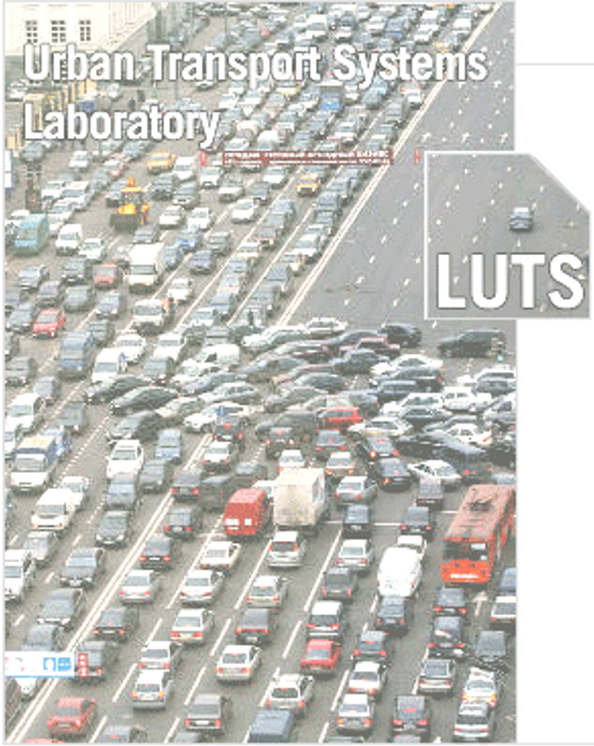


Vehicle emissions in congested networks

Prof. Nikolas Geroliminis

(thanks to Prof. Christofa, UMASS)

Lesson Objectives

- Discuss parameters affecting the type and concentration of vehicle emissions
- Describe types of vehicle emission estimation models
- List advantages and disadvantages of the different types of emission models/methods
- An eco-driving experiment
- Estimating emissions using high resolution trajectory data from a drone experiment (Intro to lab 2)

Automobile Emissions

Parameters affecting the nature and concentration:

- Type of engine & vehicle (e.g., power, weight)
- Presence and working condition of emission control devices (e.g., catalysts)
- Fuel composition
- Mode of operation (acceleration, deceleration, cruising, idling)
- Atmospheric conditions (temperature, humidity)
- Engine load (e.g., air conditioning)

Emission Factors

Expressed as:

- grams of pollutant emitted per vehicle-mile
- grams of pollutant emitted per grams of fuel consumed
- grams of pollutant emitted per unit time
- grams of pollutant emitted per day
- grams of pollutant emitted per trip made

We need to know activity data:

- Vehicle-kms traveled (VKT)
- Total fuel consumed
- Time spent for a specific emissions process

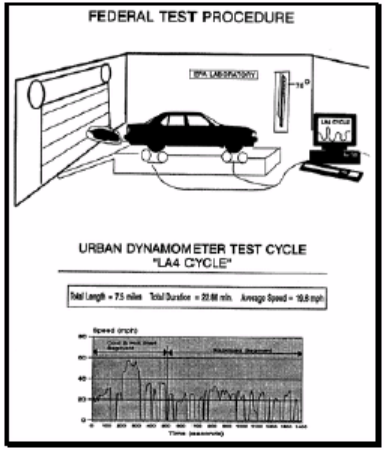
Vehicle Emission Estimation Models/Methods

1. Drive cycle-based emission factor models
2. Modal emissions-based models
3. Fuel-based approaches
4. On-road emissions data-based measurements

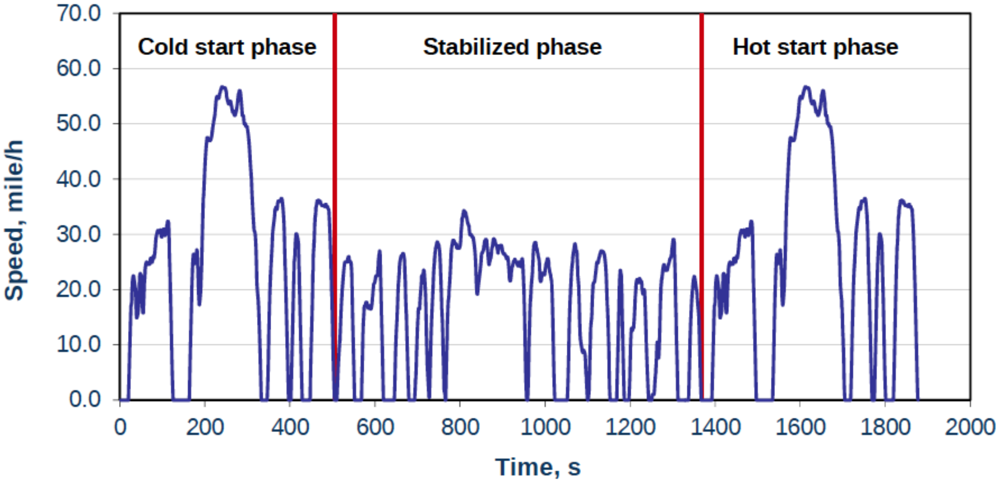
1. Drive Cycle-based Emissions Models

Drive cycle: unique profile of stops, starts, constant speed cruises, accelerations and decelerations

Different drive cycles are used to represent driving under different traffic conditions



Source:http://media.tmiponline.org/clearinghouse/airquality/wtaq/ch2.htm

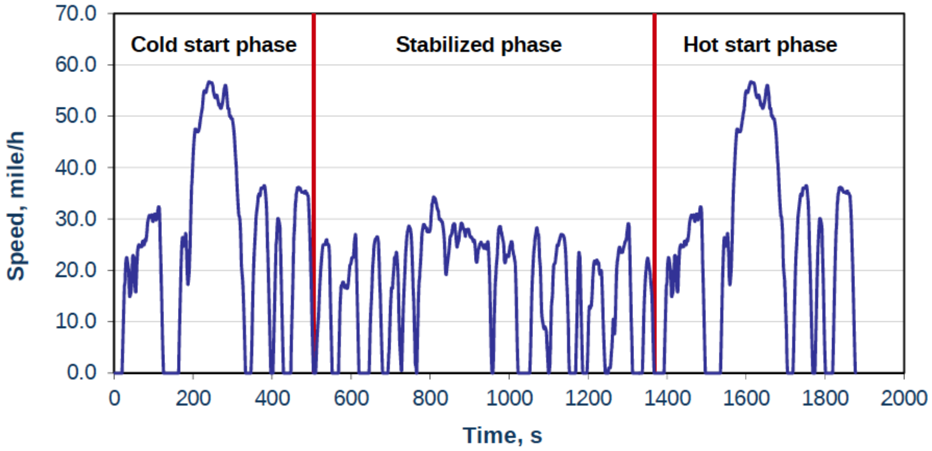


Source: http://www.dieselnet.com/standards/cycles/ftp75.php

1. Drive Cycle-based Emissions Models

Examples:

- EMFAC (California): https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-modeling-tools-emfac
- MOBILE (elsewhere): https://www3.epa.gov/otaq/mobile.htm



Source: http://www.dieselnet.com/standards/cycles/ftp75.php

Emission FACtors (EMFAC) Model

- Developed by the California Air Resources Board (most updated version in 2017) for estimation of emissions from on-road vehicles
- Can be used for statewide- and regional-level analysis

Vehicle Types:

- Gasoline
- Diesel
- Natural gas

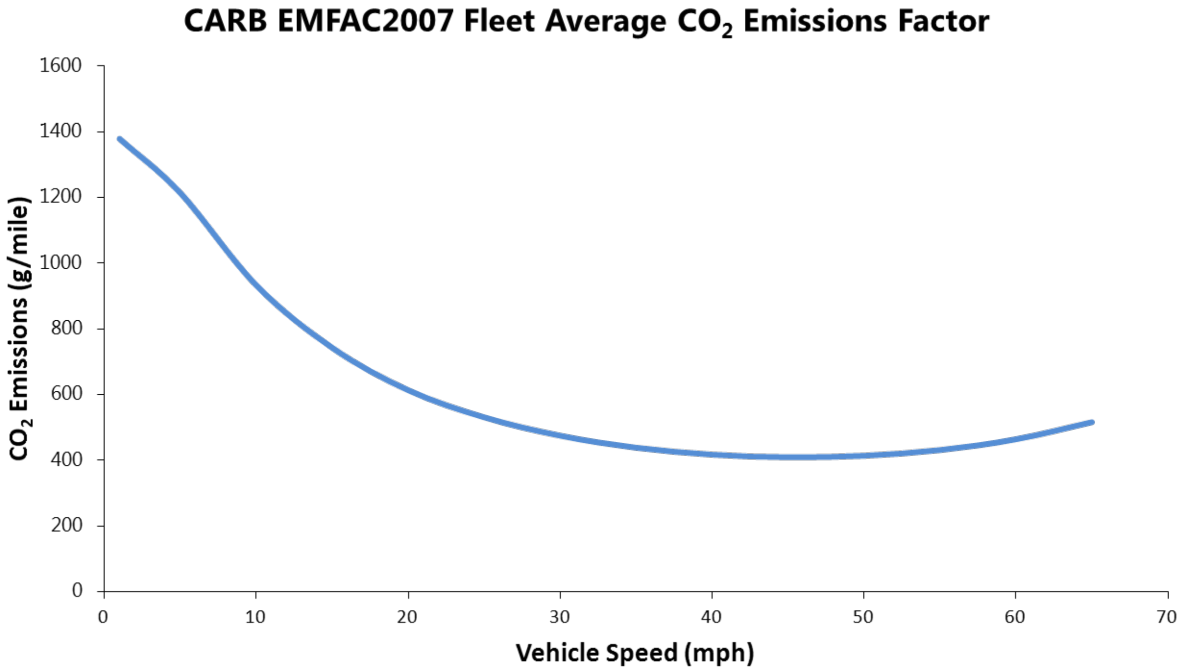
for passenger cars, trucks, motorcycles, motorhomes, and transit buses

Pollutants:

- Hydrocarbons (HC)
- Carbon Monoxide (CO)
- Nitrogen Oxides (NOx)
- Particulate matter (PM)
- Fuel consumption
- Oxides of Sulfur (SOx)
- Greenhouse Gases:
    - Carbon Dioxide (CO_2)
    - Nitrous Oxide (N_20)
    - Methane (CH_4)

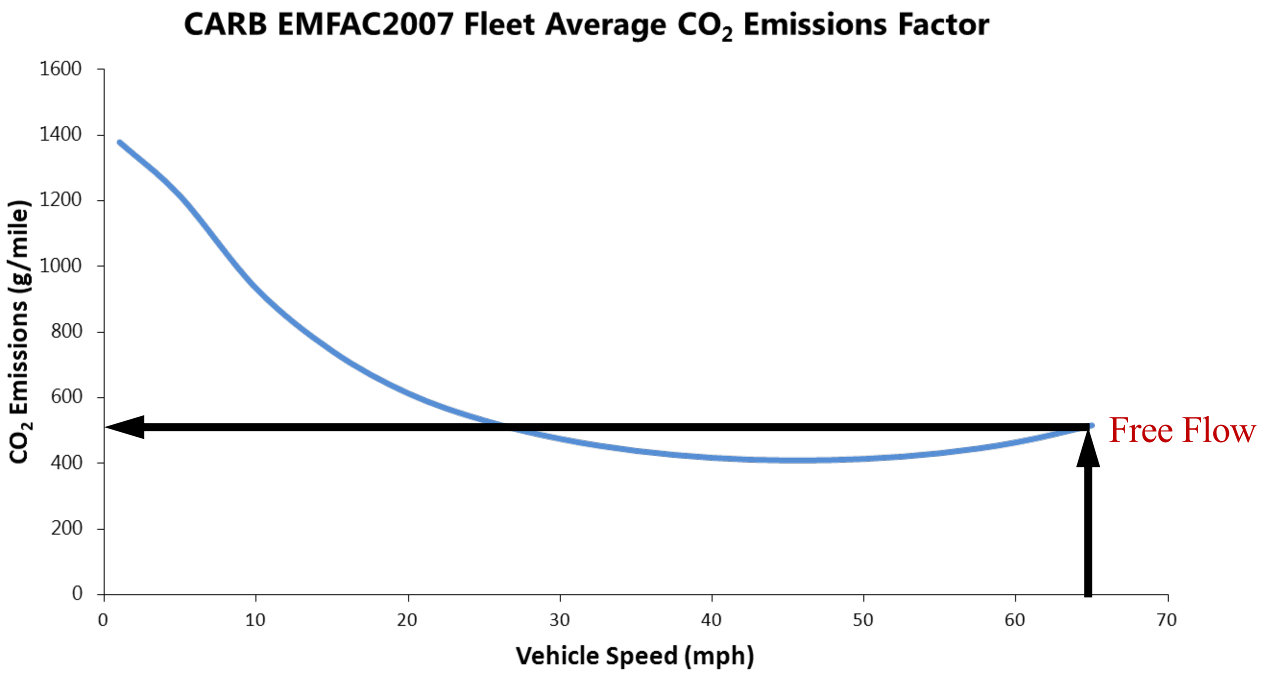
Emission FACtors (EMFAC) Model: Vehicle Classes

