A Review on Algorithms Used to Solve Multiple Travelling Salesman Problem

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Abstract - *The multiple Travelling Salesman Problem (mTSP) is the general form of TSP, in which one or more than one salesmen can be used in the solution set. The Constraint in the optimization task is that each salesman returns to starting point at end of trip, travelling to a specific set of cities in between and except for the first one, each and every city is visited by exactly one salesman. The idea is to search for the shortest route that is the least distance needed for each salesman to travel from the starting location to individual cities and back to the location from where he has started. It is a complex NP-Hard problem and has various applications mostly in the field of scheduling and routing. The amount of computation time to solve this problem grows exponentially as number of cities increases so, the meta-heuristic optimization algorithms, such as genetic algorithms (GAs) are needed to be explored. The goal of this paper is to find out various algorithms used in literature to solve mTSP.*

***Key Words*: Genetic Algorithm(GA), Multiple Travelling Salesperson Problem (mTSP), NP-Hard problems, Multi-Chromosomes, ACO.**

1. INTRODUCTION

The multiple Traveling Salesman Problem (mTSP) is a special type of TSP which is more complex than the Travelling Salesman problem (TSP). The Constraints in the optimization task are, first is that each salesman returns to starting point at end of trip, second is that each and Every salesman must travels to a specific set of cities in between and last is that each and every city is visited by exactly one salesman, except the first city.

The idea is to search for the shortest path with the minimal distance and each salesman must travel from the starting location to individual cities and back to the location from where he begins the travelling. Thus, the total cost of visiting all routes is lessened. MTSP is harder than the TSP because it involves assigning nodes to each salesman [1]. In this paper review of various algorithms used to solve multiple travelling salesmen problem is presented.

2. PROBLEM DESCRIPTION

The mTSP problem consist of a set of nodes and all of the paths must be visited exactly once by the every salesman. In this problem, the n cities and m salesmen are regarded and the goal is to find out the shortest path for all salesmen such that the total cost of travelling (the cost of visiting all paths and time needed to travel each path and so forth) is decreased. Some possible variations of the problems are as follows.

- **Multiple depots**: If there are multiple depots and at each depot the salesmen located, then the salesman at each depot remains the same during and after all the travel.

- **Number of salesman**: The number of salesmen in the problem remains fixed.

- **Fixed cost**: If the number of salesmen is a confine variable then the usage of each salesman in the solution has an associated fixed cost. So, in this case, the minimization of this confine variable may be involved in the optimization task.

- **Other restrictions**: These additional limitations consisted of the maximum or minimum distance salesman travels [2].

The techniques used for solving the MTSP can be categorized into heuristic, meta-heuristic and exact algorithms and out of these the exact approaches are used only for relatively small problems. These techniques apply algorithms that generate a lower and an upper bound on the true minimum value of the problem instance. Although the MTSP is conceptually simple but it is difficult to obtain an optimal solution [4] or we can say, when the problem size is maximized, the exact methods cannot solve it. Then it requires heuristic or meta-heuristic methods to solve it in a reasonable amount of time particularly with large sizes. Few well-known heuristic algorithms are gravitational emulation search and local search [5]. A Meta-heuristics method tries to conflate basic heuristic methods into higher level frameworks which aim at efficient and effective exploration of a search space [6]. The term meta-heuristic derives from the composition of two Greek word, heuristic stems from the

verb heuriskein which means "to find", while the prefix Meta means "beyond in an upper degree". In general, it is vital to use meta-heuristic algorithms to solve complex optimization problems when dealing with them because the meta-heuristic approaches are very efficient for escaping from local optimum and these are also considered as the one of the best group algorithms for solving combinatorial optimization problem. Various meta-heuristic approaches which may be used are genetic algorithm (GA) [7], memetic algorithm (MA) [8], ant system (AS) [9] and particle swarm optimization (PSO) [10].
In this paper, literature review of the various algorithms used to solve multiple travelling salesman problem is presented along with the description and applications of this problem.

