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DOI:
10.1002/wea.3729

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Abstract

General awareness of air quality has grown significantly in recent years, with ‘Low Emission’ and ‘Clean Air’ zones proposed for many cities across the UK. However, cities are a complex landscape and air pollutant concentrations can vary greatly from street to street. Therefore a synthesis of techniques to quantify air pollution is required to account for variations in traffic, meteorology, and urban geometry. While the transport sector accounts for much of the outdoor air pollution in UK cities, a limiting factor of current techniques is that traffic is approximated at coarse temporal and spatial resolutions. For example, the UK Department for Transport provides manual hourly counts of traffic volume for point locations, but these tend to only be for major roadways and the data is typically collected on one day of the year. Here, we present a novel technique that helps to ‘fill in’ the gaps in our traffic data by harnessing the power of real-time queries to online mapping services, such as Google Maps, to obtain vehicle speed information. This dataset can then be used to determine more accurate emission factors for oxides of nitrogen at the resolution of a single street. Initial results are promising, shown here by the application of this technique to the Birmingham (UK) road network.

Key words

Air quality, traffic emissions, API, exposure, human health

Funding information

This research was undertaken during a PhD studentship funded by DREAM, a subsidiary of NERC. More information can be found at: http://www.dream-cdt.ac.uk/

Word count: 3498

Introduction

Countries around the world face pressing social, environmental, political and economic issues. Air quality transcends all of the above; poor air quality disproportionally impacts minorities and those on a low income (Di et al., 2017), while contributing to 40,000 premature deaths and an economic burden of £20 billion per year in the UK alone (Royal College of Physicians, 2016) As more than 50% of the world's population now resides in urban environments, it is these relatively small spatial areas in which the most acute pollution episodes are likely to have the largest impact on the greatest number of people.

The sources and profile of pollutants varies greatly throughout the world. In the UK, the key pollutants driving adverse health outcomes are nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$), with 64% of new paediatric asthma cases in urban centres attributed to elevated NO_2 levels (Achakulwisut et al., 2019). The primary source of NO_2 in roadside locations originates from vehicle transport. Yearly net emissions data from road transport is freely available at 1 km resolution from the National Atmospheric Emissions Inventory (NAEI). However, this top-down approach loses the granularity of particular roads and junctions that are emission hot-spots at different times of the day.

Measuring road traffic emissions of NO_2 at high spatial and temporal resolutions is costly and logistically challenging. Here, we develop a cheaper and universally applicable methodology to infer road transport emissions at the resolution of an individual road. We utilise the vast amount of data generated by the widespread use of mapping products to better understand traffic flows on city roads. While the total number of vehicles on a busy road link is relatively static as it is limited by road space and demand, the speed of vehicles on road links is highly variable due to congestion effects. However, this is often not included in traditional air quality models, where vehicles are assumed to be freely flowing at the legal speed limit of the road (e.g. Bright et al., 2013; Zhong et al., 2015). By capturing a real-time estimation of vehicle speed, a more accurate emission factor (g/km) for oxides of nitrogen (NO_x) can be calculated for each vehicle on a road link. Total emissions for a road link are in turn calculated from the emission factor and the number of vehicles using the road link. The subsequent pollutant concentrations that people are exposed to arise from the meteorological, chemical, and physical processing of emissions within the environment. This study focusses on improving the accuracy of traffic-related NO_x emission calculations, while future work will model environmental interactions.

Firstly, the ability of different map platform providers to capture real-time traffic conditions in an isolated study area was assessed. Secondly, the novel methodology was applied to Birmingham's road network to assess the spatial variation of road traffic activity and hence emissions. This work involved automating requests to mapping products to obtain journey times for defined road links at multiple times of the day. To the best knowledge of the authors this methodology of scraping mapping providers for such a purpose has not been reported previously.

Birmingham (UK) was chosen as a representative western city of 1.1m inhabitants (Birmingham City Council, 2018a), with changing policy measures related to air quality emissions from road transport: a Clean Air Zone (CAZ) is due to come into force in mid-2020 to reduce the number of older vehicles known to emit more pollutants (for diesel engines pre Euro 6 standard, petrol engines pre Euro 4 standard) entering the city centre (Birmingham City Council, 2018b). The proposed area to be included within the CAZ is shown in Figure 1 by yellow shading. While this study uses Birmingham as a test-bed, it is important to note that it could be applied to any road network where a mapping platform provides navigational assistance and users feed-back their anonymised location data to the platform.

