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Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

Good practice guidelines on urban traffic emission compilation

FAIRMODE
Forum for air quality modelling in Europe

FAIRMODE Technical Meeting
24-25 June 2015, Aveiro, Portugal

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Urban traffic emissions

Road traffic's contribution to air quality in European cities

ETC/ACM Technical Paper 2012/14
November 2012

Ingrid Sundvor, Núria Castell Balaguer, Mar Viana, Xavier Querol, Cristina Reche, Fulvio Amato, Giorgos Mellios, Cristina Guerreiro

European Topic Centre on Air Pollution and Climate Change Mitigation

The European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM) is a consortium of European institutes under contract of the European Environment Agency
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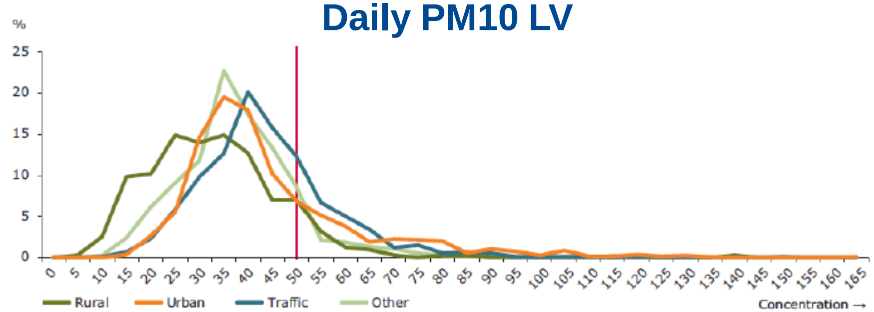
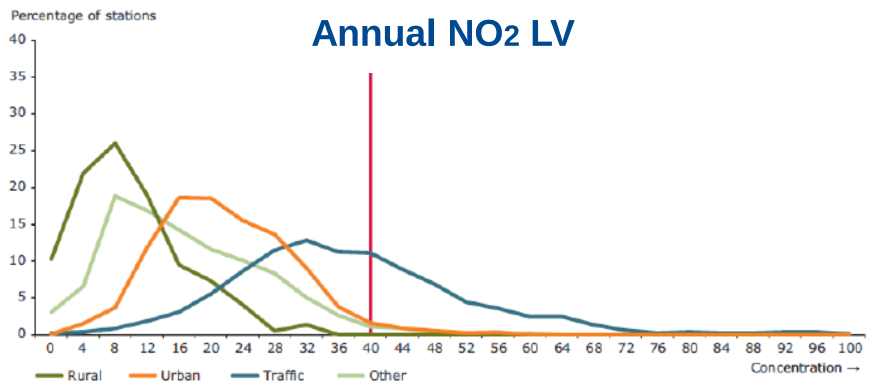
Road traffic is the emission source that contributes most to air pollution in urban areas

Daily PM10 LV



Annual NO_2 LV



Component	Station type	Local traffic % range (average)	Urban traffic % range (average)	Local and Urban % range (average)
PM10	Traffic	6-54 (21)	3-39 (13)	13-61 (34)
NO2	Traffic	10-80 (47)	3-56 (17)	34-91 (64)

Traffic emission models

INPUT

- Vehicle activity
- Vehicle fleet composition
- Exhaust EF
- f-NO2
- Non-exhaust EF

TYPES OF MODEL (Smit et al., 2010)

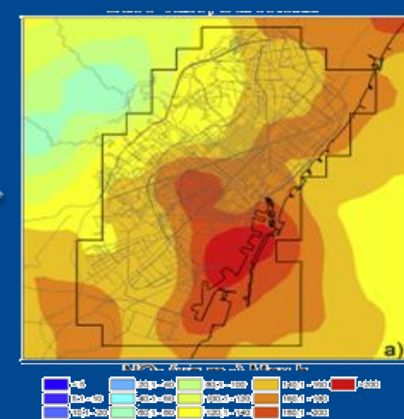
Macroscopic

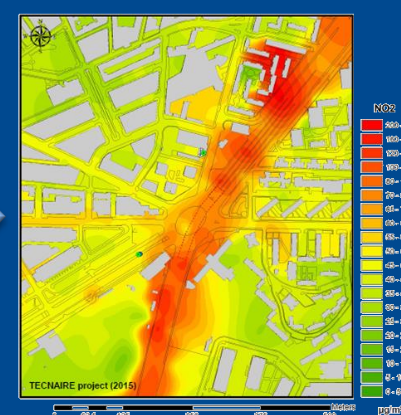
- Average-speed models (e.g. COPERT)
- Traffic-situation models (e.g. HBEFA)
- Traffic-variable models (e.g. TEE)
- Cycle-variable models (e.g. VERSIT+)
- Modal models (e.g. PHEM)

Microscopic

OUTPUT

(Soret et al., 2014)





(Borge et al., 2015)

Current review works

Atmospheric Environment 44 (2010) 2943–2953

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Review

Validation of road vehicle and traffic emission models – A review and meta-analysis

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A R T I C L E I N F O

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Road traffic
Emission model
Accuracy
Validation
Error
Greenhouse gas

A B S T R A C T

Road transport is often the main source of air pollution in urban areas, and there is an increasing need to estimate its contribution precisely so that pollution-reduction measures (e.g. emission standards, scrapage programs, traffic management, ITS) are designed and implemented appropriately. This paper presents a meta-analysis of 50 studies dealing with the validation of various types of traffic emission model, including 'average speed', 'traffic situation', 'traffic variable', 'cycle variable', and 'modal' models. The validation studies employ measurements in tunnels, ambient concentration measurements, remote sensing, laboratory tests, and mass-balance techniques. One major finding of the analysis is that several models are only partially validated or not validated at all. The mean prediction errors are generally within a factor of 1.3 of the observed values for CO_2, within a factor of 2 for HC and NO_x, and within a factor of 3 for CO and PM, although differences as high as a factor of 5 have been reported. A positive mean prediction error for NO_x (i.e. overestimation) was established for all model types and practically all validation techniques. In the case of HC, model predictions have been moving from underestimation to overestimation since the 1980s. The large prediction error for PM may be associated with different PM definitions between models and observations (e.g. size, measurement principle, exhaust/non-exhaust contribution).

Statistical analyses show that the mean prediction error is generally not significantly different ($p < 0.05$) when the data are categorised according to model type or validation technique. Thus, there is no conclusive evidence that demonstrates that more complex models systematically perform better in terms of prediction error than less complex models. In fact, less complex models appear to perform better for PM. Moreover, the choice of validation technique does not systematically affect the result, with the exception of a CO underprediction when the validation is based on ambient concentration measurements and inverse modelling. The analysis identified two vital elements currently lacking in traffic emissions modelling: 1) guidance on the allowable error margins for different applications/scales, and 2) estimates of prediction errors. It is recommended that current and future emission models incorporate the capability to quantify prediction errors, and that clear guidelines are developed internationally with respect to expected accuracy.

Atmospheric Environment 70 (2013) 84–97

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Review

Road vehicle emission factors development: A review

CrossMark

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[b] Laboratory of Applied Thermodynamics, Aristotle University, P.O. Box 458, GR-54124 Thessaloniki, Greece
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H I G H L I G H T S

► The accuracy of road emission models is directly linked to the quality of their emission factors.
► Road vehicles have a large natural variability in their emission profiles.
► Emission factors may have different resolution according to their intended use.
► Emission modellers should combine laboratory data with real-world measurements.

