Transportation Research Part E 72 (2014) 144–158

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Heuristic approaches for the flow-based set covering problem with deviation paths

Shengyin Li, Yongxi Huang *

Glenn Department of Civil Engineering, Clemson University, 109 Lowry Hall, Clemson, SC 29634, United States

A R T I C L E I N F O

Article history:
Received 14 February 2014
Received in revised form 18 September 2014
Accepted 21 October 2014

Keywords:
Heuristic method
Greedy-adding
Alternative fueling stations
Deviation paths
Mixed integer programming

A B S T R A C T

A multipath refueling location model is developed to take into account the effects of vehicle range and multiple deviation paths. It is formulated as a mixed integer linear program, which is intrinsically difficult to solve with increase in the number of deviation paths and network size. This study is focused on developing heuristic approximation solutions, specifically the greedy-adding and greedy-adding with extension algorithms. These algorithms are shown to be efficient and effective to solve the model for the Sioux Falls network. The heuristics are also applied to locate electric vehicle charging stations in the state of South Carolina.

1. Introduction

The lack of alternative fueling stations (AFSs) in the public is considered as one of major barriers to expedite a massive adoption of alternative fuel vehicles (AFVs), mainly due to the amateur AFV engine technology and the consequent limited travel range, also known as the range anxiety. For instance, the Nissan Leaf, a battery electric vehicle (BEV), can only run up to 84 miles per charge (Nissan North America Inc., 2014). Although this driving range should suffice for daily commutes, long-distance inter-city trips still have to rely on the conventional fuelled vehicles since public AFS (e.g., charging stations) are woefully inadequate on major highway corridors. Motivated by this research need, the study aims to better understand where to locate AFSs on transportation networks so that they can satisfy the travel demands in a most effective manner.

The AFS location problems have been studied in the past decades. First appeared as a flow intercepting or capturing location model (FILM, FCLM) (Berman et al., 1992; Hodgson, 1990), it has been evoked to take into account more realistic considerations, such as vehicle range, in the flow-refueling location problem (FRLP) (Kuby and Lim, 2005) and flow-based set-covering models (Wang, 2007, 2008; Wang and Lin, 2009). We develop a new, AFS location model, called the *multipath refueling location model* (MPRLM), in which AFV users could 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 deviation path, available between the O-D pair through which drivers can complete a trip with single/multiple-refueling stops. The model minimizes the total cost of locating AFSs while satisfying travel demands between all O-D pairs, subject to limited vehicle ranges. The MPRLM, formulated as a mixed integer linear program (MILP), is intrinsically difficult to solve. The number of decision

---

* Corresponding author. Tel.: +1 864 656 3661; fax: +1 864 656 2670.
E-mail address: yxhuang@clemson.edu (Y. Huang).

http://dx.doi.org/10.1016/j.tre.2014.10.013
1366-5545/

variables and constraints may increase exponentially with the number of deviation paths. Without an effective solution, this model is intractable even for a moderate sized problem.

Heuristic methods, especially greedy heuristics, have been demonstrated as effective solution approaches to solve flow-based location problems, including the FILM with deviation (FILM-D) (Berman et al., 1995), the FRLM (Lim and Kuby, 2010), and the deviation-flow refueling location model (DFRLM) (Kim and Kuby, 2013). Those are maximal coverage problems, for which the heuristics iterate to achieve maximal coverage of *flow*. The flow-based set covering models, on the other hand, aim to cover all O-D pairs using the minimum number of stations, which are distinct from those problems. Thus, those existing heuristics are not directly applicable.

