From Traffic Management to Environmental Traffic Management

Volker Diegmann
IVU Umwelt GmbH, Emmy-Noether-Straße 2, D-79110 Freiburg, Germany

Günter Gäßler
IVU Umwelt GmbH, Emmy-Noether-Straße 2, D-79110 Freiburg, Germany

Florian Pfäfflin
IVU Umwelt GmbH, Emmy-Noether-Straße 2, D-79110 Freiburg, Germany

Abstract

Strict limit values for air pollutants, demanded e. g. by the EC directives [4], [6], [7], require to reduce air pollution. Source apportionment studies for hot spots with high pollutant concentrations show a predominance of road traffic as the main source group. Thus, environmental effects of road traffic within urban areas have to be reduced.

A Traffic Management Systems (TMS) is an instrument for cities that helps managing road works, big events or unforeseeable situations like accidents. Further, it allows for a situation-related control of traffic signals and can be used to optimize road capacities in order to improve traffic flow and quality and the benefits of TMS in urban areas are widely known. Because measures of a TMS influence traffic load and flow, they have a certain impact on air quality, especially for traffic related pollutants such as PM_{10} or NO_2. Thus, traffic management systems can be used to improve air quality [2], [8]. The extension of traffic management with air quality strategies, such as decreasing traffic related emissions within critical segments, leads to an Environmental Traffic Management System (ETMS).
In addition to static measures that have been favored so far in air quality policy, temporary measures concerning road traffic have a high reduction potential with respect to both short-term and annual limit values [4] and can be implemented with an ETMS.

Air quality problems are generally widely distributed in a city and the highest pollutant concentrations are mostly found along major roads within street canyons. Focusing on a single street section, the reduction of traffic related emissions can be achieved with a number of measures like speed limits, reduction of traffic control stops, prevention of disturbances due to lane blocking (e. g. while delivering goods) and finally with partial or full road closure [2]. Before implementing specific measures to manage air quality, the range of their effects in space and time needs to be understood. The following aspects should be considered before taking action:

- What is the efficiency of the measure?
- What are the side effects?
- Is it possible to shift high emissions and/or concentrations to non-sensitive areas?
- When is the best time to apply the measure?

Answers to these questions can be obtained from citywide modeling systems that can operate in a planning or scenario mode. The efficiency of the measures can be controlled with an air quality monitoring system providing online citywide information of the pollutant concentrations.

Conventional monitoring systems based on regular station measurements can only assess air quality at the point of measurement but do not provide information on the spatial distribution of pollutants. However, air quality problems are generally widely distributed in a city. The highest values of pollution are mostly found along major roads within street canyons where concentrations will vary from segment to segment according to the local traffic (e. g.

volumes, driving pattern…) or dispersion conditions (e. g. orientation, height, width, gaps between buildings). Measurements at all potential hot spots are not feasible. Thus, air quality monitoring covering all relevant streets can only be achieved with air quality models.

For this purpose, the monitoring system IMMIS^{mt} was developed [1], [3]. This validated system is capable of quickly calculating concentration values at a given point within a street canyon on a micro scale basis using a canyon box model with online traffic data. Therefore, it can be used to monitor air quality in all relevant streets in a city. For planning single traffic control measures, IMMIS^{mt} may be operated in planning mode to simulate different scenarios.

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Environment-responsive Traffic Control

Manfred Boltze
Technische Universität Darmstadt, Transport Planning and Traffic Engineering, Petersenstr. 30, 64287 Darmstadt, Germany

Sven Kohoutek
Technische Universität Darmstadt, Transport Planning and Traffic Engineering, Petersenstr. 30, 64287 Darmstadt, Germany

Abstract

This article describes some fundamentals for an environment-responsive traffic control. It starts with a brief description of the **needs to consider environmental aspects** in urban traffic control, focusing on noise, particular matters (PM), and nitrogen oxides (NOx). Respective current **regulations by law** in Europe and Germany are explained. Comparing the regulations for the improvement of air quality and for noise reduction, important similarities and differences are pointed out.

In this context, it must not be neglected that short-term measures (regarding air pollution) will possibly have only minor impacts on the urban traffic-borne background pollution. As a consequence, there has to be a detailed investigation of appropriate situations where rigorous short-term restrictions provide better results than static restrictions with many regulatory exceptions.

The acceptance of the different types of measures by the road users is another point which has to be considered.

In the next section, the idea of a **dynamic traffic control** is introduced, which takes into account not only the traffic situation, but also the current environmental situation. The basic aim of this dynamic control is to minimize restrictions to those times, situations, and locations when and where they are really needed.
Systematically, the different options of dynamic measures to influence traffic volumes and traffic flow are analyzed. This includes measures

- to meter the accessing traffic streams to certain parts of the network,
- to shift traffic volumes within the network by influencing the route choice,
- to prioritize crossing arterials against each other,
- to shift congestion within one arterial, and
- to prioritize traffic streams within one intersection.

