Bee-Inspired Algorithms and its implementation in reducing the transportation cost: Optimizing the Travelling Salesman Problem

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I. ABSTRACT

Vehicle Routing Problems specifically the Travelling Salesman Problem (TSP), being a NP-hard problem is termed to be difficult when it comes to solving and very useful while solving different domains of manufacturing. Owing to the complexity it has with high computational costs, metaheuristics including, nature inspired algorithms are found to be useful in generating feasible solutions for TSP, which are near optimal. The following is thus a discussion of why Travelling Salesman Problem is important to be catered to and how different nature inspired algorithms have found their applications in finding solutions for TSP. It aims to describe the existing strategies being used for cost optimization in route planning for deliveries. The purpose of the paper is to understand the current implementations of a special class of Bee-inspired algorithms in optimizing the transportation costs of a supply chain with reduced transportation costs.

II. DOMAIN

Supply chain being a network of facilities and distribution centers, constitutes of suppliers, manufacturers, distributors, retailers and customers. From the supply of raw materials to its transformation into products and finally the distribution of finished products is a complete complex and expensive process. Owing to the reason that supply chain plays an important role for any manufacturing company, there is a need to regulate the total costs incurred. According to the 26th annual "State Logistics Report" by the Council of Supply Chain Management Professionals published in 2015, United States business logistics costs are $1.45 trillion US dollars in 2014, and the transportation costs for the same year run to nearly one trillion US dollars that constitute over 65% of the total logistics costs[1]. Vehicle routing problem takes the task of transportation cost optimization by searching for optimal routes, i.e. with less costs, for one or more vehicles travelling between a set of cities or customers(nodes) [2]. These optimization problems have huge number of solutions besides considering a large number and type of constraints. Travelling Salesman Problem (TSP) is one such optimization problem which is NP-hard problem, making it difficult to solve by using exact methods, due to computational costs and complexity. Metaheuristics are thus implied, which take into consideration the history of search records and propose satisfactory results, against exact solution, with less computational costs [2].

In [3], it is posited that the Supply chain should be treated as a Complex Adaptive System instead of a simple system, owing to the emergence of structured collective behavior of the complete supply chain in accordance with the interaction among the subsystems of the complete chain, without any centralized control. Self-organization resulting from the structure and emergence according to the environment makes a system a complex adaptive system, analogous to how living beings adapt themselves to the changing environment. One such meta heuristic of nature inspired algorithms has been found to give satisfactory results for Travelling Salesman Problem. Swarm intelligence, inspired by the collective behavior of natural insect colonies and animal societies, is one such nature inspired meta heuristic that uses the approximate and non-deterministic strategies to give near-optimal solutions [4]. Self-organization through the low-level interactions between the agents or the swarm members, is the important characteristics of the Swarm Intelligence (SI) systems, which results in global responses. Besides, Ant Colony Optimization (BCO) and Particle Swarm Optimization (PSO), the behavior of bee colonies shows the traits of self-organization and labor division that make them obtain swarm intelligent behavior. Bee Colony Optimization algorithms have found to give robust results for Travelling Salesman Problem.

III. DOMAIN PROBLEM

This paper will provide a survey of the different heuristics used for solving Travelling Salesman Problem. The heuristics will be that of nature inspired algorithms including different algorithms inspired from the Bee Colony behavior. The purpose of the paper is to have a detailed study of each of these heuristics and implement its knowledge in the domain of reducing transportation costs for manufacturing companies with constraints such as limited vehicular capacity, limited time window delivery among others. Travelling Salesman Problem can be described as: - given a set of cities, the salesman should visit each city once and finally come back to the starting city, with the route having the least cost of travel. The simple TSP has been modified with addition of some constraints to form different problems like: - The Multiple Travelling Salesman Problem (MTSP) which has more than one salesman and a common depot is used as the starting and ending point by the salesman [2]. Capacitated Vehicle Routing Problem (CVRP) is a Multiple Travelling Salesman Problem (MTSP) wherein each city represents a customer, with a certain demand for the product and each salesman is a vehicle with a limited capacity[2].