CO_2 Emissions: U-Curve



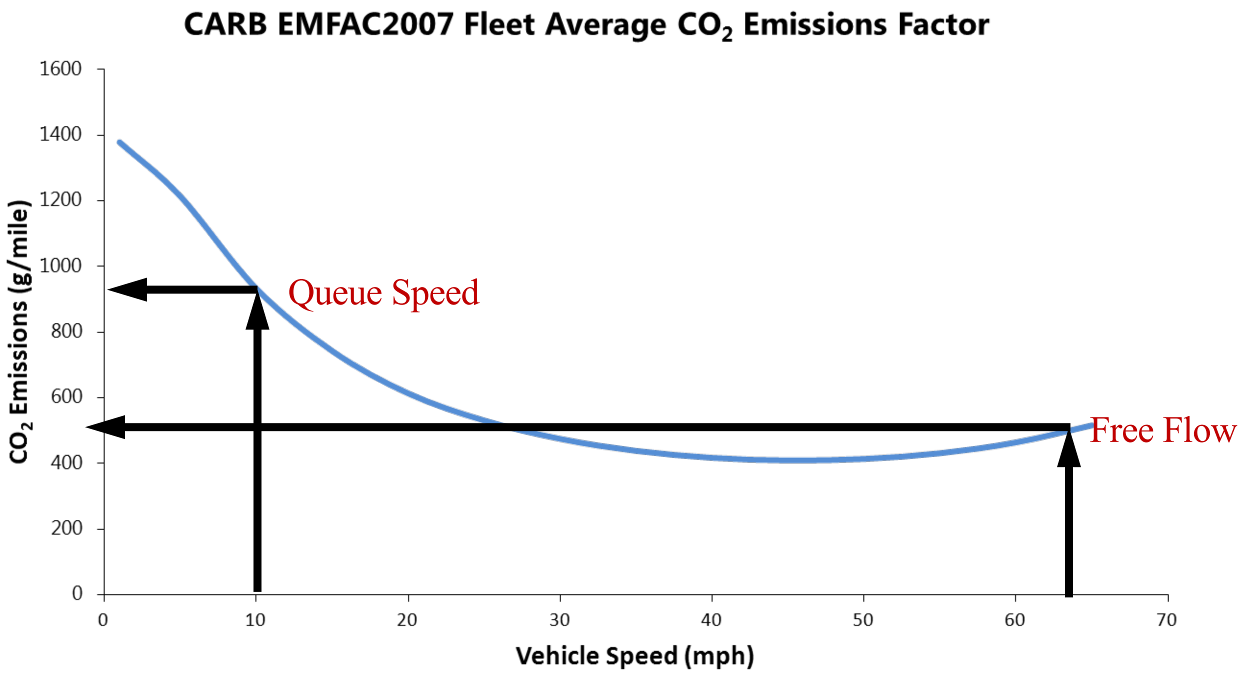
Emission FACtors (EMFAC) Model: Vehicle Classes

CO_2 Emissions: U-Curve

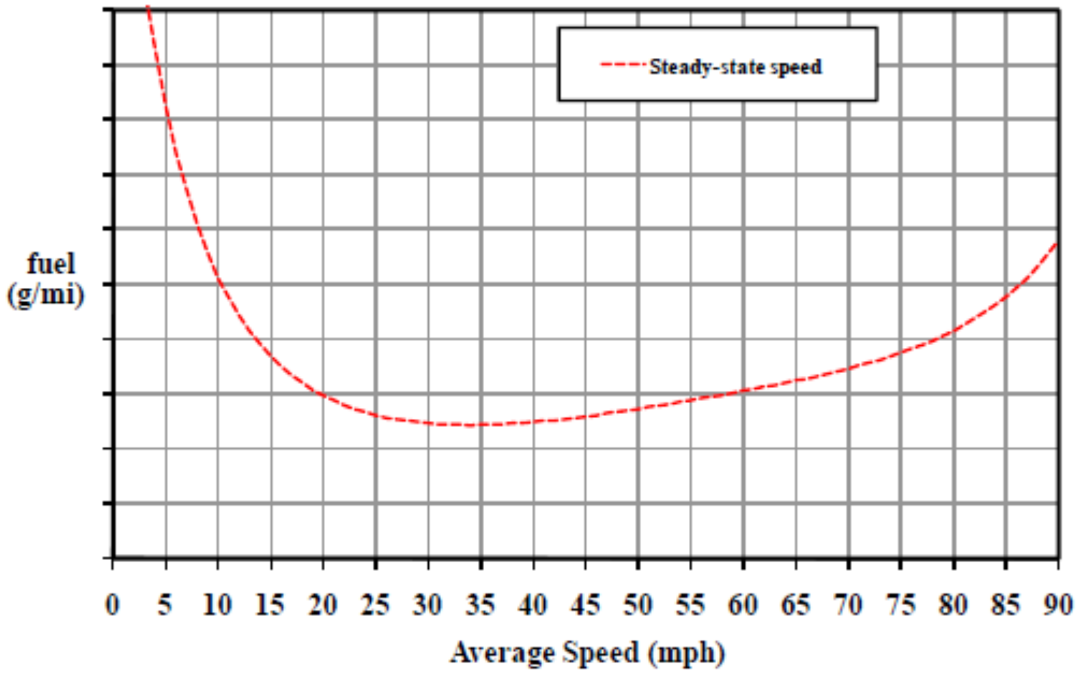


Emission FACtors (EMFAC) Model: Vehicle Classes

CO_2 Emissions: U-Curve

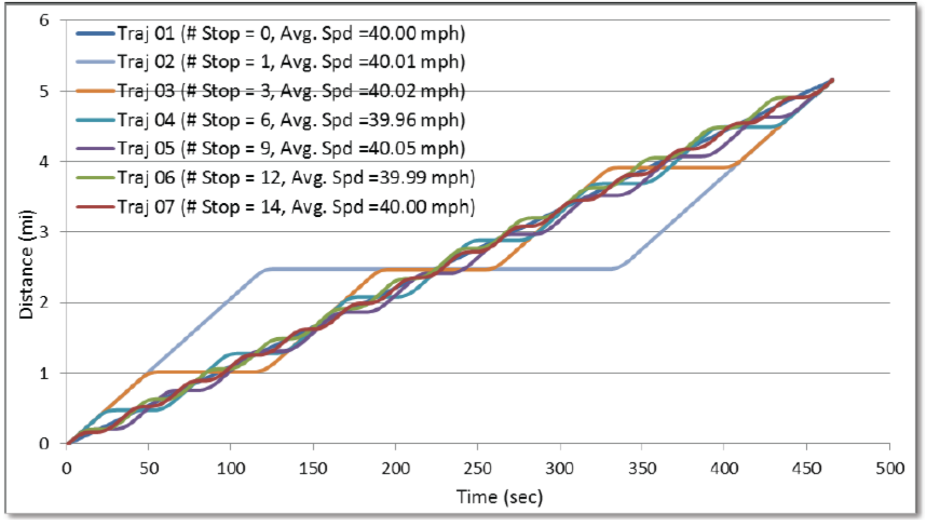


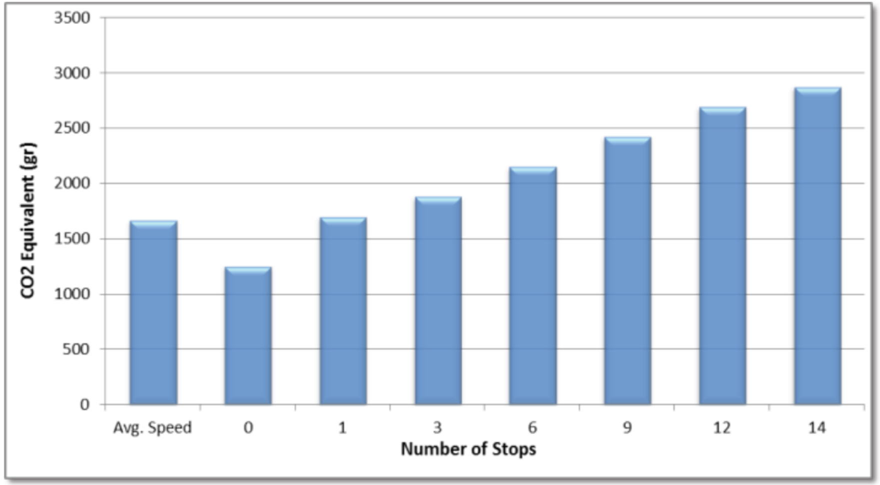
Automobile Emissions



Source: Shaheen, S., Young, T., Sperling, D., Jordan, D., and Horan, T. 1998. *Identification and Prioritization of Environmentally Beneficial Intelligent Transportation Technologies*, California PATH Working Paper, UCB-ITS-PWP-98-8.

Automobile Emissions





Source: Shabihkhani, R. (2015). Estimation of urban scale network-wide emissions based on fundamental properties of the network (Doctoral dissertation, Rutgers University-Graduate School-New Brunswick).

1. Drive Cycle-based Emissions Models

Disadvantages:

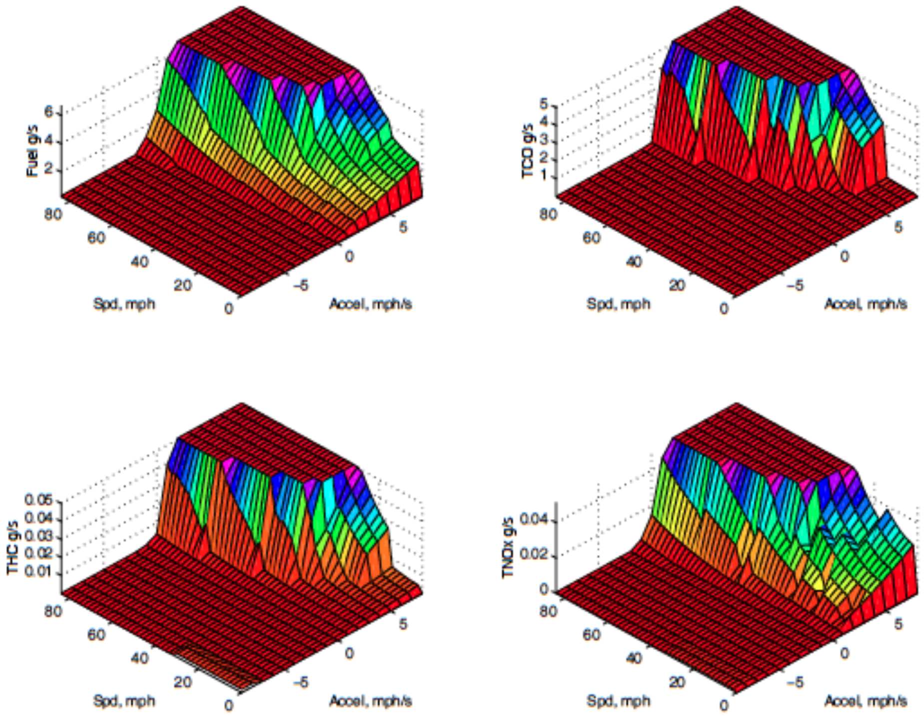
- Emission factors are based on limited tests; not representative of reality
- They do not account for the differences in engine load
- Incapable of capturing the impact of traffic operational improvements that affect traffic and driving dynamics
  - signal coordination and improved signal timings

