Delft University of Technology

Delft Center for Systems and Control

Technical report 09-017

Integrated macroscopic traffic flow and emission model based on METANET and VT-micro*

S.K. Zegeye, B. De Schutter, J. Hellendoorn, and E.A. Breunesse

If you want to cite this report, please use the following reference instead:
S.K. Zegeye, B. De Schutter, J. Hellendoorn, and E.A. Breunesse, "Integrated macroscopic traffic flow and emission model based on METANET and VT-micro," in *Models and Technologies for Intelligent Transportation Systems* (Proceedings of the International Conference on Models and Technologies for Intelligent Transportation Systems, Rome, Italy, June 2009) (G. Fusco, ed.), Rome, Italy: Aracne Editrice, ISBN 978-88-548-3025-7, pp. 86–89, 2010.

Delft Center for Systems and Control
Delft University of Technology
Mekelweg 2, 2628 CD Delft
The Netherlands
phone: +31-15-278.24.73 (secretary)
URL: https://www.dcsc.tudelft.nl

Integrated macroscopic traffic flow and emission model based on METANET and VT-micro

S.K. Zegeye*, B. De Schutter*, J. Hellendoorn*, E.A. Breunesse†

Abstract

We present a framework to integrate macroscopic traffic flow models with microscopic emission and fuel consumption models. Since macroscopic traffic flow models do not provide the acceleration as an output, while microscopic emission and fuel consumption models require both the instantaneous speeds and accelerations as input, we describe how to generate these variables. In particular, we consider the macroscopic traffic flow model METANET and the microscopic emission and fuel consumption model VT-micro. In order to integrate these models, we propose a method to generate from the METANET model the spatial and temporal speed-accelerations pairs and the number of vehicles subject to them, which are required as input by VT-micro. The integration of the models results in a new macroscopic emission and fuel consumption model called the VT-macro model.

1 Introduction

Emission and fuel consumption models can be average-speed-based or dynamic.

Average-speed-based models estimate the emissions and fuel consumption using the trip-based average speed of the traffic flow. However, such models do not capture the variation of the speed of the traffic flow (Ahn and Rakha, 2008). Hence, estimates using such models have less accuracy. To reduce the estimation error, such models can also be used with local speeds (i.e., the average speed at every sampling time step). This approach can capture some of the variation of the speed. Since the input for average-speed-based emission and fuel consumption models is the average speed of traffic flow, such models are used with macroscopic traffic flow models, i.e., traffic flow models that use aggregate or average traffic.

On the other hand, dynamic emission or fuel consumption models estimate the emissions or fuel consumption based on the instantaneous traffic variables of individual vehicles. These models thus require the second-by-second speed and acceleration of individual vehicles (Heywood, 1988). This implies that such models are typically used with microscopic traffic flow models,

*Delft Center for Systems and Control, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands. Email: s.k.zegeye,j.hellendoorn@tudelft.nl, b@deschutter.info

†Shell Nederland B.V., Carl van Bylandtlaan 30, 2596 HR The Hague, The Netherlands. Email: ewald.breunesse@shell.com

where the traffic flow is modeled by considering the behavior of individual vehicles. As a consequence, microscopic emission and fuel consumption models yield quite accurate estimates of emissions and fuel consumption (Ahn and Rakha, 2008). However, microscopic traffic flow models may require large computation times, in particular for large-scale networks. Therefore, such models are not suitable for on-line use.

To get a balanced trade-off between computational burden and accuracy one may want to combine macroscopic traffic flow modes with microscopic emission and fuel consumption models. Therefore, we propose a way to integrate these two models so that the macroscopic variables can be used to produce estimates of the emissions and fuel consumption. The integration results in a complete traffic flow, emission, and fuel consumption model that also incorporates estimates of emissions and fuel consumption taking the dynamics of the traffic flow into account. We consider in particular the integration of the METANET traffic flow model and the VT-micro emissions and fuel consumption model. However, the proposed approach is generic and can also be applied to other models.

2 Traffic Flow and Emission Models

METANET (Messmer and Papageorgiou, 1990) is a macroscopic traffic model that describes the average behavior of vehicles in a traffic network. In METANET a link (a freeway with homogeneous layout characteristics) is divided into a number of segments where the traffic behavior is described by a system of discrete-time dynamic equations that describe the relationship and evolution of the average density ρ, flow q, and space-mean speed v of the traffic flow in each segment. METANET can also include lane drops, merging lanes, on-ramps, and so on (Messmer and Papageorgiou, 1990).

VT-micro (Ahn et al., 1999) is a microscopic dynamic emission and fuel consumption model that yields emissions and fuel consumption of one individual vehicle using second-by-second speed and acceleration. The model has the form $J_x(k) = \exp\left(\tilde{v}^{\mathrm{T}}(k) P_x \tilde{a}(k)\right)$ where J_x is the estimate of $x \in \{$CO emission, NO emission, HC emission, fuel consumption$\}$, with $\tilde{v}(k) = \left[1\ v(k)\ v^2(k)\ v^3(k)\right]^{\mathrm{T}}$ the speed vector at time step k, $\tilde{a}(k) = \left[1\ a(k)\ a^2(k)\ a^3(k)\right]^{\mathrm{T}}$ the acceleration vector, and P_x the model parameter matrix for the variable x. The values of the entries of P_x can be found in (Ahn et al., 1999).

