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The Low Traffic Neighbourhoods in London: a mixed-methods study of benefits, harms, and experiences

Study details

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Study team

Principal Investigators: Professor Rachel Aldred (to 31st July 2023), Ersilia Verlinghieri (from 1st August 2023), University of Westminster, Dr. Anna Goodman, LSHTM.

Co-Investigators: Dr. Anthony Laverty (Imperial), Dr. James Woodcock (University of Cambridge), Dr Haneen Khreis (University of Cambridge), Dr Ersilia Verlinghieri (University of Westminster, to 31st July 2023), Professor Rachel Aldred (University of Westminster, from 1st August 2023), Associate Professor Philip Edwards (LSHTM), Professor Benedict Armstrong (LSHTM), Ms. Caroline Stickland (Transport for All).

Copyright Statement

Abstract

Background: Car use harms health, the environment, and society. Increasing walking and cycling for short trips, and cutting car use, is a priority for both transport and health planning. Interventions combining 'carrot' (making alternatives to car use more attractive) and 'sticks' (discouraging car use) are needed at a range of spatial scales. One increasingly popular way to do this is through Low Traffic Neighbourhoods, or LTNs. LTNs are transport interventions that substantially reduce motor traffic in a contiguous set of residential streets. From a low baseline, LTNs were implemented rapidly in 2020, as part of the UK's Covid-19 response. London built them fastest and 4% of its population (300,000 people) live in areas covered by the 72 LTNs introduced between March to September 2020.

Methods/Design: This is a mixed-methods study of seven proposed LTNs in six different London boroughs. We will use controlled before-and-after analysis to examine potential harms and benefits of these interventions. During the baseline data collection stage, we collected data on travel behaviour, congestion, and car journey times at our intervention and control sites. A health economic impact assessment will incorporate LTN impacts on physical activity, injuries, and air pollution. Qualitative research will include interviews and focus groups with people living in or near interventions, with a specific focus on disabled people; and with stakeholders implementing schemes. A longitudinal component of the qualitative research will explore how experiences change as LTNs 'bed in'.

Discussion: The study plays an important role in gathering additional evidence about the use of area-wider traffic reduction measures (LTNs). Such interventions are often controversial and while we have found promising results from longer-standing LTNs in Waltham Forest, it is important to have more and better evidence about newer schemes in a range of contexts.

Background

Car use harms health, the environment, and society. In 2019, 30,007 people in London alone were recorded by police as having been injured in road collisions, with 3,780 of those injuries judged serious, and 125 deaths[1]. Motor traffic is a major contributor to air pollution, which causes an estimated 9,500 early deaths in London annually, and tens of thousands across the UK[2]. Traffic noise additionally increases risk of stroke and premature death[3].

Increasing walking and cycling for short trips, and cutting car use, is therefore a priority for both transport and health planning[4]. Interventions combining 'carrot' and 'sticks' are needed at a range of spatial scales[5]. 'Carrots' make alternatives to car use more attractive, while 'sticks' deter driving. One increasingly popular way to do this is through Low Traffic Neighbourhoods, or LTNs, which block through motor traffic in residential streets.

Planned intervention: Low Traffic Neighbourhoods (LTNs)
Rationale: LTNs are transport interventions that remove or substantially reduce through motor traffic from residential streets. This is intended to make active travel safer and more attractive (the 'carrot'), while making driving short trips slightly less convenient (the 'stick'). LTNs can thereby improve health through increasing active travel and hence physical activity; through reducing car use and hence reducing injuries, air pollution, noise pollution, greenhouse gas emissions and sedentary behaviour; and through other pathways such as an increase in play and a reduction in street crime.
Background: LTNs are standard practice in the Netherlands (called 'unbundling'), a planning paradigm linked both to high cycling uptake and high cycling safety. LTNs are more novel in other contexts, but in 2020 were widely implemented including in London, Barcelona, Berlin and New York.
Design: LTNs block motor vehicles using 'modal filters', which may be physical barriers (e.g. planters, bollards) or camera-enforced no entry points (e.g. to accommodate bus routes). All homes can be reached by car, but people cannot drive through the area from one main road to another.
Providers: Transport authorities, in this case the 32 London Boroughs plus City of London.
Scalability: Highly scalable, e.g. 91% of Londoners live on potentially suitable residential roads. Possible to deliver at pace, e.g. 4% of London's population lives in an LTN implemented in March-September 2020. Highly translatable, being planned across the UK and rolled out in cities worldwide.
Cost: Cheap (London built 70+ LTNs, covering 300,000 people for <£5million in 6 months of 2020), and so potentially high value for money.
Unintended consequences: First, the displacement of some motor traffic to boundary roads, which may increase congestion, air pollution and injury risk on those roads. Second, impacts on people who are dependent on cars or taxis to access destinations (e.g. some disabled people). Our research will directly examine both these key potential harms. Follow-on research using secondary data covers impacts including crime and emergency response times.

