IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-7, Issue-7, July 2019 E-ISSN: 2347-2693

Solving Travelling Salesman Problem using an Enhanced Ant Colony Algorithm

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DOI: https://doi.org/10.26438/ijcse/v7i7.214222 | Available online at: www.ijcseonline.org

Accepted: 29/Jul/2019, Published: 31/Jul/2019

Abstract— Complex Optimization problems are solved effectively by heuristic approaches. Bio-inspired algorithms play a vital role in solving various complex computational problems. Ant Colony Optimization is one such bio-inspired techniques that stand even after three decades in addressing such issues. Travelling Salesman Problem is taken as a case study and an enhanced ant colony algorithm is used to solve it using the best feature of ACO called as pheromone. The proposed technique involves a modified pheromone rule plays a key parameter in solving the TSP. The experimental medium takes a graph of cities and their distances, followed by solving it using the proposed approach. The data analytics of maximum, mean and minimum costs of the graph are analyzed using R tool. The experimental results prove that the proposed enhanced ant colony algorithm effectively solves Travelling Salesman Problem.

Keywords— Optimization, Travelling Salesman Problem, Bio-Inspired, Ant colony Algorithm, Pheromone.

I. INTRODUCTION

Travelling Salesman Problem:
The traveling salesman problem involves a visit across a set of cities. The journey must involve visiting each one of the cities starting from a random one and returning to the same city. The main challenge of the problem is that the journey wants to minimize the total length or cost of the journey. Let us consider a graph $G = (V, E)$, where V is a set of cities and E is a set of weighted edges. An edge $e(u, v)$ represents that vertices u and v are connected. Distance between vertex u and v is $d(u, v)$ which should be non-negative. Let C be the total cost of journey.
Problem Description: Minimized Cost for a journey that involves visit to all cities exactly once from the same start and end city.
Input: Number of cities, Distance (Cost) between the cities.
Output: Minimized Cost of journey

Travelling Salesman Problem:
Inspiring the behaviour of ants' nature, Macro Dorigo started to frame research framework involving nature of ants. Ants possess a chemical substance called pheromone which they are found lying on the ground surface as they travel. This chemical substance has a smell by nature which other ants use to follow the same path. The pheromone has evaporation nature. This led to heuristic solutions for various complex computational problems.

II. LITERATURE SURVEY

Ant Colony algorithm is used to address combinatorial optimisation problem in paper [1]. More than 10 variations of ACO was implemented and executed for Travelling Salesman Problem. ACO can also be used to provide solution to Dynamic Network routing problems. The versatile nature of Ant colony optimization helps to provide solutions for problems like Travelling Salesman Problem (TSP), Single Machine Total Weighted Tardiness Problem (SMTWTP), Set Covering Problem (SCP), Dynamic Network Routing Problem. The ant colony optimization is thus used to solve problem types like routing, assignment, scheduling, subset, machine learning, bio informatics, multi-objective optimization problem, continuous optimization etc. The paper further explores about hybridization of Ant Colony Optimization with Branch and Bound techniques, Constraint and Integer Programming techniques, etc. This increased the trend of applying Ant colony optimization to various real-world problems.

Three variations of Ant Colony Optimization namely, Max-Min Ant System, Ant Colony System with Local search and continuous Ant Colony has been focused upon in paper [2]. This paper aims on swarm intelligence technique namely Ant Colony Optimization and its impact in solving Travelling Salesman Problem (TSP). This paper visualizes the effect of ACO in solving combinatorial problems. A new way to solve Travelling Salesman Problem using a combination of Ant Colony algorithm with Tabu search algorithm has been suggested in paper [3]. This combination addresses the loopholes of basic ant colony algorithm's problems like slow convergence speed, selection of certain paths repeatedly, etc. This integration of two algorithms gets worked using an additional table called tabu table to store the ant's recently searched path. The performance of this combination is found to be more effective than the traditional ant colony algorithm. Ant colony- Particle Swarm algorithm is designed to provide solution to supermarket chain supply route using TSP solution of Ant Colony algorithm as its base in paper [4]. Performance of this proposed algorithm addresses the issues of classical ant colony algorithm like convergence problem and is compared with performance of Simulated Annealing algorithm, Genetic algorithm. A multi-strategy improved ant colony algorithm is used to solve Travelling Salesman Problem in paper [5]. The algorithm adopts weighted initial pheromone distribution based on Nearest Neighbour method, path evolutionary strategy based on improved transition probability and an improved strategy for pheromone updating. The weighted initial pheromone distribution based on Nearest Neighbour method gets initiated with pheromone distribution matrix and filters optimal solution with larger deviation. Therefore, it acts a basis for updating pheromone. The path evolutionary strategy provides the ability to skip out of local optimum.

