National Propensity to Cycle Tool Project: Summary Report

Executive Summary

The Summary Report describes the work undertaken for the Department for Transport on the National Propensity to Cycle Tool (NPCT) project. It summarises Stage 1 of the project and lays out a plan for the future work. In addition to the main report, full details are available in a series of appendices.

Based on the results from the project and user feedback, the NPCT team are well-placed to deliver Stages 2 and 3 of the project. This short Executive Summary briefly describes the key outputs of Stage 1 and provides an outline of the planned work over the next three years.

We have designed, developed and deployed on-line a public-facing **Prototype for Three Cities (NPCT Prototype).** This is now live at http://geo8.webarch.net/master/ and hosted under a contract with Webarch.net until January 2016. This has a high quality and user-friendly interface, thanks partly to user-testing sessions with Local Authority transport planners and other key stakeholders. The user testing has demonstrated a clear demand for the tool, indicated features to add, and shown what is needed to ensure that practitioners have the resources and expertise to use it. Different use cases have become apparent. The tool is available with open-source code providing transparency and supporting future development of the work.

The prototype tool allows users to see commuting cycling potential at the area and route level comparing the 2011 Census against three scenarios ('Government Target', 'Gender Equality', and 'Go Dutch', with an e-bike scenario to be added soon). See Page 2, Figure 1.

Rapid progress has been achieved in parallel with the other strands of the project:

Analysis of **Propensities to Cycle** has, for the first time, provided detailed comparison of cycling patterns in England and the Netherlands. This includes analysis on how propensity to cycle varies by age and gender, and how this interacts with distance. For England we also have a new quantitative understanding of the role of hilliness in the decision to cycle, and can use this to appropriately adjust 'go Dutch' scenarios to English topography.

The two **Evidence Reviews** have identified a clear *stated* preference for separation from busy or fast motor traffic, plus some support from intervention studies that creating such routes can increase cycling levels. Stated preferences for separation from motor traffic are particularly strong for women and appear also to be stronger for older people. The related **Inequalities Report** has developed key principles and recommendations for addressing inequalities in cycling. The **Policy and Practice** report draws out the policy implications of the work.

Both the **Co-Benefits Model (CBM)** and **Transport and Health Assessment Tool (THAT)** provide insights into the potential and limitations of trip based scenario modelling. These insights will inform the NPCT in Stage 2. The **CBM** provides results on the health, mode shift, and carbon impacts if we created new cyclists or e-bikers. It indicates substantial health benefits (6% reduction in years of life lost due to premature mortality) and reductions in car miles (8%) if non-cyclists had the same propensity to cycle as current cyclists. We have created a prototype webtool visualising National Travel Survey data and the model's results.

The **Spatial Microsimulation (SMS) feasibility study** for Manchester provides complementary analysis to the aggregate approach implemented in the **NPCT Prototype**. We have generated a novel SMS technique and used this to allocate individuals to Census flows for Manchester. Compared with the prototype the **SMS** approach provides greater detail about *who* is cycling and *which* modes they switch from, better estimating health and environmental impacts.

We have also developed a preliminary **National Model** for estimating cycling potential at the local authority level. Results from this will be presented early in Stage 2.

NPCT Prototype

In Figure 1 we see for Coventry the fours scenarios with the 20 highest flows indicated and the highest cycling areas indicated in yellow. It should be noted the shading is normalised for each scenario and the highest rate of cycling changes from 159 cycle commuters in the top Medium Super Output Area to 819 cycle commuters under 'Go Dutch'.