Study area and data

Crowdsourced real-time traffic data

This study exploits advances made by mapping platforms that integrate real-time traffic information into their algorithms to predict the journey time for a determined route (Google, 2019; Here, 2019; Microsoft, 2018; TomTom, 2019). While the providers historically relied on in-situ traffic measuring equipment at limited sites, they are now able to incorporate data received from the users of the platforms on any road, assuming the correct location settings configuration and user sharing permissions (Dhar and Garg, 2014). When drivers actively use such applications to determine routing information during a journey, their location is periodically fed back into the system to determine their travel speed, which then informs other drivers of the road conditions ahead (Google, 2009). This is known as crowdsourcing as it utilises a large population of users contributing data to a server, which are then anonymised and aggregated to identify useful patterns of traffic. While the raw database is not freely available from such providers on individual trips, by utilising the platforms' Application Programming Interfaces (APIs) it is possible to collect journey time data that is influenced by such patterns for specific road segments at regular intervals.

Road network

Information regarding the road network for the Birmingham area was obtained from the Ordinance Survey Open Roads dataset. The study area covers a total extent of approximately 5 km by 5 km, centred on the city's Central Business District. This area includes both within and outside the proposed CAZ, but it was necessary to limit the spatial extent due to the free usage limits of the mapping platforms. Only major (‘A’ and ‘B’) roads were included in this analysis to balance temporal and spatial resolution given the limitation of the monthly requests to the mapping products. In total, 920 road links were included within the analysis, with an average link length of 71.3 m.

Traffic counts

Traffic counts of vehicle flows were required to provide the total number of vehicles and fleet composition on different parts of the road network. The UK Department for Transport (DfT) conducts manual counting of road traffic volume and composition on selected roads which is freely available for download from their interactive web portal. The data consists of hourly totals between 0700 and 1900 UTC for both traffic flow directions (if applicable), classed by different categories of road traffic: motorbikes, cars and taxis, buses and coaches, light goods vehicles (LGVs) and heavy goods vehicles (HGVs). There are several limitations to be aware of when using this data: not all roads are monitored with this method; field counts are not necessarily conducted every year; and data collected for a specific day is assumed to be representative of an average day for the whole year. However, this is currently the most accessible way to freely obtain the total number of vehicles for a road link and the fleet composition. Therefore, a road link was associated to the nearest available count point and the most recently recorded data for each location was obtained for analysis. We note that that this could be improved by investigating other avenues of data acquisition, but at present this method provides a basis for initial exploration. In total, 87 count points were used, 53 and 34 for A and B roads respectively, where the most recent count data was recorded in October 2017.

Methodology

Collecting real-time traffic data

Before applying this method to all of Birmingham's major road links, it was necessary to test and compare multiple mapping providers with an API; several mapping platforms provide this service, but there is limited information on the algorithms used to generate journey time results. For a one week period in December 2018 four products were tested on a 1.6 km stretch of the A4540 ring road in Birmingham: Google Maps' Distance Matrix API, TomTom's routing API, HERE's routing API, and Bing Maps Routes API. These were chosen due to the availability of an API service that claimed to be updated with real-time traffic information. Each API was queried every 15 minutes for a total of 7 days for the preliminary testing area denoted in Figure 1.

The time taken to travel each road link was obtained by querying a map provider's API. The inputs to the API specify the origin, destination, mode of transport, and typically a 'key' which is unique to the user to enable accountability. Once submitted, a script was returned containing the journey time it would take to travel between the specified origin and destination at the exact time that the request was submitted, due to live traffic influencing the result. This is conceptually akin to the popular use of a mapping application, but by using the API it is scalable to multiple roads and repeatable at different times of the day with only minor adjustment.

