Submicroscopic framework to model mixed highway traffic

Mullakkal-Babu, Freddy; Wang, Meng; van Arem, Bart; Happee, Riender

DOI
10.2760/722699

Publication date
2018

Document Version
Final published version

Published in
2nd Symposium on Management of Future Motorway and Urban Traffic Systems (MFTS 2018)

European Commission

JRC CONFERENCE AND WORKSHOP REPORTS

2nd Symposium on Management of Future motorway and urban Traffic Systems (MFTS 2018)

Booklet of abstracts
Ispra, 11-12 June 2018

Editors:
Ciuffo, B., Alonso Raposo, M.,
Mourtzouchou, A.Belov, A.,
Makridis, M., Mattas, K., Mogno, C.

2018

MFTS 2018

11-12 June 2018, Ispra (Italy)

Joint Research Centre

EUR 29248 EN

Contact information
Name: Biagio Ciuffo
Address: European Commission, Joint Research Centre, Via E. Fermi 2749, I-21027, Ispra (VA), Italy
Email: maria.alonso-raposo@ec.europa.eu
Tel.: +39 0332 789732

JRC Science Hub
https://ec.europa.eu/jrc

JRC112141

EUR 29248 EN

PDF	ISBN 978-92-79-87680-6	ISSN 1831-9424	doi:10.2760/722699
Print	ISBN 978-92-79-87679-0	ISSN 1018-5593	doi:10.2760/794584

Luxembourg: Publications Office of the European Union, 2018

How to cite this report: Ciuffo, B., Alonso Raposo, M., Mourtzouchou, A., Belov, A., Makridis, M., Mattas, K., Mogno, C., *2nd Symposium on Management of Future motorway and urban Traffic Systems (MFTS 2018) - Booklet of abstracts - Ispra, 11-12 June 2018*, EUR 29248 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-87680-6, doi:10.2760/722699, JRC112141

3.2 Parallel Session 3a - Modelling

3.2.1 Submicroscopic framework to model mixed highway traffic

F. A. MULLAKKAL-BABU[a], M. WANG[a], B. VAN AREM[a], R. HAPPEE[a,b]

[a] *Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, TU Delft*

[b] *Department of Cognitive Robotics, Faculty of Mechanical, Maritime & Materials Engineering, TU Delft*

Introduction

The task of driving a vehicle can be hierarchically divided into three coupled levels of subtasks: strategic level (route choice); tactical level (manoeuvre planning) and operational level (control input to accomplish the manoeuvres)[1]. These subtasks are concurrently executed within the hierarchical framework to realise the vehicle trajectory. Microscopic traffic models have conventionally been used to simulate the movement of individual vehicles in traffic, and to deduce the collective performance of the traffic flow comprising several such vehicles. The microscopic models have enabled us to better understand the individual driver behaviour and effectively derive phenomenological insights; however, their representation of the driving task has been widely criticised to be over simplistic. Firstly, they depict the tactical and operational subtasks as open-loop processes; whereas in reality, there exists a closed loop interaction (to and fro information exchange) between these subtasks. Therefore they cannot model the dynamic modification of the tactical plan, such as abortion of a lane change manoeuvre. Secondly, they represent the vehicle as a point mass unit that can perfectly track the reference signal subject to static kinematic constraints. However, in reality the realised trajectory may differ from the desired trajectory due to the dynamic behaviour of the vehicle operation and due to the delays involved in cyber-physical systems. Consequently, the simulated vehicle trajectories are often unrealistic such as an instantaneous lateral jump representing a vehicle lane change. Finally, the lack of an explicit and realistic vehicle model make the microscopic models inadequate to study the performance and traceability of Driving Automation Systems (DASs) at an operational level. For instance they cannot model the in-lane lateral movement of a vehicle operating on an Automated Lane Keeping System, and they cannot accurately reproduce the trajectory of a vehicle manoeuvring on an Automated Lane Change System. Sub microscopic simulation models have been proposed to overcome these limitations; however, the existing submicroscopic simulation models solely capture the longitudinal vehicle movement [2],[7],[8] and leave out the lateral manoeuvres. To summarise, the over simplistic representation of the vehicle movement in existing microscopic models compromises their predictive validity. This presents a compelling case for the extension of the microscopic traffic modelling framework to the submicroscopic level, which can provide a high-detail description of the vehicle trajectory taking into account vehicle dynamics, driver behaviour of manually driven vehicles and control strategies of automated vehicles in highway conditions.

