HE Dynamic Speed Limits: Peer review of Air Quality Analysis (April 2017) by David Carslaw and Nigel Bellamy

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Purpose

- To critique the analysis of air quality and traffic data for UK motorway locations. This includes reviewing the underlying data and processing/ handling routines.
- To suggest potential avenues for further analysis to strengthen the approach and findings.

The peer review is structured:

- Overview comments on the approach, analysis and findings
- Data review
- Analysis and Model review
- Recommendations for further work

The review and comments are made from prior experience analysing traffic, vehicle emissions and air quality data, notably applying the statistical approach Boosted Regression Trees (Sayegh, Tate & Ropkins, 2016).

Overview comments

The working document ‘Summary of Air Quality Analysis’ report (April 2017, version 3) presents a comprehensive body of high quality work. Straight-forward, open access to the underlying data and associated code to process, analyse and replicate the models is exemplary and has facilitated a thorough review.

Key developments and findings include:

- Developing open-source methods to collate and analyse UK motorway traffic flow and air quality data, also considering the prevailing meteorological conditions. The methods developed to routinely handle the somewhat cumbersome 1-minute averaged MIDAS traffic data, split into daily files for multiple years and sites are efficient, appropriate and warrant wider use.
- Exploratory analysis to understand the relationships between traffic flow factors and roadside ambient concentrations accounting for prevailing meteorological conditions. Key innovations being examining the influence of flow levels of ‘short’ and ‘long’ vehicles, and effort made to quantify the variation in speed (inferring more changeable traffic flow conditions with a higher density of more polluting acceleration phases) from the 1-minute averaged MIDAS traffic data.
- The exploratory analysis includes novel visualisations of traffic flow, speed (including variation in speed) and ambient concentrations (numerous variations) to help communicate how complex the interactions are. The building of appropriate statistical models to explain the inter-relationships are of most use, as they help establish relationships and rank the importance of variables in explaining ambient concentrations of NO_X and NO_2.
- The NO_X model relationships and relative importance are plausible and as expected. The relative low importance of traffic flow speed is perhaps surprising and inherently limits the ability of the study to understand the impact of speed on concentrations.
- The finding that the expected drop-off in concentrations as wind speed increases is only observed above ≈ $9 m.s^{-1}$. Interpretation of this result that traffic-induced mixing and transport has a stronger influence below this threshold is an important new finding.
- The differences in the results for the NO_X and NO_2 model relationships and variable importance are arguably the most important findings i.e.

- Roadside concentrations of NO_X are strongly influenced (31.7%) by the flow of 'long' vehicles. 'Long' HDVs are almost entirely powered by diesel engines that all emit relatively high levels NO_X (in 2013 no Euro VI HDVs were in operation). HDVs also predominantly occupy lane 1 of the motorway, closest to the receptor (roadside air quality monitoring site). The dispersion distance is therefore shorter and are expected to have a relatively higher importance.
- Conversely the flow of 'short' vehicles is more important to the roadside concentrations of NO_2 (21.8%). At lower wind speeds e.g. below $9 m.s^{-1}$, primary emissions of NO_2 (tail-pipe) will strongly influence roadside concentrations. Euro I – V HDVs are known to have a low NO_2/NO_X fraction (< 10% | Hausberger et al, 2011), whereas more modern diesel LDVs that now dominate the motorway fleet emit much more NO_2 directly e.g. Euro 5 diesel f-NO_2 36% (Hausberger et al, 2011). This switch in the importance of the 'short' and 'long' traffic flow is considered plausible and important. As stated in the report, it is important if the HE needs to work towards lowering roadside levels of NO_2 rather than further away from the motorway (source). If the critical performance indicator is roadside concentrations then this result suggests encouraging the LDV fleet to shift to powertrains (petrol, petrol-hybrid, EV) that emit less primary NO_2 is more important than renewing the HDV with a Euro VI fleet for example. Understanding the primary NO_2 emission performance of both LDV and HDVs in motorway driving conditions is considered a priority for the HE (Tate, 2017).
- The increasing importance of air temperature on NO_2 concentrations above ≈ 19 ^{o}C (as opposed to falling importance for NO_X) is well explained by the atmospheric chemistry processes (higher ozone concentrations and NO + O_3 reactions leading to NO_2 production).