The results of the preliminary analysis are shown in Figure 2. As a guideline, the expected time to drive the distance of 1.6 km during free-flow conditions at the speed limit (48 km/h) would be 2 minutes. Bing Maps showed the least variability in predicted journey times, ranging from 5 minutes 24 seconds during peak afternoon rush hour (1700 UTC), to 2 minutes 46 seconds overnight, whilst only updating the traffic-influenced journey time every hour. TomTom, Google, and HERE returned similar journey times to each other with traffic data updated (i.e. reported times changing) between each 15 minute query. All three highlight a peak in morning traffic (0800-0900 UTC) returning journey times of between 4 and 6 minutes, and a larger peak in afternoon traffic (1630-1730 UTC) returning journey times of between 6 and 10 minutes. Throughout the one week period, broadly three phases of traffic flow were shown: a typical weekday (Monday, Tuesday, Wednesday, Friday), weekend (Saturday and Sunday), and the effect of scheduled but infrequent social events (Thursday). On Thursday (December 13, 2018)the measurement period coincided with a local football game held at Birmingham City Football Club, only 0.5 km from the ring road (A4540). The largest journey time reported was by Google Maps at 1700 UTC (17 minutes 40 seconds), corresponding to a travel speed of just 5.5 km/h for the 1.6 km of road sampled. In comparison to a typical weekday, this shows an increase in journey times by a factor of 2. While Bing's performance was limited, the other three products show a potentially great improvement on the current knowledge of traffic flow in comparison to manual counts, both in temporal resolution and extent.

While Bing was ruled out of further analysis, the remaining products were compared by their respective availability of free queries to the platforms. TomTom included 2,500 free transactions per day, HERE allowed 250,000 transactions per month (approximately 8,300 per day), and Google provided 40,000 elements per month (correct as of October 2019). A single API request of one origin-destination pair constitutes one query to the API. Due to the quantity of data that could be obtained by using the HERE platform, this was chosen as the source of journey times for all of Birmingham's major roads.

The technique outlined for the comparative preliminary study above was scaled up and applied to all 920 major road links in a 5 km by 5 km area covering Birmingham City Centre and the A4540 ring-road. This was achieved by generating an individual URL for each road link using the start and end latitude/longitude co-ordinates as the origin and destination fields, the mode of transport was set to “car”, real-time traffic updates were enabled, and the departure time was specified as the time that the script was being submitted. When run, this R script then returned the journey time taken to travel from the start to the end of each link with real-time traffic information influencing the output. This script was then scheduled to run every hour on the hour between 0700 and 1900 UTC to mirror the count data, and would typically take less than 2 minutes to complete. The only restriction on number of calls to the API was the free usage limit. By utilising 12 runs of the script (920 calls in each script) every weekday for a month resulted in a total monthly API call volume of just less than 250,000.

Infer average vehicle speed

Vehicle NO_x emissions are dependent on travel speed due to implications with engine efficiency. Therefore the technique explored here enables the calculation of speed-related vehicle emissions at an hourly resolution. The OS Open Roads dataset also provided the length of each road link. Hence, by using the simple relationship between speed, distance, and time, averaged across each link/segment, it was possible to calculate the average speed of vehicles per road link for every hour. While this doesn’t account for variations in speed within the link, or for an individual’s driving behaviour, it does provide a significant insight into the speed of travel experienced on road links during different periods of the day.

Calculate speed-related emissions

Total emissions are calculated from a combination of an emission factor (g/km) and the activity (veh/hr) on a road link. The NO_x emission factor was obtained from Defra’s speed-related emission function database, which itself is based on the Copert 5 model, but only requires average vehicle speed as an input (NAEI, 2017). The nearest DfT traffic count location to each road link was utilised for vehicle number and fleet composition (number of cars, motorbikes, LGVs, HGVs, and buses/coaches). DfT manual count data for the A38 have previously been compared to private manual counting, alongside data obtained from Automatic Number Plate Recognition cameras. Both total vehicle number and fleet composition from the DfT were found to be in good agreement with the other datasets. As the traffic count data didn't provide information on engine size or Euro class, an urban fleet outside of London was assumed. For passenger cars this resulted in diesel and petrol engines accounting for 45.1% and 48.8% of the fleet respectively, with further disaggregation by engine size and Euro class. Electric vehicles were not included. The speed-related and vehicle-specific emissions factors were then multiplied by the number of vehicles of the respective class to obtain the total NO_x emissions per road link (g/hr).

