Light vehicle dynamics and NO_x emissions on the motorway network

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Dispersion Modellers User Group 2021

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Disclaimer and acknowledgements

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All views expressed here are those of the author and do not necessarily reflect the views or policies of these organisations.

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Structure

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2. Highways England requirements for scheme appraisal
3. Vehicle dynamics on the motorway network
4. Using Portable Emissions Monitoring System (PEMS) data to inform decision making
5. Combining HE vehicle dynamics data with PEMS data
6. ‘Congestion’ related emissions and ‘high speed’ emissions
7. Development of revised speed bands for inclusion in DMRB LA 105 Air Quality guidance

Previous UK guidance

- **DMRB Interim Advice Note 185/15 (January 2015):** Provided "*Updated traffic, air quality and noise advice on the assessment of link speeds and generation of vehicle data into '**speed-bands**'".*
- Assigned individual road links into a **speed-band category** and identified the corresponding NO_x, PM_{10} and CO_2 emission rates
- Asserted that **congestion** on motorways tends to occur when speeds drop **below 50mph (80kph).** Assumes >50mph equates to **'free flow'.**
- The advice note identified that during periods of **congestion** on the motorway, **traffic emissions per vehicle increase** relative to free flow conditions.
- *Note: IAN 185/15 also provided guidance for Urban / Rural (Non-Motorway) Roads. Here we are just looking at motorways.*

Motorway speed band descriptors & emissions (IAN 185/15)

Category	Speed Range	General Description	Examples of Possible Characteristics
Heavy Congestion	<30kph(#)	Traffic with a high degree of congestion and stop: start driving behaviour	• Junction merges and diverges during morning and evening rush hours • Slip roads with queuing traffic • High variation in traffic speeds (represented by a standard deviation in speed of >32 kph)* (>20mph)
Light Congestion	30(#)-80kph (50mph)	Traffic with some degree of flow breakdown,	• Normally experience during the morning or evening peak periods. • Typically volume/capacity (V/C) would be >80%. • Normal operating regime for all slip roads • Medium variation in traffic speeds (represented by a standard deviation in speed of 15 kph -32kph)* (10-20mph)
High Speed	≥80kph (50mph)	Motorway with free flow driving conditions with no flow breakdown.	• V/C <80% • Low variation in traffic speeds (represented by a standard deviation in speed on < 15 kph)* (<10mph)

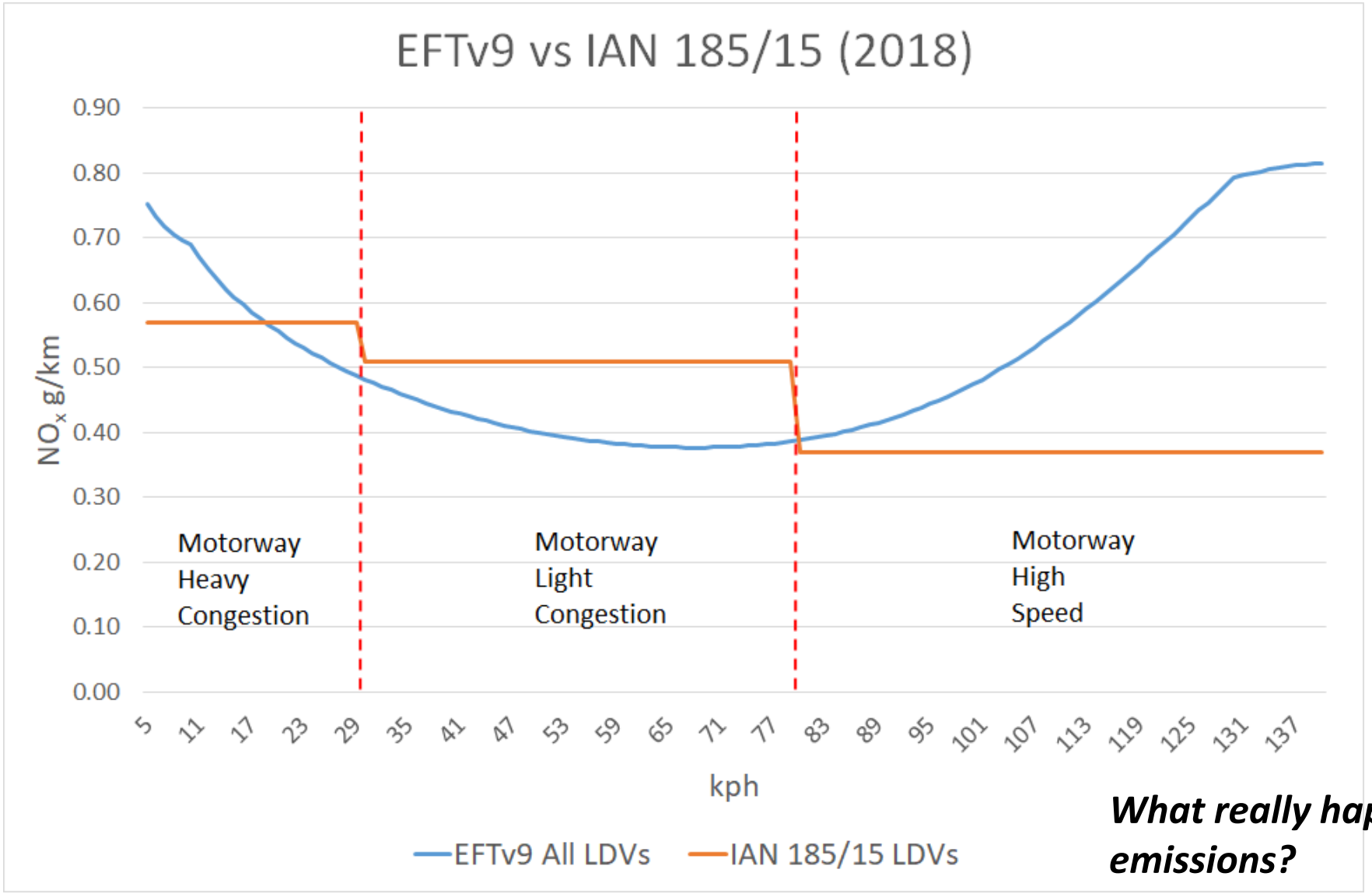
NB. Speed and SD metrics derived from MIDAS data

Analysis in 2014 indicated that **EFT tended to underestimate** emissions in congested conditions compared to free flow, hence the publication of IAN 185/15.

NO_x emissions (g/km per vehicle) – IAN 185/15

		2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017
		LDV	HDV	LDV	HDV	LDV	HDV	LDV	HDV	LDV	HDV	LDV	HDV	LDV	HDV
Motorway	Heavy Congestion	0.71	5.24	0.71	4.50	0.72	3.70	0.74	2.88	0.72	2.22	0.67	1.67	0.61	1.25
Motorway	Light Congestion	0.63	4.69	0.64	4.02	0.65	3.31	0.66	2.58	0.64	1.98	0.60	1.49	0.55	1.11
Motorway	Free Flow	0.47	3.46	0.47	2.96	0.48	2.44	0.49	1.90	0.47	1.46	0.44	1.10	0.40	0.82

EFTv9 vs IAN 185/15 speed / emission relationship



What really happens to exhaust emissions?

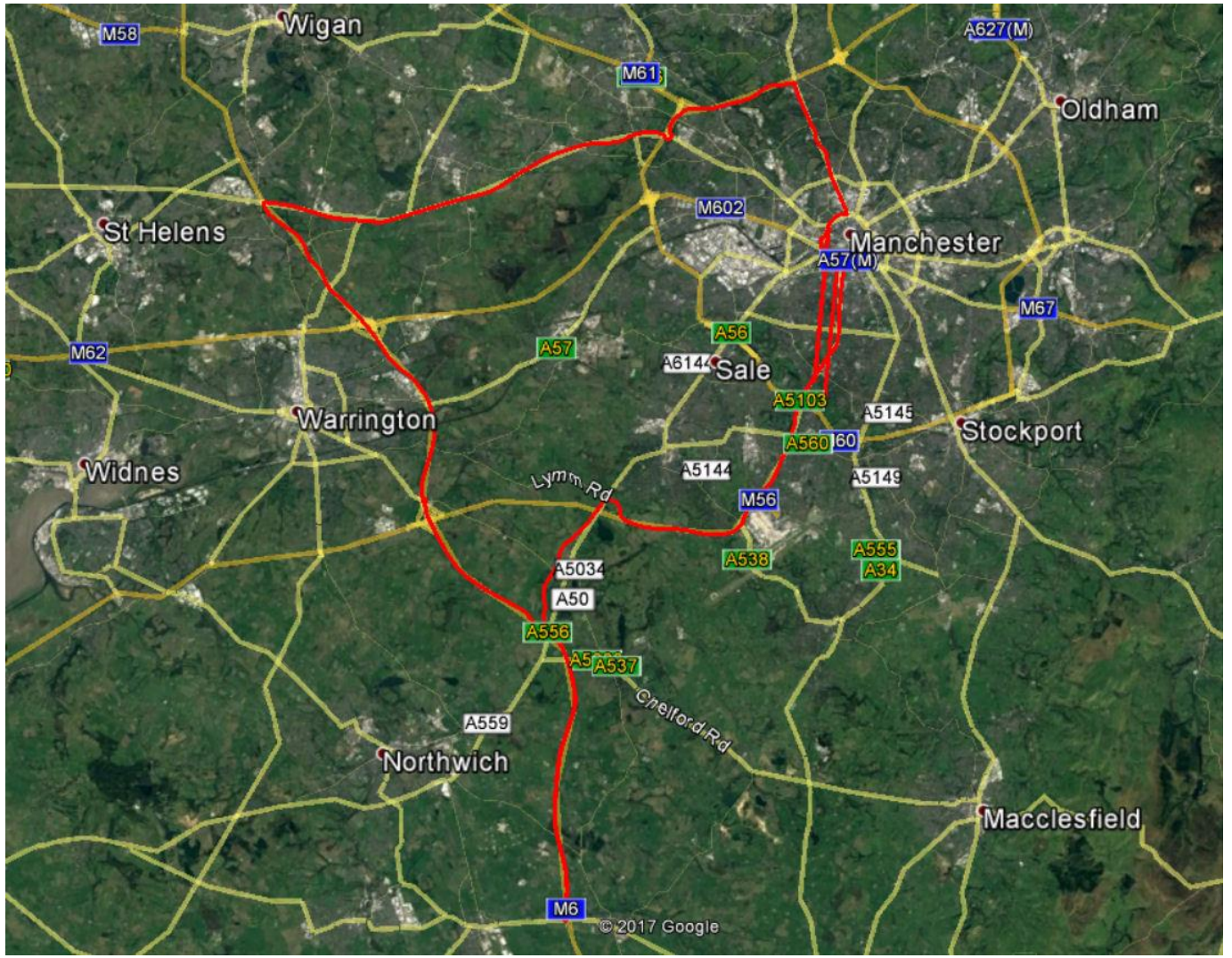
Scheme appraisal requirements & traffic modelling

