Road Traffic Injuries and LTNs: Statistical Analysis Plan

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Study aim

The aim of this work is to quantify the impacts of new Low Traffic Neighbourhoods (LTNs) in Greater London on road traffic injuries a) within their boundaries and b) on their boundary roads. This study forms part of the wider 'LTNs in London' project, funded by the NIHR.[4]

Methodology

Defining LTNs

The first task was to determine a set of rules regarding what we consider to be an LTN in Greater London, and how to define the area considered inside the LTN as well as the boundary roads outside of the area. While the majority of LTNs have been implemented since March 2020, we also include in this analysis the LTNs that were implemented between 2015 and 2019 in Waltham Forest as part of the 'Mini-Hollands' programme. This is the only programme that we are aware of that created LTNs in London between 2012 and 2019.

For a scheme to be considered an LTN, it must be sufficient in scope/extent, such that it limits through motor traffic from more than just one or two roads. In short, it should be an area-wide scheme that restricts through-traffic (typically, through filtered permeability), usually in the form of planters, bollards, or Automatic Number Plate Recognition (ANPR) cameras. An area with substantial traffic calming but that does not filter motor vehicles would not meet the criteria. In principle, the area-wide definition means that most of our examples of LTNs have more than one or two modal filters. For example, we would not consider an area an LTN that has one modal filter to create a permanent School Street or a single, pedestrianised shopping street.

There are some examples of what we might call 'edge cases' – areas that are more ambiguous in whether they meet the criteria for an LTN. The first case is where there are substantial exemptions, such that many motor vehicles can still travel through the area without any restrictions. One example is the South Fulham Clean Air Neighbourhood, where residents who live within the Hammersmith and Fulham borough are exempt, such that restrictions only apply to those driving motor vehicles who live outside of the borough. While not in the 'spirit' of an LTN, we have retained these schemes in our analysis, as we might still expect there to be a reduction in motor vehicles, and because it satisfies the area-wide criterion. The second edge cases are where there are timed modal filters i.e. the restrictions are not in place 24 hours a day. Hackney's Stoke Newington LTN is such an example where motor vehicles are restricted on Church Street between 7am and 7pm. We have retained these cases as study LTNs if a) the modal filters are operational for at least 30 hours per

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[4] https://www.westminster.ac.uk/research/groups-and-centres/transport-and-mobilities-research-group/projects/low-traffic-neighbourhoods-in-london-research-study

week, and b) the operating hours are concentrated on times of the day and week that are expected to have a large proportion of through-traffic (e.g. peak times).

After determining the LTNs that would be a part of this analysis, we were then required to determine the extent of the LTNs – in other words, which roads, and thereby associated injuries, are considered inside of an LTN. For all of our research conducted as part of the NIHR 'LTNs in London' study, we have followed a set of rules outlined in Appendix 1.

Defining boundary roads

A key aim of this study is to examine the effects of LTN implementation on road traffic injuries on LTN boundary roads. We chose to focus specifically on immediately adjacent boundary roads because we expect these to be most likely to experience any diversion of through-traffic. We therefore defined boundary roads in terms of the nearest external road to each LTN scheme which might in principle experience traffic displacement. This follows on from the definition employed by Thomas and Aldred (2024). While most boundary roads are A or B roads (major roads), we do not specify that this must be the case. In some cases, we might anticipate that through traffic could divert onto a closer minor road, in which case this road is considered the boundary. In cases where the closest boundary road is one-way but there is a nearby road that traffic in the opposite direction might plausibly be displaced onto both roads are included as boundary roads.

