

# An Assessment of VMS-Rerouting and Traffic Signal Planning with Emission Objectives in an Urban Network – A Case Study for the City of Graz

Robert Kölbl (*Corresponding Author*)

Department Mobility  
AIT (Austrian Institute of Technology)  
Vienna, Austria  
[robert.koelbl@ait.ac.at](mailto:robert.koelbl@ait.ac.at)

Bernd Cagran (*Author*)

Straßenamt  
Stadt Graz  
Graz, Austria  
[Bernd.Cagran@stadt.graz.at](mailto:Bernd.Cagran@stadt.graz.at)

Bernhard Heilmann (*Author*)

Department Mobility  
AIT (Austrian Institute of Technology)  
Vienna, Austria  
[bernhard.heilmann@ait.ac.at](mailto:bernhard.heilmann@ait.ac.at)

Margherita Mascia (*Author*)

Centre for Transport Studies  
Imperial College London  
London / United Kingdom  
[m.mascia@imperial.ac.uk](mailto:m.mascia@imperial.ac.uk)

Dietmar Bauer (*Author*)

Econometrics  
University Bielefeld  
Bielefeld, Germany  
[Dietmar.Bauer@uni-bielefeld.de](mailto:Dietmar.Bauer@uni-bielefeld.de)

Simon Hu (*Author*)

Centre for Transport Studies  
Imperial College London  
London / United Kingdom  
[j.s.hu05@imperial.ac.uk](mailto:j.s.hu05@imperial.ac.uk)

Gernot Lenz (*Author*)

Department Mobility  
AIT (Austrian Institute of Technology)  
Vienna, Austria  
[gernot.lenz@ait.ac.at](mailto:gernot.lenz@ait.ac.at)

Martin Litzenberger (*Author*)

Department Safety & Security  
AIT (Austrian Institute of Technology)  
Vienna, Austria  
[martin.litzenberger@ait.ac.at](mailto:martin.litzenberger@ait.ac.at)

**Abstract**—This paper discusses a case study evaluating the potential impact of ITS traffic management on CO<sub>2</sub> and Black carbon tailpipe emissions. Results are based on extensive microsimulations performed using a calibrated VISSIM model in combination with the AIRE model for calculating the tailpipe emissions from simulated vehicle trajectories. The ITS traffic management options hereby consist of easily implementable actions such as the usage of a variable message sign (VMS) or the setting of fixed time signal plans. Our simulations show that in the current case shifting 5% of vehicles from one route to another one leads to an improvement in terms of emissions only if the VMS is complemented with an adaptation of the signal programs, while the VMS sign or the change of the signal plans alone do not yield benefits. This shows that it is not sufficient to evaluate single actions in a ceteris paribus analysis, but their joint network effects need to be taken into account.

**Keywords**— traffic management measures, air emissions, microsimulation

## I. INTRODUCTION AND BACKGROUND

Reducing tail pipe emissions from individual transport has become a major topic of transport policy in many countries. According to the United States Environmental Protection Agency there are several possibilities for reducing tail pipe emissions [1]. Socio-economic or policy measures for influencing driver behaviour are constituted by road and congestion pricing, value pricing through parking and other taxes or “Pay-as-you-drive” vehicle insurances. Another measure are advertising campaigns to convince car drivers to change to a more environmental friendly traffic mode such as cycling, walking or using public transport. Another recommendation is to promote car- or ridesharing and supporting those measures by flexible working times, financial incentives or ‘emergency ride home services’. Alternatively even if people do not choose alternatives, emissions can be reduced by a proper management of the transportation system. Such measures include improved traffic signalization and adapting transportation infrastructure in order to reduce congestion, enhancing incident management systems or to design intelligent transportation systems [1].

The increasing communication exchange between infrastructure and vehicles (I2V or V2I) enables advanced co-operative traffic management strategies or co-operative driving assistance system. Based on optimised strategies, the information can be sent to the vehicles in real-time and thus can also influence the tactical and operational driver behaviour in real-time. Some modules for cooperative driving assistance systems have been implemented and tested in research projects, such as green light optimized driving cycles for trucks or public transport vehicles as well as recommendations for eco-routes, i.e. routes with low energy consumption (see e.g. [2]).

Since changes of the transportation system are costly and disruptive, the effects of the various measures need to be evaluated and planned before the actual implementation in order to assess the expected impact. To this end, simulations of

the transportation system and the corresponding tailpipe emission are used.