- The majority of traffic models used by Highways England to assess schemes are large scale strategic models i.e. they represent **average** driving conditions for a **broad** time period (e.g. morning peak, inter-peak, evening peak) for a particular link.
- Significant emphasis can be (incorrectly) placed on the absolute traffic speed on an individual link and the consequent vehicle emissions. It is recognised that neither the traffic model nor vehicle emissions projections have this **level of certainty**.
- Consequently the development of speed-band categories provided a pragmatic approach to support air quality assessments (without **artificial precision**).
- WebTAG traffic modelling speed / flow curve guidance specifies a maximum speed of **118kph (73mph)** for dual 3 lane motorways, and **111kph (69mph)** for dual 2 lane motorways (often reduced by other model parameters such as ‘hilliness’ and ‘bendiness’).
- So a typical traffic model would not necessarily explicitly represent ‘higher speed’ operation. *How can we deal with this?*

Vehicle dynamics on the Highways England network

- Highways England carried out a small scale programme of instrumented (probe vehicle) passenger car surveys on the network in March 2017.
- Surveys included a mix of time periods and traffic conditions.
- A total of 1584km, 39 hours of GPS data at 10Hz.
- Post processing classified the data by road category.
- Data were also structured in a manner analogous to traffic assignment model network 'links'. For example, 486 mainline motorway links, distance 1092km, average link length 2.25km.
- These data provided a **snap shot** of light vehicle dynamics in a range of traffic conditions which, when vehicle NO_x exhaust emission maps are applied, can be used to explore the relationships between vehicle dynamics and exhaust emissions.
- **N.B. Highways England surveys generally complied with speed limits…….**

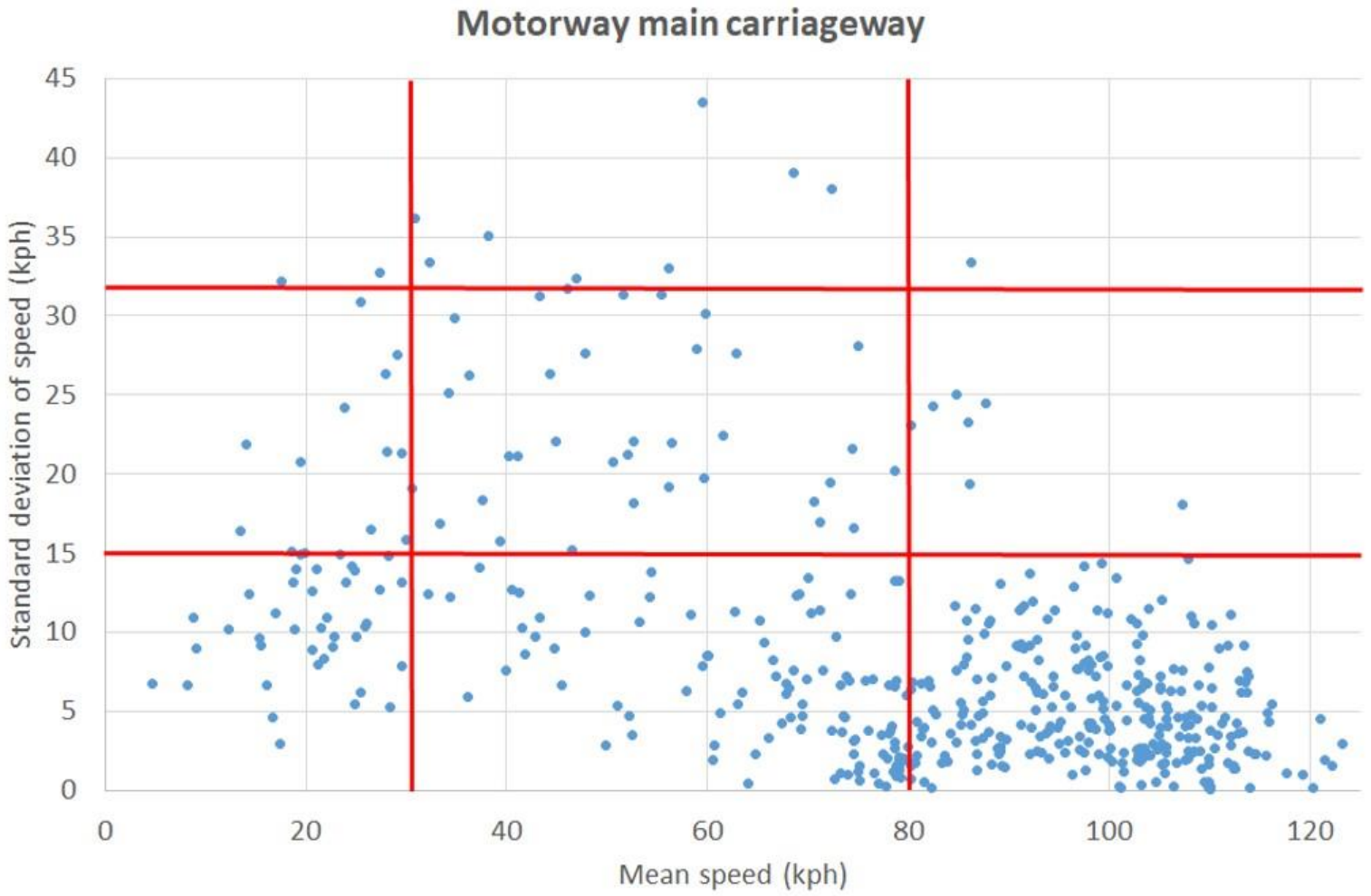
Highways England vehicle dynamics surveys



Example Highways England vehicle dynamics survey route

Map base © Google Earth Pro

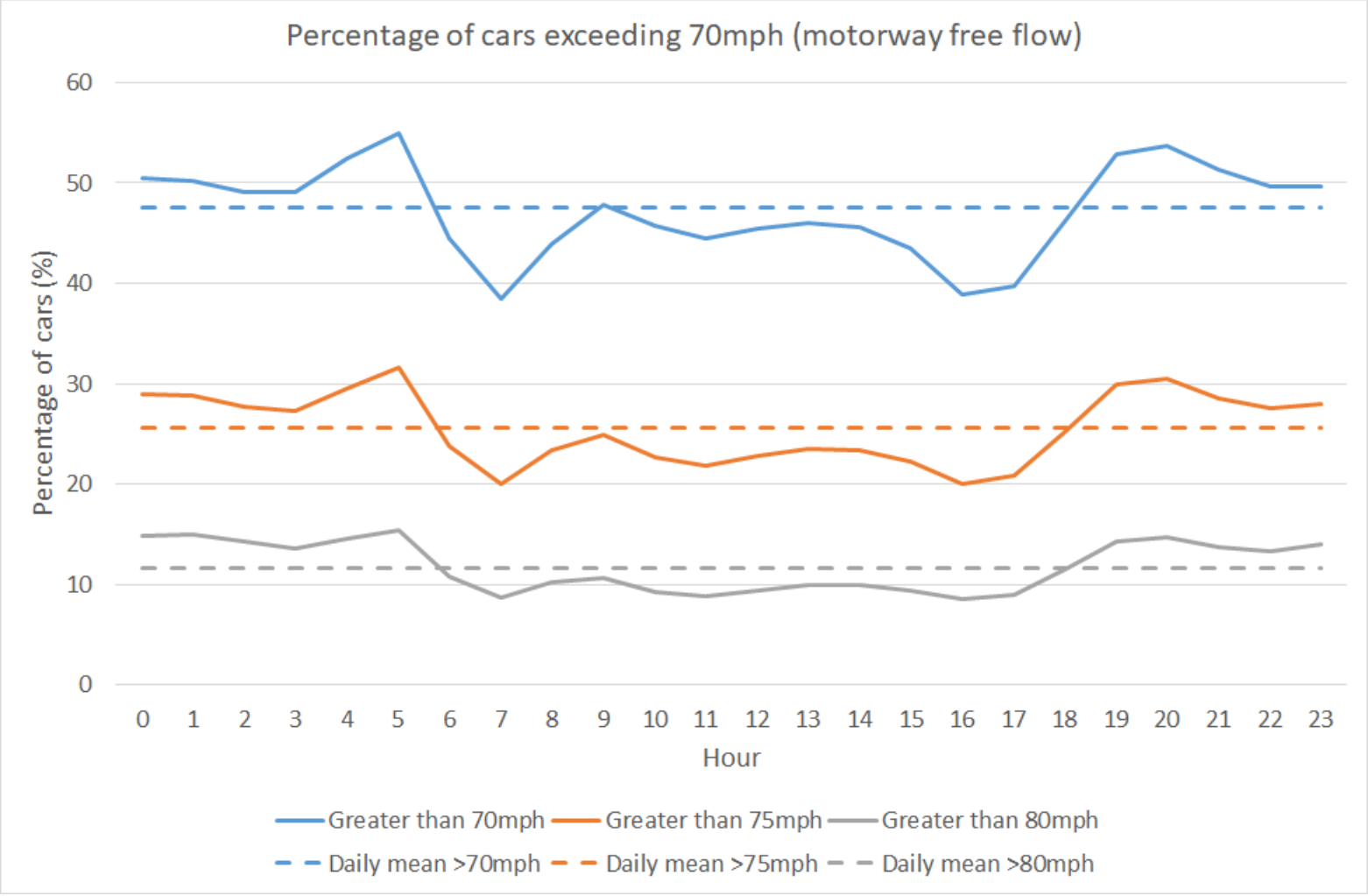
Highways England vehicle dynamics survey ‘links’



Instrumented vehicle survey data aggregated to ‘links’, analogous to traffic assignment model links.