3. MATHEMATICAL FORMULATION

Consider a graph G= (V, A), in which V is the set of n nodes and A is the set of edges. Associated with each edge (i,j)∈A is a cost (or distance) cij. We assume that there are m salesmen. We define a binary variable xij for each edge (i,j)∈A; xij takes the value 1 if edge (i,j) is included in a tour and xij takes the value 0 if edge (i,j) is not included. For the subtour elimination constraints, we define an integer variable ui to denote the position of node i in a tour and value p to denote the maximal number of nodes visited by any salesman.

Objective
Minimize $\sum_{(i,j)\in A} C_{ij}X_{ij}$
Constraints
So that exactly m salesmen depart from node 1
$\sum_{j\in V:(1,j)\in A} x_{1j}=m$
Exactly m salesmen return to node 1
$\sum_{j\in V:(j,1)\in A} x_{j1}=m$
Exactly one tour enters each node
$\sum_{i\in V:(i,j)\in A} x_{ij}=1,\ \forall j\in V$
Exactly one tour exits each node
$\sum_{j\in V:(i,j)\in A} x_{ij}=1,\ \forall i\in V$

Consider subtour elimination constraints
$u_i-u_j+p\cdot x_{ij}\leq p-1,\ \forall 2\leq i\neq j\leq n$

The main aim is to belittle the total travelling cost of the problem that is formulated as assignment based integer linear programming [11].

4. LITERATURE REVIEW

Even though, the TSP has received a great attention, the exploration and research on the MTSP is relatively confined and most of the work is linked to MTSP applications. Other Nature-inspired optimization algorithms such as ant colony optimization (ACO) [9], particle swarm optimization (PSO) [10] and artificial neural network (ANN) [12] is used to solve the TSP/MTSP [13]. These algorithms help to avoid local minima, when used in conjunction with various heuristic techniques and also reduces the computational cost. For example, *R. Jayasutha and Dr. B. S. E. Zoraida (2013) [2]* proposed the novel Genetic algorithm. The traveling salesman problem (TSP) explained the concept in which single salesperson travels the route visiting all n cities only once and returns to the starting location from where it started. In this paper, mTSP has also been explained by using GA in the sort of the vehicle scheduling problem. The work in this paper presents a chromosome methodology determining the MTSP to be solved using a GA. In addition to this, the tools developed for a modified mTSP concerned with the optimization of one to many distribution systems will also be studied.

Varunika et al. (2014) [14] presents the technique to solve the multiple travelling salesperson problem using a modified genetic algorithm. Travelling Salesman Problem (TSP) is an optimization problem. According to this, salesperson must make a path through a certain number of cities and visiting each only once and must minimize the total distance travelled by it. The Multiple Traveling Salesman Problem (mTSP) is the generalization of TSP and is a complex combinatorial optimization problem, in which one or more than one salesmen can be used in the solution. For this problem, the Constraint in the optimization task is that each salesman returns to starting point at end of trip, travelling to a specific set of cities in between and except for the first, every city is visited by exactly one salesman. The Cost Function is to search for the shortest path with the minimal distance and each salesman must travel from the starting location to individual cities and back to the location from where he begin the travelling. mTSP is a complex NP-Hard problem and has a multiplicity of applications. The amount of computation time to solve this problem grows exponentially as number of cities is increased so, the heuristic optimization algorithms, such as genetic algorithms (GAs) need to take into account. GA generates a population of solutions at each iteration& the best point in the population approaches an optimal solution. The aim of this paper is to review that how genetic algorithm can be applied to solve these problems and propose an efficient and optimal solution to mTSP.

A. Kiraly and J. Abonyi (2011) [15] presented the way to apply genetic algorithms to solve the various problems and proposed a novel interpretable representation based algorithm. The Vehicle Routing Problem (VRP) is also a complex combinatorial optimization problem consisted of group of vehicles with unvarying capacity, a common station and several costumer demands and the goal is to find the set of routes with minimum cost. The multiple travelling salesman problem (mTSP) is an abstraction of the widely used traveling salesman problem (TSP), in which solution set consists of more than one salesman. The MTSP-based algorithms can also be applied in various VRP's by incorporating some constraints.