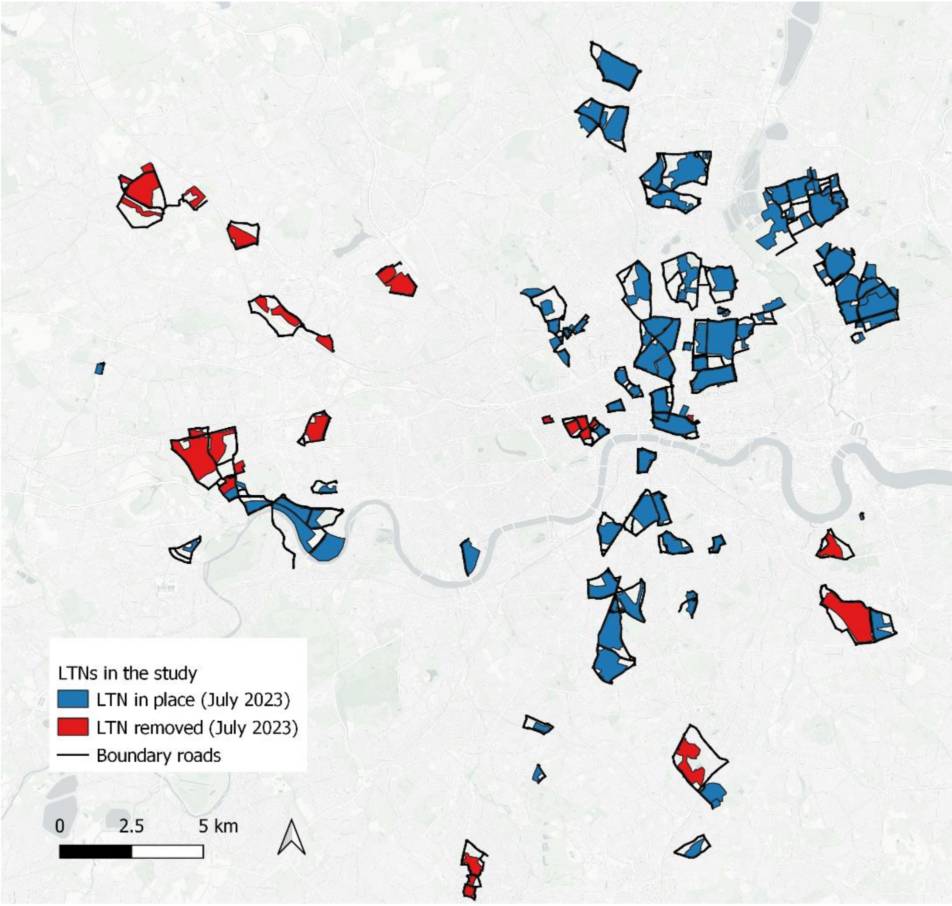
Map of LTNs and boundary roads in the study

Applying the above definitions of LTNs, their extents and the boundary roads allowed us to create our own dataset of all LTNs and their associated boundary roads a) implemented in Waltham Forest since 2015 and b) in Greater London since March 2020, up to July 2023.[5] In total, there are 111 LTNs included in the analysis, although as some LTNs comprise more than one polygon, there are a total of 141 different polygons. The total area covered by the LTNs is 37km^2. See Figure 1 for a map of all of the LTNs included in the analysis, classified by whether, as of July 2023, they were still in place or had been removed.

25 of the LTNs have subsequently been removed. Our analysis will use the date of LTN implementation/removal to determine whether injuries in such areas were inside of an LTN at particular points in time.

[5] This Statistical Analysis Plan has been written to cover analyses examining impacts up to June 2023. If our research team has time, it is possible that we will later extend this to cover all of 2023, using analogous methods.

Figure 1: Map of LTNs in London as of July 2023, and their associated boundary roads



Matching Ordnance Survey road segments to LTNs

The analysis of road injuries will be conducted at the level of road segment, such that we are able to identify, for each month of each year, the number of injuries and their types that have occurred on a particular segment. Road segments are taken from the Ordnance Survey MasterMap Highways Network, where each segment constitutes a section of a road from one junction to the next. As a result, there is significant variation in the length of each road segment. There are a total of 423,577 road segments included in the study across Greater London, with a mean length of 48.2m and a total length of 20,425.2km.

Each road segment has been intersected with the LTN polygons to determine whether the segment is inside or outside of the LTN. As the road segments do not transcend road junctions, they cannot be both inside and outside of the LTN. To identify road segments that are on boundary roads, we first intersected all road segments with a buffer around the boundary road as drawn by us. We did this selecting only those road segments where more than 40% of the road segment length falls within a 13m wide buffer,[6] and then inspected the results to finalise the definition manually. This involved manually excluding road segments that intersect with boundary roads at junctions but are not part of boundary roads. It also involved manually adding any road segments that should have

[6] These cut-offs were determined based on testing which values led to the fewest road segments being misallocated – either wrongly attributing road segments on boundary roads to being outside of the buffer, or vice versa.

been but were not captured by the boundary road buffer (e.g. where there is some kind of misalignment of the boundary roads as drawn by us versus the OS roads).