In the literature a number of studies have taken up this point. Examples in this respect dealing with the optimization of signal timings in order to reduce tail pipe emissions can be found in [3], [4] and [5]. However, one problem of these approaches is the limited area of the investigations [13]: Possible negative effects on nearby intersections or roads have not been considered. Boulter et al. have investigated in [7] tail pipe emissions on a larger scale, namely on routes. They developed a methodology for driving cycles to represent driving patterns before and after the installation of different traffic calming measures (e.g. humps). Madireddy et al estimated tail-pipe emissions also for routes, but with different traffic measures [6]. They applied a microscopic traffic model and implemented signal coordination for intersections and different speed limits. For a given route they found a reduction up to 25% for CO<sub>2</sub> emissions for different measures, without, however, quantifying potential increases on adjacent roads. Emissions on a network level and their variation in dependence of tolls and rebates have been investigated by Chen et al [8].

For this paper, traffic measures attempting to influence the route choice behaviour via variable message signs are combined with traffic signalling on a wider network area, and the potential of this combination to reduce tail pipe emission is explored using calibrated microsimulations of the corresponding area. The setting of the case study is described in Section 2. Sections 3 to 5 describe the methodological requirements and the simulation approach. The paper finishes with the results and conclusions in Section 6 and 7.

## II. CASE STUDY

CARBOTRAF is a European FP7 project with the goal to investigate the reduction potential of traffic management measures on tailpipe emissions, mainly of CO<sub>2</sub> and Black Carbon. Various ITS traffic management measures were identified to influence drivers and their vehicles in order to optimize the traffic management objectives. The available traffic management options have been discussed with the Graz city administration, the Austrian highway operator and the CARBOTRAF research team. Two different measures, i) the re-routing via a Variable Message Sign (VMS) and ii) the variation of traffic signal plans have been selected as the most promising actions, as they can be implemented based on real traffic conditions and are practically feasible from an operators’ point of view. Two other measures have been discarded due to high enforcements costs (dynamic road usage restrictions according to vehicle emission class) or legal obstacles (dynamic speed limits).

Two case studies have been conducted within CARBOTRAF, one in Graz, Austria and the other in Glasgow, Scotland, UK. For this paper, only the Graz case will be described.

A. The Test Site

The CARBOTRAF test site in Graz lies in the northern region of the city between the highway A9 and the city centre (see Figure 1). There are two adjacent exits on A9, Exit Gratkorn Süd and Exit Graz Nord. The first exit leads to the eastern arterial road, the second exit leads to the western arterial road. Both the northern boundary and the southern boundary of the test site lead over the river Mur, the main river of Graz.