Results and discussions

In this section a sample of the results will be discussed, compromising data from a typical weekday in October 2019 for an inter-peak period (1200 UTC) and a peak traffic period (1700 UTC). Both vehicle speed and calculated vehicle emissions will be presented for these time periods.

Speeds

Average vehicle speeds for road links across the Birmingham network are shown in Figure 3. It is clear that even during the interpeak period there are a significant number of road links that experience speeds below 10 km/h, namely the A4540 ring road and the A38. The average speed of travel on the A38 ranges from 8.6 km/h at 1200 UTC to 4.8 km/h at 1700 UTC. Similarly, average speed at midday on the A4540 was 11.0 km/h, reducing to 6.9 km/h in the afternoon peak. The slowest speeds (< 1 km/h) recorded at both the interpeak and peak periods occurred on the same road link to the south of the city centre where the A38 and A4540 intersect (Figure 1(c)). This junction is controlled by 4-way traffic lights and is a major interchange for travel into, out of, and around the city centre.

At midday the average speed travelled on A roads was lower (12.7 km/h) than that travelled on B roads (18.7 km/h). Meanwhile during the peak traffic flows at 1700 UTC the average speed of travel on both A and B roads decreased to 8 km/h and 14.9 km/h respectively. This can be seen visually in Figure 3 by the shift from blue road links on the outskirts of the city at 1200 UTC, to orange and red shading at 1700 UTC. This clearly shows the effect of congestion on Birmingham's road links, and highlights the importance of accounting for reduced vehicle speeds during peak travel periods; without which, models could greatly underestimate vehicle emissions on the network.

Emissions

Calculated emissions derived from vehicle speeds determined as outlined above and vehicle data from count locations are shown in Figure 4. To mitigate against visual distortion by very large emissions, the data were split into five equal quantiles for mapping purposes. Missing values on the outer edge of the maps occurred due to the sub-setting of the larger OS Open Roads dataset which disconnected some links from their origins/destinations. Missing values in the city centre were due to the model not being able to appreciate flows in one-way systems. In total, missing values accounted for 0.4% of the total length of roads links measured.

The road link with the slowest speeds was also the road link with the largest emissions at the intersection between the A38 and the A4540 at both peak and off peak times. This is expected as it is known to be a junction where there are a large number of vehicles and stop-start driving behaviour accompanied by short-lived accelerations. Figure 4 highlights that the largest emissions both at peak and off peak times occur at large junctions along the A38 which transects the city centre. This could be explained by the total vehicle flow on this major route, combining with stop-start driving behaviour resulting in inefficient drive cycles. Meanwhile the lowest emissions at 1200 UTC were calculated along a section of the B4126 (Figure 1(e)), and at 1700 UTC the lowest emissions were calculated for a short section of the A45 (Figure 1(f)). Reduced emissions typically occur in the middle of road sections, likely to be due to free-flowing traffic away from the influence of intersections and roundabouts.

Emissions on A roads were found to be more sensitive to congestion effects than on B roads; the difference in emissions calculated between off peak and peak times was larger for A roads. The majority of this difference can be accounted for by a section of the A4540 along the Belgrave Middleway, on the eastern link to the intersection with the A38. Therefore cars travelling in a westerly direction along the A4540 towards the A38 are observed to be most impacted by evening congestion across the network. A traditional approach that simply uses the legal speed limit of a road section would therefore underestimate emissions in these cases, as engines operating at lower speeds with more stop-start behaviour generate greater exhaust emissions.

Conclusions and future work

An innovative approach to generating a vehicle emissions map of Birmingham's roads at hourly intervals has been presented. By utilising mapping platforms that update in real-time due to crowdsourced feedback from users it is possible to obtain an average speed of vehicles along a specified road section. While several API platforms are available, 'HERE' was chosen due to its larger free usage allowance, enabling the scaling of the methodology to all of Birmingham's A and B roads within a 5 km radius of the city centre. A snapshot of the results for one day are presented to highlight the large spatial and temporal differences in emissions throughout the city, which are captured using this new approach, but would be missed by conventional methodologies. In summary: speeds reduce and emissions increase during peak travel times as expected. It has also been possible to identify specific hotspots of emissions, such as the A4540 and A38 intersection to the south of the city centre.