A R T I C L E I N F O

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Keywords:
Road transport
Emission inventories
Emission models
Emission factors
Chassis dynamometer
Engine dynamometer
PEMS

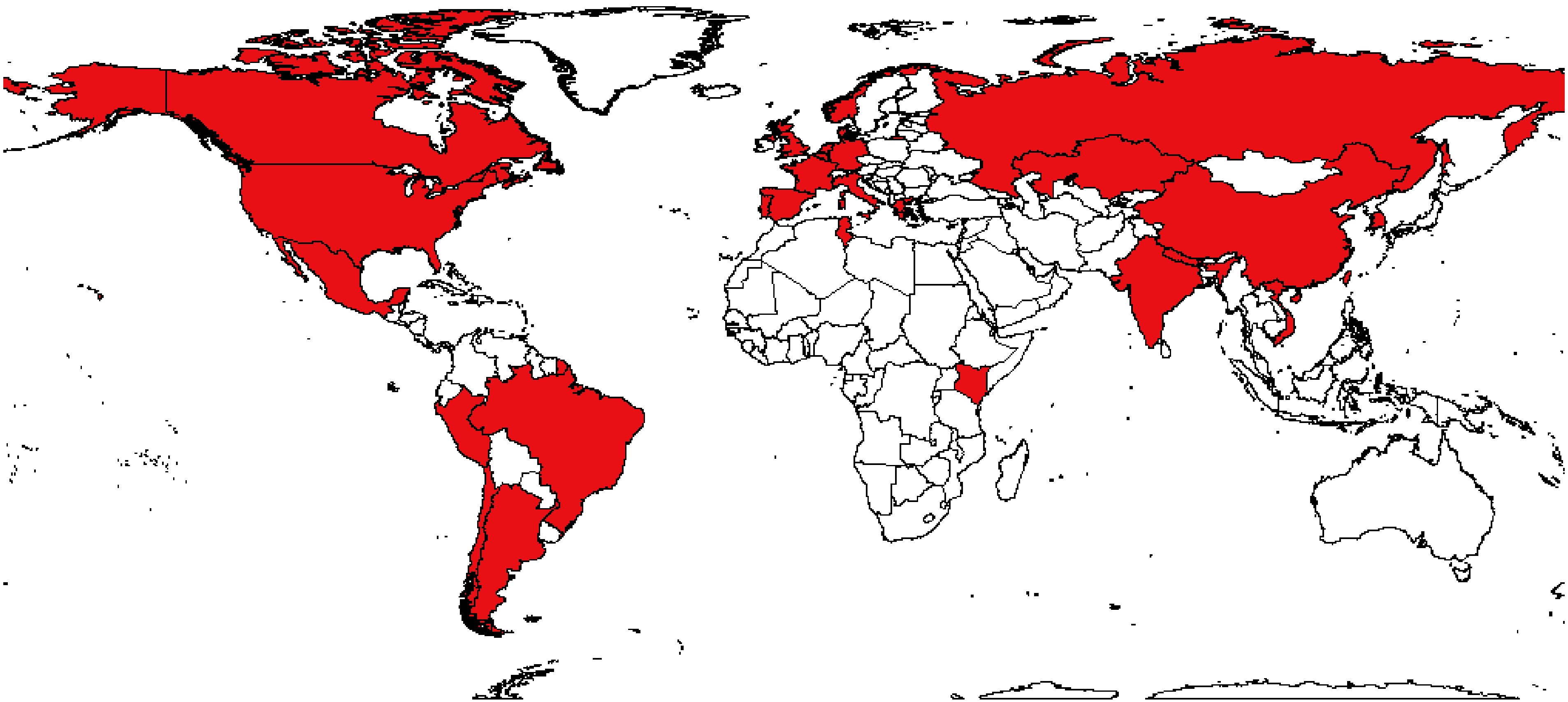
A B S T R A C T

Pollutant emissions need to be accurately estimated to ensure that air quality plans are designed and implemented appropriately. *Emission factors* (EFs) are empirical functional relations between pollutant emissions and the activity that causes them. In this review article, the techniques used to measure road vehicle emissions are examined in relation to the development of EFs found in *emission models* used to produce emission inventories. The emission measurement techniques covered include those most widely used for road vehicle emissions data collection, namely chassis and engine dynamometer measurements, remote sensing, road tunnel studies and portable emission measurements systems (PEMS). The main advantages and disadvantages of each method with regards to emissions modelling are presented. A review of the ways in which EFs may be derived from test data is also performed, with a clear distinction between data obtained under controlled conditions (engine and chassis dynamometer measurements using standard driving cycles) and measurements under real-world operation.

Research questions

1) **What methods are currently used to compile the input parameters that estimate road traffic emissions?**
2) **What is the sensitivity of the emission results to these parameters?**
3) **What are the best practices to apply when estimating urban traffic emissions?**

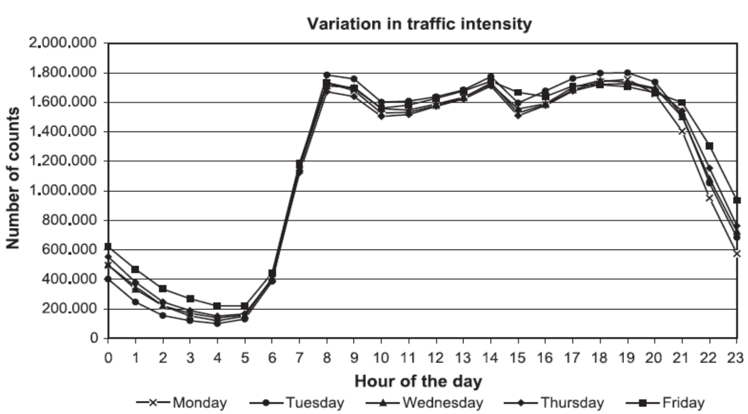
Reviewed works



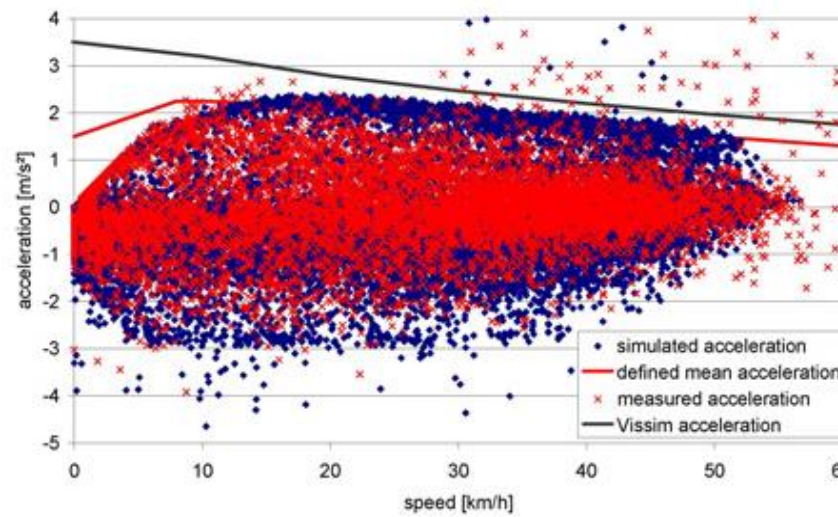
- **More than 60 papers and reports reviewed**
- **Topic: Urban traffic emission estimations**