2. Modal Emissions-based Models

- Emissions are related to the operating mode of a vehicle

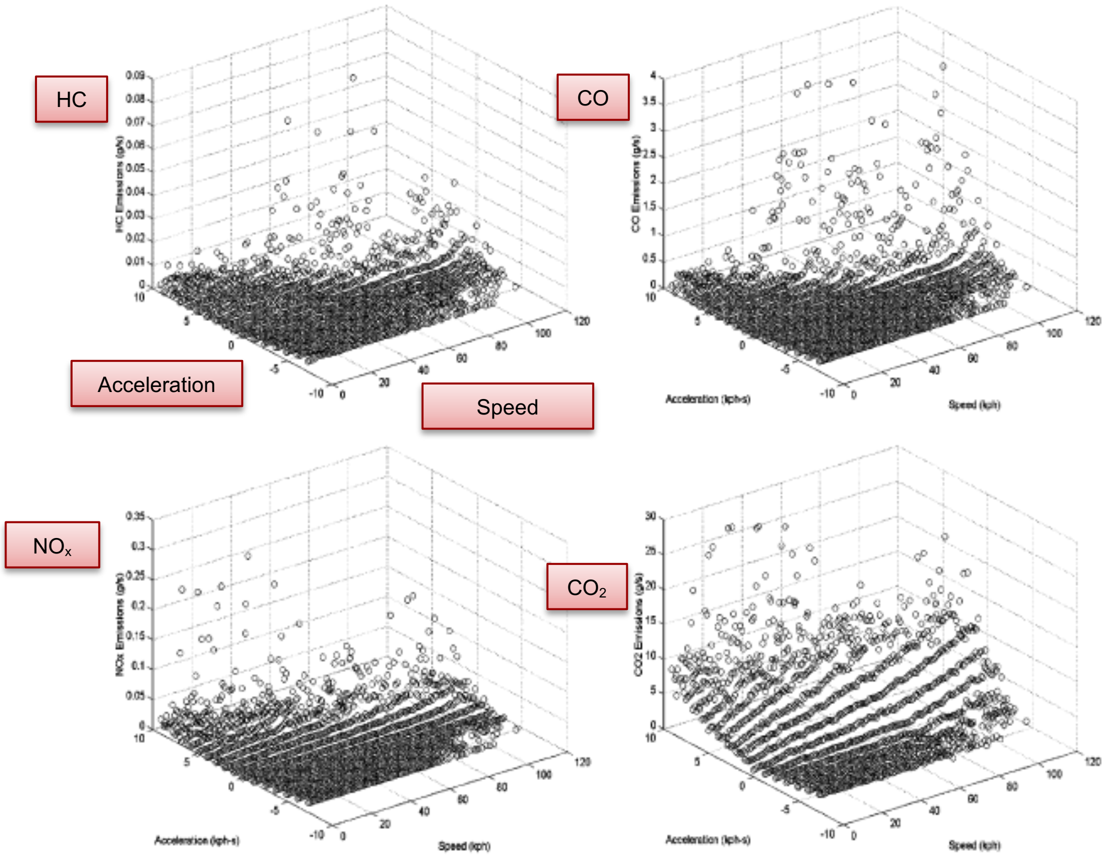
- Operating modes:
  - Acceleration
  - Deceleration
  - Cruising
  - Idling

2. Modal Emissions-based Models



Source: Barth, M., An, F., Younglove, T., Levine, C., Scora, G., Ross, M., & Wenzel, T. (1999). The development of a comprehensive modal emissions model.*Final report submitted to the National Cooperative Highway Research Program*, *255*.

2. Modal Emissions-based Models



2. Modal Emissions-based Models

- Type 1: Speed-acceleration matrix
  - It cannot capture the effect of other parameters such as road grade and accessory parameters
  - Assumes steady state emissions
  - Loss of accuracy with interpolation among bins

- Type 2: Engine power and speed map
  - It can capture grade and use of accessories
  - Assumes steady state emissions
  - Loss of accuracy with interpolation among bins

Comprehensive Modal Emissions Model (CMEM)

- Started in 1996; updated in 2000 (Sponsored by NCHRP and EPA)
- It uses a physical, power-demand approach based on a parameterized analytical representation of fuel consumption
- Predicts second-by-second fuel consumption and emissions

- Input:
  - Second-by-second vehicle trajectories (acceleration, speed, location)
  - Fleet composition, Road grade
- Vehicle Classes:
- 28 light-duty vehicle/technology categories
- 3 heavy-duty vehicle/technology categories

Comprehensive Modal Emissions Model (CMEM)

- Advantages:
  - Predictions are based on detailed engine operation and emissions production process
  - It covers all types of vehicles that exist on the roadways as of now; flexible in including future models
  - It handles all factors that can be affecting emissions (e.g., vehicle technology, grade, operating mode)
  - It can be used for both individual vehicle & fleet analysis
  - It can be used at the micro (project level) and macro analysis levels
  - It is not restricted to steady-state emission events

Disadvantages:
  - Data intensive
    - Collection of all necessary parameters
    - Variety of vehicle types

3. Fuel-based Models

- Expressed as grams of pollutant emitted per gallon of gasoline burned
- Uses information from studies on on-road vehicles

Advantages:

- More representative of on-road emissions

Disadvantages:

- It depends on how representative the vehicles that were measured are
- Age distribution used is critical

4. On-road Data-based Measurements

- Remote sensing devices utilize infrared and ultraviolet spectroscopy to measure pollutant concentrations in exhaust emissions

Uses:

- Emission factors estimation
- Identification of high-emitting vehicles

4. On-road Data-based Measurements

Advantages:

- It can measure large numbers of on-road vehicles
- Representative of real-world conditions (variability in facility characteristics, vehicle location, operation, and driver)

Disadvantages:

- It provides only instantaneous emissions (if remote sensing)
- Cannot measure across multiple lanes with heavy traffic

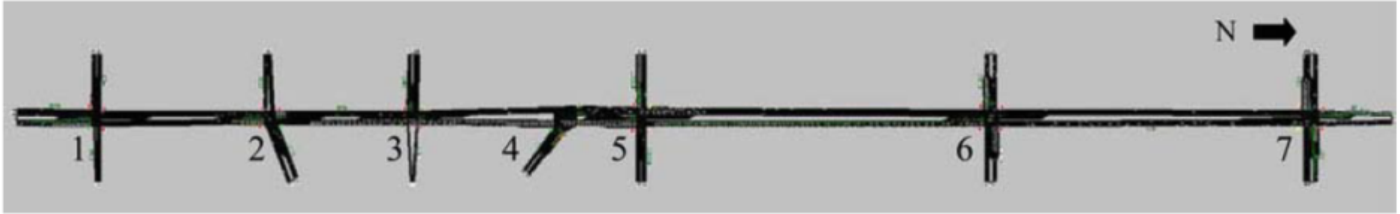
4. On-road Data-based Measurements

- On-board measurement is desirable
- Representative of real-world conditions at any location
- It had not been used extensively used due to high cost
- Low cost, portable emissions measurement system (PEMS) (e.g., OEM 2100™)

Source:http://www4.ncsu.edu/~frey/emissions/instrument.html

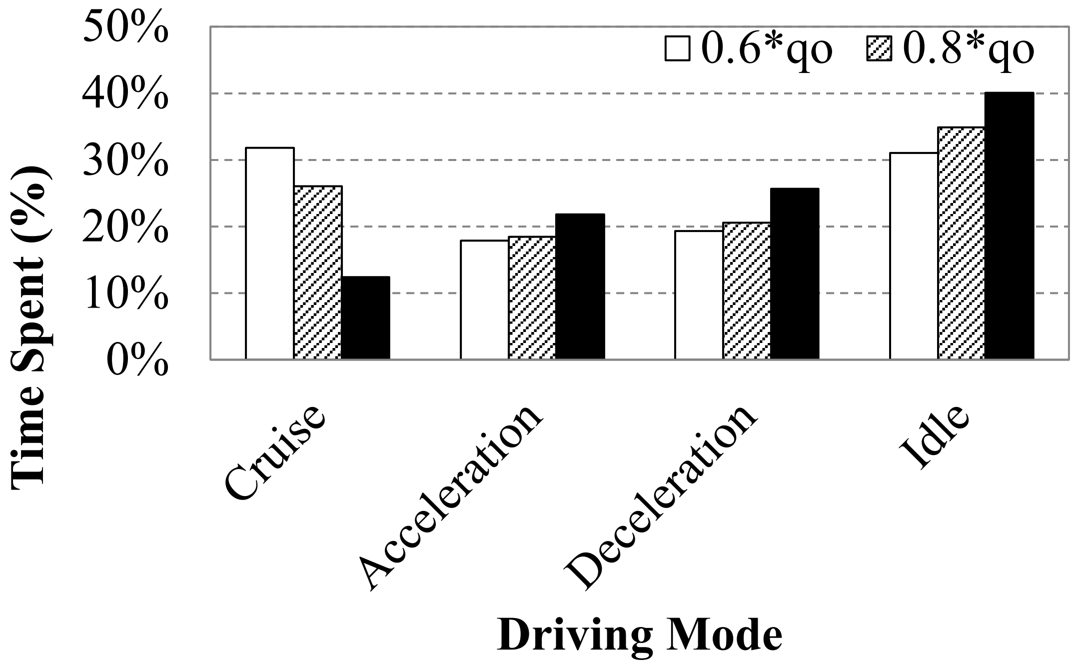
Source: Frey et al. 2001. Emissions reduction through better traffic management: An empirical evaluation based upon on-road measurements

