Uncertainty in rail emissions modelling

- Understanding and reducing it

Dispersion Modelling User Group
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Why is rail different to road – part 1

- Road emissions and their modelling is fairly well understood
- Rail has some key differences to road that make accurate modelling *more challenging* than most road cases
  - Addressing *"more challenging"* needs better quality of inputs
  - Focus of this presentation is on developing better inputs
- Key rail difference vs road differences:
  - Rail has much lower rolling resistances than road, leading to 60-85% lower overall energy requirements
    - Much more unpowered coasting while in motion (equivalent to a road vehicle in neutral)
  - Passenger rail vehicles have comparatively high auxiliary loads (including lighting and HVAC)
    - Typical auxiliary load requirements are 25-80 kW per vehicle
  - Rail Lower traction energy requirements lead to much larger proportion of idling for the whole drive cycle engine idling
    - All GB diesel rolling stock spends substantial time in idle – typically 55-75% of total engine on time
  - Rail engine idle conditions are very different to road or regulatory emission testing engine idle conditions
    - far higher power, far greater proportion of drive cycle

Why is rail different to road – part 2

- Key rail difference vs road differences continued:
  - Most of the rail AQ challenge is around NOx not PM – different to road which has traditional more equal challenge for both AQPs (more of current combustion focus for rail PM too)
  - Each engine can effectively be treated as point source that moves but the spacing of point sources is very uneven compared to road vehicles
    - A train formed of diesel multiple unit may have up to 10 engines/exhausts
    - The spacing of diesel trains is very non-uniform
      - Closely spaced in station and depot areas
      - Widely spaced outside station and depot areas
      - The difference between maximum and average emission concentrations can be far greater with rail
  - Completely different relationships between vehicle emission rates and vehicle speed compared to roads
    - With rail the highest emission rates often align with enclosed or semi-enclosed locations
  - Many type of construction equipment have similarities in drive cycles to rail have also proved challenging to model

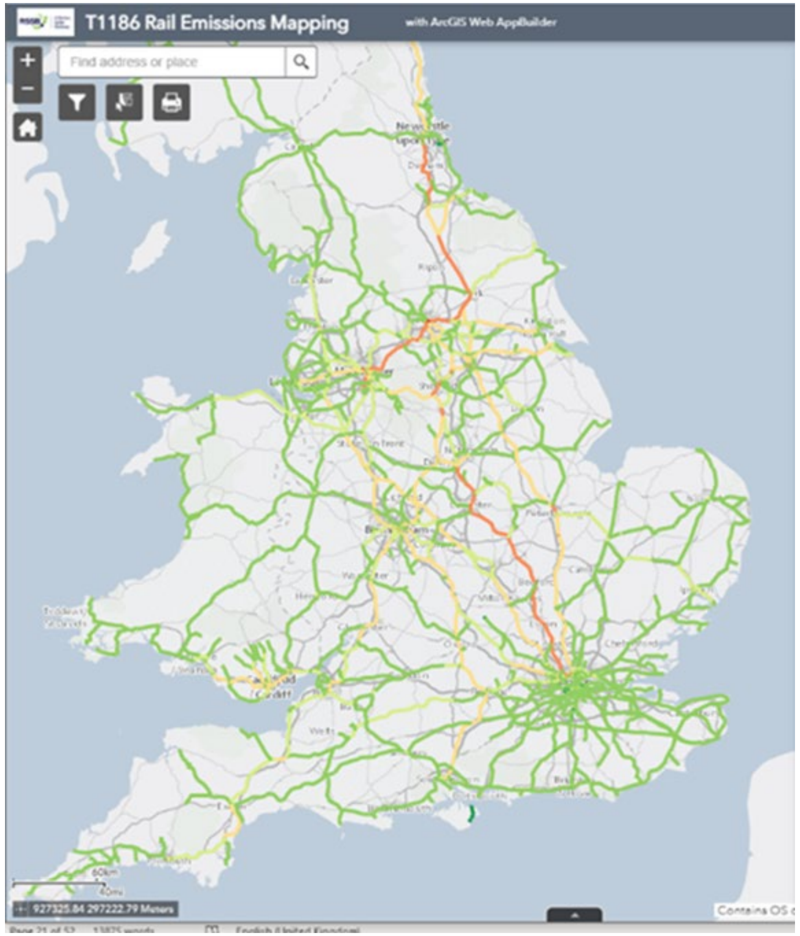
- **Key message – rail is much more heterogenous than road**

  - **Rail emissions can't be treated as average line sources for detailed modelling work**

What impacts rail emissions and their dispersion

- Not all rail diesel vehicle emissions are equal
  - What type of train?
  - What kind of engine?
  - How many engines?
  - What is the train doing?
  - Where is the train?
  - Are exhaust treatment measures operational (if fitted)?
  - How are the exhaust gases being released?
  - Exactly where are the emissions being released?
  - Can the emissions disperse easily?

- Aether Limited:
  - Emissions inventory experts (multiple pollutants, sectors and scales)
  - Specific rail emissions expertise
  - Multiple projects completed for RSSB, DfT, Defra, TfL, Rail Partners, rolling stock leasing companies

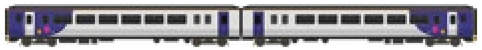


What type of train? How long is it?

- Class 220/221 Voyager engine power is twice that of a typical Class 15x Sprinter
  - Assume emissions proportional to max engine power
    - reasonable crude assumption for quick thought experiment…
  - → One 220/221 vehicle is double the emissions of a Class 15x vehicle