- The aim of assessing whether dynamically managing traffic flow through Variable Speed Limits (VSLs) influences emissions and roadside concentrations, is only considered valid for the comparison of 'no speed control' (70 mph) and 'speed control' (50 mph) conditions. This is because traffic flow varying with demand exhibits different behaviour to flow responding to a speed limit. A speed limit will reduce speed variation and 'smooth' movements (reducing the severity and frequency of polluting acceleration phases). In contrast increasing demand will introduce more turbulence in the flow, lowering average speed, but with more speed variation and consequently associated emissions.
- Unfortunately there are concerns about the validity of the 'no speed control' (70 mph) and 'speed control' (50 mph) data, limiting any understanding and conclusions that are made from this analysis. This is inferred from the significant differences in the Figure 7 (M60 plots of 'short' vehicle flow / speed / NO_X for 2013) and Figure 8 left-panel ('no speed control' in 2014). The 'no speed control' surface appears to exhibit a feature of elevated NO_X concentrations when speeds are less than ≈ 65 $km.h^{-1}$ similar to that of the 'speed control' condition. Above ≈ 65 $km.h^{-1}$ average concentrations fall rapidly in the 'no speed control' condition. This feature is not present in the 2013 data, perhaps suggesting periods of 'speed control' are present in the 2014 'no speed control' condition.

Data review

- The code merging the 1-minute averaged MIDAS traffic data, split into daily files for multiple years has been checked. Sample 'raw' MIDAS traffic data files were also checked to verify the data merging and processing are valid and correct.
- Although roadside concentrations of NO_X are known to be strongly influenced by background levels (ideally measured locally, see Sayegh et al, 2016 | Table 5) and the model includes this as a variable, no data is currently available ("NULL"). It is inferred this is considered important and

included in the model design, but no suitable background NO_X data has yet been sourced (see ‘further work’).

- Figure 10 highlights there is some erroneous, unfeasibly high traffic ‘flow’ data that should be ‘cleaned’.
- The temporal variation in traffic flow and speed for ‘short’ vehicles for directions ‘A’ and ‘B’ independently is presented in Figure 1 and 2 respectively. This highlights that direction ‘B’ has a distinct congested weekday AM and PM peak period, whereas direction ‘A’ typically only has delays in the PM peak. This is important as meteorological conditions are typically more stable in the AM peak period (lower wind speed, temperature and boundary layer) than in the evening. The elevation of concentrations due to more polluted, congested driving conditions are therefore expected to be more exaggerated in the AM than PM peak (see ‘Further work’).

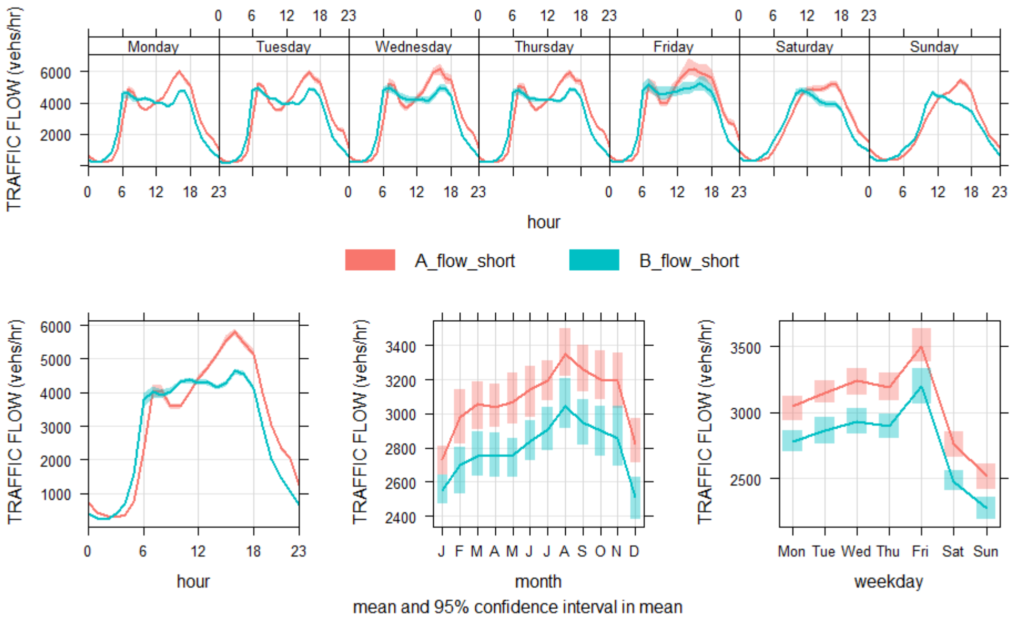

FIGURE 1. M60 2013 variation in traffic flow (‘short’ vehicles) for directions ‘A’ and ‘B’