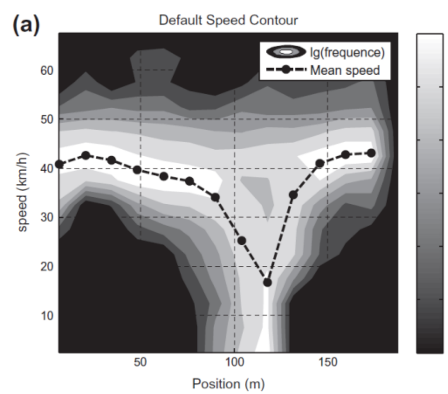
Vehicle activity: Definition

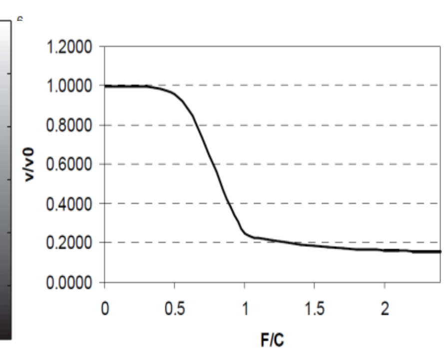
Traffic volume



Driving patterns

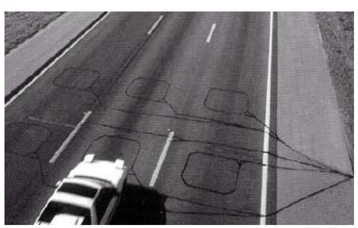






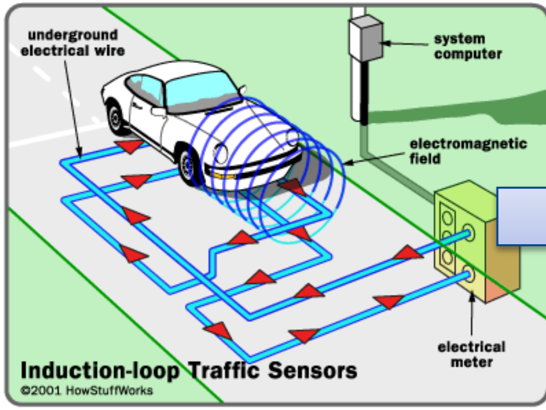
Vehicle activity: Summary of works

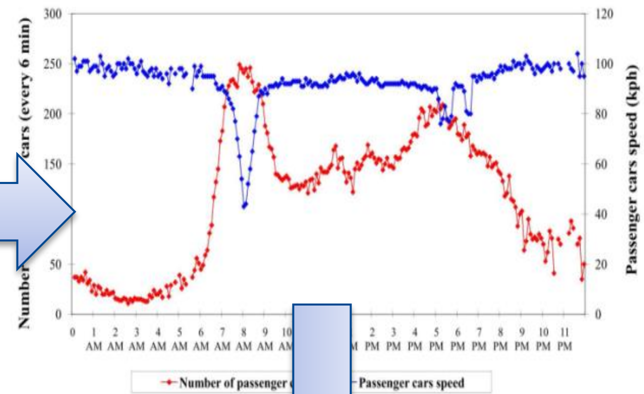
Manual counting and video recording	Davis et al. (2005); Kassomenos et al. (2006); MoUD (2008); Gokhale et al. (2011); Ho and Clappier (2011); Lozhkina (2015); Shrestha et al. (2013)
Automatic Traffic Recorders	Muller-Perriand (2014); Borrego et al. (2000); Tchepel et al. (2012); Hung et al. (2010); Guevara et al. (2013); Ariztegui et al. (2004); Pallavidino et al. (2014); Cai and Xie (2011); Malcom et al. (2003); Baldasano et al. (2010); Tchepel et al. (2012); Muller-Perriand (2014); ; Guevara et al. (2013); Cai and Xie (2011); Malcom et al. (2003); Baldasano et al. (2010)
Traffic Models	Brutti-mairesse et al. (2012); Thiyagarajah and North (2012); Jie et al. (2013); Samaras et al. (2014); Nanni et al. (2010); Radice et al. (2012); Cook et al. (2008); Borge et al. (2012); Lindhjem et al. (2012); Pallavidino et al. (2014); Nejadkoorki et al. (2008); Hatzopoulou and Miller (2010); Borge et al. (2015); Brutti-mairesse et al. (2012); Jie et al. (2013); Samaras et al. (2014); Cook et al. (2008); Borge et al. (2012); Nejadkoorki et al. (2008); Hatzopoulou et al. (2010); Hirschmann et al. (2010); Bai et al. (2007); Nanni et al. (2010); Bedogni et al. (2014); Kanaroglou et al. (2008)
Instrumented vehicles	Tate et al. (2013); ISSRC studies; Oanh et al. (2012); Wang et al. (2008); LAIE (2010); Gois and Maciel (2007); Malcom et al. (2003); MoUD (2008); Carslaw et al. (2005); LAIE (2008)
Floating car data	Gühnemann et al. (2004); Yu and Peng (2013); LAEI (2010); Lin-Jun et al. (2014); Ryu et al. (2013)

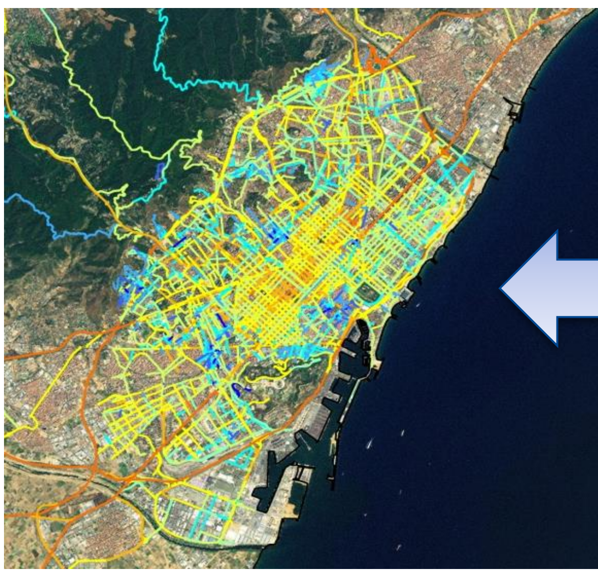



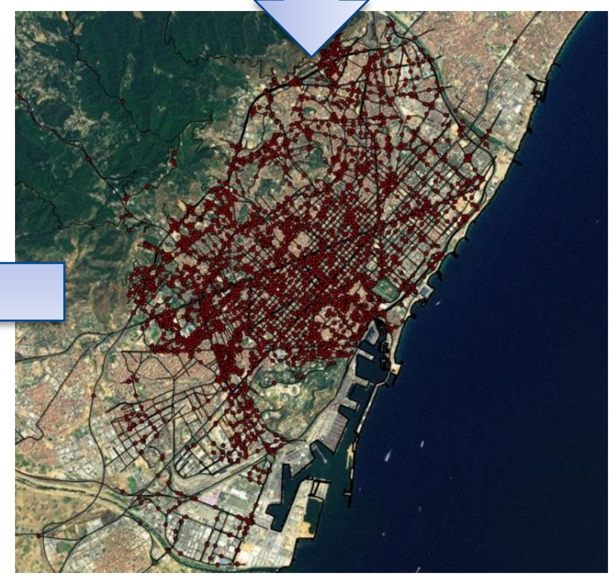

Vehicle activity: Automatic traffic recorders

Muller-Perriand (2014)







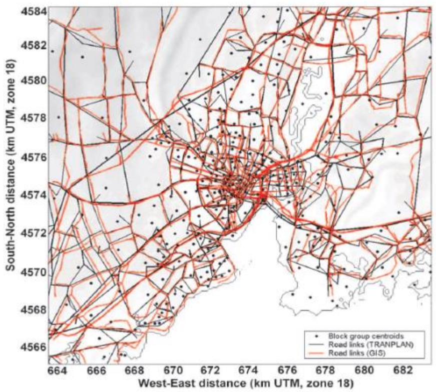


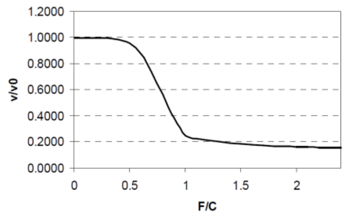
Guevara et al. (2013)