Impact of Signal Control on Emissions

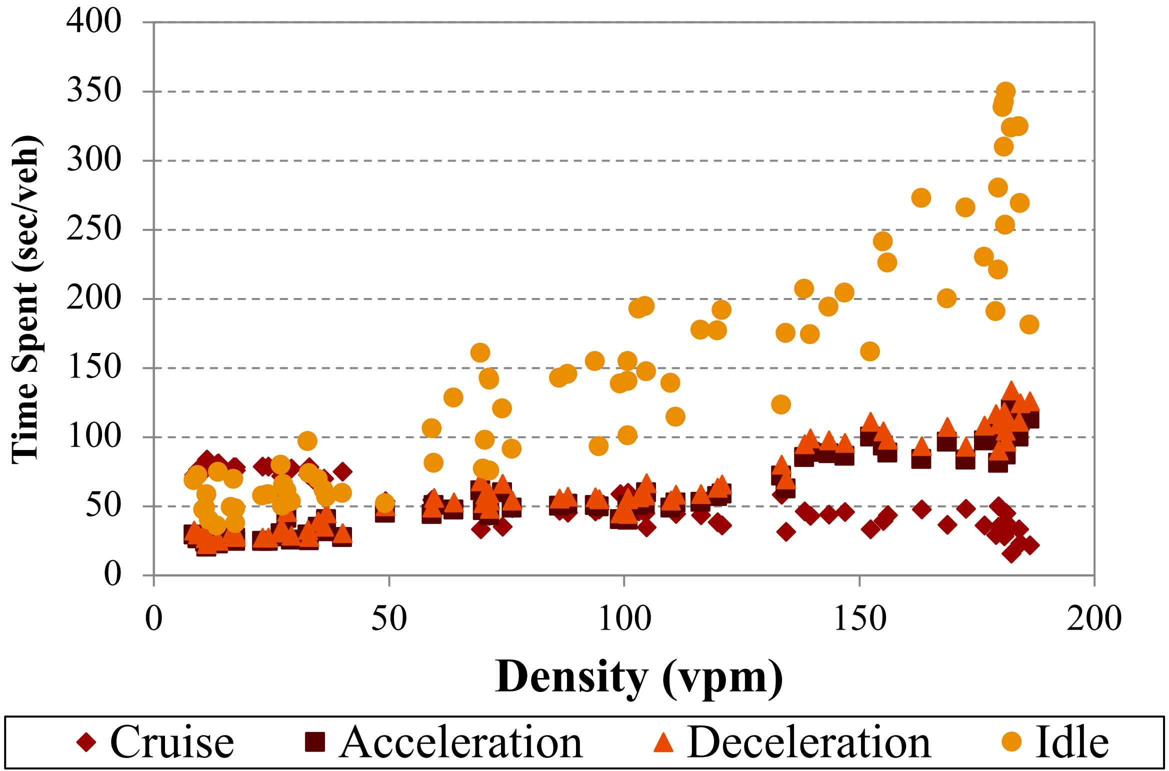


Study Site: Lincoln Avenue, Los Angeles &
Santa Monica, CA

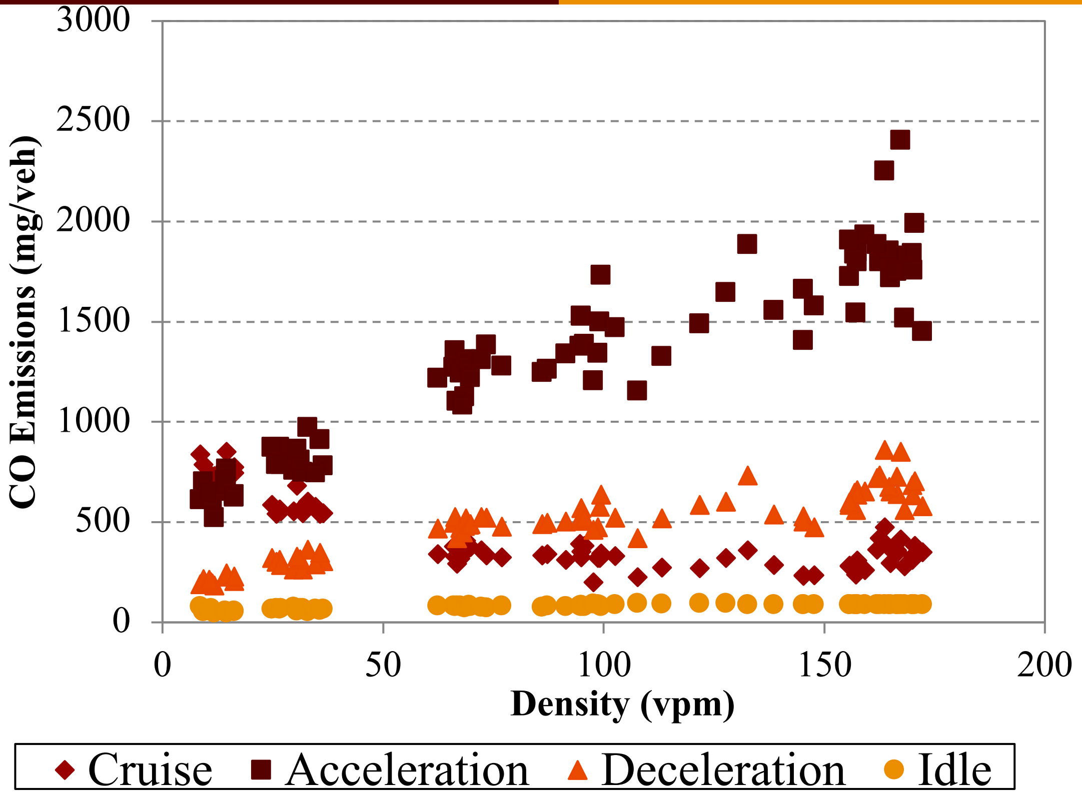
Vehicle Activity



Time Spent vs Density



CO emissions vs Density

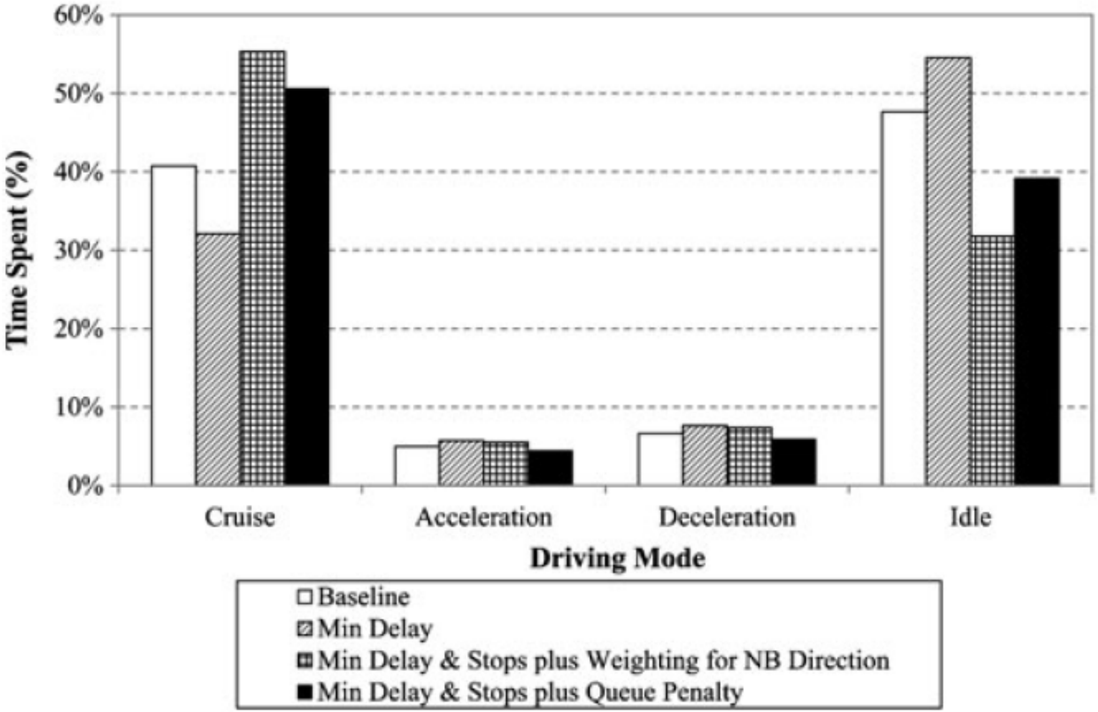


Emission Factors

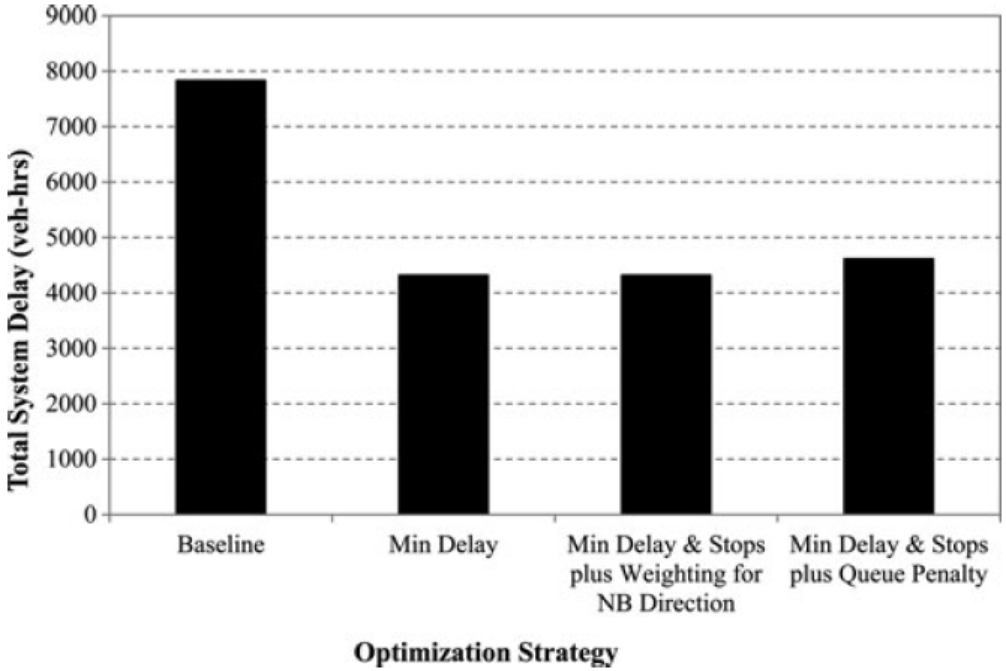
Table 1 Emission rates per driving mode (Frey et al., 2001).

	Cruise	Acceleration	Deceleration	Idle
CO (mg/sec)	10.00	22.50	7.50	1.50
HC (mg/sec)	0.60	1.10	0.40	0.25
NO (mg/sec)	1.25	1.50	0.60	0.10

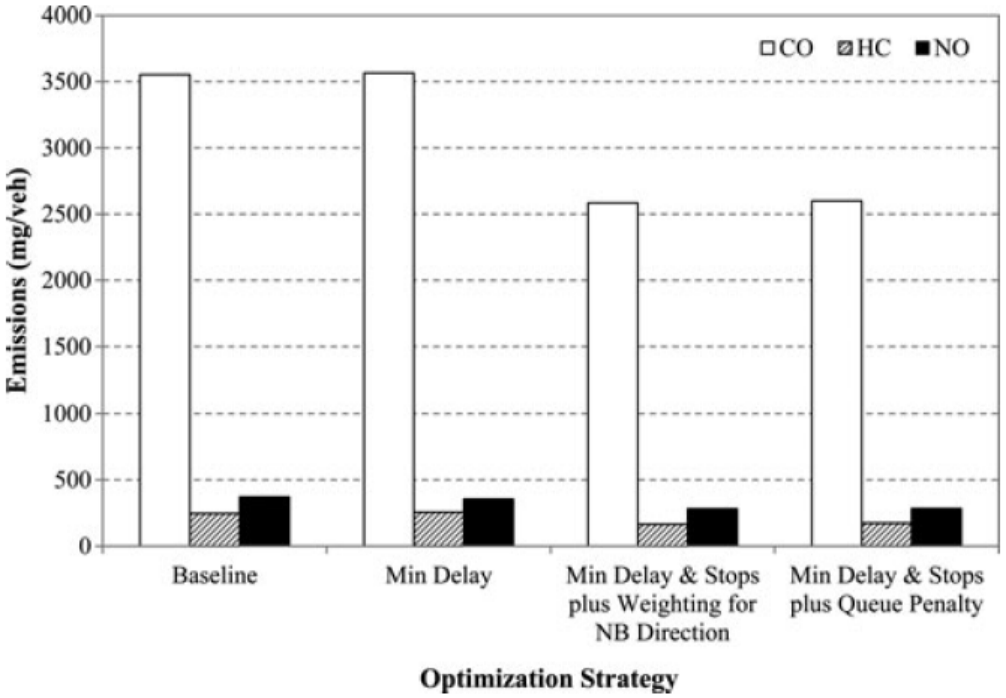
Time Spent for Different Optimization Strategies



Total System Delay vs Optimization Strategy



Emissions vs Optimization Strategy



Eco-driving

Multiple ways:

- Accelerating moderately
- Avoiding sudden starts and stops
- Maintaining an even pace
- Driving at or safely below the speed limit
- Eliminating excess idling

However, eco-driving also refers to the approaches used to assist drivers to adopt such driving behavior.

Eco-approach Technology at Fixed-time Signalized Intersections

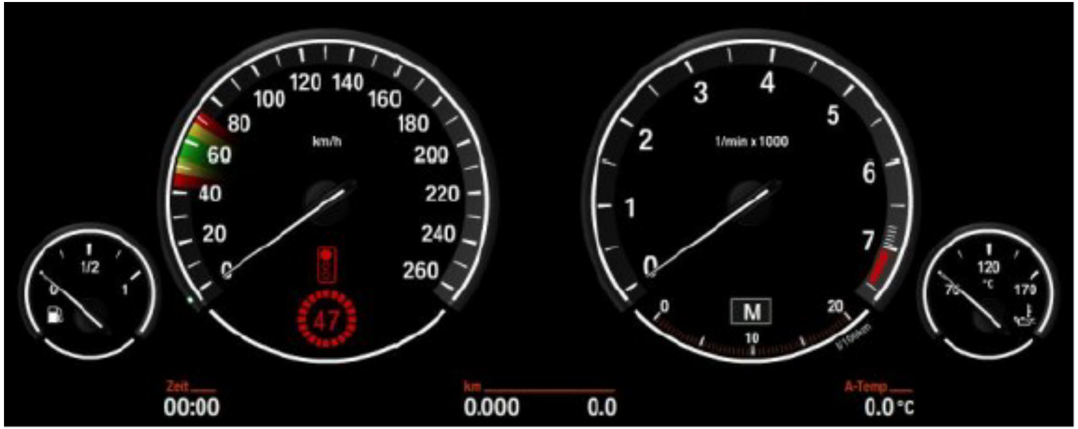
Developed as part of a Federal Highway Administration Advanced Exploratory Research Program (FHWA EAR)

Uses information on:

- Signal Phasing and Timing (SPaT)
- Intersection map

to calculate optimal speed that will minimize fuel consumption and communicate that to the driver

Eco-approach Technology at Fixed-time Signalized Intersections



Xia, H., Boriboonsomsin, K., Schweizer, F., Winckler, A., Zhou, K., and Zhang, W.-B. 2012. Field Operational Testing of ECO-Approach Technology at a Fixed-Time Signalized Intersection, 15th International IEEE Conference on Intelligent Transportation Systems.

