

# Second Generation of Pollutant Emission Models for SUMO

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Wissen für Morgen



# Emission Models

## Why?

Does traffic cause emissions? Sure...

Some regulations already exist ...

- reduce emissions of current vehicle fleets (car manufacturer)
- thresholds for  $\text{NO}_x$  and  $\text{PM}_x$  concentrations (local administration)

... as well as different approaches to reduce them:

- fleet management
- regulative actions (environmental zones, ...)
- infrastructure-based solutions (traffic lights, ...)
- in-vehicle solutions (GLOSA, ...)

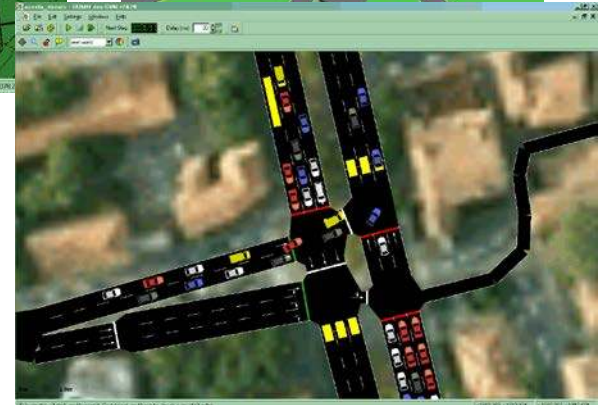
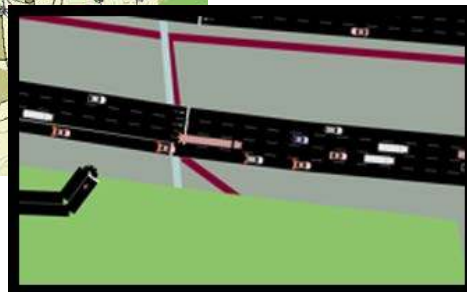
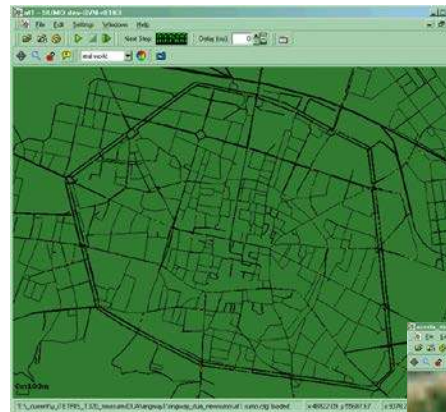
Answering whether they work is a traffic simulation task.



# Emission Models

## Requirements #1

What do we need?  
Let's take a look at typical scenarios...

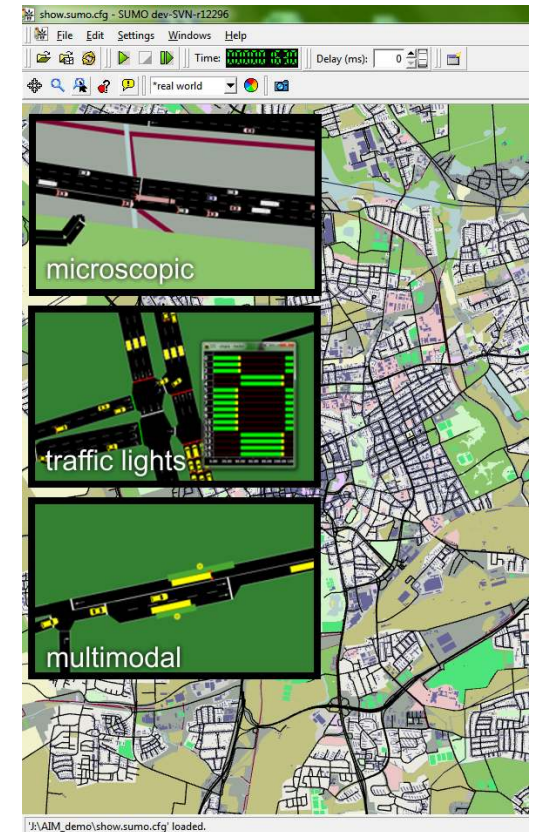


# Emission Models

## Requirements #2

How should an emission model look like to fit into SUMO? It should:

- cover the complete vehicle population;
- offer a classification into EURO-norms;
- compute CO, CO<sub>2</sub>, NO<sub>x</sub>, PM<sub>x</sub>, HC, and fuel consumption;
- sensible to microscopic parameters available in the simulation;
- require only information that is available in the simulation;
- compute emissions in simulated time steps;
- easy to parameterize;
- portable, fast in execution;
- licensed under a GPL-compatible license.