We will ultimately exclude motorways from all our analyses, as there are not any motorways that fall within an LTN nor are there any motorway boundary roads. All other road types are included. As shown in Table 1, minor roads ('C' and 'Unclassified') make up 99% of road segments by length inside LTNs, as compared to 26% for boundary roads, and 86% for roads that were never inside an LTN or on a boundary road (excluding motorways).

Table 1: Distribution of road types by LTN and boundary road status

Road type	Road class[7]	No. of segments	Percent of segments	Length of segments (m)	Percent of segment length
Ever within LTN	All roads	15,648		722	
	A	81	0.5	2	0.3
	B	221	1.4	8	1.2
	C	510	3.3	21	2.9
	Unclassified	14,836	94.8	691	95.7
Ever a boundary road	All roads	10,407		333	
	A	6,554	63	201	60.2
	B	1,439	13.8	45	13.6
	C	774	7.4	27	8
	Unclassified	1,640	15.8	61	18.3
Other roads, excluding motorways	All roads	397,522		19,370	
	A	53,645	13.5	2,215	11.4
	B	13,250	3.3	496	2.6
	C	17,929	4.5	782	4
	Unclassified	312,698	78.7	15,877	82

What about 'new' roads?

While all road segments were in place when the MasterMap data was created by Ordnance Survey (May 2023), there are some roads that will not have existed across the entire time period from 2012 to the present – for example, roads inside newly-built estates. Unfortunately, OS do not provide data on when each road segment became operational. To overcome this, we matched each road segment to a larger 'streets' by their Unique Street Reference Number. Most streets have a 'valid from' variable that denotes, according to Ordnance Survey, 'the time when the transport property started to exist in the real world'.[8] It was our aim to exclude road segments from our analysis prior to the date when their associated street was 'valid'. However, for various reasons, it has not been possible to exclude these road segments from the analysis:

[7] In the OS road classification, there is no 'C' classification. We have assigned this to roads classified as 'classified unnumbered'. Our category of 'Unclassified' roads includes roads that OS define as 'unclassified', 'not classified' and 'unknown'.

[8] https://www.ordnancesurvey.co.uk/documents/product-support/tech-spec/osmm-highways-network-rami-technical-specification-v2.5.pdf

1) 66,127 (15.6%) road segments did not match to streets because they did not have an associated Unique Street Reference Number.
2) Among road segments that could be matched to a street, 14,712 (3.5% of all road segments) had a 'valid from' date after January 2012, suggesting that they were newly built since January 2012. Upon investigation, however, it became clear that many of these new road segments were not in fact new.
    a. Investigation of these roads using Google Street View indicated that, while some were newly created since 2012, many had existed throughout the entire time period, though perhaps not in Ordnance Survey Mastermap data.
    b. There was a very uneven spatial distribution of new roads across Greater London. For example, a very high proportion of streets in Harrow were coded as 'new' in the OS dataset with an identical start date.[9] This equated to some 43% of the total road segments with a 'valid from' data as after January 2012. These were clearly not accurately recorded by Ordnance Survey.

We have subsequently received confirmation from Ordnance Survey that, because the 'validfrom' field in the Street data is sourced from local authorities, each with their own distinct practices around managing this data, there is no guarantee that the variable carries the same meaning across different areas of London.

As a result, no road segments have been removed from this analysis because of their date of implementation. We know that genuine new roads are rare, likely well under 2% of the road network.[10] We further assume that genuine new roads are evenly distributed across space and time, such that they would not have a significant impact on the relationship between LTN/boundary road segments and injuries.

Matching road segments to injuries by location and road classification

Road injury data will be taken from DfT's 'Stats19' Road Safety Data release, and currently covers the period up to June 2023.[11] This Stats19 data includes the injury severity and travel mode of casualties of road traffic injuries, as well as the crash location in both geographical coordinates and Police-recorded road classification. Note that data from 2023 is provisional and unvalidated.

Each road traffic injury from January 2012 to June 2023 has been matched to its nearest OS road segment that has the same road classification as that recorded in Stats19 as follows:

- The nearest OS Motorway if the injury is reported in Stats19 as being on a Motorway.[12]
- The nearest OS A road if the injury is reported in Stats19 as being on an 'A' road.
- The nearest OS B road if the injury is reported in Stats19 as being on a 'B' road.

