Integrating an Emission Minimizing Extension in an Adaptive Signal-Control Optimization Algorithm

M. Haberl[1], M. Fellendorf[1], R. Luz[2] and S. Hausberger[2]*

[1] Institute of Highway Engineering and Transport Planning, Graz University of Technology, Rechbauerstrasse 12/II, A-8010 Graz, michael.haberl@tugraz.at
[2] Institute of Internal Combustion Engines and Thermodynamics, Graz University of Technology, Inffeldgasse 19, A-8010 Graz

Introduction and Motivation

Several cities need to reduce traffic related emissions in order to meet the European Directive 2008/50 on ambient air quality. Fuel consumption and air pollution do not only depend on the technology used in the cars itself. Poor traffic signal timing contributes to traffic congestion and delay, consecutively leading to high emissions. Since environmental performance measures become more important in decision making of traffic signal control there is a need for further investigations. The main focus of this work is to integrate emissions caused by individual and public traffic as a direct and explicit objective for local adaptive signal-control optimization in order to guarantee emission-minimizing signalization.

Conventional fixed signal control systems use pre-programmed, daily signal timing schedules. Adaptive traffic control is a traffic management strategy in which traffic signal timing changes based on actual traffic demand, gained from detection facilities on road. Mertz and Weichenmeier (2002) developed an urban adaptive signal-control algorithm (EPICS - Entire Priority Intersection Control System). EPICS was designed especially for single intersections with integrated public transport prioritization. EPICS achieves excellent signal control with mathematical optimization of a performance index (PI) that mainly minimizes waiting time. Present work upgrades the PI of EPICS by an emission-minimizing weighting coefficient. The emission-minimizing weighting coefficients were investigated by coupling a microscopic traffic flow simulation (VISSIM) with an emission model (PHEM).

Methodology

The heavily travelled inner city of Salzburg (Austria) serves as investigation area. It contains 10 signalized intersections, 4 out of these are capacitive bottle necks and got equipped with the optimization tool EPICS, an urban adaptive signal-control algorithm. In order to test the effects of EPICS a microscopic traffic flow network was parameterized in VISSIM (PTV AG, 2012). VISSIM is a microscopic, behaviour-based multi-purpose traffic simulation and is frequently used to analyse and optimize traffic flows as well as to improve signal control or to provide the data base in order to calculate traffic-related emissions, Fellendorf and Vortisch (2010). The microscopic network was built via an Import of a state-wide macroscopic model of Salzburg. The Import determines the route network, the traffic flow input and also static route profiles of the traffic flow model in order to reflect reality. To ensure these input variables in the best possible quality, the investigation area of the macroscopic model was fine-tuned with the help of detector data and current intersection counts. On the basis of aerial photographs the microscopic traffic flow model was further refined, see Figure 1.

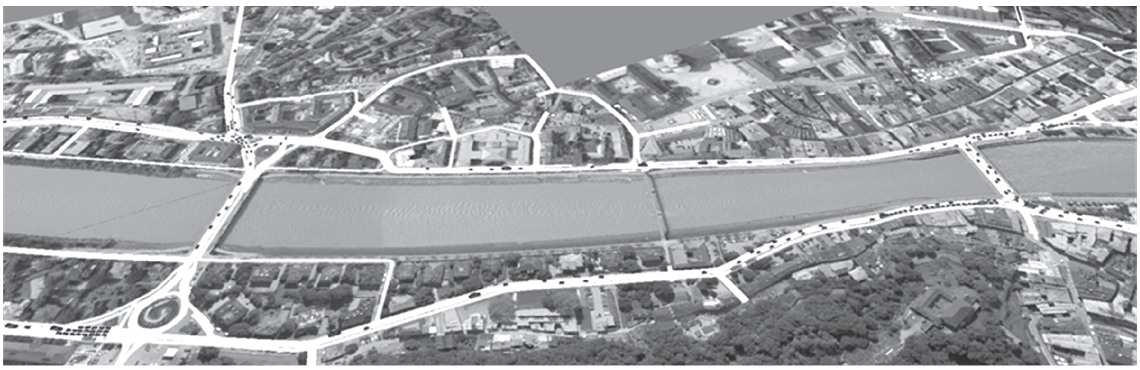

Figure 1: Microscopic traffic flow network of the investigation area

The microscopic traffic simulation contains any relevant transport mode (cars, trucks, buses, pedestrians, cyclists). An iterative process of calibration of the lateral and longitudinal motion model of the traffic flow simulation was processed based on comprehensive high-resolute (20-100 Hz) GPS supported test runs of in total 60 hours. The calibration process (see figure 2) was based on the results of intermediate PHEM analysis (with the GPS trajectories as input variables) closed by manual analysis on parameters which can be used to adjust the lateral and longitudinal motion model. Thereby the acceleration and deceleration behaviours were adapted as well as the desired speed distribution and other handling sets of parameters which affect the longitudinal and lateral movements of the simulated vehicles especially at intersections.

