Department for Transport

DEEPENING THE UNDERSTANDING OF HOW TO ADDRESS INDUCED TRAVEL ON THE STRATEGIC ROAD NETWORK

Options for Improving the Measurement of Induced Travel

70064578
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EXECUTIVE SUMMARY

Background

The UK Department for Transport (DfT) has a long-standing interest in understanding the extent to which improvements on the strategic road network (SRN) induces new travel. While induced travel can occur on a range of modes, within the context of this research, induced travel is defined as travel that occurs as a result of road infrastructure improvements to the SRN that would not have happened if such infrastructure improvements had not been made. The basic underlying principle is that making road improvements is likely to make journeys faster and easier, which can lead to people switching from making journeys by public transport to cars, making more frequent and/or longer car trips (either as a result of changing route and/or destinations or as a result of changes to where they work or live). All of these changes will lead to more traffic on the road network.

There is a growing body of international evidence – although limited UK-specific evidence - on the size of induced travel effects. However, there is less evidence on what responses lead to these effects, how these effects vary across different types of road investment and the degree to which effects vary in the short and long term. The objective of this study is to set out what needs to be done to deepen our understanding for how changes in road capacity on the SRN impacts the level of induced travel, what responses contribute to induced travel and how induced travel varies in the short and long run. A further aim is to provide guidance about how insights from empirical analysis of induced travel could be used to help improve transport modelling processes.

The study focussed on two approaches for improving the estimation of the size of induced travel:

- Econometric approaches, that quantify the relationship between road capacity changes and observed traffic levels using time series road traffic information;
- Before and After studies, that quantify changes in traffic from road capacity changes by comparing data collected before and after the intervention.

As both approaches have different strengths and weaknesses, we conclude that each has sufficient merit to include in a two-pronged approach.

We judge that it would be **valuable to develop a more robust estimate of induced travel effects for the UK using an econometric approach**. Such analysis may also be able to inform on the geographical impacts of interventions, as well providing information on variation in traffic count data, which could help to improve some of the shortcomings of before and after studies. At the same time, the potential for data sources that have not previously been used to estimate induced travel – particularly the use of mobile phone data - may make it feasible to better quantify before and after changes **providing estimates of the impacts of different types of responses**. Both approaches may also provide additional, useful information and evidence on other factors influencing background growth.

SUMMARY RECOMMENDATIONS

Measurement Recommendations

We propose a two-pronged approach for measuring induced travel that expands on the way in which induced travel is currently measured (that being primarily before and after studies that compare travel across screenlines in before and after situations).

- We recommend undertaking **econometric analysis to improve estimates of the size of induced travel for the UK using existing data**, at two levels of aggregation: an area-level analysis (as done in the USA and Spain, for example) and a more detailed analysis by road segment (as done in The Netherlands). Testing both methods of data aggregation will provide evidence on the robustness, as well as strengths and weaknesses, of differing econometric approaches. We recommend that a first phase of work using econometric methods focus on existing road data to manage the complexity of the analysis. Future stages of work could explore the feasibility of incorporating additional data sources, including new data sources (such as mobile phone data) and/or data around demand for other modes (to better understand the impact of differing responses).
- We also recommend exploring whether **estimates of induced travel from before and after studies could be improved through the use of mobile phone data**. We recommend undertaking a pilot using before and after mobile phone data from a scheme implemented before the Covid-19 pandemic.[1] The pilot could also explore whether mobile phone data can help to understand the impact of new road capacity on assignment, mode and destination choice and frequency responses.

Modelling recommendations

We do not see the need for fundamental changes to the way four-stage variable demand models are calibrated or estimated to better reflect induced demand. However, we recommend:

- If mobile phone data can provide better information on assignment, mode and destination choice and frequency responses that this information be used to compare against model predictions to **validate the sensitivity of different model responses in travel demand models**. Before and after studies could also explore and **provide evidence on land-use changes as a result of new road capacity**.
- Further research is undertaken to **better quantify appropriate car time elasticities** and use these to update TAG guidance on the basis that road capacity changes are likely to have a larger impact on car times than on fuel costs(which have much more stringent model elasticity requirements in the current TAG guidance).
- Tests be undertaken using existing models to explore what level of induced travel they predict for road capacity increases. These could be compared with published values. Such tests could explore the **feasibility of validating fuel cost elasticities, car time elasticities and cost damping alongside tests of induced travel**.

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[1] We propose that we should focus on examples where before and after mobile phone data are collected before the Covid-19 pandemic. Although econometric studies can in principle control for extreme exogenous events like Covid-19 through the use of time constants, we would recommend in the first instance that only data preceding the outbreak is used for analysis.

1 INTRODUCTION

1.1 BACKGROUND

1.1.1. The UK Department for Transport (DfT) has a long-standing interest in understanding whether and the extent which improvements in roads induces new traffic.

1.1.2. Within this report, the terms 'Induced Travel' and 'Induced Traffic' are terms which are used interchangeably and is defined as travel that occurs as a result of road infrastructure improvements that would not have happened if such infrastructure improvements were not made. The basic underlying principle is that road capacity improvements make journeys faster and easier, which has the potential to result in an increase in vehicle kilometres travelled.

1.1.3. Induced travel is not simply a road phenomenon, it is equally applicable to infrastructure improvements for other modes. However, although this is the case, the focus of this study is on improving the measurement **of induced travel as a result of capacity improvements to the SRN.**

1.1.4. The first study on induced travel for the UK government was undertaken by the Standing Advisory Committee on Trunk Road Assessment (SACTRA) in 1994. SACTRA concluded that 'induced traffic can and does occur, probably quite extensively, though its size and significance is likely to vary widely in different circumstances' (SACTRA, 1994).

1.1.5. The 1994 SACTRA report also emphasised the importance of accurate traffic forecasts for appraisal of road schemes, noting that the 'economic value of a scheme can be overestimated by the omission of even a small amount of induced traffic' and that this matter was of 'profound importance to the value for money assessment of the Road Programme'. Accordingly, SACTRA recommended the use of 'variable demand models (VDMs)', which are able to account for induced travel effects. Today, VDMs are a key part of the DfT's Transport Appraisal Guidance (TAG) and their use is standard practice for major road investments.[2]

1.1.6. SACTRA also recommended that the DfT enhance its scheme 'before and after' monitoring studies, so as to provide more information on induced traffic. An opportunity to investigate this issue arose with the completion of the M60 Manchester Motorway Box in October 2000, which completed a major link in the UK's national road network. A large program of before and after data collection was undertaken to better understand the size and drivers of induced travel (Rohr et al. 2012). This study is discussed in more detail in Chapter 2.

1.1.7. In 2018, DfT commissioned a study to identify and review the latest econometric and case study evidence on induced travel demand to inform the development of the second Roads Investment Strategy (RIS 2), covering investment in the English Strategic Road Network (SRN) between 2020 and 2025. This work was carried out by WSP and RAND Europe (and is referred to as Dunkerley et al. 2018 throughout this report). That report concluded that induced demand effects are likely to be significant and are therefore important to take into account. It also concluded that further work needed to be undertaken to develop the evidence base on induced demand in the UK in terms of:

[2] TAG (Transport Analysis Guidance) is the Department for Transport's appraisal guidance toolkit. It consists of software tools and guidance on transport modelling and appraisal methods.

- Short and Long Run responses to investment in road capacity;
- The responses of different types of traffic (for example by journey purpose or by vehicle type) to new road investment; and
- How responses vary accordingly to different types of road investment.

1.2 STUDY OBJECTIVES

1.2.1. This study follows on from the WSP and RAND Europe work reported in Dunkerley et al. (2018). Its purpose is to scope what work needs to be done to better understand how changes in road capacity on the SRN impacts the level of road traffic. The longer-term aim is to build the evidence base in order to help DfT more robustly address stakeholder concerns about the impact that demand responses have on the case for road investments.

1.2.2. This research represents a first step in providing recommendations to establish the necessary evidence base by scoping out how the gaps in the evidence might be filled.

1.2.3. The objectives of the research are to scope what needs to be done to deepen our understanding on how road capacity changes on the SRN impacts road traffic levels across the whole road network. The research considers methods that could be employed in both the short term and the longer term, where in the longer term the aim will be to build a more robust evidence base to help DfT assess the scale of induced travel and how this impacts the case for road investment.

1.2.4. A further aim is to provide guidance about how insights from empirical analysis of induced travel can be used to help improve modelling processes, specifically to consider how the elasticity of road traffic volumes with respect to capacity change relates to the standard four-stage modelling approach and to determine whether this elasticity could be used to calibrate and/or validate models. In the longer term. This work could also explore whether elasticities can be identified from empirical analysis for the different choice steps in the demand model hierarchy.

1.2.5. It should be emphasised that measuring traffic impacts is complex. The issues are summed up in the Manchester Motorway Box study (Rohr et al, 2012): "As a result of additional road capacity, and improved travel conditions on roads, we might expect travellers to change the route that they use, to switch from public transport to a car (if they have one, or consider purchasing a car if they do not) or to switch back to making a car journey in peak periods, to travel to another (more accessible) destination, to make more journeys or perhaps even, in the long term, to change their home location. Many of these responses may occur simultaneously, increasing the complexity of measuring the impact. Also, the size of an impact will vary for different people, depending on where they live, where they want to go, when they want to travel, etc. Furthermore, because the additional capacity itself is limited, there could be congestion impacts, albeit at a lower level which limit the extent of changes that are possible."

1.3 TERMINOLOGY AND KEY ASSUMPTIONS

1.3.1. The 2018 rapid evidence review on induced travel demand (Dunkerley et al., 2018) forms the starting point for this study.

1.3.2. This study uses the definitions and terminology specified in that earlier work. Specifically, we use the terms induced travel and induced traffic to refer to **'the increment in new vehicle traffic that would not have occurred without the improvement of the network capacity'**, where traffic is usually measured in vehicle-kilometres travelled (VKT).

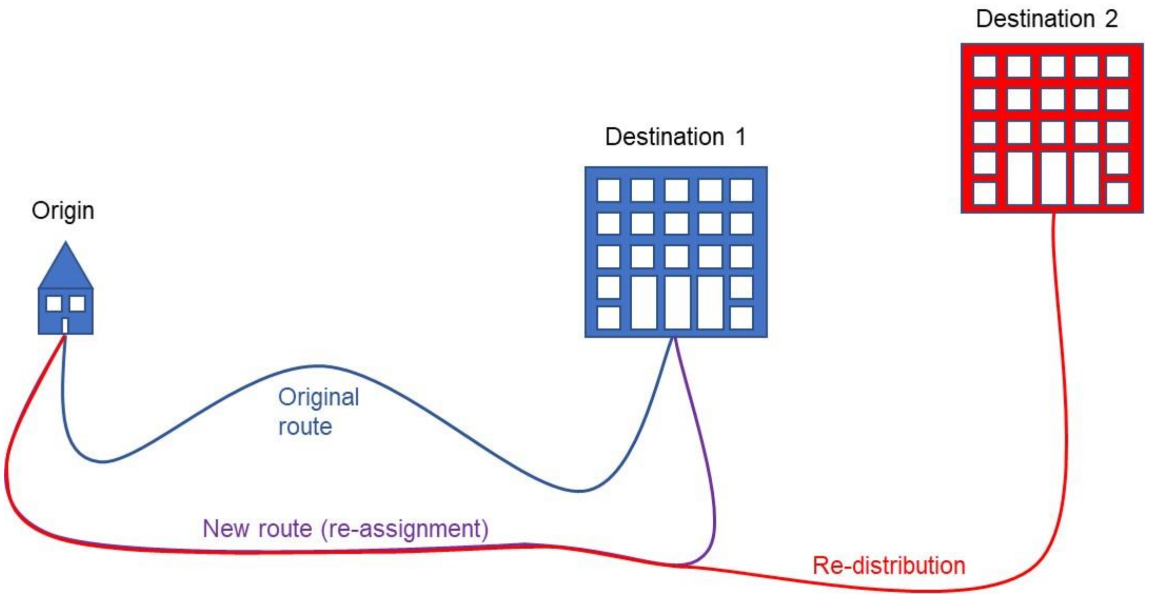
1.3.3. Induced traffic can then be considered to consist of the change in traffic VKT on a network that results from a change in:

- Mode of travel, e.g. switching from public transport to driving;
- Frequency of travel, i.e. making additional trips that were not made before the road infrastructure improvement;
- Changing route (to the same destination) to take advantage of the new infrastructure, which may lead to longer trips;
- Changing journey destination, which may lead to longer trips; and
- Changing residential or employment location, as a result of changes in land-use.

1.3.4. A change in trip timing is not usually considered an induced demand effect if the trip is still made within the measurement period of interest.

1.3.5. In transport modelling a change in route for a trip between a fixed origin and destination is known as re-assignment. Redistribution occurs when either the origin or destination also changes. Re-assignment and redistribution contribute to induced traffic only when there is an associated increase in trip length.[3] Figure 1-1 illustrates the differences between re-assignment and redistribution.

Figure 1-1 Illustration of re-assignment and redistribution



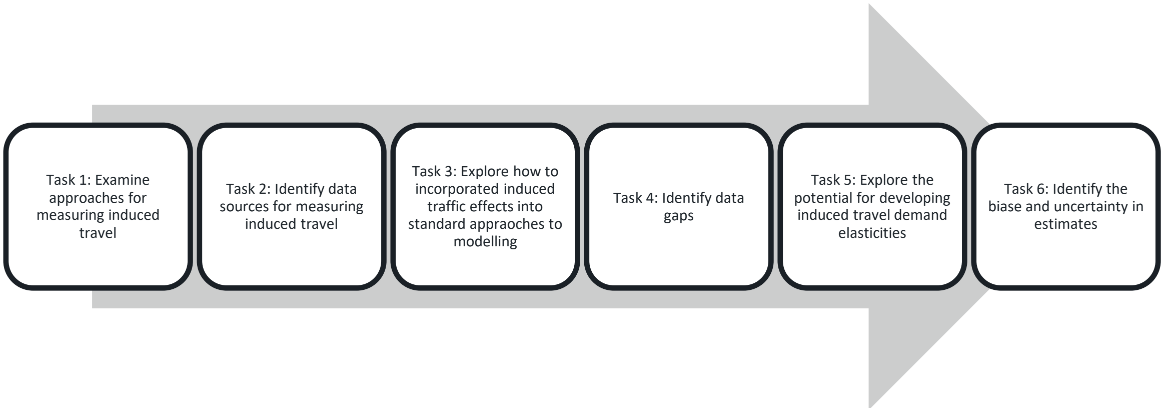
[3] Some may argue that trip reassignment should not be included in induced travel. At this stage we choose to include all possible responses that lead to changes in vehicle-kms in our definition and this includes the additional (or potentially reduced) vehicle-km associated with a re-assigned trip. This is consistent with the definition used in the evidence review by Dunkerley et al. (2018). We also note that improvements in road capacity could reduce trip lengths. However, in this study we focus on increases only, as increases are associated with induced travel.

1.3.6. The assessment of background growth is an important factor in measuring induced travel. Travel increases due to a number of exogenous factors such as GDP growth or car ownership. Induced travel is very specifically the amount of travel induced as a result of infrastructure improvement. It is therefore vital that **any measurement of induced travel needs to control for background traffic growth, and this is not always straightforward**.

1.4 STRUCTURE OF THE STUDY

1.4.1. This study was structured across six tasks as shown in Figure 1-2 (with Tasks 4, 5 and 6 being conducted in parallel).

Figure 1-2: Study Tasks



1.4.2. This report presents the culmination of this work. It is structured as follows:

- Chapter 2: Sets out the review of different approaches for measuring induced travel;
- Chapter 3: Sets out available data for measuring induced travel;
- Chapter 4: Sets out the proposed approach for improving the measurement of induced travel;
- Chapter 5: Sets out how evidence on induced demand could be incorporated in travel demand models;
- Chapter 6: Sets out our recommendations for a way forward for improving the measurement of induced travel and how this can be incorporated in travel demand models; and
- Chapter 7: Sets out the Recommendations from the Research.

2 REVIEW OF APPROACHES FOR MEASURING INDUCED TRAVEL

2.1 OVERALL AIM OF THIS TASK

2.1.1. The aim of the first task of this study was to undertake a detailed review of existing approaches for measuring induced demand. The most promising of these were identified for potential further development as measures to more robustly quantify the impact of increased road capacity on the SRN on road traffic volumes.

2.1.2. The Dunkerley et al. literature review (2018) identified two main methods for calculating the induced travel effects:

- Econometric approaches to calculate an induced demand elasticity; and
- Case studies to quantify the impact of induced travel, these included before and after studies and modelling studies (like the Manchester Motorway Box (MMB)).

2.1.3. Elasticities of traffic volumes with respect to road capacity (induced demand elasticities) can be estimated using econometric approaches, using evidence from observed changes in demand, usually measured in terms of traffic volume (VKT)[4] for each kilometre of road expansion on the network. The analysis can be undertaken at a disaggregate level, for example at the level of individual road sections, or at more aggregate levels, reflecting changes in demand on road networks at metropolitan or regional levels. Chapter 4 presents the details of such an analysis.

2.1.4. Case study evidence on induced travel has been derived for individual road expansion projects using data from a more limited area. Such evidence is presented as additional traffic volumes measured due to road expansion across screenlines within a limited geography of the road expansion project and not as elasticities. Because of the different approaches that are used in case studies – particularly the use of modelling as in the MMB study – we consider two types of case studies:

- Case studies based on before and after data collection;
- Case studies based on before and after data, including modelling to quantify responses.

2.1.5. Transport models can also be used to estimate induced travel effects. However, we do not consider transport models alone as a means for measuring induced travel, because the measurement of observed induced travel is the focus of this study. We therefore focus on approaches that require collection of data to measure induced travel, noting that some modelling may be required to quantify the impacts. Requirements for replicating the impacts of induced travel in transport models are explicitly considered in Chapter 5.

2.1.6. Thus, we consider three broad types of approach to measure induced travel:

- Econometric approaches to calculate an induced demand elasticity;
- Case studies based on before and after data collection; and
- Case studies based on before and after data, including modelling to quantify responses.

[4] A time period is implicit for all measurements, both econometric and case studies, and will depend on the data used. Typically, this has been AADT.

2.2 KEY QUESTIONS FOR EACH APPROACH

2.2.1. We set out twenty questions that formed the basis of the investigation into each approach. The idea of these “deep dive” assessments was to get a much more detailed understanding of each of the approaches as well as addressing some of the issues included in later tasks. The questions are shown in the box below.

Box 1: Key questions to be addressed for each broad approach for measuring induced travel

1. Approach
2. Key paper(s)
3. Key author(s)
4. Brief description of approach
5. Induced travel measure
6. Type of intervention, e.g. additional road capacity, etc.
7. Area/geography of measurement (could cover country, area covered (national, state, specific project, urban/non-urban))
8. Does the methodology quantify induced demand by journey purpose? Could it?
9. Does the methodology quantify induced demand by vehicle type, e.g. passenger cars, freight? Could it?
10. Does the methodology quantify induced demand by response type, i.e.: increases in veh-kms because of route changes (re-assigned traffic), mode of travel, destination shifting, frequency of travel, land-use changes? Could it?
11. Does the methodology distinguish induced travel by time period, i.e. peak or off-peak? Could it?
12. Does the methodology quantify short-term or long-term (induced travel) responses?
13. How does the study account for background growth?
14. What data were used to calculate induced travel responses (POPE, NTS/household surveys, Mobile phone data, journey to work data, roadside interview data, trip rates, other?)? What period were the data collected? Was the data collection deemed adequate?
15. Is the approach transferable to other projects or schemes?
16. Can the measure of induced travel generated by this approach be compared with other measures? How could this be done?
17. What are the strengths of this approach (endogeneity, treatment of concurrent schemes)?
18. What are the weaknesses of this approach?
19. What are the key assumptions of the approach? Are there any potential biases built into the approach?
20. How could the approach be improved?

2.2.2. The approach for obtaining the information was twofold. First, key papers from the Dunkerley et al. (2018) literature review study were reviewed in detail to provide specific information to address these questions. Second, authors of key papers were then interviewed to review our understanding of the approaches and address remaining evidence gaps.

2.2.3. We selected key papers to review (and their authors were included on a list of potential people to interview) to cover as wide a cross section of the types of evidence as possible but focusing on primary evidence that is most relevant to the UK SRN context. Both econometric and case study approaches were considered important sources of evidence. Further it was considered important to take account of different econometric approaches. Also, as much as was possible, we focussed on recent evidence (specifically we prioritised studies undertaken in the last 10 years). In the table in Appendix A we highlight what were judged to be the most important papers for the deep-dive review, based on these criteria, i.e. recent evidence and reflecting differing methodologies (econometric approaches and case studies).[5]

2.2.4. We undertook three interviews and had a written response from a further expert.[6]

2.2.5. We created template summaries for each method. These are presented in Appendix B.

2.2.6. Summary information from each completed template was discussed at a workshop held on the 17th June 2020. The workshop focussed on the strengths and weaknesses of each approach and how they may be improved.

2.3 KEY FINDINGS

2.3.1. The key characteristics of the three broad approaches for measuring induced travel are summarised in Table 2-1. More detail on the characteristics of each are provided in Appendix B.

Table 2-1 Three Possible Approaches for Measuring Induced Travel

Approach	Econometric Studies	Before and After studies	Before and After studies, with modelling
Description	Quantify relationship between induced travel and road capacity changes using time series (count) data and econometric (regression) methods.	Analysis of changes in traffic from traffic data collected before and after road improvement.	Analysis of changes from model developed from traffic data collected Before and after road improvement, plus other available data.
Key examples	NL, USA, Japan, Spain	Post-Opening Project Evaluation (POPE) studies	Manchester Motorway Box Amsterdam Ring Road
Measure of induced travel	Vehicle kms (or miles) travelled (VKT)	Change in traffic across screenline(s)	Theoretically could calculate VKT changes

5 This table comes from the Dunkerley et al. (2018) literature review, and more detail of the different aspects of the table are contained in that report.

6 Interviews were undertaken with Professor Gilles Duranton, Han van der Loop and Highways England. Jasper Willigers later addressed detailed questions on the estimation methodology used in the Dutch approach for measuring induced travel. Professor Andrew Daly reviewed the summary material on the Manchester Motorway Box study.