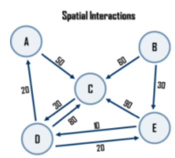
✗ Limited spatial coverage (main streets)

Vehicle activity:
Traffic and travel demand models

Macroscopic models





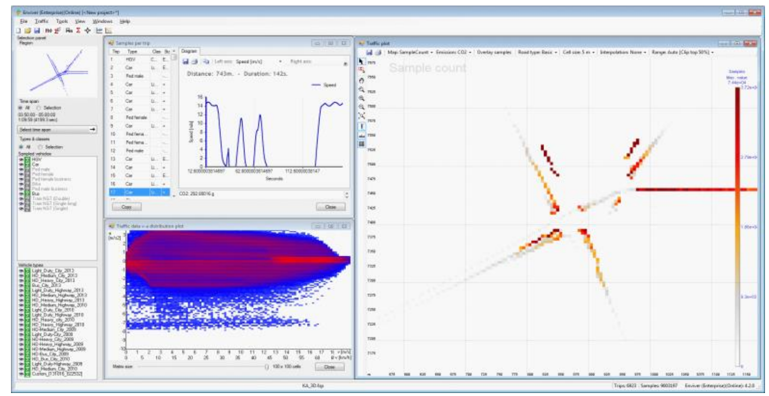


O/D Matrix

	A	B	C	D	E	Ti
A	0	0	50	0	0	50
B	0	0	60	0	30	90
C	0	0	0	30	0	30
D	20	0	80	0	20	120
E	0	0	90	10	0	100
Tj	20	0	280	40	50	390

Traffic volume and speed at the link level

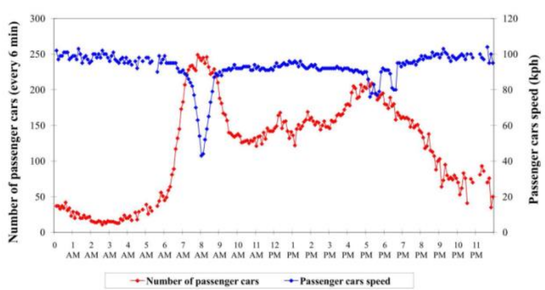
Microscopic models



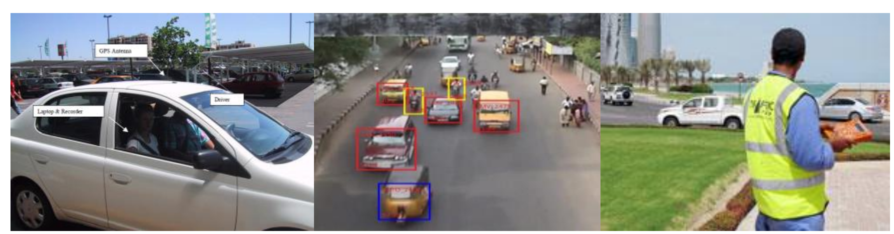
Driving patterns of each vehicle in the traffic stream

Calibration / Validation

Automatic Traffic Recorders



Probe vehicle or image processing

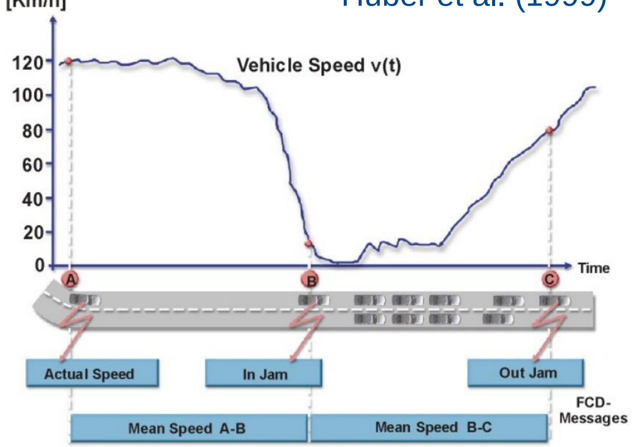


Vehicle activity: Floating car data (FCD)

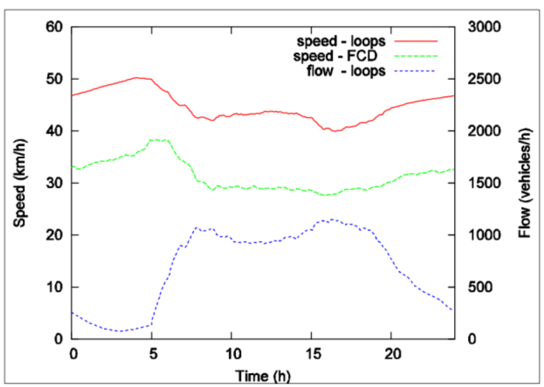
Collects real-time traffic state information from individual vehicles equipped with positioning (GPS) or cellular-based (e.g. GSM, GPRS) systems

Speed. Very high spatial and temporal resolution

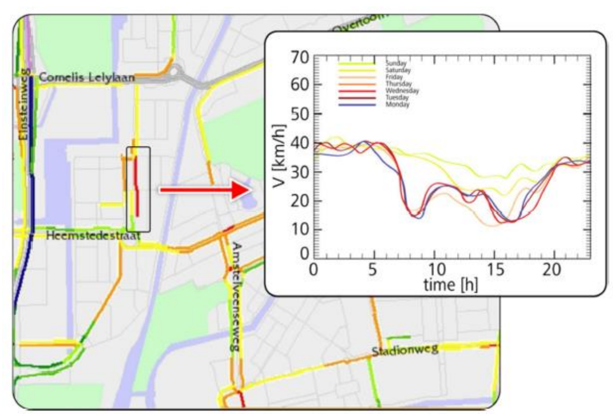
Huber et al. (1999)



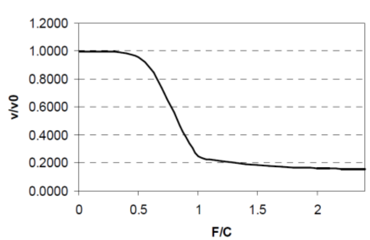
Gühnemann et al. (2004)

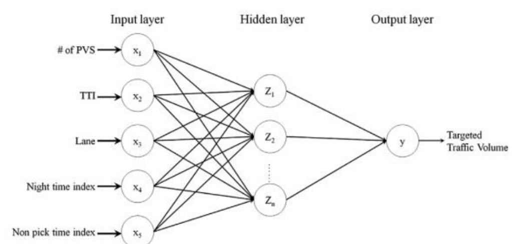


Brower (2014)