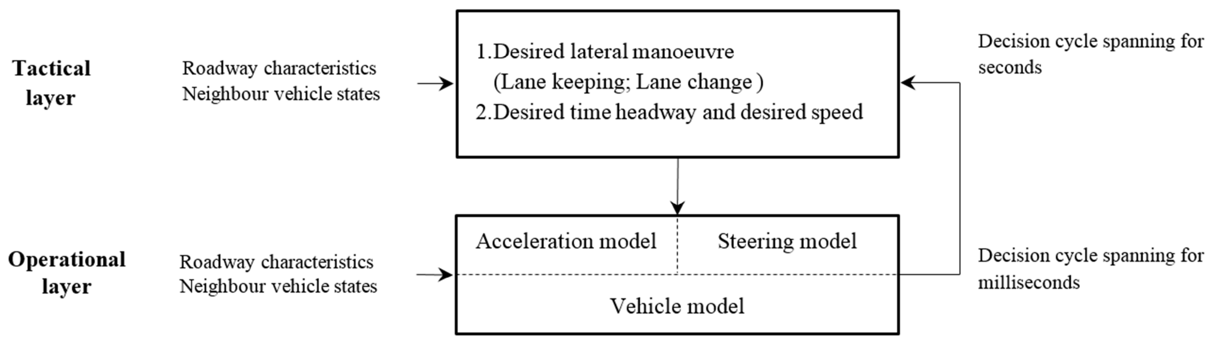
Model framework

This work aims to incorporate the lateral and the longitudinal manoeuvres into the traffic modelling framework and thereby formulate a submicroscopic traffic model. Figure 1 shows the hierarchical modelling framework with an upper tactical decisions layer, and a lower operational actions layer. However certain tactical decisions, such as a lane change, might be altered during the operational actions, and we therefore include a two-directional information flow between the operational and the tactical layer. The submicroscopic simulation model is implemented in MATLAB with an update time step of 0.1s.

Tactical layer

At the tactical layer we build upon the lane change decision model-Lane change Model with Relaxation and Synchronisation (LMRS)[5]. We extend LMRS to include two elementary lateral manoeuvres that are empirically observed among HDVs: Lane-keeping and Lane Change. The lane change manoeuvre is modelled as a multi-step process requiring feedback from the operational layer, so as to decide whether to proceed or abort a lane change. The time headway to be maintained w.r.t the preceding vehicle and the desired speed are regarded as the longitudinal tactical decisions.

Figure 21. The framework of submicroscopic simulation



Source: Own elaborations.

Operational driver model and vehicle dynamics

The tactical decisions are operationalised via two loosely coupled operational decision models: an acceleration model and a steering model. They jointly generate a reference trajectory, which is the time series of desired longitudinal acceleration (u_x) and desired front steering angle (θ_f), to be followed by the vehicle. Thereafter the reference trajectory is passed on to the vehicle model that updates the vehicle state: longitudinal position (*x*), lateral position (*y*) and yaw angle (ψ). The vehicle model is chosen so as to describe the vehicle movement with a level of detail high enough to reproduce the collective traffic impact and low enough to avoid irrelevant system state information. In the longitudinal dimension, the reference acceleration is executed with a delay (perception time) and implemented with a lag: response time, τ. However, the actual acceleration (a_x) is constrained by limits of tyre force friction and powertrain. The longitudinal vehicle position (x) and velocity (v_x) and actual longitudinal acceleration (a_x) is manipulated by control input – desired acceleration (u_x) based on the following third order model