[9] We do not know the reason for this, but speculate it reflects some sort of administrative change in their status.
[10] After excluding the 'new' roads in Harrow, the vast majority of which are evidently incorrect , the proportion of streets that have a 'valid from' date after January 2012 is 2% by length. This is undoubtedly a considerable overestimate, given that manual inspection via Google street view indicates than many of these roads are not in fact 'new'.
[11] https://www.data.gov.uk/dataset/cb7ae6f0-4be6-4935-9277-47e5ce24a11f/road-safety-data.
[12] The data preparation sequence was first to match all injuries to road segments, and then subsequently to exclude all Motorway road segments along with their associated injuries.

- The nearest OS 'minor' road[13] if the injury is reported in Stats19 as being on a 'C' or 'Unclassified' road.

Injuries that are greater than 50m away from the nearest road segment of the same classification have been matched to the nearest road of any classification type. After examination, it was clear that most of these cases did not appear to be incorrect locations in the Stats19 data, but rather, instances of a discrepancy between the road classification used in Stats19 versus the most recent OS road classification. Injuries more than 100m away from the nearest road segment of any classification have been removed from the analysis.[14] This amounted to only 0.9% of all injuries recorded in the time period.

Injuries and roads link falsely classified as outside the LTN

As the LTN polygons have been drawn to exclude buildings that face onto external or boundary roads (i.e. where it appears that the entrance is likely to be outside of the LTN), there are some very short road links at junctions with external roads that have been falsely classified as 'outside of the LTN'. The example below shows this: the road section highlighted red is classified as its own short road link, rather than as a continuation of the line in black below it, despite them both being the same road. As a result, the section in red does not intersect with the LTN polygon, and so the injuries matched to this road link (orange dots) have been wrongly classified as being external.

To correct this, we manually extended the polygons to cover all road links with injuries that should be inside of the LTN according to our definition of the polygon extents. Subsequently, we have re-intersected the road links with the amended LTN polygons.

[13] OS 'minor' roads were defined as our C and unclassified roads. Our C road classification is the OS 'classified unnumbered' classification and our 'Unclassified' classification is the OS 'unclassified' 'not classified' and 'unknown' classification.
[14] This is the same approach that was used by Grundy et al. (2009)

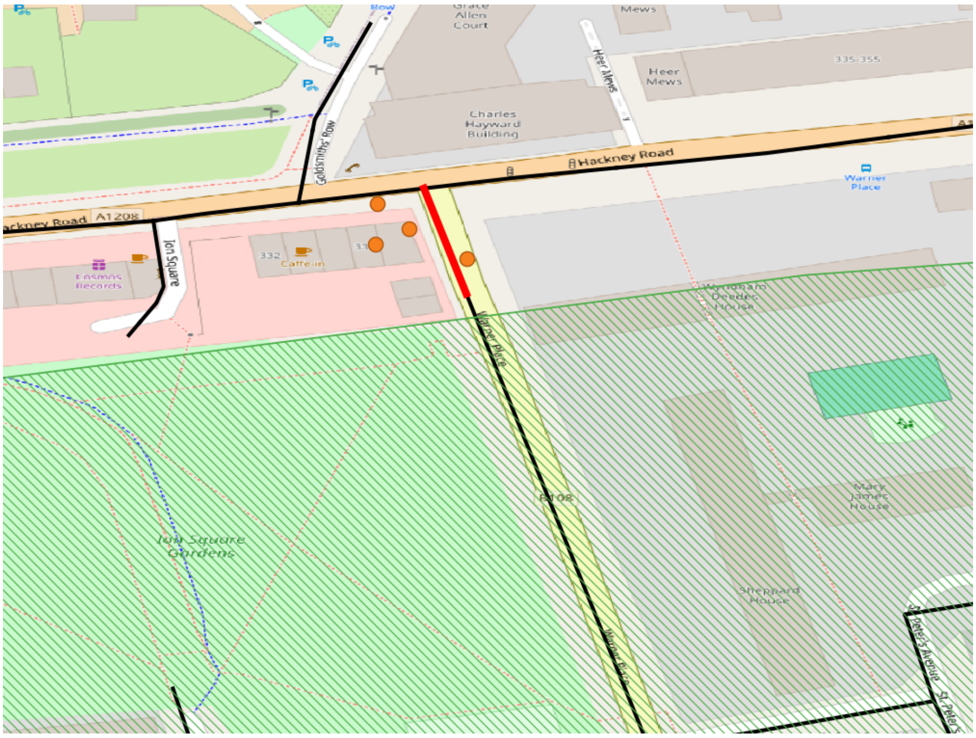


Figure 2 Example of injuries and associated road link falsely classified as outside the LTN