So 1x

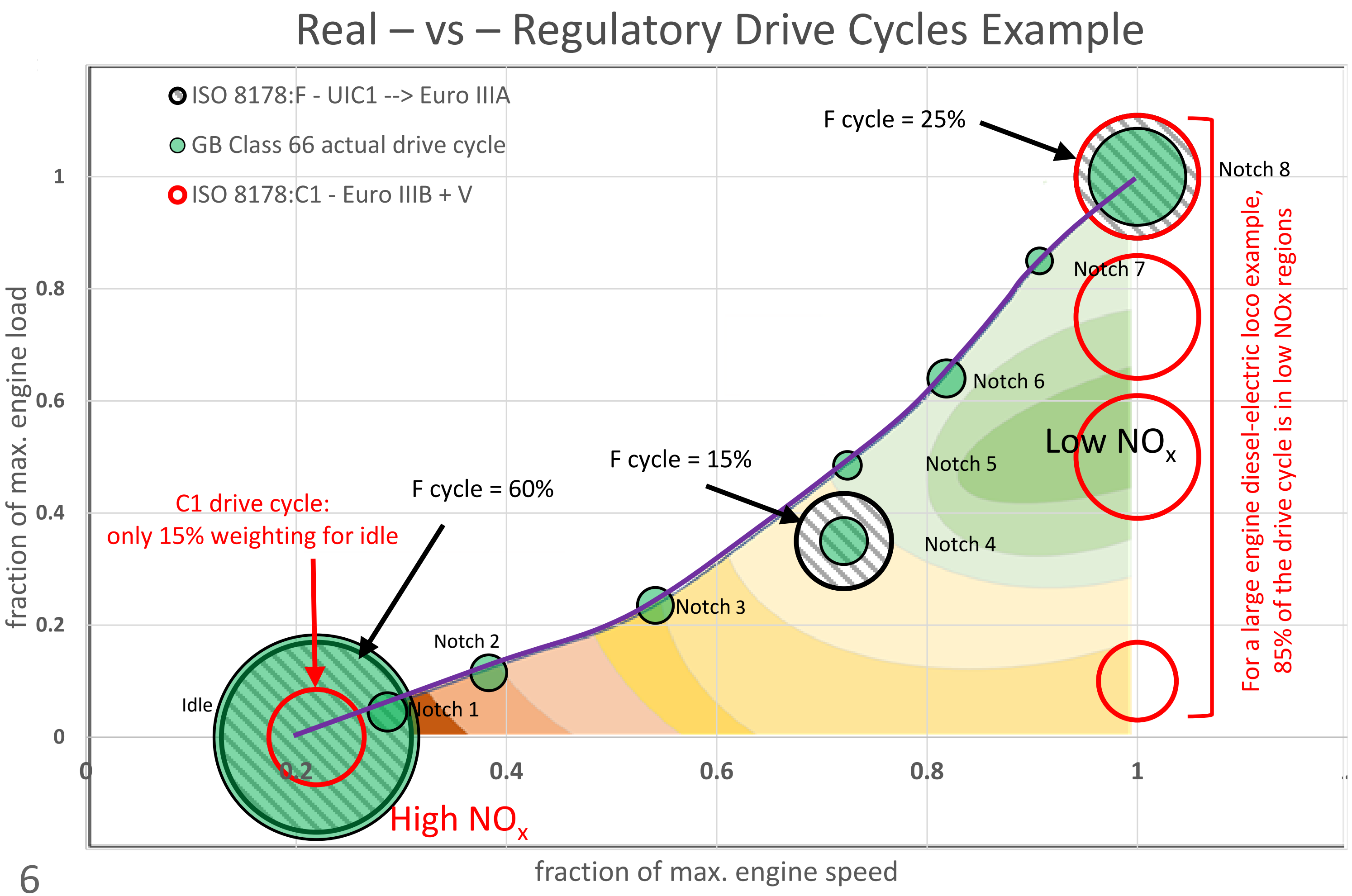
= 10x



- ***Understanding the nature of the traffic as well as the route is critical***

Rail drive cycles – the importance of idling emissions

- Engine operating conditions along with real freight, ISO 1878:F and ISO 8178:C1 drive cycles:

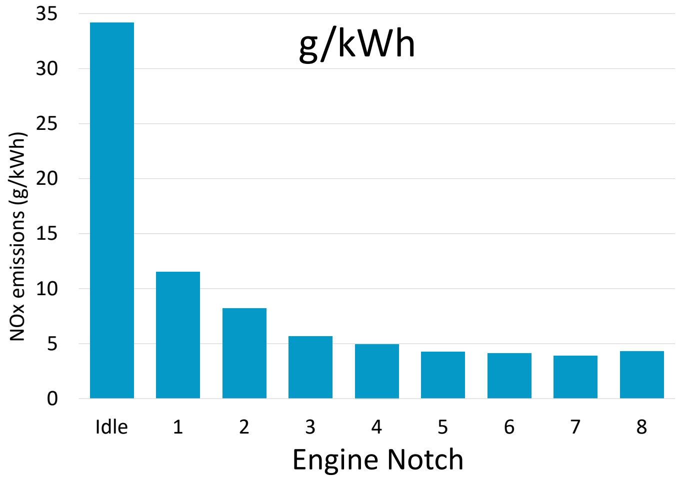


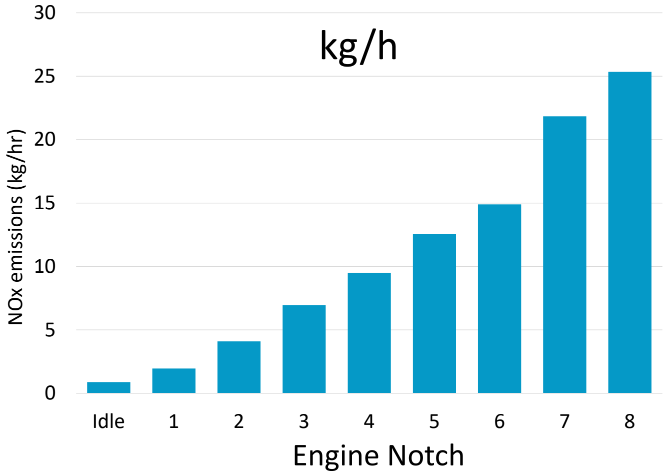
- All GB diesel rolling stock spends substantial time in idle (~55-75%)
  - Includes coasting/braking as well as stationary idle
- In the voluntary and Stage IIIA emissions era, the F cycle with 60% idle was used
- The non-road mobile machinery (NRMM) Stage IIIB and V drive cycle (in red) closely follows Heavy Duty road drive cycles and vastly underrepresents the amount of time in idle – just 15%
- Most Stage IIIB and V drive cycle test conditions aren't that appropriate for rail especially for electric transmission

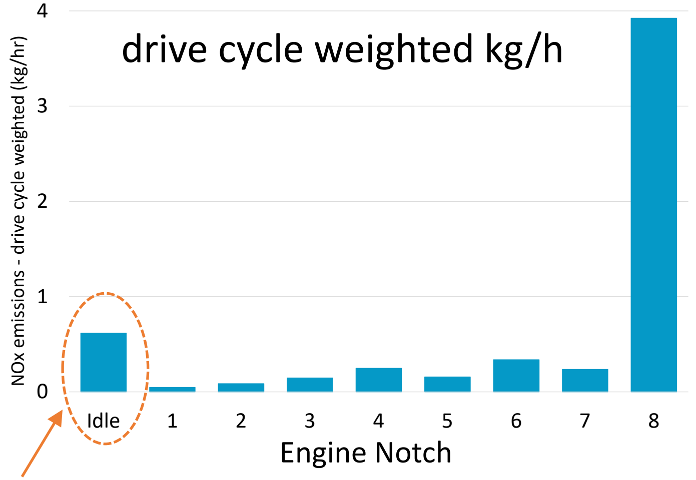
Not all emissions are created equal...