The different options are assessed for their general potential to improve the environmental situation while avoiding unnecessary restrictions for motorized traffic. In this context, it is important to consider

- the predictability of critical (environmental) situations to allow measures to be applied sufficiently in advance, as well as
- the time-offset until applied measures can deploy their full efficiency.

An **overview on measures** is given which have been applied so far to improve the environmental situation, concentrating on traffic control measures. E.g. this includes approaches to optimize traffic signal control, restrictions for heavy vehicles to pass certain parts of the network, “environmental zones” (Umweltzonen), and speed limits.

Fundamental **advantages and disadvantages of these measures**, which mostly are of static nature and do not consider the actual situation, are discussed. This addresses the positive impacts of such measures on the environmental situation, but also the problems which may arise.

Furthermore, different **methods to assess the potential of traffic control measures** as a basis for a situation-dependent selection of measures are described, especially regarding the quality of their results (accuracy, time resolution, and spatial transferability) and regarding the required efforts to apply the method. For example, modeling of air polluting emissions seems to be a quite efficient and accurate way to assess the traffic related fraction. However, conclusions regarding the compliance with legal thresholds for local impacts are not possible because major influencing factors (such as meteorology) are not considered. Other methods seem to be suitable on a large time-scale only, and they are not accurate enough to assess measures with an optimization potential in the lower percentage range.

The **role of ITS** to support an environment-responsive traffic control is explained. While especially in urban areas traffic signal control will play a major role, further systems will be needed to enable and support some functions of such traffic-responsive traffic control.

Finally, **research and development needs** are outlined. This includes, for example,

- a detailed assessment of different control strategies regarding their environmental impacts,
- new procedures to cope with additional environment-related criteria in the traffic control optimization process,
- the integration of environmental models and traffic models, and
- new and cost-efficient technologies and methods to detect the environmental situation.

Emission minimizing traffic control – simulation and measurements

Karin Hirschmann
Institute of Highway Engineering and Transport Planning, Graz University of Technology, Rechbauerstrasse 12, 8010 Graz, Austria

Martin Fellendorf
Institute of Highway Engineering and Transport Planning, Graz University of Technology, Rechbauerstrasse 12, 8010 Graz, Austria

Abstract

It is well known that signal control has an impact on traffic related emissions. Traditionally signal control related emissions are estimated using average queue length and number of stops. A toolbox will be presented to quantify changes in emissions as a result of different actuated signal control strategies and other ITS measures. The microscopic traffic flow simulator VISSIM has been linked to the instantaneous emission model PHEM (Passenger car and Heavy duty vehicle Emission Model). An interface between traffic flow simulation and the adaptive Urban Traffic Control System MOTION by Siemens has been developed as well. PHEM calculates emissions based on modelled trajectories of each individual vehicle. Intensive calibration of the traffic flow simulation has been conducted to match measured acceleration rates. The measurements considered travel time investigations as well as high fidelity recordings of GPS coordinates. PHEM was also subject of the calibration process since the recorded trajectories were used as driving cycles on a chassis dynamometer. The toolbox has been applied using an urban arterial in Graz. First results indicate that emissions can be reduced by about 5% to 12% depending on pollutant and signal control changes. The simulation environment has proven to be an appropriate tool for detailed emission calculations without cost intensive measurements on a chassis dynamometer.

Keywords:
emission model, traffic flow simulation, traffic flow calibration, adaptive signal control

Model-Based Traffic Control for the Reduction of Fuel Consumption, Emissions, and Travel Time

S. K. Zegeye
Delft University of Technology, Mekelweg 2, 2628 CD, Delft, The Netherlands

B. De Schutter
Delft University of Technology, Mekelweg 2, 2628 CD, Delft, The Netherlands

J. Hellendoorn
Delft University of Technology, Mekelweg 2, 2628 CD, Delft, The Netherlands

E. A. Breunesse
Shell Nederland B.V., Carel van Bylandtlaan 30, 2596 HR, The Hague, The Netherlands

Introduction

Despite of the rise of fuel prices and the imposition of more stringent environmental policies for emission levels, the demand for mobility and transportation is continuously increasing. Consequently roads are frequently congested, creating economical, social, and ecological challenges. Road traffic exhaust emissions account for 40% of volatile organic compounds, more than 70% of NO_x, and over 90% of CO in most European cities [7], and for about 45% of the pollutants released in the US [6]. Frequent and longer congested traffic conditions make this even worse.