Defining start and end dates for LTNs and boundary roads, at the month level

For road segments inside of LTNs, the start and end date that they became 'LTN roads' is determined by the date of implementation of the LTN. For some LTNs we only have the month and year of implementation, and in many cases there was no enforcement until one to four weeks after implementation. For this reason, the first month for which the LTN was in place for the whole month is considered the start month. For example, if an LTN was implemented on 08/10/2020, its associated road segments would be classified as within an LTN from 01/11/2020 onwards. Similarly, in cases where the LTN has subsequently been removed, the last full month for which the LTN is operational is the end month. For example, if the LTN was removed on 08/10/2021, associated road segments would be considered inside an LTN until the end of September 2021. After this date, the road segment is coded as being part of a 'removed' LTN.

We anticipate that unfortunately we will not have sufficient statistical power to examine robustly what happens to injury rates on a road segment once an LTN is removed. We therefore plan in general to censor road segments from our analysis once they move into the 'removed' category. We will, however, present results for these 'removed LTN' road segments for our most highly powered analysis, namely all injury severities for all modes.

For boundary roads, in most cases, they follow the same logic: they are considered boundary roads from the first full month until the last full month the LTN was in place. Where a boundary road segment is associated with more than one LTN polygon (i.e. if it is a boundary road for more than one LTN scheme, or for more than one area within the same LTN), it is considered an LTN from the first full month it is a boundary road for any LTN area. In cases where one associated LTN area is removed but not another, it remains a boundary road for as long as it still adjoins one active LTN area. There are a small number of boundary roads that are only designated boundaries for a short period – this is the case when one LTN area has been implemented with a short delay until the implementation of an adjacent area. These cases are included in the study, but only where the length of time for which they are boundary roads exceeds one month.

We hope to run our analyses at the level of months, using the methods described above. If this does not prove feasible from a computational point of view – e.g. models do not converge, or take too long to converge, then we will switch to a quarterly analysis using three-month windows of time. In this case, we will give to each road segment in each quarter the LTN or boundary road category (e.g. no LTN / LTN / removed LTN) that is most common across its three constituent months.

Statistical Analysis

Datasets

The aim of this research is to understand the impact of LTN implementation on road traffic injuries, after accounting for the wider trends in injuries across Greater London. Our approach analyses changes in the numbers of injuries **within the same road segment over time**, rather than making comparisons between road segments. By comparing the same road segments pre- and post- LTN implementation with wider trends in Greater London, we can remove the possibility that any time invariant road or area characteristics could be confounding factors. We will specifically estimate the effects of becoming an LTN road/becoming a boundary road compared to other roads that remain non-LTN and non-boundary roads. To increase the statistical power of the model, we have used data from January 2012 – more than 3 years before the first LTN was implemented in Greater London. This also means that we can, alongside LTNs implemented since March 2020, also account for the impacts of the Waltham Forest Mini-Holland schemes that were first implemented in 2015.

Our final dataset will consist of long-format data, in which every combination of a road segment and month of each year will have its own row. For the period January 2012-December 2022 this means 423,577 segments * 11 years * 12 months = 55,912,164 rows, plus for the period January 2023-June 2023, 423,577 segments * 6 months = 1,541,462 rows. That is a total of 58,453,626 rows.

