A GEAR-BASED VEHICLE EMISSION MODEL FOR CO_2, CO AND NO_X ESTIMATION

Hajar Hajmohammadi

Centre for Transport Studies, UCL
Hajar.Hosseinabadi.14@ucl.ac.uk

Benjamin Heydecker
Professor of Transport studies, UCL

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Introduction

Why we need vehicle emission model?

- To evaluate the impacts of traffic policies on the air quality
- To develop traffic control policies that can reduce air pollution in critical areas

Influential variables in the vehicle emission modelling:

- Vehicle-related parameters: e.g. model, engine size, fuel and catalyst type and technology level
- Operational factors: driving cycle

Dataset: Laboratory vehicle emission tests

Vehicle type

Fuel	Petrol - Diesel
Transmission	Automatic – Manual
Engine Size	from 1000 to 3200 cc

Measurements

emission: CO_2, CO, THC, NO_x, PM_n

vehicle: Roll speed, Engine speed

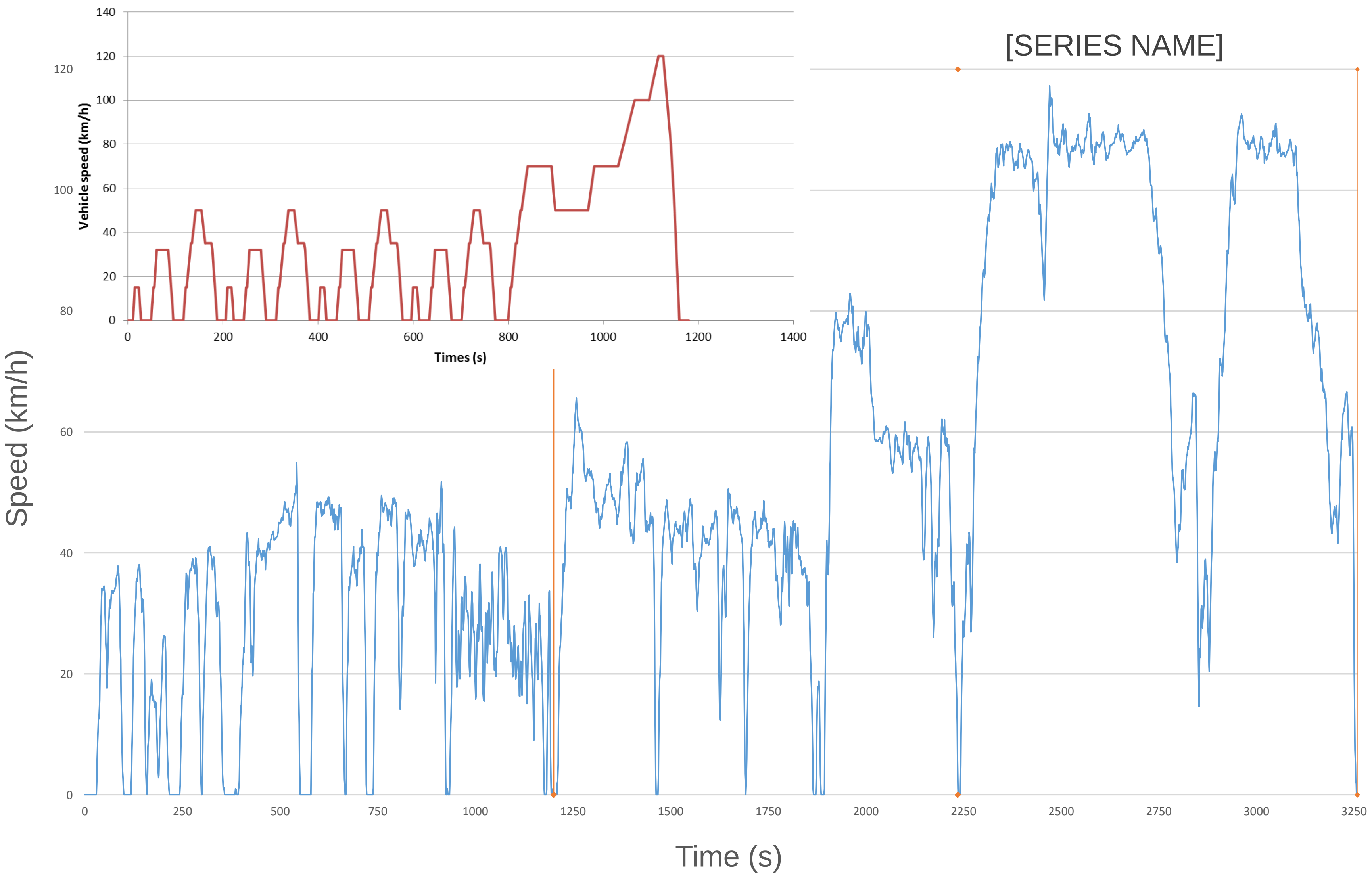
Real Driving Cycle for London

Traffic Conditions:

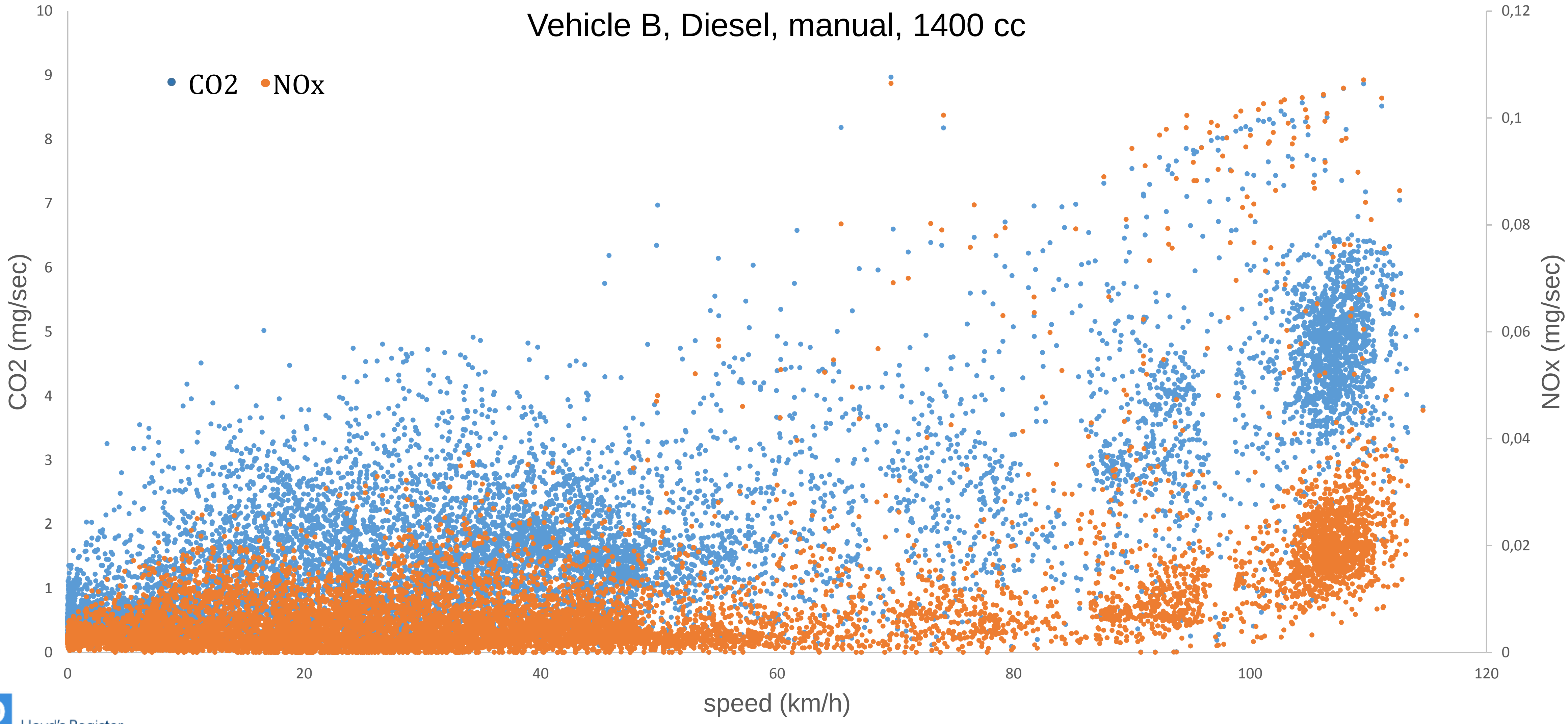
Free Flow

AM peak

Inter peak



Statistical modelling



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Background

Single model

$$y = c + \sum_{j=1}^{J} \beta_j x_j + \varepsilon$$

y= emission

x= Roll Speed, v

Acceleration, a

Power demand

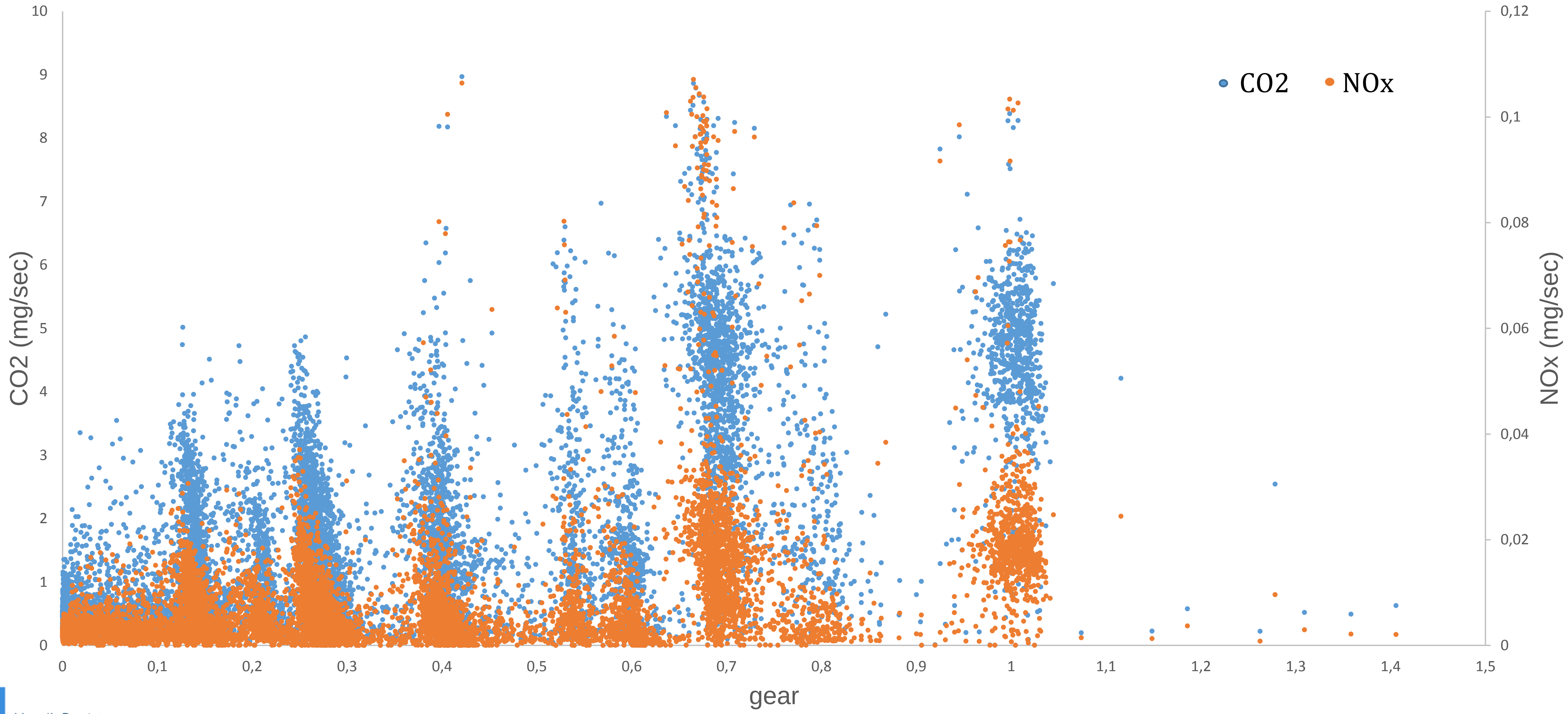
$VSP = (^A/_M)v + \ (^B/_M)\ v^2 + (^C/_M)v^3 + (a + g\sin\theta\ )v$

Classified model: Acceleration, Cruising, Idling, Deceleration (CADI)

VT-micro emission model

$$y = \begin{cases} exp(\sum_{i=0}^{3}\sum_{j=0}^{3}(L_{i,j} \times v^i \times a^j)) & for\ a \geq 0 \\ exp(\sum_{i=0}^{3}\sum_{j=0}^{3}(\gamma_{i,j} \times v^i \times a^j) & for\ a < 0 \end{cases}$$