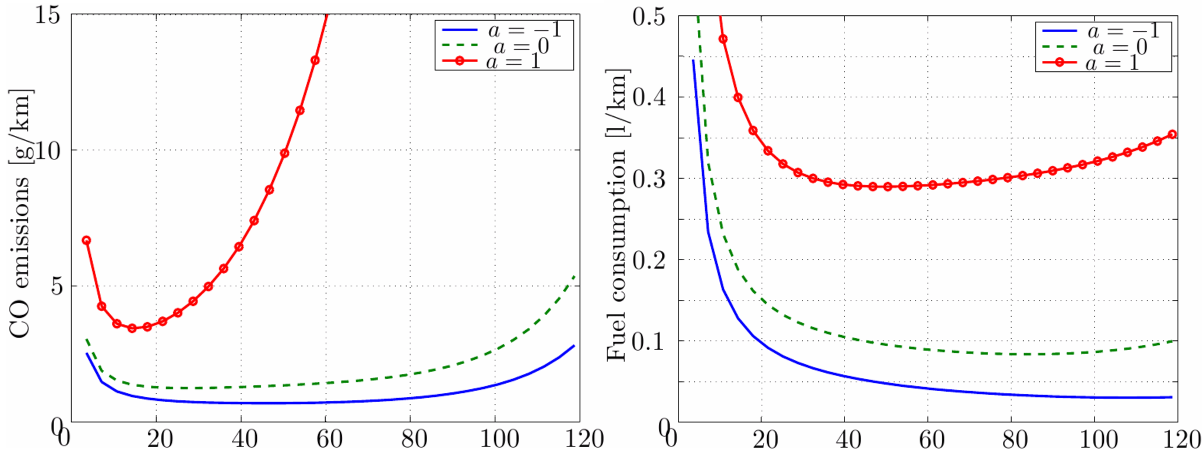
In this paper we use a model-based traffic control approach to determine dynamic speed limits with the aim of reducing fuel consumption and emissions, while still guaranteeing small travel times. The approach we propose is based on model predictive control (MPC) and uses microscopic traffic flow, emission, and fuel consumption models. In the sequel we describe and demonstrate the approach.

Model predictive traffic control

The basic concept of MPC [2,5] lies in the on-line optimization of control inputs (in this case dynamic speed limits) based on a prediction model and combined with a moving horizon approach.

MPC allows various performance criteria such as, total emissions, total fuel consumption, and total time spent, or a combination of these. In each MPC control step first the current states (such as flow, density, fuel consumption, emission levels, etc.) are measured or estimated, and next in order to compute optimal control inputs an optimization method is used in combination with a model that provides a prediction of the future evolution of the traffic states. Our MPC approach accommodates a traffic flow model, an emission model, and a fuel consumption model.

The proposed approach is generic and modular and hence various models can be used (as long as they provide a good trade-off between accuracy and simulation speed). As prediction model we propose to use Gazi-Herman-Rothery (GHR) stimulus-response car-following traffic flow model [3] along with the microscopic emission and fuel consumption model developed by Ahn [1], viz. VT-micro. The GHR model is a microscopic traffic model that describes the dynamics of individual vehicles in a traffic flow. The VT-micro model is a dynamic model that yeilds emission and fuel consumption using second-by-second speed and acceleration of individual vehicles. Fig. 1(a) and Fig. 1(b) portray some CO emissions and fuel consumption curves generated using the VT-micro model.



(a) CO emissions (b) Fuel consumption

Figure 1: CO emissions and fuel consumption curves of a vehicle as a function of the speed for acceleration a∈ {-1, 0, 1} m/s.

In the MPC framework the optimal control inputs are applied to the traffic system using a moving horizon approach. This works as follows. At each MPC step, first on optimal control input sequence is determined that optimizes the performance criterion over the given future time horizon. Next, only the first sample of the optimal sequence is applied tor the traffic system during the subsequent control sample period. Afterward, the new state of the system is measured and a new optimal control sequence is computed. Once again, the first control sample is applied, and so on, until the end of the simulation or running period.