This paper will survey the different bee-inspired algorithms being used for Traveling Salesman Problem (TSP) and implement the use in the field of decreasing costs of transportation.

IV. SOLUTION STRATEGIES

The NP-hard Travelling Salesman Problem has find its solutions in different techniques. This section will deal with the different techniques being used so far to get optimum solutions to the Travelling Salesman Problem namely :- Genetic Algorithms, Ant Colony Optimization.

IV.A. GENETIC ALGORITHMS

An initial population of chromosomes is randomly generated, and their fitness is evaluated, on which the operators: crossover, mutation and selection are applied. Three different selection techniques are studied here: - Tournament selection, roulette wheel, and rank based roulette wheel selection [12]. The execution of Genetic Algorithms is implemented on 8 TSP instances with 10-city, 20-city, 30-city, 40-city instances and known optimal solutions of burma14, bay29, dantzig42 and eil51 [12]. A combination of linear order crossover and inversion mutation was utilized for producing offspring at each iteration. The result showed an improvement of the solution when using rank-based roulette wheel as the selection technique than using tournament and proportional roulette wheel. In terms of computational time, tournament selection proved to be consuming less time as compared to the other two techniques, but it's applicable to cases with small problem like 10-city and 20-city. The Genetic Algorithm is found to yield excellent near optimal solutions.

IV.B. ANT COLONY OPTIMIZATION

Ant Colony Optimization is one of the nature inspired algorithms that finds its implications in the field of finding solutions for the Travelling Salesman Problem. This is derived from the ability of the ant colony to find the shortest path from their origin to the food sources. The communication among the ants is through the pheromones which they place on ground while searching for food [13]. Multi-depot Multiple Travelling Salesman Problem (MMTSP) has been studied in [14], with more than one depot and salesmen or vehicles making a round trip. The work uses two ways of selecting depots- randomly and with Round Robin Scheduling. The test is done on 27 observations each of 10 runs. The ACO is able to give better solutions for MMTSP when the number of salesmen is minimum. Ant Colony Optimization has been studied widely and has been implied in the field of reducing transportation costs by optimizing the Travelling Salesman Problem (TSP). Another nature inspired algorithm, the Bee Colony Optimization Algorithm has not been explored much and has a great scope of exposure in the field of Travelling Salesman Problem.

The following section thus gives an overview of the Bee Colony inspired algorithms, followed by their implications in reducing the transportation costs in a supply chain by optimizing the Travelling Salesman Problem (TSP).

V. LITERATURE REVIEW

There are four properties of self-organization seen in bees:- positive feedback promoting the creation of appropriate structures, negative feedback acting as the counterbalance to positive feedbacks, oscillations including random behaviors, errors and task switching; and multiple interactions among the agents and the environment, for exchange of information [5]. For a swarm to present intelligent behaviors it need to follow five principles of :- 1)stability, wherein the agents shouldn't be changing their behavior in response to all the changes in the environment, 2)adaptability, the swarm of agent must be able to adapt to the changes when its necessary, 3)diversity, the resources must be distributed and not allocated to a single medium, 4)proximity with the individual agents able to perform tasks assigned to them, 5) quality being the most important principle wherein the swarm must be sensitive to quality features [6]. There is also a clear division of tasks between the bees namely: - the Scout bees, the Employed bees and the Onlooker bees. Depending on the behavior of the bees, there are bee inspired algorithms that are divided into 2 classes of foraging and Marriage [2]. Foraging is the most important task for the beehive, wherein the worker leaves the hive in search of good food and after finding one it stores it in its stomach and brings it back to the nest to deposit the nectar in the combs. Dancing is the mode of communication among the bees about the quality, direction and distance of the food from the source. The bees do waggle dance after it has found the attractive food source, thus informing other bees about it.

The Bee inspired algorithms are divided into two subclasses based on the bee's behavior, which are, foraging and marriage. This paper will have a brief overview of the algorithms according to the foraging behavior of bee colony and their different implications for reducing the transportation cost in the Travelling Salesman Problem (TSP).

