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Integrating a simplified emission estimation model and mesoscopic dynamic traffic simulator to efficiently evaluate emission impacts of traffic management strategies

Xuesong Zhou [a,*], Shams Tanvir [b], Hao Lei [c], Jeffrey Taylor [c], Bin Liu [b], Nagui M. Rouphail [d], H. Christopher Frey [b]

[a] *School of Sustainable Engineering and the Built Environment, Arizona State University, USA*
[b] *Department of Civil, Construction and Environmental Engineering, North Carolina State University, USA*
[c] *Department of Civil and Environmental Engineering, University of Utah, USA*
[d] *Institute for Transportation Research and Education (ITRE), Department of Civil, Construction and Environmental Engineering, North Carolina State University, USA*

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ABSTRACT

This paper presents a computationally efficient and theoretically rigorous dynamic traffic assignment (DTA) model and its solution algorithm for a number of emerging emissions and fuel consumption related applications that require both effective microscopic and macroscopic traffic stream representations. The proposed model embeds a consistent cross-resolution traffic state representation based on Newell's simplified kinematic wave and linear car following models. Tightly coupled with a computationally efficient emission estimation package MOVES Lite, a mesoscopic simulation-based dynamic network loading framework DTALite is adapted to evaluate traffic dynamics and vehicle emission/fuel consumption impact of different traffic management strategies.

Introduction

The continuous growth of travel demand leads to increasing energy consumption and greenhouse gas (GHG) emissions. In order to reduce greenhouse gas emissions and fuel consumption, several transportation agencies have adopted, or are considering adopting, a number of new active traffic management strategies. Many organizations are encouraging public transit, carpooling or non-motorized transportation, while others may also consider integrated corridor management systems with optimized traffic signal controls to mitigate congestion and improve air quality. Through the interplay between changing traveler demand and traffic network conditions, these policies are expected to address increasing congestion and environmental issues. A systematic evaluation of advanced traffic management strategies requires a set of effective transportation simulation and modeling tools which can efficiently assess operational performance and emission impacts at different spatial and temporal resolutions (e.g., network, corridor and segment levels; second-by-second, peak hours, 24-h, multiple days).

* Corresponding author.
E-mail addresses: xuesong.zhou@asu.edu (X. Zhou), stanvir@ncsu.edu (S. Tanvir), hlei@eng.utah.edu (H. Lei), jeff.d.taylor@utah.edu (J. Taylor), bliu7@ncsu.edu (B. Liu), rouphail@eos.ncsu.edu (N.M. Rouphail), frey@ncsu.edu (H. Christopher Frey).

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To conduct project-level traffic environmental impact studies, microscopic emissions models are often adopted in transportation evaluation projects (Ahn et al., 2002; Nam et al., 2002; Stathopoulos and Noland, 2003). Microscopic traffic simulation tools have been widely used to generate vehicle emissions estimates by evaluating driving speed and acceleration characteristics/profiles on a vehicle-by-vehicle and second-by-second basis. Although a high-fidelity traffic simulator is desirable for analyzing individual movement delays and facilities with complex geometric configurations, microscopic simulation can be computationally intensive and typically requires a wide range of detailed geometric data and driving behavior parameters, which can be difficult to calibrate, especially for the purpose of producing high fidelity emissions estimates.

Alternatively, many organizations have utilized post-processing techniques for estimating vehicle emissions from their static traffic assignment model results. Recognizing that conventional static traffic assignment models are not sensitive to the dynamic interaction of vehicular travel demand and time-dependent road conditions, planning practitioners have increasingly recognized the capabilities of mesoscopic Dynamic Traffic Assignment (DTA) models. However, many planners and engineers are still concerned that DTA tools, typically based on fine-grained network representations, are computationally intensive and lack model components/details necessary for accurately representing high-fidelity traffic dynamics.

