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Stochastic traffic assignment of mixed electric vehicle and gasoline vehicle flow with path distance constraints

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Abstract

This paper addresses a general stochastic user equilibrium (SUE) traffic assignment problem (TAP) for transport networks with electric vehicles (EV), where EV paths are restricted by the EV driving range limits. A minimization model for path-constrained SUE is first proposed as an extension of path-constrained deterministic user equilibrium (DUE) TAP, which also extends the existing general SUE models with link-based constraints to path-based constraints. The resulting SUE model and solution algorithm can be used for other conditions with similar path-based constraints. The equilibrium conditions reveal that any path cost in the network is the sum of corresponding link costs and a path specific out-of-range penalty term, while path out-of-range term should equal to zero to ensure feasible flows. We develop a modified method of successive averages (MSA) with a predetermined step size sequence where both multinomial logit and multinomial probit based loading procedure are applied to solve the TAP. The suggested methods incorporate K-shortest paths algorithm to generate the path set on a need basis. Finally, two numerical examples are presented to verify the proposed model and solution algorithms.

Keywords: Traffic assignment; stochastic user equilibrium; path distance constraints; K-shortest path algorithm; Multinomial Logit; Multinomial Probit

1. Introduction

Carbon-based emissions and greenhouse gases (GHG) are critical global issues as addressed by the Kyoto Protocol in 1998 (U.S. Envirionmental Protection Agency, 2006). The transport sector is a significant contributor to

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GHG emissions in most countries, comprising 23% (worldwide) of CO2 emissions from fossil fuel combustion in 2005 while automobile transport is the principal CO2 production source. From the energy safety point of view, the transport sector as a whole is 98% dependent on fossil oil which is also exceedingly affected by changes in energy resources (OECD-ITF Joint Transport Research Centre, 2008). So changes to the current energy structure in transport sector are in urgent need.

Alternative fuels are addressed as a new fuel choice to reduce GHG emissions and electric vehicles (EV)are believed to be a sustainable solution (OECD-ITF Joint Transport Research Centre, 2008). Governments and automotive companies have recognized the value of these vehicles in helping the environment and are encouraging the ownership of EV through economic incentives (Hacker et al., 2009). It is mentioned that one million plug-in hybrid and electric vehicles will be on the road by 2015 in United States to reduce greenhouse gas emission and dependence on oil (Saber and Venayagamoorthy, 2009). According to Electric Drive Transportation Association, the plug-in electric vehicles (PEV) in US has exceeded 190,000 between January of 2011 and Mach of 2014 (Ghamami et al., 2014).

Although many cities are planning construction and expansion of charging infrastructures for EV, it is likely that in the foreseeable future EV commuters will need to charge their vehicles at home most of the time (Morrow et al., 2008). It is obvious that the driving range limit inevitably adds a certain level of restrictions to EV drivers' travel behaviors, at least in a long future period prior to the coverage of recharging infrastructures reaching a sufficient level (Jiang et al., 2013). EV companies are trying to overcome this limited range requirement with fast charging stations, where a vehicle can be charged in only a few minutes to near full capacity. Besides being much more costly to operate rapid recharge stations, the vehicles still take more time to recharge than a standard gasoline vehicle would take to refuel (Botsford and Szczepanek, 2009).

However, the widespread adoption of PEV calls for fundamental changes to the existing network flow modelling tools for properly capturing changed behaviors and induced constraints in forecasting travel demands and evaluating transportation development plans (Jiang et al., 2013).

In order to take into consideration of driving range limit and insufficient charging facility status in traffic assignment, Jiang et al. (2012) proposed an approach to restrict flow of a path to zero if the path distance is greater than the driving range limit of EV. They employed a path travel time function that is the sum of the corresponding link cost such as the Bureau Public Road (BPR) function and showed the Lagrangian multiplier of its optimal solution stands for the unit out-of-range travel distance cost. Classic Frank-Wolfe algorithm with a constrained shortest path algorithm as its subroutine can be applied to solve this problem.

The deterministic user equilibrium (DUE) condition characterizes route choice behavior where users have perfect traffic network information and always choose the shortest path accurately. A convex minimization model for DUE conditions can be built by adding path distance constraints into the Beckmann's conventional DUE model. A more realistic and general situation is that travel times are random variables or travel times are perceived by travellers in imperfect, stochastic manner. Although the stochastic user equilibrium (SUE) principle plays a more realistic role than DUE principle in addressing road user's route choice behavior, the SUE traffic assignment problem with path- distance constraints has received little attention. To be consistent with the generalized DUE with path distance constraints, the SUE traffic assignment model with generalized path travel times are referred to as generalized SUE traffic assignment with path distance constraints. A milestone in formulating SUE conditions is Daganzo's unconstrained minimization model (Daganzo, 1982) of conventional SUE conditions, which can lead to a convergent algorithm for solving the general SUE traffic assignment problem. However, adding side constraints (e.g. link capacity constraints) into Daganzo's model cannot yield solution fulfilling generalized SUE conditions.

1.1. Literature Review

It is well known that the standard TAP under DUE can be solved efficiently with a Frank-Wolfe type algorithm