A Review of Traveling Salesman Problem with Time Window Constraint

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Abstract

The Traveling Salesman Problem (TSP) is a famous combinatorial problem which is intensively studied in the area of optimization. TSP solution has wide variety of applications but generally is used in industrial application and has great importance in operation research. Along with TSP there are different constraints associated with it which are being studied. This paper reviews various literatures particularly related to the studies of TSP with time window constraints.
Keywords: Traveling Salesman Problem, Time Windows, Vehicle Routing Problem

I. Introduction

Traveling salesman problem is the problem to find the short route for a person who has to travel from origin to n number of cities where each city to be visited only once and then returns back to the origin. Traveling salesman problem is a NP- Hard problem which is easy to state but difficult to solve. The complexity of the problem is O(n!) for finding the tour for n number of cities. It means that as the number of cities increases the problem becomes more and more difficult to solve. This problem was first formulated in the year 1930 [3]. After that continuously research work is going on to reduce the time required to solve the TSP. One of the constraints is time window which means a span of time required to complete the job at every particular city to be visited. The literature is classified into simple TSP, then adding a constraint to TSP that is time window and finally into vehicle routing problem with time window.

The Traveling Salesman problem lies at the heart of distribution management. It is faced each day by thousands of companies and organizations engaged in the delivery and collection of goods or people. Because conditions vary from one setting to the next, the objectives and constraints encountered in practice are highly variable. Most algorithmic research and software development in this area focus on a limited number of prototype problems. By building enough flexibility in optimization systems one can adapt these to various practical contexts.

II. Review of TSP papers

Chauhan C. et al. [1] explains the various methods/techniques available to solve traveling salesman problem and analyze it to make critical evaluation of their time complexities. There are two types of TSP solver namely exact solver and non exact solver. There are two groups of exact solvers. One of these is solving relaxations of the TSP Linear Programming formulation and uses methods like Cutting Plane, Interior Point, Branch-and-Bound and Branch-and-Cut. Another smaller group is using Dynamic Programming. Branch and bound was discovered independently by at least three groups. The Branch and Bound method implicitly enumerates all the feasible solutions, using calculations where the integer constraints of the problems are relaxed. In other words the branch and bound strategy divides a problem to be solved into a number of sub-problems. In non – exact solver there are Approximation Algorithms, Heuristic Algorithms.

Dominique Feillet et al. [4] explain Traveling salesman problems with profits (TSPs with profits) which generalizes of the traveling salesman problem (TSP), where it is not necessary to visit all vertices. A profit is associated with each vertex. The overall goal is the simultaneous optimization of the collected profit and the travel costs. These two optimization criteria appear either in the objective function or as a constraint. In this paper, a classification of TSPs with profits is proposed, and the existing literature is surveyed. Different classes of applications, modeling approaches, and exact or heuristic solution techniques are identified and compared. Conclusions emphasize the interest of this class of problems, with respect to applications as well as theoretical results.

Exnar Filip et al. [5] explained the TSP so that it can be used in the logistics industry. For a 15 node problem four matrix were obtained viz. two for distance and time matrix of shortest route and two for distance and time matrix of fastest route. It was found that the shortest route was taking the highest amount of time and the fastest route was the longest in terms of distance. So the nodes were divided into two parts; one part transporting the goods by owns vehicle and other by subcontracting. The main aim was to economically benefit the company.

Mohammad Asim et al. [13] proposed traveling salesman problem. Through this paper authors describe how the traveling salesman problem is solved by the heuristic method of genetic algorithms. The purpose is to find the most approximate solution that gives the least distance, which is the shortest route for traversing the cities given in the data set such that each city is passed through just once and the traveling salesman comes back to the initial city from where he started. Authors accomplish this by carrying out the algorithm through generating a fitness formula and with the help of genetic operators like selection, crossover and mutation.

Sumanta Basu [16] explain the Traveling Salesman Problem (TSP) and its allied problems like Vehicle Routing Problem (VRP) are one of the most widely studied problems in combinatorial optimization. It has long been known to be NP-hard and hence research on developing algorithms for the TSP has focused on approximate methods in addition to exact methods. Tabu search is one of the most widely applied met heuristic for solving the TSP. Author review the tabu search literature on the TSP and its variations, point out trends in it, and bring out some interesting research gaps in this literature.