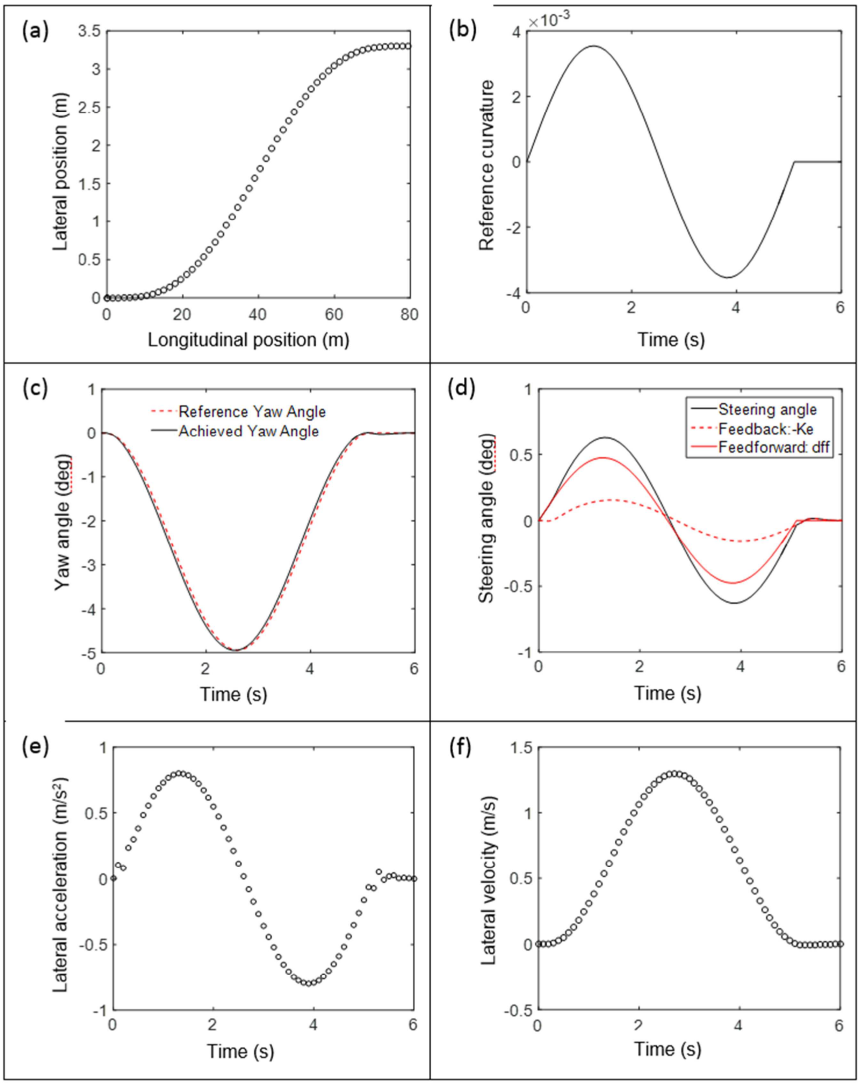
$$\frac{d}{dt}\begin{Bmatrix} x \\ \dot{x} \\ \ddot{x} \end{Bmatrix} = \begin{Bmatrix} v_x \\ a_x \\ \dfrac{a_x - u_x}{\tau} \end{Bmatrix} \tag{1}$$

In the lateral dimension, we use the classical dynamic bicycle model [6] assuming a linear relation between lateral tyre force and slip angle, which is reasonable for the typical highway conditions [7]. Accordingly, the lateral vehicle position (y) and orientation (ψ) is manipulated by front steering (θ_f) as shown in equation 2.