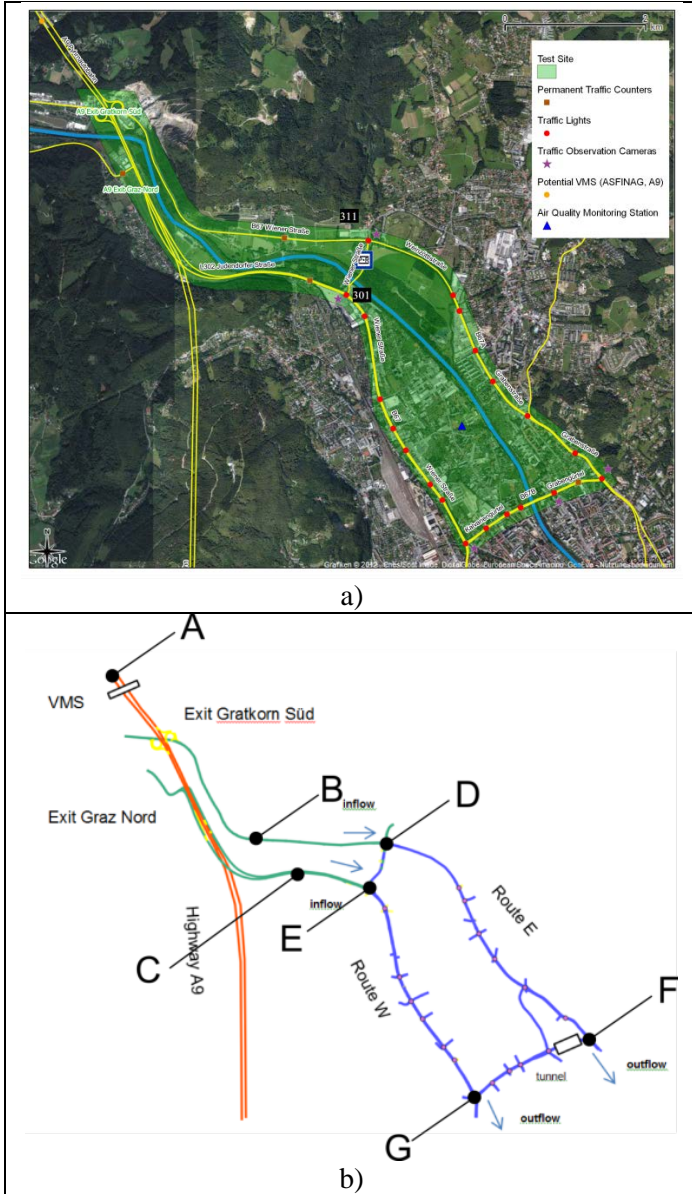


Figure 1: a) The CARBOTRAF test site in GRAZ: with the locations of traffic lights (red dots), traffic cameras (purple stars), stationary traffic sensors (brown dots) and the variable message sign on the A9 highway. Blue triangles mark the environmental measurement locations. ©: Google Maps. b) Possible traffic flow directions with main origins and destinations

In terms of settlements structure, the test site comprehends mainly mixed residential areas. On the top-eastern part of the test site lies Graz-Andritz, a mainly residential area, but also accommodating a large metal and machinery factory. In the middle of the test site, on the western side of the Mur, is a popular recreational centre. Close to intersection 301 (see Figure 1b, E), there is a shopping centre, which is a major traffic hot spot. Just next to it is a park&ride facility, with around 130 parking lots. Along the southern boundary, there are several large schools, which are also main traffic attractors.

A number of urban and regional bus services run within the test site. However, there are no separate bus lanes and due to their low frequency they have a negligible influence on traffic. Hence, they have not been considered any further for the traffic model.

From a topological point of view, the area runs along the river Mur and is mainly plain without any hills. Hence, it can be considered as a flat area for the modelling in 2D, i.e. longitude and latitude, neglecting any slopes.

III. 3 REQUIREMENTS FOR THE SIMULATION

A. Traffic Count Data

A total of 143 induction loops at 21 intersections with initial data over 964 days provided the basic data. The loop counts were aggregated to fifteen minute intervals and pre-filtered for non-plausible values (see e.g. [14], [15] or [16]). After data pre-processing 102 loops, i.e. 85% of data, were used as input for path flow estimation and calibration of the VISSIM model. Additional information was provided through signal plan documents, which contained also counts and turning ratios for the 21 intersections.

B. Measurements for the calibration

Test drives with 18 cars have generated floating car data (FCD) at the test site over the course of two days in December 2012, where the test drivers circled in both directions on the arterial routes. These data have been analysed and are used for the detailed calibration of the VISSIM model.

C. The Simulation Period for Traffic Management

The case study focused on the morning peak period, where many drivers drive towards Graz from the north and pass the Variable Message Sign (VMS) on the motorway (next to point A in Fig. 1b). In this period congestion problems commonly occur in the urban network in the simulation area and traffic management measures are justified.

Depending on their destination in the city centre, drivers have the choice between the Route West or Route East going towards the City Center of Graz.

During the morning periods all routes heading for south east carry the main traffic load (points F and G in Figure 1b). To identify the morning peak, the travel times of the two main routes have been analysed (Figure 2 b and c), since travel time is a good indicator for describing traffic performance and is strongly correlated to traffic density. While travel time on both

routes in direction southbound increases strongly during the morning peak, this is not the case for the northbound direction. Consequently the network is exposed to increased pollutants and greenhouse gas emissions during the morning peak, which is a serious problem for the whole area of Graz.