New latent variable, Gear=roll speed/engine speed



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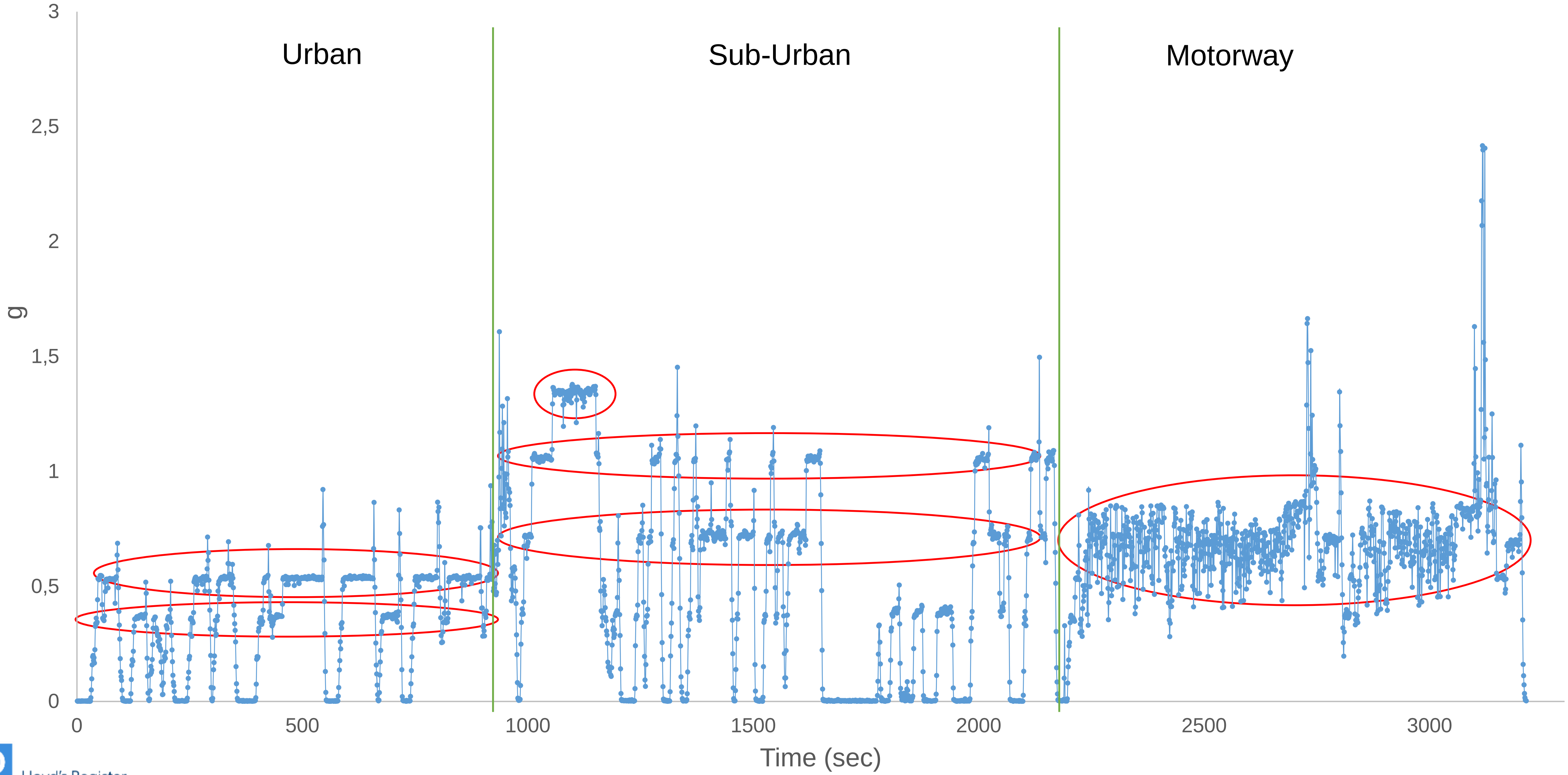
New latent variable, Gear=roll speed/engine speed



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Mixed distribution model

$$F(g \mid \pi;\theta) = \sum_{k=1}^{K} \pi_k \, F(g \mid \theta_k)$$

Bayes' theorem

$$w_{tk} = \frac{f(g_t \mid \theta_k)\, \pi_k}{\sum_{j=1}^{K} f(g_t \mid \theta_j)\, \pi_j}$$

Gear-memberships

Log-likelihood

$$\log l\,(\pi, \theta) = \sum_{n=1}^{N} \left(\log \sum_{k=1}^{K} \pi_k f\,(g_n \mid \theta_k)\right)$$