- Testing shows non-CO_2 emissions are not proportional to engine power:

NOx emissions by engine notch



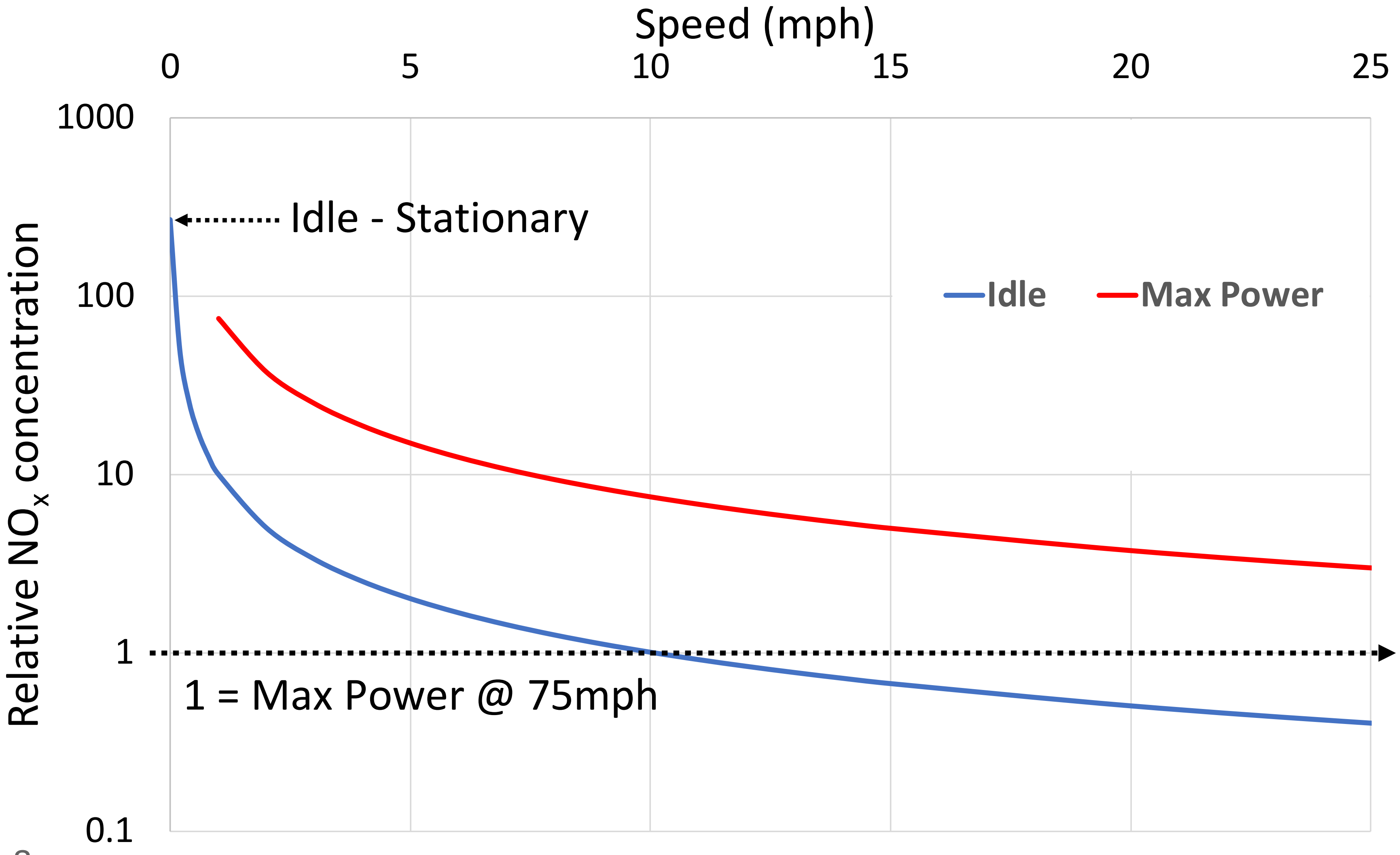




- Why more is there proportionately more NO_X at idle?
    - More time at higher temperatures to form NO and then convert to primary NO to NO_2 very quickly
    - More oxygen available at low engine fueling rates to form NO and then NO_2
- On a drive cycle weighted basis, stationary idling emissions will be significant
- What then happens to those emissions?

Not all emissions are created equal...

- Highest local concentrations where trains are stationary or accelerating at low speeds:

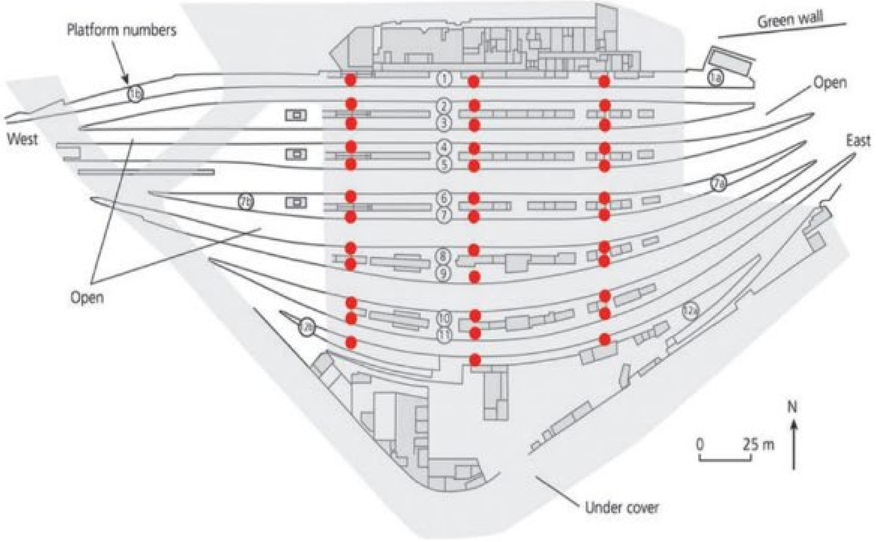


- Comparison of relative NOx concentrations at a fixed location versus speed and notch for a freight example Class 66 with EMD 710 engine
- Simple example for emissions close to the track modelled for single locomotive at idle and max. power

Implications for air quality in different locations

- Hickman et al. (2018), Evaluation of air quality at the Birmingham New Street railway station. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, 232(6): 1864-187.