In this study, we are primarily concerned with developing greedy heuristic approximation solutions, particularly the greedy-adding and greedy-adding with extension (combined processes of pre-selection, substitution, and solution refining) algorithms. The research efforts were concerted on designing effective node weighting schemes, considering the effects of *vehicle range* and *multiple deviation paths* on transport networks. Distinct from the heuristics for maximal coverage problems, the proposed heuristic solutions will iterate until all the O-D pairs on the network are covered. We implement the heuristics on two networks: the Sioux Falls network (Leblanc et al., 1975) which is a well-regarded test network in transportation network modeling society, and a real-life highway network based on the state of South Carolina. Compared with the exact solutions, our heuristic solutions have been demonstrated for quality solutions with substantially reduced solving times.

The remainder of the paper is organized as follows. The literature review on flow-based location models are first provided in Section 2, followed by the presentation of the MPRLM. In Section 3, we start with the literature review on greedy heuristics, justify the needs of developing new heuristics, and then propose the greedy-adding and greedy-adding with extension algorithms. The results of numerical implementations of the heuristics on the two networks are presented in Section 4. We conclude the study and outline some future work in Section 5.

2. The flow-based location models

We first provide a literature review on the flow refueling location models in Section 2.1 and then present the MPRLM in Section 2.2.

2.1. Literature review on flow based location models

The fundamental question on how to deploy the discretionary facilities relates to the well-studied facility location problems (Daskin, 1995), including the covering, center, and median problems, which all assume that there is a central planner who allocates supplies or services to satisfy demand on a spatial network. Many applications, including AFS location problems (Frade et al., 2011; Frick et al., 2007; Ip et al., 2010; Nicholas et al., 2004; Stephens-Romero et al., 2010), have treated demands as if they are located at specified nodes with cost measured by distance or travel time from these demand locations to the facilities.

However, it may be more realistic to model the demands as flows on the network if goods or services are obtained "on the way", which leads to the evolutions of flow based location models. First, the FILM or FCLM (Berman et al., 1992; Hodgson, 1990) is a maximal coverage model that entails facility locations to serve passing flows which are considered as captured if a facility is located on the flow paths. The model has been evolving to capture more realistic concerns, such as the different sized facilities (Tanaka and Furuta, 2012) and flow uncertainty (Teodorović and Šelmić, 2013). A critical issue – *limited vehicle range*, that was neglected in the FILM or FCLM was incorporated in the FRLMs (Kim and Kuby, 2005, 2012, 2013; Upchurch et al., 2009), a new set of maximal flow coverage models that consider the effects of limited vehicle ranges for undertaking long-distance trips via multi-stop refueling. Distinct from the maximal flow coverage models, a series of flow-based set-covering models were developed to locate a minimum number of AFSs while satisfying travel demands (Wang, 2007, 2008; Wang and Lin, 2009, 2013; Wang and Wang, 2010). More recently, You and Hsieh (2014) further extended the model to consider heterogeneous types of AFVs and fueling capacities. A comprehensive review on the flow-based facility location problems is referred to (Farahani et al., 2012; Zeng et al., 2010). Both the maximal coverage and set-covering models were recently generalized in (Mirhassani and Ebrazi, 2013; Wen et al., 2013).

All the models were formulated based on a general assumption that drivers would only consider a shortest distance/time path between origins and destinations. Due to the sparse distribution of AFSs on networks, AFV users, however, may be willing to take a slightly longer path (i.e., a *deviation path*) to ensure that they can refuel their vehicles en route, particularly for long-distance trips. This alternate routing consideration is realistic as drivers can now use available mobile map applications (e.g., Google Map®) to familiarize themselves with the transportation network. Building upon the Berman et al. (1995)'s deviation assumption in the FILM-D, Kim and Kuby (2012) formulated the DFRLM which extends the FRLM to maximize the total flows covered via at most one path (including deviation paths) for each O-D pair which contributes most to the objective.

As seen in the literature, both maximal coverage and minimum cost are possible objectives for different purposes. The maximal-coverage models provide budget-constrained location solutions which however do not intend to satisfy all demand. In contrast, minimum-cost models satisfy all demands, which can be used to provide cost assessment of long-term strategic plans of AFS placements. The major differences between these two types of models are summarized in Table 1.