As a novel intervention (in the UK) LTNs are under-researched. Our own work has provided some initial data about impacts from Waltham Forest, London, which implemented several LTNs between 2015-19. In these LTNs, compared to control sites, we found: an increase of +115 minutes walking and +20 minutes cycling per week after three years[6]; a 7% drop in car/van ownership after three years[7]; approximately a 70% reduction in injury risk for driving, walking and cycling alike[8]; an 18% decline in street crime after three years[9]; and no negative impact on emergency response times[10].

These findings are dramatic compared to other transport interventions. The impacts we found for active travel and can/van ownership were many times larger in LTN areas than in areas receiving other active travel infrastructure such as new cycle tracks. As another comparison point, 20mph speed zones in London have been associated with just over a 20% reduction in injuries[11].

The above research only relates to one London borough, however, which did not have to introduce measures at pace in the context of a national emergency. It is essential to study new LTNs directly, particularly as these are being rolled out rapidly. Between March-Sept 2020, 4% of London's population was covered by new LTNs, and the population coverage may double or more in 2021[12]. Other UK towns and cities are proposing LTN programs. Monitoring and evaluation remain limited, however, with transport authorities using inconsistent methods; typically lacking control groups (a key limitation in identifying impacts of interventions given travel disruptions caused by the pandemic); and often also lacking 'before' data.

Methods

This project is a mixed-methods evaluation of LTNs built in London in 2021-22, incorporating a controlled before-and-after study of potential positive and negative impacts and the health and health economic impacts of these, alongside in-depth qualitative research.

Levels of active travel are one key focus of data collection. We will also assess diversity in active travel, particularly cycling which in the UK has sharp demographic inequalities not found in high-cycling contexts. This will include examining changes in the proportion of children among pedestrians and cyclists. We will examine changes in types of bicycles, e.g., cargo bikes. An 'intercept survey' will allow us to estimate the proportion of any observed increase in walking and/or cycling that is likely to be due to new uptake (change from other travel modes or completely new trips), as opposed to existing pedestrians or cyclists changing the routes they walk or cycle.

We will examine changes in motor vehicle volumes and congestion, including potential negative impacts on boundary roads that may see traffic displacement. We will also examine impacts on congestion and local car journey times, using Google API data to measure typical car journey times along boundary road segments and for car journeys to key local destinations. This strand will assess unintended outcomes and provide evidence on the balance between traffic 'evaporation' (e.g., people walking instead of driving) and displacement (e.g., drivers changing route).

Crucially, our study will provide timeframes for shifting from disruption to a new stability. This is important because directly after LTN implementation some traffic 'chaos' is typical as drivers get to grips with the new layout. This reduces as the scheme 'beds in' but we lack evidence on how quickly this happens and whether boundary road traffic typically ends up higher, lower or unchanged from pre-LTN levels.

We will conduct a health and health economic impact assessment of the interventions. Our primary data (on changes in walking and cycling in intervention areas compared to control areas, and the proportion of any change that is likely to represent increased usage) will be used to model health pathways via physical activity, and hence reduced mortality and absenteeism. For change in injury risk, we will use secondary data (Stats19 police injury data). We will model change in air pollution exposure using both our own data and local authority monitoring data on changes in motor traffic volumes and speeds.

LTNs generate controversy and public scrutiny. It is therefore also crucial to improve our understanding of how and why local communities experience different scheme aspects positively and negatively, including how and why perceptions vary across population groups and schemes. New qualitative research will explore experiences and views of LTNs in London, through interviewing both local residents and the policymakers implementing these schemes. This will contribute to a better understanding of what shapes scheme success and impact, and help determine the elements that can facilitate transferability and scalability whilst minimising controversy and unintended consequences. We will use a portfolio of qualitative methods including go-along interviews with residents, focus groups conducting accessibility audits, video ethnography, and stakeholder interviews. The qualitative research draws on the expertise of our PPI co-applicant and partner Transport for All.

Research Questions

To be answered through quantitative research, building on already collected baseline primary data

In London, what is the impact of introducing LTNs on the following outcomes, as compared to matched control streets or areas (selected as described in Sections 4.4 and 4.5 below):

RQ1. Volume of active travel (walking and cycling) inside LTNs. We will also estimate how motor vehicle volumes change, and how much of any increase in active travel seen inside LTNs is mode shift from cars.

RQ2. Diversity of active travel users inside LTNs, including by age group, gender, and use of mobility aids.

RQ3. Congestion on LTN boundaries. What is the impact soon after scheme implementation, and how does this change over time as the LTN 'beds in'?

