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Site dependent vehicle routing problem with soft time window: Modeling and solution approach ☆

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ABSTRACT

This paper presents two meta-heuristic algorithms, an ant colony system with local searches and a tabu search algorithm, for Site-Dependent Vehicle Routing Problem with Soft Time Window (SDVRPSTW). In the SDVRPSTW a fleet of vehicles must deliver goods to their allowable set of customers, preferably in their time windows while the capacity constraints of the vehicles must be respected. Based on our best knowledge, this problem which challenges the distribution task of public services and private organizations in an urban context with heavy traffic has not yet been considered in practical aspects, especially where the vehicles entrance to some areas needs traffic license. Hence, in addition to present an Integer Linear Programming (ILP) model, we present the two mentioned algorithms to handle the problem in large scale instances. Furthermore, the algorithms efficiency and their optimality are analyzed by experimental results both in small and large dimensions.

1. Introduction

The Vehicle Routing Problem and its multiple variants, is a core problem in transportation, logistics, and supply chain management. Logistics, and especially the distribution of goods, lies at the heart of business activity because it is often coupled with inventory and production decisions, and the delivery cost accounts for a significant portion of the total logistic costs (Baños, Ortega, Gil, Márquez, & De Toro, 2013). In this problem, fleet type can be homogeneous as well as heterogeneous fleet of vehicles with different capacities (Repoussis & Tarantilis, 2010). Various characteristics of the demand for transportation in terms of volume, time and geography may motivate the use of vehicles with different characteristics. Due to the operational constraints rarely a homogeneous fleet of vehicles is applied in today's industry, while in the basic VRP it is assumed that the fleet is consists of only one type of vehicle. Different characteristics of vehicles in the fleet are divided into three basic classes, physical dimensions, cost factors and compatibility constraints. Physical dimensions such as length, width and height of a vehicle often determine the carrying capacity of the vehicle and their accessibility for different customers in various locations. Cost factors represent the costs occurred during serving process such as fuel cost per distance, depletion cost of the vehicle, and the vehicle driver cost per hour. Compatibility constraints or site-dependency refer to the situation in which each customer needs a special type of vehicle to be served. For instance, consider the goods demanded by a customer, that require vehicles with special equipment for loading or unloading them or the case that a customer located in a special area of the city in which only the vehicles with permission are allowed to enter. The necessity of modeling the compatibility constraints is unfolded when encountering various practical needs in transportation in metropolitan area. For example, traffic inhibitory rules are one of the strategies applied in traffic control, especially in metropolitan centers with high volume of daily transportation. Based on these rules, transportation in some crowded regions is restricted and only allowable vehicles are permitted to travel to these regions. Another example is the traffic restrictions through residential or therapeutic areas in which air and noise pollution are the important concerns. These requirements arisen in practice, limit the fleet open access to all sites, hence, serving customers all over the urban environment needs a heterogeneous fleet with site-dependent allowable vehicles. Residential solid waste collection is another real-world application of the presented problem. In the mentioned problem, each vehicle collects solid waste from the district which is assigned to it based on its specifications such as capacity, size, and shape. It means that, for example, larger vehicles cannot serve districts with small alleys or bridges that can support

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only a specific weight. In such cases, the site-dependency aspect of the problem can be applied to handle these types of constraints.

We propose modeling these practical requirements via Site-Dependent Vehicle Routing in an urban environment scale in which the customers prefer to be served in predetermined time window. Furthermore we present two meta-heuristics algorithms to handle the problem instances in this scale. Time window constraint refers to this situation in which each customer must be serviced within a specified time window, and a vehicle is not allowed to begin service at a customer location after the time window's upper bound. A waiting time is incurred if a vehicle reaches a customer before the lower bound (Küçükoğlu & Öztürk, 2015). Extensive studies have been done on the VRPTW. Baldacci, Mingozzi, and Roberti (2012) provide a recent review of mathematical formulations, relaxations and exact methods for the VRPTW. The VRPTW treats time windows as hard constraints. However, some practical applications imply that customer time windows can be treated as soft constraints, i.e., may be violated at a cost. This setting gives rise to the VRPSTW, which is significantly less studied than the VRPTW. The VRPSTW considers the existence of time windows, however it assumes that customers are available at any moment in time to receive their goods. Therefore, vehicles incur penalty costs for time window violations. As such, the VRPSTW is a special case of the VRPTW, where the relaxation of time windows is unbounded, i.e., infinite flexible bounds (Taş, Jabali, & Van Woensel, 2014).

The SDVRP is a problem belonging to NP-hard category (Cordeau & Laporte, 2001). Since SDVRP with Time Windows (SDVRPTW) is an extension of SDVRP, it is obvious that SDVRPTW belongs to NP-hard problems. Most real world sized problems cannot be solved to optimality within a reasonable time by existing exact approaches. Heuristic algorithms instead can find solutions of very high quality in much shorter time. Chao, Golden, and Wasil (1999) presented a solution approach for the SDVRP in which the customers are clustered based on their allowable vehicle types such that the customers in each cluster have a same type of vehicle. In the next stage the vehicles tours in each cluster are determined via solving the VRP basic model. They used the record-to-record travel procedure of Dueck (1993) and Dueck and Scheuer (1990). The improvement phase considers a series of uphill and downhill one-point movements that move one customer at a time.