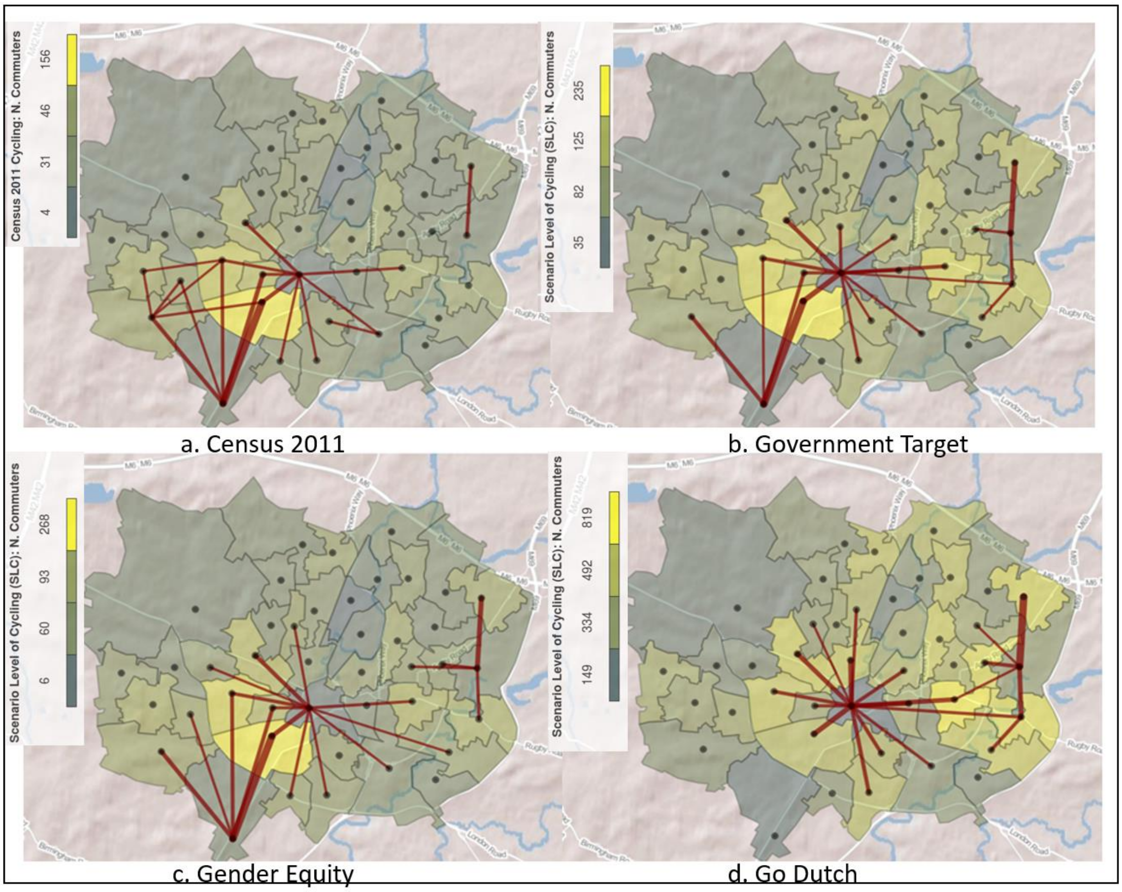

Figure 1a, b, c, d: Cycle commuting in Coventry: 'Census 2011', 'Government Target', 'Gender Equity', 'Go Dutch'.

Stages 2 and 3

The models developed, analysis undertaken, and evidence synthesised in Stage 1 provide a robust basis for implementing and rolling out the NPCT in Stage 2. In Stage 1 these separate strands have spread out to each contribute to an understanding of what a propensity to cycle model would look like and how it should be constructed. In Stage 2 we will weave these strands together to create the NPCT. In the past five months, our dedicated team of experts has produced a high quality, fully operational prototype. User testing has indicated the demand and range of potential use cases for the tool.

For Stage 2 we propose to roll-out the NPCT in two versions. Version 1 will be an aggregate version, similar to the current prototype but taking account of the key features requested at user testing. Version 2 will be use full microsimulation. This two-step approach allows the very real benefits of the NPCT to be realised in the short term (England roll out mid-2016), while allowing us to bring the even greater benefits from microsimulation on stream in 2017.

The key features of Version 1 will be a fully operational web based propensity to cycle model for the whole of England. With this interactive tool, local authority transport planners will be able to visualise which small areas and routes have the greatest cycle commuting potential under different scenarios. At the regional and national level planners will be able to investigate which towns and cities have the greatest potential. The tool will be WebTag compatible, including health economic savings estimated using the World Health Organization Health Economic Assessment Tool (HEAT) approach. Concurrently we will produce a new version of the CBM web tool, incorporating benefits on specific diseases and using more detailed methods for calculating greenhouse gas emissions.