RQ4. Journey times to a range of destinations by car, and relative speed of car versus active travel trips, for people living in or near to LTNs.

RQ5. Health and health economic impact of LTNs. Our primary data will be used to model health pathways via physical activity, and hence reduced mortality and absenteeism. For change in injury risk we will use secondary data (Stats19). We will model change in air pollution exposure using both our own data and local authority monitoring data on changes in motor traffic volumes and speeds.

To be answered through new qualitative research

RQ6. What is the **lived experience** of LTNs for those living inside or on the boundary of new schemes? What general or specific scheme elements elicit positive and negative reactions?

RQ7. How can we make LTNs **more inclusive**, including for disabled people?

RQ8. What do **local policymakers** perceive as the barriers and enablers to successfully and equitably implementing LTNs?

Study Design

Our evaluation will treat our seven study LTNs as a natural experiment and make controlled before and-after comparisons to matched control areas in the same borough where no substantial transport intervention is planned.

For our primary active travel related outcomes, our intervention group is streets that are key travel desire lines inside LTNs, with a comparison group of similar matched streets in control areas. For outcomes related to changes in congestion, we are comparing 'boundary roads' which might see increased motor traffic if traffic is displaced from LTNs, near both LTN and control areas. For changes in car journey times, we are comparing journeys to key local destinations in and around LTNs and matched control areas.

Sampling LTNs

Our primary sampling unit is the LTN, and during the baseline data collection phase we sampled seven schemes in six London boroughs. Planning and implementing schemes is challenging and initial lists of planned schemes do not always materialise. We therefore did not randomly sample LTNs but purposively selected schemes that we were confident will happen within our data collection timeframe, deciding to choose seven rather than our originally planned six as additional risk mitigation. Our selection was based on the borough's past performance, current resources, and information from borough officers.

Control areas were selected and matched to each of the LTNs. As controls, we identified for each LTN a similar sized area in the same borough that would in principle be amenable to LTN treatments, but which was not in practice due to receive an LTN or any other major transport intervention. We guarded against spill-over effects by ensuring that control areas were not immediately adjoining intervention areas, and nor did they form part of the same active travel desire lines. We tried to ensure that key destinations were similarly present or absent, e.g., where there was a school inside an LTN area we looked for a control area which had a school.

We matched LTN and control areas based on a range of characteristics, for instance, car ownership levels and cycling (using 2011 Census data on cycle commute mode share). Baseline travel patterns may shape intervention impacts in different directions: for instance, areas with currently higher cycling levels may have less 'suppressed demand' for cycling but conversely more supportive cultural contexts. Our qualitative research will explore such factors further, through interviews with stakeholders implementing schemes, and with residents of LTN areas. Our intervention and control areas and streets were closely matched on demographics and travel patterns, and both tended to be more characteristic of Inner than Outer London demographic and travel patterns. This reflected both the types of borough and types of areas within boroughs where LTNs were being implemented at this time (e.g., generally lower car ownership than London or borough averages).

We also matched control and LTN areas based on the street network characteristics and as far as we could ascertain (data not being available), on traffic volumes (walking, cycling, and motor traffic). Our baseline data collected after site selection confirmed that traffic volumes were indeed similar when comparing LTN and control street segments (e.g., active travel mode share).

Sampling desire lines and boundary roads

An LTN is typically small, covering a few thousand residents. Within each selected LTN and control area, we chose two 'inside LTN' intervention points that were on separate travel desire lines (e.g., avoiding already quiet cul-de-sacs). These 14 + 14 points (two LTN and two control sites per LTN) provide a comparison between streets that should register a change in active travel if the LTN does indeed have this effect, with changes in sites with similar characteristics within the same borough (to separate any changes that are due to the LTN from changes that would have happened without it).

We defined boundary roads for LTN and control sites in order to measure changes in congestion that might be due to displaced traffic. We defined boundary roads as being a nearby set of external roads most likely to see an increase in displaced traffic from an LTN, should such traffic displacement happen. In many cases, this was straightforward and entailed selecting the roads surrounding an 'LTN cell' that literally formed a boundary to it. However, this was not always the case because of road network or other characteristics, e.g., a railway line that severed connections to the wider street network on one side, or one-way roads that implied different displacement routes for those travelling in different directions. In such cases, this meant that those defined boundary roads were not always immediately adjacent to the LTN or control site.