A limitation of this methodology is the fleet composition and volume used from count point locations sporadically located across the study region. However, at the time of analysis this was the most robust available data that could be sourced. Future analysis could address whether there are diurnal, weekly, and seasonal vehicle emission patterns. Furthermore, a sensitivity test could be conducted by comparing the emissions calculated as above by using real-time speed per link, to the emissions generated if all cars were able to travel in free flow at the speed limit of the road link. Additionally, there could be a comparison to emissions generated by following the methodology used for the UK's road transport emissions inventory, including typical average speeds per road type.

The API requests will continue to be automated during the implementation of the Clean Air Zone, enabling a comparison between before and after policy implementation. There is potential that the CAZ will improve vehicle flow on roads within the zone due to a reduced number of vehicles using the network. However this may also shift vehicles to the A4540, resulting in greater congestion and increased journey times away from the city centre. While this methodology is in its infancy, it is clear that it could provide significant insight into real-world vehicle behaviours at the spatial and temporal scales relevant for public health and policy planning. We note that in the future, increasing penetration of electric and hybrid vehicles are likely to reduce at-source tailpipe emissions, but also alter non-exhaust emissions (brake, tyre and road-surface wear, resuspension) all of which also display a significant vehicle speed dependence (Air Quality Expert Group, 2019), necessitating treatments such as that pioneered here.

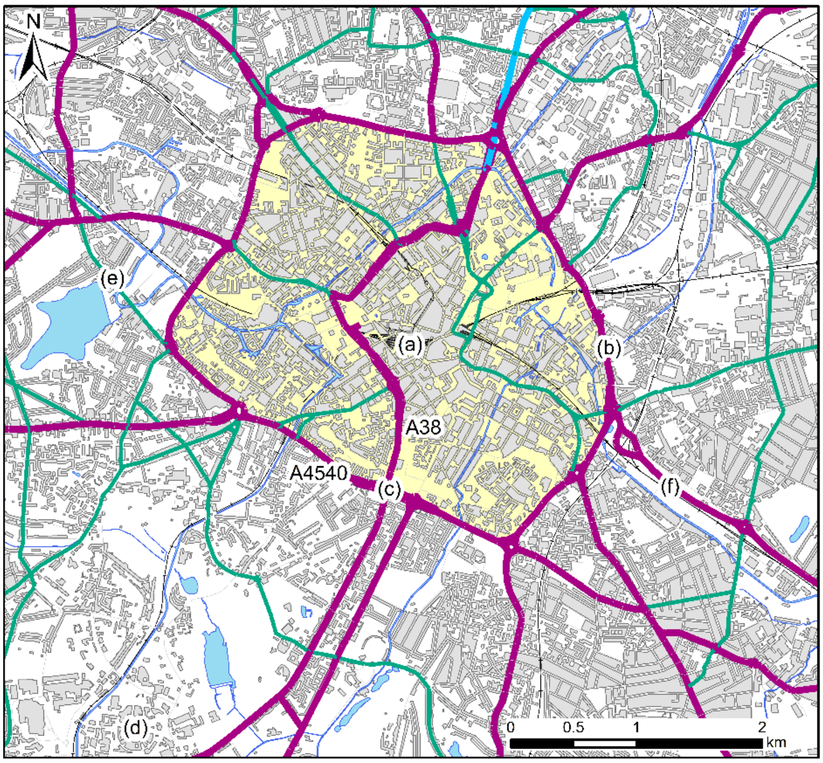


Figure 1 *Map of Birmingham with reference points: New Street Station (city centre) (a), preliminary testing area (b), A38/A4540 cross-roads (c), University of Birmingham (d), B4126 (e), and the A45 (f). A roads are coloured in pink with the A38 and A4540 highlighted, while B roads are coloured in green. Yellow shading indicates the area within the ring-road that will be included within the Clean Air Zone.*