Multimodal optimization technique is adopted in the proposed novel niching ant colony system in paper [6]. It handles multiple pheromone matrices to preserve and keep track of multiple paths. The global pheromone updating is done by the optimal ant in each niche. Ants are divided into groups or niches and the number of ants assigned to each niche is determined by the quality of that niche. Travelling Salesman Problem is solved using an improved negative feedback mechanism with ant colony algorithm in paper [7]. This paper focuses on enhancement of the algorithm's ability to come out of local optima by overcoming the restrictions over pheromone concentration through the proposed pseudo-dynamic search approach. In addition to that the convergence speed is also increased by updating the weight of pheromone concentration in the optimal path.

A new version of ant colony algorithm namely Social Interaction Ant Colony Optimization for addressing Travelling Salesman Problem is introduces in paper [8]. Concept of game theory is hybridized with ant colony algorithm that outlooks the performance of the traditional algorithm. The proposed approach enables each ant to initiate with a behaviour during an entire iteration. A new version of ant colony system named P-ACO (Population based ant colony algorithm) has been proposed in paper [9]. The pheromone update is the part of enhancement with respect to the proposed technique from that basic ant colony system. A solution archive is maintained by keeping track of a population of solutions. The proposed approach keeps a keen role in reducing the computational time gracefully. This proposed approach is applied to TSP. A focus on parallel ACO algorithm tailored for GPUs is done to achieve higher performance in paper [10]. A large range of about 198 to 4461 cities of TSP instances were used as input instance to the proposed algorithm. The experimental results proved positively with speedup of up to 44x in the TSP problem. The results were compared with that of GPU data parallel ant colony system.

The problem of premature convergence and weak robustness of Ant colony optimization (ACO) algorithms has been addressed in paper [11]. Phys arum-based pheromone matrix optimization strategy in ant colony system (ACS) is proposed for solving NP-hard problems such as traveling salesman problem (TSP) and 0/1 knapsack problem (0/1 KP). The proposed model has a unique characteristic of reserving critical tubes in the process of network evolution to speed up the feedback process of the Ant Colony System resulting in quick convergence of the optimal solution.

Ant Colony Optimization along with its various variants has been described in a detailed manner in paper [13]. Ant Colony System is gaining more importance because of its efficiency in solving discrete optimization problems. In addition to that the paper addresses various dimensions of dynamic problems, stochastic problems and multiple objective problems in the view of solving it using Ant Colony System. A new evolutionary optimization algorithm to solve travelling salesman problem has been presented in paper [14]. The algorithm first searches for the best solution by using fast opposite gradient search and then improves the candidate solutions using ant colony optimization. The results claim to achieve shorter distance in all generations. The algorithm performs search for solution like binary search.

A new way to solve the travelling salesman problem by applying both particle swarm optimization and ant colony optimization has been proposed in paper [15]. First particle swarm optimization is used to find the solution which is later improved using ant colony optimization. The results are compared with various TSP benchmark in terms of completion time and best length. The proposed method has been proven to be efficient. Modification of pheromone update has been done to conventional ant colony optimization to improve the performance in solving the travelling salesman problem in this paper [16]. It is found that the goal is reached earlier than conventional ACO using this algorithm. paper tries to address the difficulty that ant colony optimization has in addressing dynamic optimization problems. An ACO framework is proposed where different immigrant schemes are integrated into ACO algorithms. Each algorithm has been found to perform well in different environmental cases and all proposed algorithms has been found to be better than many other ACO algorithms.