M.Sedighpour et al. (2011) [3] has evaluated the performance of different meta-heuristic algorithms. The multiple traveling salesman problem (mTSP) includes assigning m salesmen the n nodes such that each node is visited exactly once. The MTSP has a multiple of application in many fields and is also an example of combinatorial optimization problems. In this paper, for solving the MTSP a modified hybrid meta-heuristic algorithm named GA2OPT is proposed. Firstly, the MTSP is solved by the modified genetic Algorithm (GA) by using number of iterations and secondly, the 2-Opt local search algorithm is used for enhancing solutions for that iteration. The proposed algorithm was trialed on a 6 benchmark instances from the TSPLIB and in all of the four instances the best known solution was improved and for the rest of benchmarks, the quality of the produced solution varies less than 0.01% from the best known solutions ever.

H .Larki and M. Yousefikhoshbakht (2014) [16] presented an effective and evolutionary optimization algorithm which has been formulated through combination of Modified Imperialist Competitive Algorithm and Lin-Kernigan Algorithm (MICA) in order to solve the MTSP. An absorption function and several local search algorithms as a revolution operator are used for work in the proposed algorithm. The performance of this algorithm was quite well and competitive when tested on several MTSP benchmark instances and the results confirmed that the MICA performs well with other meta-heuristic algorithm. In this paper, a hybrid algorithm called MICA was proposed for solving the MTSP. This algorithm is more efficient than SA+EAS, ICA and the modified genetic algorithms for dealing with MTSP. The algorithm was tested in 26 benchmark problems with 20–150 nodes and it was found capable of improving the BKS of 6 instances.

T.Mohammadpour and M. Yadollahi (2014) [17] proposed an algorithm that would lead to better solutions when compared with other algorithms. Multiple Travelling Salesman Problem (mTSP) is a NP hard problem and is the general form of the well-known Traveling Salesman Problem (TSP). The MTSP will be more appropriate for posing real-world situations because it is capable for handling more than one salesman and many of the situations are related to different scheduling and routing area. In the MTSP, the two works must be done simultaneously: Firstly, each salesman is allocated a separate city and in other case, an order is specified by which salesman will visit each city. That's why MTSP is more complicated than TSP. The one way to solve MTSP is to translate it in to standard TSP. Till now; lots of algorithms have been demonstrated for solving this problem. In this paper, a new Hybrid method has been introduced for solving the MTSP, by combining gravity and Genetic algorithmic program. Experimentally the results showed that the suggested algorithm would lead to better solutions when compared with other algorithms.

In recent work, Xu *et al. (2011) [18]* evaluated an extended Christofides heuristic for the k-depot TSP (multiple depot multiple travelling salesman problem) and specified proof that showed that it achieves a closed approximation ratio of (2 - 1/k), which is close to 3/2 when k is close to 2which is better than the algorithm available in the current literature. The proof of this is established on the derivation of bounds for the minimal perfect matching used in the extended heuristic.

Shuai et al. (2013)[19] proposed an operator called two-part chromosome crossover (TCX) operator for solving the multiple travelling salesmen problem (MTSP) using a genetic algorithm (GA) for near-optimum solutions. They adopt the proven two-part chromosome representation technique which minimizes the size of the problem location. The existing crossover method for the two-part chromosome representation has two limitations. First of all, in the second part of the chromosome it has extremely limited diversity that greatly confines the search ability of the GA and the other limitation is that, in the first part of the chromosome the pre-existing crossover approach tends to break useful building blocks that reduces the effectiveness of GA and its solution quality. Hence, they proposed the TCX to overcome the above two limitations and to improve solution. For minimizing total travel distance and minimizing longest tour they evaluated and compared the TCX with three distinct crossover methods. The result show that compared to three existing crossover approaches TCX can better improve the solution quality of the GA.