Platform level



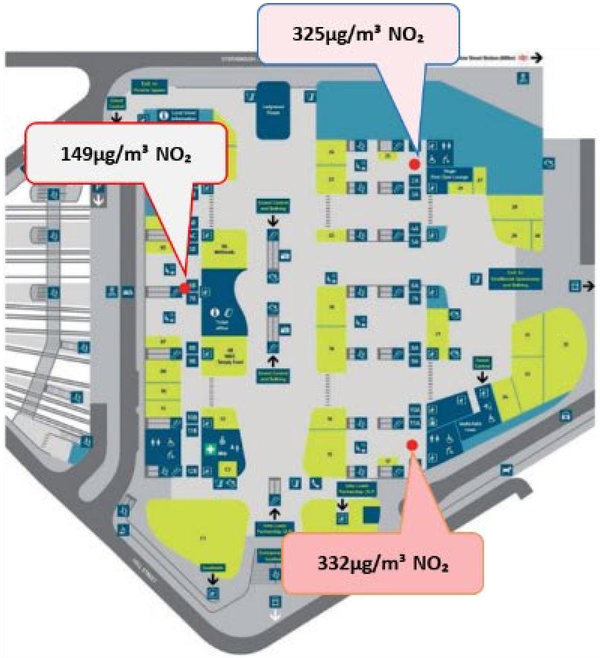
Continuous monitoring

Pollutant	B	C	A
NO2 (µg/m³)	170	395	251
PM10 (µg/m³)	36	53	40
PM2.5 (µg/m³)	26	42	29
Black Carbon (µg/m³)		20	
CO2 (ppm)	438	658	472

Diffusion tubes

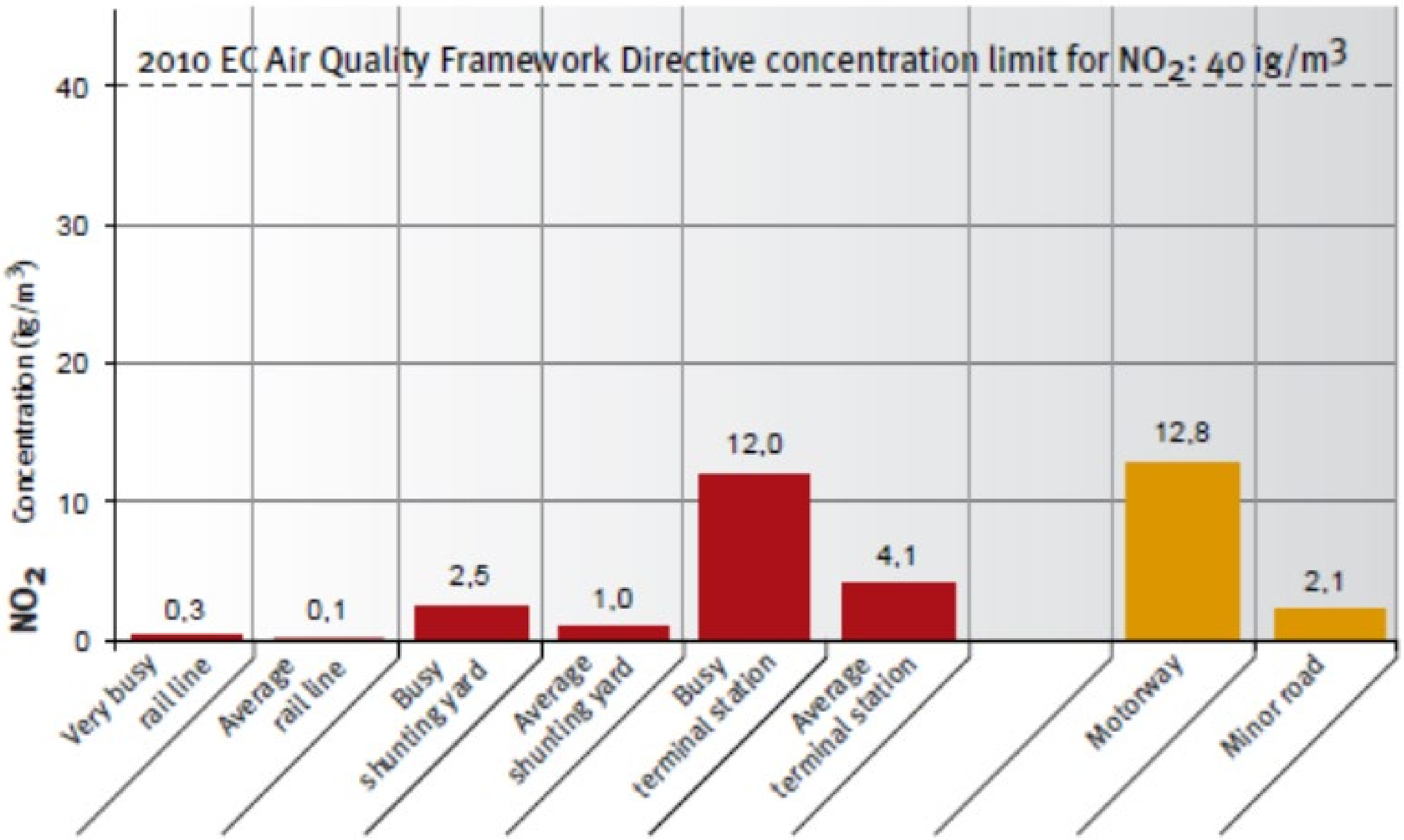
Platform	NO_2 concentration (µg/m³)		
	West	Centre	East
1	281	452	317
2	318	473	350
3	261	458	338
4	298	386	300
5	254	373	305
6	235	333	238
7	201	370	254
8	246	384	297
9	272	440	386
10	289	461	343
11	223	449	310
12	361	404	303