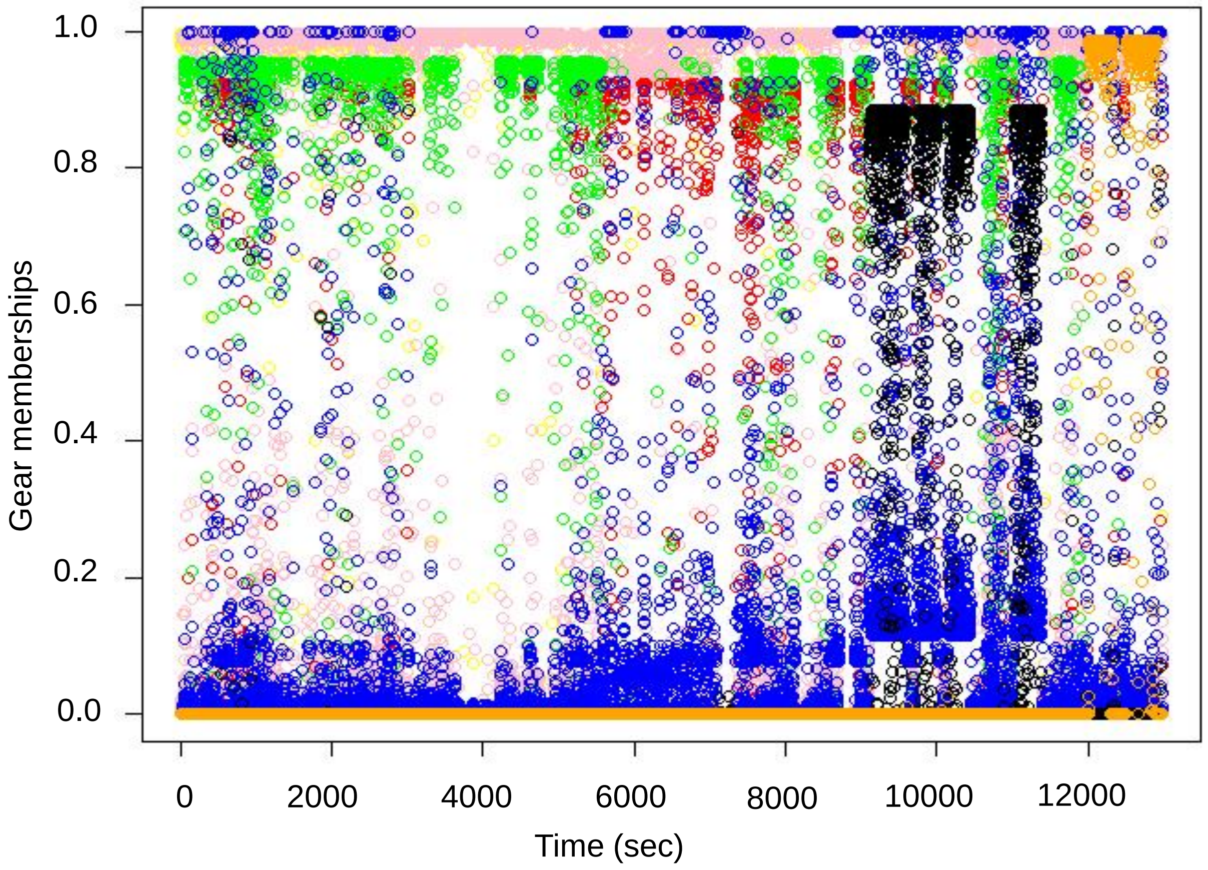
Maximization

Expectation-Maximization (EM) algorithm

$\boldsymbol{w(t,k)}$

$\boldsymbol{\pi}$, $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$ for each component k

Gear memberships



Vehicle B
Diesel – Supermini – Manual

- Component 1
- Component 2
- Component 3
- Component 4
- Component 5
- Component 6
- Component 7

Gear-based emission modelling

$$\boldsymbol{y} = \mathbf{x}.\beta + \mathbf{w}.\varphi + (\mathbf{x}.\mathbf{w}).\gamma + \boldsymbol{\varepsilon}$$

$\mathbf{x}$: Explanatory variables

$$v, a, av, v^3$$

$\boldsymbol{w}$: Gear membership (latent variable)