Volume. Only equipped vehicles. **But….**

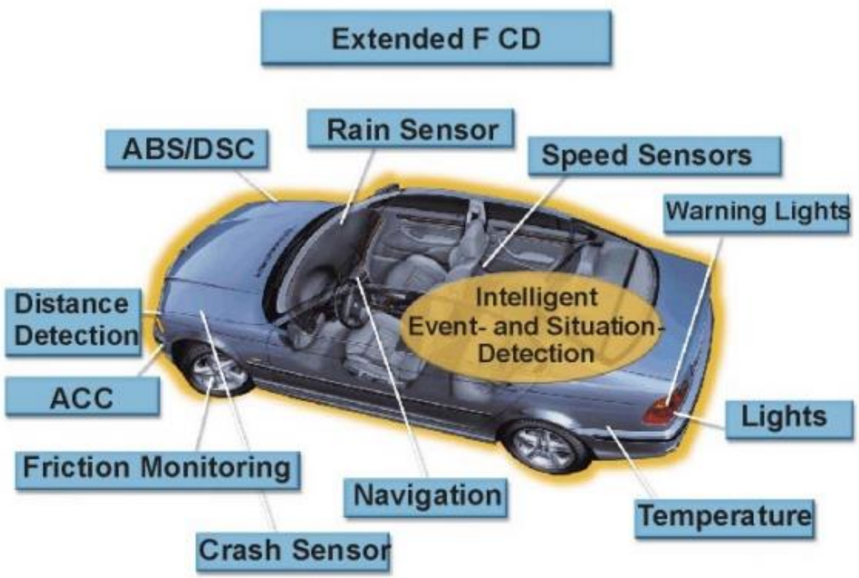


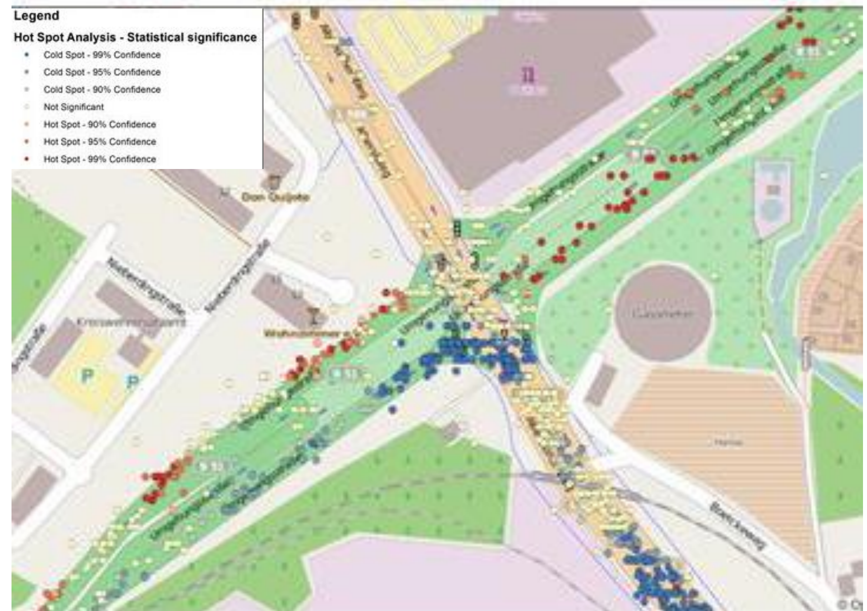


eCall

Vehicle activity: Extendend Floating car data (xFCD)

Extended Floating Car Data (xFCD)
Beside the vehicle speed, there is a whole range of other operating and switching data available in digital form on the bus systems of modern vehicles





Huber et al. (1999)

Prummer (2014)

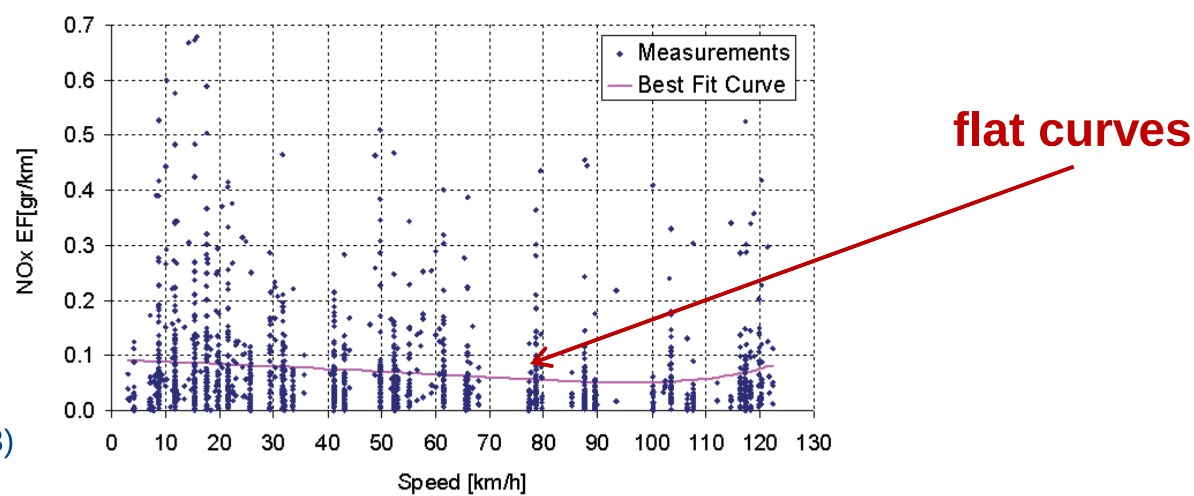
Car's fuel consumption

Car's CO_2 emissions

Vehicle activity: Sensitivity analysis

	Reference	Demand	Non-calibrated SFC	Akçelik SFC
NOx (ton)	1.18	+8%	-5%	+6%
PM (ton)	0.14	+7%	-3%	+3%
Veh.km $x10^6$	1.85	+10%	-3%	-2%
Speed (km/h)	47	-10%	+17%	-31%

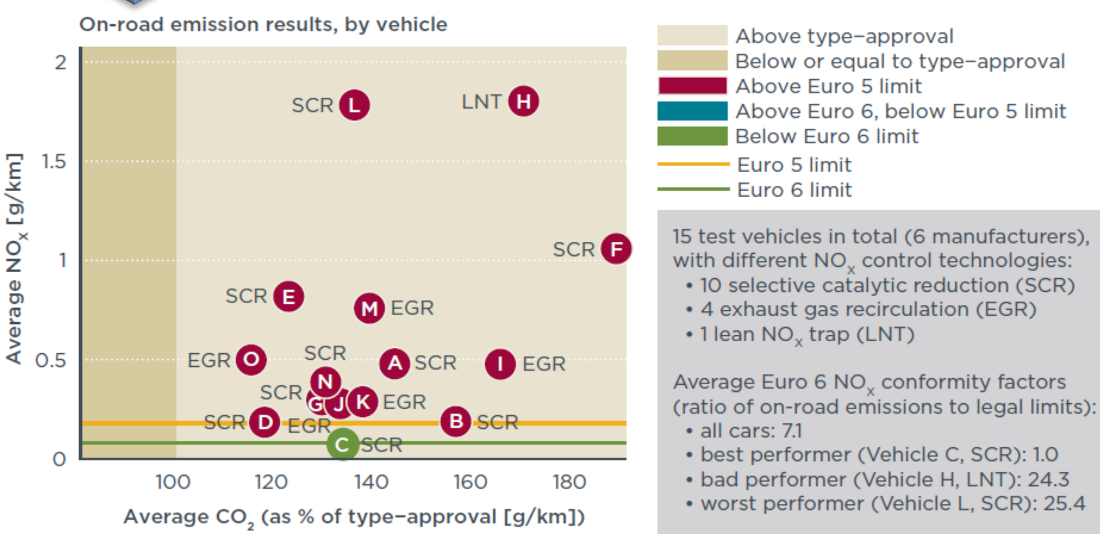
Brutti-Mairesse et al. (2012)



Samaras et al. (2013)

