Insights from UK vehicle dynamics and exhaust emissions analysis: Informing policy interventions

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Vehicle dynamics and emission rates

Two key areas of uncertainty:

- Measuring and quantifying **vehicle dynamics** (speed & acceleration), and:

- Quantifying vehicle **exhaust emission rates** in different phases of vehicle dynamics.

Robust and representative data in the UK is relatively scarce……

DfT 2015/2016 PEMS 'on-road' test route

PEMS data collected in Dec 2015 to Feb 2016 on-road (winter).

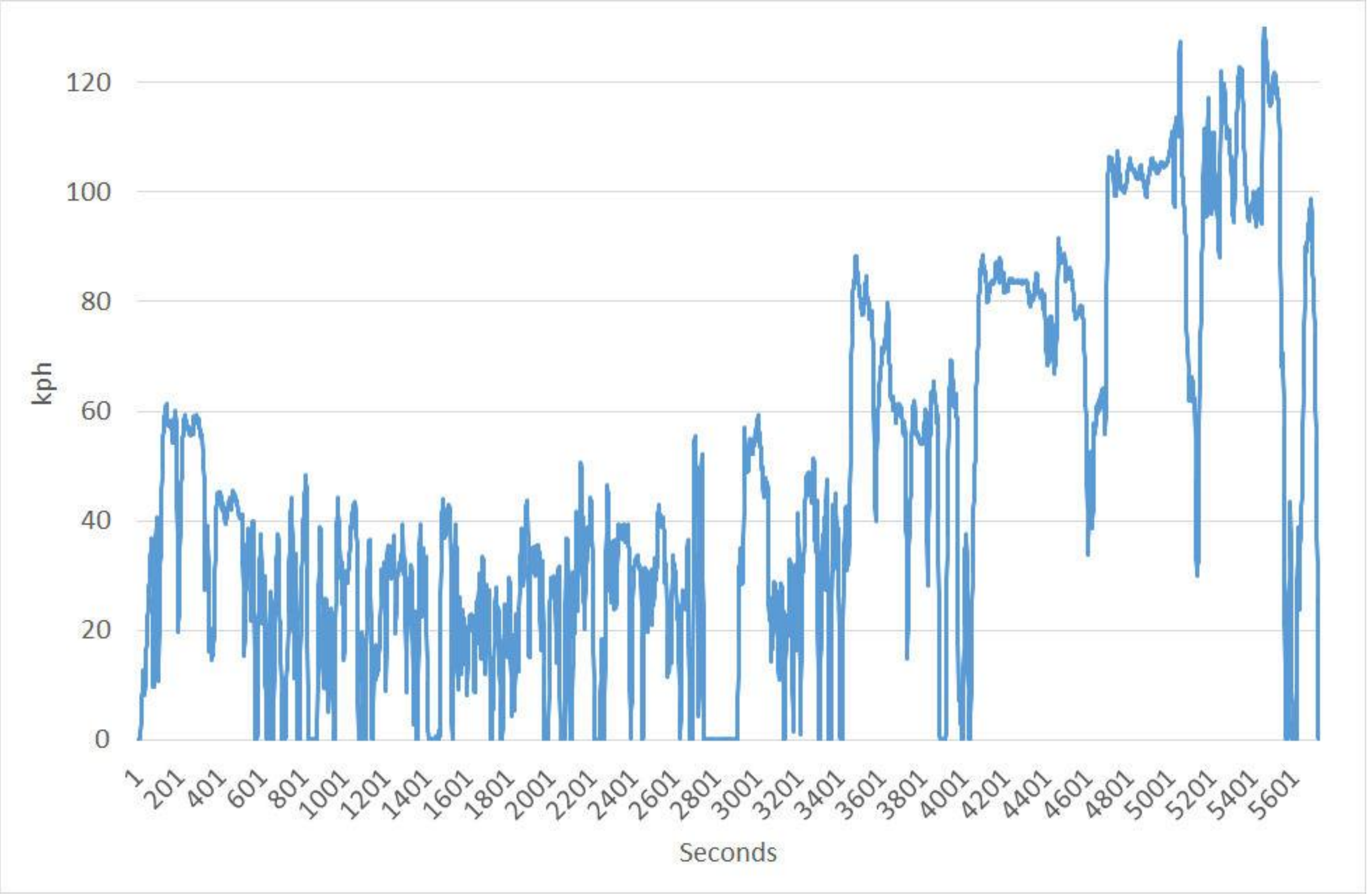
Combines urban (Nuneaton), inter-urban (A5), and motorway (M6).

Other data were also collected on the test track, and in the laboratory.

DfT PEMS equipment

Source: DfT (2016)

Example speed profile from DfT 'on-road' test route



DfT PEMS ‘on-road’ Euro 5 diesel car summary (n=19)

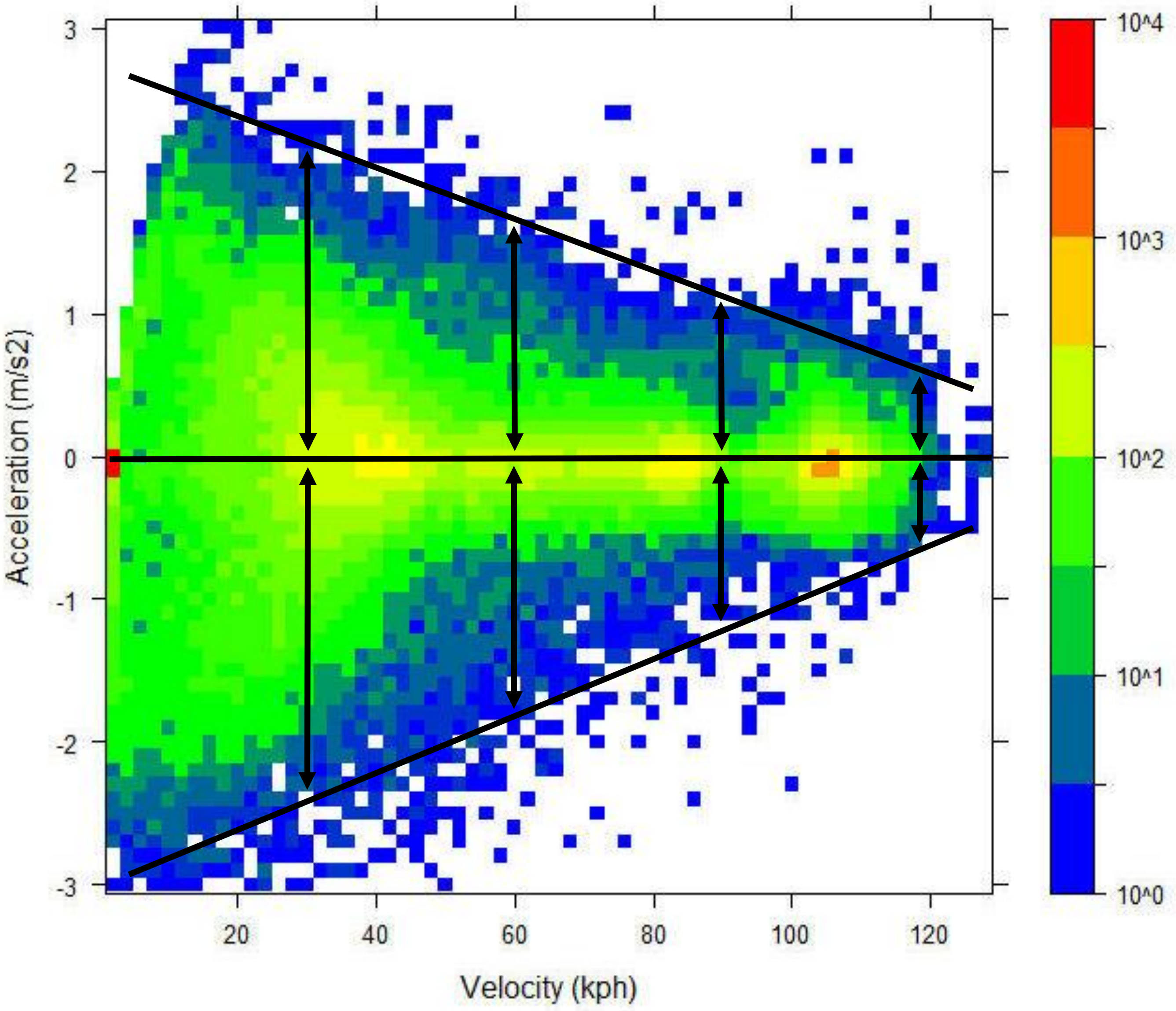
Vehicle	Engine cc	Euro class	Technology	Temp °C	CO2 g/km	NOx mg/km
Citroen C4	1560	Euro 5	EGR, DOC, DPF	11.6	134	518
Ford Mondeo	2000	Euro 5	EGR, DOC, DPF	10.3	193	579
Peugeot 208	1398	Euro 5	EGR, DOC, DPF	8.8	123	589
Honda CR-V SE i-DTEC	2199	Euro 5	EGR, DOC, DPF	7.8	174	813
Skoda Octavia	1600	Euro 5	EGR, DOC, DPF	4	140	854
Hyundai iX35	1685	Euro 5	EGR, DOC, DPF	14.4	153	861
Hyundai i30 auto	1582	Euro 5	EGR, DOC, DPF	12.5	161	981
Kia Sportage	2000	Euro 5	EGR, DOC, DPF	7	232	1018
Vauxhall Corsa	1248	Euro 5	EGR, DOC, DPF	7.5	146	1110
Land Rover Freelander	2179	Euro 5	EGR, DOC, DPF	13	243	1174
Mercedes Benz E250	2143	Euro 5	EGR, DOC, DPF	5.7	195	1213
Vauxhall Astra	1686	Euro 5	EGR, DOC, DPF	12.8	131	1227
Range Rover Sport	2993	Euro 5	EGR, DOC, DPF	6.1	155	1269
Hyundai Santa Fe	2199	Euro 5	EGR, DOC, DPF	10.8	251	1311
Nissan Qashqai	1461	Euro 5	EGR, DOC, DPF	10.1	151	1439
Nissan Qashqai	1598	Euro 5	EGR, DOC, DPF	10.3	152	1461
Volvo V40 Cross Country D2 auto	1560	Euro 5	EGR, DOC, DPF	6.5	141	1549
Range Rover Sport HSE	2993	Euro 5	EGR, DOC, DPF	7.2	237	1720
Vauxhall Insignia CDTI Ecoflex	1956	Euro 5	EGR, DOC, DPF	11.6	170	1881

DfT PEMS ‘on-road’ Euro 6 diesel car summary (n=18)