Concourse level



Implications for air quality in different locations

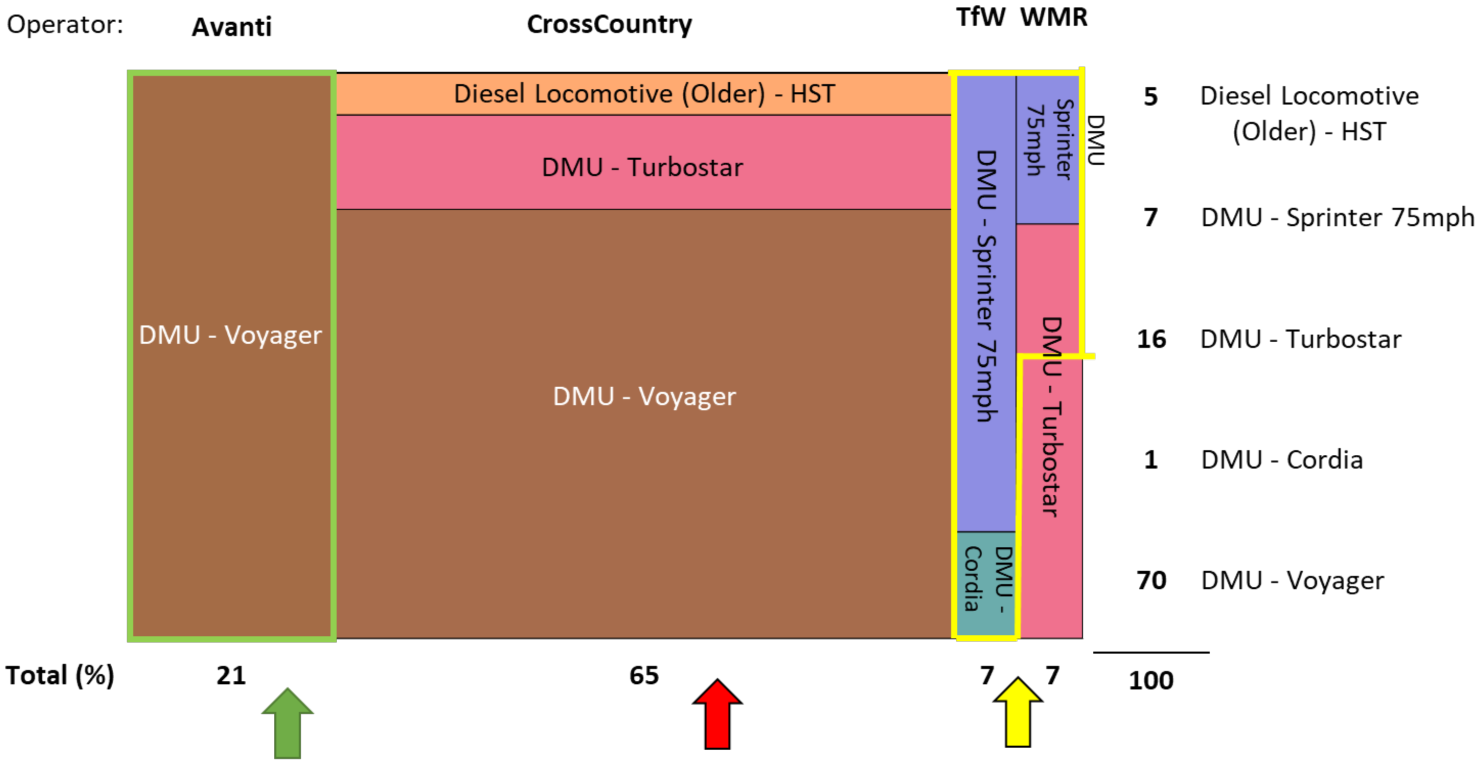
- NO_2 concentration in micrograms/m^3 for different typical locations based on Deutsche Bahn's work for the 2004-06 UIC rail diesel emissions study:



- Not the best quality modelling work 20 years ago but good enough to identify differences in type of locations
    - Ignore the numbers but look at the relative differences between location types

Implications for air quality targets

- Largest pre-Covid NOx source at Birmingham New Street was CrossCountry Voyager trains



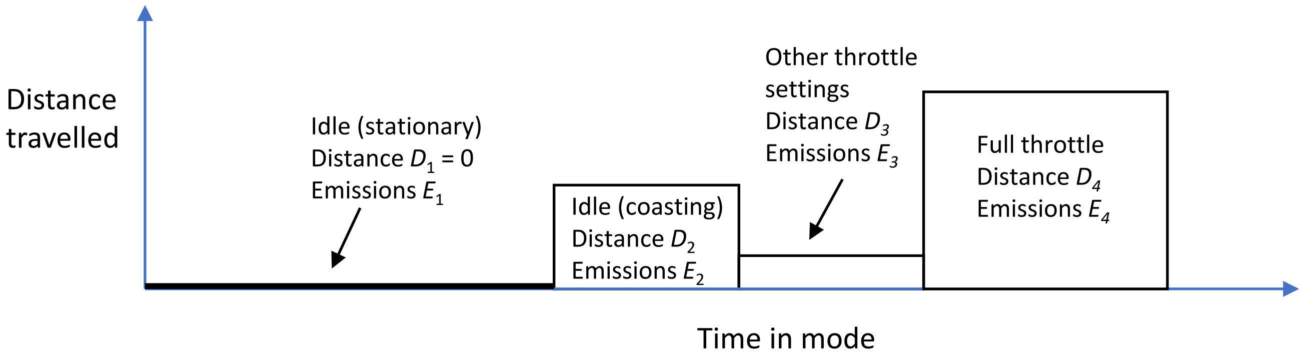
Avanti Voyagers replaced by Bi-modes

Pre-Covid plan saw XC increase usage of all 3 stock types

Some older local and regional stock replaced

Using g/km factors

- RSSB project T1887 developed fleet-wide g/kWh emission factors. These account for different emissions in different modes (engine "notch)
- However, sufficiently detailed activity data may not be available to fully utilise these g/kWh emission factors
- National network activity data may only be available in terms of train (or vehicle) kilometres travelled
  - This is the level of information available for the UK NAEI timeseries (which goes back to 1970)
- The new g/kWh factors have been used to refine the g/km factors used in the NAEI
- From a review of on-train monitoring recorder (OTMR) data the following are obtained:
  - Average distances covered
  - Proportions of time in:
    - Idle – which can be coasting as well as stationary
    - Full throttle
    - Other intermediate settings
  - Using g/kWh factors an average emission rate per km for the typical drive cycle is then determined:



g/km Emission Factor =

$$\frac{E_1 + E_2 + E_3 + E_4}{D_1 + D_2 + D_3 + D_4}$$

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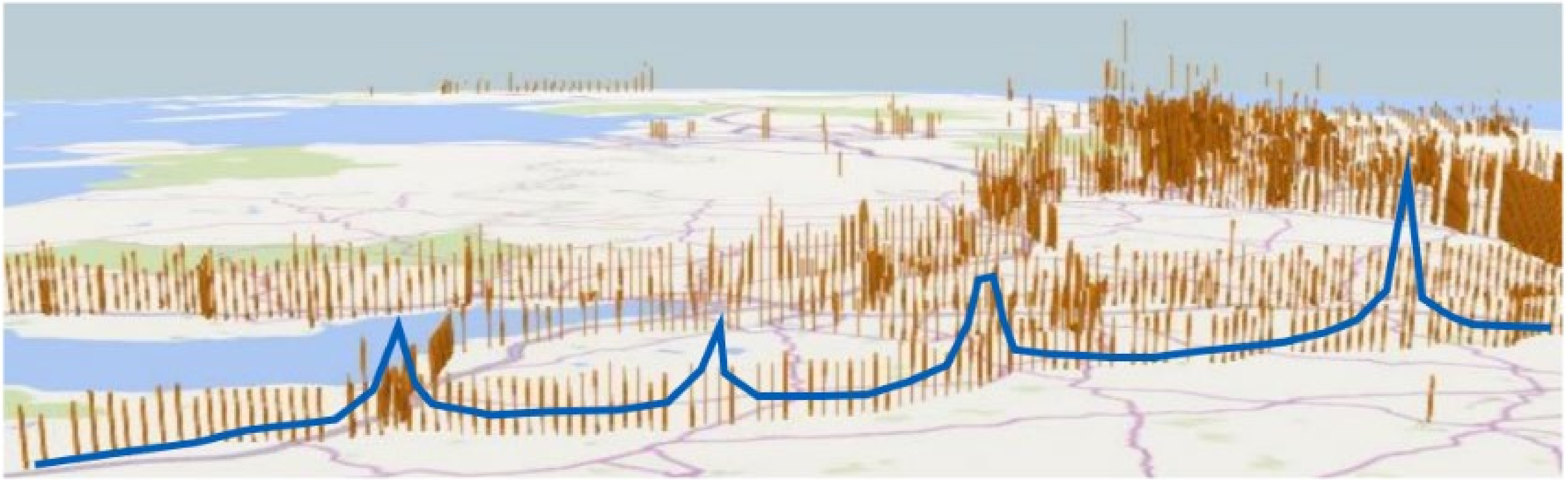
Rail emissions will vary along a route