Approach	Econometric Studies	Before and After studies	Before and After studies, with modelling
			Change in traffic across
Measure of road capacity change	Generally measured by an increase in lane-kms, but also could be represented through road policy indicator variables	None, focus is on specific intervention	Measured as generalised cost change (in model)
Induced travel	Elasticity measuring change	Percentage change in	Percentage change in
Treatment of background growth	Analysis controls for background growth by including GDP growth, car ownership, fuel price change and land-use changes, e.g. population, in analysis so that these variables are taken into account in elasticity estimate.	Ad hoc treatment of background growth	Background growth explicitly taken into account by modelling effect of land-use change, changes in economy, car ownership and fuel prices
Data	Usually data from counts	Count data	RSI counts before and
Able to distinguish responses by purpose or behavioural response type	Not easily, but if counts on differing road types may be able to quantify re-assignment effects	Not really, although some estimate of re-assignment is made from count data	Methodology can distinguish responses by purpose and by travel response
Strengths	Robust evidence base to	Reflects specific road	Measured impacts of

Approach	Econometric Studies	Before and After studies	Before and After studies, with modelling
	System approach provides		
Weaknesses	Elasticity may not distinguish specific interventions Can't identify responses by purpose or response type A range of equations used for estimation, not clear which is best (but tests can be made) Potential for omitted variable bias	Treatment of background growth unclear Geography of analysis may not be adequate Can't identify responses by purpose or response type, although some estimate of re-assignment is made Substantial variation in count data – better for interventions that may generate large changes Hard to attribute effects to specific interventions if multiple interventions made	Relies on a model to quantify impact, model assumptions may impact results In MMB study short-term responses measured only (1999 to 2003) RSI count data did not provide a reasonable measure of changes across screenlines (and household survey data provided much more information for model estimation) Assignment not able to replicate observed changes, therefore were not able to model a counterfactual High study costs
Potential	Could look at measures for	Clarify / improve	Better measures of before

Approach	Econometric Studies	Before and After studies	Before and After studies, with modelling
		outcomes, given observed conditions, e.g. land-use, economy, fuel prices, etc.	

2.3.2. Below we set out some reflections across the different approaches.

WHAT IS THE 'BEST' MEASURE OF INDUCED TRAVEL: VKT OR TRIPS ACROSS SCREENLINES?

2.3.3. The different approaches have different measures of induced travel. Econometric methods tend to measure changes VKT as a result of road capacity improvements, usually measured as an elasticity (percentage change in VKT / percentage change in road network). Before and after studies tend to measure changes in trips across a screenline.[7] Before and after studies, with models, like the MMB or the Amsterdam Ring Road study provide measures of changes across screenlines and changes in vehicle kms (or miles) travelled. Although it is notable that because the assignment model was not able to reproduce the observed changes in the MMB context it was not possible to quantify changes in VKT.

2.3.4. The calculation of an elasticity using an econometric method for quantification could theoretically vary by geography (urban or rural areas) and for passenger and freight vehicles. Theoretically it could also allow for direct comparison across different intervention types, assuming that these can be converted into some consistent measure of capacity change. Although, with a large enough database of measures of specific changes by type, e.g. increasing road capacity, introduction of Smart motorways, bypasses, it would be possible to explore the impacts of different interventions.

2.3.5. Further different measures will be relevant in different cases. Those interested in environmental impacts of travel or safety are probably more interested in changes in VKT. Appraisal of new road infrastructure requires information on trip changes.

2.3.6. Finally, either measure could, theoretically, be used for model validation (discussed further in Chapter 5).

CAN WE RELY ON COUNT DATA TO ESTIMATE INDUCED TRAVEL EFFECTS?

2.3.7. One consistent theme across the different approaches was the observation of the substantial variation in road traffic count data, which can vary day to day due to weather, specific events, road accidents, road or other construction, public transport incidents etc.

2.3.8. Such variation can make measuring changes difficult, particularly if data is only collected for a short time. This point was picked up in the interview with HE where it was noted that it was challenging to measure changes in travel for schemes with smaller impacts. Similarly, one of the challenges in the MMB study was that the road-side interview data was not able to provide an estimate of the changes in traffic before and after the completion of the MMB.

[7] A screenline is an imaginary line for comparing traffic before and after an intervention. If the screenline is long enough, then it should take account of route changes in the After situation, so the measurement reflects increases in vehicle trips or increases in trip lengths only.

2.3.9. One of the advantages of the econometric approach using time series data is improved understanding on the variation in travel data as well as supporting measurement of changes.

IS IT VALUABLE TO HAVE A ROBUST MEASURE OF INDUCED TRAVEL AT AN AGGREGATE LEVEL?

2.3.10. Both econometric methods and before and after studies are able to make estimates of induced travel, but usually at an aggregate level. Specifically, to date, we are not aware of any examples of where such approaches have been used to measure changes in VKT as a result of a road intervention by purpose and/or by response type (although, some effort is made to quantify re-assignment effects and more could be done to measure changes for passenger and freight vehicle travel).

2.3.11. One of the advantages of the before and after approach with modelling, is that the model is able to quantify changes by purpose and response type. But the key disadvantage here is that the changes are not formally observed but are predicted by a model and are therefore subject to modelling assumptions.

2.3.12. Our view is that each approach – econometric methods and before and after studies - has some merit, but there is no single 'best' approach. We feel that future approaches need to draw on the strengths of each of the current approaches. We judge that it would be valuable to develop a robust estimate of induced travel effects using existing time series (count) data for the UK and econometric approaches **to provide a baseline estimate of induced travel**. Such analysis may also be able to inform on the geographical impacts of interventions, as well providing information on variation in traffic count data, which could help to improve some of the short comings of before and after studies. At the same time, new data sources (discussed in Chapter 3) may make it feasible to better quantify before and after changes and to make estimates of the impacts of different types of responses. Such analysis may also provide information on background growth.

CAN WE ESTIMATE THE IMPACT OF DIFFERING RESPONSES FROM OBSERVED DATA?

2.3.13. Dunkerley et al. (2018) found few studies that were able to attribute induced travel responses to differing behavioural responses, e.g. mode switching, destination switching and frequency responses, or for different journey purposes. The two studies that did this that we are aware of – the MMB study and the Amsterdam Ring Road study – both used models to do this. As noted above, the downside of using a model is that the changes are not directly observed but are estimated from the model and assumptions in the model, particularly the structure of model and choice sensitivities, may impact the results.

2.3.14. This again suggests that a two-pronged approach may be a good way forward to quantify an aggregate value on the one hand while exploring new data sources or types of analysis to measure changes by journey purpose and for different behavioural responses.

3 KEY DATA SOURCES FOR MEASURING INDUCED TRAVEL

3.1 INTRODUCTION

3.1.1. The aim of the second task was to undertake a detailed review of existing and potentially new data sources to measure induced demand responses that would inform the approaches discussed in Chapter 2. Following an extensive internet search of potential data sources, we identified a number of those data sources that are currently used and those that may be used for improving the measurement of induced traffic or alternatively that could validate the measurements. It is worth stating at this stage that no single dataset would provide sufficient information to measure induced traffic. However, using a combination of data sources would provide some increased confidence in the ability to more robustly measure induced traffic.

3.1.2. Consideration has been given to established data sources that have previously been used for the purposes of measuring induced traffic together with emerging data sources that have not previously been used but have the potential to do so. Both these sources of data can be divided into the following specific categories:

- Existing count data – independent observed counts that measure travel demand on road or public transport networks;
- Tracking data – data collected from devices which track the location of travellers or vehicle movements over time;
- Survey data – data collected by trained interviewers to understand the characteristics of travellers or trips which cannot be observed directly; and
- Population and land use data – potential key drivers of background traffic growth.

3.1.3. The existing and potential data sources that have been identified and reviewed in this task are as follows:

- Traffic Flow Data
- Journey Time Data
- Public Transport Passenger Count Data
- Mobile Network Data (MND)
- GPS Tracking data
- Automatic Number Plate Recognition (ANPR)
- Roadside Interview (RSI)
- Household Interview Surveys
- National Travel Survey (NTS)
- Census Journey to Work
- Quarterly Labour Force Survey (QLFS) / Annual Population Survey (APS)
- Business Register and Employment Survey (BRES)
- Mid-year population estimates
- TEMPro planning data
- MHCLG Land Use Change statistics

3.1.4. It should be noted that prior to use of any data to support measuring induced traffic, it is necessary to understand the provenance, definition, processing history, quality and suitability of the data. In addition, each source should be evaluated for its errors and biases.

3.2 TRAFFIC FLOW DATA

Introduction

3.2.1. Traffic flow data is a metric that is predominantly used for engineering, performance measurement and more general analysis purposes. Traffic flow data is used to monitor network usage, creating a historic record of traffic flows. Highways England, the DfT and local authorities are the key sources of traffic flow data in the UK.

Data from Highways England

3.2.2. Highways England maintains a large inventory of traffic data containing traffic flow and journey time data that can be accessed via the Highways England Traffic Information System via the Web Traffic Information Service (WebTRIS) website.[8] The WebTRIS dataset is a central collection and reporting point for 15 minute and hourly based traffic flow information. WebTRIS shows the availability of traffic data and the amount of missing data on an online mapping interface or via connection from external application through an Application Programming Interface (API). Traffic flow data is measured at dedicated sites or is extracted from the detector systems that form part of the Motorway Incident Detection System and Signalling (MIDAS) system. The latter is installed on all busy sections of standard motorways and smart motorways. The equipment installed at the traffic measurement sites, referred to as Traffic Monitoring Units (TMU), uses magnetic induction loops/radar in each lane to measure traffic flows by vehicle type, spot speeds and headways every minute.

3.2.3. TMUs are located between all major junctions on the trunk road network and on the more rural, less busy motorways. The locations can be viewed on WebTRIS with colour coding to differentiate between TMUs and MIDAS sites. There are approximately 2,200 active TMU sites for both the main carriageway and slip roads at strategic locations along the Highways England road network according to WebTRIS. Highways England also collects flow data at approximately 830 additional sites, referred to as Traffic Appraisal Modelling and Economics (TAME) sites according to WebTRIS. TAME collects similar traffic data as TMUs and MIDAS sites, including traffic volume, speed and vehicle classification.

Data from Department for Transport

3.2.4. DfT road traffic statistics team have approximately 300 automatic traffic counters at a stratified panel sample of road network (including 'B' and 'C' class roads and unclassified roads) to provide traffic flow information by road type[9] and vehicle type. These traffic counts are measured using inductive loops with piezoelectric sensors such that vehicle length and wheelbase can be identified for vehicles passing over the loops. Traffic data gathered from automatic traffic counters are used to estimate the Annual Average Daily Flow (AADF) for both major and minor roads,[10] which is used to provide a summary of all the variables available in the DfT's traffic data set.

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8 http://webtris.highwaysengland.co.uk/; Legacy traffic flow data prior to 2015 (MIDAS & TMU) are accessible via HADRIS: http://tris.highwaysengland.co.uk/

9 A total of 8 road types that includes a combination of road definitions including motorways, 'A' roads (trunk roads or principal roads), minor roads ('B' or 'C' roads) and area types (urban road, rural road and private roads)

10 Accessible via: https://roadtraffic.dft.gov.uk/about; metadata is available at: http://data.dft.gov.uk.s3.amazonaws.com/road-traffic/all-traffic-data-metadata.pdf

3.2.5. DfT also collects approximately 8,000 manual traffic counts[11] on a single weekday for a 12-hour period (7am-7pm) between March and October, covering both major and minor roads. It is not possible to count every single location every year on major roads, therefore, the sections of road are surveyed on either an annual basis or on a cycle of every 2, 4 or 8 years. Due to the vast number of minor roads in Great Britain it is not possible to count them all, instead a representative sample of minor road sites are counted each year.

3.2.6. DfT publish the traffic volume estimates in units of thousands of vehicle miles travelled (VMT), which form the basis for deriving the national road traffic estimates.[12] The annual estimates are compiled based on both continuous data from automatic traffic counters and roadside 12-hour manual traffic counts as described above.[13] The VMT estimates are derived by multiplying the AADT estimates by the corresponding road length and by the number of days in a year.

Data from Local Authorities

3.2.7. DfT also consolidates raw traffic counts and AADF from local authorities. Historic traffic count data from 2008 to 2018 for approximately 34,000 count sites in 206 local authorities are available at DfT's website.[14] It is noted that at many of these count sites data is not collected continuously, and thus specifications including the number of years, time periods and hourly variations of traffic counts vary across these count sites. The total number of count sites by region and local authorities for the traffic data available at DfT's website from 2000 to 2018 are summarised in Table 3-1.

Table 3-1 - Traffic counts by Local Authority (2000-2018)

Region	Local Authority	Count Point
East Midlands	9	2,654
East of England	11	3,470
London	33	2,991
North East	12	1,653
North West	23	4,125
Scotland	32	2,846
South East	19	5,071
South West	16	3,181
Wales	22	1,960
West Midlands	14	3,469

[11] Number of counter points (CP) available in the public traffic data set varies over year; there are 7,339 (3,153 on major roads and 4,186 on minor roads), 7,833, 7,003 CPs recorded in 2018, 2017 and 2016, respectively.
[12] https://www.gov.uk/government/statistics/road-traffic-estimates-in-great-britain-2018
[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/524848/annual-methodology-note.pdf
[14] https://roadtraffic.dft.gov.uk/local-authorities

Region	Local Authority	Count Point
Yorkshire and The Humber	15	2,856
Grand Total	**206**	**34,276**

Summary

3.2.8. A rich set of time series data which include information on vehicle classification for major arterials including SRN and A-roads are provided through the Highways England and the Department of Transport traffic flow data bases. The data collected includes information on aggregate traffic flows (i.e. they dot no distinguish travel by purposes) for every 15 minutes. It also appears that there are a significant number of counts sites where traffic data are collected by local authorities in addition. A summary of traffic count sites by data owner is provided below.

Table 3-2 – Summary of traffic counts sites by data owner

Owner	Type	# of sites	Method	Location
Highways England	MIDAS	7,250	Radar / Inductive loop	Motorways
	TMU	2,200	Inductive loop	Main carriageway and slip roads at strategic locations along HE road network
	TAME	830	Inductive loop	Inductive loop sites
Department for Transport	ATC	300	Inductive loop	Stratified panel sample of road network covering all road types
	Manual	8,000	Manual counts	Major and minor roads
Local Authority	-	34,000	-	Local roads

3.3 JOURNEY TIME DATA

Introduction

3.3.1. Journey time information is collected by the DfT and Highways England for monitoring congestion levels and the reliability of journey times on the road network. Journey information including average speed of vehicles, average travel time taken to travel along a link and average delay of journeys compared to free flow conditions are published by DfT.[15] These data are purchased from Teletrac Navman (formerly TrafficMaster) by DfT for a sample of over 100,000 vehicles, which consist of approximately 32% cars, 65% LGVs, 2% HGV and 1% other vehicle types (DfT, 2018). Highways England also source journey time data from TomTom which has been utilised in their Post Opening Project Evaluations (POPE).

[15] https://www.gov.uk/government/collections/road-congestion-and-reliability-statistics

Data from Department for Transport

Journey time statistics published annually by DfT are provided for two types of road network in England. First, journey information is provided for the SRN which includes all motorways and many of the long-distance rural roads. Second, information is also provided for local 'A' roads which are managed by local authorities. An additional reliability measure for journey times, which is computed as being the proportion of additional time needed to guarantee arriving on time for 95% of journeys, is available for the SRN only. A summary of the road congestion information published by DfT is provided in Table 3-3. All journey time routes, by region shown in Table 3-4, are provided in Table 3-4. More disaggregated journey times collected by GPS vehicles can be accessed through the DfT (DfT, 2020, TAG Unit M1.2).

Table 3-3 - Road congestion information published by DfT

		SRN	Local 'A' roads
Measures	Average delay	x	x
	Average speed	x	x
	Reliability	x	-
Breakdowns	Urban / Rural	-	x
	AM / PM peak	-	x
	Off peak / Inter peak	-	x
	Region / Local Authority	-	Annually (Feb)
	Road level / Junction level	Annually (Feb)	Annually (Feb)
Data source	Sample fleet size & composition	Travel time from up to 35K cars	Travel times from around 100K cars and light commercial vehicles

Source: Road congestion and travel time statistics: Background quality report (DfT, 2018)

Table 3-4 – Journey time routes by region provided by DfT

Region	Travel Time Routes
East Midlands	793
East of England	1,064
London	75
North East	416
North West	1,017
South East	1,344
South West	1,090
West Midlands	848

Region	Travel Time Routes
Yorkshire and The Humber	626
Grand Total	7,273

Data from Highways England

3.3.2. Highways England collects traffic speed (the average speed of vehicles on a link between two access points to the network and timeframe) and travel time (the average time taken to traverse between two defined points at a specified time).[16] Delay is calculated by comparing the current travel time with the 'expected' travel time. Speed data is collected from the monitoring sites described above, with additional data populated by GPS data from INRIX. Journey times are also measured based on "journey time routes" using the automatic number plate recognition (ANPR) cameras, which match registration plates at consecutive camera monitoring sites. Highways England currently operates an ANPR camera system through the National Traffic Operations Centre (NTOC) with around 1,100 cameras spread across approximately 500 sites on motorways and trunk roads. The ANPR cameras read a vehicle registration number as vehicles pass them. The number plates are immediately converted through a mathematical process known as hashing into non-unique reference numbers (known as tags) at the roadside and the same number plate will generate the same tag on every pass of a NTOC ANPR camera. The camera system does not transmit images of the driver, images of the vehicle, images of the licence plate or the original number plate characters. The data is retained only for the time needed to match a journey between two cameras. Journey time routes are generally shorter for road sections with higher traffic levels. Fused data is also available that combines TMU, TAME, MIDAS and ANPR and floating vehicle data from an external source to report speeds and journey times on a per link basis where links are defined in the National Traffic Information Services NTIS network model.

Summary

3.3.3. Both DfT and Highways England collect journey time data from a large number of routes for both the SRN and A-class roads. Local Authorities in area of interest may be able to provide journey time data for local roads or alternatively may be provided by navigation analytics companies, such as INRIX and TomTom.

16 http://tris.highwaysengland.co.uk/detail/journeytimedata

3.4 PASSENGER COUNT DATA

Introduction

3.4.1. Better data on public transport (PT) was identified as a data gap for the before and after studies in the light of potential modal shift induced by improvements in road capacity. Therefore, an overview of the available PT passenger demand data is provided here. Key national data is consolidated by DfT based on various sources, which includes railway data provides by the Office of Rail and Road (ORR), travel data within London from Transport for London (TfL), and data from local bus and tram operators. Historical annual passenger journeys and passenger kilometres/miles travelled for rail, buses, light rail, tram and underground systems are provided by DfT at national or system levels.[17]

Rail data from the Office of Rail and Road and train operators

3.4.2. More detailed breakdown of patronage statistics is available for rail travel. The Latest Earnings Networked Nationally over Night (LENNON) ticket sales data base contains a matrix of rail trips which covers approximately 2,500 stations on the rail network. The LENNON ticket sales data are summarised by ticket type for 13 accounting periods within a year. The LENNON data is used as the basis for deriving passenger journeys and passenger kilometres/miles travelled for rail trips by the ORR. Annual estimates of station usage including number of entries/exits and interchanges at each railway station in Great Britain, largely derived from LENNON ticketing and revenue data, are also made available by DfT.[18] It is noted that LENNON does not provide information on the characteristics of ticket holders and trips (e.g. service levels, routing, transfer between PT modes). The LENNON data base is owned by the Association of Train Operating Companies (ATOC). Rail passenger counts are also collected by train operating companies at a handful of key stations (40 regional stations and 14 London terminals) in England and Wales on behalf of DfT. These represent a 'typical' weekday in autumn and cover National Rail services run by franchised and concession train operators. Route level passenger counts collected from trains fitted with Automatic Passenger Counting (APC) are available in the Rail Passenger Counts Database maintained by DfT.

Data from Transport for London and local bus and tram operators

3.4.3. Annual bus patronage statistics are provided by DfT, derived from data received from the Public Service Vehicle (PSV) survey and travel statistics for London collated by TfL. The PSV survey is an annual survey carried out by DfT to collect information on passenger journeys, vehicle miles, passenger miles, operating revenue and costs, vehicles and staff from over 500 local bus operators (DfT, 2019). Bus usage within London is based on boarding's captured by Oyster Cards or other forms of contactless card. Bus passenger journeys are summarised by DfT at national, regional and Local Authority (LA) /Integrated Transport Authority (ITA) levels. More detailed information on bus statistics can be obtained from bus operating companies but are often subject to commercial confidentiality issues.

3.4.4. Light rail and tram annual patronage statistics compiled by DfT are derived from the Light Rail and Tram Survey, which collects information on the usage, infrastructure and revenue from all operators (DfT, 2020). Annual passenger journeys and passenger kilometres travelled are provided for each light rail and tram operator by DfT.

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17 https://www.gov.uk/government/statistical-data-sets/tsgb06
18 https://dataportal.orr.gov.uk/statistics/usage/estimates-of-station-usage/

3.4.5. Electronic ticket machine (ETM) data provide information on all journeys rather than a sample. ETM data provides time of travel and can be obtained over long periods of time, thereby avoiding day-to-day variations. They can also relate to the network of services as a whole. However, ETM data will only provide trip records in terms of fare stages at which passengers board or alight, and fare stages may differ between different operators. In areas where the use of travel cards, concessions and other pre-paid tickets are prevalent, ETM data may provide a less accurate picture of passenger movement.

Summary

3.4.6. Availability of data on passenger numbers across PT modes varies across the different modes. The LENNON ticket sales data base provides information on number of journeys for any selected geographic area for rail journeys. Bus, light rail and tram use statistics, however, are only available at LA/ITA levels only. Further details might be made available through direct contact with individual operators.

3.5 MOBILE NETWORK DATA

Introduction

3.5.1. Acquiring high-quality origin-destination data (OD) information for traffic by traditional methods such as roadside interviews or household surveys in a geographic area is both time consuming and expensive. Methods generally present only a snapshot of the traffic situation at a certain point in time. In recent years, transport modellers have developed an approach that makes use of the mobile network data (MND). Instead of monitoring the flow of vehicles in a transportation network, the flow of mobile phones in a cell-phone network is measured and correlated to traffic flow.

Data specifications

3.5.2. MND is collected by mobile network operators (MNO)[19] whenever customers communicate their positions with the network of the MNO cells, including every time they use their mobile phones to text or make a call and through ad-hoc events generated by background applications running on smart phone devices, such as web searching, location services etc. Each of these communications are referred to as an event. Each event that is recorded can be either an 'active' or 'passive' event. Active events refer to mobile phone calls, web browsing, e-mail or text exchanges, with reference to the cells which have been used by customers during such 'live' communications. Generally active events translate into handovers between each cell tower used by a mobile device when active, which generates very detailed spatial information but with a limited sample. This sample limitation applies especially for drivers owing to legal and practical restrictions on mobile device use while driving. Passive events refer to mobile devices background periodic updates and their reassignments between the MNO local area codes (LAC) and as such may not necessarily coincide with activities of the MNO customers on their devices. Passive events translate into handovers between each LAC, which generate less detailed spatial information but with much larger samples. The way the data is recorded allows for the separation of active events from passive events, and the whole pool of events is used for trip identification purposes.