Vehicle fleet composition: Definition

Vehicle category

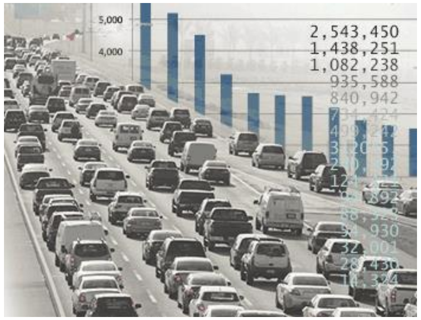


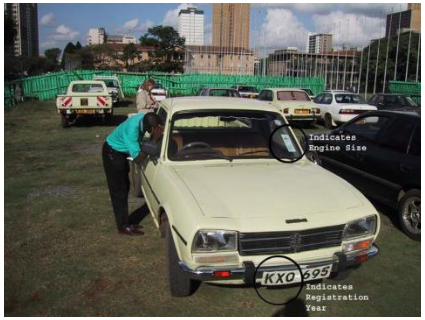
Franco et al. (2014)

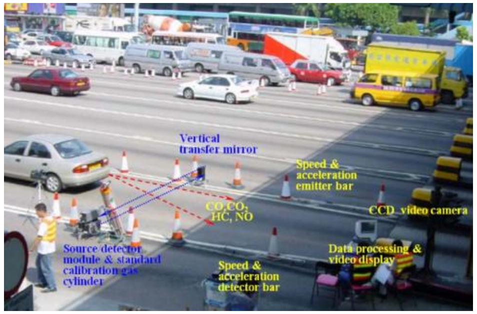
- **Type of fuel consumed**
- **Engine capacity**
- **Emission control regulation**
- **After treatment technology**
- **Manufacturer**

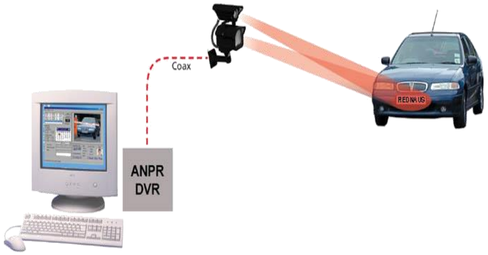
Vehicle fleet composition: Summary of works

Official vehicle registration data	Yan et al., 2011; Pandey et al. (2014); Zheng et al. (2014); Kassomenos et al. (2006); Radice et al. (2012); Cook et al. (2008); Pallavidino et al. (2014); D'Angiola et al. (2010); Coelho et al. (2014); Zamboni et al. (2009); Nejadkoorki et al. (2008); Caserini et al. (2013); Souza et al. (2013)
Vehicle owner and parking lot surveys	Davis et al. (2005); Wang et al. (2008); ; Malcom et al. (2003); Oanh et al. (2012); Ho and Clappier (2011); Gois and Maciel (2007); Ariztegui et al. (2004)
Remote sensing devices (RSD)	Tate et al. (2013); Ko and Cho (2006); Aguilar-Gómez et al. (2009), AB (2010); Guevara et al. (2013); Borge et al. (2012)
Automatic Number Plate Recognition (ANPR) data	Eijk (2012); AM (2014); LAIE (2010); Bedogni et al. (2014); Borge et al. (2015)

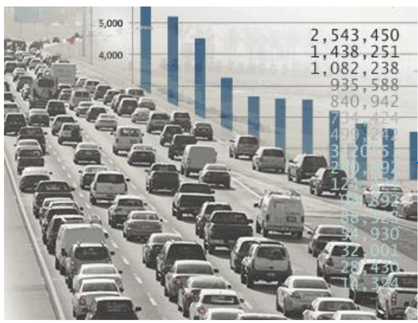




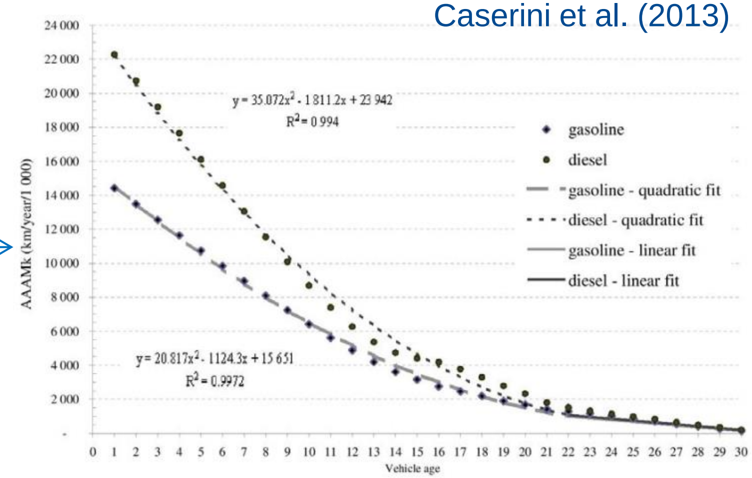




Vehicle fleet composition: Official vehicle registration data

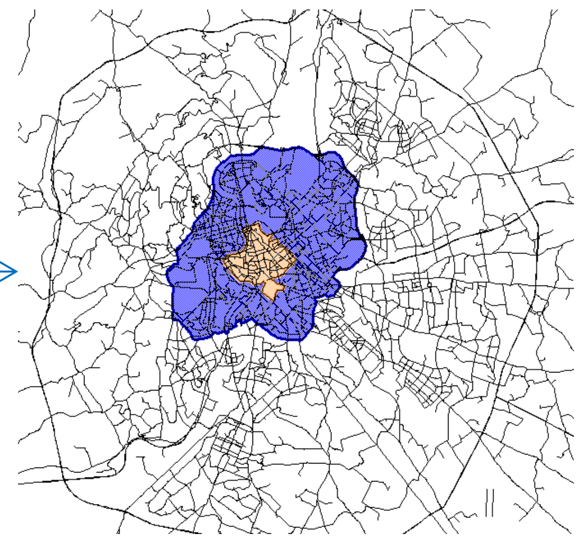


Dropping functions



Caserini et al. (2013)

Limited Traffic Zones



Radice et al. (2012)

✗ Not based on real circulation data

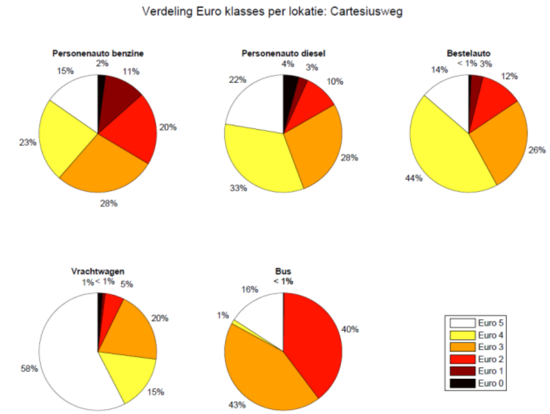
✓ Corrections can improve the representativeness

Vehicle fleet composition: Automatic Number Plate Recognition

scan locations

License plate

Data base



Results

Adapted from Ejik (2012) and Bedogni (2014)

- ✓ **Spatial representativeness.** Not limited to single streets (e.g. RSD)
- ✓ **Temporal representativeness.** Information for time slots and weekday/weekend
- ✗ Difficulties in registering license plates on: (i) mopeds (ii) bus-taxi lanes

To be completed with **manual sampling** and information from the **public transport bus service**

