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A new model and approach to electric and diesel-powered vehicle routing

Keisuke Murakami

Faculty of Business and Commerce, Kansai University, 3-3-35 Yamate, Suita, Osaka 564-8680, Japan

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ABSTRACT

Electric vehicles have recently received considerable attention given their environmental and financial implications. This paper focuses on electric and diesel-powered vehicle routing, a vehicle routing problem targeted at electric and diesel-powered vehicles. We introduce the new concept of original graph, where various conditions such as inclines of roads, vehicle speed and acceleration are considered. Moreover, we formulate the problem as a mixed integer linear programming formulation. The results of simulations demonstrate the utility of the new model in the real world.

1. Introduction

Electric vehicles (EVs) have the potential for positive environmental and financial implications on a global scale, and recently, they have attracted considerable attention. The advantages of EVs include zero gas emissions, lower fuel costs, low vibration levels, and low noise levels. However, EVs remain rather unpopular because the battery needs frequent recharging; moreover the recharge time is long and the recharge stations are relatively deficient. To overcome these problems, various optimization studies have been conducted (Schonfelder et al., 2014; Sierzchula et al., 2014; Wesseling et al., 2014). Sweda and Klabjan (2012) addressed the minimum-cost path problem with recharging stations and proposed a dynamic programming algorithm for the problem. Eisner et al. (2011) proposed a fast algorithm for the minimum-cost path problem. The characteristics of EVs in routing problems differ from those of traditional diesel-powered vehicles (DVs). Although the mileage per (re) charge is considerably smaller in EVs than in DVs, electric power is substantially less expensive than fuel oil.

This paper focuses on a specific vehicle routing problem for EVs and DVs, referred to hereinafter as "the electric and diesel-powered vehicle routing problem (EDVRP)." As mentioned above, in routing problems, EVs can be run at lower cost than DVs. However, the low mileage per recharge demands frequent recharges. Additionally, the recharge time is too long for effective travel (delivery). Thus, in our routing problem, EVs are *not* recharged, but are used to supplement DVs. By replacing certain DVs with EVs, we expect to reduce the cost of road travel.

1.1. Related work and our contributions

In this section, we present previous studies on EV routing problems, green vehicle routing problem, and plug-in hybrid EV (PHEV) routing problem. Next, our contributions of this paper are explained, where the new concept of graph and more realistic conditions are introduced.

E-mail address: k_mura@kansai-u.ac.jp

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Artmeier et al. (2010) introduced the shortest path problem that finds the most energy-efficient routes under the constraint of battery capacity. Storandt (2012) considered the travel distance and time in addition to energy efficiency. Adler et al. (2016) imposed battery recharging constraints on the shortest path problem. Rather than recharging the drained battery pallet, they suggested that drained batteries could be replaced with fully charged batteries at designated battery exchange stations. Although this approach would eliminate the time required for recharge, it would increase the cost of battery use because EVs have variable battery pallets and lack a common standard. Moreover, other car parts such as tires and wipers would also require to be changed (Shemer, 2012). Therefore, battery exchange has not become popular. Roberti and Wen (2016) introduced the electric traveling salesman problem with time windows and proposed a mixed integer linear formulation and a heuristic algorithm.

The EV routing problem (EVRP) can be classified as a *green vehicle routing problem (G-VRP)*, a type of green logistics problem that advocates the use of greener fuel sources such as biodiesel, electricity, ethanol, hydrogen, methanol, natural gas, and propane. Erdogan and Miller-Hooks (2014) formulated the G-VRP and proposed a solution technique. Felipe et al. (2014) proposed a heuristic algorithm for a variant of the G-VRP which considers multiple technologies and partial recharges. Schneider et al. (2014) considered an EVRP with time windows and recharging stations. Lin et al. (2014) presented a survey of G-VRPs. Bektas and Laporte (2011) stated the Pollution-Routing Problem (PRP) and proposed mathematical models, by considering various parameters such as vehicle load, speed, and total cost. Demir et al. (2011) addressed a realistic energy consumption model that incorporates road gradients and vehicle acceleration in addition to the above parameters. Moreover, they proposed six models and simulated several scenarios using the models. Nie and Li (2013) addressed an eco-routing problem and formulated it as a constrained shortest path problem. Goeke and Schneider (2015) proposed an adaptive large neighborhood search algorithm for the EVRP with time windows and mixed fleet, wherein they considered a realistic energy consumption model.

There are a few studies on the plug-in hybrid EV (PHEV) routing problem. Arslan et al. (2015) introduced a minimum-cost path problem for PHEVs and stated that theirs was the first article to address this matter. Their study considered battery degradation and stopping costs as well as the prices of electricity and gasoline. The electricity and gasoline usage per mile were approximated by averaging. Nejad et al. (under second review) considered a new model of the PHEV routing problem, in which PHEVs passed through each edge either in the gasoline mode or electric mode. This model could generate a concrete plan, allowing the timing of switching between modes to be decided. They also proposed exact and approximation algorithms. Murakami (available online) extended Nejad et al.'s model to consider time constraints and the availability of recharging stations, and proposed heuristic algorithms for the problem.

In the conventional VRP, all vertices must be visited by any vehicle and each edge connects a vertex to another vertex. In a real-world network, each of these edges represents the shortest (minimum-cost) path from one visited point (vertex in the VRP) to another, where the intersections of roads are treated as vertices as well. Reducing the shortest paths to the edges maintains the optimality of the VRP, but it may compromise the EVRP because the EV in this problem does not always take the shortest (minimum-cost) path between visited points. For example, in Fig. 1, each edge value represents the power consumption along that edge, where a negative value means recovery of battery power (i.e., downhill). We consider two paths from the visited point i to j, where Path B (power consumption = 2) is shorter than Path A (power consumption = 3). However, if the battery power of EV is 4 at the visited point i, Path B is unavailable because the highest power consumption along that path is 5. Thus, we must abandon Path B and instead drive along Path A. This example shows that the best paths cannot be known beforehand, because they change depending on the available battery power at that point. Therefore, we consider the "original graph" in the EVRP (Fig. 2). In the original graph, the edges are the roads between the vertices (which include both visited points and intersections). To our knowledge, previous EVRP studies have constructed reduced graphs by using only the visited points, rather than considering the original graph. Furthermore, we can consider changes in vehicle speed more precisely in the original graph. In general, vehicle speed is determined for each edge, that is, in a reduced graph, the vehicle speed cannot change midway through the path (edge) between visited points (customers), whereas in the original

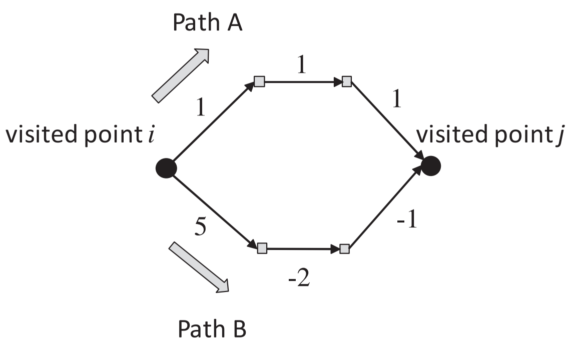

Fig. 1. Two possible paths from point i to point j.