Data collection: Vivacity sensors

Any rapid research design must be resilient to Covid-19 restrictions. These were tightened since our initial contact with NIHR, and during our baseline data collection the Department for Transport was currently advising local authorities not to conduct manual in-person counts of travel patterns. We therefore decided instead that, at each of our 28 measurement sites, we would with borough permission install a 'Vivacity' sensor on a lamppost. These sensors film the streets and use artificial intelligence in the sensor itself to classify street users into different modes of transport, also recording their location on footway or carriageway, and traffic speeds. Because this data is analysed in the sensor itself, only anonymous data is generated to the user. The Vivacity sensors record 24/7, providing much richer data and much greater statistical power than (as originally planned) a limited number of 12-hour manual counts.

To generate pedestrian and cyclist diversity metrics (e.g., apparent gender of people cycling), we will be using manual classification of additional measures of interest, using pixelated video separately recorded at the sensor sites (the Vivacity sensors do not record video). We developed classification protocols and established inter-rater reliability, at which point we found that it was not possible reliably to identify older adults (65+) but that other categories (e.g. apparent gender, children versus adults, children's independent mobility) were sufficiently robust. During baseline data collection we recorded and classified four days of footage at all 28 sites (Wed/Thu/Fri/Sat, 7am-7pm).

Data outcomes

Research question	Outcome	Method	Frequency	Where captured?
RQ1, RQ5	Number of pedestrians and cyclists	Vivacity sensors	Continuous	Inside LTNs and control areas
RQ1	Number of (i) cars/taxis; (ii) motorcycles; (iii) vans; (iv) trucks.	Vivacity sensors	Continuous	Inside LTNs and control areas
RQ1, RQ5	Estimated new pedestrian and cycle trips generated, and trips switched from motor vehicle	Vivacity sensors & route user intercept surveys	One-off (2023)	Inside LTNs and control areas
RQ2	Active travel diversity 1: % pedestrians using wheelchairs or mobility scooters.	Vivacity sensors	Annual	Inside LTNs and control areas
RQ2, RQ5	Active travel diversity 2: % female cyclists	Video data	Annual	Inside LTNs and control areas
RQ2, RQ5	Active travel diversity 3: % (i) pedestrians and (ii) cyclists who are children	Video data	Annual	Inside LTNs and control areas
RQ2	Active travel diversity 4: % children (i) walking or (ii) cycling without an adult	Video data	Annual	Inside LTNs and control areas
RQ3, RQ5	Motor vehicle congestion defined through live-traffic journey times	Google API	Continuous	LTN and control boundary roads
RQ4	Journey time by car to a range of local and more distant services. Relative speed of cars versus active travel for local trips.	Google API	Annual	In and around LTNs and control areas
RQ5	Change in a) number of road injuries and b) risk per trip (using data from LTNs across London to increase power).	Stats19 police injury data [secondary data]	Continuous	Inside LTNs and LTN boundary roads. London-wide control data.
RQ5	Change in motor vehicle volumes in and around LTNs (London-wide background data from similar roads as control group).	Vivacity sensors + local authority monitoring data [secondary data]	One-off (2022/23)	Inside LTNs and LTN boundary roads. London-wide control data.

Primary data collection 1: Vivacity sensor data on active travel volumes

Levels of active travel have been an important focus of our baseline primary data collection. This is because active travel is a) likely to be the pathway for the largest health impacts, through increased physical activity and b) not collected in spatially detailed secondary datasets, and neither is it usually the focus of local authority monitoring. To measure active travel, we installed a Vivacity sensor on each observation point inside LTNs and control areas. These sensors film the streets and use artificial intelligence to classify street users into detailed modes (e.g., pedestrian, bicycle, car, van etc). They will collect data continuously until July 2024 (5 LTNs)/October 2024 (2 LTNs).

Primary data collection 2: Active travel diversity and independent mobility

Using Vivacity sensor data, we will examine scheme impacts on the number of people using wheelchairs and mobility scooters. This will provide one measure of how LTNs affect some disabled people's mobility. The sensors do not, however, measure other important facets of active travel diversity. We therefore wish to understand LTN impacts on cycling diversity by age and gender, as well as on total cycling volume. We also wish to examine whether LTNs affect the opportunities that children have to be physically active and independent of adults in how they travel. We will therefore record apparent age group, gender and whether a child is accompanied by an adult for pedestrians and cyclists on an annual basis. We will use pixelated footage from video cameras located on the same lampposts as the Vivacity sensors, which will then be manually coded by a human. We have developed a classification protocol with a specialist subcontractor, to code age group (adult versus younger or older children), gender (male, female, unknown), and independent mobility for those aged 4-16 (alone, only with other children, with an adult). **We will repeat this exercise – collecting four-days' worth of data at each of the 28 sensor sites – in 2022, 2023 and 2024.**

Primary data collection 3: Congestion on boundary roads and car journey times

We are measuring two possible adverse impacts through primary quantitative data collection. First, we will measure changes in congestion on boundary roads. Increases would represent a negative outcome, with residents and users of those roads facing reduced amenity and increased pollution. Second, we will measure car journey times to a set of key local and less local destinations. Modest increases in journey time can be a pathway for positive scheme impacts, through discouraging car use. Very large increases and/or high journey time variability could be a cause of concern, however, for example through their impact on some disabled people who rely on cars to access destinations.