Arthur E. Carter (2003) [20] focused on solving vehicle scheduling problems by using GAs. It consist of scheduling fleet of m vehicles to visit n number of cities with each city being visited by one vehicle. The VSP typically includes constraints on the number of cities each vehicle can visit due to the capacity of each truck available and the size load to be picked up at each city. The cities must be visited between specific times called time windows in some cases. These issues lead to a number of different possible configurations for the VSP, VSP with heterogeneous/homogeneous vehicle capacities, VSP for minimum distance/minimum vehicle requirements and VSP with/without time windows. It also consist of number of objectives, such as: minimize the number of vehicles required, minimize the total distance and minimize lateness (if time windows are used).

R.Hassan et al. (2004) [21] analyzed that PSO has similarity to the Genetic Algorithm (GA) because both are population-based search methods. Also, PSO and the GA use a combination of deterministic and probabilistic rules by moving from a set of points (population) to another set of points in a single iteration with liable improvement. In addition, the GA and its many versions is popular in academia and the industry due to its ease of implementation ,intuitiveness and the ability to effectively solve mixed integer optimization problems that are complex for engineering systems. The expensive computational cost is the drawback of the GA. The work in this paper is an attempt to examine the correctness of the claim that PSO has the same effectiveness as the GA but with significantly better computational efficiency by implementing formal hypothesis testing and statistical analysis. The comparison of the GA and PSO is enforced using two space systems design optimization problems known as telescope array configuration and spacecraft reliability-based design as well as a set of benchmark test problems.

X.H. et al. (2007) [10] has focused a novel discrete PSO algorithm and has presented it by adding an uncertain strategy into the approach. Moreover, the algorithm is extended for solving the generalized TSP problems by introducing the generalized chromosome technique. To the best of our knowledge, it is the first time that the PSO-based algorithm has been used to solve the GTSP problems. Some benchmark problems are used to examine the effectiveness of the proposed algorithms. Numeric results show that the proposed algorithms are efficacious. It has also been shown that the proposed algorithms can solve larger size problems than those solved using the existing algorithms.

Q. Bai (2010) [22] has analyzed that Particle swarm optimization is a heuristic global optimization method, which is based on swarm intelligence. The idea came from the research on the bird and fish flock movement activity. This algorithm is widely used and implemented because it is easy implement and also few particles need to be adjusted. In this paper, principle of PSO is presented and also the advantages and the shortcomings are summed up. Finally this paper presents some kinds of improved versions of PSO and research condition, and the future research issues are also given.

Liu et al. (2009) [23] proposed an algorithm for solving the mTSP known as ACO. Their algorithm includes, the pheromone trail updating and limits followed the MAX–MIN Ant System strategy, and to improve the performance of the algorithm a local search procedure was used. In this paper, authors compared the existing GA approaches with the results of the algorithm on standard benchmark instances in the literature. Computational results show that their algorithm was competitive over two typical objective functions.

M. Yousefikhoshbakht et al. (2013) [9] presented a new modified edition of the ant colony optimization(ACO) mixed with insert, swap and 2-opt algorithm called NMACO for solving the multiple traveling salesman problem (MTSP) which utilizes an effective and efficient standard for escaping from the local optimum. The objective of MTSP is to minimize the total distance traveled by several salesmen for servicing a set of nodes. As this problem belongs to NP-hard Problems, indeed some meta-heuristic acts have been used to solve it in the recent centuries. In contrast to the classical Ant colony optimization, the proposed algorithm uses only a global updation for the current best solution and the best found solution until now. Moreover, a new state transition rule and an efficient candidate list are used for assessing the efficiency of the proposed algorithm. This proposed algorithm was tested on some standard benchmark instances available from the literature and when their results were compared with other well-known meta-heuristic algorithms then their results indicates that the NMACO has been able to improve the efficiency of the ACO in all instances.