Younis Elhaddad et al. [17] proposed an algorithm, a hybrid of Genetic algorithm (GA) and Simulated Annealing (SA) which uses TSPLIB instances to obtain good results. This hybrid method helps the GA to take a jump as it gets stuck after 20 consecutive iterations. Using a CPU having Matlab 7.0 the results obtained indicated that the Hybrid Genetic and Simulated Annealing Algorithm (HGSAA) produced more optimal solutions as compared to Local Search Heuristics Genetic Algorithm (LSHGA).

III. REVIEW OF TSP-TW PAPERS

Chi-Bin Cheng et al. [2] used the ant colony optimization technique to solve the TSPTW. The distances between the nodes of the benchmark instances were considered as the time so as to take the time windows into consideration. The authors obtained the numerical results of both ACS-TSPTW and ACS-Time. This problem has a number of important practical applications, including scheduling and routing. The problem is regarded as NP-complete, and hence traditional optimization algorithms are inefficient when applied to solve larger scale TSPTW problems. Consequently, the development of approximation algorithms has received considerable attention in recent years. Ant colony optimization (ACO), inspired by the foraging behavior of real ants, is one of the most attractive approximation algorithms. Accordingly, this study develops a modified ant algorithm, named ACS-TSPTW, based on the ACO technique to solve the TSPTW. Two local heuristics are embedded in the ACS-TSPTW algorithm to manage the time-window constraints of the problem. The numerical results obtained for a series of benchmark problem instances confirm that the performance of the ACS-TSPTW is comparable to that of ACS-Time, an existing ACO scheme for solving the TSPTW problem.

Imdat Kara et al. [6] explain each city (nodes, customers) must be visited within a time window defined by the earliest and the latest time. In TSPTW, the traveler has to wait at a city if he/she arrives early; thus waiting times directly affect the duration of a tour. It would be useful to develop a new model solvable by any optimizer directly. In this paper, we propose a new integer linear programming formulation having $O(n^2)$ binary variables and $O(n^2)$ constraints, where (n) equals the number of nodes of the underlying graph. The objective function is stated to minimize the total travel time plus the total waiting time.

A computational comparison is made on a suite of test problems with 20 and 40 nodes. The performances of the proposed and existing formulations are analyzed with respect to linear programming relaxations and the CPU times. The new formulation considerably outperforms the existing one with respect to both the performance criteria. Adaptation of our formulation to the Multi-traveler case and some additional restrictions for special situations are illustrated.

Jeffrey W. Ohlmann et al. [7] used compressed annealing approach to solve the traveling salesman problem with time windows (TSPTW) as constraint. Instead of using the traditional simulated annealing, the method used to solve the TSPTW was variable penalty approach of compressed annealing. Comparison with the benchmark problem was done in every step. For most of the cases the solutions obtained were nearly optimal even for constrained problems.

Jing-Quan Li [8] presents a bi-directional resource-bounded label correcting algorithm for the traveling salesman problem with time windows, in which the objective is to minimize travel times. Label extensions and dominance start simultaneously in both forward and backward directions: the forward direction from the starting depot and the backward direction from the terminating depot. The resultant label extension process scans much smaller the space than in single directional dynamic programming, substantially reducing the number of non-dominated labels. The labels for both the forward direction and backward direction are ultimately joined to form a complete route if all relevant feasibility conditions are satisfied.

John N. Tsitsiklis [9] considered a complete directed graph in which each arc has a given length. There is a set of jobs, each job i located at some node of the graph, with an associated processing time hi, and whose execution has to start within a pre-specified time window $[r_i, d_i]$. Authors have a single server that can move on the arcs of the graph, at unit speed, and that has to execute all of the jobs within their respective time windows. They consider the following two problems: (a) minimize the time by which all jobs are executed (traveling salesman problem) and (b) minimize the sum of the waiting times of the jobs (traveling repairman problem). The focus is on the following two special cases: (a) The jobs are located on a line and (b) the number of nodes of the graph is bounded by some integer constant B. Furthermore, they consider in detail the special cases where (a) all of the processing times are 0, (b) all of the release times r_i are 0, and (c) all of the deadlines d_i are infinite. For many of the resulting problem combinations, they settle their complexity either by establishing NP-completeness or by presenting polynomial (or pseudo polynomial) time algorithms. Finally, authors derive algorithms for the case where, for any time t, the number of jobs that can be executed at that time is bounded.