A model induced min max Ant colony optimization is proposed for solving asymmetric travelling salesman problem in paper [18]. The gap between hybridization and theoretical analysis has been bridged. Three propositions are made in this paper that lead to two improvements compared to classical ACO. First, development of adjusted transition probabilities and identification and exclusion of non-optical arcs. Second, based on pheromone matrix structure a terminal condition is determined. The results show more powerful search ability than classical ACO. A new optimization technique called the pheromone correction strategy is used to solve the travelling salesman problem in paper [19]. An a-posteriori heuristic significantly lowers the pheromone values for highly undesirable links. The proposed algorithm does not consider local optima, as a result avoids stagnation. Claims are that best-found solutions and mean values for multiple runs are improved. A modified ant colony optimization algorithm for solving multiple travelling salesman problem is proposed in paper [20]. The classic ACO has been modified by including insert, swap and 2-opt algorithm to form a new modified ACO (NMACO). This algorithm escapes from local optimum using an effective escape criterion. It uses only global updating for current best solution. The efficiency of the algorithm is evaluated using a new state transition rule and an efficient candidate list. This paper claims that NMACO has been able to improve the efficiency of ACO in all instances.

An efficient way to solve the travelling salesman problem using ant colony optimization algorithm is provided in paper [20]. The proposed solution has parameter optimization taken from the Taguchi method. The performance analysis shows results in favour of the paper. System performance is affected to a great extent. Using Taguchi method, it has shown the possibility to provide fewer experiments and save time and cost. The algorithm has been found to find optimum or near to optimum solutions. An adaptive control strategy for the alpha parameter in ant colony optimization has been proposed in paper [22]. The controller always maintains diversity at some level to avoid premature convergence. The results are compared with various instances of TSP and it has been found that the proposed method improves the performance of ACO algorithm. Discrete optimization problems in various engineering domain that can be solved using ACO has been discussed in paper [23]. This paper provides an optimization mechanism to solve routing problem. Recent researches and implementation have also been reviewed in this paper. The results are compared with results from single path and multi path ACO (SMACO).

An improved ant colony optimization to solve the Generalized travelling salesman problem has been presented in paper [24]. It addresses the problem of GTSP local search by using individual variation strategy. The other problems that get solved along the way are searching time and jumping to local optimal solution. Individual variation enables ants to have different route strategies. This approach also reduces the processing cost. A new algorithm which is a combination of genetic algorithm and ant colony optimization for solving the dynamic travelling salesman problem has been highlighted in paper [25]. The algorithm tries to solve premature convergence of local optimum, which is not possible by GA or ACO alone. By combining the two, the hybrid algorithm has been found to possess a good speed in convergence. The global optimal solution for travelling salesman problem using genetic algorithm and ant colony optimization has been tried to obtain in paper [26]. The proposed solution to the problem is cooperation genetic ant system (CGAS). High level of diversity in next generation solution is maintained by running the GA independently. The results in terms of capability, global optimal solution and quality of average solution has been better with CGAS.

An adaptive parallel ACO algorithm that aims to solve the problem of information exchange and time taken for information exchange has been proposed in paper [27]. The proposed algorithm is applied to travelling salesman problem in order to prove the results. Pheromone value is updated through communication between the processors. The tested results have been proven to show high convergence speed, high speed-up and high efficiency. A framework to solve bi-objective travelling salesman problem has been provided in paper [28]. The framework is named multi objective ant colony optimization. The problem is decomposed into various sub-problems. An ant colony is also divided into various sub colonies, each for a sub problem. An aggregated heuristic matrix is maintained by each sub problem. The subproblems are formed using Tchebycheff approach. The experimental results have been found to be both efficient and effective.

A dual population parallel ant colony optimization algorithm is proposed to solve travelling salesman problem in paper [29]. This algorithm separates the ants into soldier and worker ants which evolve separately and parallelly and exchange information in a timely manner. The effect of soldier ant's distribution to worker ants achieves a dynamic equilibrium between convergence speed and solution diversity. The results have shown that the algorithm has better global searching ability, higher convergence speed and solution diversity. A theoretical analysis of ant colony optimization approach to solve the travelling salesman problem has been provided in paper [30]. A new construction graph is presented which shows that it has stronger local property. Situations in which the proposed algorithm gets trapped in local optima is also pointed out. The paper also shows where the use of right amount of heuristic information is beneficial. Theoretical results of this paper show better runtime bounds through arbitrary edge insertion.