[19] MND from Telefonica (O2 data), INRIX (O2 data) and Citi Logik (Vodafone data) have been applied for transport analysis In the UK (Perret, 2015)

3.5.3. Mobile phone market penetration rates for each geographical area and bands (or generations, e.g. 2G, 3G or 4G) may be different between MNOs. This leads to heterogeneity across bands[20] and differential MNO unexpanded sample sizes[21] and may lead to selection bias (e.g. due to a particular MNO which appeals more to certain socio-demographic group). The cell maps for geo-referencing event data are also different across MNOs. The size of cells can vary significantly (from 500m in urban areas to around 7.5km in rural areas), which will influence the spatial accuracy of the events. There appears to be a consensus amongst MNOs that release of MND trips at Middle Layer Super Output Area (MSOA) is an appropriate level of geography, however in a number of studies it has also been possible to obtain data at the Lower Layer Super Output (LSOA)[22].

3.5.4. Detection of the mode of travel using MND has not yet been fully developed beyond segregation of rail trips from road trips. Rail trips are readily detected using cluster and speed profile analysis, and whilst other data mining techniques[23] have been explored to identify HGV and bus trips the methods are not currently considered sufficiently robust to allow further disaggregation of these modes.

Highways England Trip Information System (TIS)

3.5.5 The Highways England Trip Information System (TIS) comprises of a database of trip information and a web-based interface which allows users to extract origin/destination matrices for motorised road or rail trips. The database has been built for Highways England by O2 Telephonica using data extracted from its UK mobile phone network. The system currently contains anonymised trip records covering the whole of Great Britain for the years 2016 and 2019. Either of these two years can be selected for at least 20 separate days and the results provided are an average of those days. Individual hours for the selected days (e.g. 08,00 – 09.00), groups of hours (e.g. 07.00 – 10.00), or a whole day for the matrix time period can be provided. The matrices are segmented by 'commuting' and 'other' trip purposes. Trips can be Home-Based/Non-Home Based or combined.

3.5.6 The data contained in TIS is based upon the observed trip patterns of O2 users which have been expanded to represent the full GB population i.e. person trips. However, person trips by motorised road mode are not segmented by vehicle type. Data is provided in the form of trip matrices for a user specified zoning system based upon Middle Super Output Areas (MSOA's) and Scottish Intermediate Zones (IZ's). The zone system must cover the whole of GB and zones will typically be individual MSOA/IZ in the area of interest and aggregation of MSOA/IZ elsewhere. The MSOA/IZ is the minimum spatial resolution to which data can be provided.

3.5.7 Verification tests of the data are reported in the TIS User Guide of the comparison of TIS data with other data sources (NTS, Census, TfL, ORR passenger rail totals and screenline counts). Data is provided in the form of trip matrices containing the average number of observed (expanded) trips during dates and times specified. A 'Full Matrix' will contain all trips in the zone system. For motorised road matrices, a 'Route Matrix' can also be provided in relation to any Full Matrix. A Route

[20] An example is that 2G users will generate significantly fewer events as only older handsets will likely to connect to 2G cells.
[21] Sample rate can reach 30% approximately for a given road for repeated sampling over certain time frame from full population of operator's subscribers (Tolouei et al., 2017)
[22] MSOAs have an average population of 7500 residents or 4000 households; LSOAs have an average population of 1500 people or 650 households. There are 9,326 and 42,143 of MSOAs and LSOAs defined in 2011 Census, respectively
[23] Mode detection based on CDR data can be carried out by using the clustering technique (Wang et al., 2010), kernel density estimation (Doyle et al., 2011) or logistic regression model (Qu et al., 2015); latest advancement include the use of machine learning including neural network (NN) using GPS, accelerometer and magnetometer data streams from smartphones could potentially improve the mode detection capability significantly using MND (see Byon & Liang, 2014).

Matrix will contain only those trips in the corresponding Full Matrix which pass through a series of points on the major route network selected by the user.

3.5.8 The TIS output is provided in the form of trip matrices which relate to the average number of trips, aggregated over a period of at least 20 days. At a spatial level, aggregation is to MSOA's which contains a minimum of 5,000 residents. TIS matrices should not be inserted directly into transport models without further work first being undertaken by the modeller. Verification of the data in the area of interest should be undertaken by reference to other data sources.

3.5.9 TIS matrices for motorised road trips are person trips by motorised road. The person trips are not segmented by motorised vehicle types and employer's business trips are included in the 'other' trip type category. Since these are the minimum requirements for highway models, it will be necessary to dd these attributes to the data using other data sources.

3.5.10 The TIS website and database is available for use to support the business activities of both Highways England and the UK Department for Transport. Access is granted in relation to specific Highways England and DfT projects subject to the terms and conditions set out in the TIS website. The trip record data within TIS contains no personal information. The O2 User Identification in each record is also anonymised and is not part of any TIS output.

Summary

3.5.11 One of the strengths of Mobile Network Data compared to traditional link-based count information is that it provides information on the origins and destination of users. Key strength of MND is large sample sizes: for example, each of the major network providers contains travel information for about 30% of the population over long periods of time.

3.6 GPS TRACKING SYSTEM

3.6.1 During the COVID-19 pandemic, Google released data collected through smartphone tracking data showing mobility trends of citizens in areas such as parks and residential spaces to show movement patterns during the coronavirus lockdown. Google would typically collect the data to help customers plan visits to businesses and for businesses to see customer trends, showing information including popular times, live visit information, waiting times and typical visit duration.

3.6.2 Work from home, shelter in place, and other policies aimed at flattening the curve of the pandemic revealed huge changes in public movement through the data. The reports use aggregated, anonymised data to chart movement trends over time by geography, across different high-level categories of places such as retail and recreation, groceries and pharmacies, parks, transit stations, workplaces and residential. Trends were depicted over several weeks. Whilst percentage point increases or decreases were displayed, the absolute number of visits were not shared.

3.6.3 Changes for each day were compared to a baseline value for that day of the week (the baseline was the median value for the corresponding day of the week). The reports showed trends over several weeks (data was typically presented for trends 2 or 3 days beforehand – this being how long it takes to produce the reports). The data used to produce this information depends on users' settings, connectivity, and whether it meets their privacy threshold. If the privacy threshold isn't met (when somewhere isn't busy enough to ensure anonymity) they don't show a change for the day. Information was presented for different activity categories that were useful to social distancing efforts as well as access to essential services.

3.6.4 Google calculate these insights based on data from users who have opted-in to Location History for their Google Account, so the data represents a sample of their users (this sample may or may not represent the behaviour of a wider population). Individuals can choose to turn off Location History at any time from their Google Account and can always delete Location History data directly from their Timeline.

3.6.5 GPS data is a reliable source of information to measure speeds and journey times, however it is not currently available in the quantities required to build a trip database such as TIS.

3.7 AUTOMATIC NUMBER PLATE RECOGNITION (ANPR)

3.7.1. As discussed in the earlier section on journey time data, there are approximately 1,100 ANPR camera sites located along the SRN for derivation of journey times between two consecutive sites and detection of traffic incidents. The current policy set out by HE restricts the transmission of images of the driver, vehicle, license plate and the characters on number plates.[24] Other than being used for the calculation of journey time across network, ANPR technology can also be used to identify vehicles by using optical character recognition (OCR) software to record and process images for every vehicle for toll collection purposes. ANPR technology is used to measure road use for the congestion charging schemes in London (2003) and Stockholm (2007). That said, despite the ANPR technology has been applied successfully these congestion charging schemes, it is unlikely that ANPR camera sites along motorways could be used for vehicle detection or capturing traffic origin-destination patterns unless there is a change in official policy around privacy of such information.

3.8 ROADSIDE INTERVIEWS

3.8.1. Roadside interview data is manually collected from drivers travelling through a specified study area. Their main purpose is to identify travel patterns usually for a specific purpose and geographical context. The data is generally used to develop trip demand matrices. In general, origin and destination data are collected, but the surveys usually incorporate additional information such as journey purpose and vehicle occupancy.

3.8.2. Roadside interview data can provide a detailed picture of the travel patterns and choices of interviewees, including origin, destination, home and work locations, vehicle type and occupancy However, the costs of undertaking these surveys is high, which limits sample sizes and geographical coverage. There are also practical limitations associated with undertaking surveys. For instance, roadside interviews cannot be carried out on motorways or roadways which carry high traffic levels.

3.8.3. However, the use of roadside interviews is unlikely to provide good estimates of induced demand because of the variation in travel across days, weeks, months and years.

[24] https://highwaysengland.co.uk/why-does-highways-england-use-anpr/

3.9 HOUSEHOLD INTERVIEW SURVEYS

Introduction

3.9.1. Household surveys provide detailed information on travel by residents of a study area; however, these surveys are rarely undertaken due to the expense and consequent very small sample size. Household surveys collect information on all travel (including trip purpose, modes used, time of travel, occupancy levels for cars, trip origins, trip destinations etc.) as well as socio-economic information on households and individuals living in the household. The primary application of data from household surveys is in the analysis of travel trends and in the estimation of demand models. Moreover, household interview sample sizes are rarely sufficiently large to provide acceptably accurate estimates of trips between geographical areas.

National Travel Survey

3.9.2. The National Travel Survey (NTS) is a continuous cross-sectional household survey designed to provide detailed information on personal travel patterns and to monitor long-term travel behavioural changes. NTS has been carried out every year since 1989. Travel data within NTS are collected based on detailed 7-day travel diaries which record all journeys[25] made during a travel week from all members of household sampled. Information on households, individuals and vehicles are collected based on interview sample.[26] Over 15,000 representative individuals across England are surveyed each year.[27] Survey data are weighted to match population estimates of household residents based on Census data in England.

3.9.3. The NTS contains information on journeys including the journey purpose, start time, arrival time, origin, destination, mode of travel, distance, time spent on travel, number in party, vehicle used, driver/passenger, parking costs, ticket type, ticket cost and number of boarding's.

3.9.4. Household and individual level data available from the NTS include household vehicle access, household composition, household socio-economic data; data available at individual level include age, gender and marital status, social and economic information, trip frequency, possession of driving license, vehicle type, employment, occupation, income, possession of season ticket details, etc.

3.9.5. NTS data are provided at different levels of detail by DfT. Trip origins and destinations are available at Local Authority/Unitary Authority (UA) level via access to the 'special license' version available at the UK Data Service.[28] Postcode sector of household sample (i.e. home location) can be accessed only via the 'secure access' version, which is subject to more restricted access conditions.

Summary

3.9.6. NTS is a continuous survey which allows the analysis of seasonal and cyclical variations of travel and captures all travel choices made by individuals and family members. It is noted that trip destinations are available at Local Authority level only and sample size.

[25] Including short walks under a mile, collected on day 7 of the travel diary
[26] Approximately 60% of interviews are carried out face-to-face, while the rest of the 40% are collected from proxy interviews (i.e., responses from a respondent about another household member) (Cornick et al., 2019, p.17)
[27] 17.7K, 16.6K and 16.6K interviews were carried out in 2016, 2017 and 2018, respectively (Cornick et al., 2019); 1,017, 681, and 625 interviews were carried out in 2018 for London, West Midlands and Yorks & Humber
[28] Accessible via: https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=7553

3.10 CENSUS DATA

Introduction

3.10.1. The UK census collects a range of demographic and socio-economic data across the whole population in the UK every 10 years since 1801. The last census was undertaken in 2011. There are four distinct types of census data produced by the national statistical offices (NSOs):[29]

- Aggregate statistics;
- Microdata;
- Origin-destination flows; and
- GIS-based boundary data.

Stillwell (2018) provides a comprehensive overview on the methods and delivery of the different products from the 2011 UK Census.

Data specifications

3.10.2. Aggregate census data provides population and household estimates at postcode level. There are established tables produced by NSOs which provide univariate summaries of census data (e.g. on single topic such as car availability) for the smallest output areas whilst more detailed multivariate tables (e.g. cross tabulations of two or more topics such as distance travelled to work by car or van availability) for small areas are also compiled.[30]

3.10.3. Microdata, containing information from individual census responses, are also available for analysis. The key advantage of using census microdata lies in the ability to conduct multivariate analyses at sample individuals' level. There are different levels of access rights to the census microdata for public and researchers. The 'safeguarded' census microdata which are accessible to researchers from academia and public sector in the UK contain 5% (~3 million) records of individuals surveyed in 2011, with a 3% sample accessible for the 2001 census data.[31]

3.10.4. In addition to cross-sectional microdata, longitudinal studies (LS) microdata provides a 1% sample which links records and life events data (e.g. births, deaths immigration) across censuses since 1971. LS census data allow researchers to explore what happens to the LS members through the life course. For instance, the linked census data allows researchers to trace the changes in the usual mode of transport to work by LS members through two or more censuses. Access to the LS data is more restrictive to ensure confidentiality.[32]

3.10.5. The UK census also captures how commuters in formal employment *usually* travel between home and their usual places of work (i.e. 'journey-to-work'). Information on workplace location and characteristics, distance to work, and mode of transport to work for commuters are provided in the census microdata, which are unaggregated outputs containing samples of anonymised individual records.

[29] The UK census is carried out in three separated but coordinated censuses by the NSOs including the Office for National Statistics (ONS) in England and Wales, National Records of Scotland (NRS) and the Northern Ireland Statistics and Research Agency
[30] These summary tables include Key Statistics (KS), Quick Statistics (QS), Detailed Characteristics (DC) and Local Characteristics (LC) tables; See a list of aggregate tables: https://www.nomisweb.co.uk/census/2011
[31] Accessible via UK Data Service: https://census.ukdataservice.ac.uk/get-data/microdata.aspx
[32] CeLSIUS provides LS research support for the academic and public sector; accessible via: http://www.ucl.ac.uk/celsius

3.10.6. Aggregated origin-destination data (or called 'flow data' or 'interaction data') for commuters are provided at MSOA level and Output Area (OA) in the 'safeguarded' and 'secure' census data, respectively.[33] OA is the smallest spatial unit for which census data could be published, which typically targets to withhold approximately 110 to 140 households in each unit.[34]

Summary

3.10.7. Since census surveys are carried out every ten years, the data is only suitable for understanding long-term changes in demographic and socio-economic characteristics over time. Also, Census Journey to Work (JTW) data consider trips travelling between home and the usual workplace for commuters only. So, there is a lack of precise information on the number of trips from the reported 'usual' journeys to work. The total number of commuting trips could be over-estimated when employees are assumed to go to work every day, without considering that employees might not go to work every day due to sickness or leave (DfT, 2014, TAG Unit M1.2). On the other hand, commuting trips could be under-estimated when workers work from home occasionally.

3.11 QUARTERLY LABOUR FORCE SURVEY (QLFS) / ANNUAL POPULATION SURVEY (APS)

3.11.1. Quarterly Labour Force Survey (QLFS) is a residence based repeated cross-sectional survey to provide information on the UK labour market. The QLFS is conducted by the Office for National Statistics (ONS) quarterly from 1992 to survey households living at private addresses in the UK. The QLFS collects information on employment, unemployment and economic inactivity and related topics such as occupation, training, place of work and personal characteristics of household members aged 16 years and over.

3.11.2. The QLFS surveys approximately 44,000 households for each quarter. The Annual Population Survey (APS) is a continuous survey of households from 2004 which combines results from the QLFS to provide information on important social and socio-economic variables at local levels. Each APS data set with 12 months of survey data contains responses from 155,000 households and 360,000 respondents approximately. The QLFS only provide reliable data at regional level while the APS provides data for Local Authority districts. The QLFS and APS are the official measures of employment and unemployment and is regarded by ONS as the best measure of total jobs in the economy.

3.12 BUSINESS REGISTER AND EMPLOYMENT SURVEY (BRES)

3.12.1. The Business Register and Employment Survey (BRES) is a survey of business which provides the official measure of employee and employment estimates by detailed geography and industry. BRES collects employment information from approximately 80,000 businesses selected from all industries and is regarded as the better data source in providing industry detail compared to household surveys such as the APS. ONS publishes the annual BRES data including the number of employees or employment on a full-time and part-time basis down to lower super output area (LSOA) geography at a five-digit UK Standard Industrial Classification 2007 (SIC 2007) on the National On-line Manpower Information Service (NOMIS). Since BRES data provides detailed industry information, the outputs are regarded as the best estimates at a regional and industrial level.

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[33] For multivariate analysis; Accessible via UK Data Service: http://wicid.ukdataservice.ac.uk/
[34] 2011 census surveys 9,326 MSOA and 232,296 OA spatial units across the UK (Duke-Williams & Routsis, 2019)

3.13 MID-YEAR POPULATION ESTIMATES

3.13.1. While the census provides the most authoritative population estimates every 10 years in the UK, the mid-year population estimates provide the official set of population estimates between censuses. These mid-year population estimates are produced by ONS at 30 June each year until the next census. The population estimates for the usual resident population are provided down to the Local Authority level by age and gender on NOMIS.

3.14 TEMPRO PLANNING DATA

3.14.1. Most transport models developed for multi-modal studies predict demand changes that are derived from exogenously defined planning data. These planning data should be largely consistent with the projections in the National Trip End Model (NTEM) as suggested by the official appraisal guidance. This is to ensure that different regions do not overstate local growth rates which are not achievable when aggregated across the whole economy, maintaining consistency in appraisal across projects. NTEM projections are published in a data base format by DfT, where results can be extracted via a data browser called TEMPro (Trip End Model Presentation Program).

3.14.2. NTEM datasets provide the industry standard for long-term traffic responses to demographic and economic trends. NTEM generates travel demand forecasts at Local Authority district level through a set of 3 interconnecting models:

- Scenario generator which forecasts demographic data (population, employment, households;
- Car ownership model which forecasts the number of cars owned by households; and
- Trip end model which applies National Travel Survey (NTS) trip rates to households for generating trip forecasts by household type and time of day, based primarily on middle layer super output area.

3.14.3. TEMPro can be used to approximate the effects on trip ends related to changes in planning assumptions about households and jobs. TEMPro forecasts are also used to calculate traffic growth in vehicle miles using the National Transport Model (NTM), the results of which are published in the Road Traffic Forecasts (RTF).[35] The latest version of TEMPro provides traffic forecasts for trips on foot, and by bicycle, motor vehicle (both as a driver and passenger), rail and bus. Traffic forecasts for 2010-2040 and 2015-2050 are produced based on the 2015 and 2018 publications of the RTF, respectively. Both the NTEM datasets and TEMPro data browser can be downloaded from the DfT website.[36]

3.14.4. TEMPro represents the industry standard for traffic growth predictions that are regularly updated to reflect changing economic conditions. However, it is acknowledged that the predictive accuracy of the TEMPro model might not reflect reality in retrospectively analyses (e.g. Clark, 2016).

[35] https://www.gov.uk/government/publications/road-traffic-forecasts-2018
[36] https://www.gov.uk/government/publications/tempro-downloads

3.15 OS/MHCLG LAND USE CHANGE STATISTICS

3.15.1. Land use change (LUC) statistics generated by the Ministry of Housing, Communities and Local Government (MHCLG) provides information on land use changes in England.[37] The LUC data base reports information annually on the nature of land-use changes, specifically the areas of land affected and the locations of the changes. The LUC statistics are produced from two data sets prepared by the Ordinance Survey (OS), which include the residential address-based change data and the land use-based change data.

3.15.2. The residential address-based change data logs the creation of residential addresses and changes in density due to building of a new property, or the conversion of buildings to residential use form a previously non-residential use (e.g. offices or retail). It also covers changes related to deletion of residential addresses due to demolition of residential property, or when residential property is converted to a commercial or other non-residential use. The land use-based change data reports changes in physical area in hectares, which can be used to assess how land uses differ between locations and land use types over time.

3.15.3. These two datasets are aggregated to Local Authority and national levels for 28 land use types, grouped into 14 land use groups and classified as either developed or non-developed land. It is advised that historical land use change statistics from 1985 to 2011 should not be compared to the more recent statistics due to a significant change in methodology implemented in 2012. It is also anticipated that the statistical releases starting from 2018 will incorporate new methodological changes as per feedback from consultation.

3.16 OS MASTERMAP HIGHWAY NETWORK CHANGE UPDATES

3.16.1 OS MasterMap brings together the Ordnance Surveys detailed road and path information together with the National Street Gazetteer (NSG) and the Trunk Road Street Gazetteer (TRSG). The NSG and TRSG contain the definitive information provided by the Local and National Highways Authorities.

3.16.2 The Roads product provides a topologically structured link and node representation of the road network. The roads product provides information on names associated to the road network whether that be the legal definitive view of a road name, the plated road name, road numbering and junction names. In addition to naming information the product also provides information on road classification, road function, primary routes, and road node classification.

3.16.3 The Roads product is available as both full supply and can be ordered as an Area of Interest (AOI) or a Managed GB set.

3.17 RELIABILITY OF DATA SOURCES

3.17.1. The key characteristics of the data sources examined are summarised in Table 3-5.

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[37] https://www.gov.uk/government/collections/land-use-change-statistics

Table 3-5 – Data sources and their key strengths and possible weaknesses

	Key Strengths	Possible Weaknesses
Traffic flow data,	Abundant set of flow data along	More information on the availability
Passenger counts (DfT)	Very rich set of LENNON ticket sales data for rail trips and station usage statistics Historical annual demand estimates are available for all PT modes at national or regional level	Lack of data on passenger demand at more refined time period or route-level statistics other than the national or regional statistics compiled by DfT
Mobile Network Data	Potentially large sample size, wide	Sample errors and errors from
Journey time and travel speed	Significant number of journey time routes for both the SRN and A-class roads collected by GPS vehicles Traffic speed information are measured continuously along the motorways by MIDAS detectors and TMUs	There is lack of travel speed information for local roads other than major arterials
Automatic Number	ANPR technology has been applied	It is unlikely that ANPR camera sites
Ticket sales data (LENNON & bus/LRT operators)	Origin-destination matrix developed based on LENNON ticket sales data provides flow information between any stations Oyster Cards and smart card payments could be used for approximation of origin-destination matrices for PT modes	Additional data sources are required to convert the ticket sales from boarding's to number of journeys Very limited ticket sales data available other than for the rail mode or travel within TfL
Roadside Interviews	Ability to provide a detailed picture of the	Labour intensive, time consuming

	Key Strengths	Possible Weaknesses
		Potential for response bias due to annoyance or lack of knowledge. Limited geographical coverage. Limits on sample size, and accordingly, spatial accuracy of data. Surveys cannot be carried out on motorways or roads which carry high traffic levels.
National Travel Survey (NTS)	A continuous survey which allows the analysis of seasonal and cyclical variations of travel. Able to capture all travel choices made by individuals and family members. Household and individual characteristics can also be captured.	Trip destinations are available at Local Authority level only. Sample size not large enough to capture changes on routes.
Census Journey to Work	Very detailed information on the characteristics of households and individuals Able to track travel behavioural changes for respondents over time based on Census Longitudinal Study data set	Census is carried out for every 10 years only Census records traveller's usual journey to work only
Quarterly Labour Force Survey (QLFS) / Annual Population Survey (APS)	APS contains a large sample size with data available for each month Best source of information on employment and unemployment The official measure of total jobs in the economy	Less reliable information at industrial level compared to BRES data
Business Register and Employment Survey (BRES)	The official measure of jobs at detailed regional and industrial level	Sample size are less than the LFS/APS
Mid-year population estimates	The most authoritative population estimates in-between censuses	Population estimates are reliable at Local Authority level only
TEMPro	Industry standard for traffic growth predictions Regular updates as per changing economic conditions	Forecasts might be different from actual outturns
OS/MHCLG Land Use Change (LUC)	A rich set of data that provides information on land use change	The residential address-use change data might not match total housing supply published by the local

	Key Strengths	Possible Weaknesses
		authorities due to differences in timing and statistical definitions. The hectarage change data reports marginal changes only without indication of the overall land use stock
OS MasterMap / Highways Network	A rich set of data that provides detailed information on the road network and road network changes	None perceived. Road network changes usually available at 6-monthly intervals.