Red lines are IAN 185/15 Speed and Standard Deviation thresholds

The prevalence of ‘high speed’ operation – Cars



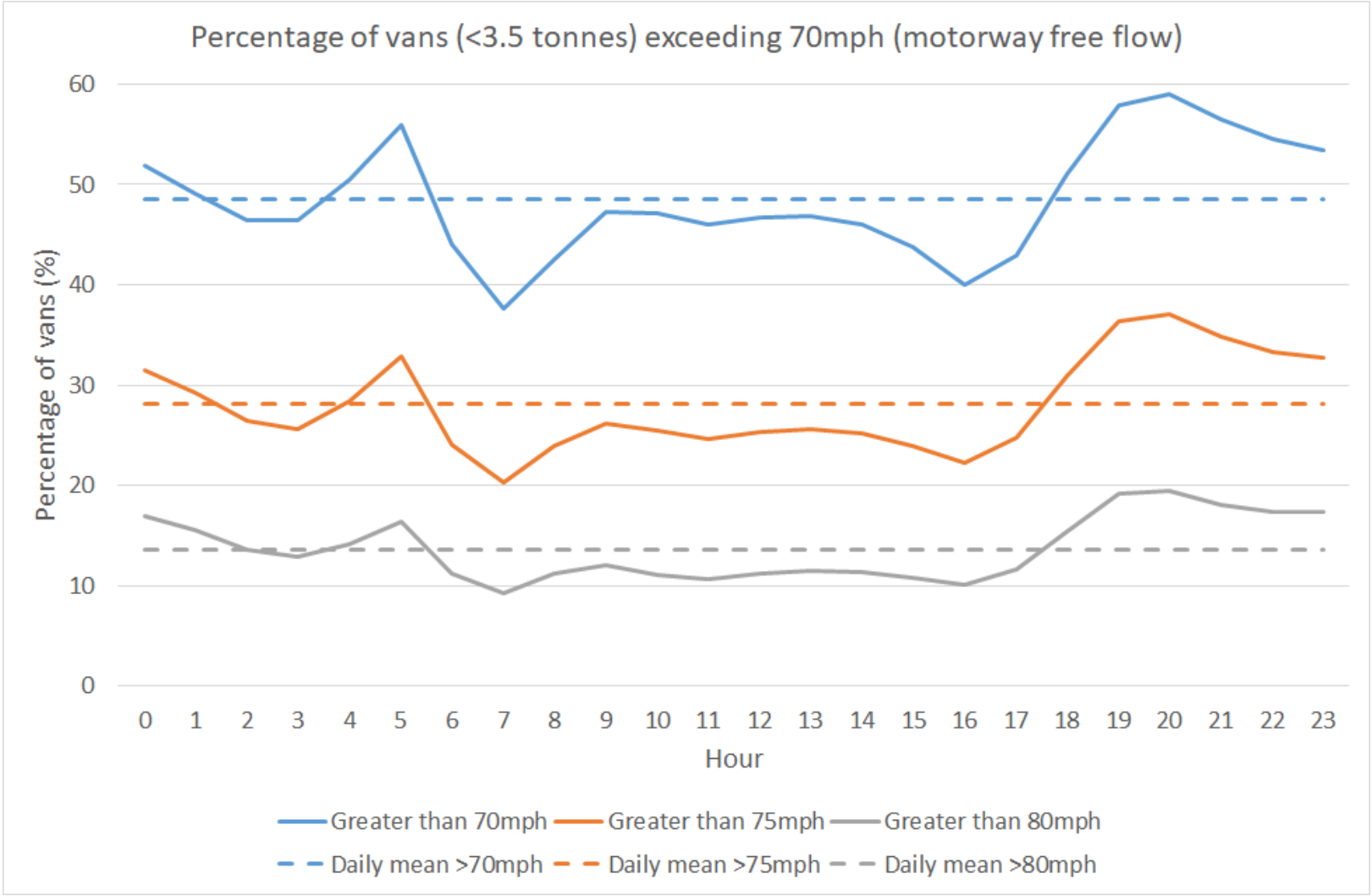
48% > 70mph

26% > 75mph

12% > 80mph

Source: DfT TSGB Table SPE0111 (2017) – Motorway ‘free flow’ speeds

The prevalence of ‘high speed’ operation – Vans



49% > 70mph

28% > 75mph

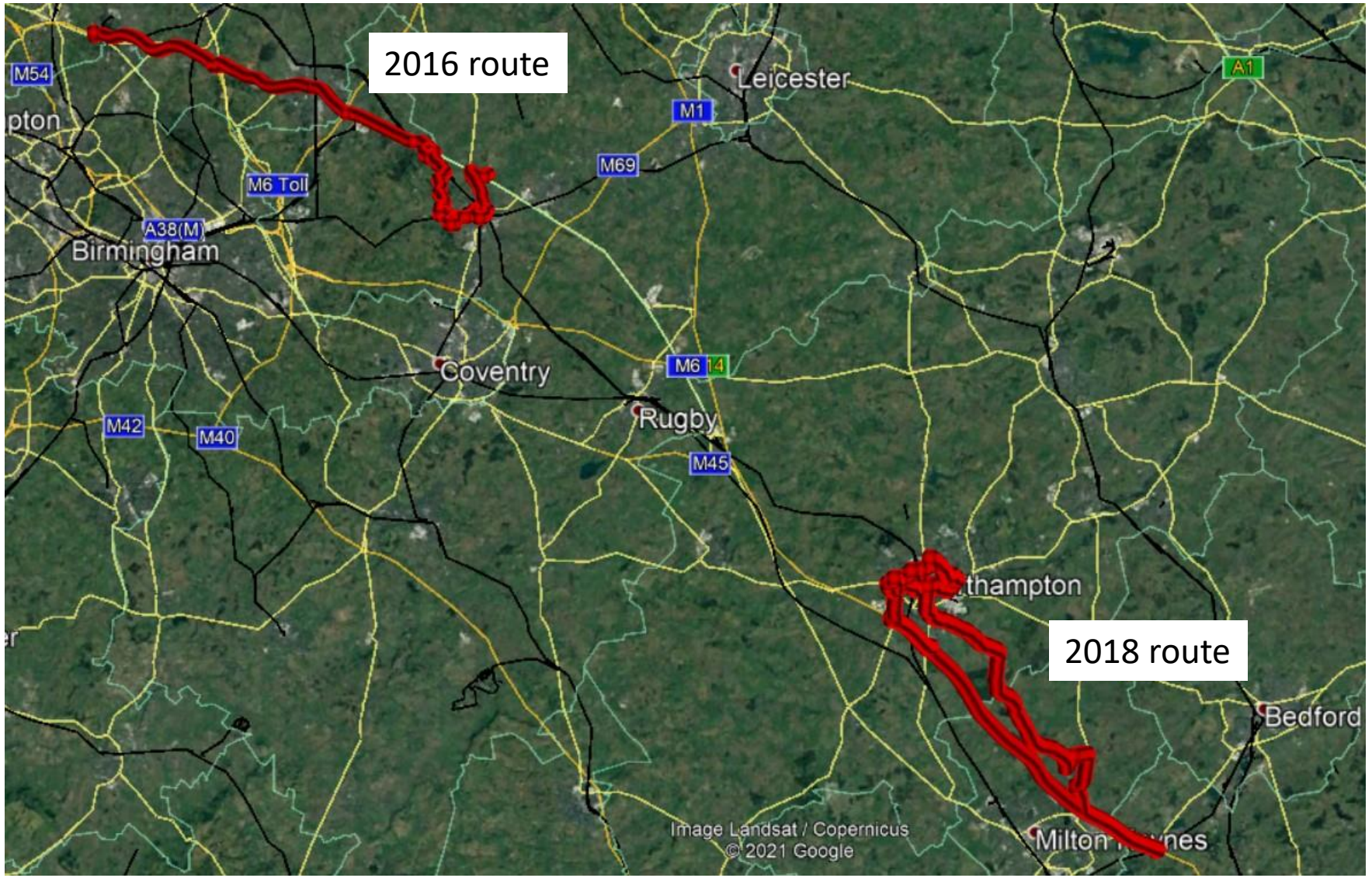
14% > 80mph

Source: DfT TSGB Table SPE0111 (2017) – Motorway ‘free flow’ speeds

DfT / DVSA Portable Emissions Monitoring (PEMS) surveys

Source: DfT (2016)