A genetic simulated annealing ant colony system with particle swarm optimization technique is developed to solve the travelling salesman problem in paper [31]. The ant colony system generates the initial population of the genetic algorithms after which simulated annealing mutation techniques are performed to gain better results. This algorithm gives a better average solution as well as reduced percentage of deviation from the best solution. A new scheme of classification of software based parallel ant colony optimization algorithms is provided in paper [32]. A systematic and comprehensive survey on current implementations of ACO is also provided. Various models and their results are discussed which include Master-slave model, Coarse-grain Master-slave model, Fine-grain Master-slave model, Cellular model, Parallel Independent runs model, Multi-colony model and Hybrid model. The main features and a list of general conclusions about the efficacy of each model is provided.

A new algorithm to solve the multi-depot multiple travelling salesman problem is suggested in paper [33]. The efficiency of the algorithm is tested by considering multiple test cases and compared along with the results of the software Lingo 8.0. The paper claims to have results very close to the optimal value and the ability to solve new problems with the possibility of applicable parameter tuning which includes the number of ants, evaporation rate, initial amount of trail and the stopping criteria. A parallelized genetic ant colony system is presented to solve the travelling salesman problem in paper [34]. The ant colony system is used to initially produce the population of genetic algorithms followed by the genetic algorithm to find better solutions. Pheromone update on a route is done using global update operation when a genetic algorithm finds a better solution than the one obtained from ant colony system.

Adaption of two strategies namely candidate set strategy and a dynamic updating rule for heuristic parameter based on entropy in an improved ant colony optimization to solve the travelling salesman problem is done in paper [35]. Candidate list captures a suitable number of nodes based on total number of nodes. Adaptive heuristic parameter is used initially since the value of pheromone trails does not have much information. The proposed algorithms claim effectiveness in terms of convergence speed and ability to find better solutions. A memetic ant colony optimization algorithm to solve dynamic travelling salesman problem is proposed in paper [36]. The problem addressed is adaptation to environmental changes after convergence. A hybridized ACO with local search is proposed. This algorithm is based on population framework and an adaptive Inver-over operator. This paper also addresses premature convergence by introducing random immigrants. The results have shown the importance of local search for ACO algorithm. The performance of this algorithm has been shown to be better than other classical ACO algorithms.

Focus on the quality of the optimal solution obtained by solving the travelling salesman problem using ant colony optimization is done in paper [37]. The higher accumulation of pheromone on edges due to higher number of ants makes the probability on those edges to be high whereas change in path is frequent in case of lower number of ants. This paper shows that in comparatively lesser iterations a relatively good result can be obtained using ACO. A concise overview of the applications of ant colony optimization algorithms is provided in paper [38]. The applications are categorized into two different groups. First group is the applications to NP-hard problems that include routing problems, scheduling problems, subset problems, assignment and layout problems, machine learning problems and bioinformatics problems. The second group is the applications to problems with non-standard features which include multi-objective optimization, stochastic optimization, dynamic optimization, communication network problems, continuous optimization problems and industrial applications. The study from the paper suggest that two ingredients are necessary for ACO to be applied successfully. One, an effective mechanism for iteratively constructing solutions. Two, specialized features that allow to carefully control the balance between exploration of new solution and intensification of search around the best solution. An ant colony optimization algorithm with scout characteristics to solve the travelling salesman problem is proposed in paper [39]. The use of scout ants along with common ants reduces the search time and effectively obtains the optimal solution. The results of this algorithm are pitted against the results of the min max ant system (MMAS) algorithm. While both reach the optimal solution, the SCACO is found to have lesser worst case and average case solutions.

Use of pattern reduction enhancement in order to improve the computation time of ant colony optimization algorithm is done in paper [40]. The redundant computations are eliminated thus reducing the quality of the optimal solution. The factor by which the computation time is reduced is significantly high compares to the percentage of loss of quality of solution. A hybrid ant colony optimization and beam search has been designed known as the Beam ACO approach to solve the travelling salesman problem with time window in paper [41]. The use of pheromone update and stochastic sampling ensures a good performance thus a minimized travel cost. This hybridization ensures a good approximation of solution in a short time. A general distributed framework for different ant colony optimization algorithm based on agent middleware is proposed for solving the travelling salesman problem in paper [42]. The Receive_Ant functionality is initiated followed by the Adjust_Attribute () to adjust ants attributes which are then sent out to address determined by the Best_Neighbour () method. The experimental results support the effectiveness of the framework. A new optimization problem: the one commodity travelling salesman problem with selective pickup and delivery (1-TSP-SELPD) is introduced in paper [43]. Only profitable pickup locations are included in the tour in order to minimize the cost. Ant colony optimization is used to solve the problem. Using ACO the problem is solved within reasonable time and space constraints. The exploration strategy is exploited to accelerate convergence in dense networks. Results show that ACO outperforms all existing competitive approaches. High quality solution is obtained by applying min max ant system (MMAS) to the (1-TSP-SELPD).

