Transportation Research Part C 40 (2014) 201–214

Contents lists available at ScienceDirect

Transportation Research Part C

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

A network wide simulation strategy of alternative fuel vehicles

Parth Bhavsar [a,*], Mashrur Chowdhury [b,1], Yiming He [c,2], Mizanur Rahman [d,3]

[a] Clemson University, Glenn Department of Civil Engineering, 123 Lowry Hall, Clemson, SC 29634, United States
[b] Clemson University, Glenn Department of Civil Engineering, 216 Lowry Hall, Clemson, SC 29634, United States
[c] Mathworks Inc., 3 Apple Hill Dr., Natick, MA 01706, United States
[d] Clemson University, Glenn Department of Civil Engineering, 18 Lowry Hall, Clemson, SC 29634, United States

ARTICLE INFO

Article history:
Received 15 May 2013
Received in revised form 1 December 2013
Accepted 31 December 2013

Keywords:
Alternative fuel vehicles
Plug-in hybrid vehicles
Electric vehicles
Integrated simulator
Routing
Traffic simulation
Network wide simulation

ABSTRACT

This paper presents an integrated simulator "CUIntegration" to evaluate routing strategies based on energy and/or traffic measures of effectiveness for any Alternative Fuel Vehicles (AFVs). The CUIntegration can integrate vehicle models of conventional vehicles as well as AFVs developed with MATLAB-Simulink, and a roadway network model developed with traffic microscopic simulation software VISSIM. The architecture of this simulator is discussed in this paper along with a case study in which the simulator was utilized for evaluating a routing strategy for Plug-in Hybrid Electric Vehicles (PHEVs) and Electric Vehicles (EVs). The authors developed a route optimization algorithm to guide an AFV based on that AFV driver's choice, which included; finding a route with minimum (1) travel time, (2) energy consumption or (3) a combination of both. The Application Programming Interface (API) was developed using Visual Basic to simulate the vehicle models/algorithms developed in MATLAB and direct vehicles in a roadway network model developed in VISSIM accordingly. The case study included a section of Interstate 83 in Baltimore, Maryland, which was modeled, calibrated and validated. The authors considered a worst-case scenario with an incident on the main route blocking all lanes for 30 min. The PHEVs and EVs were represented by integrating the MATLAB-Simulink vehicle models with the traffic simulator. The CUIntegration successfully combined vehicle models with a roadway traffic network model to support a routing strategy for PHEVs and EVs. Simulation experiments with CUIntegration revealed that routing of PHEVs resulted in cost savings of about 29% when optimized for the energy consumption, and for the same optimization objective, routing of EVs resulted in about 64% savings.

1. Introduction

In response to ever increasing urgency of developing strategies to combat global warming and reduce US dependence on overseas energy stocks, automobile manufacturers have built fleets of variously powered Alternative Fuel Vehicles (AFVs), such as Flex Fuel Vehicles (FFVs), Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs) and Electric Vehicles (EVs). Though these vehicles hold the promise of an energy efficient future, unfortunately they cannot promise less congested highways or freeways. Further, vehicular and infrastructure technologies are evolving towards a full integration of

* Corresponding author. Tel.: +1 (404) 574 9552; fax: +1 (864) 656 2670.
E-mail addresses: parthb@clemson.edu (P. Bhavsar), mac@clemson.edu (M. Chowdhury), yimingh@clemson.edu (Y. He), mdr@clemson.edu (M. Rahman).
[1] Tel.: +1 (864) 656 3313; fax: +1 (864) 656 2670.
[2] Tel.: +1 (865) 824 8065; fax: +1 (508) 647 7001.
[3] Tel.: +1 (864) 650 2926; fax: +1 (864) 656 2670.

0968-090X/$ - see front matter
http://dx.doi.org/10.1016/j.trc.2013.12.013

infrastructure and vehicles. These Connected Vehicle Technology (CVT) supported vehicles hold promise to solve congestion, and environment related problems. One of the systems available in these vehicles is a navigation system. With the recent development of navigation systems, traffic prediction and route information technologies are now an essential part of the modern intelligent vehicles. One of the main functionalities of any navigation system is a route guidance system, the function of which is to obtain origin and destination from the driver and find a route based on shortest distance or travel time. The focus of most available route guidance systems entails minimizing both the travel distance and travel time for the driver while ignoring driver's individual preferences regarding energy consumption and emission. With the evolving vehicle technology, a driver is not only concerned about saving travel time but also has a desire to save energy.