$$\frac{d}{dt}\begin{Bmatrix} y \\ \dot{y} \\ \psi \\ \dot{\psi} \end{Bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & -\dfrac{2C_{\alpha f}+2C_{\alpha r}}{mv_x} & 0 & -V_x-\dfrac{2l_f C_{\alpha f}-2l_r C_{\alpha r}}{mv_x} \\ 0 & 0 & 0 & 1 \\ 0 & -\dfrac{2l_f C_{\alpha f}-2l_r C_{\alpha r}}{I_Z v_x} & 0 & -\dfrac{2l_f^2 C_{\alpha f}+2l_r^2 C_{\alpha r}}{I_Z v_x} \end{bmatrix}\begin{Bmatrix} y \\ \dot{y} \\ \psi \\ \dot{\psi} \end{Bmatrix} + \begin{Bmatrix} 0 \\ \dfrac{2C_{\alpha f}}{m} \\ 0 \\ \dfrac{2l_f C_{\alpha f}}{I_Z} \end{Bmatrix}\theta_f \qquad (2)$$

where l_f, l_r represents the distance of point front and rear tire from the Centre of Gravity; m denotes the physical mass of the vehicle; $C_{\alpha f}, C_{\alpha r}$ denotes the cornering stiffness of front and rear tire, I_Z denotes the moment of Inertia about the z-axis.

Figure 22. An example submicroscopic simulation of an automated lane change manoeuvre with: duration 5.1 s; lateral displacement 3.31m; average longitudinal velocity 15 m/s; reference LC trajectory is based on sinusoidal lateral acceleration; and the steering signal is generated by the lower level controller (combining state feedback and feedforward term). (a) simulated trajectory, (b) curvature of the reference trajectory, (c) reference and achieved yaw angle, (d) steering input and corresponding state feedback and feedforward, (e) vehicle lateral acceleration profile, (f) vehicle lateral velocity profile



Source: Own elaborations.

Case study

An example simulation of automated lane change manoeuvre is shown in Figure 2. Similarly, we deploy the proposed submicroscopic simulation framework to evaluate few representative automated lane change control strategies. The experiment scenario is a straight 4 lane highway with a lane - drop at the downstream resulting in a 3 lane end stretch. In this experiment, the automated lane change controller performs the mandatory lane change while approaching the lane drop. The comparison is done in terms of the following measures: traceability of the reference trajectories; the comfort of the manoeuvre; safety of the manoeuvre; impact on the neighbouring vehicles; and efficiency of the overall traffic flow.

Summary

We proposed a hierarchical submicroscopic simulation framework in which the lower operational layer consists of a separate driver behavioural and a vehicle model. In comparison to the conventional traffic models, the proposed framework can simulate the vehicle trajectory with a higher level of detail and better mimic the functioning of DAS controllers.

References

[1] J. Michon, "A critical view of driver behavior models: what do we know, what should we do?," *Hum. Behav. traffic Saf.*, pp. 485–520, 1985.

[2] J. Ludmann, D. Neunzig, and M. Weilkes, "Traffic Simulation with Consideration of Driver Models, Theory and Examples," *Veh. Syst. Dyn.*, vol. 27, no. 5–6, pp. 491–516, 1997.

[3] P. Kumar, R. Merzouki, B. Conrard, V. Coelen, and B. O. Bouamama, "Multilevel Modeling of the Traffic Dynamic," vol. 15, no. 3, pp. 1066–1082, 2014.

[4] S. P. Hoogendoorn and P. H. L. Bovy, "State-of-the-art of vehicular trafficc ow modelling," *Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit*, vol. 215, pp. 283–303, 2001.

[5] W. J. Schakel, V. L. Knoop, and B. Van Arem, "Integrated Lane Change Model with Relaxation and Synchronization," *Transp. Res. Rec.*, no. 2316, pp. 47–57, 2012.

[6] R. Rajamani, *Vehicle Dynamics and Control*, 2nd ed. New York: Springer Science & Business Media, 2011.

[7] D. E. Smith and J. M. Starkey, "Effects of Model Complexity on the Performance of Automated Vehicle Steering Controllers: Model Development, Validation and Comparison," *Veh. Syst. Dyn. Int. J. Veh. Mech. Mobil.*, vol. 24, no. 2, pp. 163–181, 1995.