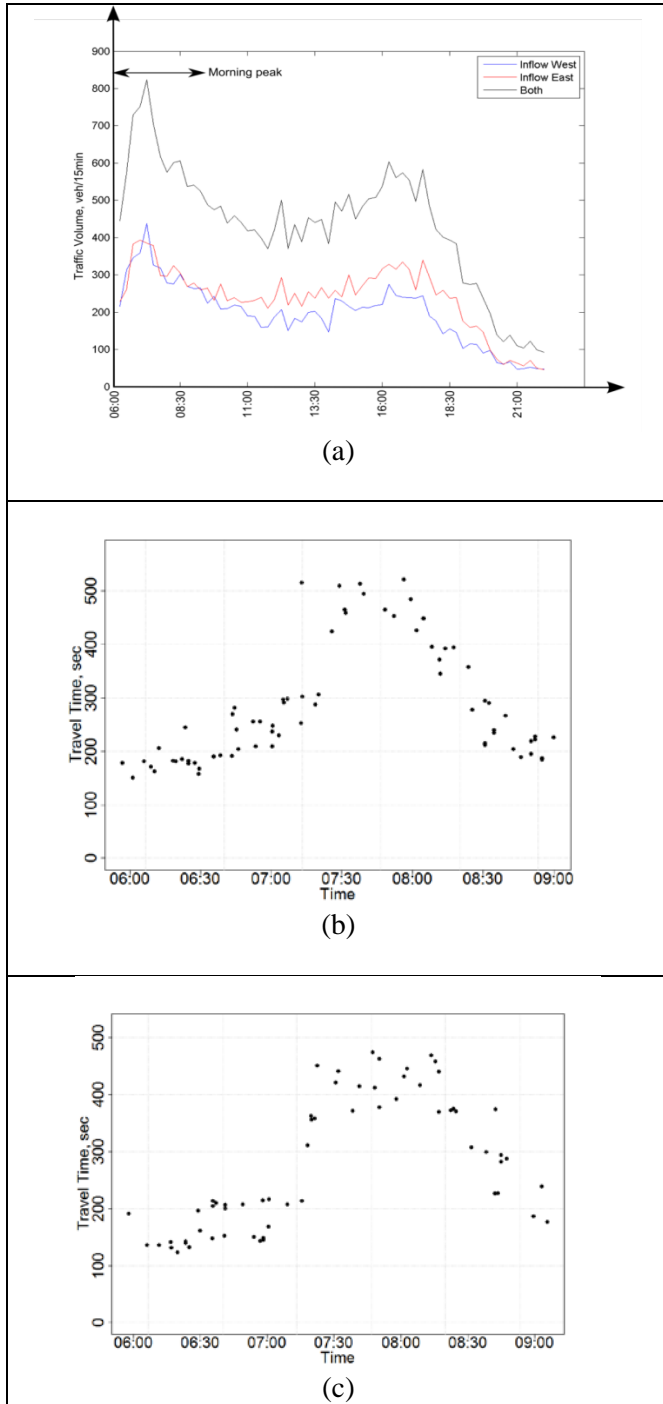


Figure 2: Traffic flow and travel time on both main routes on the investigated network. Workday traffic inflow (from northern direction towards city Graz) (a), travel time Route East direction south (b), travel time Route West direction south (c)

Based on Figure 2b and c the morning peak has been defined as the time span between 6 a.m. and 9 a.m. In addition, this period also shows the most interesting traffic patterns with increasing traffic density, followed by a period of high traffic density and a period of decreasing traffic density. Traffic density gives an indication for the timing of implementing the ITS actions.

#### D. Traffic signalling

The network of the test site Graz has several control zones for signalized intersections. Signalization uses fixed time plans currently which are coordinated along the arterials. Different signal programs exist for different times of the day with varying typical traffic load, i.e. there are on-peak and off-peak programs.

For the morning peak period, there are two pre-defined traffic signalling plans for each control section of the two arterials, with the same numbering:

- Route West (E-G in Figure 1b): control area 30 with S2
- Route East (D-F in Figure 1b): control area 32 with S2

An alternative signal plan (called S5) is available for off-peak hours. This plan is less optimal for the through-traffic from North to South and favours also traffic inflow from side roads to the route.

### IV. SCENARIO DEVELOPMENT AND ITS-ACTIONS

#### A. The base Scenario

A base scenario has been defined representing the traffic condition of recurrent working days during the morning peak. The base scenario defines the basic traffic conditions, which will be superimposed by different traffic management measures. It contains three crucial periods during the weekday morning peak hours:

- increasing traffic density (6:30 to 7:30 a.m.)
- high traffic density (7:00 to 8:00 a.m.)
- decreasing traffic density (7:30 to 8:30 a.m.)

#### B. The traffic management measures (ITS-actions)

In this paper we investigate two ITS actions, firstly the settings of the Variable Message Sign (VMS) at motorway A9 and secondly, different signalling programs at the traffic lights along the two main arterials. By combining different VMS actions with different traffic light actions (TLA), several traffic scenarios were defined. Moreover, different scenarios have been defined for different time periods when the VMS was active.

There are 3 different levels of VMS actions including the base scenario:

- No VMS action (reflects the base scenario, as the TLAs need to be simulated without any VMS action)

- “Go west”: Recommend drivers to take Exit Graz Nord and enter the urban network at the beginning of Route West
- “Go east”: Recommend drivers to take Exit Gratkorn Süd and enter the urban network at the beginning of Route East

For the VMS actions, scenarios with different compliance rates of drivers are assumed, in which a predefined fraction of drivers follows the advice for going West or East. It should be noted that only drivers, who come directly from the North on the motorway and go into the city of Graz for their final destinations, can be reached by the VMS. According to the City of Graz, these are about 30% of all drivers. The other drivers (from the adjacent non-motorway network) cannot follow the advice of the VMS and therefore stick to their usual route. Among the 30% of total drivers, 5%, 10% and 15% of total drivers have been assumed to comply to the VMS recommendation.