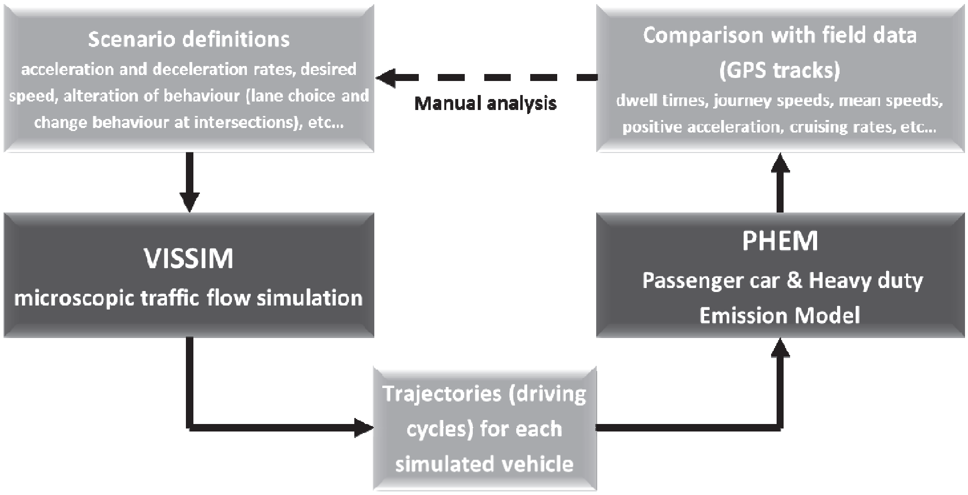

Figure 2: Calibration of microscopic traffic flow simulation model

PHEM (Passenger Car and Heavy Duty Emission Model) is a microscale emission model developed at the Institute of Internal Combustion Engines and Thermodynamics, Hausberger (2003). It calculates the engine speed and power in constant time steps of 1 Hz using the backwards longitudinal dynamics approach (wheel-to-engine). FC and raw exhaust emissions are calculated from engine power and -speed considering driving resistances and transmission losses. Temperature-dependent effects in the after treatment system can be considered using an approach with its own thermal and catalytic properties.

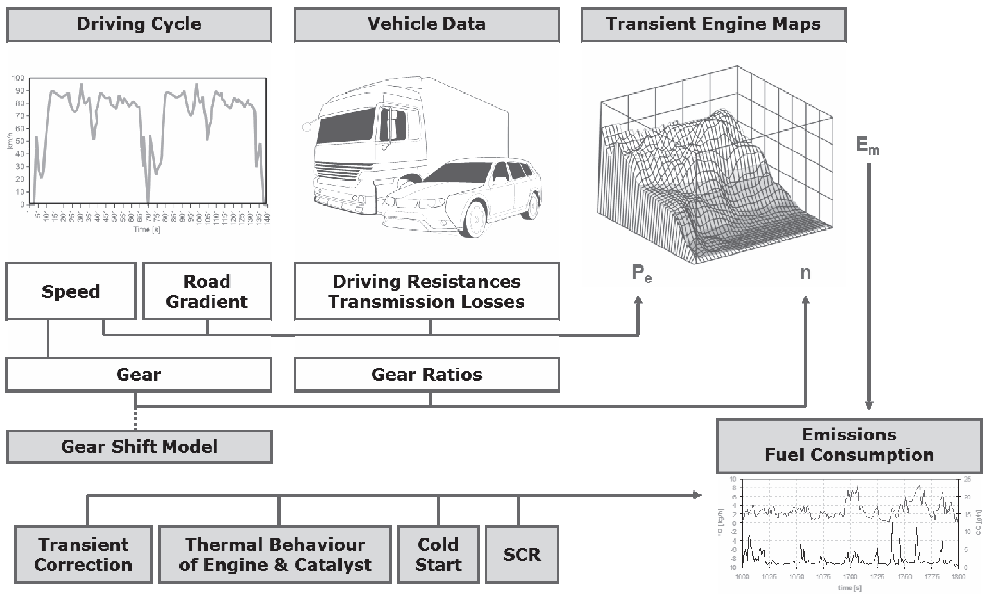

Figure 3: Microscopic emission model - PHEM

For each of the 4 intersections equipped with EPICS a set of 5 possible emission-minimizing weighting coefficients, for a set of 25 to 125 various traffic situations (different relations of traffic flows), was investigated by coupling the microscopic traffic flow simulation VISSIM with the emission model PHEM. Thereby the number of traffic situations depends on the number of detection facilities per intersection and its complexity. The traditional method of vehicle detection is performed through inductive loops embedded in the road's surface. These inductive loops also allow classifications of vehicles in order to prioritize public transport. In total 1500 simulation runs were performed. The coupling of the models has already successfully been shown in Hirschmann et al. (2011).