Associated variables will be:

- 'Inside an LTN': a categorical variable coded 0 for all road segments in the first month of 2012. It will remain at 0 for all subsequent months unless an LTN is implemented and it becomes 'inside an LTN', at which point it will change to 1. If the LTN is subsequently removed, it will be coded as 2.
- 'On an LTN boundary road': a categorical variable coded 0 for all road segments in the first month of 2012. It will remain at 0 for all subsequent months unless an LTN is implemented and it becomes 'on an LTN boundary road', at which point it will change to 1. If the LTN is subsequently removed, it will be coded as 2. Note that it will not be possible to be both inside an LTN and on an LTN boundary road simultaneously
- Month-and-year: A categorical variable covering each of the 138 months from January 2012 up to June 2023.
- Road type: a four-level categorical variable that denotes whether the road is one of the following: a) major Inner London road, b) minor Inner London road, c) major Outer London road, d) minor Outer London road. We define 'major' roads as A or B roads and 'minor' roads as C or Unclassified. The definition of Inner and Outer London (and the associated shapefiles) comes from the London Plan Consultation 2009. [15]
- Number of injuries, recorded on that segment during that month. This will be calculated by:

[15] https://data.london.gov.uk/dataset/inner-and-outer-london-boundaries-london-plan-consultation-2009

a) victim mode (four types: any mode, cycle, pedestrian, motor vehicle driver or passenger)
b) injury severity (two types: any injury, or 'Killed and Seriously Injured' (KSI) injuries only)

In total, these will represent our 8 outcome variables on interest. Among these, 'any injury by any mode' and 'a KSI injury by any mode' are our two primary outcome. As well as running these analyses for London as a whole, we will stratify by Inner vs Outer London in Supplementary Analyses.

One complication with examining the number of 'Killed and Seriously Injured' (KSI) injuries is that the London Police introduced an 'injury-based' recording system in 2016. This altered the way in which slight versus serious injuries were classified, and the total proportion of injuries classified as 'serious' increased thereafter.[16] The Department for Transport has produced 'adjustment factors' for slight injuries recorded in Stats19 under the previous non-injury-based recording system. These adjustment factors estimate, at the level of an individual injury, the probability that the injury in question would have been recorded as 'serious' not 'slight' under the new system. This value is never zero, instead ranging from 0.00095 to 0.34, with a mean of 0.069, across the injuries in our dataset. This affects 100% of slight injuries in the pre-2015 system, which is equal to 41% of injuries in our dataset.

Using these adjustment factors means that the calculation of injury severities for pre-2016 returns non-integer values. For example, an injury may have previously been coded as 'slight' and would have not contributed to the count of KSIs. Now, this injury has a probability of being slight and serious that are both values greater than zero but less than 1. These are the values that are summed to give an adjusted count of KSI injuries on a road segment during a given month.

We propose to treat the raw, integer KSI values as our primary 'KSI' outcome, and to use the adjusted KSI injury count as a sensitivity analysis. This decision has the advantage of allowing us to work with count data for all our primary outcomes, thereby better meeting the assumptions of a Poisson model. Given that the change in the injury recording system happened early in our study period, and given that we do not expect differential effects of the two systems by LTN status, we anticipate the different models will give similar results.

Model specification

Following the approach of Grundy (2009) and Steinbach et al. (2015), we will fit a conditional fixed-effects Poisson model to estimate the number of injuries on a given road segment, though will do so for a given month rather than a given year. The two key predictor variables of interest will be 'Inside and LTN' and 'On an LTN boundary road', as we will examine the impact of a road segment becoming an LTN or boundary road on the number of injuries. The model will be estimated in RStudio using the pglm package, with the dataset specified as panel data, indexed on the road segment ID. As a validation exercise, the model will be replicated in R using the feglm function of the fixest package, and in Stata using the command xtpoisson.

The model will be specified with an interaction term between the month variable and road type variable, to allow for the fact that in the exploratory analysis, we found that these different road types had different injury trends over the 2012-2023 time period. This partly reflects differing long-term trends (e.g. injury numbers have increased more on minor roads than on major roads since 2012), and partly differing patterns of injuries during the Covid-19 pandemic (e.g. injuries fell more in Inner London than in Outer London during the pandemic). As supplementary analyses we will

[16] https://www.gov.uk/government/publications/guide-to-severity-adjustments-for-reported-road-casualty-statistics/guide-to-severity-adjustments-for-reported-road-casualties-great-britain

present results stratified by Inner versus Outer London, to establish whether there is any evidence that the effect of LTNs differs between these two contexts.