In order to support the impact of the VMS actions, the traffic signalling program for off-peak hours (S5) was set on the route that should be avoided. The signal program for off-peak hours causes a reduced flow to the congested route of the network. If this ITS action is prolonged for a longer period, the travel time on routes with S5 as a signal program will be increased for a longer period and therefore it can be assumed that drivers will avoid that route.

The following scenarios with changed signal timings are considered:

- if VMS shows “Go West”, set S2 on Route West and S5 on Route East
- if VMS shows “Go East”, set S5 on Route West and S2 on Route East

### C. Simulation Scenarios

The following scenarios have been defined for the traffic simulation in VISSIM, which also defines the abbreviations for all scenarios:

- Three possible traffic density (TD) periods for displaying VMS recommendations (increase - TDIn, maximum - TDMa, decrease - TDDe)
- The traffic light (TL) action on route west (W) or east (E) with the peak setting program S2 or the off-peak signalling program S5 (e.g. TLW2E2 or TLW5E2)
- Two different messages for variable message sign (VMS go east – VMGE, or VMS go west - VMGW)
- Three different compliant driver rates (DR) in % (DR05, DR10, DR15)

Hence, TDIn\_TLW2E5\_VMGW\_DR05 means increasing traffic density, with traffic light action on the West route set to S2 and on the East route set to S5, the variable message sign showing “Go west” with an assumed compliant driver rate of 5%.

This distinction results in  $3*2*2*3 = 36$  scenarios. Including the base scenario there are 37 scenarios to be simulated. In order to account for the statistical variation, each scenario has been simulated with 24 random seeds, from which the key performance indicators (KPIs) have been calculated (see Table I). In total, 888 simulation runs have been performed, providing a comprehensive data set for the appraisal.

### V. CALIBRATION OF MICROSIMULATION AND LINKING MICROSIMULATION AND EMISSION MODEL

As a detailed description of the calibration of the microsimulator is beyond the scope of this paper, only some important methodological aspects are discussed.

Traffic demand has been modelled by specifying time varying route flows, which were estimated based on available traffic counts. Traffic supply was modelled with the VISSIM microsimulator, which allows for a non-stationary representation of traffic density and queue formation. Furthermore, the real traffic signal programs were used for the simulation. In this way, only the direct short-term impact of traffic management measures was represented without considering medium-term effects (e.g. changes in path choice due to adaptation effects).

An important objective for the calibration of the VISSIM microsimulation is to model traffic states (i.e. flows, local speeds and route travel times) that correspond to observed traffic states in the investigated network. A close similarity between simulated and measured travel times throughout the morning peak period (including formation and dissolution of congestion, cf. Figure 2) on selected routes ensures a realistic modelling of traffic state. The FCD survey from 18 drivers provided the measured data in this respect.

Another important objective for calibrating the VISSIM microsimulation model is the similarity between simulated and measured vehicle speeds and accelerations, since realistic vehicle driving cycles are an important requirement for obtaining a correct emission simulation with an instantaneous emission model (such as AIRE).

In the VISSIM simulator, the car following model according to Wiedemann 74 [12] has been used, which has been developed for urban areas. According to physical considerations and studies on VISSIM calibration (see [5], [9], [10] and [11]), the following VISSIM parameter sets have been selected for calibration:

- distribution of desired speeds
- parameters impacting desired deceleration
- safety distance parameters

These parameter sets were adjusted, until simulated path travel times were close to the measured path travel times on the main routes of the test network. So the calibration of the macroscopic state variable travel time could be considered as satisfactory. On the other hand, calibration of microscopic state

variables as single vehicle speeds and acceleration remained largely unsolved. Especially low speeds below 5 km/h and speeds between 40 and 55 km/h are overestimated by the microsimulation model. Extreme acceleration values above 2 m/s<sup>2</sup> and below -2 m/s<sup>2</sup> occur more frequently in simulated cars. As single speeds and acceleration values are directly used for estimation of vehicle emission factors, using values from microsimulation likely led to overestimated absolute emission values from road traffic. The corresponding consequences will be discussed in Section VI.

The AIRE (Analysis of Instantaneous Road Emissions) model has been developed to use outputs from traffic microsimulation models such as VISSIM (speed, position, acceleration of each simulated vehicle) to generate vehicle emissions based on detailed dynamic data for each individual vehicle for each simulation step [17].

AIRE incorporates an Instantaneous Emission Modelling (IEM) table, which was derived from PHEM (Passenger Car and Heavy Duty Emission Model) developed by the Technical University of Graz and enables emissions to be output for various engine speeds and engine loads. Local variations in fleet composition were reflected by adapting the fleet composition with data from the Austrian vehicle fleet composition in 2012.