DfT / DVSA PEMS survey routes 2016 & 2018

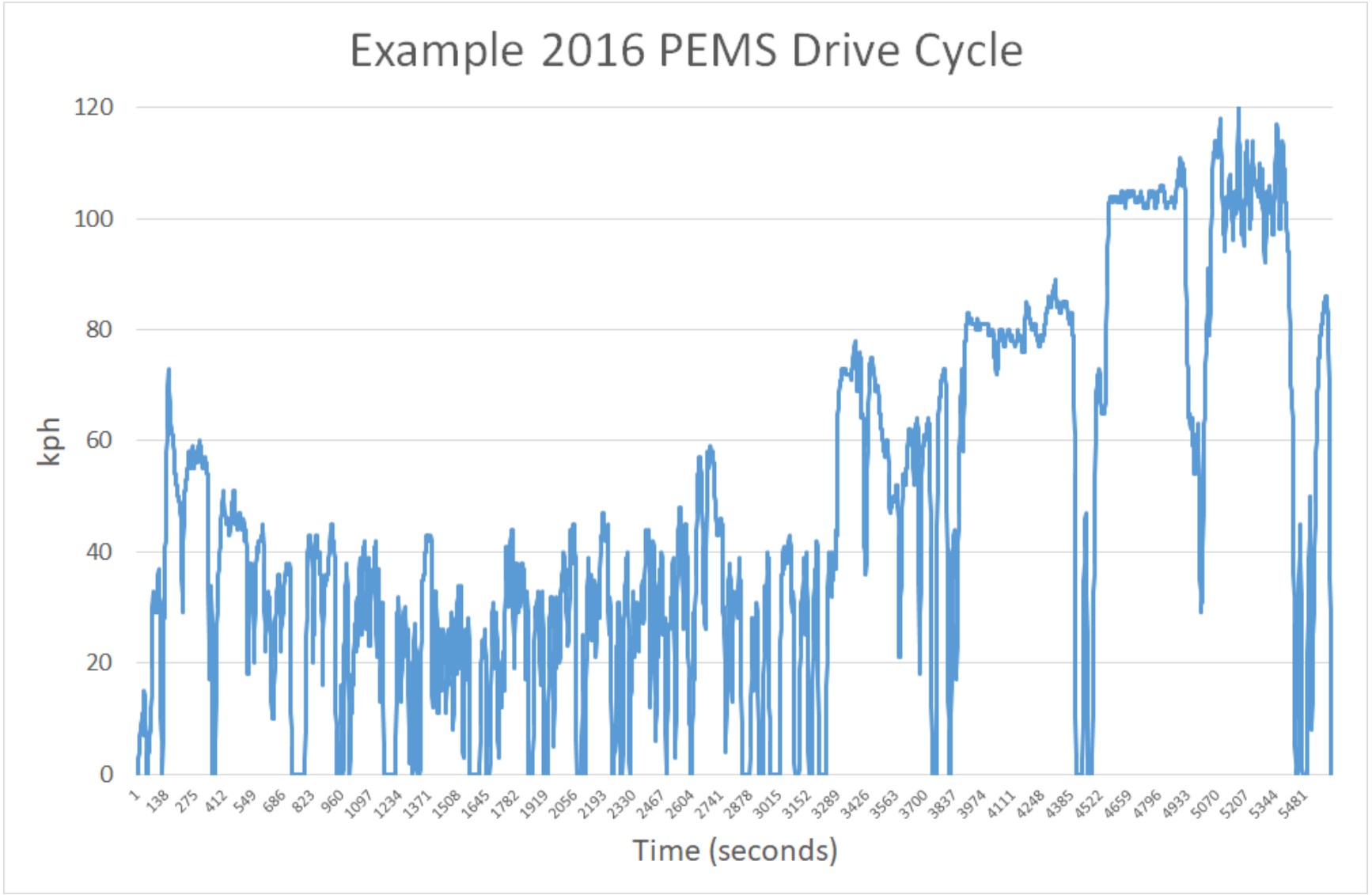


Annual DVSA Vehicle Market Surveillance Unit PEMS tests since 2017

DVSA withheld GPS coordinates from published 2017 data

Map base © Google Earth Pro

Example speed profile from DfT ‘on-road’ test route



UK PEMS data availability in the public domain

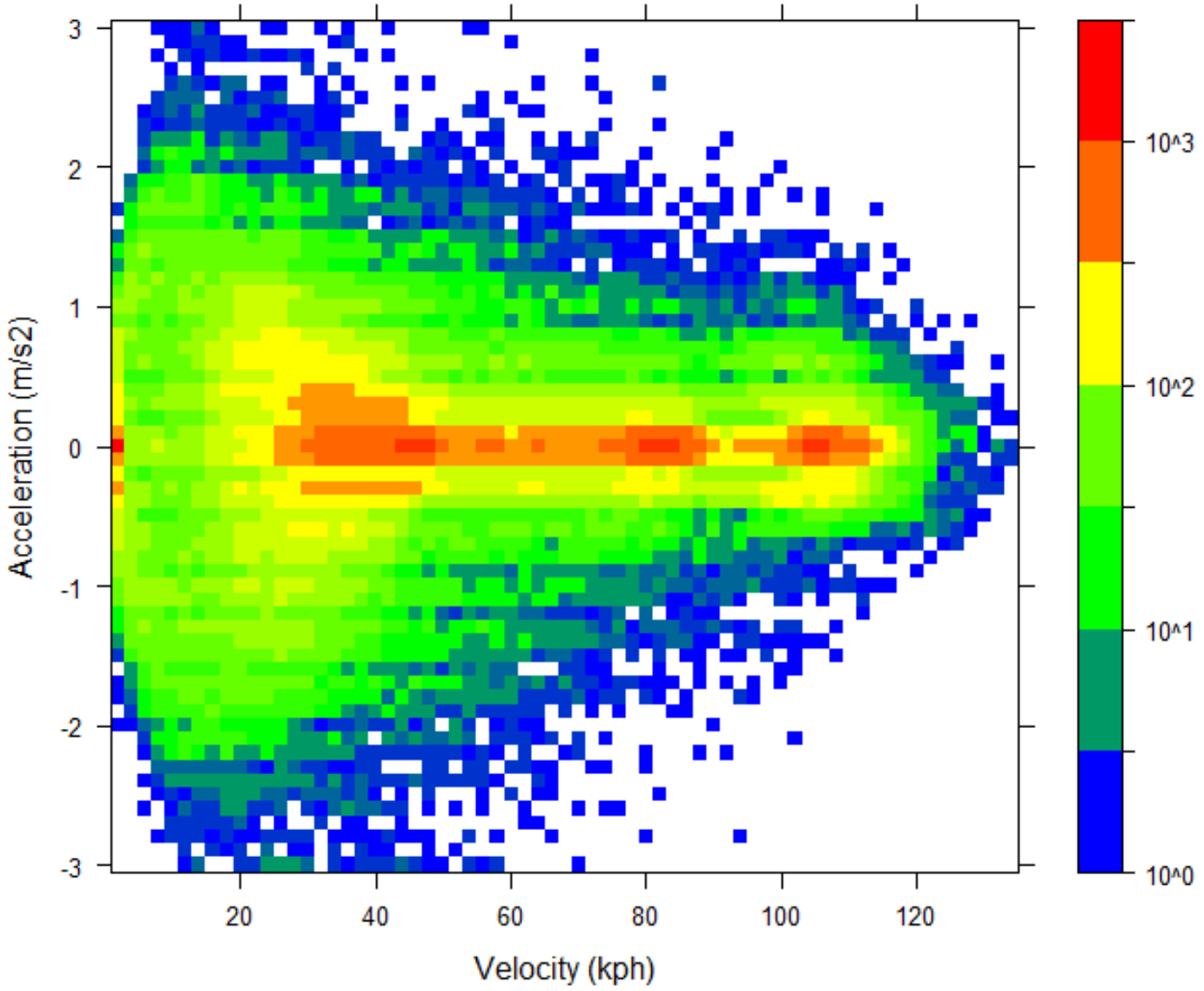
			DfT*	DfT/DVSA**				
Type	**Fuel**	**Euro**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**
Car (M1)	Diesel	5	19	2				21
		6	19	2	9	?	?	30
	Petrol	6		15	7	?	?	22
Van (N1)	Diesel	5		5				5
		6		1	4	?	?	5
Truck (N2,N3)	Diesel	VI		5	3	?	?	8
PSV (M2,M3)	Diesel	VI		3	2	?	?	5
Total			38	33	25			96