Based on driving cycles respectively trajectories PHEM calculates engine speed and power in constant time steps of 1 Hz. As result of the simulation environment produced emissions (FC, NOx, CO, HC, PM, PN and NO) of every traffic situation for each investigated weighting coefficient of an intersection exist. Hence, emission-minimizing weighting coefficients can be assessed for every traffic situation of each intersection.

In real operation on the street EPICS receives the currently detected traffic situation each 15 minutes directly from the detectors on road. Then EPICS adapts the emission-minimizing weighting coefficient of its PI for the next 15 minutes by choosing the emission-minimizing weighting coefficient of the modelled traffic situation which reflects the currently detected one. The emission-minimizing weighting coefficient shifts green and red time of competing traffic flows.

Methodology at a Glance

The general concept contains 4 sequential steps. Figure 4 recapitulates the previous described methodology. First step of the system design covers the parameter calibration of the microscopic traffic flow model. In the second step simulations at single intersections for different traffic situations and weighting coefficients were conducted. Thereafter the longitudinal dynamics emission model PHEM calculates emissions and fuel consumption. Finally the adaptive signal control EPICS integrates the emission-minimizing weighting coefficients of the current traffic situation on road, measured with detectors.

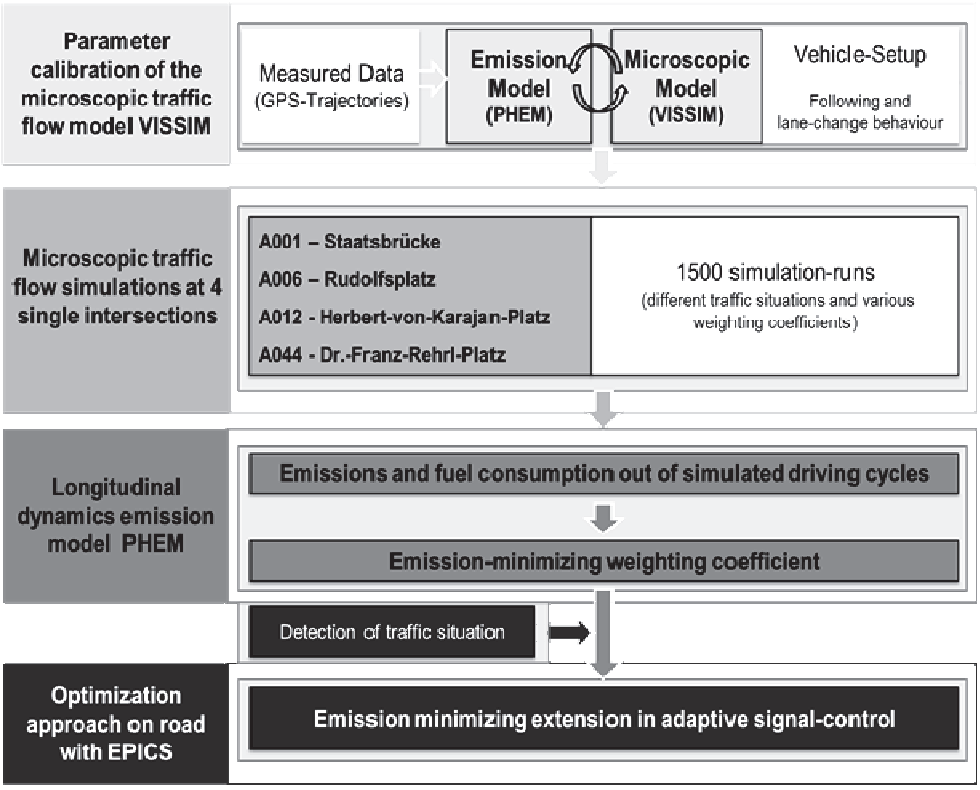

Figure 4: System design of the methodology

Results

Within this paper the simulated potential savings of fuel consumption (FC) by integrating an emission-minimizing extension in EPICS are shown for Herbert-von-Karajan-Platz, see figure 5. The absolute results of FC [g/km] of the standard weighting coefficient (Epics00) are exemplarily shown for 5 out of 25 different traffic situations with varying traffic flow values. FC of Epics00 acts as benchmark for the relative decrement respectively increment (ΔFC) of the alternative weighting coefficients (Epics20-Epics80).