Version 2 will be released in 2017. It will come with significantly improved functionality and much richer data, allowing investigation of impacts across multiple population subgroups, e.g. age, gender, ethnicity, car-ownership. This will be achieved through use of synthetic spatial microsimulation. Version 2 will go beyond commuting data to incorporate other trips purposes, including education trips at route and area level and other non-commuting trips at area level.

More advanced health impact modelling methods will allow estimation of impacts on mortality and morbidity across different subgroups. The wider range of outcomes will include *which* mode cycling trips are coming from, including associated change in greenhouse gas emissions, and with results stratified by age, socioeconomic status, ethnicity and gender. This will allow us to estimate impacts on health and social inequalities.

For Stage 3 we will produce a report on pathways to impact. This will be involve collating information from Stage 2, bringing out the policy implications of the findings, and laying out the options for achieving the Government’s cycle ambition. The report will be based on the material from the NPCT modelling, as well as updating and expanding reviews from Stage 1. We will conduct a new online survey to enhance understanding as to what practitioners see as the key local and national policies that could support our achieving the national cycling ambition.

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Workpackages and Appendices

The research for Stage 1 of the National Propensity to Cycle Project consisted of the following Workpackages.

1. Rapid Evidence Assessment (REA) and Inequalities Report
2. THAT model: A web-based tool of cycling potential and its impact on health in London
3. Co-Benefits Model
4. Comparing propensities to cycle in England and the Netherlands
5. Propensities to cycle with prototype model for three cities
6. Scoping Report

With the development of the project, the clearest structure is not a one-to-one correspondence between the Workpackages and the sections but rather we have presented results from some Workpackages across more than one summary section and Appendix. Therefore, for each section of this summary report, we indicate which Workpackage it corresponds to.

The full reports for each section are available in the following appendices:

- Appendix 1: Policy and Practice
- Appendix 2: User Testing
- Appendix 3: Prototype for Three Cities (NPCT Prototype) using an Aggregate Model
- Appendix 4: Review on evidence on cycling infrastructure and uptake
- Appendix 5: Rapid Evidence Assessment: How Age and Gender Affect Cycle Infrastructure Preferences
- Appendix 6: Inequalities Review
- Appendix 7: Spatial Microsimulation Feasibility Study
- Appendix 8: Propensities to Cycle
- Appendix 9 THAT model: A web-based tool of cycling potential and its impact on health in London
- Appendix 10: Co-benefits model

- Appendix 11: Server Requirements

An overview of how the different workpackages across the three Stages of the project come together is presented in Figure 2 below.