To summarize, the current transportation system includes conventional vehicles and AFVs that are constantly evolving and moving towards full integration with infrastructure. Further, the future transportation system will include CVT supported conventional vehicles and AFVs. The evaluation of these current and future transportation systems will require a performance evaluation tool which can model all types of vehicles including AFVs. This research focuses on developing an integrated simulator, capable of incorporating different types of vehicles, for evaluating travel and energy related impacts. In addition, an example of routing of PHEVs and EVs based on the driver's choice of (1) saving travel time, (2) saving energy, or (3) saving both is provided through the integrated simulator to demonstrate an application.

2. Related work

The first objective of this study is to develop an integrated simulator 'CUIntegration' to integrate a traffic micro simulator and a vehicle model. The second objective is to evaluate the applicability of the CUIntegration in the development of a routing strategy for PHEVs and EVs, which considers travel time and energy consumption in the selection of the best route. The review of related work is thus divided into two sections; (i) integration of different simulation models and (ii) routing strategies.

2.1. Integration of different simulation models

The concept of integrating two or more models to achieve higher accuracy without compromising the stochastic nature of the real-world transportation system has been applied to different fields of research, such as emission modeling and evacuation modeling. In case of emissions modeling, the emission rate per vehicle changes with every movement of a vehicle and depends on different road and traffic flow conditions, changes that are simulated by integrating traffic micro simulation with emission models. Rakha and Ahn combined the traffic micro assignment and simulation model INTEGRATION with the Virginia Tech Microscopic energy and emission model (VT-micro) to estimate vehicle emissions (Rakha and Ahn, 2004). To develop the VT-micro model, the authors utilized a chassis dynamometer at Oak Ridge National Lab (ORNL) and experimented with various combinations of speed and acceleration levels (Rakha and Ahn, 2004). The VT-micro model was then added as a subroutine within the INTEGRATION (Rakha and Ahn, 2004). Another example is the SIMulation of Traffic induced Air Pollution (SIMTRAP) project which represents an integrated simulation platform for traffic related air pollution (Schmidt and Schafer, 1998). For the SIMTRAP project, researchers integrated mesoscopic traffic flow model with air pollution model using remote High Performance Computing Network (HPCN) and tested the system in different European cities (Schmidt and Schafer, 1998). The Air pollution model Dynamic Model for Smog analysis (DYMOS) and a mesoscopic traffic simulation tool Dynamic Net Model (DYNEMO) were the two main components integrated in the SIMTRAP project. DYMOS is a simulation system that contains a air pollutant transport model and a air-chemistry model (Schmidt and Schafer, 1998; Heimann, 1985; Gery et al., 1988). The traffic simulation model DYNEMO was developed as a mesoscopic model in which the mean speed and traffic density relationship is used as an input for each section of the network (Schwerdtfeger, 1984). This model was parallelized for faster processing. The DYNEMO requires traffic flow parameters as well as emission parameters as input to the model and provides grid emissions of different pollutants (such as Oxides of Nitrogen (NO_x) and Carbon monoxide (CO)) per simulation interval. These output data can then be fed into the DYMOS along with other weather related data such as air and water temperature, wind velocity and direction, to get output such as mean concentrations of air temperature (Schmidt and Schafer, 1998).

Integrated simulators have also been developed for evacuation modeling and emergency management. De Silva and Eglese (2000) developed a decision support system by combining the Configurable Emergency Management and Planning Simulator (CEMPS) with the Geographical Information System (GIS) software ARC-GIS. The CEMPS model was developed by Pidd et al. (1996) for emergency planners to help them design contingency plans for mass evacuations from disaster areas. Dixit and Wolshon (2011) predicted the hurricane evacuation demand and evacuation destination choice using two different logit models and used these data as an input to Transportation Analysis SIMulation System (TRANSIMS) to simulate the evacuation traffic for the city of New Orleans. The authors were able to predict the traffic patterns observed during the Hurricane Katrina evacuation.

With the recent development in the field of communication and move towards Vehicle Infrastructure Integration (VII), several researchers have developed an integrated simulator to simulate vehicle-to-vehicle or vehicle-to-infrastructure communication. Wegener et al. (2008) integrated a network simulator, ns-2, with the open source traffic simulator, SUMO (Simulation of Urban MObility), to evaluate Vehicle Ad-Hoc Networks (VANET). The authors developed a Traffic Control Interface (TraCI) in which SUMO and ns-2 communicated over a Transmission Control Protocol (TCP) connection to simulate