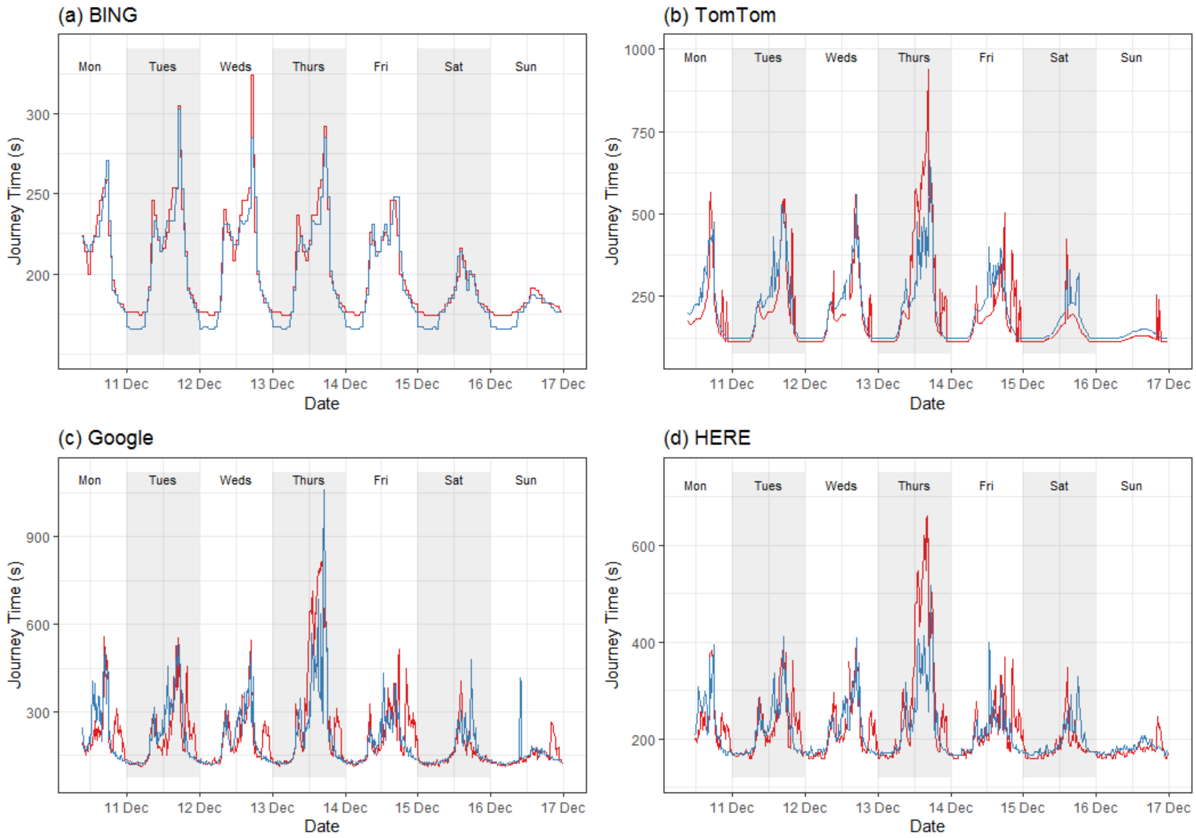


Figure 2 *Comparison of journey times returned by four different mapping platforms: Bing (a), TomTom (b), Google (c), and HERE (d). Data gathered during one week in December for southerly (blue) and northerly (red) vehicle travel for a one mile stretch of A4540 ring road. Note: dates are denoted at 0000 UTC.*