Case study and results

Using the aforementioned approach we now investigate the impact of dynamic speed limit control on the improvement of the total CO emissions, the total fuel consumption, and the total time spent (TTS) in a traffic network. In particular, we consider a single-lane one-way 12 km-long freeway. As shown in Fig. 2, the freeway is divided into six sections, where the speed of each section is controlled with a dynamic speed limit. Initially, the freeway is assumed to be congested from 6.8km to 6.935km, while the remaining parts are noncongested. We have put the initial congestion at a distance that is relatively far from the origin so that we can illustrate that dynamic speed limit control is effective for reducing travel time (see also [4]). In addition, we consider the following uncongested demand profile:

$$d_o(k) = \begin{cases} (0.024 + 0.057\,\mathrm{sinc}(0.001k - \pi/4))T & \text{for } 0 \le k \le \dfrac{3N_{\mathrm{sim}}}{4} \\ 0 & \text{for } k > \dfrac{3N_{\mathrm{sim}}}{4} \end{cases}$$

where $\mathrm{sinc}(x) = \sin(x)/x$, $T = 1$ s is the simulation sampling time, and $N_{\mathrm{sim}} = 1800$ denotes the number of the simulation time steps. The demand profile is depicted in Fig. 3. It shows the variation of the rate of the number of vehicles arriving at the origin of the freeway.

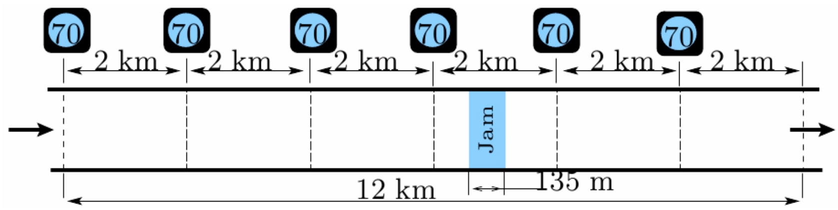


Figure 2: Layout of the case study

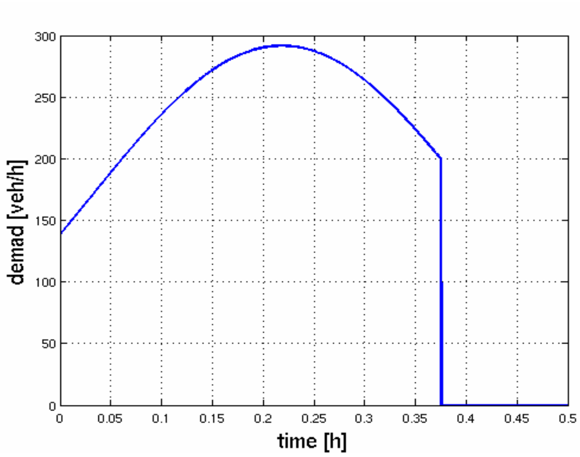


Figure 3: Profile of the demand

The setup will now be simulated for different control objectives. The simulation results are tabulated in Table 1 for three scenarios:

S1. uncontrolled,

S2. controlled with the objective of reducing both total CO emissions and total fuel consumption, and

S3. controlled with the objective of reducing total CO emissions, total fuel consumption and total time spent all together.

In general, the objective function is defined as:

$$J = \lambda_1 \frac{\text{TTS}}{\text{TTS}_{\text{nominal}}} + \lambda_2 \frac{\text{CO}}{\text{CO}_{\text{nominal}}} + \lambda_3 \frac{\text{fuel}}{\text{fuel}_{\text{nominal}}}$$

where TTS, CO, and fuel indicate respectively the total time spent, total CO emissions, and total fuel consumption during the prediction (for MPC) or simulation period (for the closed-loop operation), and where $(\cdot)_{\text{nominal}}$ denote the ``nominal'' values of the performance criteria obtained when the speed limit is set to 80 km/h and the system is not controlled. The coefficients λ_1, λ_2, λ_3 are weighting factors. We have set $\lambda_1 = 0$, $\lambda_2 = \lambda_3 = 1$ for scenario S2 and $\lambda_1 = \lambda_2 = \lambda_3 = 1$ for scenario S3.

Table 1: Simulation results

Simulation scenario	TTS (veh·h)	Total CO (kg)	Total fuel (l)
S1	23.563	28.009	21741
S2	27.826	1.0614	1027.7
S3	14.004	20.093	16730

The simulation results indicate that the CO emissions and fuel consumption can be reduced by 96.21% and 95.28% respectively, when the objective function of the MPC controller is a combination of CO emissions and fuel consumption. But in this case the TTS is worsened by 18.09%. However, when we incorporate the travel time in the objective function (scenario S3), the TTS is reduced by 40.57%, and the CO emissions and fuel consumption are reduced by 23.05% and 28.26% respectively.

Conclusions

Performance indicators of a traffic flow such as the emissions, fuel consumption, and travel time are in general conflicting, i.e., the reduction of one performance criterion does not necessarily guarantee the reduction of the other criteria, and in general will even result in an increase of the other criteria. However, we have proposed an optimization-based model predictive control approach that allows to determine optimal speed limits for a balanced weighted combination of various performance criteria. The proposed approach has also been illustrated using a case study for which we could reduce emissions, fuel consumption, and travel time all together at the same time.

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