Vehicle	Engine cc	Euro class	Technology	Temp °C	CO2 g/km	NOx mg/km
Mini Countryman	1598	Euro 6	EGR, DOC, LNT, DPF	8.1	145	131
BMW X5	2993	Euro 6	EGR, DOC, SCR, DPF	10.1	258	157
VW Golf	2000	Euro 6	EGR, DOC, LNT, DPF	12.2	159	158
Skoda Octavia	1598	Euro 6	EGR, DOC, LNT, DPF	8.8	154	204
Toyota Avensis	1998	Euro 6	EGR, DOC, LNT, DPF	4.1	146	292
Mazda 6	2191	Euro 6	EGR, DOC, DPF	7.2	153	313
Hyundai i30	1582	Euro 6	EGR, DOC, LNT, DPF	13	107	356
Vauxhall Mokka	1598	Euro 6	EGR, DOC, LNT, DPF	6.4	141	393
Honda CR-V EX-I DTEC	1597	Euro 6	EGR, DOC, LNT, DPF	6.6	181	451
BMW 320 X	1995	Euro 6	EGR, DOC, LNT, DPF	5	196	455
Kia Sportage	1685	Euro 6	EGR, DOC, LNT, DPF	8.5	192	576
Ford Focus	1499	Euro 6	EGR, DOC, LNT, DPF	5	144	658
Jaguar XE	1999	Euro 6	EGR, DOC, SCR, DPF	7.5	154	666
Ford Mondeo	2000	Euro 6	EGR, DOC, LNT, DPF	13.2	172	670
Vauxhall Insignia	1956	Euro 6	EGR, DOC, SCR, DPF	6.9	156	745
Renault Megane	1461	Euro 6	EGR, DOC, LNT, DPF	9	124	918
Mercedes A Class	1461	Euro 6	EGR, DOC, LNT, DPF	9.7	153	1035
Peugeot 3008	1560	Euro 6	EGR, DOC, SCR, DPF	4.8	168	1104

Euro 5 diesel cars – Frequency distribution (seconds)

DfT 'on-road' PEMS test route 2016



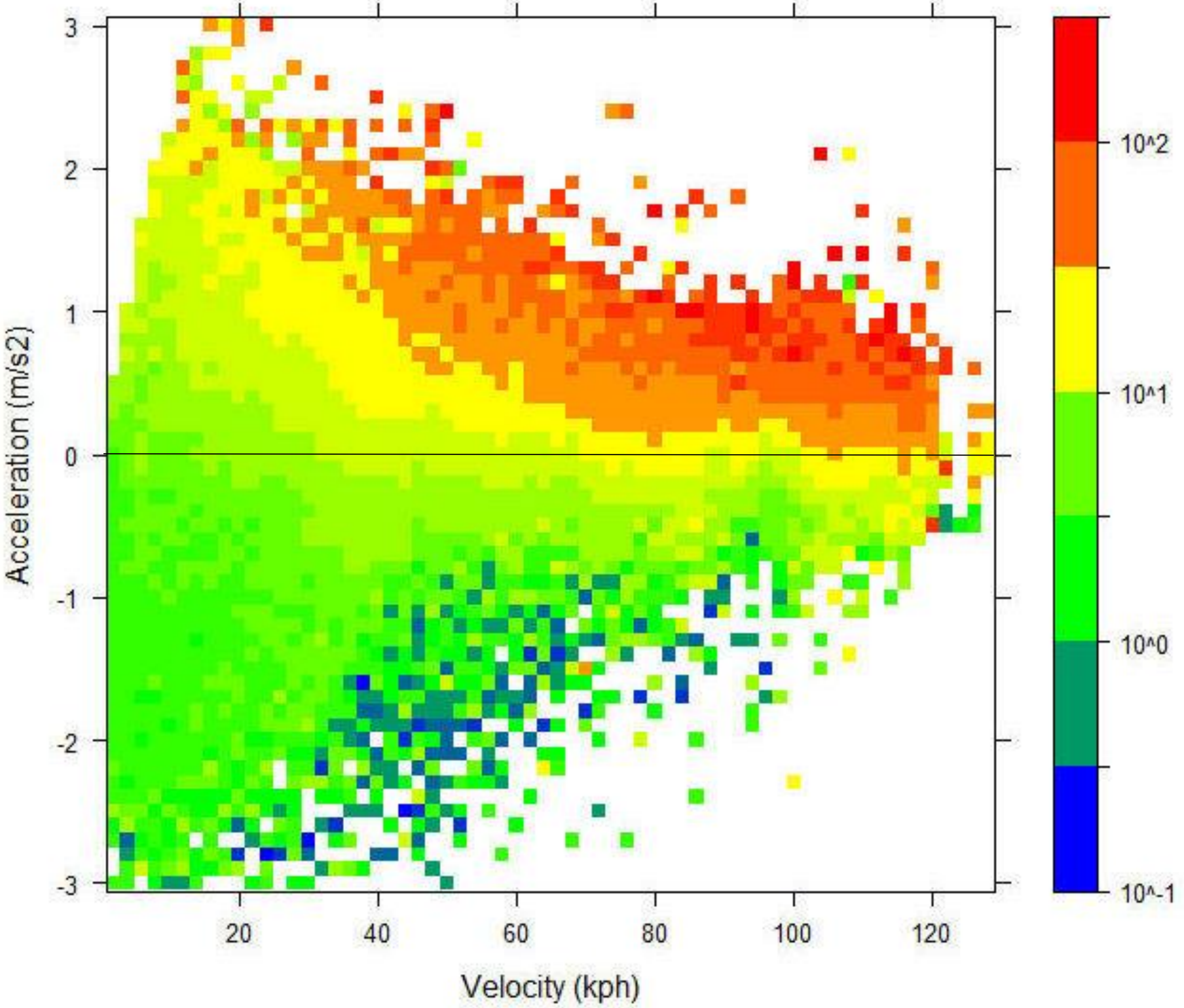
+ve acceleration constrained by:

a) Vehicle power / weight ratio
b) Driver behaviour

-ve acceleration (deceleration) constrained by:

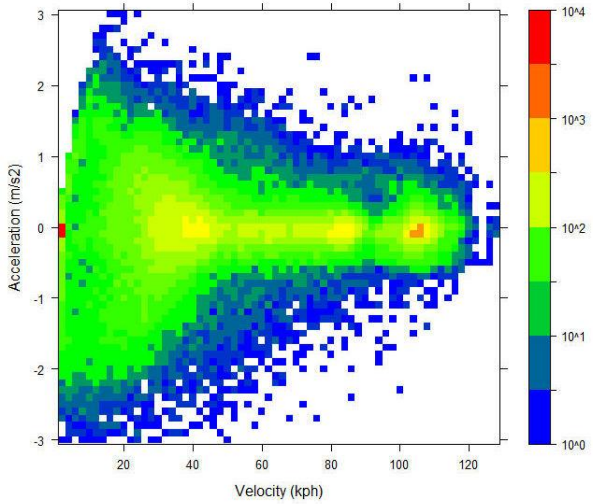
a) Vehicle technology
b) Driver behaviour

Euro 5 diesel cars – Mean NO_x (mg/second)



Euro 5 diesel cars – Total drive cycle NO_x (mg)

Time (seconds)



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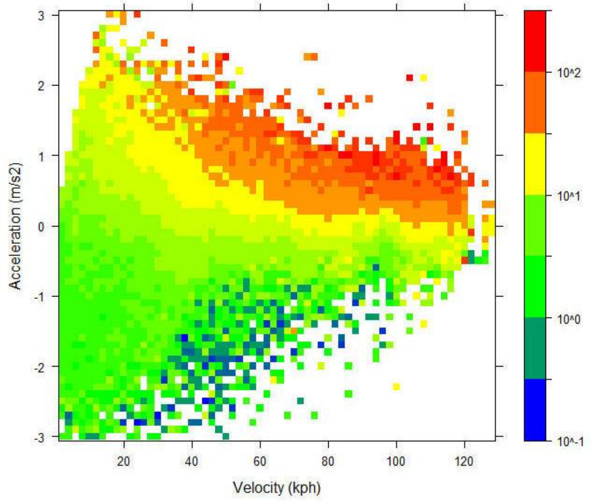
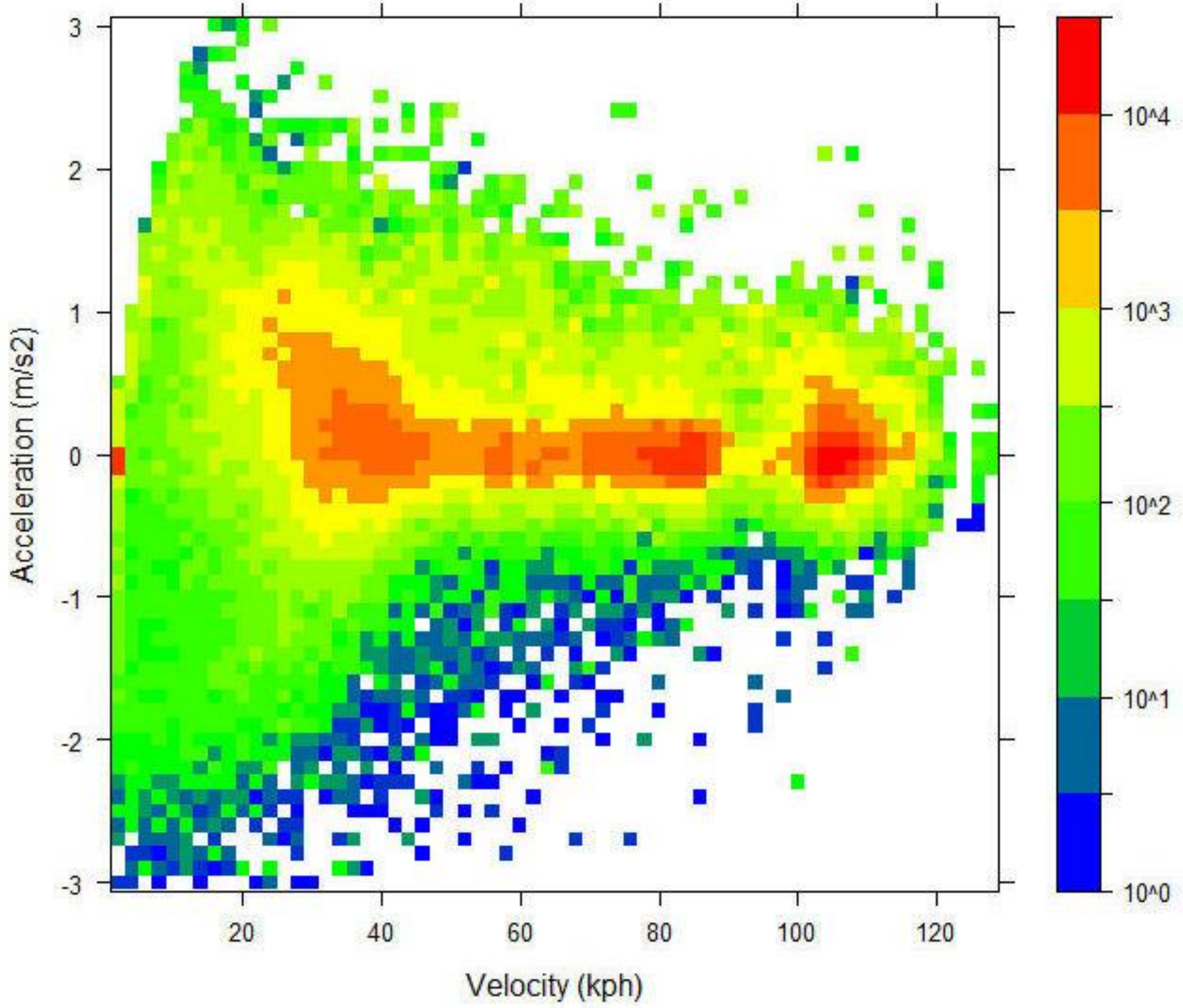
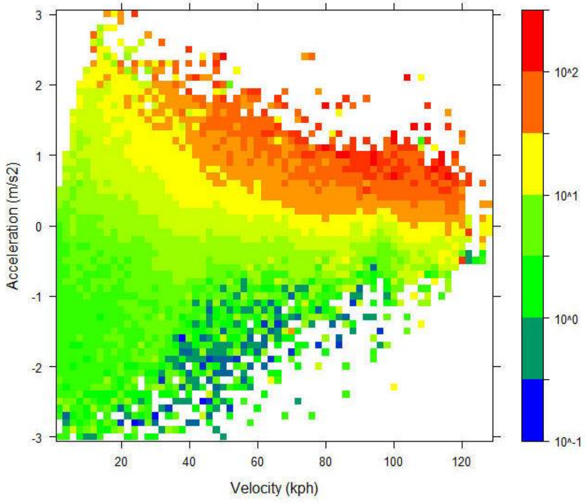