This clustering strategy has also been applied in the work of Chao and Liou (2005) but, the objective function in this study is to minimize the total distance traveled while in work of Chao et al. (1999) it is minimizing the maximum fraction of total capacity used for each type of vehicle. Cordeau and Laporte (2001) considered SDVRP as a variant of the Periodic VRP (PVRP) and showed that a tabu search algorithm previously developed for the PVRP by Cordeau, Gendreau, and Laporte (1997) can be applied to the SDVRP. Sniezek and Bodin (2006) presented a hybrid approach for solving the capacitated arc routing problem with vehicle-site dependencies (CARP-VSD). They introduced the solid waste collection of the residential area as a major application of the CARP-VSD. In this case, vehicle-site dependency comes from that some streets or alleys are too narrow for certain vehicle class to traverse or some bridges are too weak to bear the weight of some vehicles. Alonso, Alvarez, and Beasley (2008) considered a periodic vehicle routing problem in which while the classical constraints have been considered, it is possible that a vehicle traverses more than one route per day. They developed a tabu search algorithm for the problem and they evaluated its efficiency via solving some test problems.

The widespread strategy encountering SDVRP is that it is solved in two stages: at first, the site-dependency is incorporated by solving an allocation problem in which customers with the same vehicles are clustered and then in the second stage some basic VRPs are solved to determine the tours in each cluster. Although this disintegration simplifies the solving process and makes it possible to achieve acceptable solution in large scale problems, it removes the optimality guaranty from the solution approach and may results in poor solutions. In this paper we present an integrated model and solution approach for the SDVRP with soft time window in which vehicles-customers assignment and vehicle-tour determination are performed simultaneously.

The remainder of the paper is organized as follows. Section 2 presents the problem definition and mathematical model of the SVRPSTW. In Section 3, we present the Ant Colony System (ACS) and Tabu Search (TS) algorithms for the discussed model. Some computational results are discussed in Section 4. Concluding remarks are provided in Section 5.

2. Problem formulations

Let $G = (N, A)$ be a graph, in which $N = \{0, 1, \ldots, n, n+1\}$ is the set of nodes corresponding to n customers where both nodes 0 and $n+1$ represent the depot for tour start and tour end respectively, and $A \subseteq N \times N$ is the edges set determining the travel possibility between customers. Also let $V = \{1, \ldots, k\}$ be the set of available vehicles such that the set is heterogeneous and each vehicle has a capacity Ca_v and also a fixed cost f_v occurred as applying the vehicle. Each customer $j,\ j \in N/\{0, n+1\}$ has the demand d_j which should be met during its time window $[e_j, l_j]$ by only one vehicle belonging to its allowable vehicle types set named $A_j \subseteq V$. The problem is to find the tours in G and their assigned vehicle type with start and end point $\{0, n+1\}$ respectively, such that all constraints are fulfilled while the sum of total traveling cost, earliness and tardiness cost and vehicle procurement cost is minimized. Followings are a number of parameters used in the presented mathematical model.

2.1. Parameters

c_{ij} = Travel cost of edge $(i,j),\ \forall (i,j) \in A,\ c_{ii} = 0$.
t_{ij}^v = Travel time of vehicle v on arc $(i,j),\ \forall (i,j) \in A,\ v \in V,\ t_{ii}^v = 0$.
S_i = Service time for customer $i,\ i \in N/\{0, n+1\}$.
$[e_i, l_i]$ = Service time window of customer $i,\ i \in N/\{0, n+1\}$.
r_i = Earliness penalty of customer $i,\ i \in N/\{0, n+1\}$.
h_i = Tardiness penalty of customer $i,\ i \in N/\{0, n+1\}$.

2.2. Decision variables

The decision variables used in the presented model are as follows:

$X_{ij}^v = 1$, If vehicle v travel by arc (i,j); Otherwise it is $0, \forall (i,j) \in A$;
y_i^v = Arrival time of vehicle v to customer $i, (i \in N/\{0, n+1\}, v \in V)$.
E_i^v = Earliness of vehicle v while arriving customer $i, (i \in N/\{0, n+1\}, v \in V)$.
L_i^v = Tardiness of vehicle v while arriving customer $i, (i \in N/\{0, n+1\}, v \in V)$.

The problem is formulated as the following IP model:

$$\min Z = \sum_{v=1}^{k}\sum_{i=0}^{n}\sum_{j=1, j\neq i}^{n+1} c_{ij}X_{ij}^v + \sum_{v=1}^{k}\sum_{j=1}^{n} f_v X_{0j}^v + \sum_{i=1}^{n} r_i \sum_{v=1}^{k} E_i^v + \sum_{i=1}^{n} h_i \sum_{v=1}^{k} L_i^v$$