We will use Google API real-time journey data to measure changes to journey time or journey time variability by car on segments of LTN and control site boundary roads. For each journey, Google estimates the duration in seconds given live traffic conditions. In combination with the distance in metres, this gives average speed along a road segment. This 'live traffic' data can only be purchased to query in real-time – i.e. it requires prospective primary collection, as done in this study at baseline.

Speed changes will be used as a proxy for congestion on LTN boundary roads. The measurements will be used to assess changes in congestion including providing timeframes for changes in travel behaviour stabilising. Timeframes are important because any initial acute congestion is expected to reduce as schemes 'bed in', but we lack evidence on how fast this happens and whether boundary road congestion typically ends up higher, lower, or unchanged from pre-LTN levels.

To collect this data, we have divided boundary roads (for both LTN and control sites) into segments between junctions/nodes, aiming for lengths of around 250m to 500m. Each segment is treated as a separate short journey, with a separate journey in each direction on two-way roads. In total, the LTN and control boundary roads are described by 149 of these short journeys. We then use Google API to route each of these journeys by car 30 times each week on Tuesdays (N=24 measurements across the day) and Saturdays (N=6 measurements from 10:00-15:00, this being the weekend period with the most car driving trips in London in the National Travel Survey 2017-19).

We started collecting this Google API data in June 2021 and will continue to do so continuously – every Tuesday and Saturday – until October 2024.

We are using Google API to quantify the increased journey times faced by local car drivers. To collect this data, we have taken a random selection of 10 census output area centroids inside each LTN/control area plus 10 centroids outside the areas but <500m from the boundary. For each centroid, we selected the nearest destination (by straight line distance) of the following types:

- Very local destinations: Doctor's surgeries, Primary schools, Convenience stores and independent supermarkets, Post offices.
- Additional destinations: Supermarket chains, Accident & Emergency hospitals, Shopping centres and retail parks, Vets and animal hospitals, Recycling centres, Hospices.

These destinations were identified from Ordnance Survey's Points of Interest database, except the schools which were identified from Edubase. The four very local destinations correspond to those used in the Index of Multiple Deprivation 'Geographical Barriers' sub-domain. The additional destinations were chosen as a) frequently involving somewhat longer distances and b) involving trip purposes that may be harder to shift to non-car modes. The result is 14 LTN/control areas * 20 origins * 10 destinations * 2 directions = 5600 journeys. We will use Google API to route each of these journeys by car every Tuesday (at 08:30, 13:00, 17:30) and Saturday (at 13:00). For each journey, Google estimates the duration in seconds given live traffic conditions. We will examine how the average duration and/or variability of journeys changes in LTN areas versus control areas.

Each journey has also been routed once by foot and by bicycle (only once per year, as Google active travel routing is not sensitive to time of day or live traffic conditions). We will use this to assess the extent to which active travel journey speeds for local trips become more competitive with car speeds, once LTNs are introduced.

We collected this Google API data for 5 LTNs in June 2021 and will do so for the other 2 in September 2021. We will repeat this for the corresponding period in June/September 2022, 2023 and 2024.

Primary data collection 4: route user intercept surveys

During June/September 2023, we will conduct route user intercept surveys in LTN areas only. We will use an adapted version of a standard Department for Transport questionnaire, previously used to evaluate several national sustainable transport investment programmes. Surveyors will ask all passers-by to fill in the questionnaire in person or afterwards online (using cards with unique survey codes and offering a range of community languages). They will stand at our 14 observation points inside LTNs for four days (weekday and weekend) between 7am-7pm, surveying people walking and cycling. Key questions are:

- Would the respondent have made this trip if the LTN did not exist?
- If so, would they have used the same or a different mode of transport? And would they have used the same or a different route?

These responses, in combination with sensor data, will allow us to estimate the proportion of active travel uplift that comes from *new active travel trips* versus active travel trips that would have been made anyway but have *diverted their route* through the LTN[d]. This will inform how much walking and cycling we assume to reflect additional physical activity in our health impact modelling. It will also allow us to estimate the extent of mode shift away from cars.

Health and Health Economic Modelling

We will conduct a health economic evaluation, estimating impacts via the pathways of physical activity, road traffic injuries, and air pollution.