# Emission Models

## Emission Models Survey – 2008, freely available only

	factors	vehicle model/class	fuel type	macroscopic average velocity	velocity	acceleration	engine temperature (cold/hot)	time line of velocities	time line of accelerations	vehicle mass	rolling resistance coefficient	road grade	engine displacement	air drag resistance	fuel-to-air equivalence ratio	engine parameters (1)	speed correction rolling coefficient	total tractive power	idle rate	rotational inertia coefficient	vehicle curb weight	VSP	engine stress	drive-train efficiency	accessoirs' consumption
#a09: DAT-Table																									
#a10: HBEFA																									
#a04: COPERT III																									
#a14: CT-EMFAC																									
#a15: Bai																									
#a01: Eissfeldt																									
#a02: MOBILE6																									
#a06: VT-M																									
#a03: INTEGRATION																									
#a05: EMIT																									
#a07: CMEM																									
#a08: AskPablo																									
#a11: Biggs/Akcelik																									
#a12: EcoGest																									
#a13: Kebin He																									

legend:



already included in SUMO  
 easy to implement  
 rather complicated to be determined for a vehicle population  
 complicated to be determined for a vehicle population  
 impossible to be determined for a vehicle population / not given (factors)  
 part of the model

(1) such as engine speed, engine indicated efficiency, idle engine friction factor

	consumption	HC	NOx	CO	VOC	PM	NM VOC	CH4	CO2	further
#a09: DAT-Table										
#a10: HBEFA										several others
#a04: COPERT III										
#a14: CT-EMFAC										SOx
#a15: Bai										
#a01: Eissfeldt										
#a02: MOBILE6										
#a06: VT-M										
#a03: INTEGRATION										
#a05: EMIT										
#a07: CMEM										
#a08: AskPablo										
#a11: Biggs/Akcelik										
#a12: EcoGest										green house gas
#a13: Kebin He										



# Emission Models

## HBEFA Implementation from iTETRIS

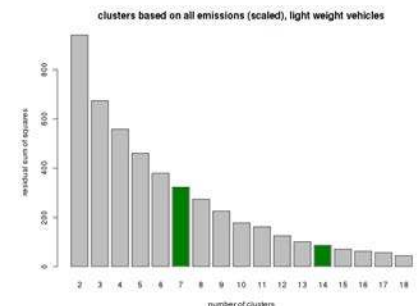
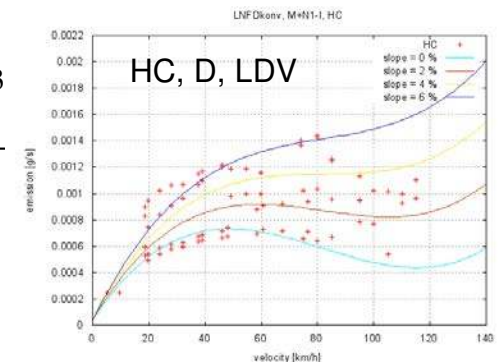
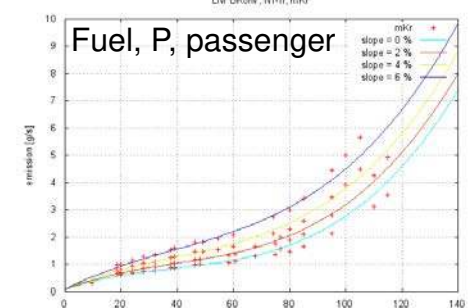
In the end, we have

- chosen an inventory model (HBEFA v2.1)
- extracted the data
- fitted them to a function

$$EF_p(v, \alpha) = \frac{c_0 + c_{va_1} v a + c_{va_2} v a^2 + c_1 v + c_2 v^2 + c_3 v^3}{3600}$$

- clustered the so obtained curves
- embedded this in SUMO

(that all was already described, in fact)



## Emission Models

### HBEFA Implementation from iTETRIS – Issues

Great?! So why do we need new models?