III. Proposed Enhanced Ant Colony Algorithm To Solve TSP

Travelling Salesman Problem

Problem Definition: The travelling salesman problem is applicable in many real-world problems. It is described as an important NP-Complete problem. The objective of this problem is simple. Consider a salesman who is travelling across cities. The salesman must adhere to the following conditions to satisfy the travelling salesman problem: -

1. The salesman must start and end at the same city, which means the source and destination must be the same city.
2. No city can be visited more than once.
3. The salesman must visit all the cities before returning to his starting point.
4. The total distance covered by the salesman after visiting all the cities and returning to starting point must be minimum.

Let us consider a salesman who wishes to travel six cities starting from some city within the six cities. By plotting the cities in the graph, let us consider the cities are arranged as follows:

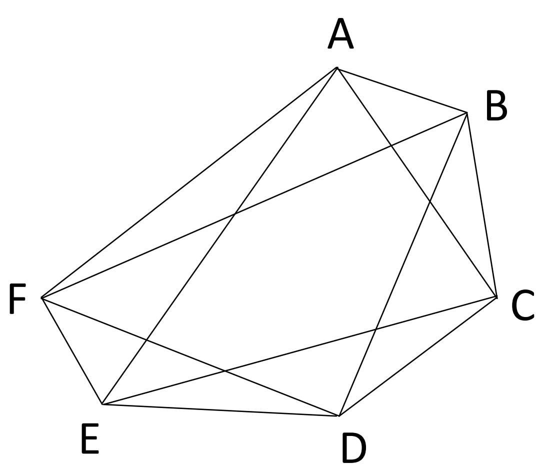

Figure:1 Input Graph

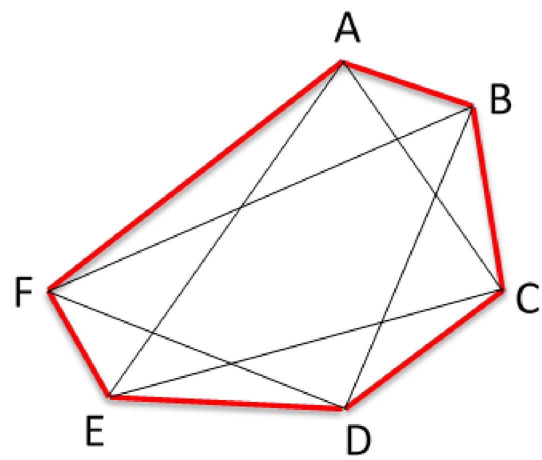

Figure: 2 Path with Minimum Cost

The salesman can travel through the path A-B-C-D-E-F-A. By doing so, he covers every city once before returning to city A and covers it through the shortest path. Hence the salesman has satisfied the travelling salesman problem.

Proposed Enhanced Ant Colony Approach

Enhanced Ant Colony is used to solve Travelling salesman problem. This heuristic approach helps to find the minimized cost and its path that satisfies the constraints of Travelling Salesman problem. Depending upon the pheromone evaporation and local best ant agent, every time the next city is opted, and its cost is updated. In 2015, an enhanced version of ant colony algorithm was used for mining frequent patterns [12]. This enhanced ant colony algorithm had an enhanced pheromone updating rule. It is shown in below equation (I). It was found that the proposed algorithm works faster than the algorithm that I proposed in my previous research work [43]. It is found that this proposed approach is much suitable for databases of dynamic nature.

$$\tau_{ij}(t)_{new} = \left[\{1-\rho\}/\{1+\rho\} * \tau_{ij}(t)_{old}\right] + \left[\{(\rho(1-\rho))/(1+\rho)\} * \Delta\tau_{ij}(t)\right]$$

Where,

$\tau ij(t)_{new}$ → Trail intensity of the $edge(i, j)$

ρ →Evaporation rate.