NOx (mg/sec)

= NOx (mg)

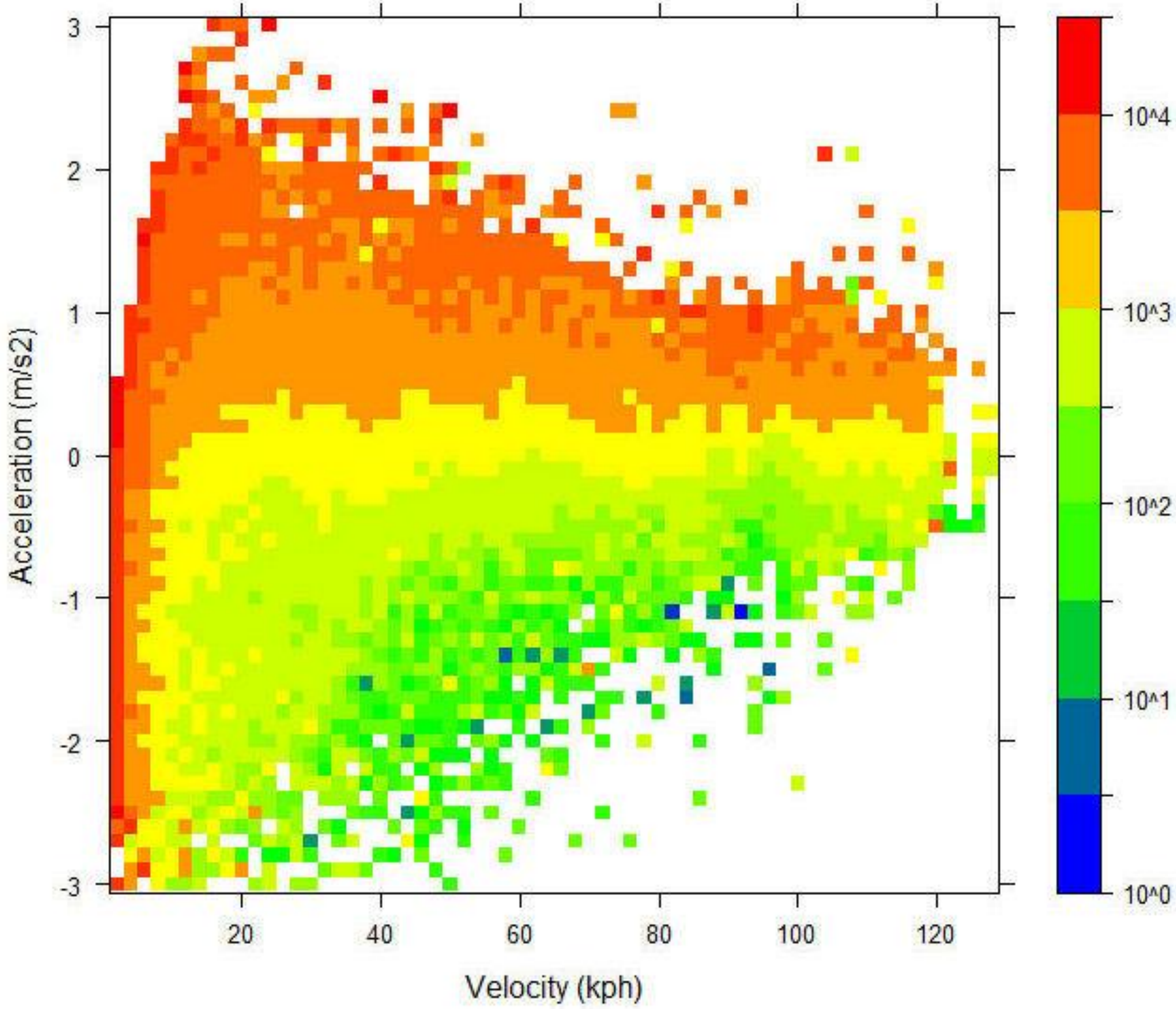


Euro 5 diesel cars – Mean NO_x (mg/km)

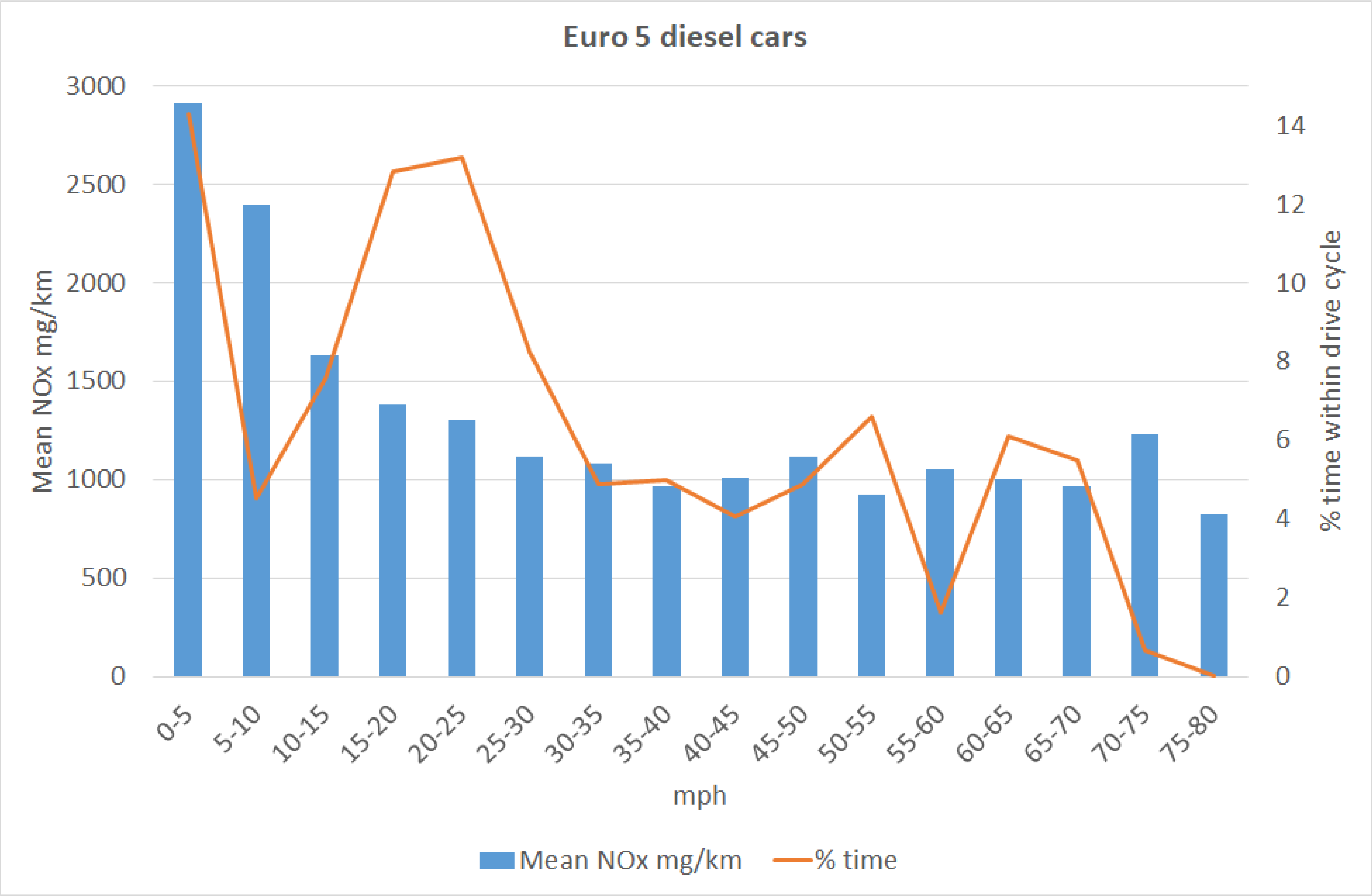


NOx (mg/sec)