V.A. ARTIFICIAL BEE COLONY

Inspired by the foraging behavior of the bees, this algorithm was first introduced by Karaboga to solve numeric optimization problems, further modified by Banharnsakun et al [7] to solve the travelling salesman problem. Scout bees does random search to find the food sources, with the employed bees going out to exploit the found food sources, beside looking out for better food source nearby. These employed bees return to the hive to inform the onlooker bees regarding the quality of food found through their waggle dance. The onlooker bees depending on the richness of the food sources follow the employed bees to further exploit the found sources, themselves becoming employed bees. After a few iterations when the food is exhausted, the respective employed bee becomes scout bee and starts finding a new food source [4]. [8] suggests the use of a roulette wheel to help with the selection of the employed bee for the onlooker bee to follow, with the quality of the food available being used as the fitness function for the process. The ABC algorithm proposed by Karaboga and Gorkemli [9] made use of the neighborhood searching mechanism to create the initial solution. The mutation operator of a Genetic Algorithm, Greedy Sub Tour Mutation (GSTM) was used during the onlooker bees and employed bees phase. Two variants of the algorithm were created and tested on a set of 15 TSP test problems. The results of these when compared with eight different variants of Genetic Algorithm, the solution out of the ABC algorithms showed better results than with GA. Zhang et al. [4] in their work developed a Hybrid Artificial Bee Colony Algorithm by using concept of genetic algorithm and the local search algorithm used in Environmental Vehicle Routing Problem (EVRP). The EVRP is developed to reduce the impact on the environment due to the routing of the vehicles. For the onlooker bees, the crossover concept from Genetic Algorithms is incorporated into the ABC algorithm and the rule of maximum retention exchange is used to use the already present information. Also, within the newly generated solutions, local search mechanism is used besides using 2-optimzation and 3-optimzation approaches to improve the already created routes or solutions. 19be benchmark instances from literature were used to test with 31 to 51 customers and 3 to 7 vehicles. The results showed that the hybrid ABC algorithm with aspects of initialization of new mechanism, integration of new operator namely crossover and local search operators, along with continuous improvement, surpassed the Artificial Bee Colony Algorithm. Thus, the artificial bee colony algorithm has found a lot of implication sin the field of TSP.

V.B. BEE COLONY OPTIMIZATION

This algorithm is inspired from the foraging behavior of honeybees, like the Artificial Bee Colony algorithm. Nearest neighbor or random search is used to create the candidate solution. The bee before leaving for the foraging process, decides if it has to observe the waggle dance of other bees or not, depending on the criteria that its solutions is better than the average solution of the hive or not. If its solution isn’t better than the average of the hive, it observes the waggle dances and decided which one to follow, making this as the preferred solution for the bee. The foraging process I then brought into action by the bee, as it constructs the complete solution to the TSP by moving from one city to the another, selecting the city based on the probabilistic transition rule considering the distance between the two cities and if the next city is present in the list of recommended solution for the bee. This is followed by the waggle dance step, wherein the bees come back to their hive and inform other bees about the quality of the food source found.

The Bee Colony Optimization’s implementation in the TSP differs from the Artificial Bee Colony in that, for every iteration the starting point of the bees changes randomly, and new bees are introduced into the system during the search process. Wong et al. [10] made some changes to the originally developed Bee Colony Optimization algorithm, by introducing frequency based pruning strategy (FBPS) after the foraging process, to investigate if the bee needs a transformation using the fixed-radius near neighbor 2-opt(FRNN 2-opt). The FRNN 2-opt is a 2-optimization heuristic being used to optimize the solution locally. This work proposed the use of fragmentation state transition rule (FSTR), wherein the bees no longer add one city per iteration, rather they add a fragment of cities in each iteration, called sub-route. The FSTR along with the use of FBPS after the foraging process with the fixed-radius near neighbor 2-optimization heuristic, shows an overall improvement of 0.11% over the known optimum value with a decrease in the computational time without hampering the quality of the solution. Thus, this proposed work of using Bee Colony Optimization in the TSP with some modifications is found to give competitive result when compared to other works from the literature.