Kjetil Fagerholt et al. [10] proposed an algorithm for TSP along with time window, allocation and precedence constraints. The application of the algorithm was used in ship scheduling. The TSP-ATWPC occurs as a sub problem of optimally sequencing a given set of port visits in a real bulk ship scheduling problem, which are a combined multi-ship pickup and delivery problem with time windows and multi-allocation problem. Each ship in the fleet is equipped with a flexible cargo hold that can be partitioned into several smaller holds in a given number of ways, thus allowing multiple products to be carried simultaneously by the same ship. The allocation constraints of the TSP-ATWPC ensure that the partition of the ship's flexible cargo hold and the allocation of cargoes to the smaller holds are feasible throughout the visiting sequence. The TSP-ATWPC is solved as a shortest path problem on a graph whose nodes are the states representing the set of nodes in the path, the last visited node and the accumulated cargo allocation. The arcs of the graph represent transitions from one state to another. The algorithm is a forward dynamic programming algorithm. A number of domination and elimination tests are introduced to reduce the state space. The computational results show that the proposed algorithm for the TSP-ATWPC works and optimal solutions are obtained to the real ship scheduling problem.

Manuel L´opez-Ib´a˜nez et al. [11] explains combinatorial optimization. It is not rare to find problems whose mathematical structure is nearly the same, differing only in some aspect related to the motivating application. For example, many problems in machine scheduling and vehicle routing have equivalent formulations and only differ with respect to the optimization objective, or particular constraints. Moreover, while some problems receive a lot of attention from the research community, their close relatives receive hardly any attention at all. Given two closely related problems, it is intuitive that it may be effective to adapt state-of-the-art algorithms—initially introduced for the well-studied problem variant—to the less-studied problem variant. In this paper authors provide an example based on the travelling salesman problem with time windows that supports this intuition. In this context, the well-studied problem variant minimizes the travel time, while the less-studied problem variant minimizes the makespan. Indeed, the results show that the algorithms that they adapt from travel-time minimization to makespan minimization significantly outperform the existing state-of-the-art approaches for makespan minimization.

Roberto Baldacci et al. [15] explain the traveling salesman problem with time windows (TSPTW). The problem of finding in a weighted digraph a least-cost tour starting from a selected vertex, visiting each vertex of the graph exactly once according to a given time window, and returning to the starting vertex. This NP-hard problem arises in routing and scheduling applications. This paper introduces a new tour relaxation, called ngL-tour, to compute a valid lower bound on the TSPTW obtained as the cost of a near-optimal dual solution of a problem that seeks a minimum-weight convex combination of no necessarily elementary tours. This problem is solved by column generation. The optimal integer TSPTW solution is computed with a dynamic programming algorithm that uses bounding functions based on different tour relaxations and the dual solution obtained. An extensive computational analysis on basically all TSPTW instances (involving up to 233 vertices) from the literature is reported. The results show that the proposed algorithm solves all but one instance and outperforms all exact methods published in the literature so far.

IV. REVIEW OF VRP-TW PAPERS

Martin Desrochers et al. [12] explained vehicle routing problem with time windows (VRPTW). It is a generalization of the vehicle routing problem where the service of a customer can begin within the time window defined by the earliest and the latest times when the customer will permit the start of service. Authors present the development of a new optimization algorithm for its solution. The LP relaxation of the set partitioning formulation of the VRPTW is solved by column generation. Feasible columns are added as needed by solving a shortest path problem with time windows and capacity constraints using dynamic programming. The LP solution obtained generally provides an excellent lower bound that is used in a branch-and-bound algorithm to solve the integer set partitioning formulation. The results indicate that this algorithm proved to be successful on a variety of practical sized benchmark VRPTW test problems. The algorithm was capable of optimally solving 100- customer problems.

Olli Bräysy et al. [14] presents a survey of the research on the vehicle routing problem with time windows (VRPTW). The VRPTW can be described as the problem of designing least cost routes from one depot to a set of geographically scattered points. The routes must be designed in such a way that each point is visited only once by exactly one vehicle within a given time interval, all routes start and end at the depot, and the total demands of all points on one particular route must not exceed the capacity of the vehicle. Both traditional heuristic route construction methods and recent local search algorithms are examined. The basic features of each method are described, and experimental results for Solomon’s benchmark test problems are presented and analyzed. Moreover, we discuss how heuristic methods should be evaluated and propose using the concept of Pareto optimality in the comparison of different heuristic approaches.

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