Given seconds per km

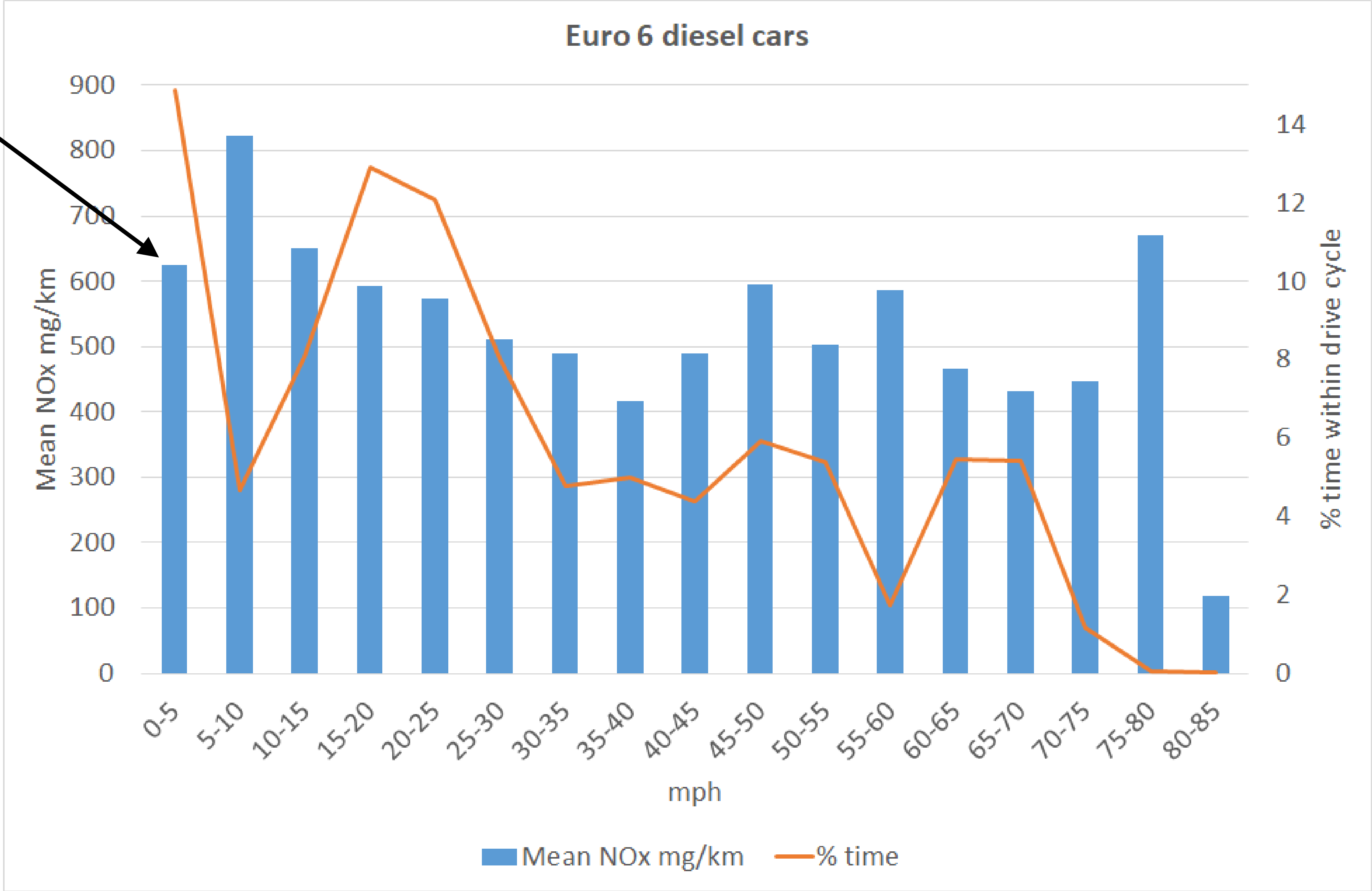


Euro 5 diesel cars – NO_x mg/km by speed band



Euro 6 diesel cars – NO_x mg/km by speed band

Impact of stop / start engine control systems in the Euro 6 diesel cars?



Applying emission data to vehicle dynamics - Example

- Netherlands Organisation for Applied Scientific Research (**TNO**) www.tno.nl/en/. TNO report R10188 *"On-road determination of average Dutch driving behaviour for vehicle emissions"* (TNO 2016)
- Implemented a test program in 2015 to determine driving behaviour by randomly following / shadowing light vehicles across the Netherlands highway network using an instrumented vehicle.
- Instantaneous speed, acceleration and position were recorded at 1Hz.
- In this way, 'average' driving behaviour for Dutch drivers on Dutch roads (in terms of instantaneous speed and acceleration) was determined across different road types, traffic situations, and levels of congestion, as at 2015.

Applying emission data to vehicle dynamics - Example

- **Professional driver** used to ‘shadow’ a sample of light vehicles
- **108 hours** of total driving time, covering a distance of 6640 km, comprising 180 trips (motorway, rural, urban).
- Output set of ‘driving vectors’ (‘q’), describing and quantifying the mix of passenger car driver behaviour (vehicle speed and acceleration) across different road types, levels of congestion, speed limits, and modes of speed enforcement.
- These ‘vectors’ (‘q’) are then associated with average exhaust emission rates, so that total exhaust emissions for a particular passenger car type can be estimated, typically using TNO’s VERSIT+ emissions model.

Applying emission data to vehicle dynamics - Example

- ‘q’ values quantify the fraction of driving **time** at different velocities and accelerations **normalized to 1 km** of total distance travelled.
- ***Driving dynamics are*** defined by the dynamic variable **‘w’**, defined as:

  $w = a + 0.014v$

  where ‘a’ is in units of m/s^2, and v is in units of kph.
- Emission factors (EF) in g/km are a function of the emission map ‘u’ and the driving vector ‘q’:

  $EF(g/km) = (q_1 * u_1) + (q_2 * u_2) + (q_3 * u_3) + \ldots + (q_9 * u_9) + (q_{10} * u_{10})$

TNO ‘w’ values and ‘q’ vectors

Acceleration (m/s^2)

Speed (kph)	-2.50	-2.25	-2.00	-1.75	-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
0																					
5	-2.43	-2.18	-1.93	-1.68	-1.43	-1.18	-0.93	-0.68	-0.43	-0.18	0.07	0.32	0.57	0.82	1.07	1.32	1.57	1.82	2.07	2.32	2.57
10	-2.36	-2.11	-1.86	-1.61	-1.36	-1.11	-0.86	-0.61	-0.36	-0.11	0.14	0.39	0.64	0.89	1.14	1.39	1.64	1.89	2.14	2.39	2.64
15	-2.29	-2.04	-1.79	-1.54	[illegible]	-1.04	-0.79	-0.54	-0.29	-0.04	0.21	0.46	0.71	0.96	1.21	1.46	1.71	1.96	[illegible]	2.46	2.71
20	-2.22	-1.97	-1.72	[illegible]	[illegible]	-0.97	-0.72	-0.47	-0.22	0.03	0.28	[illegible]	[illegible]	1.03	1.28	1.53	1.78	[illegible]	[illegible]	2.53	2.78
25	-2.15	-1.9	-1.65	-1.4	-1.15	-0.9	-0.65	-0.4	-0.15	0.1	0.35	[illegible]	0.85	1.1	1.35	1.6	1.85	[illegible]	2.35	2.6	2.85
30	-2.08	-1.83	-1.58	-1.33	-1.08	-0.83	-0.58	-0.33	-0.08	0.17	0.42	0.67	0.92	1.17	1.42	1.67	1.92	2.17	2.42	2.67	2.92
35	-2.01	-1.76	-1.51	[illegible]	[illegible]	[illegible]	-0.51	-0.26	-0.01	0.24	0.49	0.74	0.99	1.24	1.49	1.74	1.99	2.24	2.49	2.74	2.99
40	-1.94	-1.69	-1.44	-1.19	-0.94	-0.69	-0.44	-0.19	0.06	0.31	0.56	0.81	1.06	1.31	1.56	1.81	2.06	2.31	2.56	2.81	3.06
45	-1.87	-1.62	-1.37	-1.12	-0.87	-0.62	-0.37	-0.12	0.13	0.38	0.63	0.88	1.13	1.38	1.63	1.88	2.13	2.38	2.63	2.88	3.13
50	-1.8	-1.55	-1.3	-1.05	-0.8	-0.55	-0.3	-0.05	0.2	0.45	0.7	0.95	1.2	1.45	1.7	1.95	2.2	2.45	2.7	2.95	3.2
55	-1.73	-1.48	-1.23	[illegible]	-0.73	-0.48	-0.23	0.02	[illegible]	0.52	0.77	1.02	1.27	1.52	1.77	2.02	2.27	[illegible]	2.77	3.02	3.27
60	-1.66	-1.41	[illegible]	-0.91	-0.66	-0.41	-0.16	0.09	[illegible]	0.59	0.84	1.09	1.34	1.59	1.84	2.09	[illegible]	2.59	2.84	3.09	3.34
65	-1.59	-1.34	-1.09	-0.84	-0.59	-0.34	-0.09	0.16	0.41	0.66	0.91	1.16	1.41	1.66	1.91	2.16	2.41	2.66	2.91	3.16	3.41
70	-1.52	-1.27	[illegible]	[illegible]	[illegible]	-0.27	-0.02	0.23	0.48	0.73	0.98	1.23	1.48	1.73	1.98	2.23	2.48	2.73	2.98	3.23	3.48
75	-1.45	-1.2	-0.95	-0.7	-0.45	-0.2	0.05	0.3	0.55	0.8	1.05	1.3	1.55	1.8	2.05	2.3	2.55	2.8	3.05	3.3	3.55
80	-1.38	-1.13	-0.88	-0.63	-0.38	-0.13	0.12	0.37	0.62	0.87	1.12	1.37	1.62	1.87	2.12	2.37	2.62	2.87	3.12	3.37	3.62
85	-1.31	-1.06	-0.81	-0.56	-0.31	-0.06	0.19	0.44	0.69	0.94	1.19	1.44	1.69	1.94	2.19	2.44	2.69	2.94	3.19	3.44	3.69
90	-1.24	-0.99	-0.74	-0.49	-0.24	0.01	0.26	0.51	0.76	1.01	1.26	1.51	1.76	2.01	2.26	2.51	2.76	3.01	3.26	3.51	3.76
95	-1.17	-0.92	-0.67	[illegible]	-0.17	0.08	0.33	0.58	[illegible]	1.08	1.33	1.58	1.83	2.08	2.33	2.58	[illegible]	[illegible]	3.33	3.58	3.83
100	-1.1	-0.85	[illegible]	[illegible]	-0.1	0.15	0.4	[illegible]	[illegible]	1.15	1.4	1.65	1.9	2.15	2.4	[illegible]	[illegible]	[illegible]	3.4	3.65	3.9
105	-1.03	-0.78	-0.53	-0.28	-0.03	0.22	0.47	0.72	0.97	1.22	1.47	1.72	1.97	2.22	2.47	[illegible]	2.97	3.22	3.47	3.72	3.97
110	-0.96	-0.71	-0.46	[illegible]	0.04	0.29	0.54	0.79	1.04	1.29	1.54	1.79	2.04	2.29	2.54	2.79	3.04	3.29	3.54	3.79	4.04
115	-0.89	-0.64	-0.39	[illegible]	0.11	0.36	0.61	0.86	1.11	1.36	1.61	1.86	2.11	2.36	2.61	2.86	3.11	3.36	3.61	3.86	4.11
120	-0.82	-0.57	-0.32	-0.07	0.18	0.43	0.68	0.93	1.18	1.43	1.68	1.93	2.18	2.43	2.68	2.93	3.18	3.43	3.68	3.93	4.18