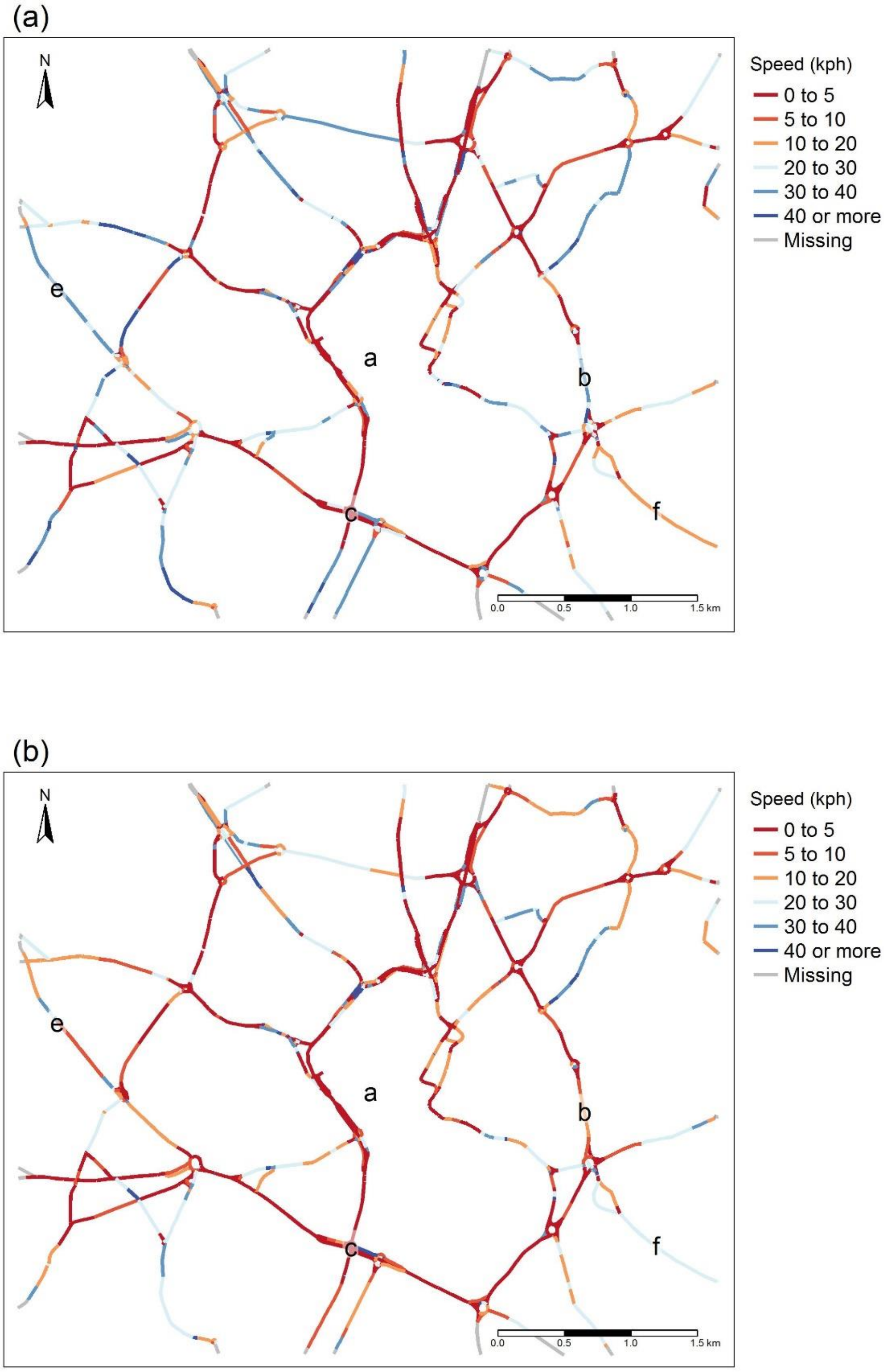
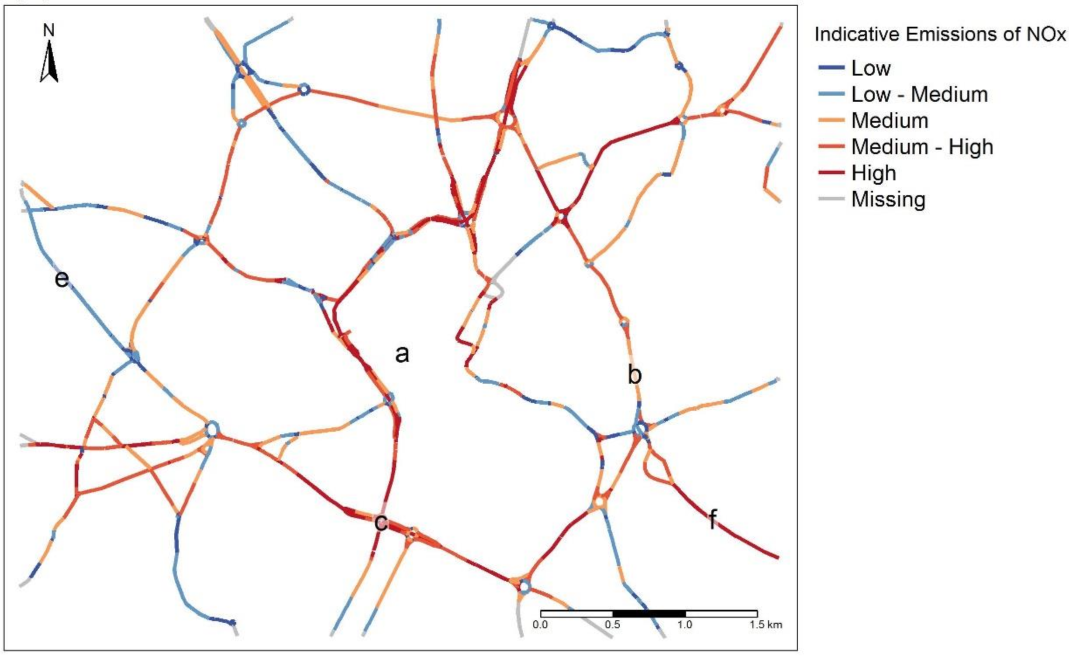