Physical activity: We will use sensor data to estimate the absolute change in the number of walking and cycling trips within the LTNs and will use the route user intercept data to estimate the proportion of the uplift that comes from new active travel trips (as opposed to trips diverted from a different route). This measured absolute change in walking and cycling trips will be an underestimate because we are only capturing trips on selected roads within the LTN but will provide a minimum health economic benefit. Trip distance distributions will be estimated using data from the London Travel Demand Survey. We will use our coded video data and our intercept surveys to estimate age group and gender, and this will be included in the health impact calculations. We will estimate impacts on premature mortality (years of life lost) and sickness absence and monetise these using Department for Transport (DfT) 'TAG' methods. Our team contributed to the development of these methods for DfT and have experience of improving upon them when more detailed data are available, e.g., by including local authority level mortality.

Injuries: We will use police recorded Stats19 injury data. We will estimate how numbers of fatal and serious injuries change inside LTN areas and on LTN boundary roads after implementation of schemes, controlling for background trends on similar roads elsewhere in London. For this, we will adapt methods we have previously used to quantify the effects on road traffic injuries of interventions involving street-lighting and 20mph zones. We will conduct this analysis for all ≈120 LTNs implemented in London in 2020 and 2021, to increase study power and generalisability. We will estimate changes stratified by mode (walk, cycle, car, other). We will quantify the health economic impact of changes in injury numbers using standard DfT methods. We will also draw on our sensor data to comment on likely changes in injury risk per trip. We will analyse how extending LTNs to all potentially suitable London neighbourhoods (using Transport for London analysis identifying future LTN areas) would contribute to injury reduction targets.

Air pollution: We will subcontract elements of air pollution modelling to Cambridge Environmental Research Consultants Ltd (CERC), a group that has already conducted such modelling in relation to 2020 LTNs for the London boroughs of Lambeth and Southwark. CERC will use their comprehensive urban air quality modelling software 'ADMS-Urban', to provide detailed street-level estimates of hourly and annual NOx, NO2 and PM2.5 concentrations (the air pollutants for which long-term exposure is most closely associated with health harm). A London-wide model will be set-up to estimate baseline hourly and annual air pollution in 2021, using emissions data from London Atmospheric Emissions Inventory and detailed scheme area traffic flows, alongside meteorological and regional pollution inputs. This pre-scheme implementation baseline will be verified against 2021 air quality monitoring, both using hourly and annual averages, to provide confidence in subsequent estimates of scheme impacts. This model set-up and validation will be verified by the study team.

CERC will estimate post-scheme changes in air pollution for roads inside and around LTNs, based on a) our sensor data plus local authority monitoring data on changes in traffic volumes and speeds, supplemented by b) our Google congestion data on boundary roads. All the local authorities we are working with are planning to measure LTN impacts on traffic volumes using before-and-after data from automatic traffic counters placed on a variety of roads inside and around their schemes. We will collate this data for use by CERC. Based on changes in modelled hourly and annual average of NOx, NO2 and PM2.5 concentrations, CERC will calculate local mortality burdens from air pollution both before and after scheme implementation. This will follow Public Health England guidance.

We will additionally incorporate the source exposure- response functions for traffic-related air pollution and premature mortality that and childhood asthma onset, which the Health Effects Institute of Boston is due to publish in 2022. Those functions will represent the latest and most inclusive functions and are more specific to traffic-related air pollution. We will also search the literature for exposure response functions relating the modelled pollutants to asthma exacerbation outcomes. We will quantify the health impacts in terms of changes in years of life lost, new cases of childhood asthma, and exacerbations of pre-existing asthma, all stratified by ethnicity and socio-economic status (measured at the output area level, population ≈300 people). The pre-/post scheme impacts on air pollution by hour will also be useful to examine whether there are air quality benefits or harms at particular times of day (e.g., during the school run) that might be masked by the annual average.

Data and statistical analysis

In our matched design we will initially stratify analyses by LTN-control pair. We will then use multi-level meta-regression models to pool results across LTN-control pairs.

For active travel data, we will aggregate sensor data to provide daily totals, e.g. bicycles per day, for each site. We will seek to conduct an interrupted time series (ITS) analysis separately for each LTN site, assuming necessary assumptions are met (e.g. a sufficient volume of 'before' data). We will then seek to create a single model - a controlled ITS - for each pair of LTN-control sites, with the difference between the sites as the outcome. We will have most confidence in our findings if an impact is seen in both ITS analysis for the LTN site and in controlled ITS analysis. In estimating before-after change, we will examine impacts according to the number of months since LTN implementation, allowing us to examine how impacts unfold as the LTN 'beds in'. We will adjust for weekday/weekend, holidays, calendar month, time trend, volume of precipitation, and mean daily temperature. A similar approach will be used to examine how congestion impacts unfold over time.