- Modern vehicles (EURO-5, EURO-6) were not covered by HBEFA 2.1 properly
- The obtained fits to the data do not always fulfil basic constraints
  - emission at idling  $> 0$
  - no emissions  $< 0$
- Joining emission classes into clusters is a bad idea – one loses the control over the vehicle fleet

So both had to be done:

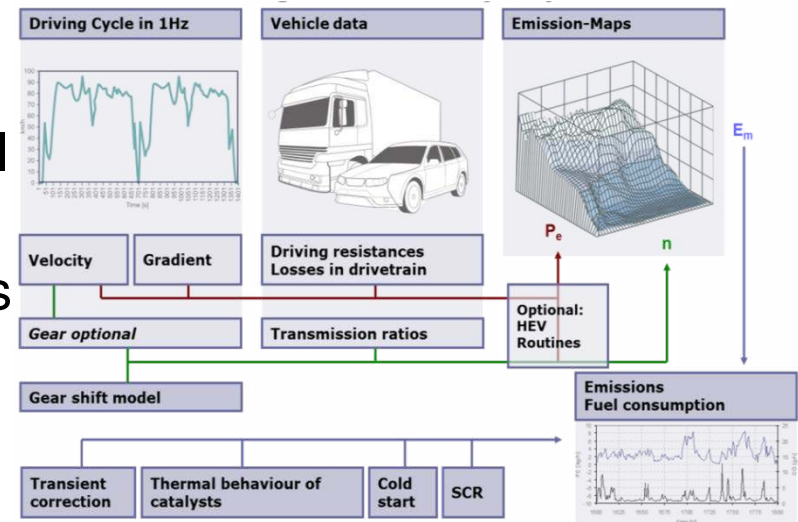
- Updating the database
- Improving the data processing



## Emission Models PHEMlight #1

Based on PHEM („Passenger Car and Heavy Duty Emission Model”)

- Product of TU Graz
- An instantaneous emission model
- Consists of several sub-models
- Calibrated to real-world measures
- Feeds HBEFA and COPERT
- Commercial license



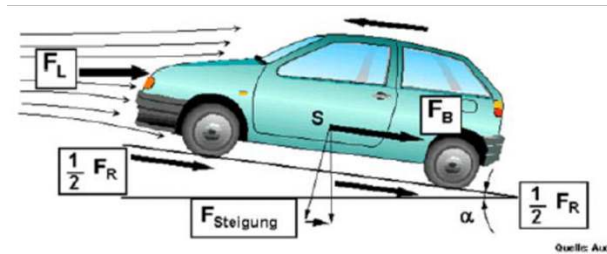
Joint work between TU Graz and DLR within the COLOMBO project  
Besides implementing PHEMlight, TU Graz also extended PHEM by models for start/stop systems, hybrid electrical and fully electrical vehicles, vehicles running on compressed natural gas



## Emission Models PHEMlight #2

Slightly different approach than HBEFA-derivations  
-Compute the needed power, first

$$P_e = (P_{\text{rolling resistance}} + P_{\text{air resistance}} + P_{\text{acceleration}} + P_{\text{road gradient}}) / \eta_{\text{gearbox}}$$



$$P_R = (m_{\text{Vehicle}} + m_{\text{Load}}) \times g \times (Fr_0 + Fr_1 \times v + Fr_4 \times v^4) \times v$$

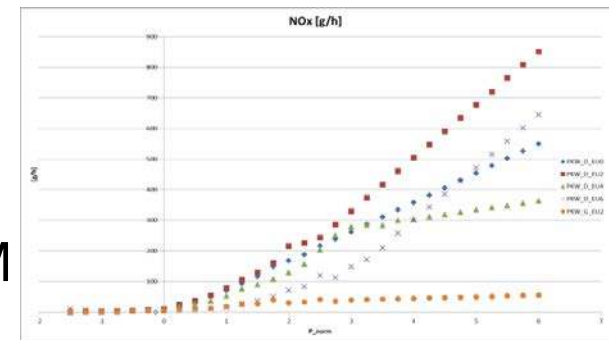
$$P_{\text{Air}} = (Cd \times A \times \frac{\rho}{2}) \times v^3$$

$$P_a = (m_{\text{Vehicle}} + m_{\text{Rot}} + m_{\text{Load}}) \times a \times v$$

$$P_{\text{grad}} = (m_{\text{Vehicle}} + m_{\text{Load}}) \times \text{Gradient} \times 0.01 \times v$$