V.C. BEE SYSTEM

The Bee Colony Optimization is a modification of the Bee System , wherein the hive location for the bees is changed in every iteration. The bees construct sub tours in each iteration until a solution is reache for the TSP. The next city to be visited is decided based on the factors like distance from the source to the next city, the number of iterations already spent on that route and the number of bees that have already visited the same link in the past. This foraging process is followed by the abandoning of food source if the distance of the current sub tour is greater than the distance covered by other bees. The waggle dance is the last step in this algorithm which is performed if the cost of the cost of the advertised sub-tour of the bee is less than the cost of other sub-tours. At the end of the tour, the bee also does local search besides using 2-optimization or 3-optimization based on the size of the TSP set [2]. The implementation of the Bee System in the Travelling Salesman Problem was performed in [11], to use Bee System for the Stochastic Vehicle Routing Problem (SVRP), wherein the algorithm helps in making real time decisions for route with known values of the vehicle capacity, customers to be served, and location of the distribution centers, and unknown value of the demand which are then approximated for solution derivation. It creates a giant tour which is divided into sub-tours for each vehicle based on the fuzzy rules. Using 10 sets of solutions for cities ranging from 51 to 1002 customers, the algorithm proved to be successful in giving average solutions.

VI. CONCLUSION

Vehicle Routing Problem is one of the biggest cost incurring domain of a supply chain, that needs to be regulated to decrease the total cost of production of the product. These problem have huge number of constraints and features, making it impossible to solve them using exact methods. Thus, metaheuristics come into play which give near optimum solutions for this problem, using the history of solutions generated. These meta-heuristics include nature inspired algorithms of the class- Swarm Intelligence, including ant colony optimization, bee inspired methods. First an overview of how genetic algorithms and ant colony algorithms have been utilized to generate feasible solutions for travelling salesman Problem has been discussed. It has been found that a lot of literature is available for ant colony and genetic algorithms' implications in this field. Bee-inspired algorithms have found their relevance in the recent years for solving the Travelling Salesman Problem. This term paper dealt with the thorough review of the bee-inspired algorithms to solve the TSP. The different algorithms based on the behavior exhibited by the bees were discussed and correlation among them through different modifications was identified. Furthermore, the implication of these algorithms was seen in the different literatures studied, showing how Travelling Salesman Problem was tweaked by using different constraints and bee-inspired algorithms were utilized to generate solutions. Foraging was the main behavior discussed throughput this paper, since it has the most implications in the TSP domain. The literature review showed that the Artificial Bee Colony (ABC) algorithm is the most explored algorithm so far and a few modifications to it, help in coming up with better optimal solutions. The same holds true for Bee Colony Optimization and Bee System. As seen in the case of Bee Colony Optimization, the bee decides before moving out of the hive, if it has to observe the waggle dance of other bees, depending on whether its solution is better than the average of the hive's solution or not. This finds a lot of applications when it comes to reducing the cost of the transportation as the vehicles before moving out of the depot can determine in the same manner if the route they took the last time for the same customer is efficient enough or there is some other route which was followed and had lesser cost of transportation. This will save the overall costs and also the time, since the driver will not have to wait and see all other routes followed if it already knows that its route is the most efficient of all. Thus, Bee Colony Optimization (BCO) or in general Bee inspired algorithms have a lot of scope of implementation in the supply chain to reduce the overall cost of the chain.

VII. PROJECT PROPOSAL

The Travelling Salesman Problem (TSP) is the highly studied problem when it comes to optimizing the supply chain in terms of reducing costs. The TSP takes into consideration a single depot and a return trip from the depot to the customer and back, and how the route can be optimized to reduce the overall cost of production. This problem with some modifications can be utilized in the field of courier services. Courier services company like UPS [14] uses the Bee-Inspired Algorithms to prepare a layout of the routes to be followed by their drivers to optimally deliver the couriers with less cost of transportation. Still there are services like DHL, which struggles every morning to jot down the best routes for their drivers, manually taking upto 3-4 hours daily. I would like to perform a detailed study of how Bee inspired algorithms are being used by the Courier service UPS and analyze and try to come up with a solution for manufacturing companies dealing with intermittent demand (on-line supply chain). In this case, the capacity of the vehicles will be limited, since the demand isn't known in advance, as is the case with the courier services.

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