- Average g/km emission factors are suitable for determining national emissions totals but they don't capture significant spatial variation

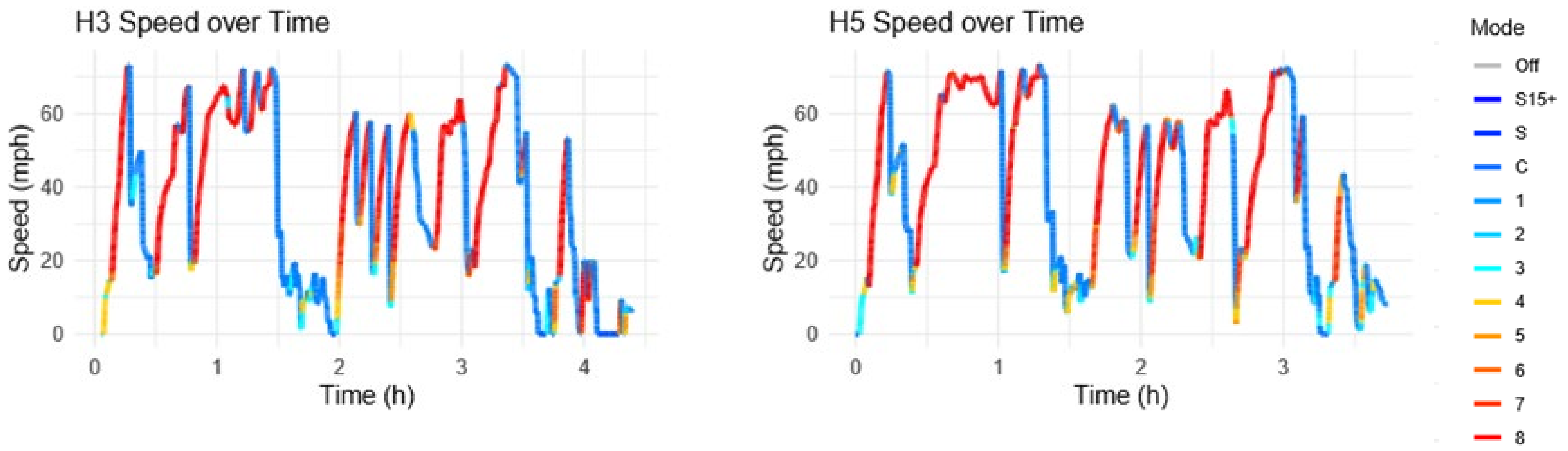
- 1 km^2 grid values in the NAEI reflect general traffic levels:



- Orange bars show NAEI derived emissions. Blue line illustrates how emissions are more likely to vary along a rail line

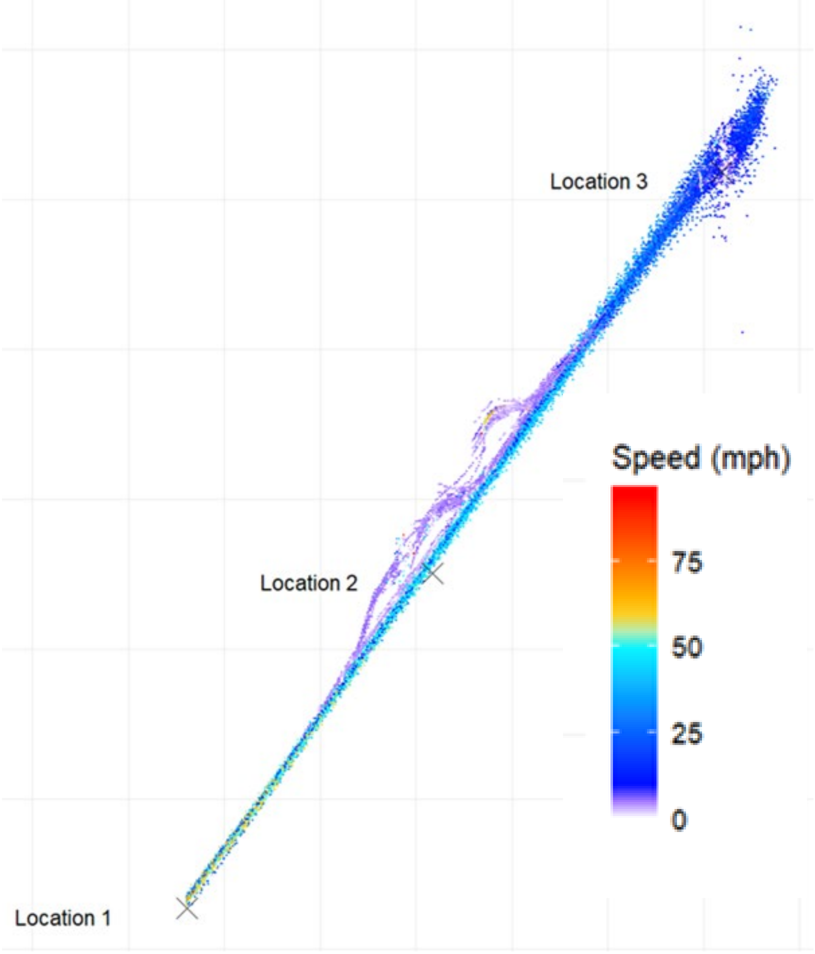
Observed variations in emissions along a standard journey

- Freight example: same locomotive, same wagons, same loading, same route, consecutive days
- Journey H3 (which experienced more delays) emits 1.13 kg NOx, 0.045 kg PM, and 108 kg CO_2 more than journey H5 over same route.
- These differences are **12%**, **16%** and 3.5%, respectively, of total journey NOx, PM and CO_2 emissions



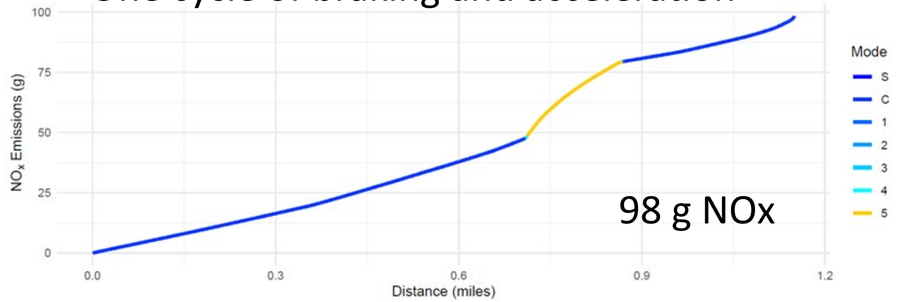
Observed variations in emissions outside a major station