Our Vivacity sensors will collect data 24/7 for 38 months, giving very high statistical power. For example, the median cycling volume at baseline was 4600 cycles per LTN or control site per week, range 750 to 10,700. Even for the lowest-cycling LTN site, a weekly sample size of 750 gives 90% power to detect an 8% pre-post difference in the first month of follow-up. This is smaller than the median difference of +69% (range 14%-91%) that has been reported in borough monitoring data, and power will increase further if we pool months of follow-up. The high granularity and high statistical power will allow us to conduct detailed complementary analysis e.g. by time of day.

For annually-collected outcomes we will use linear and logistic regression, initially stratifying by LTN- control pair and then pooling results using multi-level models. The outcome will be measures of active travel diversity (binary) and car journey times (continuous). Among the predictors, we will fit an interaction term between pre/post status (e.g., 2022 versus 2021) and LTN/control status, taking a statistically significant interaction as evidence of an intervention effect. Statistical power is lower but sufficient. For example, in the lowest-cycling LTN site, we would have 90% power to detect a change from 10% to 18% of cyclists being children[f] This is large but is not impossible, given that we have previously estimated a 3-fold increase in cycling to school at one existing LTN. Across 7 sites pooled we would have 90% power to detect a change from 10% to 11%.

We will examine impacts on road traffic injuries using conditional Poisson models applied to events (road injuries) for every individual road segment across new LTNs, with 'road injuries per km of road' as the outcome and controlling for background trends on similar roads across London[11]. This gives 90% power to detect a 26% change in cycling injuries inside LTNs and a 13% change on boundary roads. For other modes power is similar or higher. Inside LTNs, such an effect is large but credible, being smaller than the 65% decrease in total cycle injuries (including slight injuries) observed in the Waltham Forest LTNs.

Qualitative data collection and analysis

Qualitative analysis, and in-depth participatory methods, can uncover factors influencing perceptions and use of an intervention that may be invisible to quantitative analysis. Our qualitative data will complement the quantitative evidence, including considering how design and implementation processes and scheme characteristics affect people's reactions to a scheme. Additionally, we will study stakeholders' motivations and experiences to further generate knowledge about scalability and transferability, e.g., by understanding why specific areas were chosen, what influences perceived 'success' and 'challenges' from a stakeholder perspective, and lessons for future interventions.

*RQ6: What is the **lived experience** of LTNs for those living inside or on the boundary of new schemes? What general or specific scheme elements elicit positive and negative reactions?*

In answering RQ6, we will seek a diverse set of perspectives on the schemes. We will draw our sample equally from residents living inside LTNs and residents on boundary roads, both of which groups may experience negative or positive impacts. We will prioritise voices less often heard in media debates or online discussions, including disabled residents (see RQ7), and the majority without strong views for or against. Primarily in-situ methods will enable us to explore concrete issues and experiences, rather than abstract views, and examine how people interact with schemes on a micro level.

We will initially purposively sample four of our seven LTNs, using planning, design, and early usage criteria developed by the qualitative and PPI co-leads with our study steering committee by April 2022. This will permit us to focus qualitative resources on an in-depth study of a subset of LTNs chosen to have diverse characteristics of interest.

In each of those four selected LTNs, we will: (i) recruit around 10 participants living inside the LTN, with a mix of demographics (e.g. by ethnic and age groups) and attitudes to the LTN; (ii) recruit around 10 participants living on LTN boundary roads, with a mix of demographics and attitudes. These two samples will come from those responding to leaflets delivered to addresses on boundary roads and in LTNs. We will seek to interview each recruited individual in Spring-Summer 2022 (around 80 interviews) and again in 2023. Thus, we will be able to explore LTNs bedding- in, experiences shifting, and individuals changing behaviour. This will generate rich layered data about how a controversial and hyper-local intervention affects people's lives over time.

In line with our focus on local travel and local places, interviews will take the form of a 'go-along' where we invite participants to walk or wheel with us along a route or section of route that they habitually travel (that travel could be by any type of transport), taking in the LTN and/or the boundary road. If they usually travel with others, we will encourage them to bring along the companion/s that they would normally make the journey with, allowing discussion of shared travel experiences. Go- along interviews are now an established research method and unique way to explore social life and responses to place, complementing other qualitative and quantitative approaches.

Building on the findings from the qualitative and quantitative data, in the final phase of the project we will also hold 3-5 virtual or in-person focus groups with those supportive, oppositional, and with less strongly held views, reporting back some of our findings and inviting them to comment and add additional insights. The focus groups will deepen our understanding of why people oppose, support, and/or feel more or less affected by LTNs".

*RQ7: How can we make LTNs more **inclusive**, including for disabled people?*

Interviewees in RQ6 will be selected to be demographically diverse (e.g. by ethnicity) and hence we will have begun through that work to answer RQ7. We will further explore inclusion and diversity through two more targeted and in-depth participatory methods: a) in-situ and virtual focus groups; and b) video ethnography. We will do this further work in 2023 after schemes have bedded in and we have completed and analysed our first wave of qualitative resident interviews.