4 THE POTENTIAL FOR IMPROVING THE MEASUREMENT INDUCED TRAVEL

4.1 INTRODUCTION

4.1.1. In this section the potential for developing more detailed estimates of induced travel is assessed, taking account of information on approaches for measuring induced travel (set out in Chapter 2) and data (set out in Chapter 3).

4.1.2. It explicitly addresses the potential for deriving:

- Short-run and long-run elasticities;
- Elasticities for different journey purposes, e.g. for commuting, business and other travel purposes; and
- Elasticities by different types of road users, e.g. passenger and freight travel.

4.2 RATIONALE FOR A TWO-PRONGED APPROACH

4.2.1. A key finding from the evidence review was that it is difficult to compare evidence from econometric studies, which report elasticities that represent the percentage change in vehicle kilometres travelled (VKT) relative to a percentage change in road capacity and case studies that report percentage changes in traffic relative to the baseline associated with a specific road network improvement. However, these approaches can be used in a complementary way to provide information on induced traffic that can be used to improve transport appraisal.

4.2.2. As discussed in Chapter 1, induced traffic can be considered to consist of the change in traffic VKT on a network that results from a change in:

- Mode of travel, e.g. switching from public transport to driving;
- Frequency of travel, specifically in terms of making additional trips that were not made previously;
- The distance travelled by changing route to the same destination or to a new destination;
- The distance travelled by changing destination (change location of activities); and
- In the longer term, the distance travelled due to changes in residential or employment location or as a result of changes in land-use.

4.2.3. In practice, measured induced traffic effects will depend on the time period over which they are measured (e.g. peak hour or daily averages) the geographical area and whether short-run or long-run effects, particularly on land use, are included, although these factors are not often clearly specified in the definition of induced demand used.

4.2.4. As it is unlikely that any one method can fully take account of all these aspects, we see value in using a two-pronged approach for measuring induced travel:

- Approach 1: Undertaking an econometric approach to provide an estimate of the elasticity of induced demand, from analysis of historic count data.
- Approach 2: Improved before and after case studies, making use of existing data sources previously used in these studies to a higher specification and new data sources that have not previously been used in these studies i.e. mobile network data (MND).

4.2.5. An econometric analysis should provide a robust estimate of induced travel, measured through changes in VKT. This approach would make use of the large-scale time series count data already collected on the SRN. Ideally, it would also make use of count information on other roads, which could help determine how much of the measured VKT on the SRN can be attributed to re-assigned traffic that does not change total VKT on the network (i.e. VKT travelled on the SRN instead of on another road) and therefore does not contribute to induced travel. Only the additional VKT arising from a route change is included in induced travel along with VKT from mode shifts and newly generated traffic (suppressed demand). The output would be an aggregate measure (elasticity of demand per lane-km, for example). The value is in providing a **robust estimate of induced demand**. The quality of this estimate will be influenced by the data used in the econometric analysis. Careful data assembly, undertaking analysis at both aggregate and detailed levels and careful comparison of results to understand their differences can be used to improve quality.

4.2.6. Theoretically it should be feasible to explore short-run and long-run elasticities and to explore differences between passenger and freight travel. An econometric approach would also quantify the impacts of background growth, which could inform before and after case studies. Tests could be undertaken as part of the analysis to explore whether it is feasible to quantify different induced travel effects according to the level of aggregation of count data, for urban and non-urban road settings or for different levels of congestion and by the type of intervention, e.g. widening schemes, bypasses, new roads, smart motorways, etc. The key shortcoming of this approach is that an approach based on SRN counts only would not provide induced travel measures by journey purpose or behavioural response, e.g. re-assignment, mode shifting or destination choice (although it may be possible to quantify re-assignment and mode-shifting effects, depending on data availability, which is discussed in subsequent sections).

4.2.7. Improved before and after studies could provide more information on how road capacity changes impact the number of trips (across a screenline) in specific contexts. It could also provide information on the size of differing behavioural responses, e.g. re-assignment, mode and destination shifting. We propose a number of improvements from current practice, including:

- Use of mobile phone data to quantify before and after traffic (matrices) to provide a better measure of traffic with more geographical representation (as matrices). This information may help to quantify the size of different behavioural responses, e.g. re-assignment, mode and destination switching and frequency responses.
- Better estimation of background growth, incorporating information obtained from the econometric approach in terms of elasticity of demand with respect to GDP changes, car ownership changes and fuel price changes, as well as inclusion of observed detailed land-use changes. We also recommend inclusion of comparator sites to provide measures of background growth for validation purposes.

4.2.8. Details of the econometric and before and after approaches and what would be needed to undertake each of these are set out in the following sections.

4.3 KEY CONSIDERATIONS FOR THE ECONOMETRIC APPROACH

GENERAL APPROACH

4.3.1. Econometric techniques have been quite widely applied to estimating the impact on road travel that result from changes in road supply, albeit not in the UK (WSP, 2018). These approaches aim to provide a quantitative estimate of the demand response to a change in road capacity using data collected over a given time period and geographical area.

4.3.2. In its most simplistic, linear form, a regression equation to estimate the demand response can be expressed as:

$$\mathrm{D}_{\mathrm{it}} = \alpha_i + \beta_t + \gamma R_{it} + \sum_k \delta_k X_{kit} + \varepsilon_{it} \qquad (1)$$

where *D* denotes the demand for road travel, *R* the road supply, subscripts *i* and *t* the unit of spatial and temporal measurement respectively and the coefficient γ represents the portion of demand that can be explained by supply. Other variables that influence demand are captured in X_k, where variables are distinguished by subscript *k*, or through wider effects not easily measured through specific variables and that only vary spatially (α_i), often referred to as fixed effects, or over time (β_t) only. Finally, the error term, ε represents any remaining influences on demand not captured by the explanatory variables.

4.3.3. Many econometric studies directly estimate or derive the demand response as an elasticity. This measure indicates the percentage change in demand that would occur in response to a percentage change in road capacity. This is a useful measure for quantifying the size of induced transport effects. It may also be able to be used to validate transport models (see Chapter 5).

4.3.4. Using a log-log formulation allows the elasticity to be estimated directly from the regression as the coefficient γ.[38]

$$Log(\mathrm{D}_{it}) = \alpha_i + \beta_t + \gamma Log(R_{it}) + \sum_k \delta_k X_{kit} + \varepsilon_{it} \qquad (2)$$

From a mathematical perspective, this approach requires that road supply is measured as a continuous variable (normally lane-kilometres).[39] We note here that, although the elasticity measures the percentage change in demand with respect to a percentage change in supply, the coefficient is obtained from an estimation that uses measured demand and supply (and not changes).[40]

4.3.5. The above formulation can also be extended so that the demand response with respect to other variables are also measured as an elasticity (as long they are included in the estimation in logarithmic form). For example, the demand response (traffic growth) to background variables such

[38] We note that for regressions that involve more complex systems of equations but use the log-log form (e.g. Hymel et al), elasticities can still be obtained from a combination of the estimated coefficients.

[39] This approach will therefore not be able to incorporate dummy variables for other supply characteristics that may impact road capacity.

[40] Differentiating (2), one obtains $\frac{R}{D}\frac{\partial D}{\partial R} = \gamma$. Other estimation approaches could be formulated in terms of changes in the variables but would not lead directly to an elasticity estimate.

as population could be quantified as elasticities. These could be compared to background growth estimates in transport models. They could also be useful for before and after studies to help understand and quantify the share of observed demand that can be attributed to background growth, when data on changes in background variables are available.

4.3.6. It is also possible to obtain the elasticity from the econometric results in other ways. Van der Loop et al. (2016) derive the elasticity in two steps, for example, because they incorporate dummy variables to represent the road supply change. They first estimate a linear equation to determine the demand response to road capacity changes (or interventions) represented by indicators (dummy variables). The demand response is then used to calculate the share of demand that can be explained by the road capacity change. The elasticity is obtained by dividing this percentage change in demand by the percentage change in road capacity, where road capacity is measured in lane-km. This is a more approximate approach for calculating the elasticity but also requires data on road supply in lane-km, although this is not used directly in the regression.

We are not aware of any study that has compared the approaches for calculating elasticities. This is something that could be tested in subsequent research to test differing approaches – and the impact of these approaches – on estimates of induced demand.

Beyond the exact formulation of the regression equations, there are a number of key points to consider when developing an econometric approach to estimate the demand response to changes in capacity on the road network in England. We address each of these in turn and provide recommendations on what this would mean for future analysis (in Section 2.4).

OBSERVATION UNIT FOR DATA

4.3.7. A spatial unit of measurement for the road traffic demand and supply data (subscript i in equation (1)) must be specified to determine the induced demand response. Most econometric studies use data aggregated to the state or metropolitan area level (e.g. Duranton and Turner, 2011, Hymel et al., 2010, Hsu and Zhang, 2014, Gonzales and Marrero, 2012). This means that the demand response is an average response to changes in road capacity on the whole road network and while this could include both additional lanes and new roads, local variation in responses to particular road schemes cannot be captured. Cervero (2003) considers lane expansions for 24 separate road projects in one state (estimating a single demand response across the 24 projects but including fixed effects for each one). Van der Loop et al (2016, 2018) use data at the detailed road segment level to estimate road-specific responses. As noted earlier, it is common practice to include a fixed effect constant (α_i) corresponding to the spatial unit of the analysis in the estimation to control for time-invariant characteristics that are not covered by the other variables.

4.3.8. The unit of measurement for time – with regard to the measurement of travel demand specifically, but possibly other variables, e.g. GDP, fuel prices, etc. - is also an important consideration. Annual average daily traffic flow (AADT) is a common unit of measurement for road traffic and is most often used in studies in which the regression variables are specified at the area (i.e. state or metropolitan) level. Although time trends or dummies (β_t) are often included, these are designed to capture broader, background effects that could influence road traffic demand over and above the other factors included in the regression equation, e.g. background traffic changes. Using annual data means that any variation over the year on the road network of interest due to changes in 'situational characteristics' such as major roadworks or other localised interventions that influence road travel are unlikely to be picked up. Including more frequent data measurements could control for these effects, particularly when provided for data at the more detailed road scheme or road segment level. Van der Loop et al. (2016, 2018) undertake their analysis using average monthly traffic flow data.

4.3.9. The time period of the analysis may be to a certain extent be determined by data availability. It is also relevant for determining short run and long run responses. Time periods ranging from 8 years (Gonzales and Marrero, 2012) to 38 years (Hymel et al., 2010) have been used. In theory, as the demand response (ɣ) is time-invariant, a larger number of years provides a larger dataset for the estimation. However, when selecting the time period, account may need to be taken of societal changes that could influence travel behaviour in a way that is not captured in other control variables.

MEASURING ROAD TRAVEL DEMAND

4.3.10. Vehicle-kilometres travelled (VKT)[41] is almost exclusively used as the measure of road traffic demand in econometric studies. This is consistent with the definition of induced demand used by DfT (see WSP, 2018). It is determined by multiplying traffic counts (or flows) by road length (in kilometres).

4.3.11. As discussed earlier, re-assigned traffic does not form part of induced demand unless it adds to VKT on the road network. It is, however, difficult to quantify the portion of re-assignment that adds to VKT in econometric approaches as the VKT measure of demand is likely to include **all re-assigned traffic not just the additional VKT that is added to the network as a result of the route change** (along with traffic from other modes and newly generated traffic).

4.3.12. Studies that consider **total demand and supply changes on all roads in a region** take account of such re-assignment effects because traffic moving from one road type to another as a result of a supply change that does not add to VKT on the network (re-assigned traffic) will not affect the total demand. Hence the change in total demand will reflect only new VKT on the network (induced demand).

4.3.13. For studies that examine demand and supply changes on a **particular road type (e.g. motorways or the SRN)**, the VKT measure of demand will include all traffic that has moved from (or to) other road types. One approach to deal with the re-assignment problem is to estimate the demand response on other roads as a result of a capacity change on the road of interest (effectively a cross-elasticity). Including these demand responses separately in the estimation requires appropriate data to be available across the road network (Rentziou et al.,2012, Duranton and Turner, 2011). This may be simpler for an area-based approach, although for strategic routes, the choice of route may cover more than one area. For road scheme/road segment-based approaches, the geographical scope would need to be decided empirically. However, even with this caveat, there is value in having a measure of the size of induced demand. Moreover, the resulting demand elasticity (including re-assignment) may still a useful comparator for transport models (see discussion in Chapter 5).

MEASURING ROAD SUPPLY

4.3.14. Several different specifications have been used for road supply, with road capacity, measured in lane-km, being the most common (e.g. Hymel et al 2010, Duranton and Turner, 2011). Dummy

[41] Or vehicle-miles.

variables can also be used to indicate that a policy designed to improve road capacity has been implemented (Van der Loop, 2016, 2018). The use of dummy variables is likely to be most effective for estimations using data at the road-segment level rather than a less detailed spatial level but also has implications for the estimation approach. While this approach can distinguish between policy options that are implemented on different roads or road segments (e.g. a one lane widening on 60 km of the M1 and a two lane widening on a section of the M6), multiple options, such as smart signage, variable speed limits and lane-widening, implemented on the same road segment cannot be differentiated. Moreover, although the dummy variable does not provide information on the amount of lane-km added on a road segment, this information is used in the elasticity calculation.

4.3.15. Road supply affects demand for road travel by reducing the time element of the generalised cost to the traveller.[42] In essence, when the cost is lower than the user's willingness to pay, road travel will increase as a result of mode switching or additional VKT from new or longer trips. In urban areas or on highly congested routes, the demand response is also likely to be larger as there is more suppressed demand.[43] However, the level of congestion on a route is a function of both the demand and the capacity of that route. Hence an increase in road capacity may reduce congestion, which reduces the cost of travel leading to increased demand, which in turn again increases congestion.[44] There are a number of ways in which these responses could be accounted for.

- A separate demand response can be estimated for roads in urban and non-urban areas. This does not necessarily deal with highly congested inter-city routes.
- Two types of road supply can be included to separate a congestion related response, measured through urban lane capacity, from an accessibility or coverage response as a result of new roads or rural roads. (Hymel et al., 2010, Hsu and Zhang, 2014).
- Congestion is included in the estimation in some form. This is usually done by simultaneously estimating a separate equation for congestion as a function of road capacity and demand. Possible measures for congestion include hours of delay (Hymel et al., 2010) or vehicle operating speed (Cervero, 2003).

4.3.16. A second complicating factor with respect to road supply is that road capacity is not randomly assigned, and new roads are often built where there is high demand. This makes the relationship between the dependent variable D and the dependent variable R in equation (1) endogenous as R depends on D. Hence the coefficient ɣ may not strictly represent the demand response resulting from the supply change. Instrumentation is the most common econometric approach to deal with this problem.[45] The use of instrumental variables is something that could be tested explicitly in the econometric analysis. It is not clear whether the use of instruments will affect the accuracy of the estimation more than the unit of measurement, data quality and/or the choice and specification of control variables. For example, in two studies that report induced travel elasticities in the range 0.82 to 1.39 across different specifications, the instrumented results are generally 0.1. to 0.2 higher than those without instrumental variables (Duranton and Turner, 2011, Hsu and Zhang, 2014). However,

[42] Generalised cost of travel refers to both the monetary (out-of-pocket costs) and non-monetary costs of travel (for example, travel time). An increase in road supply should lead to a reduction in travel time.
[43] Suppressed demand and induced traffic are effectively two sides of the same coin. If prices fall, the demand for a goods increase (this is the induced traffic). If prices rise the demand for a goods decrease (this is the suppressed traffic).
[44] In the extreme case, all new capacity is absorbed by additional demand and congestion reverts to its pre-expansion level.
[45] An instrument is a variable that is correlated with the endogenous explanatory variable, conditionally on the value of other covariates. It should be uncorrelated with the error term.

these studies also differ from other studies that report lower elasticities in terms of the variables included, the frequency of the time data and focus on urban areas.

4.3.17. While lane-widening and other capacity changes that are made to existing roads are a key part of improvements to the SRN, there is a need to estimate the induced demand effects of new roads, which could extend the SRN. The induced demand response on new roads may include the effect of new destinations being made accessible as well as a congestion relieving effect. However, most area-based studies do not distinguish between road widening and new roads in terms of lane-km (Hsu and Zhang, 2014 being the exception). Road scheme or segment-based studies have also only looked at road widening (Cervero, 2003, Van der Loop, 2016). This limitation is related to the estimation method used.

THE INFLUENCE OF OTHER BACKGROUND VARIABLES

4.3.18. Over time there may be changes in road traffic levels that are not associated with changes in road supply but result from changes in population, vehicle fleet, economic circumstances and fuel prices, for example. Any measurements of road traffic will reflect these 'background growth' effects and these need to be controlled for to isolate the effect of road supply in the estimation. This is normally done by including variables, denoted by X_k in equation (1). There is some variation between studies in terms of the specification of these control variables and it is not clear what effect this has on the estimation of the road supply response as studies invariably use different datasets and estimation techniques, so a direct comparison is not possible. In one study, where a comparison was made, the results were found to be sensitive to the choice of income variable, used to reflect economic growth (Hymel et al., 2010). Further considerations in relation to background variables are the units of measurement and the geographical area over which they apply, and these will depend to a certain extent on the estimation method used and the data availability. For example, population or GDP may be measured at a different spatial unit (and less frequently) than the road demand or supply. For studies that use the state or metropolitan level as the spatial unit, background variables are usually specified at the same level. Where road segments, or road schemes are considered, an area of influence for the background variables needs to be defined. For the Dutch road network, a distance decay (gravity model) approach is implemented, with the distance determined empirically by trial and error (Van de Loop et al., 2016). The influence of changes in background variables within 30km of the road stretches were tested using different weights in the decay function.

SHORT RUN AND LONG RUN RESPONSES

4.3.19. The duration of a short run or long run response is in general not well defined. Most studies use annual data to determine a short run elasticity, so that the elasticity represents the year on year change. Some studies that use annual data and include a lag of demand (D_{it-1}) as an explanatory variable are able to derive a long run elasticity directly from the estimation (e.g. Gonzales & Marrero, 2012, Hymel et al., 2010).[46] However, the theoretical reasoning for including the lagged term is not clear cut. Hymel et al. (2010) justify the use of a lagged effect on the basis that vehicle usage, ownership and fleet fuel intensity may only partially change from one period to the next. Alternatively, other studies (Duranton and Turner, 2011, Hsu and Zhang, 2014) that are only interested in longer run effects use annual average data at larger time intervals (5 or 10 years).

[46] If the lagged demand coefficient has a coefficient ø, then in its simplest terms the long run elasticity is determined as ɣ/(1-α).

It is noteworthy that when a lagged term is used it has large explanatory power (a large coefficient) and the induced demand response is small, whereas studies that don't include such a term tend to estimate a larger induced demand response. The elasticities reported by Van der Loop (2016) are based on monthly data but represent the cumulative impact of interventions implemented from the start of the analysis period and hence reflect a long run response.

SOURCES OF INDUCED DEMAND

4.3.20. For transport appraisal and to improve transport modelling capabilities, it is helpful to know where traffic has come from; both from other roads as discussed above or from other modes or, in the longer run from land-use changes. While, data permitting, supply side effects of other modes can be included in the regression (e.g. Duranton and Turner, 2011) to estimate their effect on road traffic demand, approaches similar to those used for re-assignment would be needed to assess the impact of road supply changes on demand for other modes. Additional analysis would then be required to determine what this means for the sources of induced demand as the share of demand moving to the SRN cannot be directly inferred from the estimated coefficients. In all cases, the same question of geographical scope arises as for re-assignment from other roads.

4.3.21. There are existing methods within demand forecasting for determining the source of new demand on a mode as a result of supply side interventions. In the case of induced demand, where the overall demand response is estimated, diversion factors could be used, for example, to provide an indication of the proportions in which this demand has come from other modes.[47]

4.3.22. Employment and density or sprawl are included as explanatory variables in several studies. Cervero (2003) considers not only the impact of land use changes (residential, industrial, office etc) on road traffic demand but also. the possibility that some land development may arise in response to road capacity changes (induced growth), using lagged terms in both cases. There is therefore also a potential land use endogeneity in relation to actual and planned road supply changes with implications for estimating induced demand that does not appear to be well studied in the literature.

ESTIMATION METHODS

4.3.23. There are a range of estimation methods that could be used to generate consistent and unbiased estimates of demand responses.[48] The exact approach will be influenced by the choice and specification of variables in the regression equation, the need to account for endogeneity(s) and the available dataset A fixed effects approach using some form of Least Squares (LS) is the most common estimation method used in the literature, although Rentziou et al.(2012) use random coefficients, for example. To illustrate that their estimates are robust, some studies report results using different specifications in terms of variables included, variables that are instrumented to control for endogeneity and estimation method (e.g. Duranton and Turner, 2011, Hsu and Zhang, 2014).[49]

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[47] For more information see Dunkerley F, Wardman M, C Rohr (2017) Bus fare and journey time elasticities and diversion factors for all modes. A rapid evidence assessment. Department for Transport, UK.

[48] Definitions of consistent and unbiased estimators can be found in standard econometric and statistics textbooks, see for example, Verbeek (2001).

[49] More information on the general approach to estimation using panel data (for which both cross sectional and time series data are available) can be found in Baltagi (2008).