Eco-approach Technology at Fixed-time Signalized Intersections

Test Vehicle: BMW 535i sedan 2011

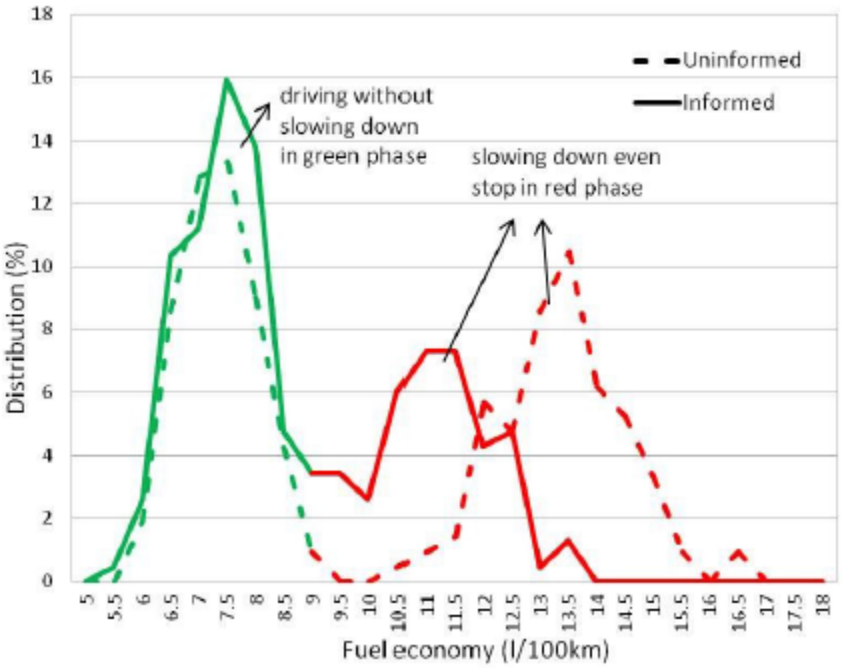
Experiment characteristics:

- Speed: 25 mph
- Cycle length: 60 sec
- Green interval: 30 sec
- Red interval: 27 sec

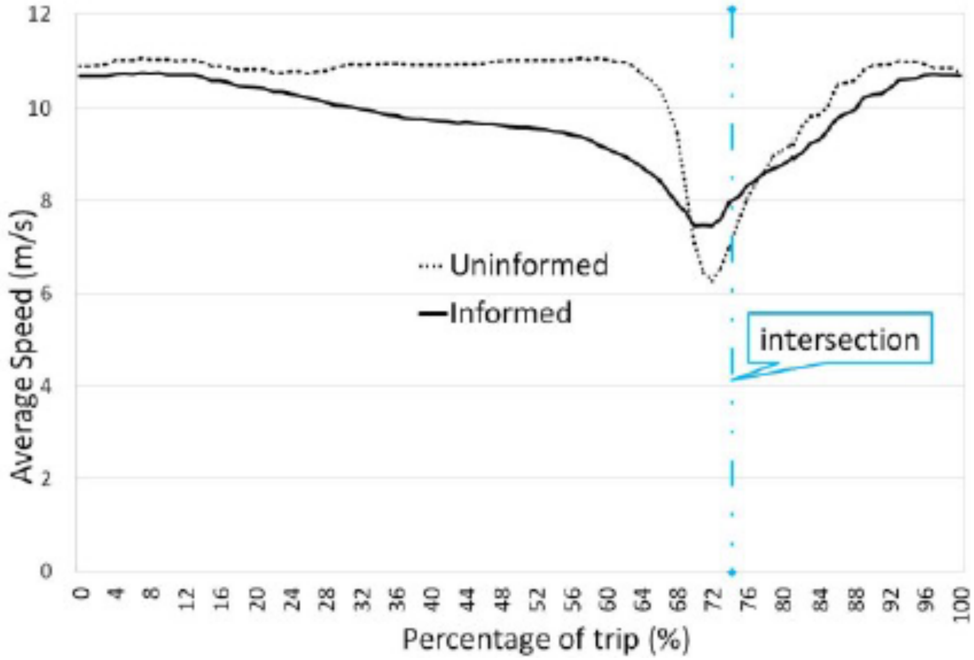
Simulation tests were also performed a
fuel consumption was estimated with CMEM

Xia, H.et all, 2012

Eco-approach Technology at Fixed-time Signalized Intersections



Eco-approach Technology at Fixed-time Signalized Intersections



ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Urban Transport Systems Laboratory

Utilizing a swarm of drones for Traffic Monitoring & Modeling

Our experience from the experiment

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Nikolas Geroliminis
Associate Professor EPFL
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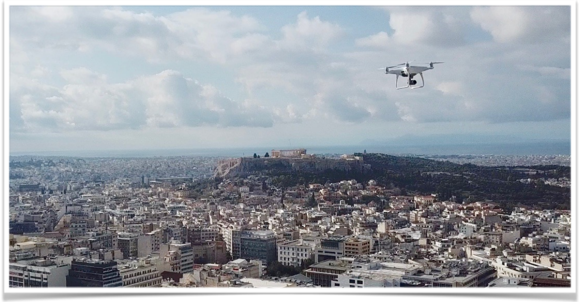
Designing the experiment

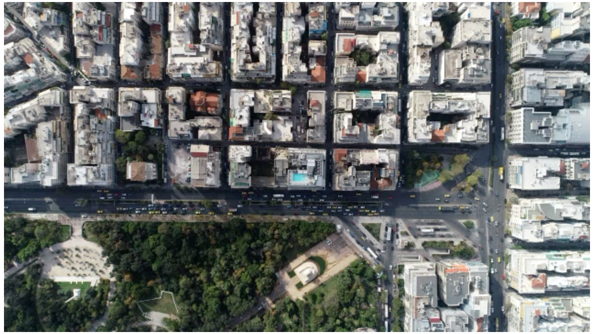
📍 Athens, Greece 🇬🇷



one of the most congested European cities
dense urban environment
queues, spillbacks
multimodal traffic
pedestrians

Morning Peak Hours [8:00 - 10:30]
10 drones || ~20 minutes flight duration
5 days || 5 flights per day || 1.5 hours recordings
40 km-lanes road network
Low | Medium | High Volume Arterials
More than 60 intersections (signalized or not)
30 bus stops

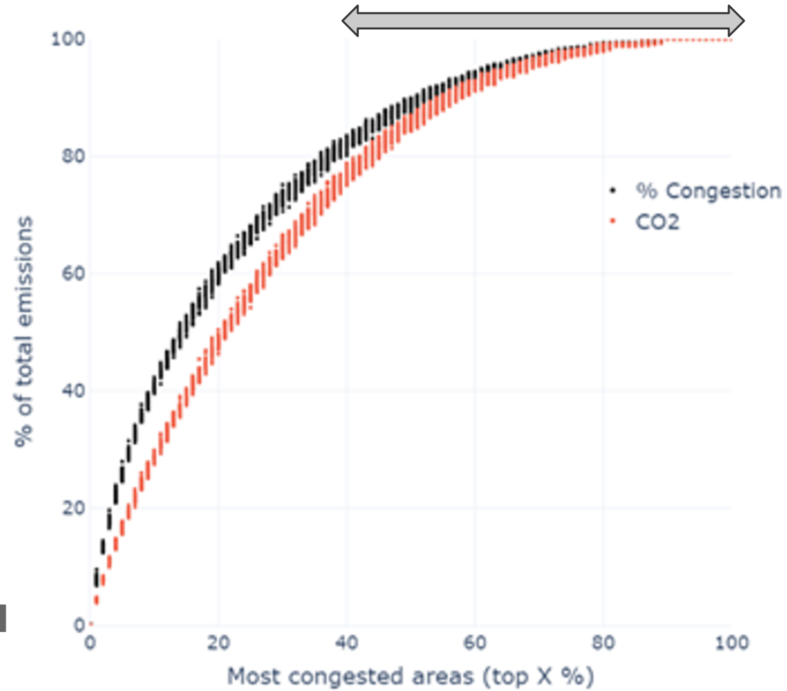
Over 500.000 trajectories!

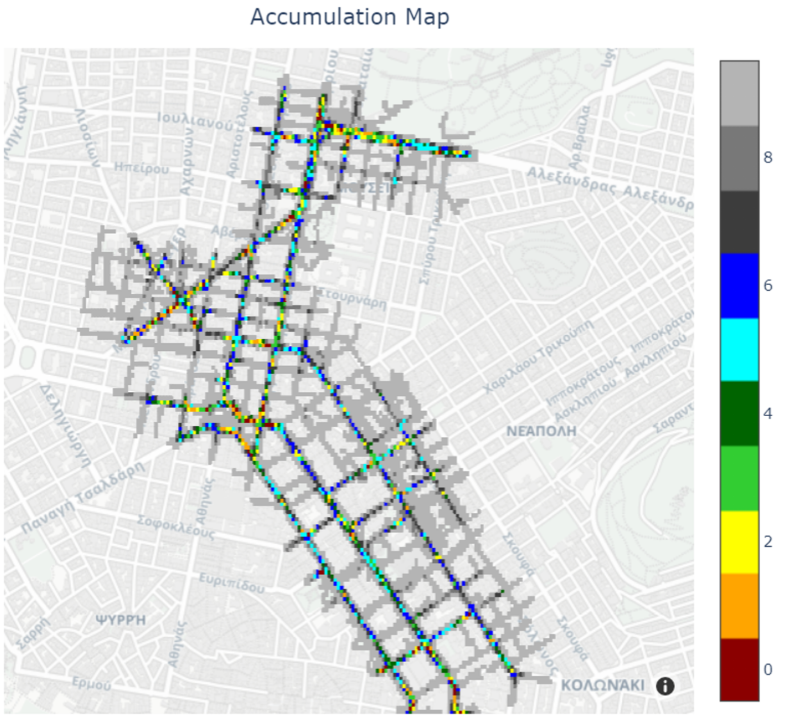


Cluster 1 - 5

Static clustering

- Partition into 10 clusters with equal accumulation *(as congestion in the graph)*
- No spatial connectivity within the same zone
- Last clusters may add noise (include buildings...)