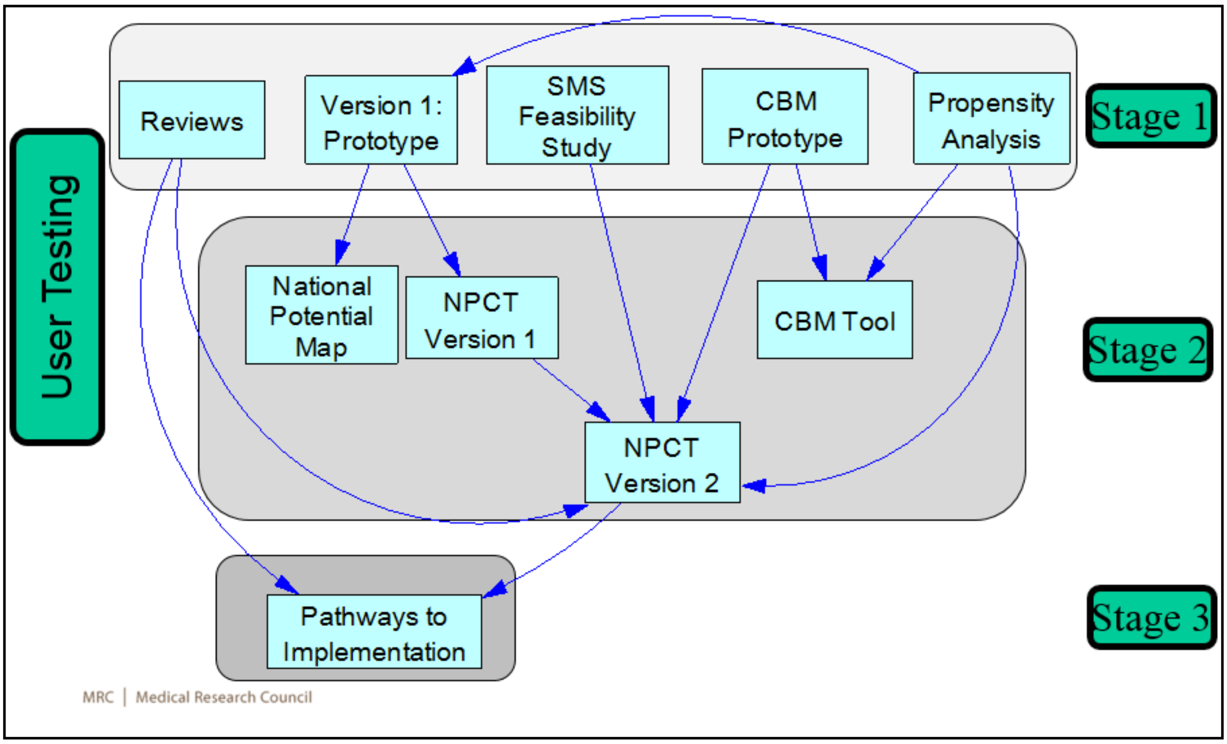

Figure 2: Conceptual map showing links between selected project workpackages

1.0 Introduction

This document summarises results of Stage 1 of the National Propensity to Cycle project. In a short timeframe, the team has produced one advanced prototype model (the NPCT), an earlier stage prototype interface for the co-benefits model (illustrating the health, carbon, and transport impacts of higher cycling scenarios), new data analysis of English and Dutch travel patterns, a feasibility study on the potential for a full microsimulation model, and three reviews to inform the development of our tool and broader cycling policy. To test out the practical relevance of our work we have carried out two half day user testing sessions plus shorter sessions and demonstrations.

2.0 Policy and Practice

This summarises the work described in Appendix 1.

Realising England's cycling ambition requires attracting a much more diverse demographic spread. Accordingly, the NPCT will allow planners to explore not just trips made by current cyclists, but potential origins, destinations, and even routes of new cycle trips, if mode share increases. For some trip purposes (primarily commuting) it will help answer the question 'where do we need to build routes if we want to get to X% of trips by cycle', as well as allowing targeting of local trips made by specific groups. Our work on co-benefits helps evidence the benefits that investing in cycling can provide under different scenarios, enabling policy-makers to consider targeting policy to specific aims (e.g. health, equity, travel time, CO_2 reduction).

Our data analysis of the English and Dutch travel survey highlights the potential to increase cycling among women and older people, groups currently under-represented in English cycling but whose trips tend to be relatively short. Our systematic review of infrastructure preferences by age and gender demonstrates the particularly strong preferences of these groups for cycle infrastructure separated from motor traffic. Growing evidence suggests creating high-quality cycle routes can increase cycling, if built in the right place and as part of a developing network.

2.1 The need for the NPCT

Our reviews and data analysis have provided evidence for what kind of infrastructure to build in order to grow and diversify cycling. The tool itself will transform cycle planning by creating an evidence base for prioritising routes; telling us where routes should be built.

As investment in cycling grows – confirmed by the review of evidence on infrastructure and uptake – it is crucial to build not just the right thing, but to build it in the right place. While primarily aimed at indicating where new cycle routes might be built, the tool can also add economic value in other ways, e.g. identifying locations to set up new cycle shops, or where to locate new cycle/e-cycle hire stations or residential cycle parking.