4.3.24. We assume that most standard statistical packages could be used to undertake the estimations, noting that the size of the dataset may influence the choice of software.

UNDERSTANDING DIFFERENCES IN ESTIMATION RESULTS

4.3.25. As noted above, the estimated induced demand responses may be influenced by the data, the choice and specification of variables and the estimation method. Data assembly and cleaning will be an important part of the econometric process to avoid introducing measurement error. It will also be important to understand how measurement error could influence the results through sensitivity analysis. While, there are econometric tests that can help inform the choice of estimation method and limited consensus on the variables that should be included, testing and reporting the results of different variable specifications and estimation methods to understand how and why they differ is a useful way of determining the reliability of the estimations.

Table 4-1 Differences in econometric estimation approaches in terms of data, variable specification and estimation method

Data quality	There are several ways in which data may influence the regression estimates: Data from a range of sources may be used for the demand (VKT), supply or control variables. For example, demand (VKT) will be constructed based on existing AADT data or directly from count data, combined with data on road length. There may be differences in how these data are collected and processed and this may change over time. There may be gaps in the data. Data may need to be aggregated or disaggregated to the appropriate geographical unit or time period. Again, this may require combining data from different sources. For monetary variables that need to be expressed in real values, different conversion methods can be used which may influence the regression results.
Variable specification	A range of control variables have been included in published studies that could be included. It is not clear how including different variables may affect the estimation results. Variables may be specified over different spatial and time units. More aggregate analysis may smooth out variation, but the size of this effect is not well understood. The inclusion of lagged dependent and explanatory variables may be justified on the grounds of inertia in the response but the impact of this (and the appropriate length of lag) should be tested.
Estimation method	Estimation approaches may differ, particularly in terms of how they use instruments to take account of endogeneity. While the effect of this is reported for some long-run estimations, it is not reported for other studies. There are different approaches to estimating long-run elasticities that result in different estimates and that may also influence the short-run estimate.

4.4 IMPROVING BEFORE AND AFTER STUDIES

4.4.1. There are a limited number of case studies that focus specifically on induced demand. Case study evidence that is available comes primarily from evaluations, where the focus is on understanding how well schemes have met a specified set of objectives, with assessment of induced traffic a more peripheral issue. In the UK, the Post Opening Project Evaluations (POPE) are a prime example of such case studies. These case studies have been undertaken for all of Highways England's major schemes since 2002. The overall objectives of POPE are as follows:

- Provide a quantitative and qualitative analysis of scheme impacts consistent with national transport appraisal guidance (TAG) and specific scheme objectives;
- Identification and description of discrepancies between forecast and outturn impacts;
- Explanation of reasons for differences between forecasts and outturn impacts; and,
- Assess whether the scheme delivered the published objectives.

4.4.2. POPE evaluations are carried out one year and five years after scheme opening, the latter building on the initial findings presented in the one year after study. The case study evidence is generally undertaken by means of before and after data collection, where evidence is presented as a change in traffic flow and journey times prior to scheme opening and pre-defined periods after scheme opening. They are undertaken to evaluate the strengths and weakness in the techniques used for appraising schemes and to assess whether the scheme delivered the published scheme objectives. The assessment is undertaken by comparing information collected before and after the scheme opening and comparing against forecasts made during the planning process and the scale of induced traffic is assumed to be that over and above the growth that has been observed in county and regional trends that is discussed in 4.5.5 below. For evaluation purposes, actual traffic volumes that arise following scheme opening are compared to the forecast traffic volumes 'without' the scheme i.e. the Do-Minimum case derived from the transport model, based on growth forecasts assumed in the model which may over or understate the general rate of traffic growth. Therefore, the evaluation may over or understate the difference between traffic volumes 'without' and 'with' the scheme. As stated in 4.4.1, the focus of the POPE evaluations is on understanding how well the scheme met a specified set of objectives, such before and after studies could be extended such that greater emphasis is given to the assessment of induced traffic.

4.4.3. It recognised that there are potential problems which confront any attempt to improve the measurement of induced traffic. Such problems include the inherent variability of traffic flow data, difficulty in establishing what would have happened without the scheme i.e. the Do-Minimum, also referred to the counterfactual, together with uncertainties in the attribution of cause and determining the most appropriate time to collect traffic data. Some of these problems have no clear solution, while others can be addressed with appropriate data sources and control studies. However, given the availability of an appropriate set or sets of traffic count data, together with other relevant data sources, including screenline data together with comparative data derived from control areas, it is considered practical, with reasonable precision, to measure increases in traffic associated with a scheme.

4.4.4. In general, changes in traffic volumes can be determined across appropriately defined screenlines such that the full impact of the scheme on all road users can be assessed. The changes in traffic volumes at the screenlines between before and after periods are composed of two effects: those arising as a consequence of background growth between the intervening years and the direct impact of the scheme. In order to determine the change in traffic volumes directly resulting from the scheme, it is necessary to control for background growth resulting from growth in GDP, car ownership and fuel price changes and land-use changes that are not brought about by the scheme and thereby provides the 'counterfactual' case.

4.4.5. In the most recent POPE studies, the evaluations assessed the increase in traffic growth across screenlines and counts at or near the scheme against the regional growth trend and the growth trend in the relevant local authority as comparators. Given the inherent difficulty in defining appropriate comparators, the above approach may be best that can be offered in this area. However, there may be further value by also comparing counts at or near the scheme to other similar local authorities or regions in terms of similar demographics, socio-economic and employment characteristics where no road schemes have commenced construction or opening in the appropriate years. It is also considered that further improvements could include collection and analysis of traffic count data over several years in advance of the scheme being opened enabling before and after comparisons of traffic trends for the scheme and comparator locations. An alternative approach could be adopted by taking the outcomes from the econometrics approach in respect of overall elasticities that can differentiate impacts by geography, can quantify long and short term elasticities and would provide further information on size of impacts for case studies in addition to comparator locations.

4.4.6. Satellite navigation data is used to determine changes in the average journey times and speed along the road scheme. In addition, it is also used to determine whether the distribution of journey times has changed from scheme opening. For post-opening data, one month of data within a neutral month is generally used, avoiding the construction periods of neighbouring schemes or particular events which may affect journey times through the scheme. Pre-scheme journey times along the scheme are compared with post-opening journey times. The journey time analysis is split into three components; analysis of pre and post-scheme journey time differences along the scheme, a comparison of forecast and outturn journey times and a comparison of journey time reliability pre-scheme and post opening.

4.4.7. As previously stated, POPE is currently undertaken to evaluate the strengths and weaknesses in the techniques used for appraising schemes and to assess whether the schemes delivered the published scheme objectives and not on determining induced travel. However, such before and after studies could be extended such that greater emphasis is given to the assessment of induced travel, whilst maintaining the current POPE approach The of comparing before and after flows across screenlines after accounting for the effects of improved ways of determining background growth, the remaining growth across the screenlines and on particular highway links would provide an aggregate estimate of the traffic flows that have occurred directly as a result of the scheme itself but would not lend itself to differentiate the contributors of the increased traffic flow, such as:

- Mode of travel, e.g. switching from public transport to driving;
- Frequency of travel, specifically in terms of making additional trips that were not made previously;
- The distance travelled by changing route to the same destination;

- The distance travelled by changing destination (change location of activities); and
- In the longer term, the distance travelled due to changes in residential or employment location or as a result of changes in land-use.

4.4.8. The use and application of Mobile Network Data (MND) offers a way forward in understanding the disaggregate behavioural changes, as shown above. One of the strengths of MND against traditional link-based count information that currently form the basis of before and after studies, is that the data allows an understanding of the origins and destinations of users of a transport system, in this particular case the highway network in before and after timeframes. Current statistics suggest that 90-95% of the adult population own a smartphone. Because of the large sampling size that can be obtained from anyone of the three main mobile network providers, each of which have in the region of 30% of the market information on trip making can be collected from 30% of the population over long periods of time, capturing day-to-day variations that cannot be satisfactorily be achieved with traffic count data collected for before and after studies. MND also avoids risks of lumpiness and incidental observations that may be present in traffic count data. In using MND in a longitudinal way over a long period of time, it is possible to understand the catchment area for a specific scheme. Furthermore, if baseline MND data prior to the opening of the scheme is available, then many of the re-assignment and demand responses that are usually very hard to identify can be detected, these are:

- Clear rerouting patterns by identifying routes previously used by Origin/Destinations identified to have used the new infrastructure;
- Possible impact in mode shift, by identifying if the mode of travel has changed for Origin/Destinations identified to have used the new infrastructure;
- Redistribution impacts, over a long period of time, as MND can help understand home and work locations of users of the new piece of infrastructure and how these evolve over time; and
- New trips which prior to the opening of the piece of infrastructure did appear to take place.

4.4.9. For the purpose of understanding the behavioural changes brought about by a new road scheme, it is important to appreciate the different timelines at which the behavioural responses are likely to occur. Hence, the analysis of MND would need to account for these issues as follows;

- MND data would need to be collected for a reasonable sample time, possibly over a number of years from prior to scheme opening and after opening to capture the demand responses to the scheme arising, thereby recognising that certain behavioural changes are likely to occur at different times in the future e.g. reassignment would likely to be an immediate behavioural response whilst redistribution would occur gradually over time. Using the whole year worth of MND data on each occasion would not be cost effective, but selecting 3 months representing various periods of the year, such as a neutral month in Spring, one in Autumn and a holiday month to be collected every year may provide sufficient information to derive demand responses and address any bias, however this selection of the appropriate periods to collect MND data requires careful consideration.
- Because demand responses can be relatively minimal, and in some cases potentially close the level of error in the data, the analysis of the MND data should be undertaken at expanded level i.e. expanding the data provided by a mobile network operator to represent the full population.

4.4.10. MND highway and public transport matrices can be developed for both the before and after situations at any prescribed time periods and compared to provide an understanding of the behavioural changes brought about the scheme as follows:

- The total number of trips in the highway and public transport matrices in the before and after situations can be compared, accounting for background growth derived from one of the methods adopted in 4.4.7 above. The resulting difference, after accounting for background growth would then infer a potential aggregate increase in trips arising solely from the direct impacts resulting from the scheme.
- Frequency of travel could be estimated from the MND specifically in terms of making additional trips that were not made previously.
- The distance travelled by changing route to the same destination and identification of the changed route.
- The distance travelled by changing origin or destination, (change location of activities) and the scale of change by comparing the matrix cell cells which have been subjected to change.
- In the longer term, the distance travelled due to changes in residential or employment location as a result of changes in land use; and
- Comparing the ratio of highway and public transport trips in before and after cases to see if the ratio has remained constant or not. In the latter case, this would imply a switch from highway to public transport or from public transport to highway.

POTENTIAL SOURCES OF BIAS TO BE ADDRESSED

4.4.11. There will be background changes to the customers for any mobile network operator between before and after data collection. Some factors may occur naturally such as:

- Increase in the number of customers due to population growth; and
- Background changes to a MNO's customer base arising from customers transferring to other MNOs. The former bullet point is linked to the general background growth that would need to be accounted for with any before and after datasets. There is no current evidence available of the general rate of change of customers between MNOs. There is no current evidence available of the general rate of change of customers between MNOs.

However, whilst people may change device between the before and after data collection periods there will is likely to be a significant number of customers who remain with the same MNO and simply change device. If it can be determined that there is a significant benefit in having identical users between the before study and after study, it could be investigated if the MNO and/or Data Provider have the ability to use the customer database to pair a user's devices in the before study with their latest device in the after study. This would improve the sample for analysis of the before and after data from a fixed population in the before and after studies, given that people who only changing device (rather than operator) could be included. However, there are other aspects of MND that will need to be accounted for in analysis as follows:

- Step change in the local market share for the MNO. The expansion is usually undertaken by the Data Provider who have access to device-level data and so it would be contingent on their expansion methodology to account for this. The most 'extreme' change of this type would likely be linked to acquisition and / or mergers in the MNO market.

- Perceived change in the target market and composition for the MNO. For example, O2 are currently perceived as primarily targeting the leisure market compared to Vodafone primarily targeting the business market. If these strategies changed, this would impact on the outturn trip purposes, and consequently on the distribution given variation in trip length by trip purpose is known.
- Changes to customer behaviour such as propensity to own a mobile device by different age bands, device ownership rates, preference for contract over that of Pay as You Go. These facets can all add bias into the MND processing, and any significant change over time would impact on the degree of bias between the before and after study datasets.

4.4.12. The mobile network infrastructure, including mast density and strength of signal can impact on the detection of trips. This is commonly found to have a greater impact on the detection of short distance trips and trips in rural areas. Ongoing investment in the infrastructure could lead to an improved detection of trips in the after period. That could lead to an apparent increase in demand which may in part be attributed to improved trip.

4.4.13. If direct comparisons are to be made specifically between the before and after data, it is important that the MND processing by the Data Provider remains consistent. Otherwise any changes would need to be replicated (if possible) or understood. For example, if the rail mode allocation algorithm was significantly upgraded by the time the after study was undertaken, it would be ideal to rerun the before data using the latest version of the algorithm. If that was not possible for a processing reason, it would be important to understand the changes in the algorithm so that changes could be attributed to the scheme or background processing updates.

4.4.14. Particular issues may arise with multiple vehicle occupancy if the mobile service is provided by the same operator which cannot be effectively disentangled. Each MNO track devices within their own segment of the market, expanded to overall population data from which the output is person trip Matrices. Therefore, it is then necessary to derive and apply occupancy rates into vehicles. For before and after studies analysis, there is a need to derive separate before and after study occupancy that are generally derived from NTS.

4.4.15. Whilst it is recognised that there is bias in mobile network data, such bias can be satisfactorily addressed through the detailed application of adjustment and application of appropriate algorithms. As stated in Para 4.5.9, There is now significant experience in developing mobile network data and deriving mobile network data matrices within the industry for the purpose of developing transport models. Generally, nearly all transport models are developed in this way. In particular, the Highways England Regional Traffic Models and the three sub-regional models in Wales have been developed utilising mobile network data to derive the transport demands.

4.4.16. As stated previously, MND data will need to be collected for a reasonable sample time, possibly over several years as stated in 4.4.9. In addition, the selection of the appropriate periods to collect MND data requires careful consideration. Using the whole year worth of MND data on each occasion would not be cost effective, but selecting 3 months representing various periods of the year, such as a neutral month in Spring, one Autumn and a holiday month to be collected every year should provide sufficient information to derive demand responses and address the recognised bias.

5 INCORPORATING EVIDENCE ON INDUCED TRAVEL DEMAND MODELS

5.1 INTRODUCTION

5.1.1. In this section we discuss how evidence on induced travel can be incorporated in transport models. We explore this topic with regard to traditional four stage models and other models, in turn. We then discuss how the available evidence on induced travel could inform the calibration or estimation of a four-stage model and how it might be used for model validation.

5.2 INDUCED TRAVEL IN FOUR STAGE MODELS

INTRODUCTION

5.2.1. As set out in Dunkerley (2018), economic theory tells us that generally if there is a reduction in the price of a good or service, demand for it will increase. This principle also applies to the demand for transport. In this case, however, the price of transport reflects all costs associated with travelling, such as the time taken, in addition to out-of-pocket costs. This is referred to as the **generalised cost** of travel.

5.2.2. Dunkerley et al. (2018) also found evidence to suggest that induced travel is greater when there is a high level of congestion and in urban areas where there may be suppressed demand. In these contexts, the provision of an additional capacity results in a larger generalised cost improvement relative to less congested interurban contexts.

5.2.3. However, at the other extreme, if a currently uncongested road is widened in anticipation of future growth there may be no change in travel times and congestion in the short term. In this case no induced travel would be expected.

5.2.4. Therefore, the remainder of this Chapter focusses on **generalised cost changes** that result from increases in network capacity as it is the extent of the generalised changes that drive the induced travel responses in a model.

5.2.5. It useful therefore to define generalised cost:

$$GC = cost / VOT + time$$

Where: GC is the generalised cost (in minutes)

cost is the cost of the trip (in pence)

VOT is the value of time (in pence per minute)

time is the travel time in minutes

5.2.6. Generalised cost combines terms for the monetary cost of the trip with the trip travel time. This is done by converting the cost of the journey into equivalent minutes using the value of time. UK transport modelling convention is to use the term generalised cost even though time units are being used.

5.2.7. In a traditional four-stage model, accounting for induced travel is no different to other travel changes. A model is run for two scenarios with and without a new scheme and the difference in vehicle kilometres between the two scenarios provides an overall estimate of induced travel. There are no special model parameters for induced travel.

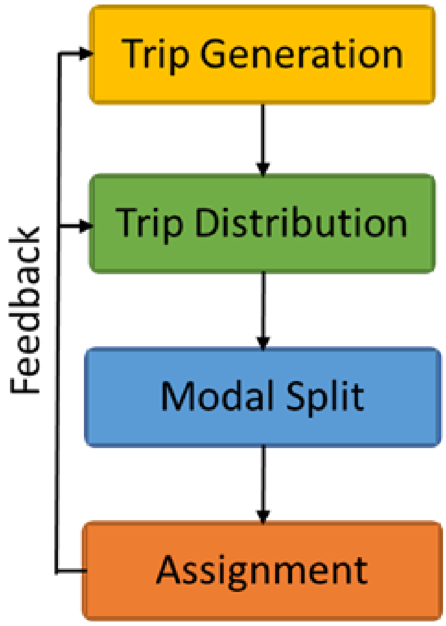
5.2.8. The **traditional** four-stage model represents four linked components:

- Trip generation;
- Trip distribution;
- Mode split; and
- Assignment.

5.2.9. In a four-stage model changes in generalised cost will result in reassignment, mode split and distribution responses and so these components of induced travel will be represented. In some models the generation component[50] is responsive to changes in generalised cost – this is typically termed a **frequency** response - and so this component of induced travel is also represented. This issue is discussed further below.

5.2.10. Figure 5-1 shows how the responses are linked in a traditional four-stage model. Note that the trip generation component is not always responsive to changes in generalised cost.

Figure 5-1 Four-stage Model Structure



5.2.11. The other components of induced travel being considered in this study are changes in residential or employment location and other land use changes. These responses are not modelled in a four-stage model but in principle could be represented through changes in inputs to the model. Alternatively, land-use transport interaction (LUTI) models represent these responses endogenously. These issues are discussed further below.

[50] In this chapter we are talking about the generation of trip origins and the frequency response to trip origins.

5.2.12. As noted in Chapter 1, time period changes are not considered in this study. While these responses may be important in some contexts to better understand the travel demand implications from the introduction of a new scheme, e.g. when assessing an urban highway scheme that provides additional capacity to relieve peak period congestion which may allow more people to travel in the peak period. However, as stated in paragraph 1.3.4, a change in trip timing is not usually considered to be an induced demand effect if the trip is still made within the measurement period of interest. Such a change would not result in induced traffic (although it is important to understand in terms of congestion and could also be important for appraisal). Therefore, if only peak hour or peak period travel is included, changes in time period responses may be incorrectly interpreted as induced travel.

5.2.13. Given the above, if a four-stage model includes a cost-responsive frequency model then all of the transport related components of induced travel being considered in this study are represented.

5.2.14. An important observation about the four-stage structure is that the model sensitivities (referred to as lambdas in TAG) reduce as you go up the hierarchical structure.[51] The relative sensitivity of mode and destination choice varies between different models, an issue which is explored later in this chapter, but we can say that for demand on the SRN assignment would be expected to be the most responsive component, and frequency the least responsive component, to generalised cost changes.

ASSIGNMENT RESPONSES

5.2.15. Assignment is the most sensitive response to generalised cost changes in a four-stage model and therefore is an important component of induced traffic.

5.2.16. Assignment models are used to determine the routes between origins and destinations - with and without the scheme - and as such are key to the calculation of the generalised cost changes associated with the scheme. These costs will feed into the other response mechanisms in the four-stage model structure. Therefore, it is important that the assignment model is able to provide an accurate measure of supply with and without the scheme. TAG Unit M3.1 provides guidance on developing highway assignment models.[52]

5.2.17. Road capacity improvements may result in increases in trip length, e.g. a bypass of a congested town, or decrease in trip length, e.g. a bridge over a river estuary.

MODE AND DESTINATION RESPONSES

5.2.18. In the traditional four-stage model the destination response was termed ‘distribution’ and the mode response was termed ‘mode split’. In the remainder of this section the destination response is termed **destination choice** and the mode response is termed **mode choice**.

[51] Generalised costs pass up the model structure in the form of logsum (weighted averages) over the alternatives at the lower levels. A theoretical properly of the overall model structure is that the model sensitivities must reduce as you go up the structure.

[52] Department for Transport (2020). TAG Unit M3.1 Highway Assignment Modelling, May 2020 release.

5.2.19. While the **traditional** four stage model represents destination choice above mode choice in the hierarchical structure, current UK guidance for studies unable to estimate mode-destination nesting structures suggests a structure with mode choice above destination choice.[53] The TAG guidance is based on empirical findings from a number of UK models where alternative structures for mode and destination choice were tested, though it should be emphasised that TAG guidance is that the structures should be estimated from local data where possible.

5.2.20. Our experience from developing mode-destination models for a number of studies is also that a structure with modes above destinations is most consistent with UK evidence. Our experience is also that the value of the nesting parameter for the mode-destination structure[51] has an important impact on the model elasticity and in particular the fuel cost vehicle kilometrage elasticity. This issue is discussed further in Section 5.6.

5.2.21. Our understanding is that the guidance parameters in TAG for mode-destination hierarchical model structures are largely taken from urban models. It would be useful to investigate whether these parameters are appropriate for models focussed on inter-urban travel, such as models used to assess schemes on the SRN.

5.2.22. Another important consideration in the specification of models of mode and destination choice is **cost damping**. In a model with cost damping the marginal impact of generalised cost, or monetary cost, decreases with increasing cost. There is substantial evidence for cost damping both from model estimation (for example in the mode-destination models used in version 5 of the National Transport Model and in the MoTiON model for London) and stated preference discrete choice experiments to measure values of time (including the latest UK VOT study[54]). Including cost damping in models can also yield more plausible realism responses. TAG provides specific advice on inclusion of cost damping in four-stage models. However, Highways England experience is that the introduction of cost damping can have a significant impact on the level of induced demand associated with a scheme.

5.2.23. Thus, for any cost damping mechanism introduced it is important to understand the impact it has on model sensitivity. Stronger cost damping will result in generalised cost changes being damped for destinations with higher generalised costs, typically more distant destinations. If a scheme has a significant amount of long-distance traffic, then the degree of cost damping will impact the level of induced travel.