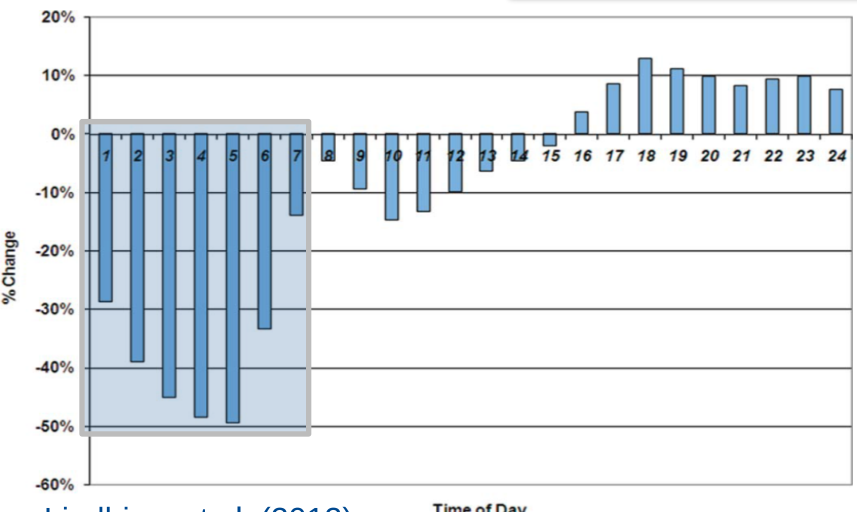
Vehicle fleet composition: Sensitivity analysis

Registration vs circulating data

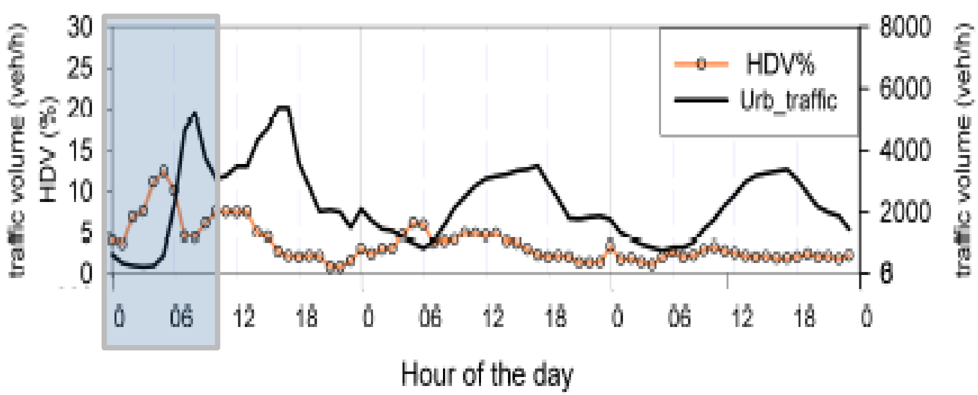
CMEM/DMV (g/mi)	Riverside	Yorba Linda	La Puente
CO	17.31	18.77	16.96
HC	1.57	1.83	1.59
NOx	1.22	1.36	1.21
CMEM/On-Road (g/mi)	Riverside	Yorba Linda	La Puente
CO	10.93	7.66	12.92
HC	0.54	0.42	0.64
NOx	0.81	0.61	0.75

Malcom et al. (2003)

Temporal resolution



Lindhjem et al. (2012)



Wang et al. (2010)

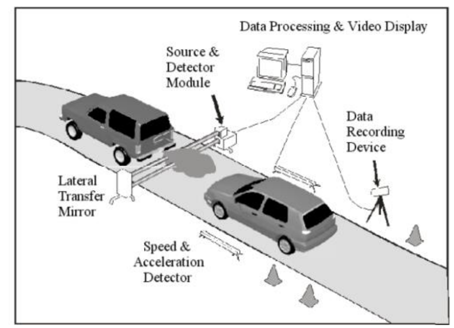
f-NO2:
Summary of works

- ✗ Fleet-weighted value and influence of other species
- ✗ Based on limited tests/vehicles
- ✓ Thousands of vehicles scanned within a day under “real-driving” conditions

Franco et al. (2014)

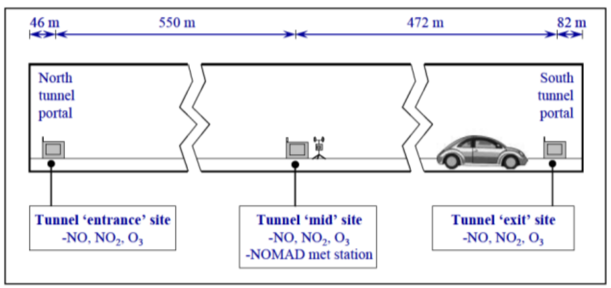
Portable Emission Measurement Systems

Remote sensing devices



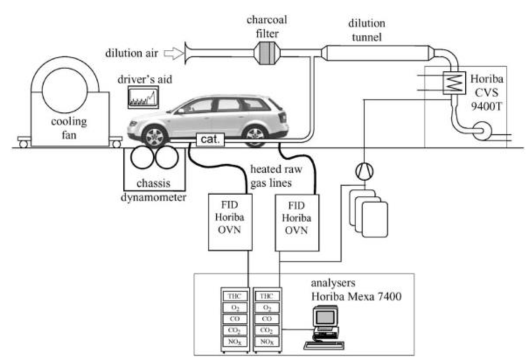
McClintock (2007)

Boulter et al. (2007)



Tunnel measurements

Dynamometer measurements



Soltic et al. (2003)

Abbot et al. (2005)

Ambient monitoring data

$$[NO_2]_1 = [NO_2]_0 + ([O_3]_0 - [O_3]_1) + A([NO_x]_1 - [NO_x]_0) + B^*$$

5%

f-NO2: Remote Sensing Devices

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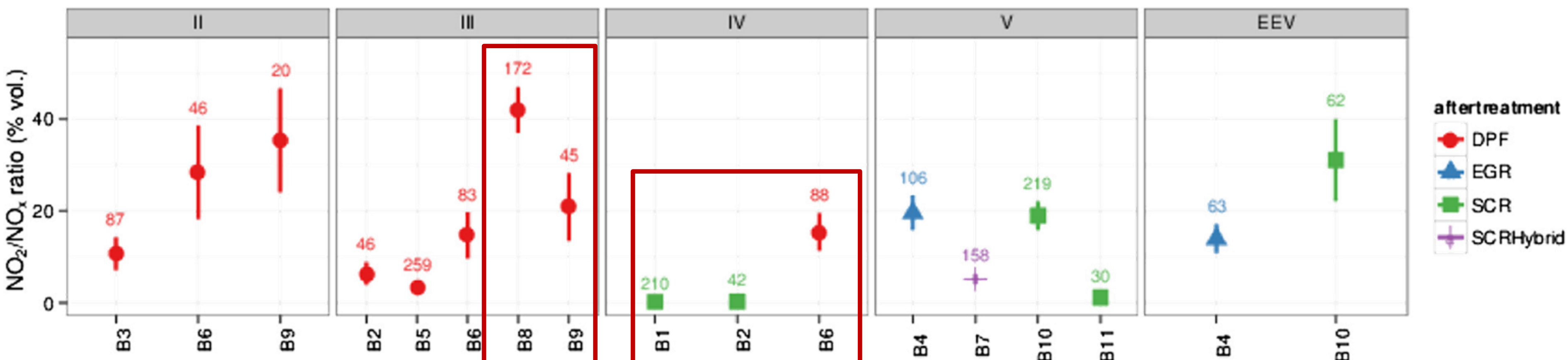
Vehicle type	Fuel/type	Euro class	n	NO_x	NO_2	NO_2/NO_x (%)
Passenger car	Petrol	0	204	85.1 ± 10.7	0.5 ± 0.4	0.6 ± 0.4
Passenger car	Petrol	1	392	54.1 ± 6.5	0.7 ± 0.3	1.3 ± 0.6
Passenger car	Petrol	2	2848	39.3 ± 2.4	0.5 ± 0.1	1.4 ± 0.4
Passenger car	Petrol	3	5593	15.3 ± 1	0.3 ± 0.1	2.1 ± 0.5
Passenger car	Petrol	4	8843	10.3 ± 0.7	0.4 ± 0.1	4.1 ± 0.7
Passenger car	Petrol	5	1998	4.8 ± 0.7	0.4 ± 0.1	8.4 ± 3
Passenger car	Petrol hybrid	4	154	1.6 ± 1	0.2 ± 0.4	12.9 ± 27.8
Passenger car	Petrol hybrid	5	605	7 ± 3.2	1.1 ± 0.4	15 ± 8.9
Passenger car	Diesel	0	15	47 ± 8.7	7.2 ± 2	15.3 ± 5
Passenger car	Diesel	1	62	55.7 ± 7.4	7.6 ± 1.5	13.7 ± 3.3
Passenger car	Diesel	2	363	65.5 ± 4.1	5.7 ± 0.5	8.7 ± 0.9
Passenger car	Diesel	3	2610	62.9 ± 1.5	10.3 ± 0.4	16.3 ± 0.8
Passenger car	Diesel	4	5836	47.7 ± 0.9	13.5 ± 0.4	28.4 ± 0.9
Passenger car	Diesel	5	4577	49.9 ± 1	12.6 ± 0.4	25.2 ± 0.9
London taxi	FX	2	877	90.1 ± 2.8	3.9 ± 0.3	4.3 ± 0.3
London taxi	Met	2	80	149.4 ± 20.3	11.9 ± 2.1	8 ± 1.8
London taxi	TX1	2	4148	95.7 ± 1.3	5.6 ± 0.2	5.9 ± 0.2
London taxi	Met	3	148	52.5 ± 3.1	3.6 ± 0.5	6.9 ± 1
London taxi	TXII	3	4050	52.7 ± 1	6.3 ± 0.2	11.9 ± 0.4
London taxi	MV111	4	594	64.1 ± 1.3	11.9 ± 0.9	18.6 ± 1.5
London taxi	TX4	4	4719	49.2 ± 0.7	6 ± 0.3	12.3 ± 0.5
London taxi	TX4	5	185	79.7 ± 7.4	15.8 ± 2	19.9 ± 3.2
London taxi	MV113	5	329	62.9 ± 3.1	23.6 ± 1.2	37.6 ± 2.7