Figure 3 *Example of speeds obtained from HERE API queries on road links across the Birmingham network on October 22 2019 for* ***(a)*** *inter-peak (1200 UTC) period and* ***(b)*** *peak (1700 UTC) period. Within figures, labels refer to the location of reference points: New Street Station (city centre) (a), preliminary testing area (b), A38/A4540 cross-roads (c), University of Birmingham (d) [out of bounds], B4126 (e), and the A45 (f).*

(a)



(b)

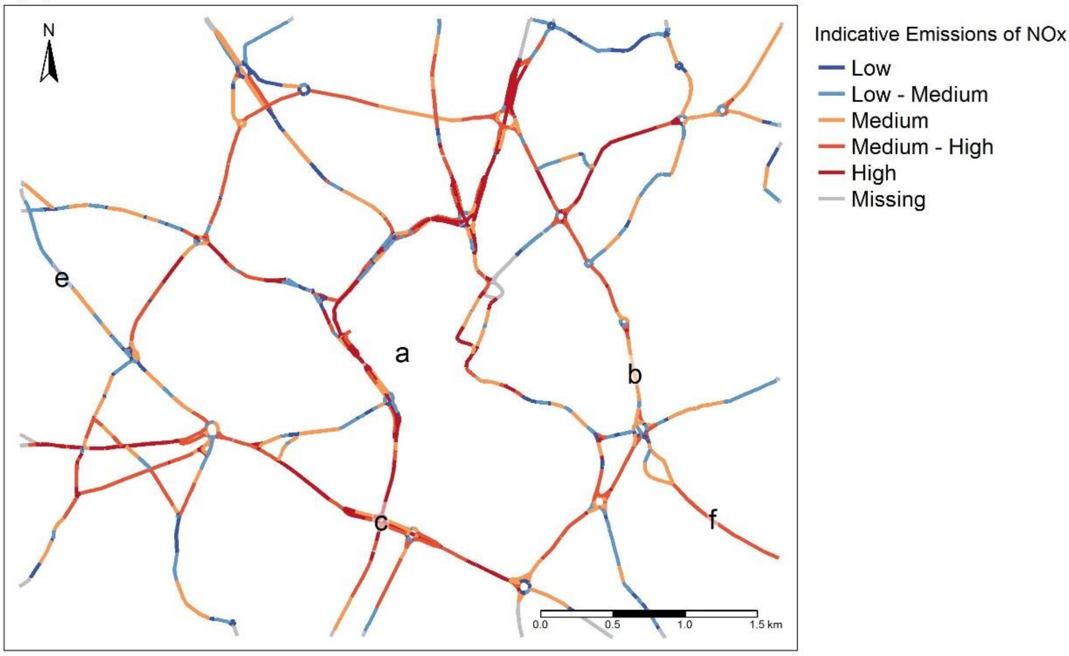


Figure 4 *Example of emissions obtained from HERE API queries on road links across the Birmingham network on October 22 2019 for* ***(a)*** *inter-peak period (1200 UTC) and* ***(b)*** *peak (1700 UTC) period. Within figures, labels refer to the location of reference points: New Street Station (city centre) (a), preliminary testing area (b), A38/A4540 cross-roads (c), University of Birmingham (d) [out of bounds], B4126 (e), and the A45 (f).*

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