In recent years, a multi-resolution modeling approach has been exploited by many practitioners. Typically, this approach aims to integrate many existing simulation tools in a loosely coupled software platform that can provide multiple levels of modeling detail regarding network dynamics and traveler/driver choices. For example, in a subarea study, one can simply extract vehicle path data from a (macroscopic/mesoscopic) DTA tool for use in a microscopic simulation model (e.g., VISSIM, Paramics, TRANSIMS) to generate second-by-second vehicle speed and acceleration outputs for microscopic emissions or mobility-related analysis.

In the above multi-resolution modeling system, mesoscopic DTA has a relatively low simulation resolution (e.g., 6 s per interval), while microscopic traffic simulators typically use 0.1 s as the simulation interval. To ensure theoretical convergence of the integrated models, it is necessary to use multiple iterations between different simulation/assignment components to determine the mobility and emission impact of high-level demand and traveler behaviors. However, internal discrepancies between different modeling resolutions make tight interconnections and consistent modeling extremely challenging.

In this paper, we propose an alternative approach based on post-processing for a lightweight mesoscopic traffic simulation model with an integrated microscopic emissions estimation model. Given a set of link-based mesoscopic traffic simulation results from multi-day DTA (e.g., using a time resolution of 6 s), this study uses a post-processing procedure to generate second-by-second detailed vehicle trajectories based on a simple linear car-following model (LCF) proposed by Newell (1999, 2002). It should be remarked that, a simplified linear car-following model has been also proposed and developed by Mahut (2001), who further embedded the related discrete flow traffic model in an efficient event-based vehicular simulator. In our proposed modeling framework, the second-by-second data is then used to estimate emissions using a simplified MOVES model (Frey and Liu, 2013).

The remaining sections of this paper are organized as follows. First, we describe the simplified MOVES model, MOVES Lite, and its data requirements in the second section. Third section describes the system architecture of integrating the traffic simulation model with the microscopic emission model, and offers details on the cross-resolution traffic flow models used to efficiently reconstruct the vehicle trajectory on each link. Fourth section offers numerical experiments testing computational efficiency and vehicle emission sensitivity to demand/capacity changes. In particular, we also discuss the challenges in applying Newell's simplified car following model for trajectory-based emission estimation.

Overview of a simplified moves emission model

MOVES (Motor Vehicle Emission Simulator) is an air pollution emissions estimation software designed by the US Environmental Protection Agency (US EPA). The state-of-the art emission model implemented in MOVES is able to estimate emissions from a wide range of on-road vehicles (e.g., cars, trucks, motorcycles and buses). The release of MOVES 2010 officially replaced the previously widely-adopted emission model, MOBILE 6.2 (USEPA, 2012).

In this modal-based estimation approach, vehicle emission rates are described as a combination of two factors affecting emissions – the emission source and the vehicle operating mode. Emission sources are categorized in bins by vehicle characteristics such as vehicle types, fuel/engine technologies, ages, model years, engine size, and average weight fraction. Operating modes refer to vehicle operating conditions and are categorized in bins of second-by-second vehicle activity characteristics, represented as Vehicle Specific Power (VSP). VSP is a function of vehicle speed, road grade, and acceleration which accounts for kinetic energy, rolling resistance, aerodynamic drag, and gravity (Jimenez-Palacios, 1998). The equation to calculate VSP adopted in MOVES (USEPA, 2012) is expressed as

$$\mathrm{VSP} = (A/M) \times v + (B/M) \times v^2 + (C/M) \times v^3 + (a + \sin(\phi)) \times v \tag{1}$$

where A (metric ton), B (metric ton/(m/s)) and C (metric ton/(m/s)^2) refer to the rolling term, rotating term and drag term, respectively; M = vehicle mass (metric ton); v = vehicle speed (m/s); a = vehicle acceleration (m/s^2); ϕ = road grade. The parameters for Eq. (1) are provided for each vehicle type. For example, a typical vehicle mass for a passenger car is 1.4788 metric tons and 7.64159 metric tons for a single unit short-haul truck. The calculated VSPs are then categorized by speed and VSP ranges. A detailed classification is defined in Table 1.