In this type of fixed effect model, any road segment that never has an injury through the whole observation period is excluded. The proportion of road segments dropped for this reason will vary by outcome but will be at least three-quarters even for our widest definition (any injury for victims using any mode). After these 'never an injury' segments are excluded, we will check the validity of a Poisson modelling approach by assessing a) whether the mean number of injuries is approximately equal to the variance, and b) whether our results are similar in equivalent negative binomial models. If these conditions are not met then we will take appropriate steps, e.g. use a zero-inflated Poisson model.

The outcomes from the above Poisson analyses will be incidence rate ratio (IRR), which is calculated by exponentiating the coefficients of the key predictor variables. The IRR will provide a measure of the multiplicative change in the expected count of injuries once a road changes to become either inside of an LTN or on a boundary road.

To complement these rate ratios, we will present descriptive statistics of the number of injuries per year across time, for areas that were a) ever inside an LTN that was implemented in 2020/2021, b) ever a boundary road to an LTN implemented in 2020/2021, or c) never in an LTN implemented at any time. This will provide a graphical way to illustrate visually any similarities or differences in the number of injuries over time for roads that ever were versus never were in an LTN (e.g. were trends similar before 2020, did they diverge in 2022?). This illustrative analysis will focus on schemes implemented in 2020/21 as this is when the largest number of schemes were implemented.

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Appendix 1 – Defining the boundaries of LTN and control areas

A new LTN is an area where we expect a substantial reduction in through motor traffic. To capture this, we draw a minimal continuous polygon covering streets where through motor traffic is not permitted or is substantially restricted. Our rules for drawing these polygons were as follows:

1. DO include streets inside the polygon that were already impermeable to through traffic or otherwise very quiet (i.e. don't create holes inside the polygon).

2. DON'T include streets still expected to carry more than a small amount of through motor traffic.[17] For example, we do not include New Park Road in the Brixton Hill LTN, which is filtered in one direction only. We do not include the south part of Murray Street in the Camden Square LTN, which has had one of its cut-throughs blocked but not the other.

Streets adjacent to the polygon that were. already impermeable to motor traffic are a difficult edge case when implementing the above. Because of the 'don't create holes' rule (Rule 1 above), a cul-de-sac inside an LTN area is not excluded. It would become a bit arbitrary to exclude a cul-de-sac coming off a newly filtered road if the orientation of that cul-de-sac points towards the boundary, but to include it if it points towards the centre. The same is true of housing estates, and we also note that it is potentially harder to associate a given block with a single specific road in estates. However, we did not want to include large networks of previously filtered streets in our definition of a 'new LTN'.[18]

There exists a spectrum of street designs and no clear place to draw the line on this point, but we needed some rules that could be operationalised.[19] Ultimately, we determined on the following rules:

3. DO include adjacent housing estates, cul-de-sacs and single-road crescents/loop roads if the main 'way in' for motor vehicles is via a street inside the new LTN. For estates, DO also include if there is a main way in both from inside the LTN and from a boundary road and if the downstream LTN may now reduce previously possible through traffic.

4. DON'T include adjacent housing estates, cul-de-sacs and single-road crescents/loops if their only 'way in' for motor vehicles is via a street not inside the new LTN (e.g. we exclude Wellingham Terrace, which is accessed by a boundary road to the Camden Square scheme). If a housing estate has one way in from inside the LTN and one way in from a main road, but these two ways in don't connect, then we split the estate in half (e.g. we split in half Kerswell Close estate in St Anns LTN).

5. DON'T include sets of two or more adjacent residential streets that are already filtered or otherwise low traffic by design, even if they can exclusively be accessed via roads inside the new LTN. For example, we exclude Seaford Road and Roslyn Road in St Anns LTN as these

[17] Whether more than a little through motor traffic is expected on a given street can be partly judged from design and, if needed, potentially partly from the post-implementation change in observed motor traffic.
[18] This is relevant for schemes like Camden Square where a new LTN sits inside a larger low traffic area, which may include pre-existing modal filters. For some outcomes this larger area might be the better focus of investigation, but for our present analysis we were trying to look at the impact of changes to the streetscape.
[19] This is especially true since another strand of our NIHR study involves mapping all 100+ LTNs in London, to look at impacts on road traffic injuries.

are already filtered. We also exclude Southey/Elizabeth/Russell Road in St Anns LTN as these are low traffic by design as they form a circuitous loop that would not be expected to carry through traffic.