q2 q3 q4 q5 q6 q7 q8 q9 q10

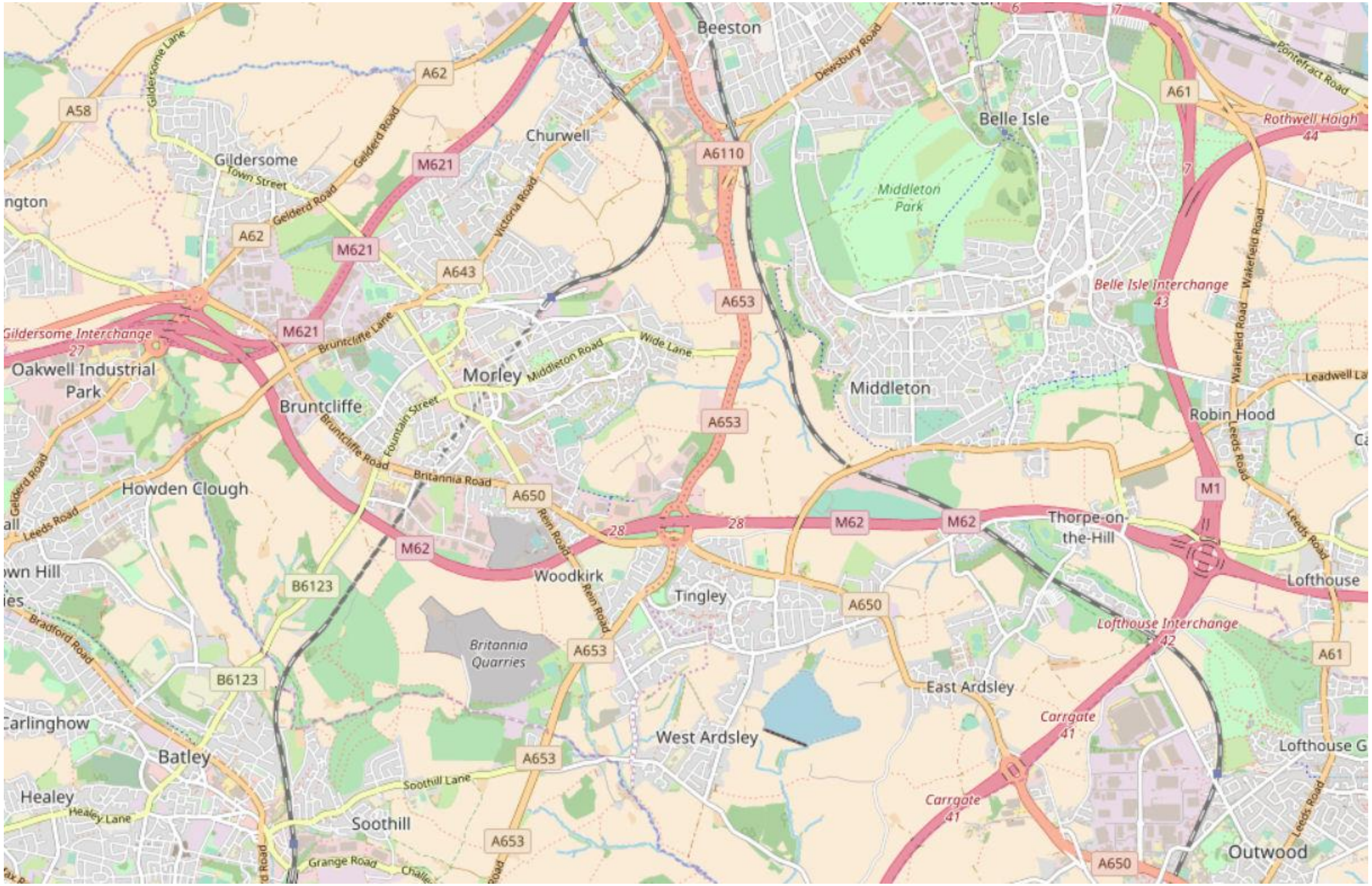
Comment:

‘w’ values;

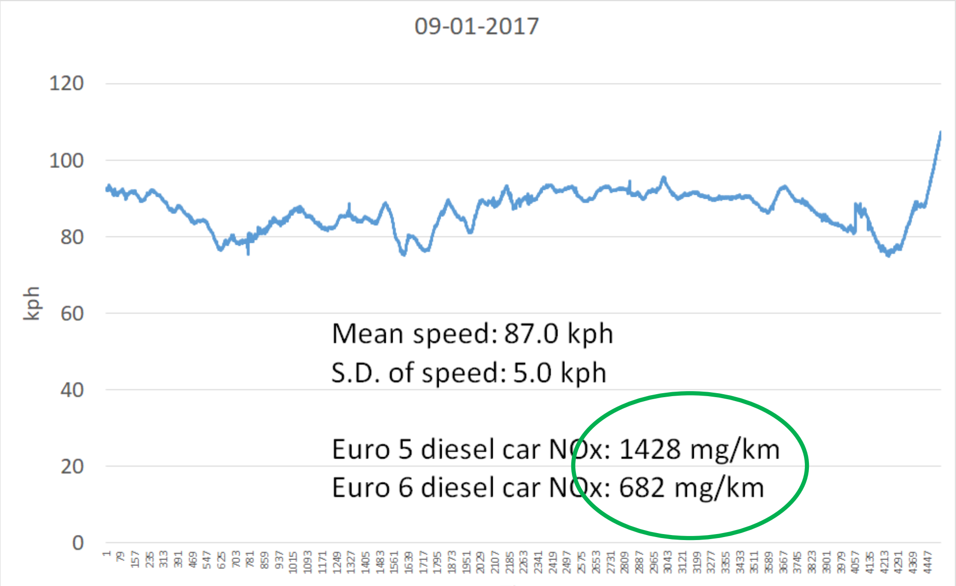
‘q’ values;

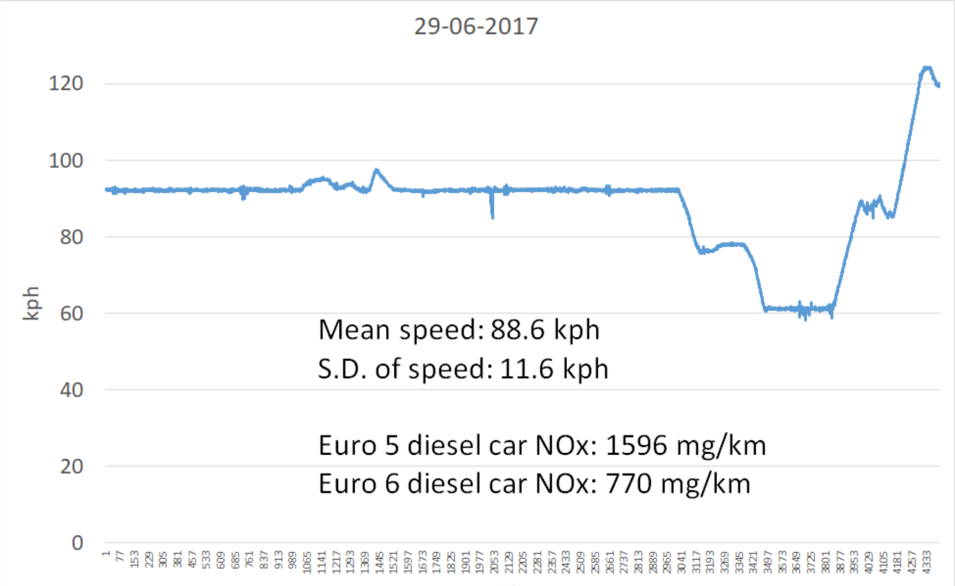
Terminology

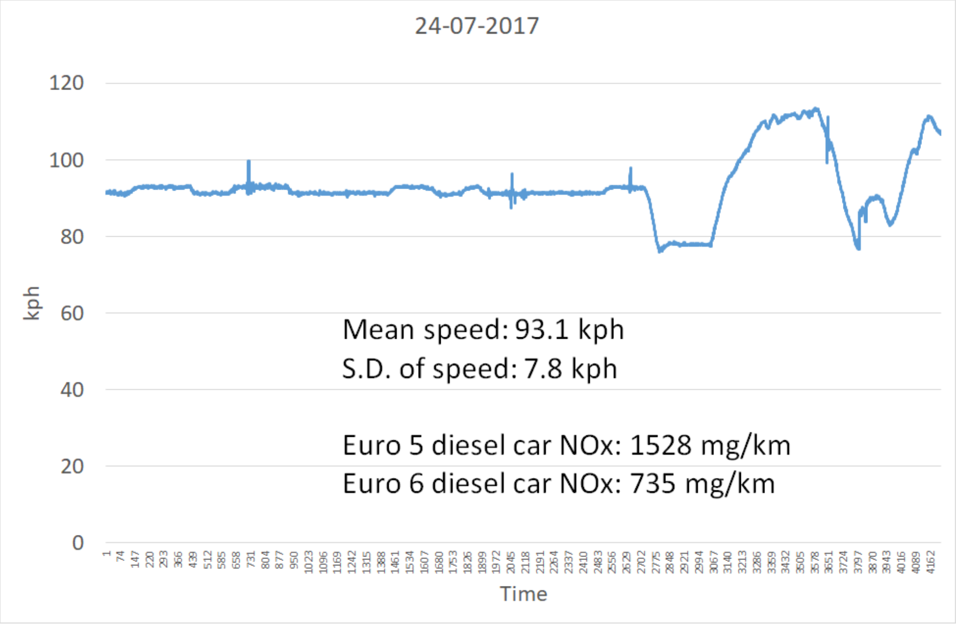
Sample of vehicle speed data – M62 J27 to J29 (eastbound)

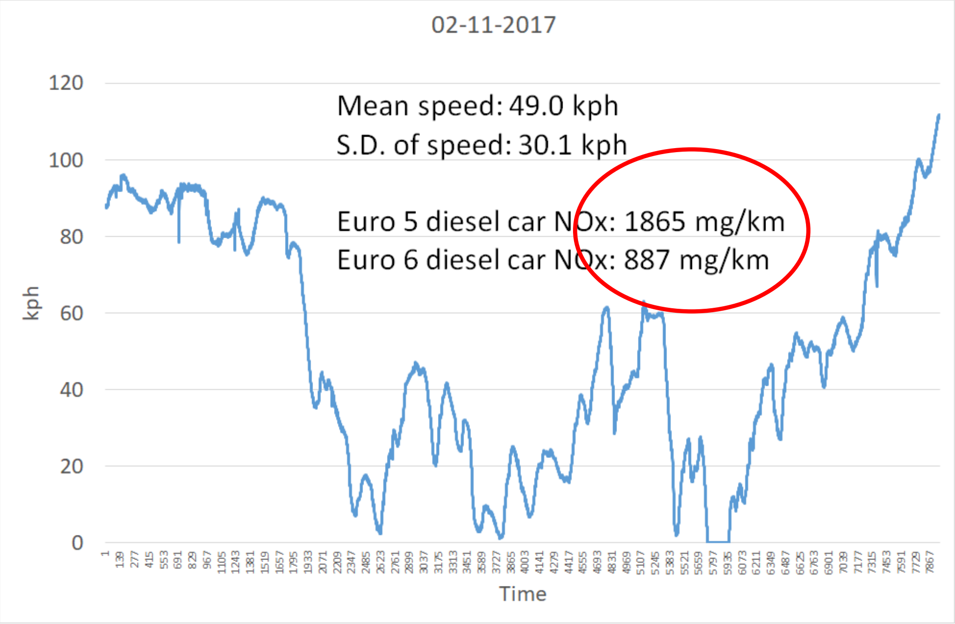


Sample of vehicle speed data – M62 J27 to J29 (eastbound)