Number of vehicles subjected to on-road PEMS test

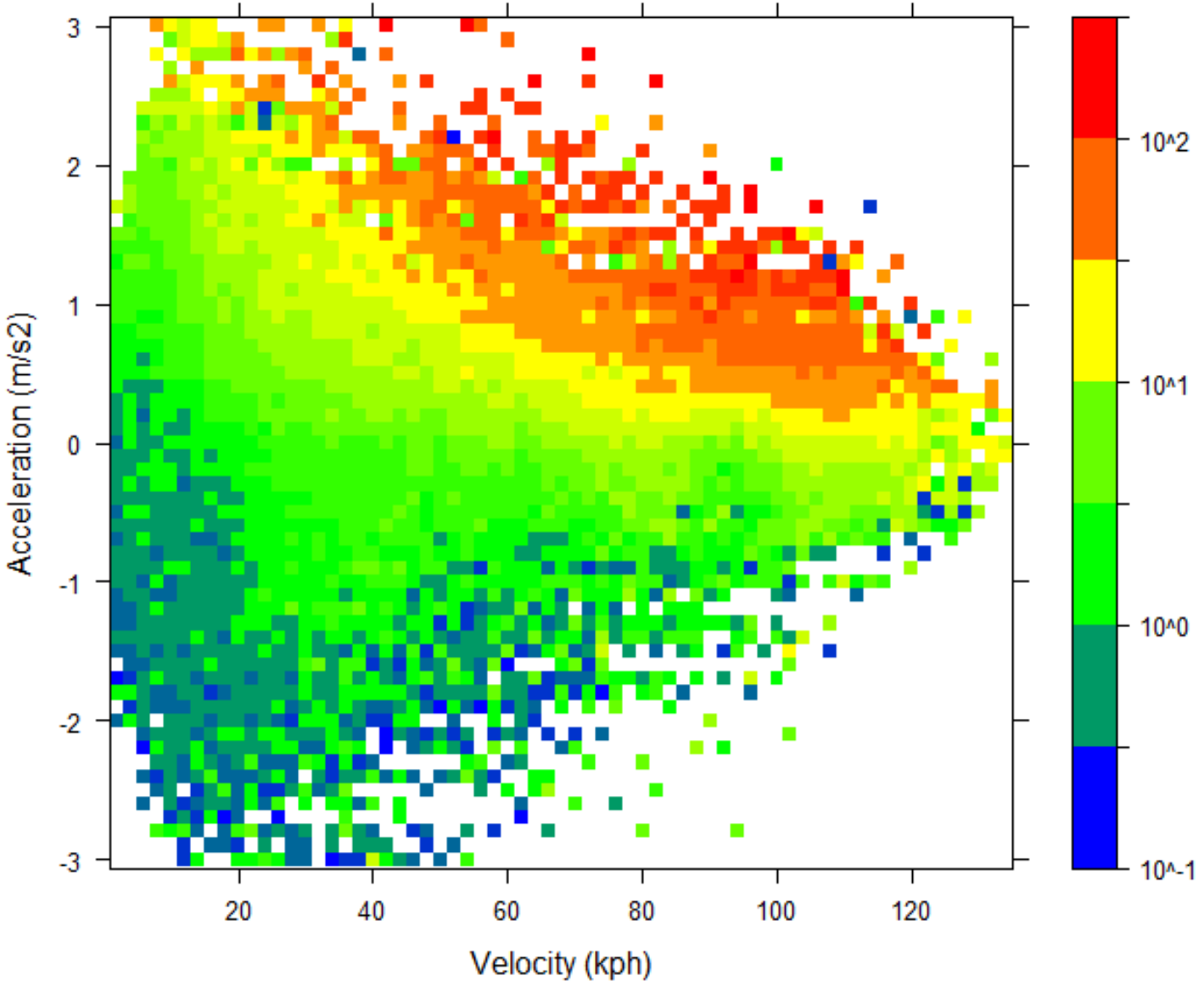
* DfT post 'Dieselgate' tests

** DVSA Vehicle Market Surveillance Unit tests

Euro 6 diesel cars – PEMS frequency distribution (seconds)



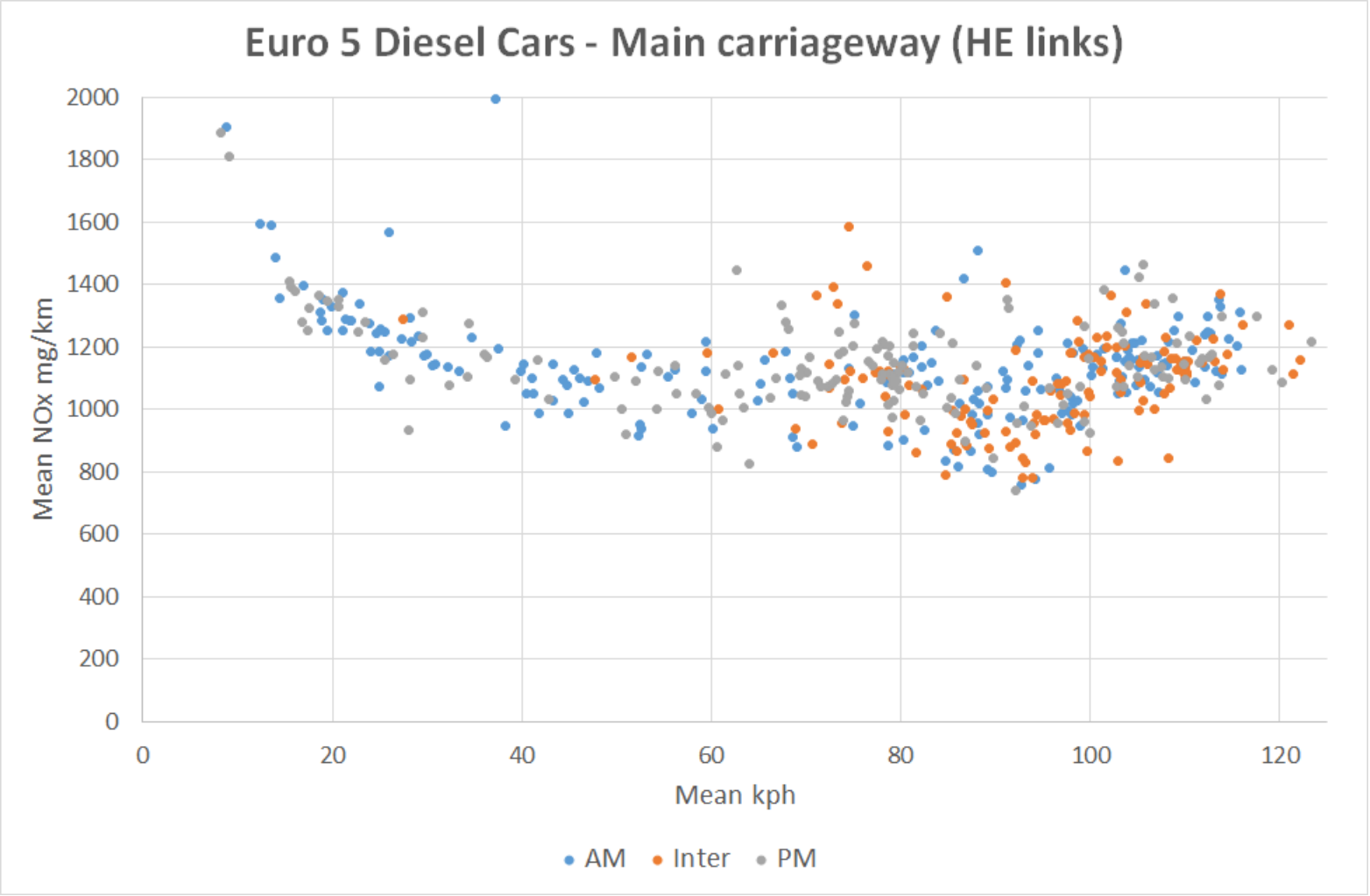
Euro 6 diesel cars – PEMS mean NO_x (mg/sec)



Application of DfT / DVSA NO_x data to Highways England vehicle dynamics data at a link spatial resolution

- The NO_x mg/sec emission maps derived from the 'on road' PEMS data sets are applied to each of the **'links'** created from the Highways England vehicle dynamics surveys, on a **second by second** basis, i.e. each 'one second' data point (with its associated speed and acceleration parameters) within the 'link' is allocated an emission rate (NO_x mg/sec) from the emission maps. The total NO_x emissions for the 'link' can then be calculated.
- N.B. Aggregating data to 'links' tends to 'average out' emission rates within a link (masking variability in vehicle dynamics and emissions within a link).
- **Emission maps** (NO_x mg/sec by speed and acceleration) have been created for Euro 5 diesel cars, Euro 6 diesel cars, Euro 5 diesel vans, and Euro 6 petrol cars.
- It should be noted that some vehicle classes (vans, trucks, buses) currently have a **very small sample**, are not representative of the fleet mix, and should therefore be interpreted accordingly (with caution).

Application of DfT / DVSA NO_x data to Highways England vehicle dynamics data at a link spatial resolution