5.2.24. Some evidence on the relative contributions of mode and destination choices to induced traffic is available from the Manchester Motorway Box study.[55] When a disaggregate four-stage model was used to predict the impact of the completion of the M60 Manchester Motorway Box the destination responses were two to three times as large as the mode choice responses (estimation of the models identified a structure with modes above destinations). The responses were the percentages of trips predicted to cross screenlines.

[53] Department for Transport (2020). TAG Unit M2.1 Variable Demand Modelling, May 2020 release.

[51] The sensitivity of the mode choice responses to changes in generalised time is the mode choice lambda (λ_m) and the sensitivity of the destination choice responses to changes in generalised time is the destination choice lambda (λd). The mode-destination nesting parameter is then (λ_m / λd).

[54] ITS, Accent and Arup (2015) Provision of market research for value of travel time savings and reliability: non-technical summary report. Prepared for Department for Transport.

[55] Rohr, C., A. Daly, J. Fox, B. Patruni, T. van Vuren & G. Hyman (2012): Manchester Motorway Box: Post-Survey Research of Induced Traffic Effects, disP - The Planning Review, 48:3, 24-39.

5.2.25. A consideration when attempting to generalise findings is that both the context of the scheme and the model sensitivities will influence the forecast level of induced travel. For example, the extent of mode choice response to an inter-urban scheme depends on the level of service of the public transport alternatives.

5.2.26. Some models may predict scheme responses using land-use transport interaction (LUTI) models. These models typically impose a structure where mode choice is below destination choice for commute and home-education travel, meaning that destination choice would be less sensitive than mode choice. This is because in a LUTI model the choice of workplace and education location is endogenous in the model. If the 'true' model structure in the context in which the LUTI model is applied is modes above destinations, then a LUTI model may over-predict the mode choice response and under-predict the destination choice response for some travel purposes.

FREQUENCY RESPONSES

5.2.27. In a traditional four-stage model the first stage (i.e. the response that would be at the top of the nesting structure) was generation where fixed trip rates by segment were multiplied by population by segment to predict the number of trips for specific trip purposes. In these models there was no linkage between the number of trips predicted and the generalised cost of travel.

5.2.28. Frequency models have been developed that are 'cost responsive'. In this section we describe the component of trip generation that is explained by a generalised cost change as **trip frequency**, consistent with Section 4.6 of TAG Unit M2.1.

5.2.29. For models where walk and cycle are not explicitly modelled, TAG Unit M2.1 state that trip frequency can be seen as mostly the transfer of trip between active and mechanised modes. This is effectively a proxy for a mode choice rather than a true frequency response.

5.2.30. For models that incorporate both active and mechanised modes TAG Unit M2.1 suggests it will often not be necessary to model trip frequency changes since the impact of trip frequency is likely to be small. However, the TAG guidance is general and a major scheme on the SRN may result in a generalised cost change that is large enough to result in a frequency response.

5.2.31. One approach to representing frequency responses is to use a logsum from the lower-level mode and destination choice responses. In this approach, the trip frequency response to cross-sectional variations in accessibility is estimated alongside the trip generation responses that capture variations in trip rate with person and household characteristics. Such an approach is theoretically appealing because the relative impact of the generation and frequency response is estimated simultaneously.

5.2.32. Typically, such frequency responses have been estimated for discretionary travel, and in some cases for commute travel as well. However, in future, it may be more likely that frequency effects can be identified for commute travel, where more home working would be expected for those whose journeys to work are longer, more expensive, more congested, etc., which would be picked up as a worse logsum accessibility measure.[56]

[56] We note that such estimation work will be impacted by the Covid-19 pandemic and therefore should only be undertaken using historic data or future data where a new post-Covid equilibrium is reached.

5.2.33. Appendix C of TAG Unit M2.1 suggests that trip frequency can be represented using a power or exponential function. If an exponential function is applied to a compound generalised cost measure, then the approach is effectively the same as the logsum approach – the frequency response is predicted as a function of a change in accessibility measures using a generalised cost logsum and a sensitivity (lambda) parameter.

5.2.34. Whilst it is relatively straightforward to represent a frequency response in models quantifying the impact of additional capacity on the SRN, in most cases the frequency response to the provision of additional capacity would be expected to be small relative to the route and destination choice impacts consistent with the frequency response being represented as the least sensitive in the four stage structure.

5.2.35. From the induced travel sources available to us we have not been able to identify case study evidence of the scale of the scale of frequency responses relative to other induced travel responses. **We recommend further research into the scale of frequency responses as a result of road capacity improvements.**

LAND USE RESPONSES

5.2.36. Four-stage models take land use variables such as home locations, work locations and other land-use changes as inputs. Therefore, they will not predict changes in land use in response to a change in generalised cost resulting from a highway scheme.

5.2.37. However, four stage models are able to assess the impact of changes in generalised cost due to the scheme on potential changes in land use. For example, a four-stage model could be run using generalised costs calculated from the after opening networks together with predicted land use inputs for before and after the scheme.

5.2.38. On the other hand, LUTI models provide a framework for predicting land-use changes alongside the transport responses represented in a four-stage model. As such they could be used to predict all of the induced travel responses listed earlier in this section within a model. However, LUTI models place restrictions on the relative sensitivity of mode and destination choices for commute and home-education travel and these could impact on the composition of the induced traffic predicted in response to a scheme. Compared to four-stage models they need more data and are more difficult to calibrate, given the requirement to estimate both the transport models and the responses between transport and land-use change.

5.2.39. However, land use responses may represent a significant component of induced travel. This is something that could be further investigated in before and after studies.

SHORT AND LONG-RUN RESPONSES

5.2.40. It would be expected that some induced travel responses would occur more rapidly than others and as such the short and long-run responses may be quite different.

5.2.41. In 2006 Phil Goodwin assessed the evidence assembled by SACTRA and concluded that on average induced traffic represents 10% of the base traffic in the short-term and 20% of base traffic in the long-term.[57] This analysis suggests that there is therefore a substantial difference in the short and long-term responses. which are likely to include impacts from land-use changes.

[57] Goodwin, P. (2006) Induced traffic again. And again. And again. Local Transport Today, Issue 450.

5.2.42. More recent evidence of POPE schemes suggested a lower level of induced travel with growth in excess of background growth by between 5 and 10% over time periods of about 3 – 8 years.[58] However, we note concerns around measurement of background growth in POPE studies (see earlier discussion in Chapter 3 and 4).

5.2.43. Drawing on Sloman et al (2017) the following table presents the components of short and long term induced traffic within the four-stage modelling framework. Note that if a response is expected to be fully observed over the short term then the long-term column is intentionally left blank.

Table 5-1: Short and long-run induced traffic within the four-stage model

Response	Short term 1 to 5 years	Long term 5-plus years	Sensitivity
Frequency	Full response		Low ↓
Mode	Close to full response	Full response	
Destination	Some response	Some response	
Route	Full response		High
Land-use		Full response	n/a

5.2.44. The frequency, mode and route choice responses would be expected to be realised in the short term as a result of the generalised cost changes. Sloman (2017) argues that long-term impacts may magnify the mode choice response, for example increased congestion causing cyclists to switch to car. However, it seems unlikely that long-term responses such as the cycling example would have a significant effect for schemes on the SRN, noting that it would be difficult to disentangle the impact of the scheme on cycling from other changes.

5.2.45. Destination choice for some purposes could occur in the short-term in response to the generalised cost changes, in particular for those attractions that do not involve long-term choices by the individual such as business travel or discretionary travel (shopping, visiting friends and so on).

5.2.46. Destination choice for purposes such as commute, and education cannot respond as quickly as they depend on longer term choices of workplace or education location. Thus, we would expect destination choice for these purposes to be long-term choices.

5.2.47. Land-use responses will typically be longer term. These include responses such as the development of housing, workplaces and shopping centres in response to the scheme. If in turn these revised inputs were fed into a four-stage model they would result in significant destination switching. However, trip patterns may also change due to changes in trip productions if the scheme results in the construction of new housing.

[58] Sloman, L., L. Hopkinson, I. Taylor (2017) The Impact of Road Projects in England.

5.2.48. In some cases, developers build new developments in anticipation of a scheme's completion. If these have been given planning consent, then they are taken into account when developing future year forecasts. Otherwise developments are taken to be speculative and are not included in future year forecasts.

5.2.49. In summary, we would expect the difference between the short-term and long-term induced traffic responses to be due to land use changes, with associated impacts on destination choice, as well as a longer term re-distribution of trips for commute and education in response to the scheme (which could occur to unchanged attractions).

5.3 LAND-USE TRANSPORT INTERACTION MODELS

5.3.1. LUTI models predict changes in land-use in response to changes in generalised cost. This is their key advantage in the context of induced travel, and the evidence presented above suggests that land-use changes and their associated impact on travel patterns can have substantial induced travel impacts.

5.3.2. As discussed earlier, one concern with LUTI models is that they impose a model structure with destination choice above mode choice for commute and home-education purposes. This structure differs from the guidance presented in TAG M2.1 and is likely to impact on the *level and composition* of induced travel predicted for these purposes. Specifically, models with destination choice above mode choice in the hierarchical structure would be expected to predict a lower level of destination switching, and a higher level of mode switching, compared to models that use the TAG M2.1 structure with mode above destination choice.

5.3.3. The greater range of choices represented in a LUTI model mean that they require more data to calibrate and validate than a four-stage model.

5.4 ACTIVITY-BASED MODELS

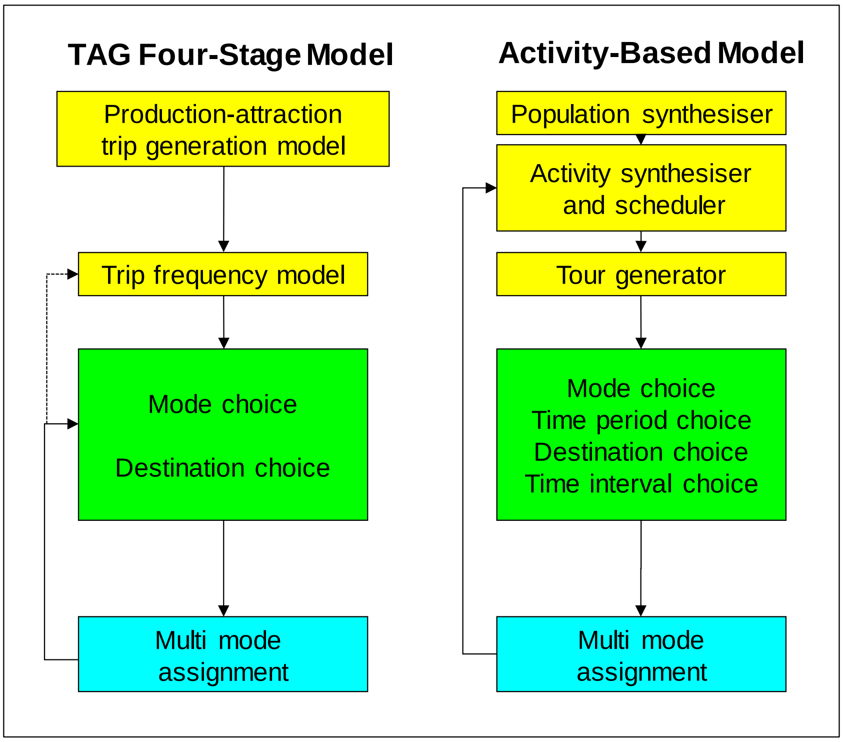
5.4.1. Activity-based models (ABMs) have two key differences compared to a four-stage model:

- They replace the generation (and potentially frequency) model stages with a process that simulates the travel patterns of individuals, typically taking account of scheduling constraints and interactions between different members of the household. This process is termed **activity scheduling**.
- They are implemented by simulating outcomes for each component of the model for individuals, which are summed to produce estimates of aggregate demand (this is in contrast to the aggregate methods that have been used typically to predict demand in four-stage models, although these models too could be implemented through simulation).

5.4.2. There are a range of types of ABM with different levels of complexity, but their overall architectures are broadly similar.

5.4.3. The differences between four-stage models following the structure suggested in TAG and activity-based models are illustrated in Figure 5-2. Because time period choice is not relevant for induced travel, it is not shown in Figure 5-2. However, time period choices are included as fifth response in some 'four-stage' models. Given this it can be seen from Figure 5-2 that the main difference between the four-stage and activity-based approaches are in the top-level stages that predict how much travel is made.

Figure 5-2 Comparison of TAG four-stage and activity-based models



Source: Adapted from a presentation made by Peter Davidson Consultants and Parsons Brinkerhoff to the then Highways Agency in 2011.

5.4.4. The point about whether a model is implemented using simulation does not impact on the ability of the model to represent induced demand, it is a choice on implementation approach and a four-stage model could be implemented in the same way, particularly if the model is estimated using disaggregate data of individual traveller choices.

5.4.5. Our understanding is that the activity scheduling process of these models is, in four-stage modelling terminology, purely a generation response. However, there is no reason why a frequency response could not be incorporated so that the predictions of travel are cost responsive.

5.4.6. Mode, destination and assignment responses are typically modelled. Like LUTI models, ABMs tend to model the choice of workplace or education level as a higher-level choice. As such, for these purposes the model structure is destination choice above mode choice. As discussed earlier, this may result in predictions of induced traffic for these purposes where the relative contributions of mode and destination choice differ from what would be predicted by a locally estimated model, or a model that assumes a choice hierarchy on the basis of TAG.

5.4.7. We can see no obvious advantages of using an ABM model to model induced travel compared to a four-stage approach.

5.5 ELASTICITY MODELS

5.5.1. An alternative modelling approach used for Highways England for 'contingency' schemes with a small modelled area is the use of **own-cost elasticity models.**[59]

5.5.2. In an own-cost elasticity model, a simple function is applied to the generalised cost changes for each origin-destination pair to adjust the highway demand. Thus, the approach does not model separate responses (frequency, mode, destination) but instead approximates the total changes in demand to generalised cost changes.

5.5.3. The ARUP-AECOM study (2017) concluded that such approaches tend to slightly under-state the benefits of highway schemes relative to a variable demand model (VDM). However, own-cost elasticity approaches performed better than a fixed demand approach.

5.5.4. Comparing the elasticity model results to the VDM, the two models are calibrated to exhibit similar sensitivities of *traffic* response so that they are compliant with the TAG fuel cost realism test. In a VDM, this sensitivity is in part achieved through changes in trip length in the destination choice model. However, in an elasticity model this is not possible and all changes in traffic must be achieved through changes in trip totals. This means that the elasticity model shows larger impacts in terms of trip changes.

5.5.5. The tests undertaken in the ARUP-AECOM study showed that the elasticity models were unable to predict redistribution responses associated with a scheme (as this response is not represented) whereas in one of the test examples the VDM predicted an increase in local traffic.

5.5.6. **In summary, own-cost elasticity models are unable to say anything about the composition of induced demand but may be able to approximate the total level of induced traffic. As such they may be an appropriate approach in contexts where the development of a VDM cannot be justified. That said, their inability to predict the redistribution impacts of a scheme is a major limitation.**

5.6 MODEL CALIBRATION, ESTIMATION AND REALISM TESTING

MODEL CALIBRATION / ESTIMATION

5.6.1. Section 5.2 considered how induced traffic could be represented in a four-stage modelling framework. **Except for land-use changes, all the components of induced travel being considered by this study are represented by a four-stage model provided that the model includes a frequency response to generalised cost changes.**

5.6.2. Therefore, **representing induced travel does not require a fundamental change to the way four-stage models are calibrated or estimated.**[60] Further, from a modelling perspective there is no difference between induced traffic and all other traffic and as such the same set of model parameters apply.

5.6.3. The limited induced travel case study evidence summarised in Section 5.2 suggests that destination choice responses to new road capacity are greater than mode choice sensitivities. This is consistent with a model structure with mode choice above (less sensitive than) destination choice, this is also

[59] ARUP, AECOM (2017) Evaluation of Scheme Forecasting Phase 2 Report, prepared for Highways England.

the structure recommended by TAG guidance for models that cannot identify the sensitivities from local evidence.

5.6.4. For LUTI models it may not be possible to work with modes above destinations structure and this is likely to affect the relative contributions of mode and destination choice to induced traffic.

REALISM TESTING

5.6.5. The completion of a major scheme on the SRN will result in changes in generalised cost which result from changes in journey times and monetary costs. Typically, the realism of a model's responses will be validated by conducting tests to illustrate the model's sensitivity to fuel price and car time changes (measured as elasticities).

5.6.6. However, there is a paradox in the TAG realism testing elasticity requirements, which will influence modelling of induced travel, which we set out below.

5.6.7. Table 5-2 shows the mean journey times and mean travel costs for observed return tours. Using an average value of time these can be converted into generalised cost (minutes) and then the proportion of the total generalised cost that is due to the journey cost is calculated. The tours represent all travel observed by English residents in the 2010-2015 waves of NTS data.

Table 5-2: Characteristics of tours in NTM v5 estimation sample

Purpose	Journey time (mins)	Journey cost (pence)	Journey cost as % of generalised cost
Commute	47	353	28%
Home-business	78	1207	29%
Home-other	32	258	48%

5.6.8. It can be seen that for all three purposes presented **journey time is the most important component of generalised cost, particularly for commute and home-business travel where the values of time are higher**.

5.6.9. Assuming that the relative contributions of journey time and monetary cost to the generalised cost changes resulting from a scheme on the SRN are broadly similar to those presented in Table 5-2. Then depending on the travel purpose, how a model responds to changes in car time is as important, or more important, than how the model responds to changes in journey cost.

5.6.10. The sensitivity of models to changes in monetary cost is often a key focus during model calibration/estimation because the TAG realism test guidance sets out a range of elasticities that should in most cases be replicated in models (-0.25 to -0.35 for fuel cost vehicle kilometres).

5.6.11. However, for changes in car time the acceptable range of elasticities is so wide (0 to -2) that it serves no useful purpose as a validation test. As a result, sensitivities to car time changes are not usually a focus during model calibration/estimation.

5.6.12. As a result, a four-stage model can be well validated, according to TAG guidance, if it meets the fuel cost realism test but it can do so with a car time elasticity ranging from anything between 0 and -2. Clearly this wide range of values could result in a wide range of induced travel responses associated with the journey time changes associated with a scheme.

5.6.13. A related issue is that in models that estimate separate monetary cost and journey time sensitivities, these two effects are correlated. As a result, changes made to achieve a compliant fuel cost elasticity often impact on the sensitivity of a model to car time changes. The TAG realism test guidance on car time gives such a range that almost whatever happens to car time in response to model changes it still meets with guidance. This seems inconsistent with the importance of time changes in how a model responds (this point applies in general, not just to induced traffic). **Therefore, we recommend that more research and guidance on car time elasticities by undertaken. If possible, it would be helpful to provide guidance by journey purpose.**

5.6.14. Improved car time elasticity guidance to complement that available for fuel cost would provide greater confidence that a model responds sensibly to journey time changes as well as changes in monetary cost.

5.6.15. However, to assess the level of induced traffic predicted by a model more directly a further realism test would be required. One option would be to provide guidance on the likely composition of induced travel. However, SACTRA did not feel able to provide advice on the composition of induced travel, noting that the composition will vary with particular circumstances, and the review undertaken by Dunkerley et al. (2018) did not identify much more evidence on the composition of induced travel. The best evidence is from the Manchester Motorway Box study, but that evidence is from a model and it does not include frequency responses. Additional case study evidence could provide further evidence on the composition of induced travel, which could then be used as a validation test for models as to whether they are able to estimate plausible levels of induced travel from new road schemes.

5.6.16. One last validation test may be whether models are able to estimate measures of elasticities, such as those reproduced by econometric studies. It would be interesting to explore the predicted increases in VKT on the SRN with increases in capacity of the SRN in some existing models to see what the size of increase is predicted and whether these are in line with estimates from other countries (or estimates derived for the UK if an econometric approach is advanced).

6 ALTERNATIVE APPROACHES FOR IMPROVING THE MEASUREMENT AND MODELLING OF INDUCED DEMAND

6.1 INTRODUCTION

6.1.1. The objectives of this study were twofold: (i) firstly, to scope what empirical analysis could be undertaken to deepen the Department's understanding of induced travel and provide more robust estimates for road capacity changes on the SRN; and, (ii) secondly to provide guidance about how insights from this analysis could be used to help improve transport modelling processes, specifically to consider how the elasticity of road traffic volumes with respect to capacity change relates to the standard four-stage modelling approach and to determine whether this elasticity could be used to calibrate and/or validate models.

6.1.2. The primary benefit of an **econometric approach** is that it should provide a **robust estimate of induced travel** as a result of capacity improvements on the SRN (measured as an elasticity reflecting changes in VKT resulting from changed capacity). Theoretically, it should be feasible to explore short-run and long-run elasticities and to explore differences between passenger and freight travel. The key shortcoming of this approach is that an approach based on SRN counts only would not provide induced travel measures by journey purpose or behavioural response, e.g. re-assignment, mode shifting or destination choice (although it may be possible to quantify re-assignment and mode-shifting effects, with inclusion of a wider range of data sources, we recommend that the priority would be to get such an analysis set up using traffic count data only in the first instance). Whilst analysis undertaken at the road-segment level may provide some information on the impact of different types of road investment, elasticities generated from econometric approach do not generally make such distinctions.

6.1.3. **Improved Before and After studies** could provide more information on how road capacity changes impact the number of trips (across a screenline) in specific contexts. It could also provide information on the relativity of differing behavioural responses, e.g. re-assignment, mode and destination shifting. Improved Before and After studies may provide further information on short and long run responses, although we have not seen strong evidence from existing studies. Collation of data from improved Before and After studies over time could provide evidence on how responses vary across different types of road investment.

6.1.4. The table below describes key aspects of each approach, along with its strengths and weaknesses, building on the summary presented in Chapter 2.