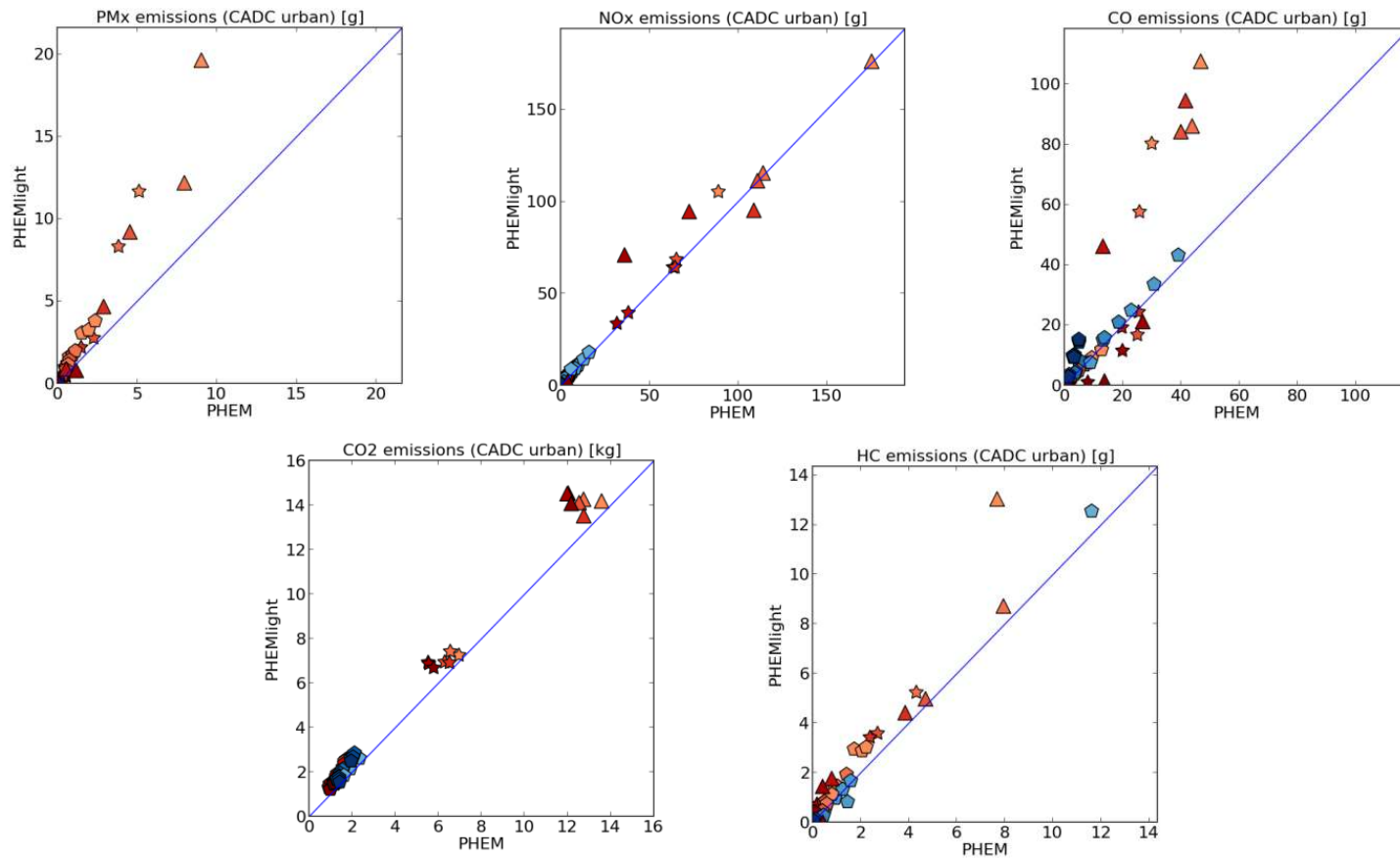
$$\eta_{\text{gearbox}} = 0.95 \quad (\text{average efficiency})$$