$\Delta\tau ij(t)$ →Additional pheromone when next transaction is traversed.

The algorithm of enhanced ant colony algorithm is shown in Figure 3.

Algorithm Enhanced_ACO_TSP (N_{ants} , ρ , N_{city} , Distance[][], Visiting_Order[], Cost)
//Problem Description: To make a journey of minimum cost that visits all cities exactly once and stops at the city from where the journey started.
//Inputs: Number of ant agents(N_{ants}), Pheromone (ρ), Number of cities (N_{city}), Distance between the cities(Distance[][]), Current visiting path (Visiting_Order)
//Output: Minimum Cost of journey (Cost)
Begin
Initialize the pheromone value (ρ).
While lists of cities in N_{city} is empty do
For each city in N_{city} do
Start each ant agent to visit each of the cities connected to currently visited city;
Distance [][];
End For
Choose the best choice of next state using state transition probability

$$\rho_{ij}(t)^k = [\tau_{ij}(t)]^{\alpha} * [\eta_{ij}(t)]^{\beta} \Big/ \sum_{u \in allowed(k)} [\tau_{ij}(t)]^{\alpha} * [\eta_{ij}(t)]^{\beta}$$

Current visiting path: Visiting_Order[]
Until every ant has built a solution
Update the pheromone (if required)

$$\tau_{ij}(t)_{new} = [\{(1-\rho)/(1+\rho)\} * \tau_{ij}(t)_{old}] + [\{(\rho(1-\rho))/(1+\rho)\} * \Delta\tau_{ij}(t)]$$

End While
Display Current visiting path (Visiting_Order)
End

For example: let us consider the same graph with some weights on each edge.

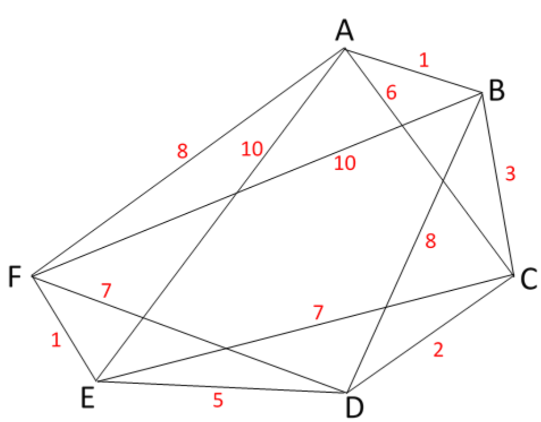

Figure:4 Weights assigned to Input Graph 1

The weights on each edge is:

AB=1	BA=1	CA=6	DB=8	EA=10	FA=8
AC=6	BC=3	CB=3	DC=2	EC=7	FB=6
AE=10	BD=8	CD=2	DE=5	ED=5	FD=7
AF=8	BF=10	CE=7	DF=7	EF=1	FE=1

IV. Experimental Results

Manually the above example was traced to check the feasibility of the proposed approach. It is presented in the table 1. R tool was used for experimenting our proposed approach. The same example was taken while coding was performed. Ant function takes the following inputs namely number of ants, values for evaporation rate, alpha and beta. Evaporation rate takes the value of 0.5, number of cities was taken as 50, alpha as 2.5 and beta as 3 initially. The average cost of all possible paths is calculated to analyze paths that satisfy the constraints of Travelling Salesman Problem and their cost deviation from the actual path cost.

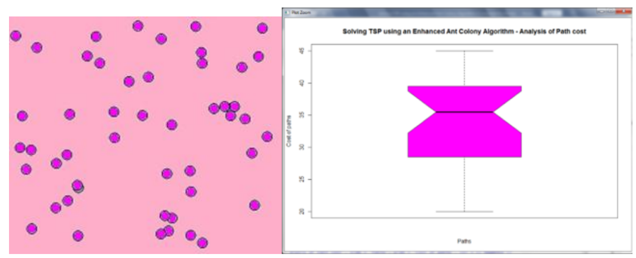

Figure:5 Input and the path cost

The example graph discussed earlier was given as input to check whether the proposed approach suits small input size of totally 6 cities with evaporation rate as 0.5, alpha as 2.5 and beta as 3. The transition probability of all possible paths is calculated to see the level its intensity in each path. It is shown in Figure 6.