Table 6-1 - Strengths and weaknesses of econometric and before and after studies

Approach	Econometric Studies	Before and After Studies
Description	Quantifies relationship between induced	Analysis of changes in traffic from
Key examples	NL, USA, Japan, Spain	Post-Opening Project Evaluation (POPE) studies
Measure of induced	Vehicle kms (or miles) travelled (VKT)	Change in traffic across screenline(s)
Measure of road capacity changes	Generally measured by an increase in lane-kms, but also could be represented through road policy indicator variables	Specific to case study – over time, database could be collated to explore how different types of intervention may impact induced travel numbers
Induced travel measure	Elasticity measuring change in road traffic	Percentage change in road traffic
Treatment of background growth and other factors influencing road traffic demand	Analysis controls for background growth by including GDP growth, car ownership, fuel price change and land-use changes, e.g. population, in analysis so that these variables are taken account of in elasticity estimate Analysis may take account of congestion Detailed (disaggregate) analysis may take account of other factors, e.g. weather, accidents, construction, etc.	Estimate of background growth is a shortcoming of current studies; more reliable estimates of background traffic can be derived
Data	Time series data on travel demand on SRN –	Historically undertaken using count
Able to estimate short-term vs long-term estimates	Theoretically possible to estimate short-term and long-term elasticities, but not much evidence of such analysis	Yes, theoretically

Approach	Econometric Studies	Before and After Studies
Able to differentiate responses separately for passengers and freight	Theoretically yes (if data is able to distinguish between freight and passenger vehicles), although we have not seen studies that do this	Theoretically yes (may depend on data)
Able to identify response by journey purpose of travel for passenger travel	No	Perhaps, depending on data
Able to identify responses by response type	No (although may be able to identify some re-assignment effects if data exist)	Yes
Other strengths	Robust evidence base to provide overall elasticity (including information on variation in count data) May be able to differentiate impacts by geography, e.g. urban/rural System approach provides valuable information on comparator sites for Before and After studies	Able to provide more context-specific information on induced travel. May be able to provide information on changes in land-use on background growth for econometric analysis.
Other weaknesses	Elasticity may not distinguish specific interventions A range of equations used for estimation, tests to be undertaken to explore best formulation	May not be able to identify responses by purpose. May be better for measuring larger demand changes
Biases	Analysis may omit important variables that cannot be measured Endogeneity between road building and demand – may be controlled for in some formulations, e.g. instrumental variables	

6.2 A PROPOSED WAY FORWARD USING AN ECONOMETRIC APPROACH

6.2.1. One of the key differentiators in terms of the econometric approaches that could be implemented to estimate induced demand responses to road supply changes on the SRN is the spatial unit of observation and analysis; namely whether data at the aggregate or area level or at the road-segment level are used. Given that data for the road network, road demand and background explanatory variables in England are available at both aggregate (for example for regions or local authorities) and at road segment level, we recommend that analysis is undertaken at both an aggregate and detailed level to examine whether the differing approaches provide similar estimates of induced travel and if they do not to understand differences between the two approaches.

6.2.2. In the first instance, **analysis should be focussed on the use of road traffic flow data** from Highways England, DfT and Local Authorities. The advantage of using traffic count data is that there already exists a sufficient time series for estimating induced travel demand, it is well understood, and it is comparable to data used in econometric estimations reported in the literature. While other data sources, such as data from mobile phones could potentially be used in the future to augment the analysis, particularly in terms of sources of induced demand or differentiating by trip purpose, the process for doing so is currently less clear. We recommend focussing on the use of road traffic flow data initially, which could later be extended to include new data sources.

6.2.3. For both aggregate and more detailed analysis approaches, the implementation follows a set of common steps:

- Changes in demand and supply on the existing SRN only are estimated in the first instance. We would expect this to be an overestimate of induced demand as it would not account for re-assignment. Once an estimation procedure has been established, the analysis may be able to be extended to include this effect.
- A common set of background variables should be specified, potentially aligned with NTEM (see Chapter 3), although different specifications could be tested.
- The effects of changes in land use should be included where possible through explanatory variables.[61] These could be included as lagged variables and the choice of lags should be tested. The potential endogeneity of land use changes could be explored at a later stage.
- Wider influences on demand not captured by the explanatory variables should be accounted for; this could be done using spatial fixed effects, for local geographical, cultural or other effects that are not clearly definable and do not change over time and time dummies, for events, in a given period that affect demand across all areas, such as a pandemic.
- Recognising that the potential endogeneity of road supply changes could introduce error into the demand response estimate, comparison should be made where possible between results from methods that explicitly control for this effect through instrumentation and methods that do not.[62]
- Estimations should take account of congestion. This could initially be done controlling for urban/non-urban area types or urban/non-urban road supply. A more sophisticated approach could then be developed as a second stage improvement.[63]
- Different approaches for calculating short-run and long-run responses should be implemented and compared. This includes comparing methods that use a lagged demand term as an explanatory variable in the regression with those that don't, as well as the direct and indirect methods of deriving elasticities. Short run estimations will be based on changes over one year. Several annual time periods could be considered for long run estimates.
- In the first stage, the estimation approach should not include identifying sources of induced demand. Although some passenger count data are available for public transport modes, the

[61] These could be based on OS and MHCLG land use change data (Section 3.15). Potential variables include the area assigned to different land use categories (residential, industrial, office etc), their share in total land use, building activity and land use category valuations. See Cervero (2003) for examples.
[62] Please see Section 4.3.24 and Dunkerley et al. (2018) for a discussion of the comparability of estimation methods.
[63] See Section 4.3.15.

robustness of this data varies. Moreover, as with re-assignment, both the geographical area over which mode shifts might occur and the way in which these they can be included are not well understood.

- If it is feasible, from available data sources, it would be useful to test whether it is possible to estimate separate values for freight and passenger demand.

The two approaches are discussed further below. We do not recommend a preferred estimation method in either case as this should be developed to generate the most robust estimates given the variable specification (see Section 4.3 for details of the econometric equations) and dataset used. We assume that the best results would be judged from estimates of statistical model fit, judgements about the size and sign of explanatory variables and validation against published values. Estimating elasticities using two different data approaches will already provide some information on the accuracy of the estimates. Undertaking further tests to understand the effect of the estimation method and variable specifications on the estimated elasticity values would be useful in providing information on how much the estimation approach impacts the resulting values, the potential range of values and the preferred approach.

6.2.4. We emphasise that the estimated induced demand responses may be influenced by the data, the choice and specification of variables and the estimation method. Data assembly and cleaning will be an important part of the econometric process to avoid introducing measurement error. It will also be important to understand how measurement error could influence the results through sensitivity analysis. While, there are econometric tests that can help inform the choice of estimation method and limited consensus on the variables that should be included, testing and reporting the results of different variable specifications and estimation methods to understand how and why they differ is a useful way of determining the reliability of the estimations.

6.2.5. All results should be compared with evidence collected in Dunkerley et al. (2018).

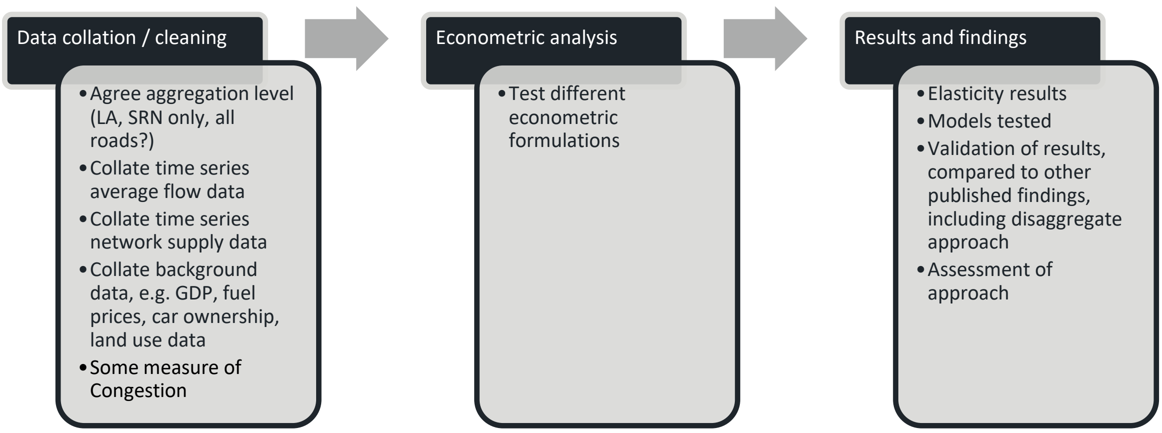
AREA LEVEL APPROACH

6.2.6. **The value of the area level approach is that it could be used to provide a direct estimate of the percentage annual average change in VKT in response to a percentage increase in lane-km added to the network as a whole** (the elasticity). While this approach would not distinguish particular road schemes or types of capacity improvements, it would provide a single, order of magnitude estimate of the expected proportionate change in demand as a result of a capacity extension. There is currently no such value available for the SRN and it is not clear that estimates from similar analyses from other countries are transferable to the UK setting, given differences in geography and transport supply and demand across modes. The analysis could, moreover, potentially be extended to estimate separate values for capacity improvements in urban and inter-urban settings. The area level demand response is based on road supply data that captures all lane-km changes in the area of interest and does not distinguish between different types of capacity interventions, nor can it take account of other road improvement measures, such as variable speed limits.

6.2.7. International studies use data at the state (regional) or metropolitan area level. For these areas, it can be reasonably assumed that changes in VKT are only influenced by changes on the road network and background variables in the same area. While, data at the Local Authority (LA) level could be used as a starting point for an analysis of the SRN, these data may also need to be aggregated to a more regional level, balancing the need for an observational unit over which changes on the SRN can be usefully measured with the need for sufficient data points for a robust estimation.

6.2.8. Annual average daily traffic flow data would be used. These data are available for total traffic at the LA level. To develop estimations for the SRN only, it may be necessary to aggregate traffic count data from collection sites. In addition to AADT's, annual road supply data in terms of SRN lane-kilometres in each area would be required. Data on background variables would also need to be collected.

Figure 6-1 Steps to undertake aggregate area-based elasticity analysis



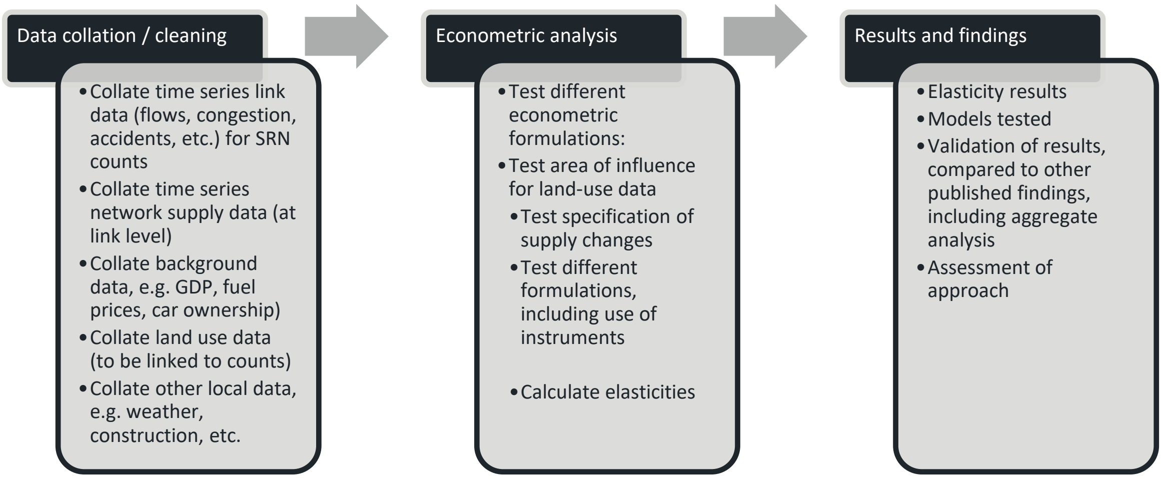
ROAD SEGMENT LEVEL APPROACH

6.2.9. **The value of the road segment level approach is that it potentially allows the demand response to different types of road capacity improvements to be determined and elasticities to be calculated separately for individual roads or even road stretches.** It also allows local characteristics to be controlled for that may influence the average demand response over the year, such as other policy interventions, road construction, weather, etc. **The use of more disaggregate data may better identify induced effects – although, to our knowledge, area-based approaches and road level segment analysis approaches have never been directly compared.**

6.2.10. The road segment level approach has been implemented on the Dutch trunk road network, where traffic count data from individual road segments (stretches) is recorded at 15-minute intervals. These data are then aggregated to monthly weekday averages for the analysis. On the SRN, traffic counts from the permanent 7,250 MIDAS sites, 2,200 TMU sites and 830 TAME sites that collect data on a regular basis could be used. Following the Dutch approach, road capacity improvements are implemented using indicators (dummies), with different indicators for different types of interventions. However, the annual road supply, measured in lane-km, is still needed to calculate an elasticity.

6.2.11. Background data variables will need to be applied over an appropriate 'area of influence'. This would have to be determined empirically, through a 'trial and error' approach (see 2.3.15). If data are available on 'local' variables that could reasonably be expected to influence monthly demand, such as accidents, construction and weather, these could also be included in the analysis.

Figure 6-2 Steps to undertake disaggregate elasticity analysis



6.3 IMPROVING AND EXPANDING BEFORE AND AFTER STUDIES

6.3.1. The prime example of Before and After studies undertaken in the UK are the Highways England's Post Opening Project Evaluations (POPE) studies. However, it is recognised that the focus is on how well specific road improvements (increases in road capacity) have met a specified set of objectives, with assessment of induced traffic a more peripheral issue. The implied 'induced demand from such a process is an aggregate of the different change in behaviours, that ultimately make up the estimate of 'induced' traffic. We would therefore recommend an approach that builds on the current POPE process that has additional controls for background growth together with the introduction of further data sources which will that provide a representation of the size of those different demand behaviours that make up 'induced' traffic.

6.4 MODELLING INDUCED TRAVEL

6.4.1. We conclude that, except for land-use changes, all components of induced travel would be represented by a four-stage model, provided that such a model includes a frequency response (sensitive to generalised cost changes). Therefore, representing induced travel does not require a fundamental change to the way four-stage models are calibrated or estimated.

6.4.2. Evidence from the Manchester Motorway Box study (Rohr et al. 2012) suggests that destination choice responses to new road capacity are greater than mode choice sensitivities. This is consistent with a model structure with mode choice above (less sensitive than) destination choice. It is also the structure recommended by TAG guidance for models that cannot identify the sensitivities from local evidence.

6.4.3. For LUTI models it may not be possible to work with modes above destinations structure and this is likely to affect the relative contributions of mode and destination choice to induced traffic.

6.4.4. We can see no obvious advantages of using an ABM model to model induced travel compared to a four-stage approach.

6.4.5. Elasticity models are unable to say anything about the composition of induced demand but may be able to approximate the total level of induced traffic. As such they may be an appropriate approach in contexts where the development of a VDM cannot be justified. That said, their inability to predict the redistribution impacts of a scheme is a major limitation.

6.4.6. Lessons learnt from adopting both the proposed way forward using both the econometric approach and improved and expanded before and after studies, could improve four stage modelling more generally by providing evidence around which model specifications and structures perform best.

7 RECOMMENDATIONS

7.1.1. Throughout this report we argue for a two-pronged approach – using econometric methods and improved Before and After studies to measure and better understand induced travel effects, because no one approach can adequately quantify the size of induced travel as well as providing understanding on:

- Short and Long Run responses to investment in road capacity;
- The responses of different types of traffic (for example by journey purpose or by vehicle type) to new road investment; and
- How responses vary accordingly to different types of road investment.

7.1.2. Moreover, the advantage of a two-pronged approach is that it takes account of the strengths of each approach; specifically, the estimation of a robust value of induced travel from the econometric approach and the ability to explore how induced travel varies across differing responses from Before and After studies.

7.1.3. Further, each approach could provide valuable information to the other. For example:

- information on the size of background growth measured in the econometric approach could inform the size of background growth in the case studies (and vice-versa).
- the econometric approach may help to provide comparator sites (similar sorts of sites and measures of background growth) for the before and after studies.

7.1.4. We would there recommend a Pilot Study that explores and provides evidence on background growth resulting from growth in GDP, car ownership and fuel price changes and changes in land use that may have generated additional traffic between the year that the data was collected in the ‘before’ situation and the year that the ‘after’ data was collected. New data sources, particularly the use of mobile network data may make it feasible to better quantify before and after changes providing better estimates of the impacts of different types of responses. In addition, the Pilot Study would also explore and provide evidence on land use changes that have arisen as a result of new road capacity, within five years of the opening of a road scheme.

7.1.5. We would also recommend that the Pilot Study explores whether estimates of induced travel can be disaggregated into their component parts through the use of mobile phone data which has been previously collected for the prior purpose of generating trip matrices for transport Model. Specifically, the pilot would focus on exploring whether mobile phone data can help to understand the impact of new road capacity on assignment, mode, destination choice and frequency response after accounting for background growth. If such disaggregation can be determined, then it could be used to compare against model predictions to validate the sensitivity of different model responses in travel demand models.

VALIDATION AND REALISM TESTS

7.1.6. We recommend undertaking an early pilot study to **explore whether the use of mobile phone data in before and after studies can help to understand the impact of new road capacity on assignment, mode and destination choice and frequency responses**. This information could be used to compare against model predictions to validate the sensitivity of different model responses informing model structure. Before and after studies could also explore the size of land-use changes as a result of new road capacity.

7.1.7. The importance of journey time in generalised cost means that the generalised cost changes that follow from changes in road capacity are likely to have a larger contribution from journey time changes than from monetary cost changes. Therefore, we recommend that further research is undertaken **to understand better appropriate car time elasticities, by journey purpose, to update TAG guidance**.

7.1.8. We recommend that **tests be undertaken using existing models to explore what level of induced travel they would predict for road capacity increases (perhaps for the SRN and all roads)**. These could be compared with values reported in Dunkerley (2018) and new work undertaken to estimate elasticities as recommended above. Such tests could explore the feasibility of validating fuel cost elasticities, car time elasticities, cost damping alongside tests of induced travel.

NEXT STEPS

In order to implement the recommendations stated above, the next steps would be as follows:

In terms of econometric approach

- Implement both road segment and area level econometric analysis of induced travel.

In terms of the Before and After studies

- Identify an appropriate scheme that has been completed where before and after data is available (particularly where mobile network data is available) to undertake the pilot study.
- Undertake the analysis, exploring whether it is feasible to measure induced travel, as well as the impact from differing responses and by journey purpose
- Compare measured findings against model predictions, in terms of: (i) size of induced travel, (ii) size and sensitivity of predicted response, (iii assumed land-use changes

In terms of modelling analysis,

- Undertaken further research to better understand appropriate car time elasticities
  - Literature review
  - Elasticities across a range of models
  - Other approaches?
- Test induced travel predicted across a number of existing models
  - Identify a handful of models, including models with frequency responses
  - Test impact of increasing SRN capacity by 10% on induced travel and size of responses
  - Compare across models and with existing evidence

REFERENCES

Dunkerley F., J. Laird, B. Whittaker and C. Rohr (2018) Latest Evidence on Induced Travel Demand: An Evidence Review, for the UK Department for Transport.

Duranton, G. and M. Turner. 2011. ‘The Fundamental Law of Road Congestion: Evidence from US Cities.’ The American Economic Review.

Gonzalez, Rosa Marina, and Gustavo A. Marrero. 2012. "Induced road traffic in Spanish regions: A dynamic panel data model." Transportation Research Part A: Policy and Practice 46 (3):pp 435-445.

Hsu, W-T and H. Zhang. 2014. “The fundamental law of highway congestion revisited: Evidence from national expressways in Japan.” Journal of Urban Economics 81: 65–76

Hymel, Kent M., Kenneth A. Small, and Kurt Van Dender. 2010. "Induced demand and rebound effects in road transport." Transportation Research Part B: Methodological 44 (10):pp 1220-1241.

Rentziou et al. 2012. ‘VMT, energy consumption, and GHG emissions forecasting for passenger transportation.’

Rohr, Charlene, Andrew Daly, James Fox, Bhanu Patruni, Tom van Vuren & Geoff Hyman. 2012. ‘Manchester Motorway Box: Post-Survey Research of Induced Traffic Effects.’ The Planning Review.

SACTRA. 1994. Trunk Roads and the Generation of Traffic, for the UK Department for Transport.

Sloman Lynn, Lisa Hopkinson and Ian Taylor. 2017. ‘The impact of road projects in England.’ CPRE Report.

van der Loop, H, Rinus Haaijer and Jasper Willigers, Transportation Research Board. 2016. "New Findings in the Netherlands About Induced Demand and the Benefits of New Road Infrastructure."

Appendix A

POTENTIAL STUDIES TO INFORM THE DEEP-DIVE ANALYSIS OF METHODS TO MEASURE INDUCED TRAVEL

The following table highlights key studies that were used to inform the deep-dive analysis of potential methods to measuring induced travel.

The colours in the table reflect the relevance of the study, as judged by the team. Those studies highlighted in green were judged to be highly relevant – and interviews were targeted at authors of these studies.

Key

(green)	Highly relevant (for interview)
(blue)	Relevant (interview back-up)
(orange)	Quite relevant
(grey)	Not relevant
(white)	Relevant to other tasks

Key Studies on Induced Travel

Study no	Authors	Evidence type	Induced demand measure	Change in supply / Supply measure	Output	Time period	Geography / Scale	Selection criteria
6	Börjesson, et al. (2014)	model	VKT (all road types - zones)	Fixed infrastructure projects	% change VKT (build/no-build)	2006-2030	Stockholm city region	Evidence is a model. Judged to be more relevant for Task 3.
9	Concas (2013)	econometric	VKT (all road types)	productive capital expenditure	elasticity	1982-2005	state level (US)	Econometric study, non-standard supply measure, less recent, focus is USA
11	Currie and Delbosc (2010)	review			elasticity	various	various	

Study no	Authors	Evidence type	Induced demand measure	Change in supply / Supply measure	Output	Time period	Geography / Scale	Selection criteria
12	Davies (2015)	case study	AADT (measured on main link only)	various fixed infrastructure, different road types	% change AADT (build/no-build)	1990s-2013	7 projects (Queensland)	Case study, recent but focus is Australia
13	Elliott (2016)	review	traffic	various	% traffic change	various	Mainly UK projects	Prefer to focus on papers that provide original analysis.
19	Gonzalez and Marrero (2012)	econometric	VKT (all roads)	lane-km	elasticity	1998-2006	16 regions, various sizes (Spain)	Econometric, European, less recent
20	Graham (2014)	econometric	VMT (all roads)	lane-miles	elasticity	1982-2007	city level (US)	Relevant and recent, but focussed on US cities so judged to be less relevant
22	Hymel et al. (2010)	econometric	VMT (all roads)	lane-miles (urban), road length/square-mile (non-urban)	elasticity	1966-2004	state level (US)	Econometric approach similar to Gonzales and less recent data
27	Kang et al. (2009)	model	trips (all roads)	2 fixed projects	% change in car trips cf baseline, am peak hour	2001-2030	single MSA (Canada)	May be more relevant for Task 3.
46	Milam et al. (2017)	review	VMT	capacity increase (secondary reporting, so not clear)	elasticity	1973- 2003	various (US)	Not relevant (secondary evidence from less recent studies).
48	Naess et al. (2012)	model	AADT	new urban dual carriageway (1650m)	% traffic difference between model	opening year only	main link (Denmark)	May be more relevant for Task 3.