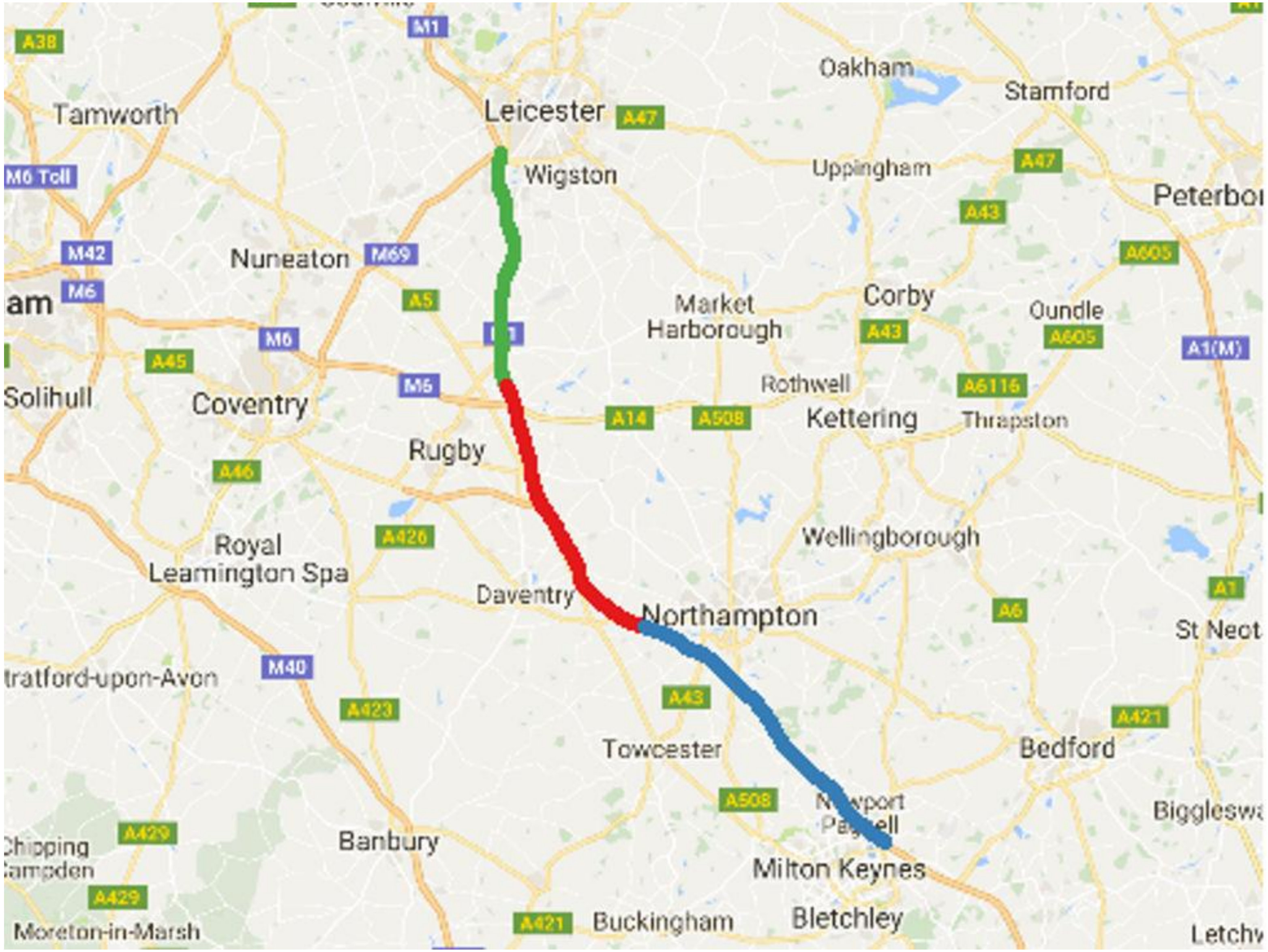






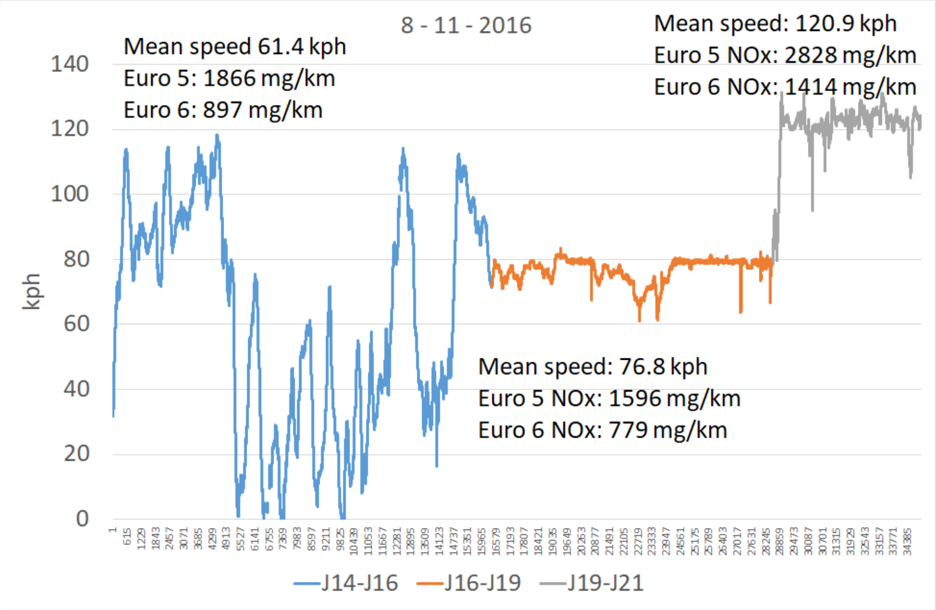


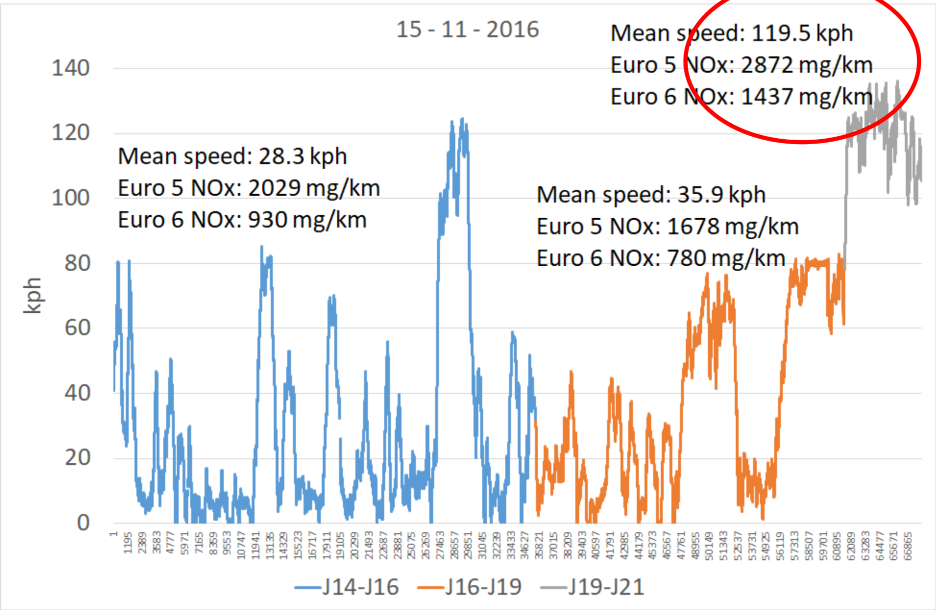
Sample of vehicle speed data – M1 J14 to J21 (northbound)

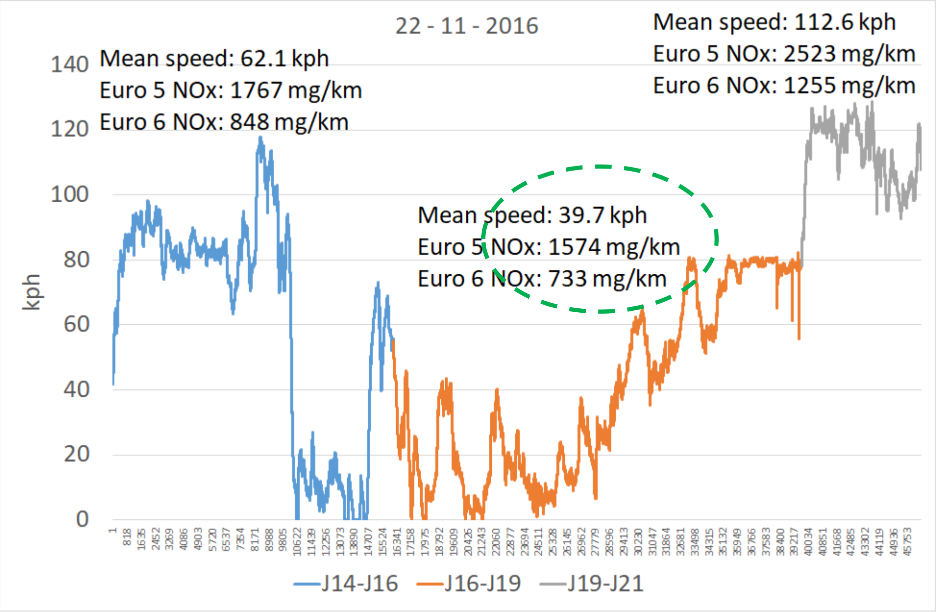


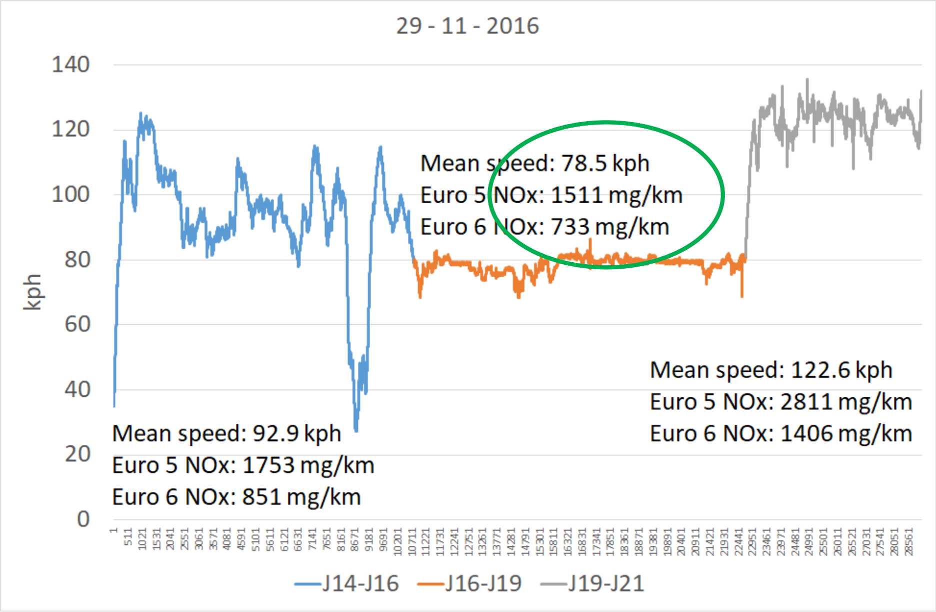
- 50mph Av. Speed cameras
- 70mph national limit
- 70mph national limit

Sample of vehicle speed data – M1 J14 to J21 (northbound)









A few closing thoughts

28 Technical Paper Transportation Professional October 2015 | Transportation Professional October 2015 Technical Paper 29

Emissions compliance proves a major challenge for the UK

Efforts to reduce emissions from vehicle exhausts is proving to be a tough ask as the UK struggles to meet European directives on air quality, says Dr Glyn Rhys-Tyler.