- Then look up in according “CEP” files  
(CEP: Characteristic Emission curves over Power)
- CEP-files are obtained by sampling PHEM



# Emission Models

## PHEM against PHEMlight





## Emission Models

### New HBEFA implementation

Almost as done in iTETRIS, but

- Using up-to-date HBEFA version 3.1
- More emission classes covered
- New, improved fitting procedure
- No clustering
- Free and included in SUMO

### Some drawbacks

- Only some major classes were selected, but the model is easily extensible
- The dependency on acceleration had to be determined from the dependency on the slope of the road, given in HBEFA
- Not all pollutants' curves can be fit well to the used function



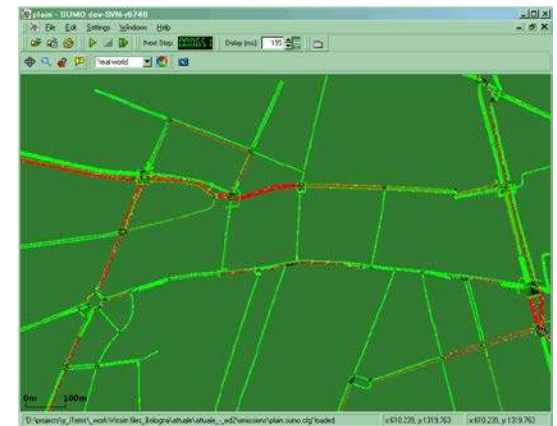
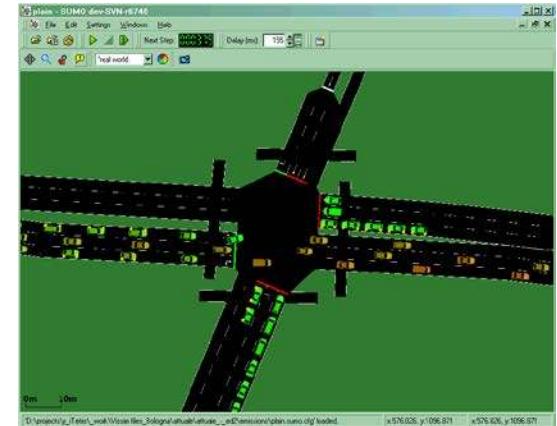
# Emission Models

## Generated Data

Several data types can be generated

- aggregation of emissions per lane with variable interval time spans
- aggregation of emissions per edge with variable interval time spans
- aggregation of emissions for each simulated vehicle
- non-aggregated (step-wise) vehicle emissions
- a vehicular trajectory file as defined in AMITRAN

... but some other (mainly areal)  
seem to be additionally needed ...



# Emission Models

## Comparison

### PHEMlight is commercial

- The source code is GPL-licensed and included in SUMO
- Two vehicle classes are included
- The other data has to be licensed from TU Graz

### HBEFA v3.1-derivation is included in SUMO

- Completely GPL-licensed

### HBEFA v2.1-derivation will be probably removed at some time

- Already deprecated



# Emission Models Comparison

Requirement	HBEFA 2.1-based	HBEFA 3.1-based	PHEMlight
No. of emission classes	56*2(+1)	45(+1)	112(+1)
coverage	no modern (Euro 6) and seldom classes	Major passenger, heavy duty, and bus classes	almost complete, new engine types
Euro-Norms	-	x	x
Covers chosen pollutants	x	x	x
Uses speed	x	x	x
Uses acceleration	x	x	x
Uses slope	-	-	x
Needs further attributes	-	-	x (are included)
Step-size resolution	x	x	x
Easy parameterization	x	x	x



# Emission Models Comparison

1.: Difficult! Compare against what?

- Only possible for single vehicles – but is this what we need?

