Development of Electric Vehicle Charging Corridor for South Carolina

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ABSTRACT
We apply a flow-based location model, called Multipath Refueling Location Model (MPRLM), to develop an electric vehicle (EV) public charging infrastructure network for enabling long-haul inter-city EV trips. The model considers multiple deviation paths between every origin-destination (O-D) pairs and relaxes the commonly adopted assumption that travelers only take a shortest path between O-D pairs. This model is a mixed-integer linear program, which is intrinsically difficult to solve. With greedy-adding based heuristics, the MPRLM is applied to optimally deploy EV fast charging stations along major highway corridors in South Carolina. Compared to engineering methods, the optimization model reduces the capital cost of establishing a fast charging network by two thirds. We also explore the interplay between the spatial distributions of cities, vehicle range, and routing deviation tolerance as well as their impacts on the locational strategies.

Key words: Electric vehicle, Charging station, Combinatorial optimization, Heuristics

1. INTRODUCTION
The nationi's transportation sector is facing grand challenges on reducing the dependence on oil imports and seeking solutions to hedge against climate change. In moving forward to a low-carbon society, replacing gasoline vehicles by alternative fuel vehicles (AFVs), such as powered by rechargeable battery packs, natural gas, and ethanol, would provide legit and viable solutions. Of the wide variety of AFVs, plug-in electric vehicles (PEVs or conventionally called EVs) including plug-in hybrid

electric vehicles (PHEVs) and all-electric or battery electric vehicles (BEVs), have been long recognized as a promising type for its fuel economy and flow fuel cost. However, several studies have documented challenges in regular uses of PEVs, of which lacking public charging stations and the consequent "Range Anxiety" is of particular concern, as majority of charging facilities are only available to PEV owners at their homes or workplaces [1–5].

There are only 8,408 pubic charging stations nationwide [6] as of 2013 and majority of the charging stations are *destination based*, e.g., workplaces, restaurants, and shopping malls. Slow charging technologies, i.e., Level 1 or 2 charging methods, are the primary charging technologies, by which a full recharge of a battery takes about 8 – 9 hours by level 1 and 3–4 hours by level 2 [7]. This characteristics make that the slow charging methods particularly useful for daily short trips (e.g., home-work commute), but ill-suited for long-distance inter-city travel [8]. This study focuses on the development of fast charging corridor network that provides *path-based* charging services. Compared to slow charging methods, fast-charging option can fully recharge a PEV in 20 minutes or up to 80% of a battery in 10–15 minutes [9] and thus can potentially work as commercial gasoline stations.

The problem of locating services on networks originates from the Flow Intercepting Facility Location Problem (FIFLP) [10–12]. It is then developed to consider limited vehicle range in the maximal-flow-coverage based Flow-Refueling Location Problem (FRLP) [13–16] with applications in Alternative Fueling Station (AFS) problems [17–20], and the minimum-cost based flow based set-covering models [21–25]. Both the maximum-coverage and minimum-cost models have been reformulated as a flexible refueling station location problem [26, 27]. The maximal-coverage models produce budget-constrained location solutions, which however do not have to satisfy all demand. In contrast, minimum-cost models yield location solutions to satisfy all demands, which can be used to provide cost assessment of AFS placement for planners (e.g., public stakeholders or industry investors).

We recently introduced a new AFS location model, called the Multipath Refueling Location Model (MPRLM), in which users can utilize *multiple deviation paths* between all O-D pairs on the network. An O-D pair is considered as covered if there is *at least* one path, either a shortest path or a path with a reasonable deviation, available between the O-D pair through which drivers can complete a trip with single/multiple refueling stops [28]. The model is formulated as a mixed integer linear program, which is a NP-hard problem and solved by greedy-adding (GA) heuristic algorithm [29].

While both the model and heuristic have been well presented with demonstrations of numerical examples, in this study, we focus on developing an EV fast charging corridor network in the state of South Carolina (SC) by applying the model and solution algorithm. The goal is to minimize the total cost of fast charging stations needed on major highways while enabling EV trips between major cities across the entire state. The model entails the locations of charging stations while taking into account real vehicle range and deviation paths. Compared to the engineering method, the MPRLM helps to reduce the cost of launching fast charging network by two thirds allowing for deviation paths.