- A smooth approach (or not) to a major station can have a big impact on local NOx

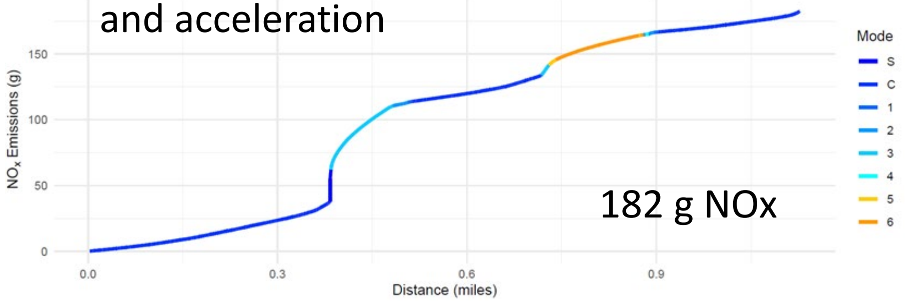


Smooth approach

One cycle of braking and acceleration

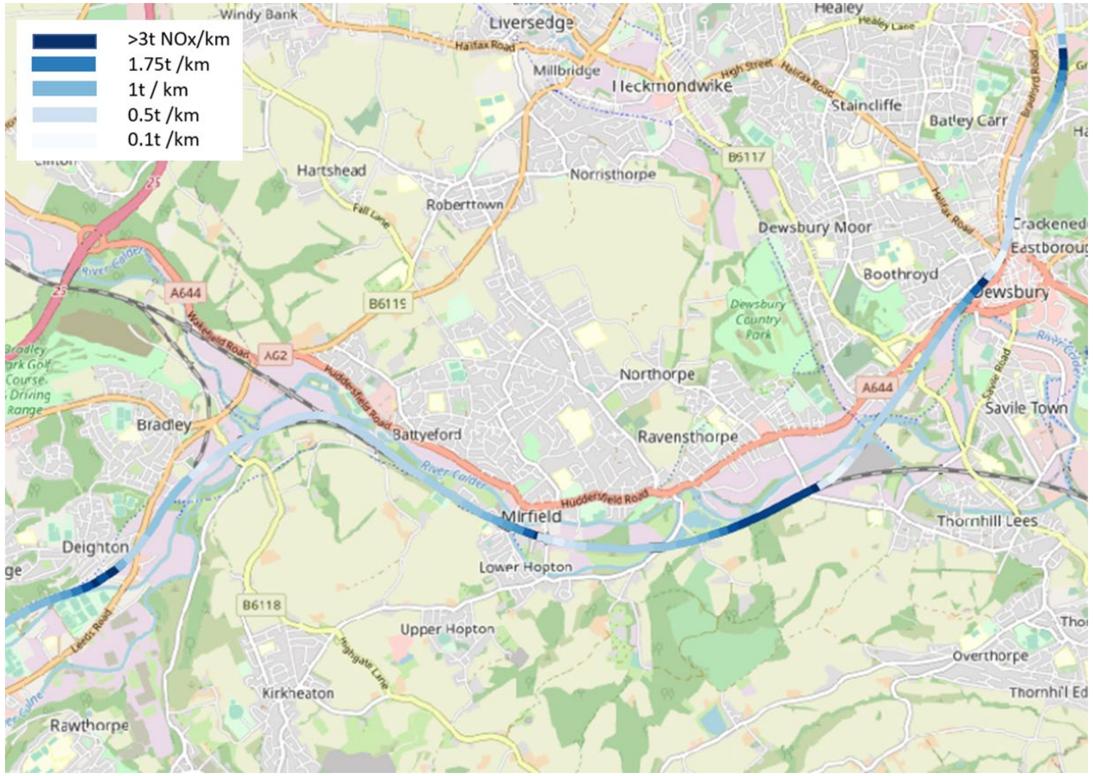


One stop-start cycle plus cycle of braking and acceleration

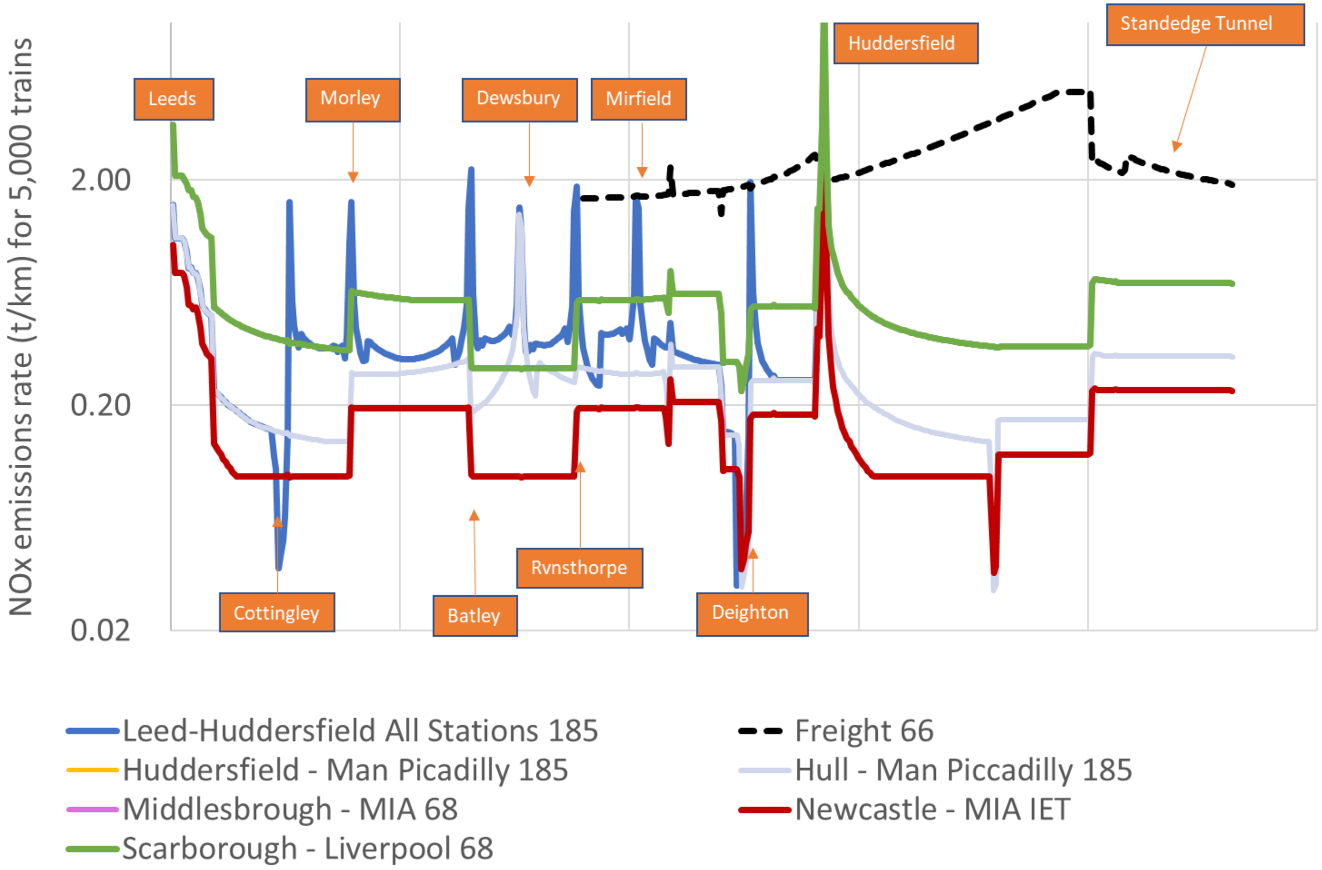


TRU air quality impacts – work for DfT

- Detailed emissions modelling using a version of the force-balance Davis equation and detail transmission models for mechanical and hydraulic transmissions. Route segmented into 10 metre segments
- Class 185 Leeds to Huddersfield stopping service (westbound):

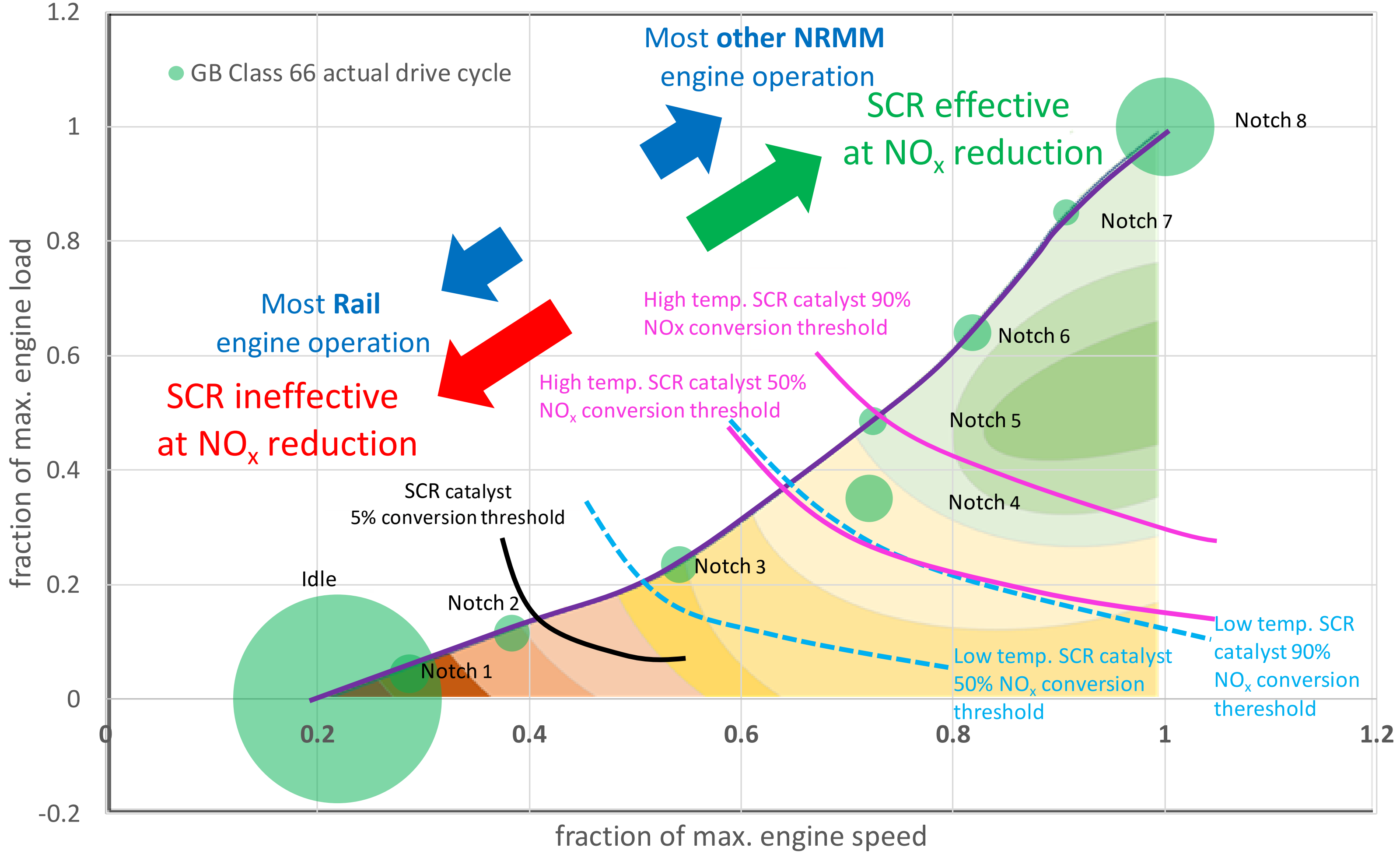


- NOx emission rates by rolling stock, Leeds to Standedge tunnel:
  - High rates for Class 185 on stopping services in urban areas



Where will SCR be effective?

- SCR conversion efficiency under different engine conditions with the iso-catalytic conversion efficiency lines for two types of SCR technology (for a modelled Class 66 example):



- Air quality solutions will need to meaningfully address emissions at idle, and not just at higher engine speeds (where abatement measures tend to be more effective)

How many engines are actually running?

- While in a station only one or two engines may be running to supply auxiliary (hotel) loads

- Just one engine running in this case

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Where are the exhausts on the train?

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- The train exhaust configuration and the station configuration (i.e. platform canopy design) may enhance local concentrations
- Potential for significant differences between rolling stock types and station configurations

Key Learnings

- Key message – rail emissions can't be treated as an average line source
    - Not all rail emissions are equal
    - Rolling resistance lower, idling for longer distances and more of the overall drive cycle
    - Gaps between trains when moving are far larger, not like motorways
    - Need to treat differently from roads and step up the detail level
- Possible to show energy demand (CO_2 emissions) and AQ emissions will vary spatially by:
    - Rolling stock type and loading
    - Service pattern
    - Route characteristics
- Addressing shorter term air quality issues can sometimes align with prioritisation of decarbonisation schemes:
    - Enclosed stations
    - Locations with a high degree of terminating diesel traffic
    - Rolling stock with the most impact in different locations

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Thank you

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