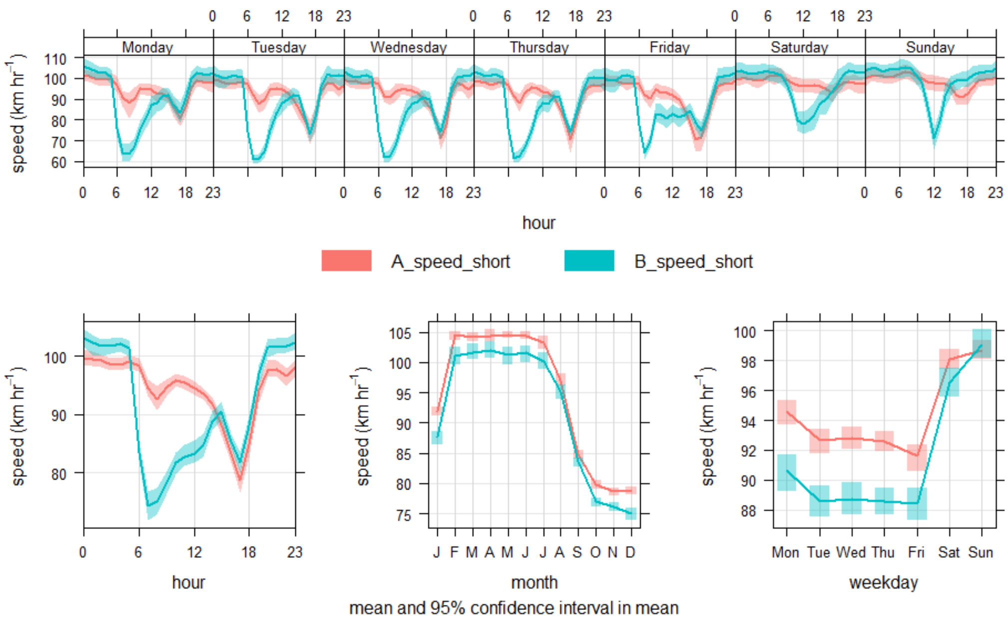

FIGURE 2. M60 2013 variation in traffic speed (‘short’ vehicles) for directions ‘A’ and ‘B’

- The lower average speeds October to December 2013 (Figure 2) suggest 50 mph speed limits were introduced in this period around preparatory improvement works. Accurate logs of interventions are needed so periods of ‘standard’ and ‘managed’ operation can be isolated and studied (see ‘Further work’).
- Very limited supporting information is provided about the location, characteristics and specification of the monitoring sites. Critically the topography or structures around the air pollution monitoring site that might influence dispersing air-flow movements and the alignment of the road.

Analysis and Model review

Detailed comments and interpretation / critique of Figures:

- A substantive point is that the ‘standard deviation of short vehicle speed’ (underlying data 1-minute averages) measure illustrates the variation in speed within an hour (to match the more aggregate, standard hourly air quality data). Considering the information available, it is perhaps the most informative metric attempting to quantify the variability in traffic flow that can be derived. Whilst a useful statistical measure its meaning needs careful consideration. A higher standard deviation may illustrate highly variable speeds, or simply a transition from a ‘free-flow’ to more ‘congested’ state, or vice-versa. i.e. the shoulders of a peak period. The scatter of points around Figure 9 show that NO_X levels are higher when speeds are low (congested, < 70 $km.h^{-1}$) and the variation in speed also low (standard deviation < 20). This suggests air pollution is elevated when speeds are consistently low as opposed to fluctuating between ‘free-flow’ (perhaps less emitting) to a more ‘congested’ state. Further thought about the true meaning of this measure by isolating the ‘shoulders’ and ‘core’ peak periods (high flow and lower speed) may help understand the true meaning of this statistical measure.
- The M60 direction J13-14 road alignment has been estimated to have an alignment of 50^o from North. If the station is on the North-West side of the M60, then it would be downwind of the road when winds in range 50 to 230^o from North. This is supported by the result in the Figure 16 and 17 wind direction influence plots, but would be re-assuring to confirm by including a site description. The relative position and separation of the MIDAS and air pollution monitoring station would also be useful supporting information.
- The effectiveness (deployment) of diesel emission controls reduces with falling temperature. The air temperature influence is therefore considered to be both an indicator of dispersion conditions and the changing source strength. Diesel EGR operation for example is often switched off below temperatures of ≈ 5 ^oC to prevent the engine from being damaged by condensation forming in the EGR system. The commentary in the report rightly attributes the increase in roadside NO_X concentrations with falling ambient temperature to associated changes in prevailing meteorological dispersion conditions (lower boundary layer height etc). This should be extended to also be attributed to changes in diesel NO_X performance. Unfortunately these effects compound each other, leading to the most severe pollution episodes occurring when high pressure systems establish themselves over the UK in winter months.

