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Electric vehicle routing problem

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Abstract

This paper presents a general Electric Vehicle Routing Problem (EVRP) that finds the optimal routing strategy with minimal travel time cost and energy cost as well as number of EVs dispatched. This is the first EVRP model to consider the vehicle load effect on battery consumption. As demonstrated with a case study in Austin TX, the effect of vehicle load on routing strategy cannot be ignored. Compared to diesel truck VRP, EVRP has comparable travel time and distance but long en-route re-charging time, which translates into a considerable amount of additional labor cost. Lastly, the network topology greatly affects the routing strategies.

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Keywords: electric vehicle routing problem (EVRP); charging station location; battery capacity; charging technology; graph representation

1. Introduction

As corporations are becoming more conscious about the environment and the associated externality costs, electric commercial vehicles are gaining tractions in firms that deliver products, goods, or service. For example, Staples Inc., PepsiCo, FedEx Corp, and AT&T Inc. are among those firms. The idea of being green has not only a long term effect on tackling climate change but also a short term business reward as fuel cost accounts for 39% to 60% of operating costs in the trucking sector (Sahin et al. 2009). EVs are much more energy efficient than the conventional petroleum-fuel powered and therefore are expected to bring considerable energy savings to urban freight. However, compared to the conventional petroleum-fuel powered vehicles, EVs have a shorter range - typically 40~100 miles -

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before being charged again. Due to the range limit, EVs may need to visit a charging station in between customer visits during its daily operation. Because of this unique feature, it makes the EVRP distinctively different from the traditional VRP in the literature as we will demonstrate throughout the paper.

In this paper, we investigate an Electric Vehicle Routing Problem (EVRP), in which electric commercial vehicles with a limited range may recharge at a charging station during their daily delivery (and pickup) operations, provided that the charging station facilities are already in place in the service area. The proposed EVRP formulation takes into account the costs associated with not only the travel time but also electricity consumption. The locations of EV charging stations are known and within the service area. Each charging station may be visited multiple times as needed by the same or different vehicles, or it may not be visited at all. There is a cost associated with electricity. At each customer location, there is a demand either to be delivered or picked up. Furthermore, there is a single depot at which all vehicle routes starts and ends. The proposed EVRP finds the optimal routing strategy in which the total cost (i.e., travel time cost + energy cost) is minimized such that: (1) each customer is visited exactly once by one vehicle on its route; (2) the total demand of the customers served on a route does not exceed the vehicle capacity; (3) each charging station may be visited more than once by the same and different vehicles, or not at all; and (4) minimum necessary number of EVs are needed to serve all the customers in the service area.

The major contributions of this research are as follows. First of all, it adds to the scientific literature of EVRP, which is in fact quite thin due to the fact that EVs as a delivery mode only started very recently, though there is much work on EV battery technology, batter swapping, and EV commuter routing, and charging location choice. Secondly, the proposed EVRP model considers the effect of vehicle load on energy (battery electricity) consumption. This is a unique feature that distinguishes this paper from the other EVRP papers. The significant effect of vehicle load on energy consumption has been documented in Suzuki (2011), Xiao et al. (2012), Chen and Lin (2014), and Zhou et al. (2015). Vehicle load is in turn affected by the customer demand (quantity and type – delivery or pickup) and the visiting order. As we will demonstrate through a case study later in the paper, the load effect cannot be ignored in EVRP routing strategies. Thirdly, the proposed EVRP formulation follows a simpler graph representation than other studies in the EVRP literature, and thus ours has an obvious computational advantage over the others. In addition, the proposed EVRP model considers both delivery and pick-up tasks, paired or unpaired, during routing, and makes no assumption about the vehicle size and battery capacity. In other words, the vehicle and the battery capacities can vary within the fleet mix.

The rest of the paper is organized as follows. First, a literature review of EVRP and related studies is given with the focus on model formulation. Then a general EVRP problem is defined and the model formulation is presented. This is followed by two small hypothetical numerical examples to demonstrate the impact of charging station topology on the routing strategy. Then a case study based on the real-world network setting in Austin, Texas is presented to compare EVRP with conventional VRP strategies. Lastly, study conclusions and future research directions are drawn in the conclusion section.

2. Literature review

The electric vehicle routing problem (EVRP) in the literature, albeit thin, can be viewed as a variant to the green vehicle routing problem (GVRP) proposed by Erdogan and Miller-Hooks (2012) in which they consider a vehicle routing problem involving alternative fuel vehicles (including EVs) that have limited travel range and must re-charge during routing. In the paper, GVRP minimizes the total distance traveled by AFVs. Each customer is visited exactly once as defined in the conventional VRP. On the other hand, the re-fueling stations may be visited by any vehicle in the fleet as many times as necessary (or none if not necessary). This represents a deviation from the conventional VRP. To accommodate potentially multiple visits to a charging station (including one at the depot) in the model formulation, the EVRP graph is augmented by creating a set of multiple copies of the vertices representing the charging stations (including one at the depot). The number of copies equals the number of potential visits to a charging station (and in the case of the depot the number equals the fleet size). By doing so, the conventional VRP formulation can be adopted for EVRP with minimal modification - the only change to the conventional VRP formulation is to add a constraint that each charging/re-fueling station is visited at most once. The paper does not consider the cost associated with energy consumption, nor does it take into account the vehicle capacity or time window constraints. In addition, the paper also assumes the refueling time is fixed.