Stakeholders see the tool as an invaluable aid that will help them take and evidence decisions, justify investment and – through an attractive visual interface – communicate the potential and its benefits:

"*We have been very pleased to be involved in early testing of the prototype and based on this experience we think it has substantial potential to help us better plan our cycling interventions and achieve our ambitious mode shift targets*." – Dominic Smith, Transport for Greater Manchester

"*Very interesting piece of work – very keen to see how we can use it!"* – Graham Lennard, Birmingham City Council

"*Very impressive use of data – looks like a great tool and I look forward to being able to use it!"* – Nick Grudgings, Surrey County Council

"*The tool shows considerable promise in terms of assessing the potential for cycling*." – Tim Mellors, Norwich City Council

3.0 User Testing

This summarises the work described in Appendix 2 and forms part of Workpackage 5.

User testing of the tool has included three well attended half day sessions with formal feedback mechanisms, held in London and Manchester (with invited attendees) in April-May 2015, and as part of the Newcastle Cycle City Active City event held at the end of June 2015. We have discussed this structured material in meetings and will use it to guide work in Stages 2-3, also putting in place a larger programme of user testing to ensure maximum relevance and usability for practitioners as we prepare for national roll-out.

The Newcastle event demonstrated the wide appeal of the tool. It attracted 35 practitioners to what was an optional session before the main conference, running alongside two other optional events. All attending wanted to be kept informed about the tool. People came from a wide range of geographical areas (from the Northern Ireland Department for Regional Development to Surrey County Council), had a range of roles, from strategic programme managers and experienced consultants to interns and early career staff, and were working for government, NGOs and private sector organisations.

The user testing has helped us think about what people want from the tool and what we can do to help ensure that practitioners have the resources and expertise to use (and potentially develop) it. We were pleased that people very much liked the look and idea of the NPCT. People said the tool was easy and intuitive, appreciated the map detail and the ability to visualise cycling potential. We were alerted to possible misunderstandings, which will help us guard against these and develop case studies highlighting ways to use the tool.

Feedback helped us to understand how people might use the NPCT. Users suggested that the tool could be used (i) to help present business cases to the DfT, for bid and proposal writing, including through demonstrating benefits of cycling (ii) in communication to members and decision makers, including communicating that there is a demand for cycling, and visually representing routes (iii) in planning where to target future infrastructure improvement, to prioritise routes, to influence design of road schemes, and to justify cycling investment, (iv) as an input for other tools e.g. TfL modelling, (v) to sense check estimates of demand provided in other ways, to challenge or confirm existing assumptions or understandings.

People liked the fact that the tool is academic led, and felt this would help provide high quality, credible evidence to inform strategy development. There has been discussion about how simple or self-explanatory it should be, and this is something we will monitor and continue to discuss within the team. One question asked was: 'Are we aiming at something that doesn't need an instruction manual?' Stakeholders discussed who would be the intended audience, and the merits of providing a 'pro' version with advanced functionality. There was also the expressed need to have something that can be used by officers to communicate with members about strategic cycle planning.

People suggested that there will be a need for training and written materials, which we have already been developing in the form of 'help text'. During Stages 2 and 3, we will be developing closer relationships with some authorities, and this may lead to further documentation providing examples of applying the tool and of using in within a policy context. Different authorities and organisations have different priorities; for example, maximising speedy take-up of cycling versus maximising health benefits. Some stakeholders are interested in the potential for cycling to benefit more deprived areas where people have fewer other transportation options, as well as the potential to reduce carbon emissions or congestion. The choice of primary outcome might imply concentrating efforts on different types of area and the tool will be able to assist in this process.

The lively and engaged discussions at these three more formal user testing events, as well as at additional shorter demonstrations and presentations, have illustrated the level of interest in the tool. We look forward to continuing to involve users and learn from their policy and practice needs and interests.

4.0 Prototype for Three Cities (NPCT Prototype) using an Aggregate Model

This summarises the work described in Appendix 3, and forms part of Workpackage 5.

The main engine driving the local and national scenarios for the NPCT in Stage 1 is a model operating at the 'flow level' based on origin-destination (OD) data between (Medium Super Output Areas (MSOAs)[i]. Overall, the model identifies areas and routes in which there is a high rate of commuting over short distances yet a low rate of cycling. The model draws attention to areas and routes that have the greatest potential for increased rates of cycling under various assumptions.