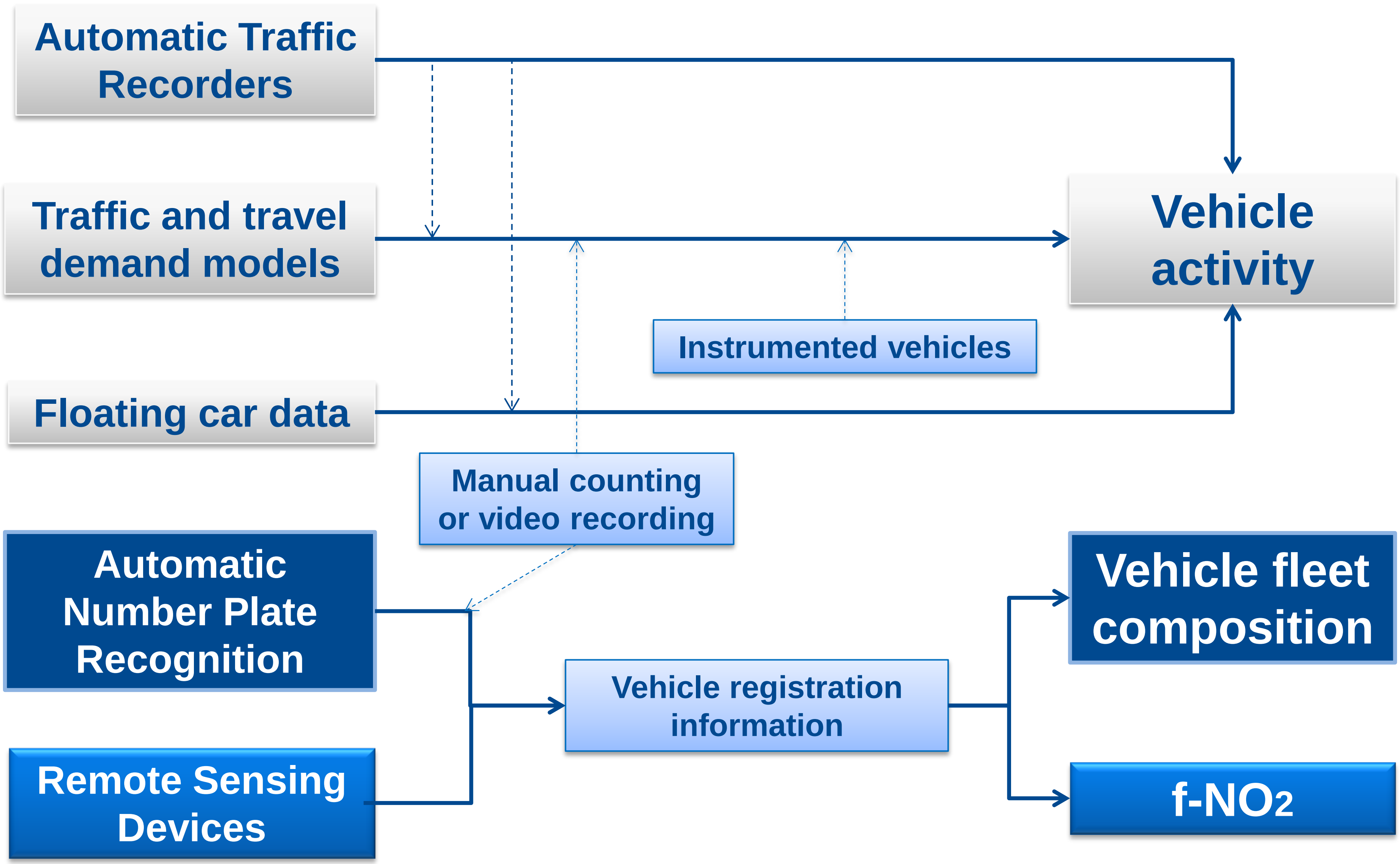


Carslaw and Rhys-Tyler (2013)

f-NO2: Databases

Vehicle type	Fuel/type	Euro class	Carslaw and Rhys-Tyler (2013)	EEA (2013)
Passenger car	Gasoline	pre-Euro	0.6±0.4	4
		Euro 1	1.3±0.6	4
		Euro 2	1,4±0.4	4
		Euro 3	2,1±0.5	3
		Euro 4	4,1±0.7	3
		Euro 5	8,4±3	3
		Euro 6	-	3
Passenger car	Diesel	pre-Euro	15,3±5	15
		Euro 1	13,7±3.3	13
		Euro 2	8,7±0.9	13
		Euro 3	**16,3±0.8**	**27**
		Euro 4	**28,4±0.9**	**46**
		Euro 5	**25,2±0.9**	**33**
		Euro 6	-	30

Best practices



Conclusions

- **Vehicle activity:** TDM calibrated/validated or ATR
  - Limited spatial coverage and spatial resolution
  - Diffusion of in-car navigators: FCD
    - Privacy concerns (eCall)
    - Big data concerns (large amount of data to process)
- **Vehicle fleet composition:** Automatic Number Plate Recognition data
  - Detailed information on vehicles (manufacturer, after-treatment tech)
  - Increase of European urban mobility policies (LEZ)
- **f-NO_2:** in-situ measurements with RSD (Carslaw and Rhys-Tyler, 2013)
- **Taxis and urban buses:** Separated treatment
- **Limited literature relating to sensitivity studies**
- **xFCD**: spatial referencing of real, non-modelling based fuel consumption data of vehicles

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Thank you!

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