordu	65--30	Van	Hakkâri	50--38	Niğde	Kayseri
45--10	Manisa	Balıkesir	52--28	Ordu	Giresun	30--73	Hakkâri	Şırnak	38--58	Kayseri	Sivas
10--17	Balıkesir	Çanakkale	28--61	Giresun	Trabzon	73--56	Şırnak	Siirt	58--60	Sivas	Tokat
17--22	Çanakkale	Edirne	61--53	Trabzon	Rize	56--72	Siirt	Batman	60--5	Tokat	Amasya
									5--19	Amasya	Çorum

Total length of the route proposed by PSO based GA and ABC algorithm is 9920 kilometer

5. RESULTS

Our research mainly focused on the application of ABC and PSO based GA algorithms in combinatorial optimization problem. Numerical experiments show that ABC and PSO based GA are very competitive and have good results compared with the ACO, when it is applied to the TSP problem. The route which we proposed takes part in table 5. The proposed route can be considered as a closed loop. So the starting city is not important it can be selected randomly. The results are shown in Table 6:

Table 6. Optimization Results Using ACO, PSO_GA and ABC Algorithms

ACO	GA	ABC
9921 KM	9920KM	9920 KM

6. CONCLUSION

In this paper, we proposed ABC method and PSO-GA approach based on clustering concept for solving Symmetric Traveling Salesman Problem. The proposed methods show competitive performance compared to the ACO algorithm. We obtained very close solutions for TSP with 81 cities. For very large size problems, selecting initial solutions with PSO supported clustering algorithm is effective method. Thus, we may conclude that the proposed PSO-GA approach is efficient methodology for very large size TSP.

7. REFERENCES

Akay Bahriye, Karaboğa Derviş, A modified Artificial Bee Colony algorithm for real-parameter optimization, Information Sciences, 192, pp. 120–142, 2012

Chen, C.Y., Ye, F., Particle Swarm Optimization Algorithm and Its Application to Clustering Analysis, Proceedings of the 2004 IEEE, International Conference of Networking, Sensing and Control, Taipei, Taiwan, March, 2004, 789-79

Diwold K., Aderhold A., Scheidler A., Middendorf M., Performance evaluation of artificial bee colony optimization and new selection scheme, Memetic Computing, Volume 3, Issue 3, Sayfa 149–162, 2011

http://www.kgm.gov.tr/Sayfalar/KGM/SiteTr/Root/Uzakliklar.aspx

Karaboğa Derviş, Akay Bahriye, A Comparative Study of Artificial Bee Colony Algorithm, Applied Mathematics and Computation 214, pp. 108-132, 2009

Karaboğa Derviş, An Idea Based On Honey Bee Swarm For Numerical Optimization, Technical Report, pp. 1-10, 2005

Kennedy J., Eberhart R. C., Particle swarm optimization, in Proc. of the IEEE International Conference on Neural Networks, Piscataway, NJ, pp. 1942–1948, 1995

Kıran, Mustafa Servet, İşcan Hazım, Gündüz Mesut, The analysis of discrete artificial bee colony algorithm with neighborhood operator on traveling salesman problem, Neural Computing and Applications, pp. 1–13. doi:10.1007/s00521-011-0794-0, 2012

Liao Y.-F., Yau D.-H., Chen C.-L., Evolutionary algorithm to traveling salesman problems, Computers & Mathematics with Applications, Volume 64, Issue 5, 788–797, doi:10.1016/j.camwa.2011.12.018, 2012

Marinakis, Y., Marinaki, M., Dounias, G., Honey bees mating optimization algorithm for the Euclidean traveling salesman problem, Information Sciences, 181(20), pp. 4684–4698, doi:10.1016/j.ins.2010.06.032, 2011

Republic of Turkey General Directorate of Highways web site (2013)

Söyler Hasan, Keskintürk Timur, Karinca Kolonisi Algoritmasi ile Gezen Satici Probleminin Çözümü, 8. Türkiye Ekonometri ve İstatistik Kongresi, 2007

Wen-liang Zhong, Jun Zhang, W. C., A Novel Discrete Particle Swarm Optimization to Solve Traveling Salesman Problem, Evolutionary Computation pp. 3283–3287, 2007

Yen-Far Liao, Dun-Han Yau, Chieh-Li Chen, Evolutionary algorithm to traveling salesman problems, Computer and Mathematics with Applications 64, 788-797, 2012