Introduction

Greater attention has been placed on the environmental impact of transport in recent years and the fact that poor air quality has a significant negative impact on human health.

The two main air pollutants of current concern from road transport in the UK are nitrogen oxides (NO_x) and particulate matter. This article focuses on NO_x from vehicle exhausts.

NO_x from vehicle exhausts primarily comprises two components: nitric oxide (NO) and nitrogen dioxide (NO_2). From a health perspective NO_2 is of most concern. However NO readily converts to NO_2 in the atmosphere, so to reduce ambient concentrations of NO_2 it is necessary to control emissions of total NO_x.

Road transport is responsible for about 46% of total NO_x emissions in England. However in locations with poor air quality, for example some parts of the highway network, the relative contribution of road transport to the NO_2 air quality problem can be up to 80%. NO and NO_2 emissions are particularly associated with diesel engines.

The legal context

Legal limit values for nitrogen dioxide in ambient air were defined and adopted in European legislation (Directive 99/30/EC) in April 1999.

These include a one hour mean limit value for the protection of human health of 200 µg/m³ not to be exceeded more than 18 times a calendar year and an annual mean limit value for the protection of human health of 40 µg/m³. Both limit values were to be met by member states by 1 January 2010.

However a review in 2005 had shown that compliance with the Directive would be difficult for a significant number of member states. A new Directive 2008/50/EC was adopted which, while keeping the limit values unchanged, introduced the possibility of extending the compliance date by up to five years (to 1 January 2015).

In addition the Directive imposed a general duty on member states to prepare 'air quality plans' for areas where the limit values were not met. Directive 2008/50/EC was made law in England through the Air Quality Standards Regulations 2010.

The problem

Despite the fact that air quality legislation was introduced in 1999 and that European governments have had 16 years (to date) to take remedial action the problem of NO_2 pollution in ambient air persists.

In September 2011 the UK Government produced projections for ambient NO_2 concentrations and published expected dates for compliance with the legislated annual mean limit values. For the purpose of air quality assessment and compliance reporting the UK is divided into 43 geographic zones. The September 2011 projections indicated 27 zones would be compliant by 2015, 42 compliant by 2020 and all 43 compliant by 2025.

However in July 2014 the UK Government published updated projections which indicated that only five zones would be compliant by 2015, 1 compliant by 2020, 38 by 2025 and 40 by 2030. The remaining three zones (Greater London Urban Area, West Midlands Urban Area and West Yorkshire Urban Area) would not be compliant by 2030.

...emissions were carried out in the London Borough of Ealing using roadside remote sensing techniques. The surveys permitted the quantification of both NO and NO_2 emission rates from different groups ...

... depending on location and buses were responsible for between 2% and 51%.

This variability highlights the importance of targeting appropriate management interventions to achieve desired local ...

... vehicles are being introduced over a different timescale but are due to be fully implemented by 31 December 2016. The revised HGV emissions standard reduces the NO_x emissions limit from 2.0 g/kWh at ...

... in locations with poor air quality, or remove the most polluting vehicles from the road.

"It remains to be seen whether the recent revelations of the use of emissions testing 'defeat devices' by Volkswagen will have a ...

... by the end of 2015.

Road transport emissions are a significant part of the problem in locations where legal air quality limit values are breached and therefore reduction of road transport emissions will necessarily form part of the solution.

The Government is currently consulting on a draft plan to improve air quality by tackling nitrogen dioxide in towns and cities, which runs until 6 November 2015. (see http://bit.ly/1VTcIMZ)

The challenge is complex, involving issues of science, technology, economics, social equity and public health and will require cross disciplinary solutions. The UK and other European member states face a significant challenge if the desired outcome of clean air is to be achieved in the foreseeable future.

Acknowledgements

This article has been peer reviewed by the CIHT Network Management & Operations Panel. The author acknowledges the kind support of Dr John Freeman and Mr Rizwan Yunus at the London Borough of Ealing when preparing this paper.

Dr Glyn Rhys-Tyler FCIHT is a consultant and researcher specialising in road transport and environmental impact. He has been a member of the CIHT Network Management & Operations Panel since 2004.

Road transport is responsible for about 46% of total nitrogen oxides emissions in England but in locations with poor air quality it can be as high as 80%

Roadside remote sensing techniques are used to survey vehicle emissions

CIHT Transportation Professional article published in October 2015

What are we trying to achieve?

Legislated 40µg/m^3 NO_2 limit values? Or wider public & environmental health?

Need for an holistic approach. For example….

THINK!
Road Safety

Climate change / CO_2

Air quality

Risks of target fixation / tunnel vision.

…Unintended consequences

The importance of effective and systematic monitoring (Air Quality & Vehicle Emissions)

Some observations

- Robust and representative emissions and vehicle dynamics data are relatively scarce;
- Consider the characteristics and scope of available data. Are they appropriate for / applicable to the policy questions / scenarios?
- Exhaust emissions from different Euro classes may respond in different ways to vehicle dynamics. Potential complication for policy development.
- Are the proposed modelling structures / forms appropriate for the problem at hand?
- Assumptions about future exhaust emissions and vehicle dynamics?
- Need to be clear about what we are seeking to achieve (objectives);
- Requires an holistic approach to policy development;
- Identify and manage uncertainty;
- Ensure that appropriate and systematic monitoring is in place.

References

- DfT (2016). Vehicle Emissions Testing Programme (Cm 9259). April 2016.
- TNO report R10188 “On-road determination of average Dutch driving behaviour for vehicle emissions” (2016)