AIRE is capable of estimating NO<sub>x</sub>, particulate matter (PM) and total carbon that result from the combustion of fuel throughout each vehicle journey and can be configured to link to trajectory data from probe vehicle data collection for validation exercises. The total carbon metric is based on the PHEM fuel consumption metric and consequently can be directly converted into a representative CO<sub>2</sub> emission.

## VI. RESULTS

### A. Key Performance Indicators

The objective of traffic management is to reduce emissions while maintaining a certain level of traffic performance. This means that the investigated key performance indicators (KPIs) should describe both, traffic performance and the amount of tail pipe emissions. For this case study, traffic performance is described by four KPIs and air pollution resp. greenhouse gases by four KPIs (Table I).

All KPIs have been calculated for each road link in the urban network and each 15 min time interval for a detailed assessment. They have been aggregated over all respective links and enable an estimation of the whole urban transportation network. If KPIs for single routes were applied, an improved KPI on one route may be accompanied by a deteriorated KPI on other routes. The further aggregation over time yields the KPIs for the simulated time period (6 a.m. to 9 a.m.) and the respective scenarios.

TABLE I: KEY PERFORMANCE INDICATORS (KPIs) FOR THE ASSESSMENT

Name	Symbol	Unit	Aggregation method
Average journey time in the network	TT	[min/km]	Arithmetic mean
Excess journey time (relative to free flow travel time)	DELAY	[min/km]	Arithmetic mean
Total vehicle*km travelled	VEH_KM	[veh*km]	Sum
Total vehicle*min travelled	VEH_TT	[veh*min]	Sum
Traffic related CO <sub>2</sub> emissions	CO2	[kg]	Sum
Traffic related black carbon emissions	BC	[kg]	Sum
Traffic related particle matter emissions	PM10	[kg]	Sum
Traffic related NO <sub>x</sub> emissions	NOX	[kg]	Sum

### B. Effective traffic management actions

For scenario comparison, KPIs have been calculated as average values of the scenario simulation runs with 24 different seeds and have been related to the values of the base scenario, yielding percentage values of their change. To give an example for KPI variability, variability of CO<sub>2</sub> emissions between simulation runs is presented (Figure 3).

Results show that emission-related simulated KPIs could be reduced by up to six percent compared to the base scenario (see Table II). The scenario with the highest win-win of traffic performance and emissions is the scenario “TDIn\_TLW2E5\_VMGW\_DR05”, where the traffic management actions have already been set during traffic increase (TDIn). Only 5% of drivers need to follow the VMS “Go West” advice (VMGW\_DR05) to switch from the eastern to the western arterial road and in order to back up the advice, the traffic signalling program is set on the eastern route to the off-peak program (TLW2E5), which is sub-optimal in terms of vehicle through-put. A further shift of drivers (10% or 15%) would also yield an improvement in terms of the base scenario (see Table II), but not in terms of the similar 5% scenario.

The effect is due to an improved balancing of loads between the Route East and the Route West. In addition, the capacity reduction, caused by the off-peak signal program, results in a small reduction of vehicle mileage (about 1.6 %). The effects of the vehicle spill-back on the rural roads adjacent to the urban network have not been investigated.

In general, simulated KPI travel time could be reduced up to seven percent for several ITS Actions (e.g. “TDDe\_TLW2E5\_VMGW\_DR10”). However, reduced travel time does not necessarily mean a reduction of emissions, because drivers might shift from their original (shortest) route to a faster but possibly longer route. Although travel times decrease, the total travelled distances and energy consumption



could increase. However, for all scenarios, KPI “vehicle-kilometre travelled” remains stable with values between 98 and 100% over all scenarios (see Table II).

The absolute values of calculated emissions are presumably overestimated due to overestimated acceleration values. As the effective traffic management actions increase or decrease average speeds and do not affect driving behaviour, single speed distribution and acceleration distribution should only undergo a small change. Therefore, the overestimation of calculated emissions is expected to have the same extent in all scenarios and the relative change of emission values is assumed to be of the correct order of magnitude. Additionally the fact that the reduction in average travel time is of the same order also supports this interpretation.

