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An iterated local search for the Traveling Salesman Problem with release dates and completion time minimization

Claudia Archetti[a], Dominique Feillet[b], Andrea Mor[a,*], M. Grazia Speranza[a]

[a] University of Brescia, Department of Economics and Management, Brescia, Italy
[b] Ecole des Mines de Saint-Etienne and LIMOS UMR CNRS 6158, CMP Georges Charpak, Gardanne F-13541 France

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ABSTRACT

In the Traveling Salesman Problem (TSP) with release dates and completion time minimization an uncapacitated vehicle delivers to customers goods which arrive at the depot over time. A customer cannot be served before the demanded goods arrive at the depot. A release date is associated with each customer which represents the time at which the goods requested by the customer arrive at the depot. The vehicle may perform multiple routes, all starting and ending at the depot. The release dates of the customers served in each route must be not larger than the time at which the route starts. The objective of the problem is to minimize the total time needed to serve all customers, given by the sum of the traveling time and the waiting time at the depot. The waiting time is due to the fact that the vehicle has to wait at the depot until the latest release date of the customers it is going to serve in the next route. We introduce some properties, propose a mathematical programming formulation and present a heuristic approach based on an iterated local search where the perturbation is performed by means of a destroy-and-repair method. Two alternative repair operators, one simple and fast and the other based on a mathematical programming model, are proposed, which give rise to two variants of the heuristic. The mathematical formulation is used to find the optimal solution on instances with up to 20 customers, built from benchmark instances for the classical TSP. Comparison with optimal solutions shows that both algorithms provide high-quality solutions. Tests are also made on larger instances to compare the performance of the two variants of the heuristic.

1. Introduction

A common trait of the classical Vehicle Routing Problems (VRP) is the assumption that the goods to be distributed are available at the depot when the distribution starts. This implies that all vehicle routes may start immediately to distribute goods to customers. However, there are different settings in which this assumption is not satisfied, i.e., goods are not all available at the depot when the distribution starts and arrive at the depot over time. In this case, vehicles need to wait at the depot for the goods to arrive before distributing them. One example is related to city logistics and city distribution centers. Such an application has been studied in Cattaruzza et al. (2016a) where the authors introduce the Multi-Trip Vehicle Routing Problem with Time Windows and Release Dates (MTVRPTW-R) in which the goods that have to be distributed arrive at the depot over time, i.e., they become available when the distribution has already started. This poses the additional question of whether it is better to wait for additional goods to arrive and have a better loaded vehicle, or to start a route with the currently available goods. The arrival time at the depot of the goods to be delivered to a customer is called its release date. Another example arises in same day delivery problems related to e-commerce logistics. In this case, customer orders arrive online when the distribution (of previously received orders) has already started. Thus, the newly received orders have to be integrated in the distribution plan by designing vehicle routes that perform multiple trips, i.e., vehicles return to the depot multiple times in order to pickup the newly arrived orders that need to be distributed.

The focus of this paper is to study a routing problem arising in the applications mentioned above. In particular, we consider the TSP with release date and completion time minimization (TSP-rd(time)), that is the problem where each customer is associated with a release date and a single uncapacitated vehicle is allowed to perform multiple trips during the time horizon (say, the day), one after the other. No restriction is imposed on the maximum time taken by the vehicle to serve all customers and the objective

* Corresponding author.
E-mail addresses: claudia.archetti@unibs.it (C. Archetti), feillet@emse.fr (D. Feillet), andrea.mor@unibs.it (A. Mor), grazia.speranza@unibs.it (M.G. Speranza).

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is to minimize the completion time of the service, that is the time at which the vehicle is back to the depot and has served all customers. The completion time is given by the sum of the traveling time and waiting time. We consider the static problem where all information about the customers and the associated release dates are known in advance. As the TSP-rd(time) is relatively new in the literature, we believe that a deeper understanding of the static and deterministic version of the problem can be useful when solving the problem where release dates are characterized by dynamicity and uncertainty.

The contributions of this paper are summarized as follows. We first devise some properties of the problem and describe an approximation algorithm derived from Christofides approximation algorithm for the TSP. Then, we propose a mathematical programming formulation and present a heuristic approach based on an iterated local search where the perturbation is performed by means of a destroy-and-repair operator. Two alternative repair operators are proposed, one simple and fast and the other based on a mathematical programming model, which gives rise to two variants of the proposed heuristic. Ad hoc neighborhoods for the local search are introduced which are based on the characteristics of the problem. The mathematical programming formulation is used to find the optimal solution on instances with up to 20 customers built from benchmark instances for the classical TSP. On all but one instances the heuristic with the simple repair operator finds the optimal solution.

The paper is organized as follows. In Section 2 we review the literature related to similar problems. In Section 3 the TSP-rd(time) is defined and the properties and the mathematical programming formulation are presented. The heuristic is described in Section 4, whereas the computational experiments are presented in Section 5. Finally, conclusions are drawn in Section 6.