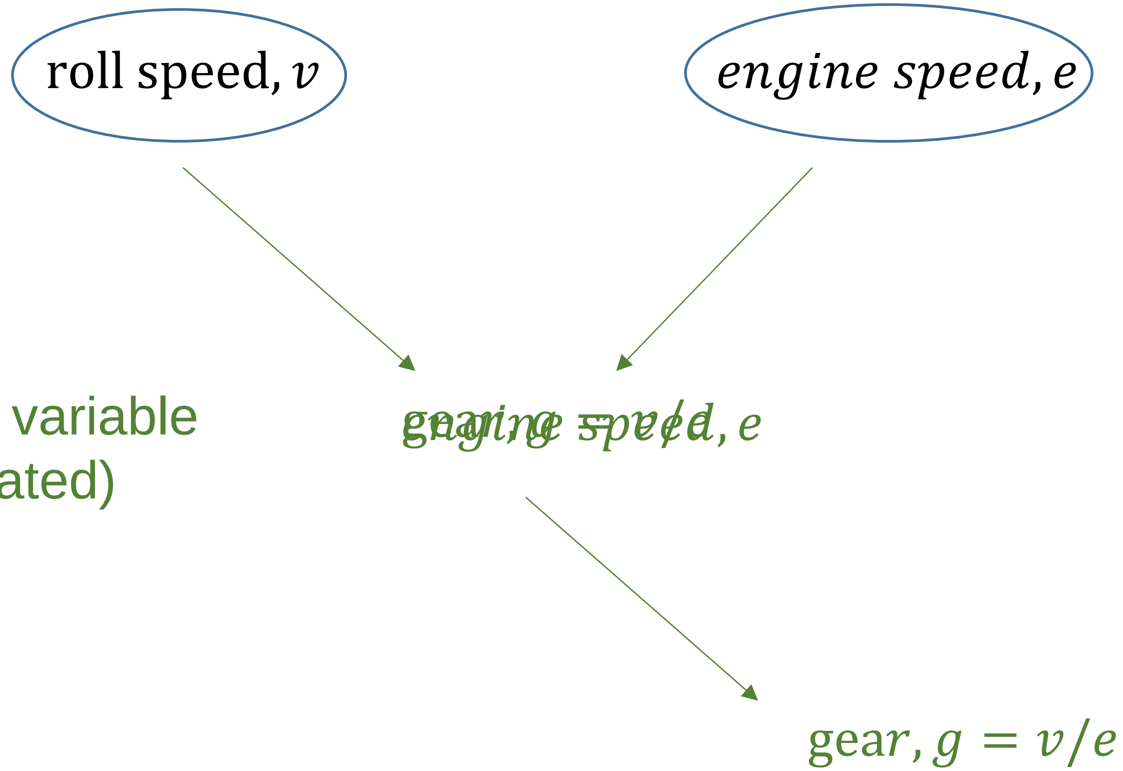
$\mathbf{x}.\mathbf{w}$: Interaction

$\boldsymbol{\varepsilon}$: Residuals

Challenge: engine speed as a latent variable

Observation

Latent variable
(estimated)



Transfer Function Model

$$e_t = t(B)v_t + \mathrm{N}_t$$

$\boldsymbol{e_t}$: engine speed at time t

$\boldsymbol{v_t}$: roll speed at time t

$\boldsymbol{t(B)}$: rational polynomial in B: $\frac{w(B)B^b}{\delta(B)}$

Systematic part

$\boldsymbol{N_t}$: noise- **can be serially correlated**

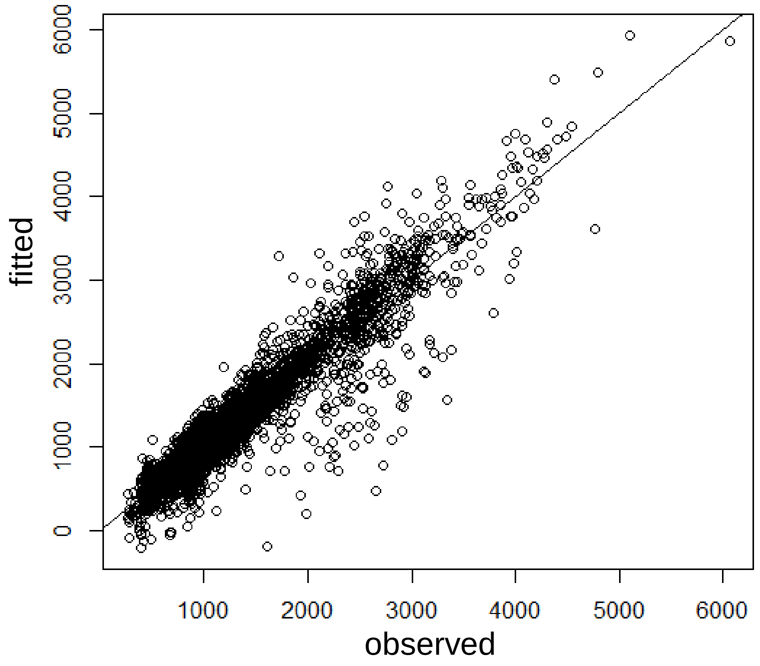
$$\frac{\emptyset(B)}{\theta\ (B)} N_t = \varepsilon_t$$