First check: emission values for Brunswick (old HBEFA)

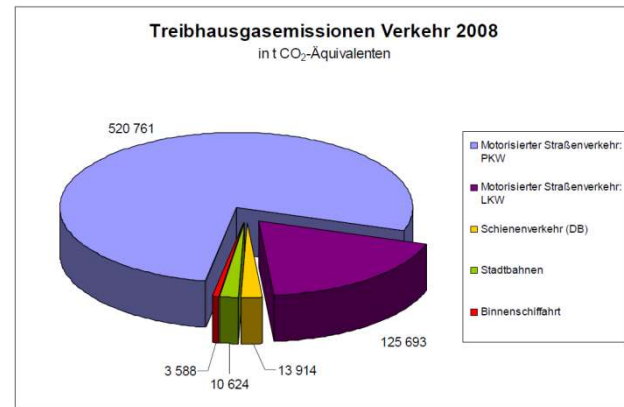
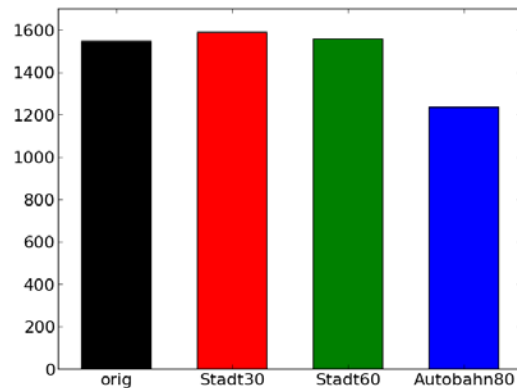


Abbildung 2.22: Treibhausgasemissionen des Gesamt-Verkehrs in 2008



$521\text{kt} + 126\text{kt} = 647\text{kt p.a.}$ ;  $647\text{kt p.a.} / 365 \text{ days} \approx 1772 \text{ t}$

10 % error? Great, but: Same area? Same population? Who knows?



# Emission Models

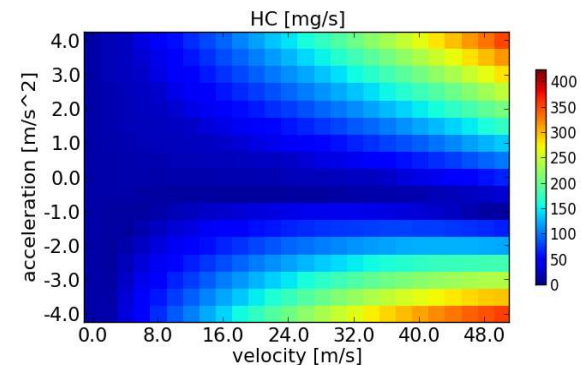
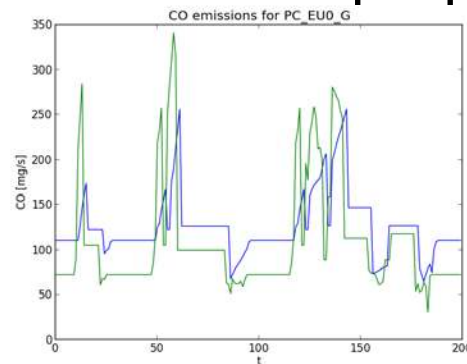
## Additional Tools #1

Well, three models  
→ Model Test Suite!

... needs some further tools, mainly for evaluation ...

- Emissions map generator
- An emissions computing application that reads trajectories
- Some visualisation scripts

... already in use for other purposes (trajectory optimisation)