Recommendations for further work

- The analysis approach, when supported by valid, accurate data is considered capable of identifying the relative air quality impacts of dynamically managing traffic conditions. It is recommended the approach is applied to traffic and air quality data as soon as it becomes available from implemented ‘Smart motorway’ schemes. This will help understand the impact of different management policies and underlying trends. The functions and code developed in this project should facilitate the efficient replication of the approach to new locations and situations. The approach and findings will be hindered by the hourly resolution of the air quality data (standard). Any ‘dynamic’ changes occurring over shorter time periods will not be able to be studied. The approach is considered to offer the HE an Internationally leading method to empirically evaluate the effectiveness of dynamic speed limits. It is not however considered able to forecast the impact of dynamic speed limits.

- Explore disaggregating the traffic flow directions and speeds that exhibit different diurnal characteristics. This will also allow the relative importance of flow directions on levels to be determined (as per Sayegh et al, 2016) and help establish clearer relationships. This analysis would be greatly enhanced if under-pin by air pollution monitoring stations established on either side of a section of motorway. This extension would also support the evaluation of dynamic management measures when not consistently applied to both directions of the motorway.
- Explore the influence of other relationships established from available data and variables e.g. headways (available in raw MIDAS data, currently un-used), ratio of long / short traffic flow for example.
- If budget is available to procure and manage new monitoring sites around a scheme, it is recommended a local background monitoring station is established so the fluctuations in background levels with seasons, weather systems and non-transport sources can be identified and isolated. This is expected to significantly improve the clarity of changes identified due to the introduction of dynamic management measures, or step-changes/ trends in fleet composition for example.
- High resolution telematics data (second-by-second) is now routinely collected in the UK (Pellecuer, Tate & Chapman, 2016) from a rapidly growing share of the operational passenger car fleet. As also illustrated by Tate & Connors (2015) it can be used to evaluate the expected changes in driver behaviour due to dynamic speed limits. The large scale of the M1 J23 – 35a Smart Motorway scheme is considered to justify the investment and resource needed to source, analyse and co-ordinate this data with the MIDAS and air quality data reported here. The potential of combining these Internationally leading data and analysis methods to finesse the rules of dynamic speed limit control to more effectively minimise emissions, particularly during winter pollution episode periods, is considered to justify the relatively modest effort and investment.

REFERENCES

Hausberger, S., Rexeis, M., Zallinger, M., Luz, R. (2011). User Guide to the PHEM Emission Model. Version 10. Technical University of Graz, Austria, January 2011.

Pellecuer, L., Tate, J. and Chapman, S. 2016. How do traffic flow and emissions it produced vary through the day, week, season and year: evidence from big telematics data. The 21st International Transport and Air Pollution (TAP) Conference, Lyon, France, May 24-26, 2016.

Sayegh, A., Tate, J. and Ropkins, K. 2016 2016. Understanding how roadside concentrations of NOx are influenced by the background levels, traffic density, and meteorological conditions using Boosted Regression Trees. Atmospheric Environment, 127 (2016) pp163-175, http://dx.doi.org/10.1016/j.atmosenv.2015.12.024

Tate, J. and Connors, R. 2015. Smart Motorway Driving. ITS Information Note. Highways England project, IEM Modelling, Task C2 . Motorway driving conditions. 22nd September 2015.

Tate, J. 2017. Summary of Euro 6 diesel Passenger car TfL London Drive Cycle data. Information Note. July 2017.