Stochastic part

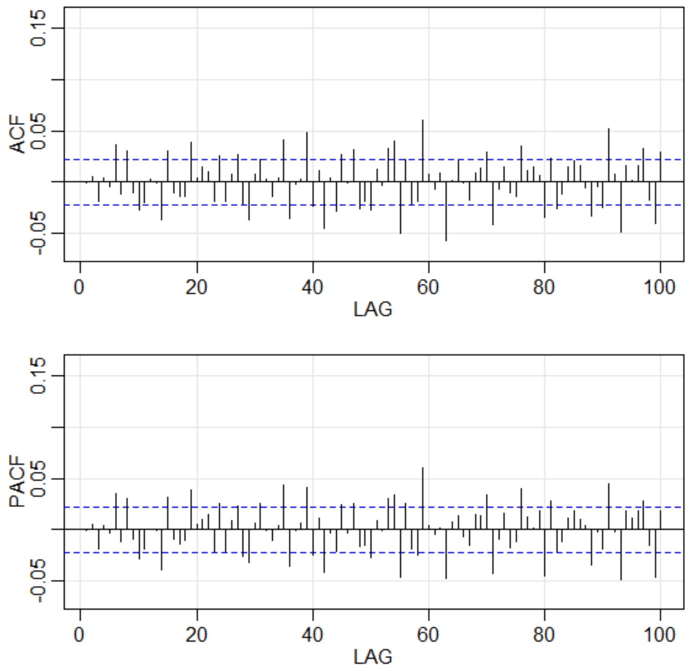
Transfer Function Model

$$e_t = c + \frac{w_0 + w_1 B + w_2 B^2}{1 - \delta_1 B - \delta_2 B^2} v_t + \frac{1 - \phi_1 B - \phi_2 B^2}{1 - \theta_1 B - \theta_2 B^2} (1 - B)\, \varepsilon_t$$

$R^2 = 0.896$



ACF and PACF of ε



Gear-based emission modelling

Driving Cycle → Explanatory variables v, a, av, v^3

↓

Transfer Function Model

↓

Engine speed

↓

Gear =roll speed/ engine speed → Mixed distribution model → Gear-memberships

$$\boldsymbol{y} = \mathbf{x}.\beta + \mathbf{w}.\varphi + (\mathbf{x}.\mathbf{w}).\gamma + \boldsymbol{\varepsilon}$$