3 Integration of the Models

To integrate the two models, speed-acceleration pairs accompanied by the number of vehicles have to be generated from the METANET traffic flow model. Since METANET is discrete in both space and time, there are two acceleration components involved in the model (see Figure 1). The first is the "temporal" acceleration of the vehicle flow within a given segment. The second component is the "spatial" acceleration of the vehicles flowing from one segment to another in one simulation time step.

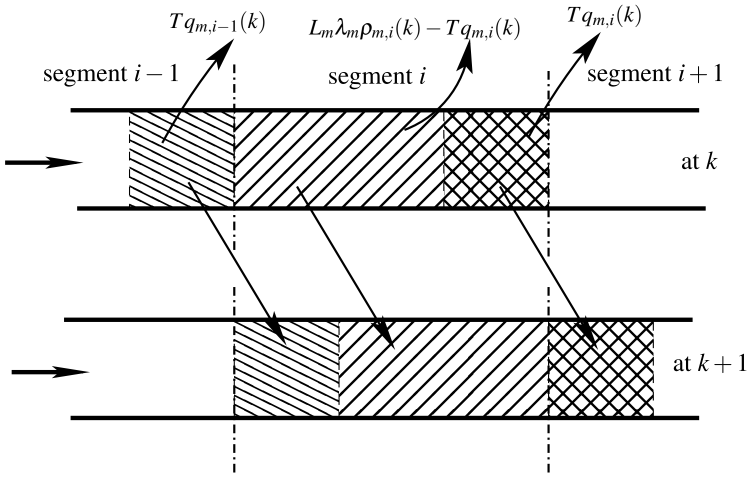

Figure 1: *Illustration of the evolution of the traffic flow in METANET.*

The temporal acceleration of vehicles in a segment i of link m is given by $a^{\text{temp}}_{m,i}(k) = \big(v_{m,i}(k+1) - v_{m,i}(k)\big)/T$ where T is the simulation time step. The number of vehicles that are subject to this acceleration is equal to $n^{\text{temp}}_{m,i}(k) = L_m\lambda_m\rho_{m,i}(K) - Tq_{m,i}(k)$ where L_m is the length of the segments in link m and λ_m is the number of lanes of link m.

From time step k to $k+1$ the spatial acceleration of the vehicles leaving segment $i-1$ and going to segment i of link m is equal to (see also Figure 1): $a^{\text{spat}}_{m,i} = \big(v_{m,i}(k+1) - v_{m,i-}(k)\big)/T$, and the corresponding number of vehicles is $n^{\text{spat}}_{m,i}(k) = -Tq_{m,i-1}(k)$.

Similar equations can be derived for on-ramps, off-ramps, and junctions.

Now we use these spatial and temporal speed-acceleration pairs to determine respectively the spatial and temporal emission or fuel consumption $J^{\text{temp}}_{m,i}(k)$ and $J^{\text{spat}}_{m,i}(k)$ using the VT-micro model. This then yields the total emission or fuel consumption $J^{\text{tot}}_{m,i}(k) = n^{\text{temp}}_{m,i}(k)J^{\text{temp}}_{m,i}(k) + n^{\text{spat}}_{m,i}(k)J^{\text{spat}}_{m,i}(k)$ for segment i of link m at time step k. We call this new model the "VT-macro" emission and fuel consumption model.

4 Conclusion

We have presented a general approach that can be used to integrate macroscopic traffic flow models with microscopic emission and fuel consumption models. In particular, we have integrated the macroscopic traffic flow model METANET with the microscopic emission and fuel consumption model VT-micro, which resulted in a macroscopic dynamic emission and fuel consumption model, called VT-macro. In our future work, we will compare and assess the performance of the VT-macro model and use these integrated models in a model-based traffic control framework to reduce fuel consumption and emissions.

Acknowledgments

Research supported by the Shell/TU Delft Sustainable Mobility program, the BSIK project "Transition towards Sustainable Mobility (TRANSUMO)", the Transport Research Center Delft, and European COST Action TU0702.

References

K. Ahn and H. Rakha. The effects of route choice decisions on vehicle energy consumption and emissions. *Transportation Research Part D*, 13(3):151–167, May 2008.

K. Ahn, A. A. Trani, H. Rakha, and M. Van Aerde. Microscopic fuel consumption and emission models. In *Proceedings of the 78th Annual Meeting of the Transportation Research Board*, Washington DC, USA, January 1999. CD-ROM.

J. Heywood. *Internal Combustion Engine Fundamentals*. McGraw-Hill, New York, 1988.

A. Messmer and M. Papageorgiou. METANET: A macroscopic simulation program for motorway networks. *Traffic Engineering and Control*, 31(9):466–470, 1990.