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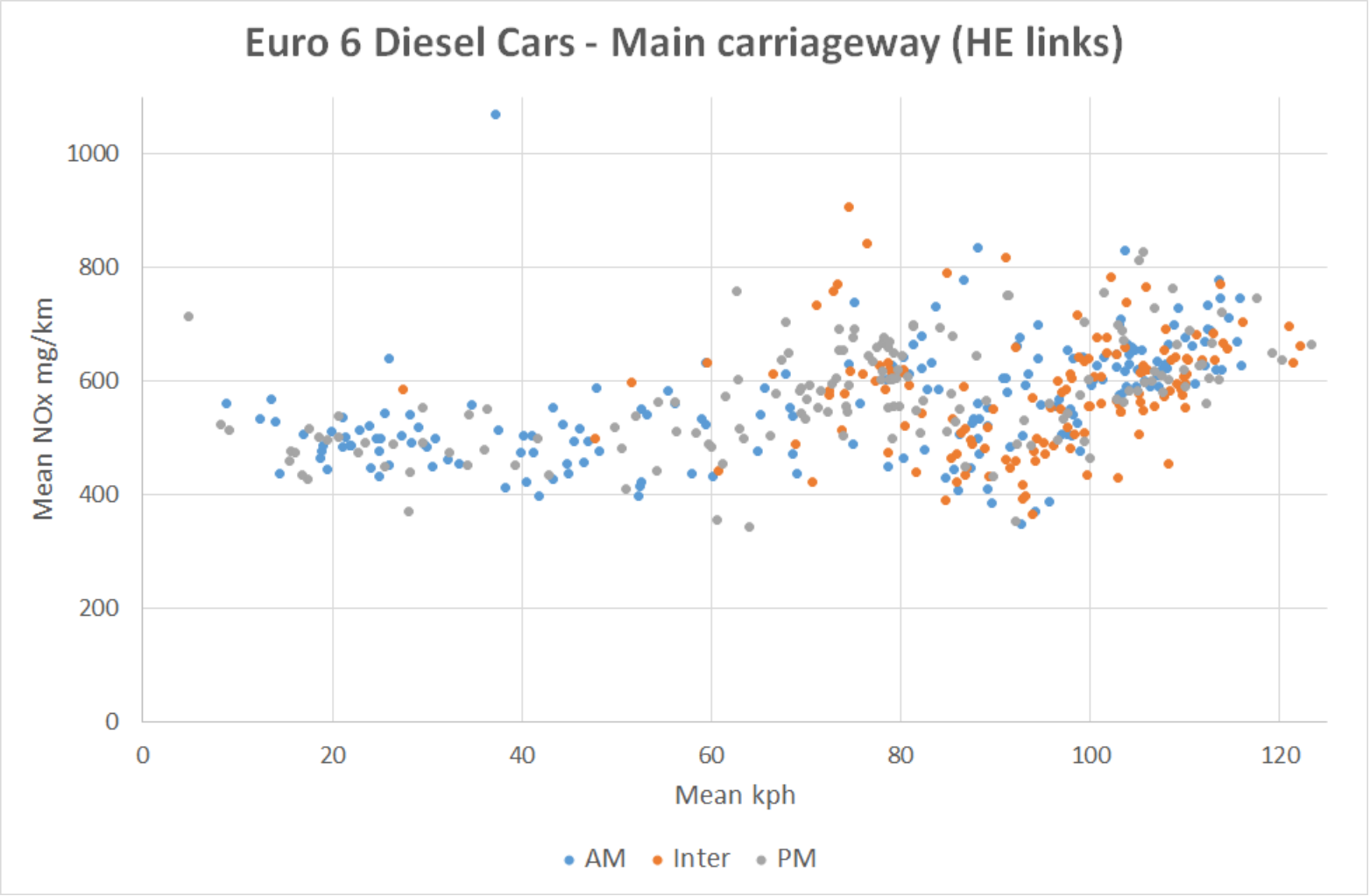
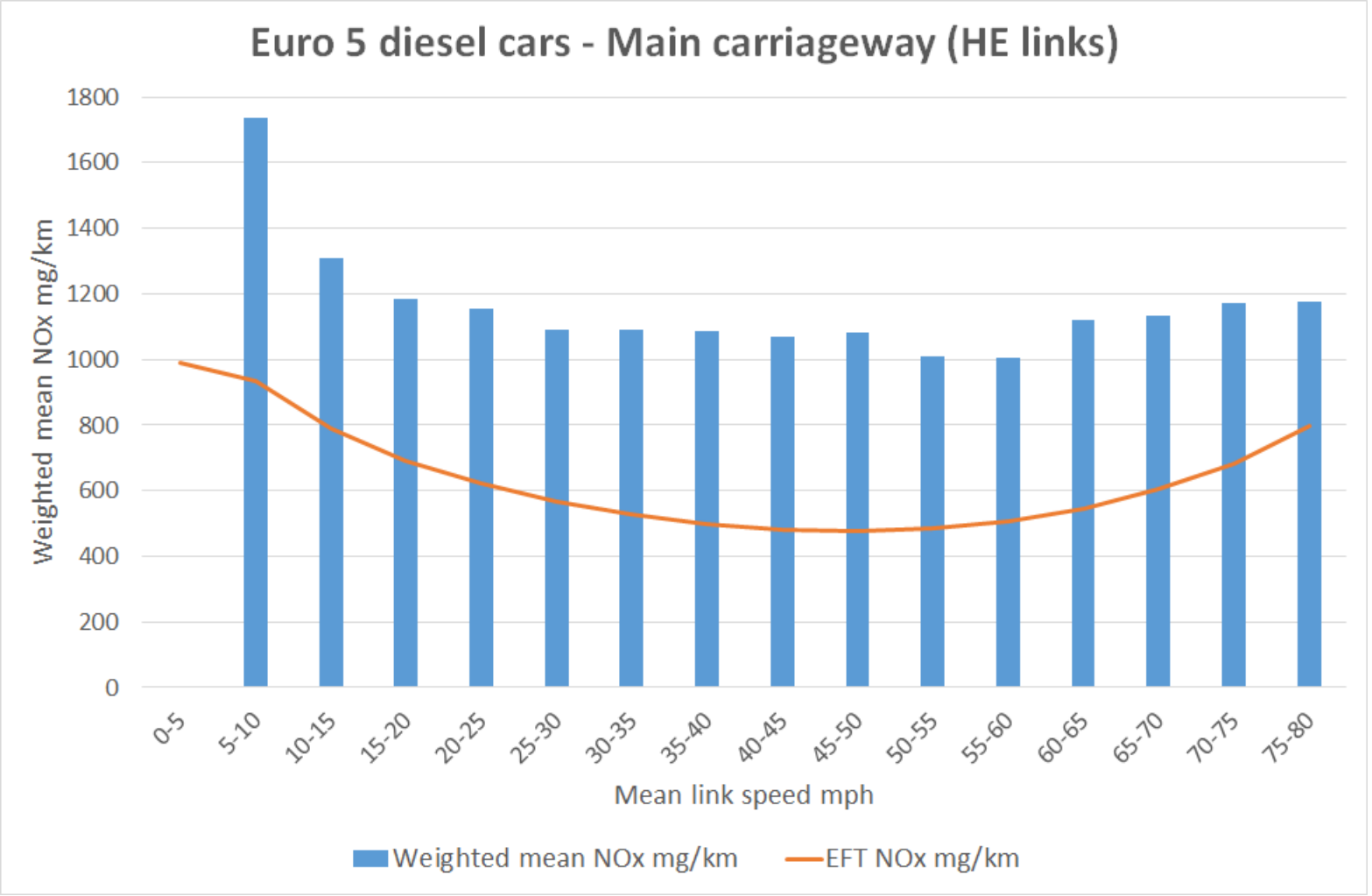


Application of DfT / DVSA NO_x data to Highways England vehicle dynamics data aggregated to speed bins (weighted by link length)

N.B. Relatively few Highways England survey links at very low speeds

39% of diesel cars Euro 5 or older at 2021, reducing to 17% by 2025 (NAEI fleet projections)



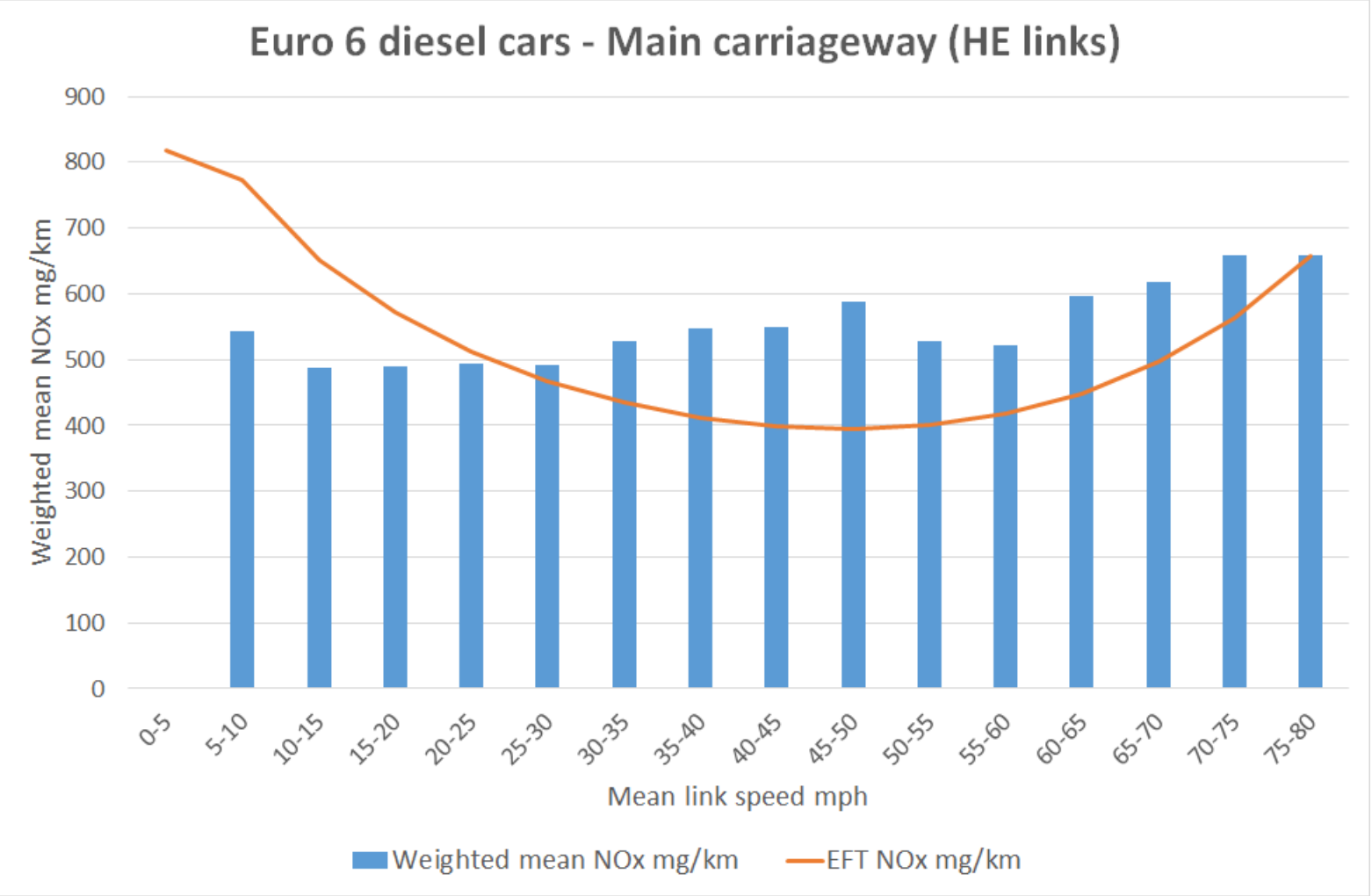
N.B. Very few Highways England survey links at higher speeds

Therefore, an incomplete picture overall

Application of DfT / DVSA NO_x data to Highways England vehicle dynamics data aggregated to speed bins (weighted by link length)

N.B. Relatively few Highways England survey links at very low speeds

'Harmonica' effect. TNO report R10827 "Definitie congestie op de snelweg voor emissiefactoren", 2017