TABLE II: KPI RANGE FOR DIFFERENT SCENARIOS (PERCENTAGE OF CHANGE RELATIVE TO BASE SCENARIO)

Name	KPI range (min – max)	ITS Action ID
Average journey time in the network	93.1	TDDe_TLW2E5_VMGW_DR10
	103.5	TDDe_TLW5E2_VMGW_DR15
Excess journey time (relative to free flow travel time)	61.0	TDDe_TLW2E5_VMGW_DR05
	119.7	TDDe_TLW5E2_VMGW_DR15
Total vehicle*km travelled	98.3	TDIn_TLW2E5_VMGW_DR05
	100.2	TDDe_TLW2E2_VMGW_DR15
Total vehicle*min travelled	88.7	TDIn_TLW2E5_VMGW_DR05
	104.1	TDDe_TLW5E2_VMGW_DR15
Traffic related CO <sub>2</sub> emissions	94.4	TDIn_TLW2E5_VMGW_DR05
	101.2	TDMa_TLW2E2_VMGW_DR15
Traffic related black carbon emissions	94.9	TDIn_TLW2E5_VMGW_DR05
	101.4	TDMa_TLW2E2_VMGW_DR15
Traffic related particle matter emissions	95.4	TDIn_TLW2E5_VMGW_DR05
	101.0	TDMa_TLW2E2_VMGW_DR15
Traffic related NO <sub>x</sub> emissions	93.3	TDIn_TLW2E5_VMGW_DR05
	101.7	TDMa_TLW2E2_VMGW_DR15

VII. CONCLUSIONS AND RECOMMENDATIONS

This paper has investigated the possible impact of traffic management measures on emission reduction for a distinct area of the city of Graz. The test area covers a crucial part of the inflow traffic between the motorway & the rural road network

and the city area, which covers an area of 3.5 km<sup>2</sup> with 21 intersections.

In terms of traffic simulation, the following extensive steps have been performed for a close-to-reality and methodologically sound simulation, which is required to obtain realistic results in terms of emissions.

- Traffic count data have been analysed from 143 loops over 964 days, from which 85% of the data satisfied the criteria for the path flow estimation.
- A cross check has been performed with additional data for the traffic signalling.
- Measurements of floating car data, performed by 18 drivers over the course of two days, have been taken, which served the calibration and validation of the VISSIM model.

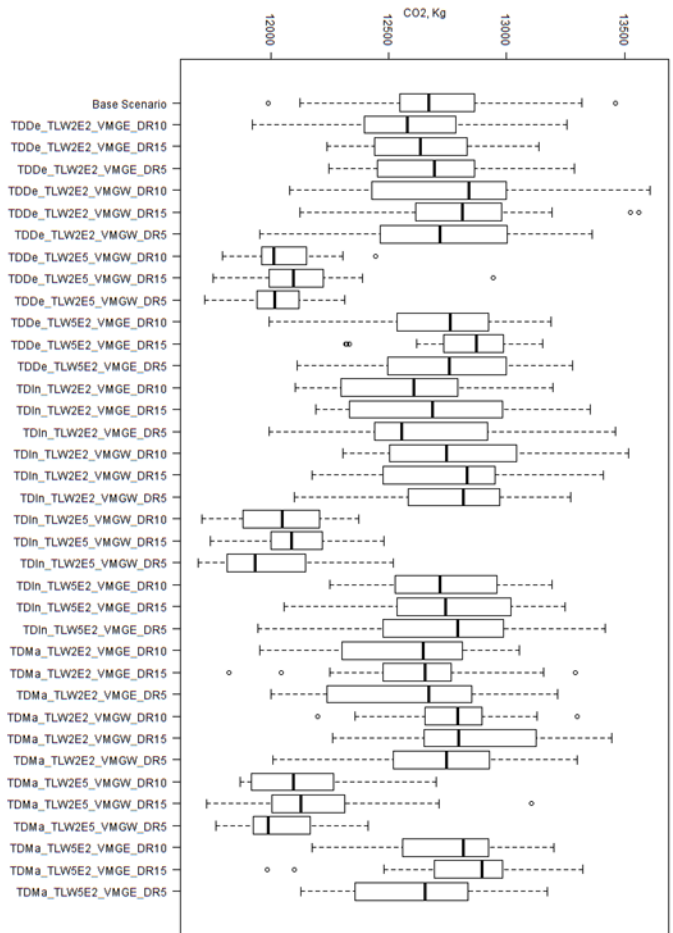


Figure 3: total CO<sub>2</sub> emissions (box plots for all traffic scenarios)

Considering the options for an implementation and field test, 37 simulation scenarios have been designed, which differ in the timing and the combination of Variable Message Signs messages (VMS) on the motorway and Traffic Light actions (TL) within the network. To include the statistical variability, the VISSIM simulations have been sampled with 24 random

seeds, leading to a total of 888 runs, yielding a stable and robust simulation base for the traffic management evaluation.

Simulated KPI “vehicle-kilometre travelled” remains stable between 98% and 100%. This indicator limits the reduction potential of traffic management measures on related tail-pipe emissions.