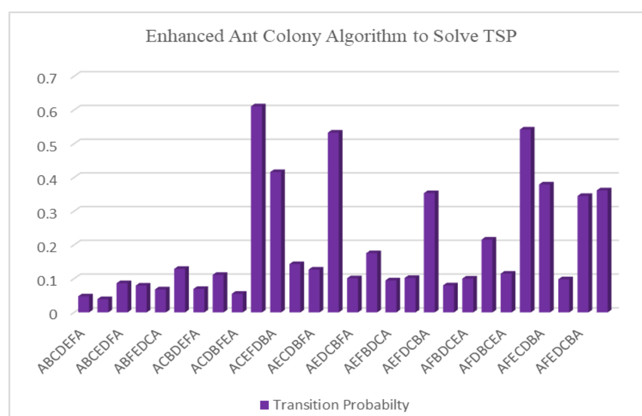

Figure:6 Transition Probability

Table 1 Finding the shortest path using ant colony optimization algorithm

ST [0]	ADJ	DST	NXT [1]	ADJ	DST	NXT [2]	ADJ	DST	NXT [3]	ADJ	DST	NXT [4]	ADJ	DST	NXT [5]	ADJ	DST	TOT
A	B	1	B	C	3	C	D	2	D	E	5	E	F	1	F	A	8	20
	C	6		D	8		E	7		F	7		A	10		B	10	
	E	10		F	10		A	6		C	2		C	7		D	7	
	F	8		A	1		B	3		B	8		D	5		E	1	
B	A	1	A	C	6	C	D	2	D	E	5	E	F	1	F	B	10	25
	C	3		B	1		E	7		F	7		A	10		A	8	
	D	8		E	10		A	6		C	2		C	7		D	7	
	F	10		F	8		B	3		B	8		D	5		E	1	
C	D	2	D	E	5	E	F	1	F	A	8	A	B	1	B	C	3	20
	B	3		F	7		A	10		B	10		C	6		D	8	
	A	6		C	2		C	7		D	7		E	10		F	10	
	E	7		B	8		D	5		E	1		F	8		A	1	
D	C	2	C	B	3	B	A	1	A	F	8	F	E	1	E	D	5	20
	B	8		A	6		C	3		B	1		A	8		A	10	
	E	5		D	2		D	8		C	6		B	10		C	7	
	F	7		E	7		F	10		E	10		D	7		F	1	
E	F	1	F	D	7	D	C	2	C	B	3	B	A	1	A	E	10	24
	A	10		A	8		B	8		A	6		C	3		B	1	
	C	7		B	10		E	5		D	2		D	8		C	6	
	D	5		E	1		F	7		E	7		F	10		F	8	
F	E	1	E	D	5	D	C	2	C	B	3	B	A	1	A	F	8	20
	A	8		A	10		B	8		A	6		C	3		B	1	
	B	10		C	7		E	5		D	2		D	8		C	6	
	D	7		F	1		F	7		E	7		F	10		E	10	

The cost of all possible paths is calculated to analyse each path that satisfies the constraints of Travelling Salesman Problem. It is shown in Figure 7.

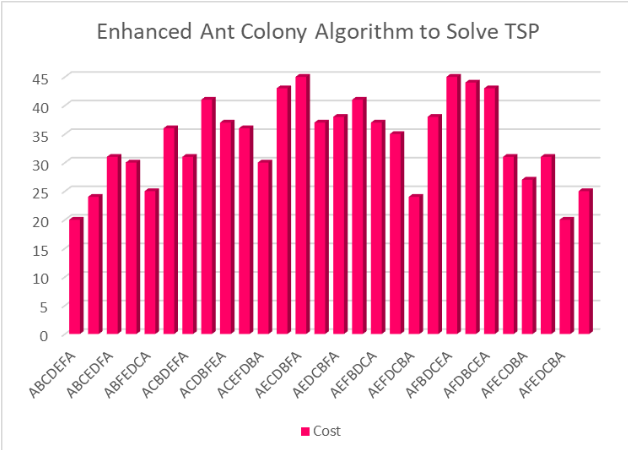

Figure:7 Path Cost

V. Conclusion and Future Scope

The proposed enhanced ant colony algorithm effectively solves the complex computational problem under consideration i.e. Travelling Salesman Problem. Data analytics paved way for further research of introducing changes in basic ant colony system to give a tough competition for the current results.

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