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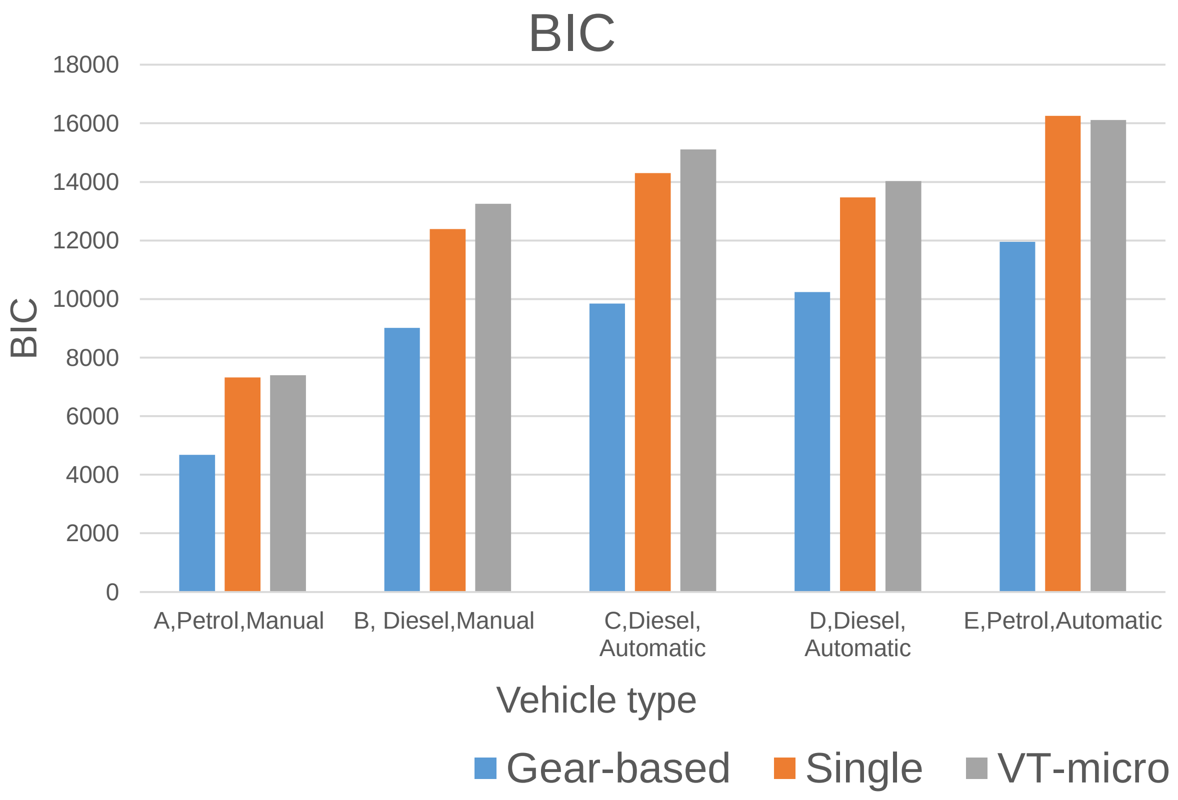
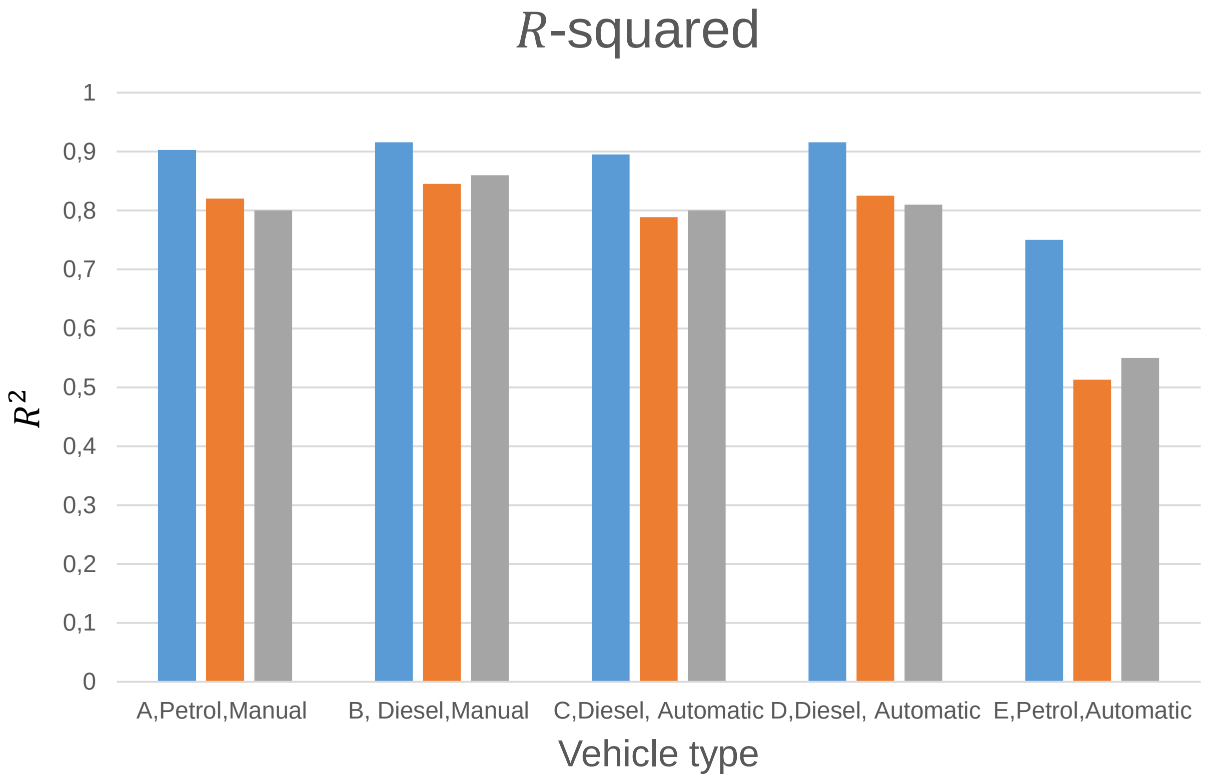
Results





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Conclusion

- Gear for driving mode instead of acceleration
- Introducing gear-membership
- Transfer function model

Thank You !

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