The results show that the measures in isolation, either the VMS action or the TL action, do not yield an improvement in terms of network performance or in emission reduction. Only a combination of drivers complying to the VMS with the sub-optimal traffic signal program yields an overall traffic performance increase and a reduction in emissions. This experiment shows that the network performance adds a distinct level of complexity, which cannot be foreseen from an intuitive perspective or from an assessment of, for example, an optimization of a single intersection [13].

In order to obtain a further reduction of emissions, other measures as mentioned in [1] such as bus or cycle lanes, may be required. This would require a long-term approach and also an extension of the test site area.

The next step will be a simulation of the pollutant concentrations with a distribution model, in order to show the interaction of the tail-pipe emission with the local and meteorological conditions. Furthermore, the recommended traffic management scenario will be tested in the test site Graz, and its real impact will be observed with accompanying traffic and emission measurements.

#### ACKNOWLEDGMENT

This study has been undertaken within the CARBOTRAF project funded by the 7th Framework Program under grant agreement n° 28786. We would also like to thank the city of Graz for their generous support of the project and for the provision of the data. We would also gratefully acknowledge the substantial support regarding the coding, design and calibration of the simulations and the simulated scenarios by our AIT-colleagues Gerald Richter, Simon Breuss, Wolfgang Ponweiser and Thomas Matyus.

#### REFERENCES

[1] Report of the United States Environmental Protection Agency, Transport Control Measures - An Information Document for Developing and Implementing Emissions Reductions Programs, 2011

[2] ECoMove (Cooperative Mobility Systems and Services for Energy Efficiency), D 5.7, Development and Testing of Traffic Management and Control Measures, FP7-ICT-2009-4 IP Proposal - 247908

[3] Qian R, Lun Z, Wenchen Y, Meng Z., A Traffic Emission-saving Signal Timing Model for Urban Isolated Intersections, *Procedia - Social and Behavioral Sciences*, 2013, 96:2404-2413

[4] Shenpei Z, Xiping Y, Chaozhong W., Optimization Model for Traffic Signal Control with Environmental Objectives, *Fourth International Conference on Natural Computation*, 2008, ICNC '08. 6: 530 - 534

[5] Hirschmann K., Fellendorf M., A toolbox to quantify emission reductions due to signal control, *TRB Annual Meeting 2010*, Washington 2010

[6] Madireddy M., De Coensel B., Can A., Degraeuwe B., Beusen B., De Vlioger I., Botteldooren D., Assessment of the impact of speed limit reduction and traffic signal coordination on vehicle emissions using an integrated approach, *Transportation Research Part D: Transport and Environment*, 2011, 16[7]: 504-508

[7] Boulter P.G., Latham S, Ainge M., Driving cycles for measuring passenger car emissions on roads with traffic calming measures, *Science of The Total Environment*, 1999, 235(1-3): 77-89

[8] Chen L., Yang B., Managing congestion and emissions in road networks with tolls and rebates, *Transportation Research Part B: Methodological*, 2012, Pages 46[8]: 933-948

[9] Toledo T., Koutsopoulos H., Davol A., Ben-Akiva M., Burghout W., Andréasson I., Johansson T., Lundin. C., Calibration and Validation of Microscopic Traffic Simulation Tools: Stockholm Case Study“, *Transportation Research Record: Journal of the Transportation Research Board*, 2003, 1831: 65–75

[10] Ge Q., Menendez M., Calibration Study for VISSIM, Final Report for city of Zürich / Dienstabteilung Verkehr, September 2012

[11] Jie L., Van Zuylen H., Chen Y., Viti F., Wilmlink I., Calibration of a microscopic simulation model for emission calculation, *Transportation Research Part C: Emerging Technologies*, 2013, 31: 172-184

[12] PTV Planung Transport Verkehr AG, VISSIM 5.40 – User Manual, 2012

[13] Li J.-Q., Wu G. Zou N., Investigation of the impacts of signal timing on vehicle emissions at an isolated intersection, *Transportation Research Part D: Transport and Environment*, 2011, 16: 409-414

[14] Lehnhoff N., Quality of Automatic Data Collection with Loop Detectors, *Proc. of the 2nd International Symposium “Networks for Mobility”*, 2004

[15] Nihan N.L., Wang Y., Cheeverunothai P., 2006. Improving dual-loop truck (and speed) data: quick detection of malfunctioning loops and calculation of required adjustments, *Technical Report WA-RD 647.1*, Washington State Transportation Center, University of Washington, 2006

[16] Belluicci P., Cipriani E., 2010. Data accuracy on automatic traffic counting: the SMART project results. *European Transportation Research Review 2*: 175-187.

[17] Analysis of Instantaneous Road Emissions (AIRE), User Guidance, Transport Scotland, June 2011