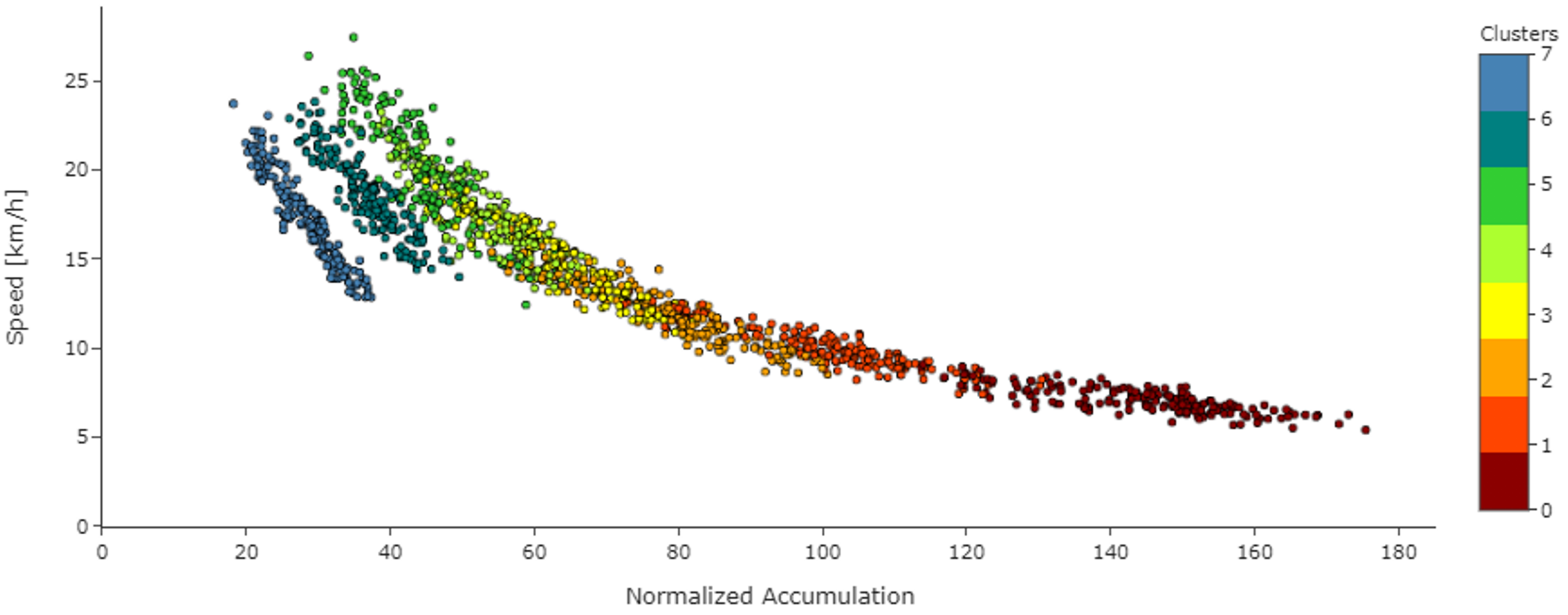




Static clustering

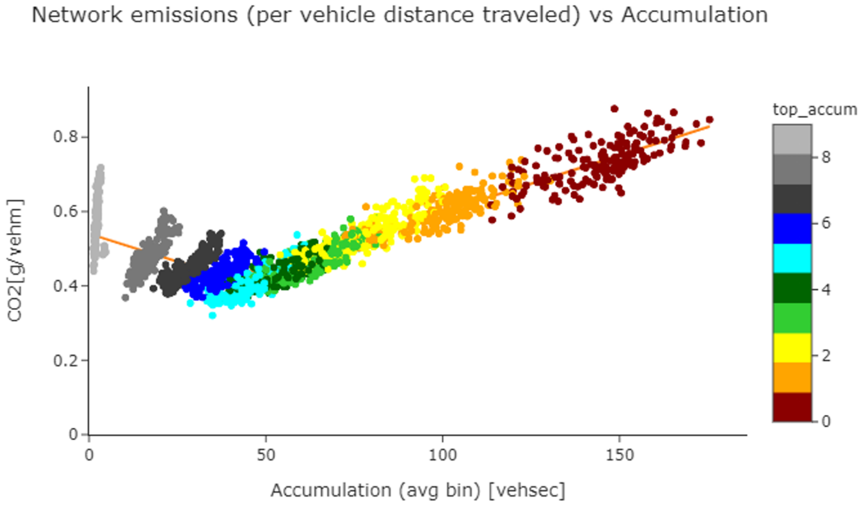
- Speed MFD

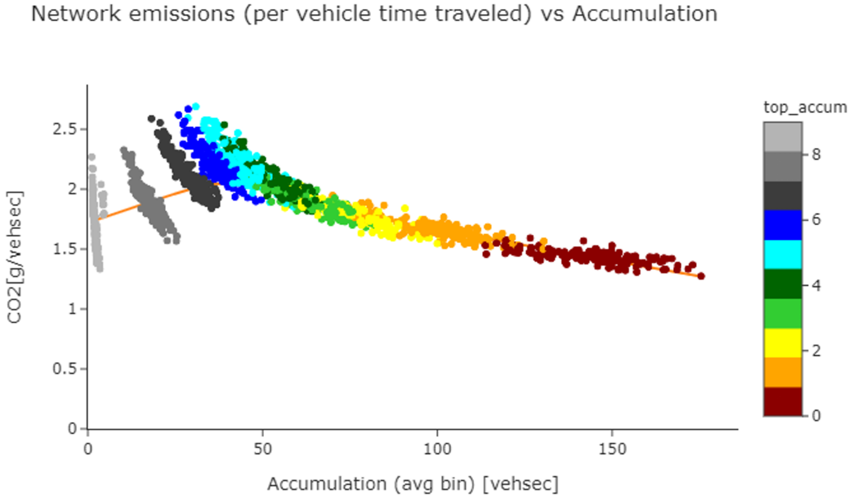
Avg Speed



What drives emissions?

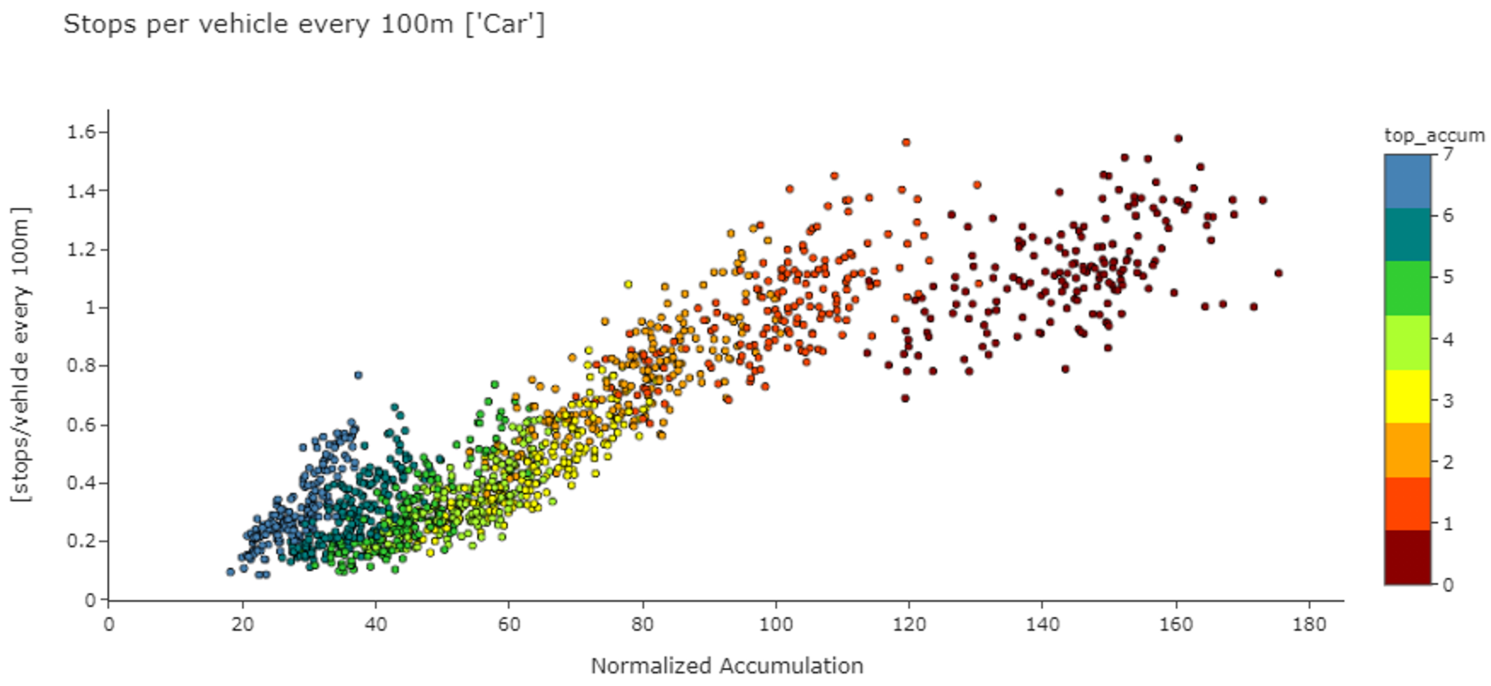
- Emissions per distance traveled increase with accumulation (root causes are analyzed later)
- Emissions per time traveled decrease with accumulation (root causes are analyzed later)



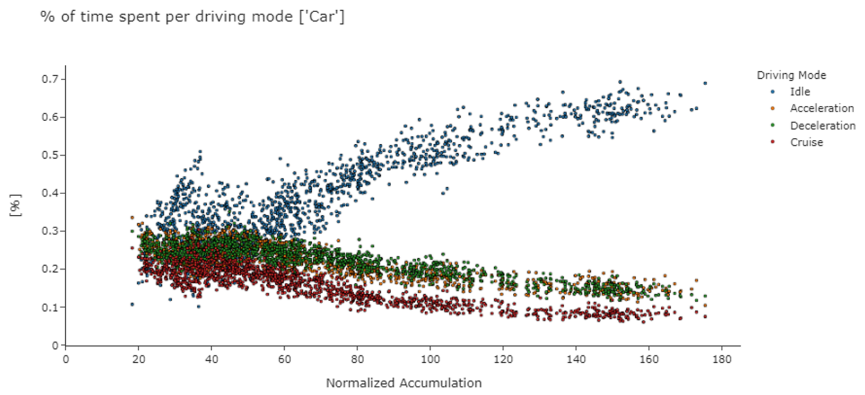


What drives emissions?

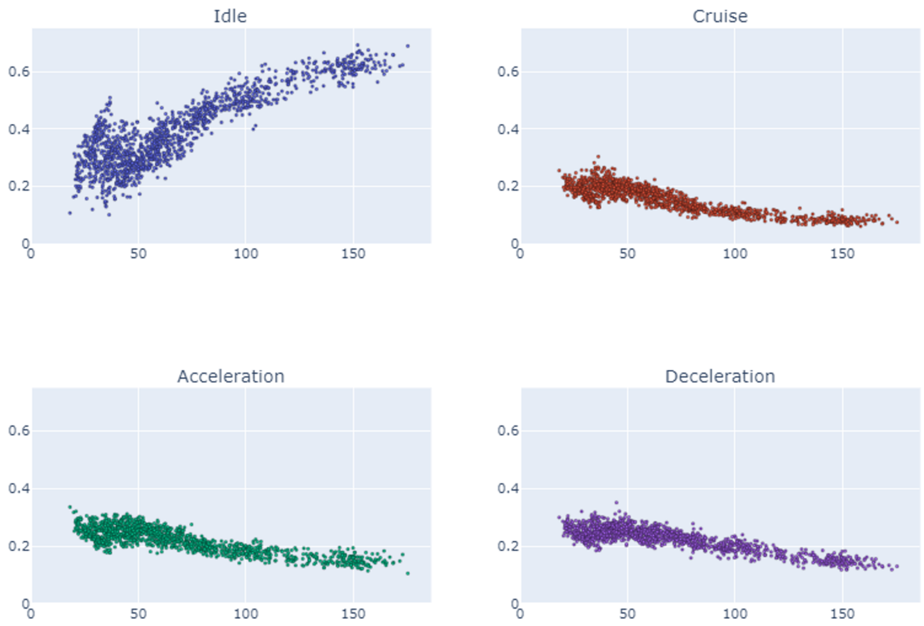
- # Stops increase with accumulation



Only cars



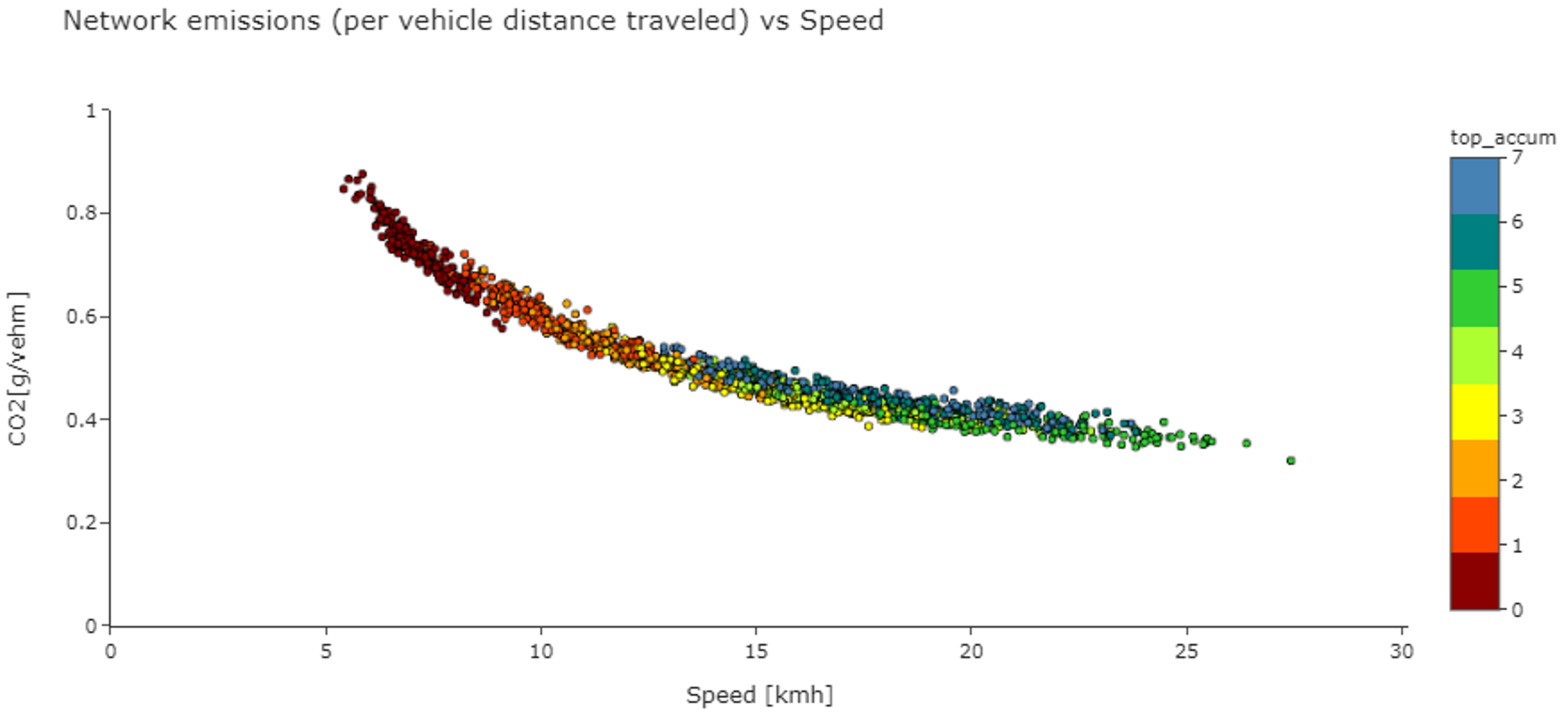
% of time spent per driving mode ['Car']
Driving Mode
Idle
Acceleration
Deceleration
Cruise
[%]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
20
40
60
80
100
120
140
160
180
Normalized Accumulation