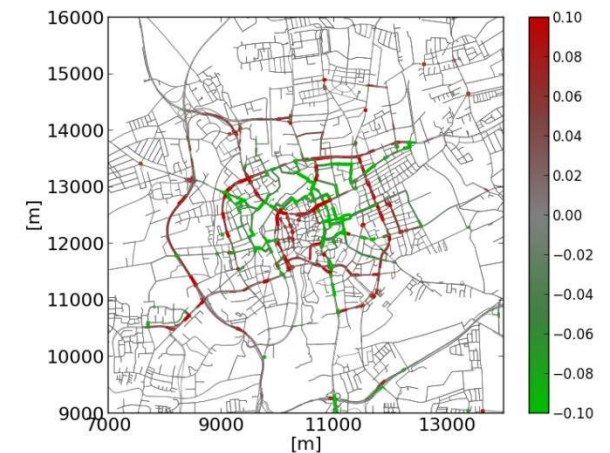
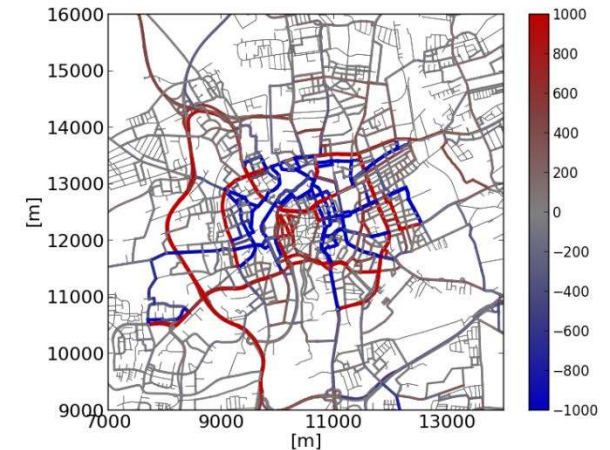
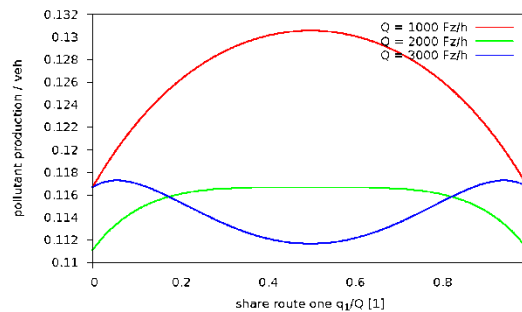
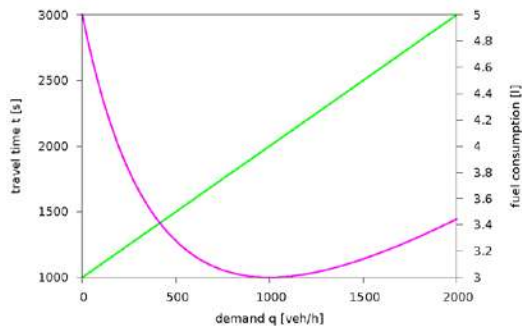


# Emission Models

## Applications #1

Large-scale investigations,  
mainly based on route choice

- abstract emission-based traffic assignment
- simulation of regulative traffic management actions (changes in speed limits, environmental zones)

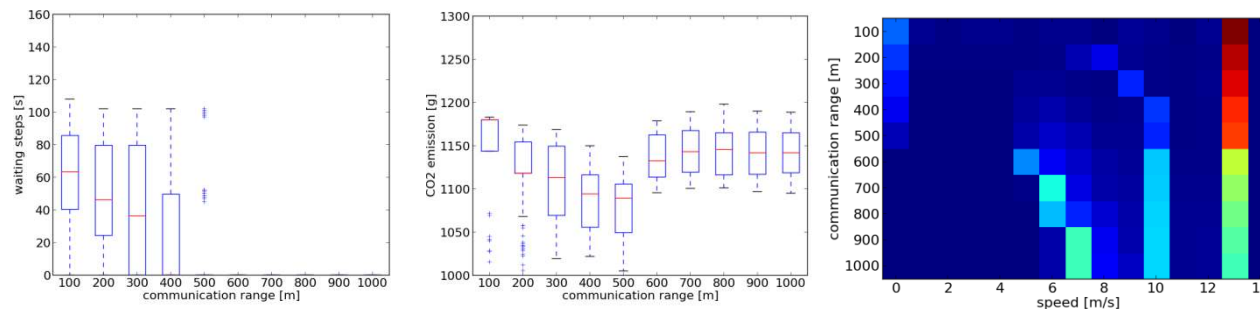


# Emission Models

## Applications #2

### Benchmarking ITS-solutions

- usually boring, but sometimes surprising (trivial GLOSA may generate more emissions)



### Current work topics in COLOMBO

- emission-optimal driving behaviour
- local emissions monitoring system
- Investigation of correlations between conventional and emission measurements



# Emission Models

## Next Steps

### Missing at most:

- a dispersion / imission model
- some better ways to interpret the measures
- some tools to ease the definition of a vehicle population
- some more evaluations, also against available measures from single vehicles



# SUMO

... in the end ...



Institut für Verkehrssystemtechnik / DLR

Aktuelle Version:

Version 0.20.0

Webseite / Download:

<http://sumo-sim.org/>

Kontakt:

sumo-user@lists.sourceforge.net