2. Literature review

To the best of our knowledge, Cattaruzza et al. (2016a) is the first work where the concept of release date is introduced in a routing setting. The problem studied is a multi-vehicle routing problem with time windows. The authors propose a hybrid genetic algorithm to solve the problem and test it on instances generated from Solomon's instances for the VRP with time windows (Solomon, 1987). The vehicle routing problem with release dates with a single uncapacitated vehicle is introduced in Archetti et al. (2015). The authors call this problem the Travelling Salesman Problem with release dates (TSP-rd). Two variants of the TSP-rd are proposed: one takes into consideration a deadline for completing the distribution and minimizes the total traveling time, the other one has no deadline and seeks the minimization of the time needed to complete the distribution. The former is referred to as TSP-rd(distance) and the latter as TSP-rd(time). The complexity of the two variants is analyzed for special topologies of the graph representing the distribution network, i.e., a line, modelling a distribution along a road, and a star, modelling the situation where the depot is the center of the distribution area. Further complexity analysis is carried out in Reyes et al. (2018), where, in addition to a distribution deadline, a service guarantee is considered, enforcing a maximum delay between the release date and the delivery to the customer. Shelbourne et al. (2017) consider the VRP with release and due dates, where the due date is the time by which the order should be delivered to the customer. The authors minimize a convex combination of operational costs and customer service level, measured by the total traveled distance and the total weighted delivery tardiness and no waiting time is considered, contrary to what happens in the TSP-rd(time). The authors present path relinking algorithm for the problem. The algorithm relies, among other things, on a parameter penalizing the solution that are infeasible with respect to the capacity constraint which makes it not suited for the TSP-rd(time), where such constraint is not considered.

As mentioned in Section 1, the vehicle routing problem with release dates finds applications in the context of the same-day delivery service. Recent contributions that study the same day delivery problem are Klapp et al. (2016), Klapp et al. (2018), and Voccia et al. (2017). In Klapp et al. (2016) the authors study the dynamic dispatch waves problem (DDWP) of a single vehicle on a line, where the problem is to decide whether to dispatch a vehicle to serve known customers or to wait for potential requests that may arrive later, with thhe objective to minimize expected vehicle operating costs and penalties for unserved requests. The study is extended to the case of a general network in Klapp et al. (2018). In Voccia et al. (2017) the same day delivery problem is investigated. A fleet of vehicles is used to serve requests characterized by time windows or a delivery deadline. Future requests are unknown but probabilistic information is available. The authors identify the circumstances that make waiting at the depot beneficial to maximize the number of requests that are served on time.

Finally, a problem which is strictly related to the one analyzed in this paper is the Multi-Trip Vehicle Routing Problem (MTVRP), where each vehicle may perform multiple trips and, thus, visit the depot multiple times. See Cattaruzza et al. (2016b) for a recent survey. The need of visiting the depot multiple times may come from the fact that routes need to have a short duration (see Azi et al., 2007 for potential applications) or because of capacity constraints. The problem with a single vehicle performing multiple routes within one workday is investigated in Azi et al. (2007), where customer requests with time windows are considered. The authors propose an exact algorithm for the problem. The work is extended in Azi et al. (2010, 2014) to consider multiple vehicles. An exact algorithm is designed in Azi et al. (2010) while an adaptive large neighborhood search is proposed in Azi et al. (2014).

In this paper we focus on the TSP-rd(time) which is introduced in Archetti et al. (2015). We propose the first mathematical formulation and solution approach for the problem. The TSP-rd(time) differs from the problem analyzed in Azi et al. (2007) as it considers release dates and does not consider duration constraints and time windows for the customers. It also differs from Klapp et al. (2016), Klapp et al. (2018), and Voccia et al. (2017) where a dynamic problem is studied and decision epochs are defined a priori, contrary to what happens in TSP-rd(time).

3. The Traveling Salesman Problem with release dates and completion time minimization

The TSP-rd(time) is defined as follows. Let $G = (V, A)$ be a complete graph. A traveling time and a traveling distance are associated with each arc $(i, j) \in A$. These two values are assumed identical and are denoted by t_{ij}. It is also assumed that the triangle inequality is satisfied. The set of vertices V is composed by vertex 0, which identifies the depot, and the set N of customers, with $|N| = n$. The release date for customer $i \in N$ is denoted by r_i, $r_i \geq 0$. This means that the goods for customer i can either arrive at time r_i, then $r_i > 0$, or be at the depot at the beginning of the distribution, e.g., because they arrived overnight, then $r_i = 0$. A single vehicle is allowed to perform a sequence of trips. Capacity constraints are not considered. The objective is to minimize the completion time, that is, the total traveling time plus the waiting time at the depot, and serve all customers. The waiting time is due to the fact that the vehicle has to wait at the depot until the latest release date of the customers it is going to serve in the next route. Without loss of generality, we assume that customers are ordered in non-decreasing order of their release dates, i.e., $r_i \leq r_j$ for $i < j$, $i, j = 1, \dots, n$. Given a solution to the TSP-rd(time), we call