Idle
Cruise
Acceleration
Deceleration
0
0.2
0.4
0.6
0
50
100
150

What drives emissions?

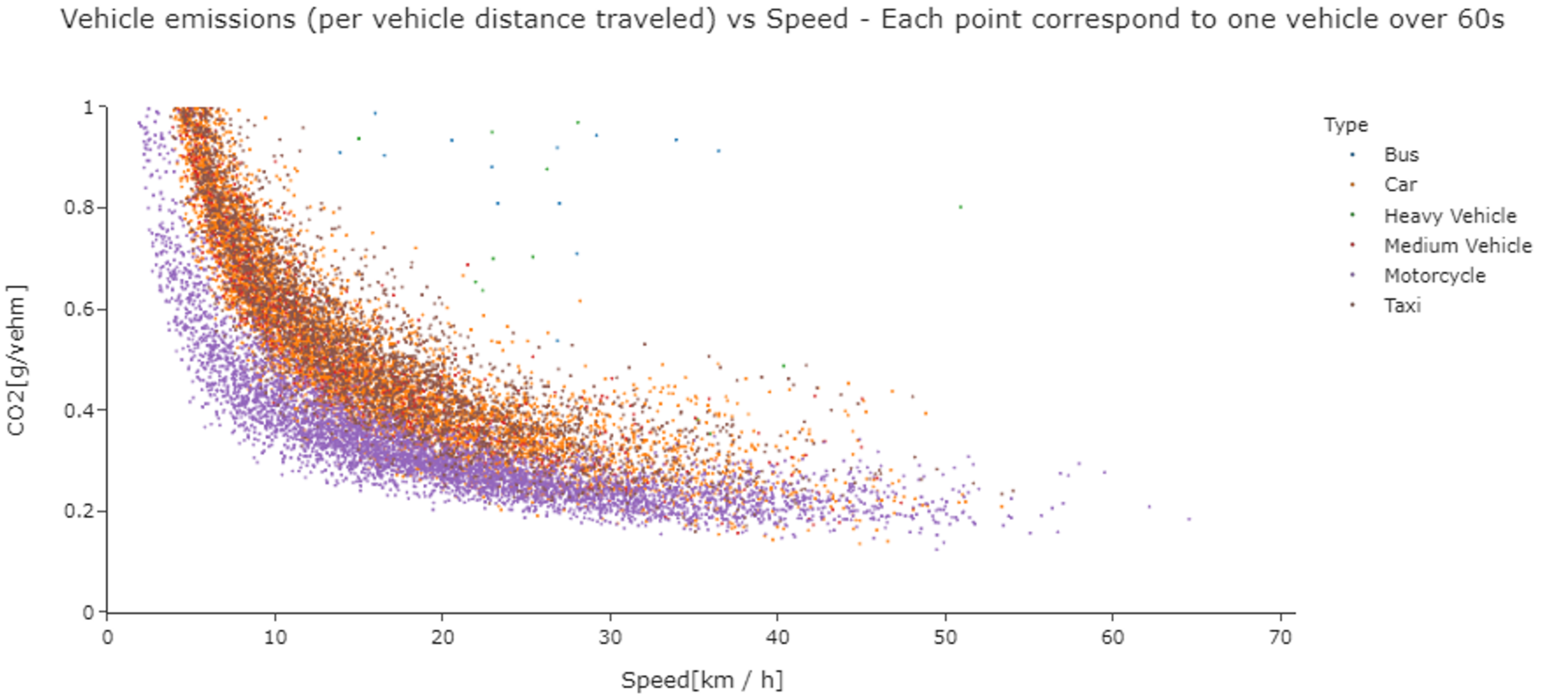
- Macroscopic level: Well-defined relationship Emissions-Speed



What drives emissions?

- Individual level: Higher variance & heteroskedasticity

**Same time aggregation (1min)*



Visualization tool

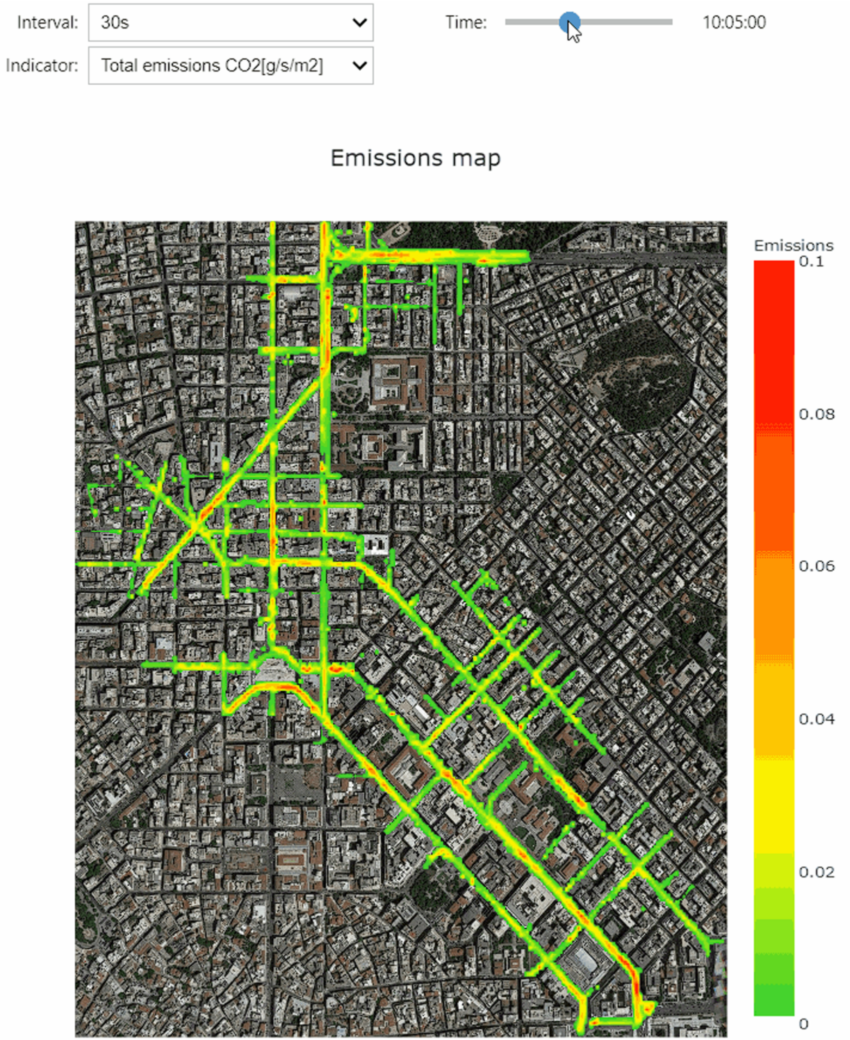
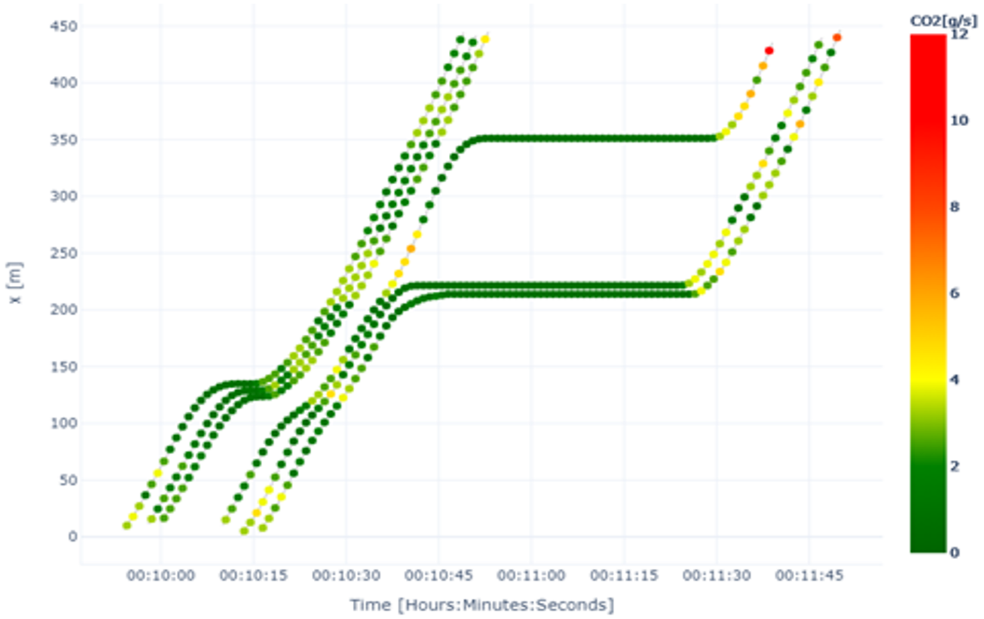
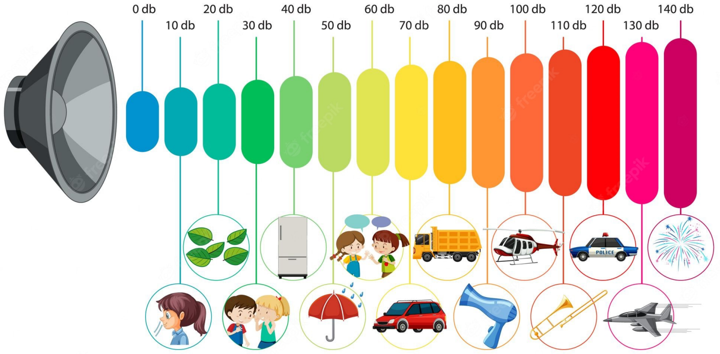


FIGURE. Space-Time diagram with emission rates of 6 consecutive cars (left). Location: left lane of Alexandras Ave towards the East (right).