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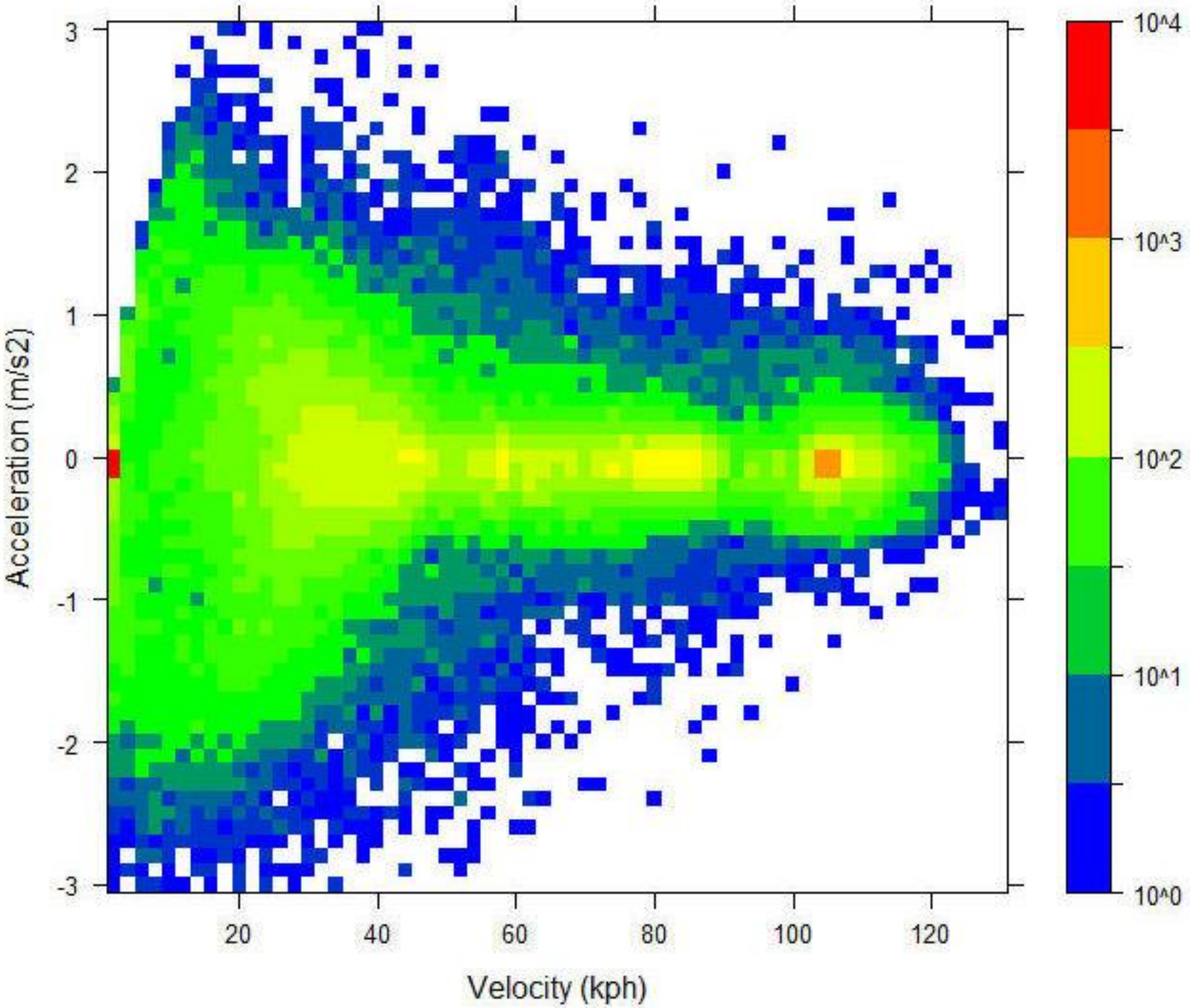
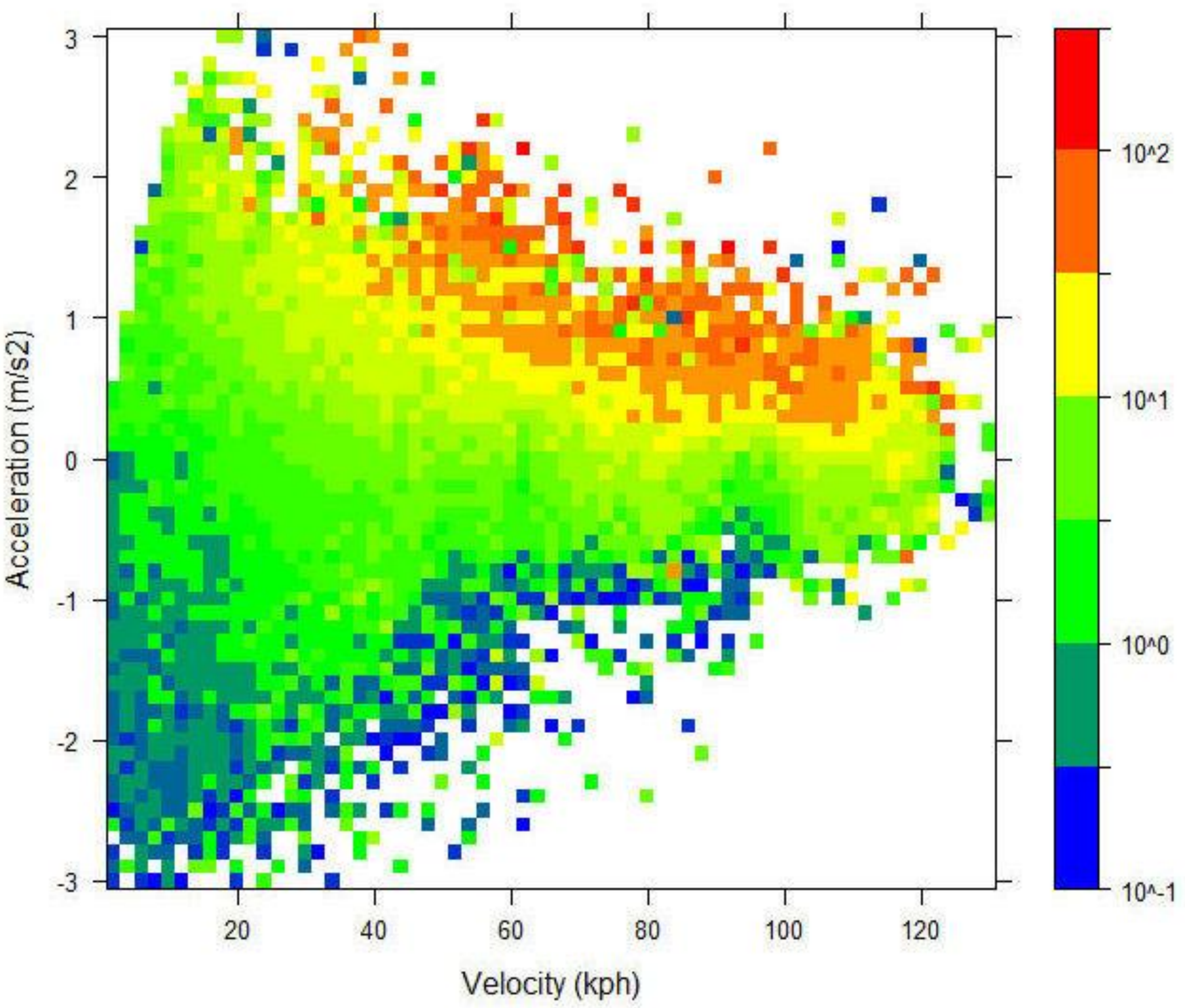
Euro 6 diesel cars – Frequency distribution (seconds)

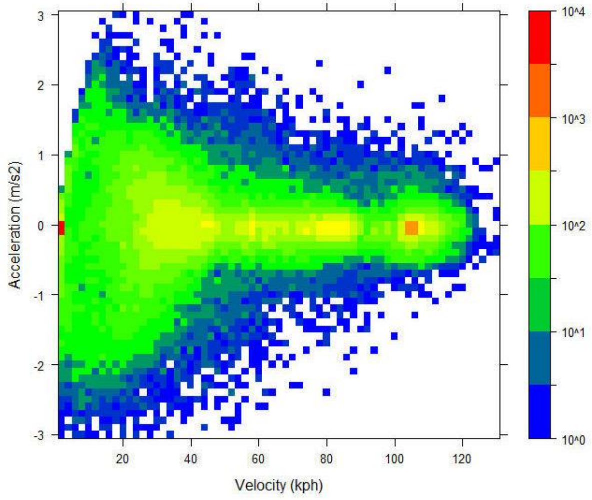


Euro 6 diesel cars – Mean NO_x (mg/second)



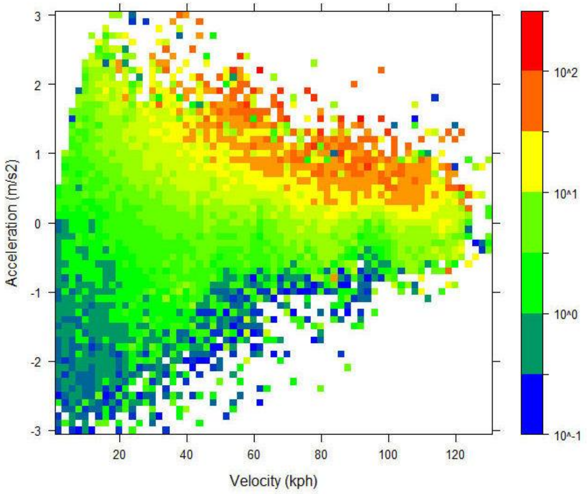
Euro 6 diesel cars – Total NO_x (mg)

Time (seconds)

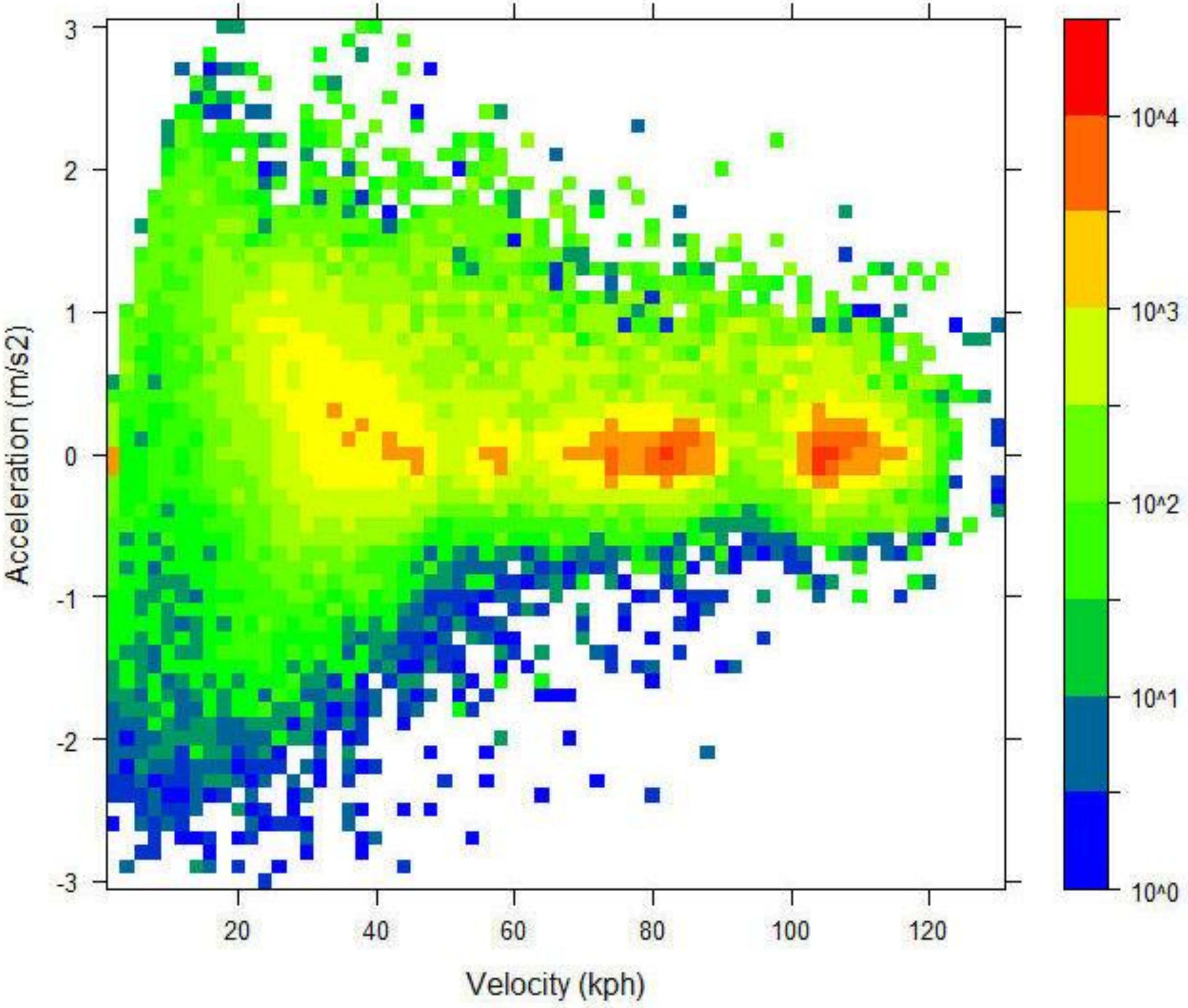


×

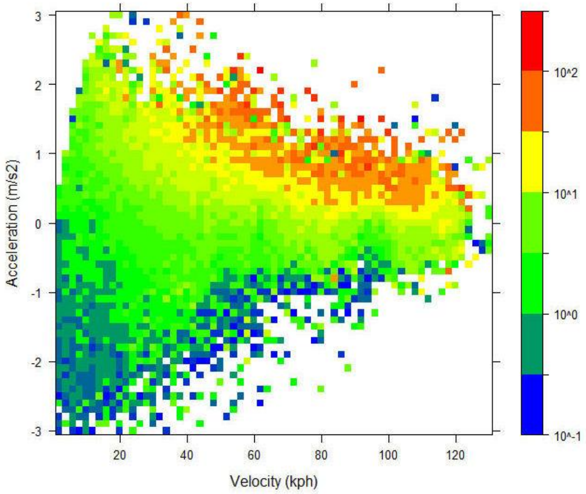
= NOx (mg)



NOx (mg/sec)



Euro 6 diesel cars – Mean NO_x (mg/km)



NOx (mg/sec)

Given seconds per km