Study no	Authors	Evidence type	Induced demand measure	Change in supply / Supply measure	Output	Time period	Geography / Scale	Selection criteria
					with and without induced demand			
50	Nicolaisen and Næss (2015)	case study	AADT	20 road projects in UK and 15 in Denmark. These were limited to projects where “do-nothing” could be empirically established.	% difference in observed and forecast Do-nothing traffic volumes	projects completed between 1985 and 2010	Projects (UK/Denmark)	Relevance in terms of how background growth is accounted for.
61	Schiff et al. (2017)	econometric	AADT	Busway	%change in vehicles relative to counterfactual	2008-2015	project (New Zealand)	Focus not on road scheme, less relevant geography.
63	van der Loop et al. (2016)	econometric	VKT	additional lanes at 150 locations on trunk road network (+10% capacity). Modelled as dummy for lane in place or not, at each observation time and place	% increase in VKT, elasticity	2000-2014	trunk road network, all road network (Netherlands)	European, econometric approach looking at increases of capacity on national trunk road network, relatively recent data.
65	Weis and Axhausen (2009)	econometric	trips, trip-length (all modes)	accessibility, based on population and travel time between municipalities	elasticity	1974-2005	individual (Switzerland)	Does not separate modes of travel.
70	Rohr et al. (2012)	model/case study	car trips (+ other modes) for	Completion of M60 motorway box scheme	% trips (screenline approach), also reports elasticities	Before (1999)/After (2003) screenline	Manchester Motorway Box region (UK)	Key case study paper, UK, looks at trip purpose.

Study no	Authors	Evidence type	Induced demand measure	Change in supply / Supply measure	Output	Time period	Geography / Scale	Selection criteria
12	Davies (2015)	case study	AADT (measured on main link only)	various fixed infrastructure, different road types	% change AADT (build/no-build)	1990s-2013	7 projects (Queensland)	Case study, recent but focus is Australia
13	Elliott (2016)	review	traffic	various	% traffic change	various	Mainly UK projects	Prefer to focus on papers that provide original analysis.
19	Gonzalez and Marrero (2012)	econometric	VKT (all roads)	lane-km	elasticity	1998-2006	16 regions, various sizes (Spain)	Econometric, European, less recent
20	Graham (2014)	econometric	VMT (all roads)	lane-miles	elasticity	1982-2007	city level (US)	Relevant and recent, but focussed on US cities so judged to be less relevant
22	Hymel et al. (2010)	econometric	VMT (all roads)	lane-miles (urban), road length/square-mile (non-urban)	elasticity	1966-2004	state level (US)	Econometric approach similar to Gonzales and Marrero but US focus and less recent data
27	Kang et al. (2009)	model	trips (all roads)	2 fixed projects	% change in car trips cf baseline, am peak hour	2001-2030	single MSA (Canada)	May be more relevant for Task 3.
46	Milam et al. (2017)	review	VMT	capacity increase (secondary reporting, so not clear)	elasticity	1973- 2003	various (US)	Not relevant (secondary evidence from less recent studies).
48	Naess et al. (2012)	model	AADT	new urban dual carriageway (1650m)	% traffic difference between model	opening year only	main link (Denmark)	May be more relevant for Task 3.

Study no	Authors	Evidence type	Induced demand measure	Change in supply / Supply measure	Output	Time period	Geography / Scale	Selection criteria
			commute and other travel		(tours and km) wrt to time and cost changes more generally	data, plus household survey data		
72	Duranton and Turner (2011)	econometric	VKT	lane miles (major urban roads and highways)	elasticity	1983-2003	MSA level (US)	Key paper and econometric approach that also looks at some
74	Litman (2017)	review	various	various	various	various	various	Secondary evidence.
75	Noland (2001)	econometric	VMT	lane miles	elasticity	1984-1996	state level (US)	Not recent.
76	Noland and Hanson (2013)	review	mainly VMT	mainly lane-km	elasticity	various	various	Secondary evidence.
78	Su (2011)	econometric	VMT	lane miles	elasticity	2001-2008	state level (US)	Similar approach to Hymel et al but more recent data.
79	Sloman et al. (2017)	case study	AADT	individual projects (mix of bypass, widening, etc)	% increase in traffic over background (screenline approach)	-2015	UK, project	Relevant geography and before/after approach.
82	Hsu and Zhang (2014)	econometric	VKT	Lane km, length of road network	elasticity	data from 1990, 1994, 1997, 1999, and 2005	MSA level (Japan)	Follows Duranton approach, geography less similar to UK.
83	Rentziou et al (2012)	econometric	VMT	lane miles	elasticity	1998-2008	state level (US)	Econometric approach that looks at induced travel at

Appendix B

TEMPLATE SUMMARIES OF CHARACTERISTICS OF KEY APPROACHES FOR MEASURING INDUCED TRAVEL

This appendix includes the current summaries of the three approaches for measuring induced travel:

- Econometric approaches to calculate an induced demand elasticity;
- Case studies based on Before and After data collection; and
- Case studies based on Before and After data, including modelling to quantify responses.

Induced travel – Task 1, Review of existing approaches

1. Approach: econometric studies
2. Key paper(s)

   Duranton, G. and M. Turner. 2011. 'The Fundamental Law of Road Congestion: Evidence from US Cities.' The American Economic Review.

   Hsu, W-T and H. Zhang. 2014. "The fundamental law of highway congestion revisited: Evidence from national expressways in Japan." Journal of Urban Economics 81: 65–76

   Hymel, Kent M., Kenneth A. Small, and Kurt Van Dender. 2010. "Induced demand and rebound effects in road transport." Transportation Research Part B: Methodological 44 (10): pp 1220-1241.

   Gonzalez, Rosa Marina, and Gustavo A. Marrero. 2012. "Induced road traffic in Spanish regions: A dynamic panel data model." Transportation Research Part A: Policy and Practice 46 (3): pp 435-445.

   Pasidis, I. 2017. 'Urban transport externalities.' PhD Thesis, University of Barcelona.

   Rentziou et al. 2012. 'VMT, energy consumption, and GHG emissions forecasting for passenger transportation.'

   van der Loop, H, Rinus Haaijer and Jasper Willigers, Transportation Research Board. 2016. "New Findings in the Netherlands About Induced Demand and the Benefits of New Road Infrastructure."
3. Key author(s)

   G, Duranton, E Rentziou, H, van der Loop
4. Brief description of approach

   Econometric studies aim to analyse the relationship between induced travel (measured by VKT) and road capacity (generally measured by an increase in lane-km) using empirical data. To do this most studies employ a regression approach, typically of the form:

   $$Log(VKT_{it}) = \alpha_i + \beta_t + \gamma Log(lane-km_{it}) + \sum_k \delta_k X_{kit} + \varepsilon_{it} \quad (1)$$

   Where subscripts i and t refer to area and time period and X represents a set of k control variables, which may also be used to control for background growth in traffic. In some formulations, lagged VKT terms are included as explanatory variables, allowing a long-run elasticity to be inferred as well as other lagged variables to account for delayed behavioural responses.

   A variety of methodological approaches are applied to generate consistent estimate of the regression coefficients. These include OLS, SURE, 2SLS and 3SLS, the latter with different forms of instrumentation.

5. Induced travel measure

   Elasticity of road traffic demand, measured in terms of vehicle kilometres (or miles) travelled (VKT) with respect to road capacity, measured in terms of lane kilometres (miles). This follows naturally from the use of logarithmic forms for these two variables in the regression equations estimated.

   Using logarithmic forms of the dependent VKT and lane-km variables in the regression equation to be estimated means that the coefficient γ can be interpreted as the elasticity of VKT with respect to lane-km; the proportionate response in demand to an increase in road capacity

   The exception is van der Loop et al, where the induced travel measure is calculated from the VKT response to a known increase in capacity on the road network, although road capacity does not enter the regression formulation directly but rather through policy indicator variables.

6. Intervention

   Most econometric studies do not consider specific interventions but look at the part of aggregate VKT that can be explained by added lane kilometres. Some studies also look at specific road types (e.g. highways or major roads only). The demand measures are usually constructed from data on AADT flows and road network length.

   Van der Loop et al., consider 483 policy interventions on whole trunk road network in the Netherlands, that together increased capacity by 10% (over 1000km).

   Other earlier studies looking at specific interventions were covered in review papers. Noland and Hansen (20130 authors include two studies that look at project level investments and account for indirect effects i.e. induced demand due to land-use development associated with the transport project. These studies found SR elasticities of 0.24 (Cervero, 2003) and 0.29 (Strathman et al., 2000).

7. Area/geography of measurement (could cover country, area covered (national, state, specific project, urban/non-urban))

   Most studies look at large regional or urban areas (MSAs, LUZ, US states, Spanish regions, NL national trunk road network). Within this there is some further categorisation of urban/non-urban areas or the contribution of urban/nonurban travel to overall demand.

8. Does the methodology quantify induced demand by purpose? Could it?

   Duranton and Turner (2011) use household survey data to look at induced demand for commuting. This analysis was separate from the aggregate analysis based on AADT data and found a much smaller response.

9. Does the methodology quantify induced demand by vehicle type, e.g. passenger cars, freight? Could it?

   Most studies appear to use data for all traffic. Rentziou et al., consider passenger traffic only.

   Duranton and Turner (2011) also estimate regressions for truck traffic based on their share in aggregated data. Regressions for passenger traffic are based on a different dataset.

10. Does the methodology quantify induced demand by response type, i.e.: increases in veh-kms because of route changes (re-assigned traffic), mode of travel, destination shifting, frequency of travel, land-use changes? Could it?

    Studies that consider all road types in given area should automatically allow for re-assignment. Studies that look at particular road types (e.g. Duranton and Turner, Rentziou et al) do not include re-assignment but do undertake some analysis of its effect. Van der Loop et al., allow for reassignment from arterial roads and the proportion of all traffic on trunk road network in their elasticity estimation.

    Few studies include mode shift. Duranton and Turner., consider bus travel. Pasidis allows for metro systems in large urban zones in the EU.

    Given the aggregate nature of the assessments, the effect of change in destination and frequency of travel should be captured. Land-use changes are not explicitly included in any of the studies reviewed. These may be implicit in long -run elasticities. Duranton and Turner also use information from a previous study to consider the migration element of population and its effect on demand.

11. Does the methodology distinguish induced travel by time period, i.e. peak or off-peak? Could it?

    Most studies derive demand based on AADT data. The van der Loop study was part of a larger analysis on travel time reliability that also considered the effect of increased road capacity on delays and peak period flows. It is not clear whether this data was incorporated into the induced demand analysis.

12. Does the methodology quantify short-term or long-term (induced travel) responses?

    Most studies use a time series (panel) of annual data to determine a short run response, with a long run response additionally possible when a lagged VKT term is included (Hymel et al.).

    Duranton and Turner use annual data at 10 yearly intervals over 3 decades to determine long-run effects only. Hsu &Zhang and Pasidis follow a similar approach for Japan and the EU 28.

13. How does the study account for background growth?

    Few studies explicitly state that they control for background traffic growth. Most studies control for population. Other controls that could account for background growth are car ownership, employment, income per capita and fuel price. These are not applied consistently across all studies.

14. What data were used to calculate induced travel responses (POPE, NTS/household surveys, Mobile phone data, journey to work data, roadside interview data, trip rates, other?)? What period were the data collected? Was the data collection deemed adequate?

    Most studies used secondary aggregate AADT data or equivalent. For example, FWHA data in the US. Duranton and Turner used (secondary) household survey data for one sub-analysis on passenger demand. Van der Loop et al used data collected on 3000 1km stretches of the road network.

15. Is the approach transferable to other projects or schemes?

    It should be possible to apply econometric methods to other geographies and/or road networks than covered in the econometric studies we reviewed. The application of this approach to particular schemes is less clear.

16. Can the measure of induced travel generated by this approach be compared with other measures? How could this be done?

    Van der Loop et al do not use the log-log formulation to generate an elasticity but could calculate one in terms of percentage change in VKT relative to capacity increase as the capacity increase across the whole network was measurable. It is otherwise not clear how the demand response for a particular scheme can be related to an elasticity measure.

17. What are the strengths of this approach (endogeneity, treatment of concurrent schemes)?

    In theory, possible to account for endogeneity of variables, control for background growth, calculate short run and long run effects and include other modes.

18. What are the weaknesses of this approach?

    Various methodologies applied to ensure consistent estimation. Not clear which of these are 'correct'. Use of a range of instruments. Studies that compare results from several estimation methods which give comparable results and where differences can be explained are probably most reliable.

    Results depend on data used.

    Potential for omitted variable bias.

19. What are the key assumptions of the approach? Are there any potential biases built into the approach?

20. How could the approach be improved?

Induced travel – Task 1, Review of existing approaches – Highways England

1. Approach: Case studies, collection of Before and After data

2. Key paper(s)/Information sources

   Post Opening Project Evaluation of Major Schemes: Evaluation Insights Paper – April 2019, Highways England

   Post Opening Project Evaluation Meta Reports -February 2016

   Post Opening Project Evaluation Major Scheme Summary Reports – 2014 to 2020

   Sloman Lynn, Lisa Hopkinson and Ian Taylor. 2017. 'The impact of road projects in England.' CPRE Report.

3. Key author(s)

   Highways England, Lynn Sloman

4. Brief description of approach to determine before and after effects, including induced traffic.

5. Induced travel measure

6. Intervention/s

7. Area/geography of measurement (could cover country, area covered (national, state, specific project, urban/non-urban))

8. Does the methodology quantify induced demand by purpose? Could it?

9. Does the methodology quantify induced demand by vehicle type, e.g. passenger cars, freight? Could it?
10. Does the methodology quantify induced demand by response type, i.e.: increases in veh-kms because of route changes (re-assigned traffic), mode of travel, destination shifting, frequency of travel, land-use changes? Could it?
11. How were changes in background growth and reassigned traffic determined? If this analysis used observed information, what is the nature of the observed information? When was it collected in relation to the opening year of the scheme in the 'before situation'? Was the data collection deemed adequate? What additional data could be collected to provide a more informed estimate of induced traffic?
12. Does the methodology distinguish induced travel by time period, i.e. peak or off-peak? Could it?
13. Does the methodology quantify short-term or long-term (induced travel) responses?
14. How do the POPE studies account for background growth? Is the approach used consistent across all POPE studies? And if not. what methods are used under what circumstances?
15. What data were used to calculate induced travel responses, volumetric traffic counts, NTS/household surveys, mobile phone data, journey to work data, roadside interview data, trip rates, other?)?
16. What before and after data were used to estimate background traffic growth and when was it collected in relation to the opening year of the scheme in the 'before situation'? What period were the data collected? Was the data collection deemed adequate (year/season/month/day/time period in day)? What additional data could be collected to provide a more informed estimate of induced traffic?
17. Is the approach transferable to other projects or schemes?
18. Can the measure of induced travel generated by this approach described above be compared with other measures? How could this be done?
19. What are the strengths of this approach (endogeneity, treatment of concurrent schemes)?
20. What are the weaknesses of this approach?
21. What are the key assumptions of the approach? Are there any potential biases built into the approach?
22. How could the approach be improved?
23. What do the POPE studies reveal about the strengths and weaknesses of the modelling and prediction process?
24. Do Highways England propose any changes to the POPE studies that would be more informative in providing estimates of induced traffic in the short, medium- and longer-term period?

Induced travel – Task 1, Review of existing approaches

1. Approach: Case study, using a model to quantify effects
2. Key paper(s)

   Rohr, Charlene, Andrew Daly, James Fox, Bhanu Patruni, Tom van Vuren & Geoff Hyman. 2012. 'Manchester Motorway Box: Post-Survey Research of Induced Traffic Effects.' The Planning Review.
3. Key author(s)

   Charlene Rohr, Andrew Daly, James Fox
4. Brief description of approach

   The opening of the Manchester Motorway Box, the M60 orbital motorway around Manchester completed one of the last major links in the UK motorway network and the scale of the new road infrastructure investment meant that its completion in October 2000 provided an opportunity to collect data to attempt to model the traffic effects before and after opening and measure the extent of induced traffic effects. Travel survey data were carefully collected for car and public transport users across key screenlines before and after the opening of the Manchester Motorway Box. In order to quantify the impact of different travel behaviour responses, a travel demand model was developed using the before and after roadside interview data (the before roadside data were collected in 1999 and the after roadside data were collected in 2003) and household survey data collected between the before and after periods, as well as level-of-service and land-use data. This combined data set was used to estimate disaggregate travel demand models, reflecting frequency, mode, destination and time-of-day choice decisions that defined induced traffic. The model was then used to quantify induced traffic effects from the infrastructure investment. Using this approach, the authors found a 15 to 17 per cent increase in car trips across the relevant screenline, of which the majority were attributed to changes in destination (9 per cent) and less to mode shift (4 per cent). Land-use, demographic and employment effects were explicitly accounted for using detailed land use data for the area and accounted for between 2.5 to 3 per cent of the changes.
5. Induced travel measure

   Percentage increase of cars crossing key screenlines
6. Intervention

   Completion of motorway box (around a major city)
7. Area/geography of measurement (could cover country, area covered (national, state, specific project, urban/non-urban))

   Study area reflected Greater Manchester area.
8. Does the methodology quantify induced demand by purpose? Could it?

   Yes, the approach quantified induced demand by purpose (because the data collected included information on journey purpose) and separate models were developed for commute, business and other travel.
9. Does the methodology quantify induced demand by vehicle type, e.g. passenger cars, freight? Could it?

   The approach quantified induced travel for passenger car travel only, no data were collected on changes in freight movements. But the method could have quantified induced travel for freight if such data were collected.

10. Does the methodology quantify induced demand by response type, i.e.: increases in veh-kms because of route changes (re-assigned traffic), mode of travel, destination shifting, frequency of travel, land-use changes? Could it?

    Yes, the methodology quantifying induced demand by response type. Below we describe the methodology used to quantify demand by response type:

- The number of cars crossing the screenline was calculated from the model for the Before situation (using Before (observed) level-of-service, car-ownership levels and land-use) and for the After situation (using After (observed) level-of-service, car-ownership levels and land-use)
    - It was not possible to calculate a counterfactual, i.e. what the transport situation was in the After situation without the MMB, because the assignment models were not able to replicate the observed car time changes – and therefore 'observed' cost and time changes were used in the Before and After model runs (so there wasn't an assignment model to calculate the counterfactual.
    - Comparing directly the Before and After road-side interview data indicated very large changes (between 42-58% increase in traffic), with some implausible patterns, a large shift from morning to evening peak – it was judged that the before and after RSI data were not able to measure the observed changes even though these data were collected very carefully, perhaps because of route changes, changes in survey sights or because of large amounts of noise in the data.
- Estimates of induced travel were made for two purposes – commute travel and other travel – on the basis that these account for most of the travel.
- Before and After model runs were made using Before and After land-use data:
    - To derive an estimate of the average increase in trips across the screenlines caused by land-use, demographic and car-ownership changes, a run was taken using the 'After' population, employment and car ownership changes with the 'Before' level-of-service (ie without the MMB). These results indicated demographic / land-use changes accounted for around:
        - ~3% of the trips across the screenline for commute
        - ~2% of the trips across the screenline for other travel
    - Mode and destination impacts were estimated as follows. Destination shifts were calculated by taking the change in total trips crossing the screenline (by car and public transport modes) and subtracting the impact of land-use, demographic and car ownership changes. Mode shifts were calculated by taking the percentage change in car trips and subtracting percentage change in total trips. These findings are presented below.
        - Commute
            - Impacts due to destination switching: ~9%
            - Impacts due to mode switching: ~4%
        - Other travel
            - Impacts due to destination switching: ~12%
            - Impacts due to mode switching: ~4%
    - Frequency models were estimated for commute and other travel. It was not possible to identify a frequency response to changes in accessibility for commuting, but it was possible to identify such a response for other travel. Checking how these were accounted for in the analysis.

11. Does the methodology distinguish induced travel by time period, i.e. peak or off-peak? Could it?

    In neither model was it possible to identify significant shifts in time of travel, even though the other travel model contained a specific time-of-day choice component. It was judged that this may be because the speed improvements were broadly consistent across time periods.

12. Does the methodology quantify short-term or long-term (induced travel) responses?

    The Before and After data were collected in 2000 and 2003, respectively. Level-of-service and land-use data also reflected these years. The estimate therefore reflects a relatively short-term response. Although the same approach could be used to estimate longer-term response (although this would be complicated by having to account for other land-use, transport and socio-demographic changes)

13. How does the study account for background growth?

    The study methodology estimates traffic changes due to changes in land-use, car ownership and income changes directly through the use of the model (discussed above).

14. What data were used to calculate induced travel responses (POPE, NTS/household surveys, Mobile phone data, journey to work data, roadside interview data, trip rates, other?)? What period were the data collected? Was the data collection deemed adequate?

    A model was developed from Before and After road and public transport intercept data and household survey data. It is noteworthy that the household survey data provided much more information in the development of the modelling. Further, it was not possible to use the Before and After data directly to provide a measure of the induced traffic effects (comparisons were judged to be not sensible).

15. Is the approach transferable to other projects or schemes?

    Yes, although it is noted that the data collection was very expensive, and it did not provide as much value as was hoped.

16. Can the measure of induced travel generated by this approach be compared with other measures? How could this be done?

    Induced travel, in this instance, is measured by a percentage increase in travel across a screenline. It would be possible to explore how increases in travel across screenlines vary for different size investments, although ideally a measure of changes in overall vehicle kms travelled would be a better measure.

17. What are the strengths of this approach (endogeneity, treatment of concurrent schemes)?

    The strength of this approach is that it attempts to measure the impact of differing behavioural responses on induced travel, including due to changes in land-use, car ownership and economic changes (often referred to as increases in background traffic). It also quantifies the impact of induced travel by journey purpose.

18. What are the weaknesses of this approach?

    The weakness of the approach is that ultimately it relied on a model to estimate induced travel. Explicit measures of (road) travel changes across the screenline were judged to be unreliable. Also, the network models were unable to predict the observed road travel time changes, which meant that observed level-of-service was used in the model estimation procedure. This meant that a counterfactual could not be constructed.

19. What are the key assumptions of the approach? Are there any potential biases built into the approach?

    The key assumption is that travel demand model, with parameters estimated from Before, After and household survey data collected in the same time period, will accurately reflect travel changes.

20. How could the approach be improved?

    Potential areas for improvement:

    - *Better estimates of measured car traffic changes Before and After implementation of the infrastructure*
    - *Better measured estimates of travel time changes on key roads*
    - *Better information of public transport service changes (including on public transport service levels and fares)*
    - *Better estimates of land use changes (these were an afterthought and should have been collected directly)*
    - *Comparator sites to measure observed changes without infrastructure investment*
    - *Use of panel survey to explicitly measure travel changes for individuals?*

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