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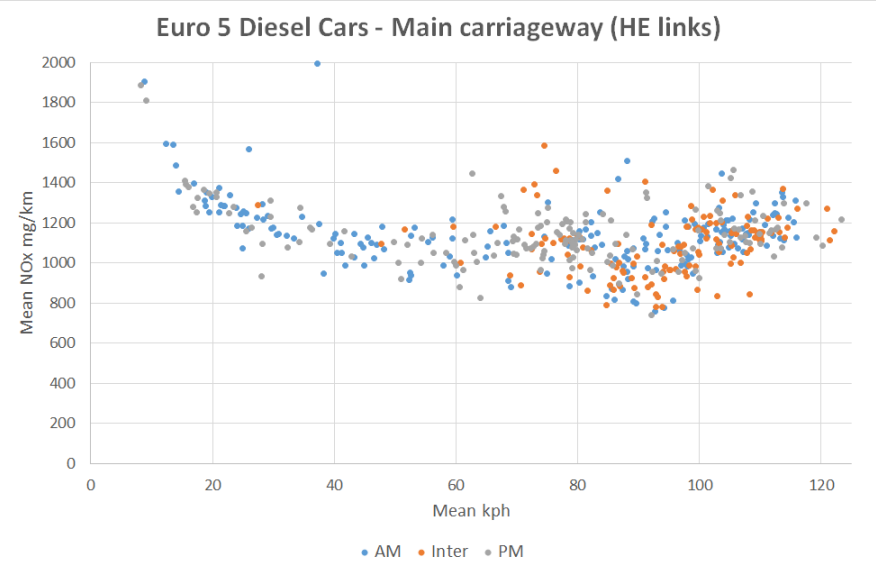
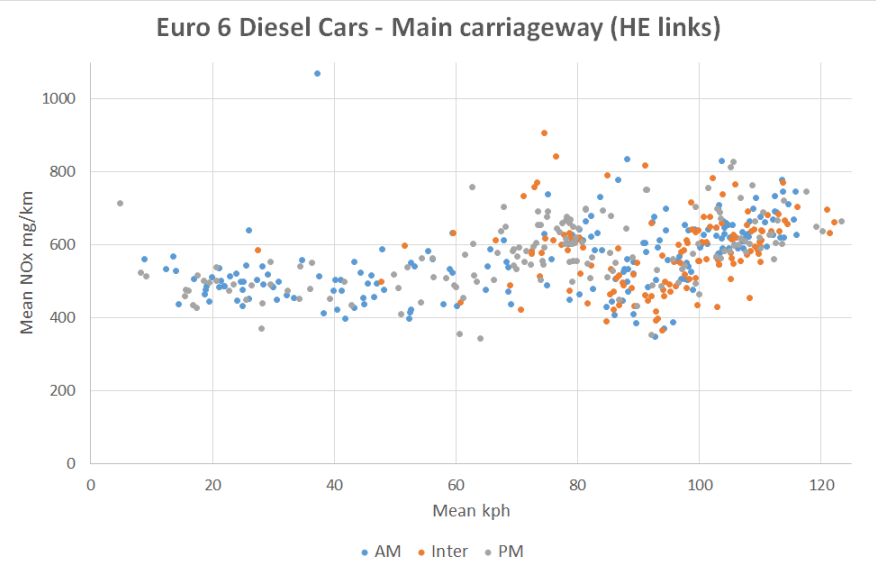
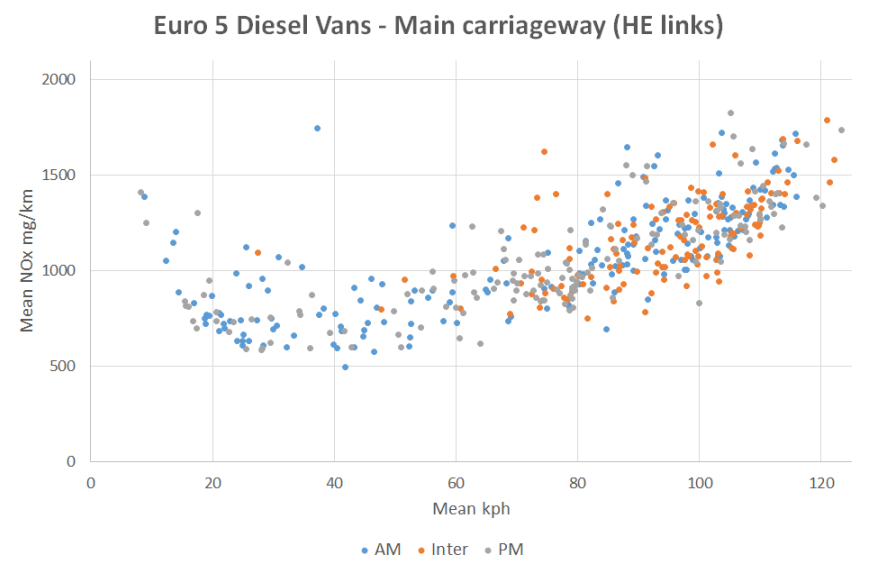
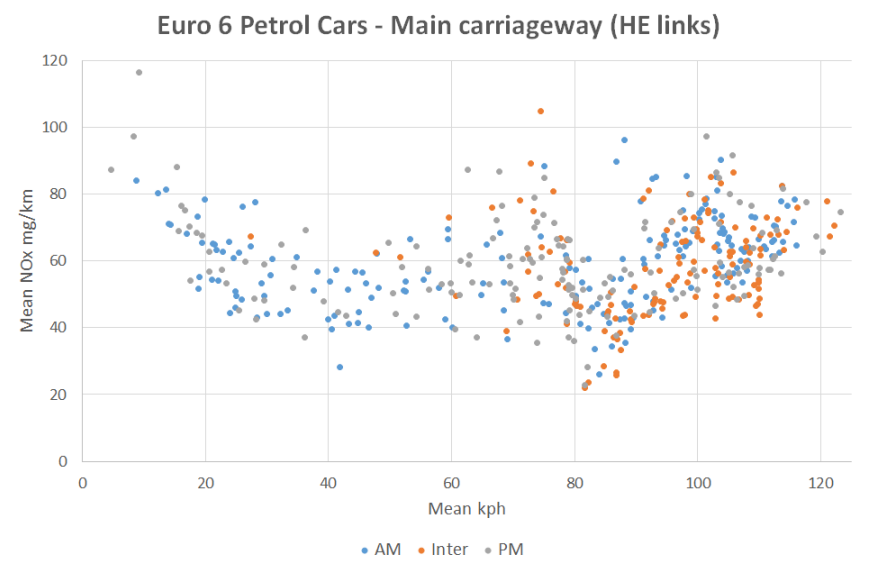
Application of DfT / DVSA NO_x data to Highways England vehicle dynamics data at a link spatial resolution