Traffic Situation		Emission-Minimizing Weighting Coefficient				
Traffic Flow 1 [veh/h]	Traffic Flow 2 [veh/h]	EPICS00 FC [g/km]	EPICS20 ΔFC [%]	EPICS40 ΔFC [%]	EPICS60 ΔFC [%]	EPICS80 ΔFC [%]
950	285	126.39	2.64%	-7.02%	-2.15%	-2.15%
850	255	106.79	3.63%	2.65%	5.95%	5.95%
750	225	106.00	-0.47%	1.41%	5.19%	5.19%
650	195	103.15	4.28%	2.19%	0.60%	0.60%
550	165	104.26	-0.31%	-1.10%	-0.34%	-0.34%

Figure 5: Potential savings of FC at Herbert-von-Karajan-Platz

If the traffic situation is determined by very high or very low traffic flow values (950/285 respectively 550/165 vehicles/h), the decrement of FC can be quantified with up to -7% respectively -1.1% for weighting coefficient Epics40. For the traffic situation with 850/255 as well as 650/195 vehicles/h the standard factor Epics00 remains the emission-minimizing one. Which weighting coefficient minimizes emissions depends on the traffic situation.

In order to underline these results of possible reduction of fuel consumption for single intersections the whole microscopic traffic flow network was simulated for the peak hour in the morning. Once with the current existing fixed traffic control and once with the adaptive signal control EPICS, with its emission optimized weighting factors. The simulations with EPICS control show an average reduction of number of stops of almost 8%, compared to the fixed signal control. In parallel, the average travel speed increases by almost 13% and the fuel consumption of the vehicles of the whole simulation network decreases even by 10% assessing the adaptive signal control

Furthermore the comparison of simulated speed-profiles in 1Hz rate of a random car in the simulation network with fixed signal control with the speed-profiles of the same random car in the simulation network with adaptive signal control - EPICS, confirms this trend, see figure 6.

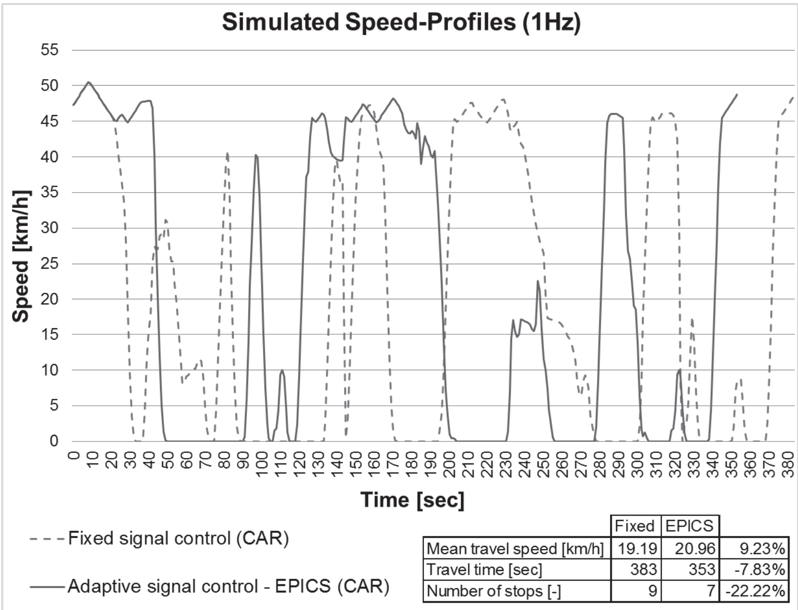

Figure 6: Simulated speed-profiles (1Hz) under the influence of different signal control systems

Conclusion and Discussion

This work integrates emissions caused by individual and public traffic as a direct objective for local adaptive signal-control optimization in order to guarantee emission-minimizing signalization by adapting the performance index (PI) of EPICS. Up to now the PI is updated every 15 minutes, taking the amount of detected vehicles in the previous 15 minutes into account. These update every quarter of an hour is still too static. The adaptive signal-control optimization algorithm EPICS has the capability to update the PI every second, therefore further investigation towards an online calculation of emissions upon the detected current traffic state would be preferable.

Nevertheless, according to present simulation results the integration of an emission-minimizing extension in EPICS can help to reduce fuel consumption, air pollution and PM. The integration of an emission-minimizing extension in an urban adaptive signal-control algorithm EPICS in comparison to an existing well-planned fixed traffic control helps to reduce number of stops (-8%), increases the mean travel speed (+13%), makes traffic more fluent and therefore helps to reduce emissions and fuel consumption (-10%).

Acknowledgements

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