First, we will recruit disabled people on a pan-impairment basis as participants in focus groups exploring the accessibility of the four sampled LTNs. This will be led by Transport for All, our PPI co- applicant and qualitative co-lead. As with RQ6, we will recruit by leafleting homes in the LTNs and on boundary roads - this time in March 2023 and specifically seeking disabled respondents who will participate in the groups. These will involve a walk/wheel around tour to explore street features and how they affect respondents, in the form of a street audit.80,81 By eliciting interaction and discussion, these groups will generate rich information around disabled people's shared or divergent experiences.

Up to 4 virtual groups will take place later in 2023 and in early 2024, recorded on MS Teams. These will build on and respond to findings from in-situ groups, involving Deaf and Disabled People's Organisations and/or advocates and local stakeholders. These groups will include facilitators sharing audio-described video material and images or information collected during in-person groups. The discussion will aim at enabling participants from a diverse range of backgrounds and disabilities to suggest how they think LTN-type interventions might work better, or problems be mitigated.

We will also conduct observational/ethnographic research at the four selected LTN sites, examining the extent to which the interventions may be associated with changes to street usage. Like the diversity analysis, this will primarily use anonymised video camera data (including one 'pre' and one 'post' year for each site), complemented by ethnographic field notes from the go-along interviews. This ethnographic research will capture elements that the quantitative data cannot explore, such as socialising and children's play. This will enable us to reflect on how the meaning and use of public space may change when new interventions are introduced and will enrich our answers to both RQ6 and RQ7. Originally, participative pop-up events were instead proposed to explore possible qualitative changes in uses of street space but this was changed due to safety concerns expressed by local authority partners.

RQ8: What do local policymakers perceive as the barriers and enablers to successfully and equitably implementing LTNs?

To address RQ8, we will interview at least twelve stakeholders from our six study boroughs. These will cover, in each borough, a) the councillor (portfolio holder) and b) the lead local authority transport officer with responsibility for introducing the 7 LTNs in our study. We are already in touch with such stakeholders through the arrangements we have made for baseline data collection in their boroughs. These interviews will focus on governance processes and challenges behind the implementation, what shaped decisions, and what policymakers see as necessary and sufficient conditions for effective and equitable scheme implementation. This will further support analysis of the scalability of LTN-type interventions, by examining perceived success factors as well as barriers that stakeholders understand as affecting such schemes. Using our Stakeholder Network to source interviewees, we will also conduct 12 interviews with portfolio holders and lead officers from authorities from outside London implementing similar schemes, in a range of contexts (e.g., small and large urban). We will seek to interview the same 24 stakeholders in both 2022 and in 2023, to gather reflections on change, including how far the various schemes are perceived to have 'bedded-in' after another year.

Qualitative Data Analysis

The focus groups, stakeholder and go-along interviews will be recorded, transcribed, and analysed using a computer-aided qualitative data analysis program such as NVivo, alongside fieldnotes and multimedia data from the pop-up events. We will use a grounded theory approach and a mixture of deductive and inductive coding, using some themes that the limited amount of existing research suggests may be important (e.g., degree of prior consultation, perceived equity) and allowing others to emerge from transcripts and field notes. Double coding and checking will allow team members to feed in and ensure our analysis is valid and adequately reflects user experiences and views.

Equality, Diversity, Inclusion and Inequalities

Our quantitative research will examine the impact of LTNs on some elements of active travel equity (e.g. age, gender, use of mobility aids) and examine the time penalty that LTNs may impose on car- dependent disabled people. Our quantitative analyses primarily use observational data (via sensors and cameras), but we will recruit human participants for our route user intercept surveys. Co-applicant Transport for All will advise on ensuring these are accessibly designed. We will translate this and other web surveys into community languages common in study sites.

We will further address equity through qualitative research. We will interview local authority stakeholders (who have duties to conduct equality impact assessments) and residents, whom we will select to ensure a range of views and characteristics. Disability representation is a main focus, but we will also incorporate other equality dimensions. For instance, in our study LTN areas 40% of residents are non-white, and this will be our target for participants. We have budgeted for items to widen participation in interviews, such as British Sign Language and other interpreters, and support workers; and we will pay for participants' time. We will involve local community groups in planning our pop-up events to ensure these reflect the diversity of the areas. As co-applicants and PPI leads, Transport for All will advise, assist and challenge the research team and our subcontractors to ensure the research is conducted in an accessible and equitable way. As part of our ongoing work to disseminate findings and achieve impact, Transport for All will in 2024 organise an event focused on LTNs, inclusion and equity.

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