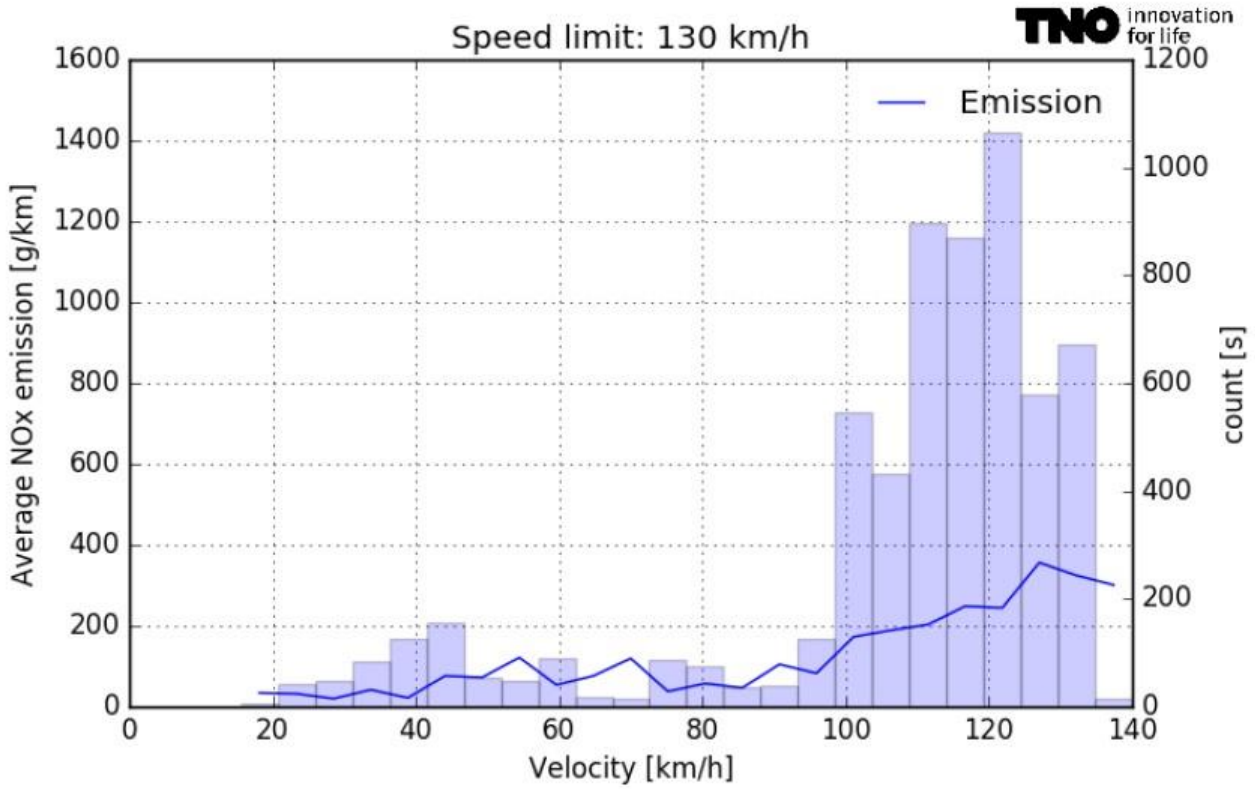






Higher speed NO_x emission rates from TNO

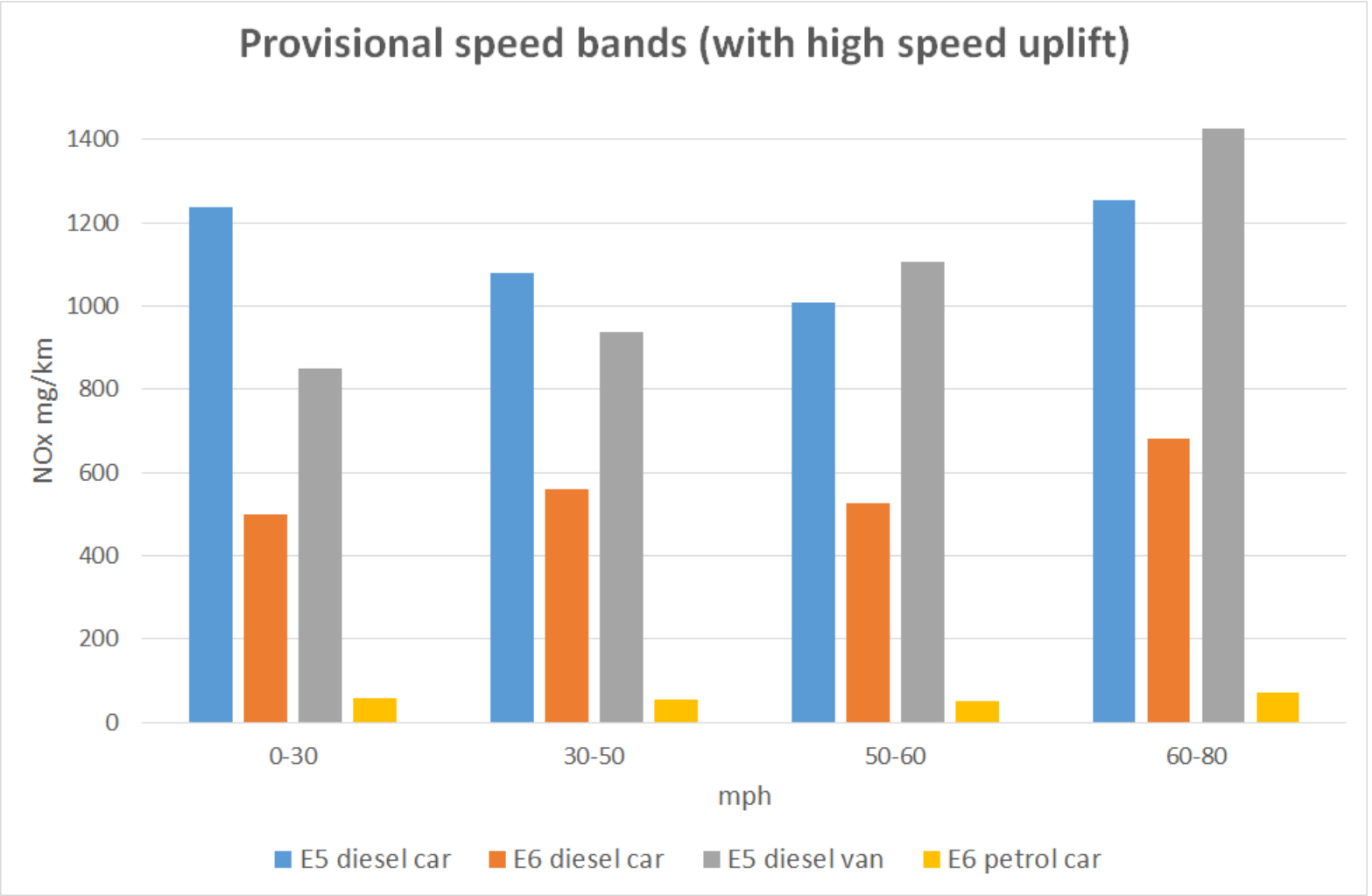
- TNO in the Netherlands have carried out PEMS emissions tests on Dutch motorways with 130kph speed limit (81mph).
- From their PEMS data, TNO estimate an increase of ***15% to 20% in NO_x emissions for every 10kph increase above 100kph*** [2].



[1] Graph source: TNO report R10827 “Definitie congestie op de snelweg voor emissiefactoren”, 2017

[2] Personal communication with TNO, Netherlands (January 2019)

Light vehicle speed bands and NO_x emissions



Based on available Highways England vehicle dynamics (links), DfT / DVSA PEMS data, DfT speed statistics, and TNO high speed NO_x uplift

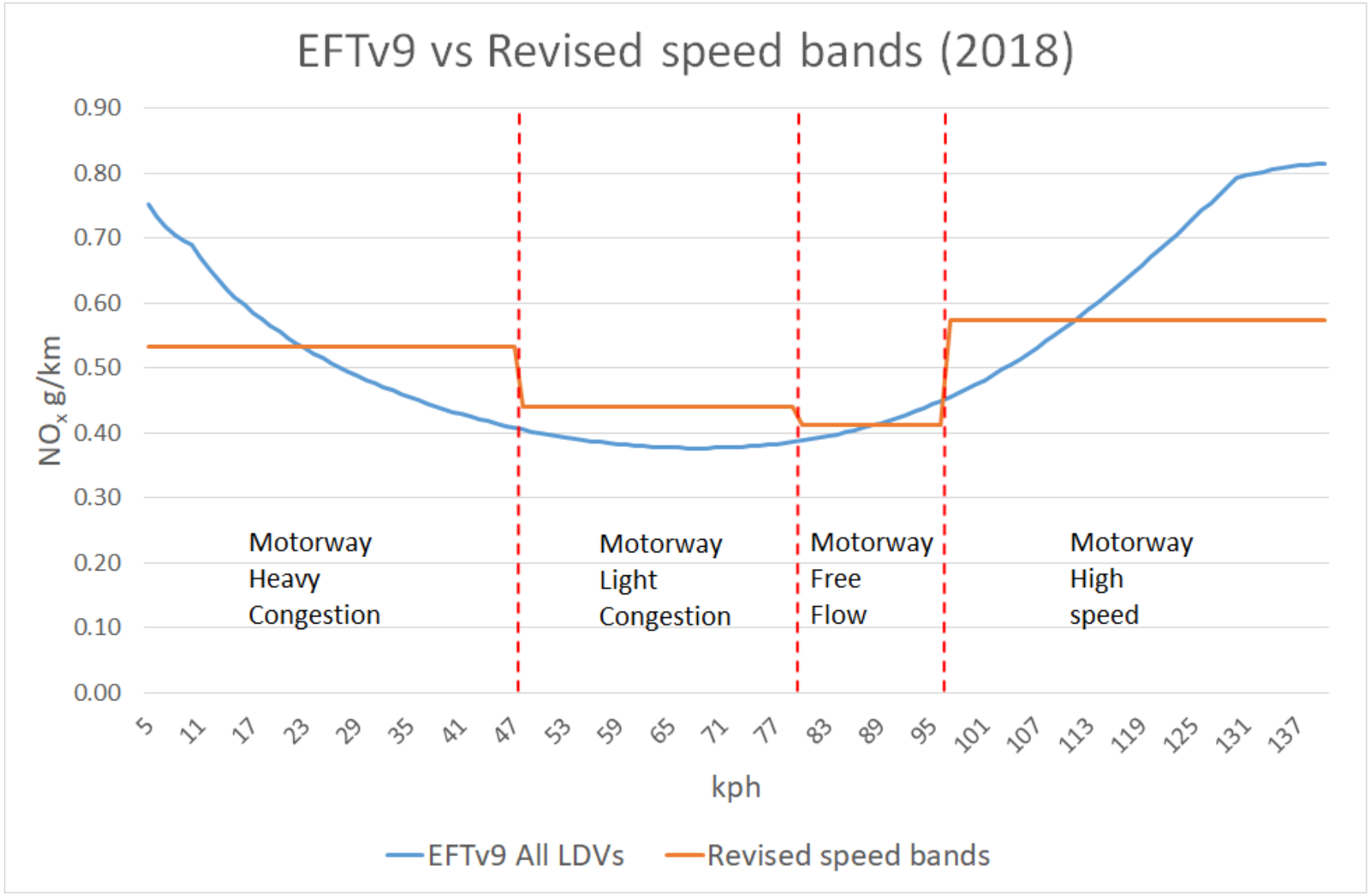
Informing EFT and IAN 185/15 using emission rate insights

The analysis provided i**nsights** into ‘real world’ light vehicle emissions, for example:

- The significance of the **‘harmonica’ effect** (higher NO_x emissions associated with higher vehicle dynamics in certain speed ranges).
- The **absolute difference** in emission rates between EFT and PEMS data for certain vehicle types and Euro classes (e.g. Euro 5 diesel cars, Euro 5 N1 class II diesel vans…).
- The significance of ‘higher speed’ NO_x emissions.

A **revised speed banding structure** was adopted in LA 105. **Emission Factor Toolkit** emission rates were retained, but adapted to reflect the ‘harmonica’ effect under light congestion, and the proportion of light vehicles operating at ‘higher speeds’.

EFTv9 vs Revised speed bands



NO_x emission rates based on EFT, with adjustments for 'light congestion' and 'high speed'.

DMRB LA 105 Air Quality

Design Manual for Roads and Bridges

Sustainability & Environment Appraisal

LA 105
Air quality

(formerly HA 207/07, IAN 170/12, IAN 174

Revision 0

Table A.1 Motorway speed bands

Category	Speed range (kph)	General description
Heavy congestion	5 – 48	Traffic with a high degree of congestion and stop: start driving behaviour, junction merges, slip roads with queuing traffic.
Light congestion	48 – 80	Traffic with some degree of flow breakdown, typical volume/capacity (v/c) >80%. Normal operation on slip roads.
Free flow	80 – 96	Motorway generally free flow driving conditions with little or no flow breakdown. Motorway busy but not congested, v/c <80%.
High speed	96 - 140	Motorway unconstrained, typical of overnight conditions when traffic light.

Contact

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https://assets.highwaysengland.co.uk/CPC_Speed_Band_17092019_v2.pdf