M. Dorigo and T. Stutzle (2010) [24] studied that Ant Colony Optimization (ACO) is a meta-heuristic Algorithm that is encouraged by the pheromone trail laying and adopting behavior of some ant species. Artificial ants in ACO are random solution construction processes that build candidate solutions for the problem instance under concern by employing (artificial) pheromone information that is adapted based on the ants' search experience and possibly available heuristic information. One thing to notice in ants is their caliber to create "ant streets". This paper focused on the development of high-performing algorithmic variants, the development of a generic algorithmic framework for ACO algorithms, successful applications of ACO algorithms to a wide range of computationally hard problems and the theoretical understanding of properties of ACO algorithms. This paper reviews these developments and gives an overview of recent research trends in ACO.

5. VARIOUS APPLICATIONS OF mTSP

The main application of mTSP arises in real situation as it is capable to handle multiple salespersons. These situations arise mostly in various scheduling and routing problems [25].The various applications described in literature are presented below:

5.1 Printing Press Scheduling Problem

The foremost application of the mTSP rises in scheduling a printing press for a periodical with multiple editions. This problem comprises of five pairs of rollers between which the paper rolls and both sides of a page are printed at the same time instance. This problem uses three kinds of forms these are 4-, 6- and 8-page forms, these are used to print the editions. In this the scheduling problem consists of deciding length of each run and which form will be on which run. In the mTSP vocabulary, inter-city costs are the plate change costs. [26], [27].

5.2 School Bus Routing Problem

This problem mainly deals with scheduling of buses as a variance of the mTSP with some restraints. It attempts to make an efficient schedule for a collection of school buses. Each bus in this problem picks up students from various bus stops and deports them to their intended schools while satisfying various constraints such as the maximum riding time of a student in a bus, the maximum capacity of a bus and the time window of a school [28].

5.3 Crew Scheduling Problem

Crew scheduling is the activity of allotting crews to control transportation systems. An application for deposit carrying between different branches of banks is reported [29]. Particularly in this problem, deposits need to be picked up at branches of banks and brought back to the central office by a crew of travelers. The goal is to determine the routes with the minimum cost.

5.4 Interview Scheduling Problem

Gilbert and Hofstra found the application of mTSP, bearing multi-period versions, in scheduling interviews between tour agents and vendors of the tourism diligence. Each and every agent represents the salesman who must visit a unique set of vendor stalls, which are presented by a set of T cities [30].

5.5 Hot Rolling Scheduling Problem

In the iron and steel aviation, scheduling of orders on the hot rolling mill in done in such a manner such that the total assembles cost throughout the production can be lessened. Here, the orders are cities and the interval among two cities is assumed as penalty cost for production conversion among two orders [31].

5.6 Mission Planning Problem

The mission planning problem determines an optimal path for each planner to achieve the goals of the mission in the minimum possible event. The mission planner uses a variation of the mTSP where there are n number of planners who have to visit m goals and a base city to which all planners must eventually return [32]. Likewise, the routing problems arising in the planning of unmanned aerial vehicle applications investigated and modeled as mTSP.

5.7 Design of Global Navigation Satellite System Surveying Networks

A recent and important application of the mTSP, arises in the design of global navigation satellite system (GNSS) surveying networks. The GNSS is a space-based satellite system which specifies worldwide coverage for all locations and is crucial in real-life applications such as environment, early warning and management for disasters and agriculture monitoring and so on. The intention is to ascertain the geographical positions of unknown points on and above the earth using satellite equipment's. These points on which receivers are placed are co-ordinated by a chain of observation sessions [33].When there are multiple receivers, then the problem of finding the best order of sessions for the receivers can be formulated as an mTSP.

6. CONCLUSION

This paper explored the various techniques used to solve the multiple travelling salesperson problem. According to the requirement & the application, the minimal number of cities travelled by each salesperson can be varied and so could be the number of cities & the number of salesperson. With the increase in number of cities, the computational complexity also increases. In this paper, it is found that meta- heuristics algorithms including genetic algorithm and simulated annealing yield better results for this problem.

7. FUTURE SCOPE

A number of genetic algorithm techniques have been analyzed and surveyed for solving mTSP. The research work can be extended for different hybrid selection, crossover and mutation operators. The novel meta-heuristic algorithm like ant colony can be applied to this problem in order to find better solutions.

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