Noise emissions

- Long-term exposure to **road traffic noise** is correlated with **human discomfort**: distress, sleep disturbance, cardiovascular diseases…
- Noise is measured in **decibels** (dB). Logarithmic scale.
- The noise emissions of a vehicle depend on:
  - Vehicle type
  - Speed
  - Acceleration
  - Atmospheric conditions
  - Pavement
  - Slope



Noise emissions

Noise emissions (L_W) = **Propulsion** component (L_{WP}) + **Rolling** component (L_{WR})

Propulsion component (L_{WP}) → Contributions from engine, exhaust, gears and air intake

Rolling component (L_{WR}) → Interaction between the tires and the road

$$L_W = 10\log_{10}\left(10^{\frac{L_{WP}}{10}} + 10^{\frac{L_{WR}}{10}}\right)$$

Noise emissions

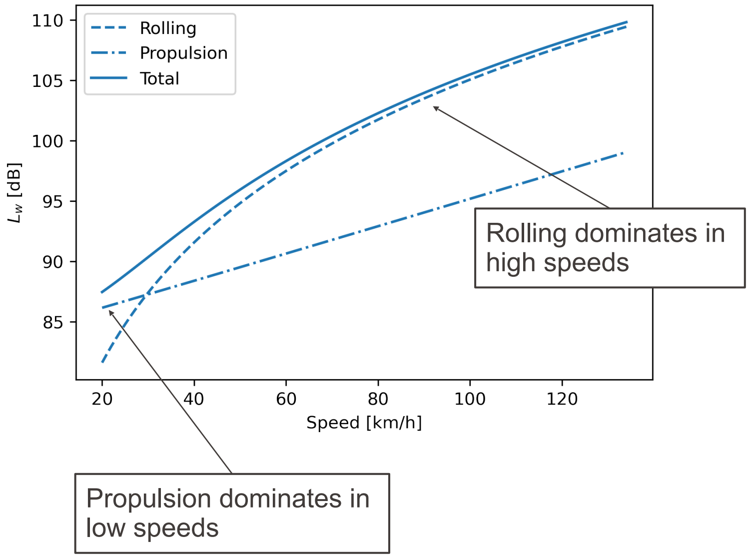
- Models: CNOSSOS-EU, Imagine, NMPB, SonRoad, Nord2000…
- **CNOSSOS-EU** is the reference model in the EU directives.

  - Propulsion component

$$L_{WP} = A_P + B_P \frac{v - v_{ref}}{v_{ref}} + \Delta L_{WP}(v)$$

  - Rolling component

$$L_{WR} = A_R + B_R \log_{10}\left(\frac{v}{v_{ref}}\right) + \Delta L_{WR}(v)$$

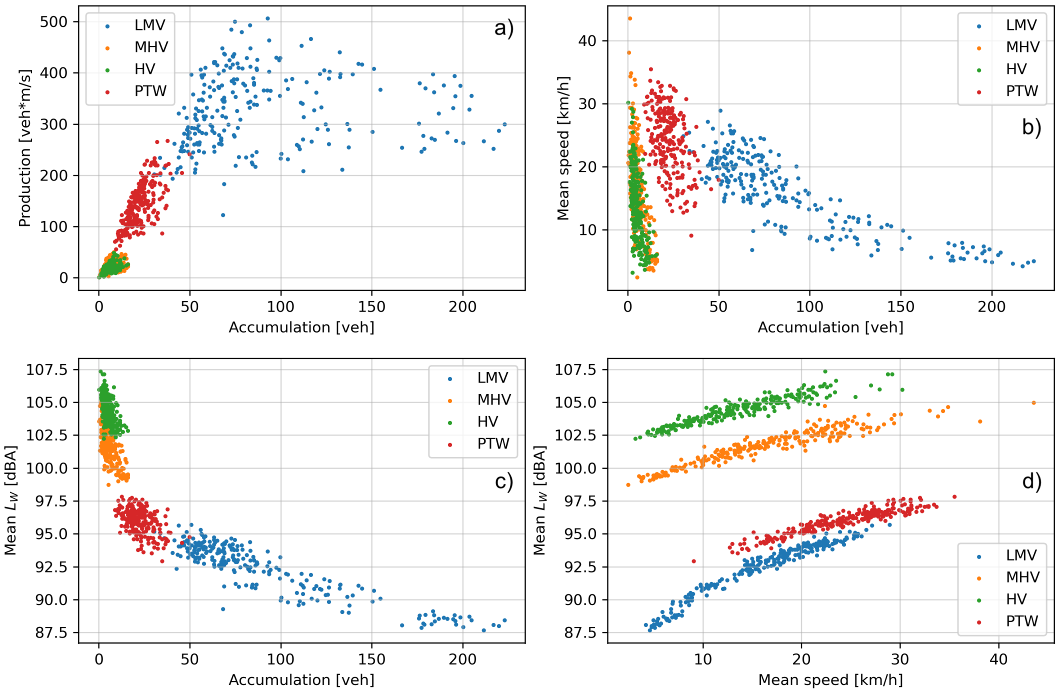


- A_P, B_P, A_R, B_R: coefficients depending on vehicle type and frequency
- ΔL: corrections due to acceleration, slope, pavement…

Noise emissions

Macroscopic relations between:

- Accumulation,
- Production,
- Speed
- Noise emissions.



Vehicle categories

- LMV=light motor vehicles
- MHV=medium heavy vehicles
- HV=heavy vehicles
- PTW=powered-two-wheelers

Noise levels

Noise level (L) = **Noise** emissions (L_W) + Sound propagation model

Noise emissions (L_W) → Noise emission from the vehicle

Sound propagation model → Sound paths, reflection on buildings…

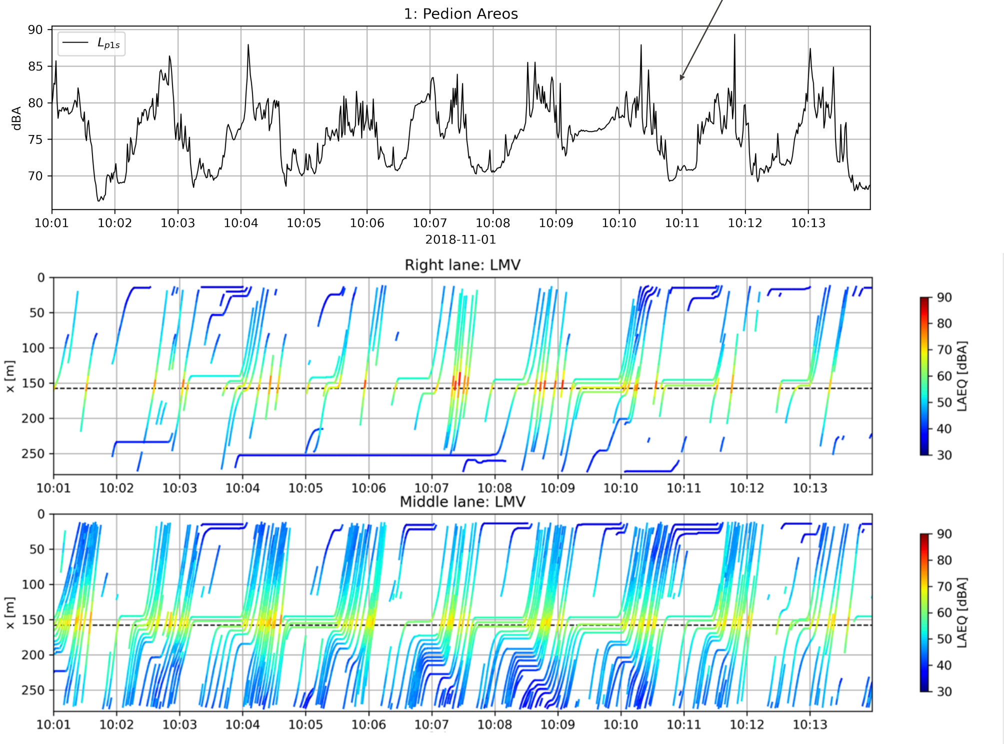
Sound attenuates from the source (S) to the receiver (R) due to the distance, sound barriers, sound reflection…

Noise levels

Noise evolution at a Bus Stop

- Next to a traffic light
- x~160m

cyclic noise levels

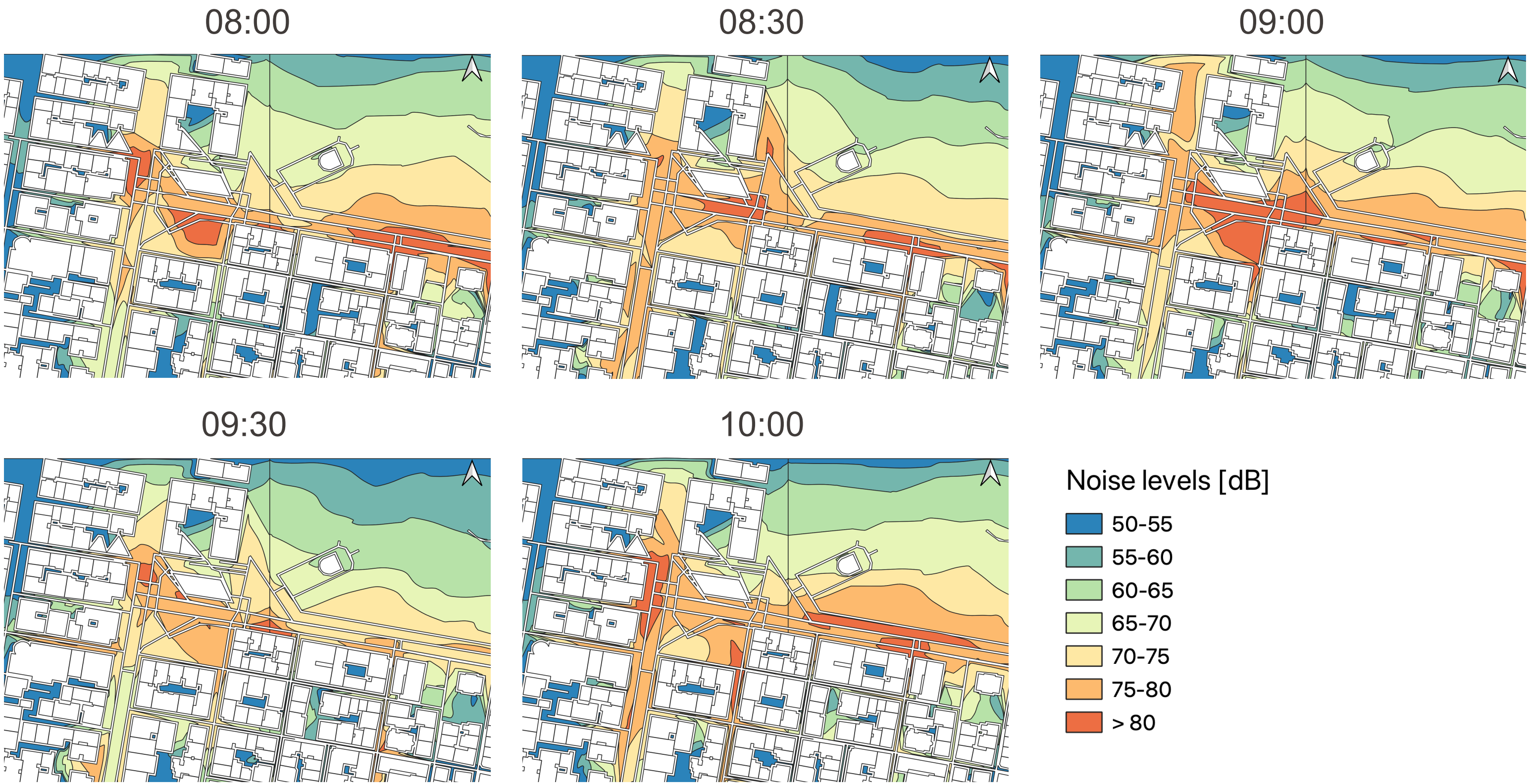


Individual contribution of each vehicle in the *right* lane

Individual contribution of each vehicle in the *middle* lane

The closer to the Bus Stop the greater noise impact

Noise levels



Noise emissions Literature

- *Kephalopoulos, S., M. Paviotti, and F. Anfosso-Lédée.* ***Common Noise Assessment Methods in Europe (CNOSSOS-EU).*** *Common noise assessment methods in Europe (CNOSSOS-EU). 180–p.*
- *Can, A., and P. Aumond.* ***Estimation of Road Traffic Noise Emissions: The Influence of Speed and Acceleration.*** *Transportation Research Part D: Transport and Environment, Vol. 58, 2018, pp. 155–171. https://doi.org/10.1016/J.TRD.2017.12.002.*
- *Can, A., L. Leclercq, J. Lelong, and D. Botteldooren.* ***Traffic Noise Spectrum Analysis: Dynamic Modeling vs. Experimental Observations.*** *Applied Acoustics, Vol. 71, No. 8, 2010, pp. 764–770. https://doi.org/10.1016/J.APACOUST.2010.04.002.*
- *Espadaler-Clapés, J., Barmpounakis, E., Geroliminis, N., 2023b.* ***Traffic congestion and noise emissions with detailed vehicle trajectories from UAVs****. Transp. Res. Part D Transp. Environ. 121, 103822. doi:10.1016/J.TRD.2023.103822*