The approach uses distance, hilliness and other explanatory variables to estimate distance decay[ii] corresponding to the current rate of cycle commuting within a Local Authority area. We then generate alternative scenarios in which the propensity to cycle increases and different distance decay functions are generated. The geographical distribution of cycling

[i] Medium Super Output Area unit of Census geography with 5000 to 15,000 people
[ii] Distance decay refers to the declining probability of making a trip by bicycle with increasing distance

potential is then estimated by applying these different distance decay curves to the existing transport flows, allowing the NPCT to identify local 'desire lines[iii]'.

Scenarios have been generated for achieving gender equity in cycle commuting uptake and achieving the National Cycling Ambition plan, and we are currently implementing a 'Go Dutch' scenario based on propensities to cycle in The Netherlands, Europe's highest-cycling country. These scenarios allow stakeholders to consider the different implications of planning for different demographics and different levels of uptake.

The primary source of input data for the model is 2011 Census OD flow results. The model provides detailed break-downs of the rate of cycle commuting under each scenario, taking into account the current rate of commuting, the circuity of the road network and hilliness (more explanatory factors will be added in Stage 2). Example model outputs are presented in the figures below. Figure 3 shows the rate of cycling by distance band under a range of scenarios for Coventry. Figure 4 illustrates the geographic distribution of cycling uptake by area (green:yellow) and for the 20 'desire lines' with the highest potential for cycling based on a scenario in which Coventry achieves the Cycling Delivery Plan,

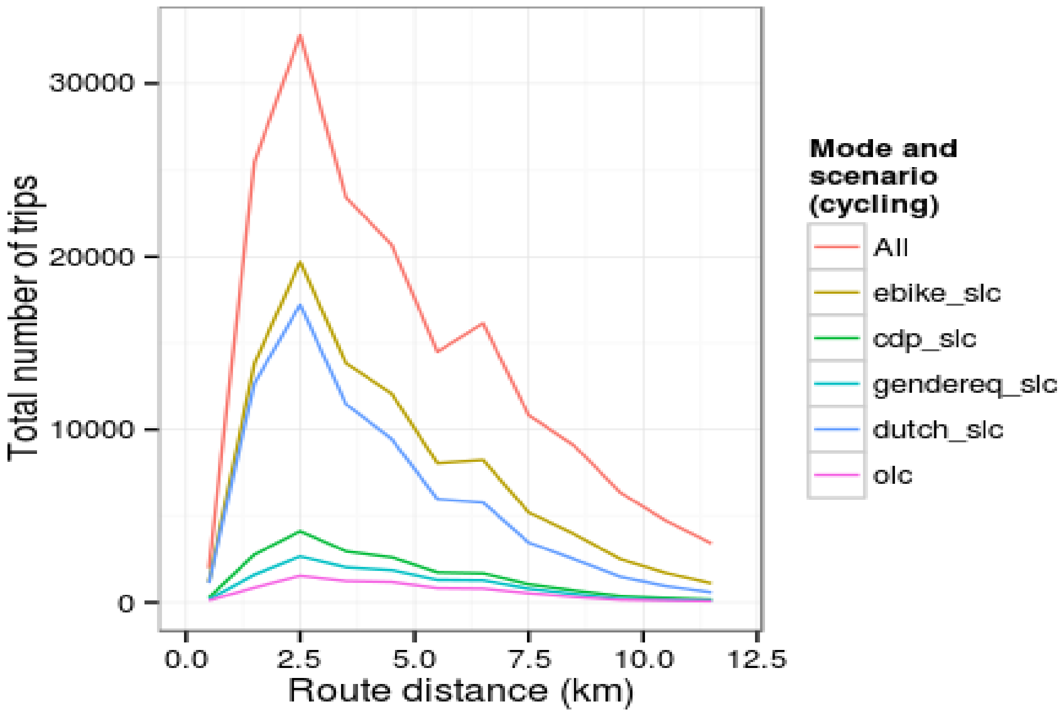

Figure 3: Model output on the rate of cycling by distance band, and under a range of scenarios, for Coventry

[iii] Desire lines represent the shortest or most easily navigated route between an origin and destination for walking or cycling.

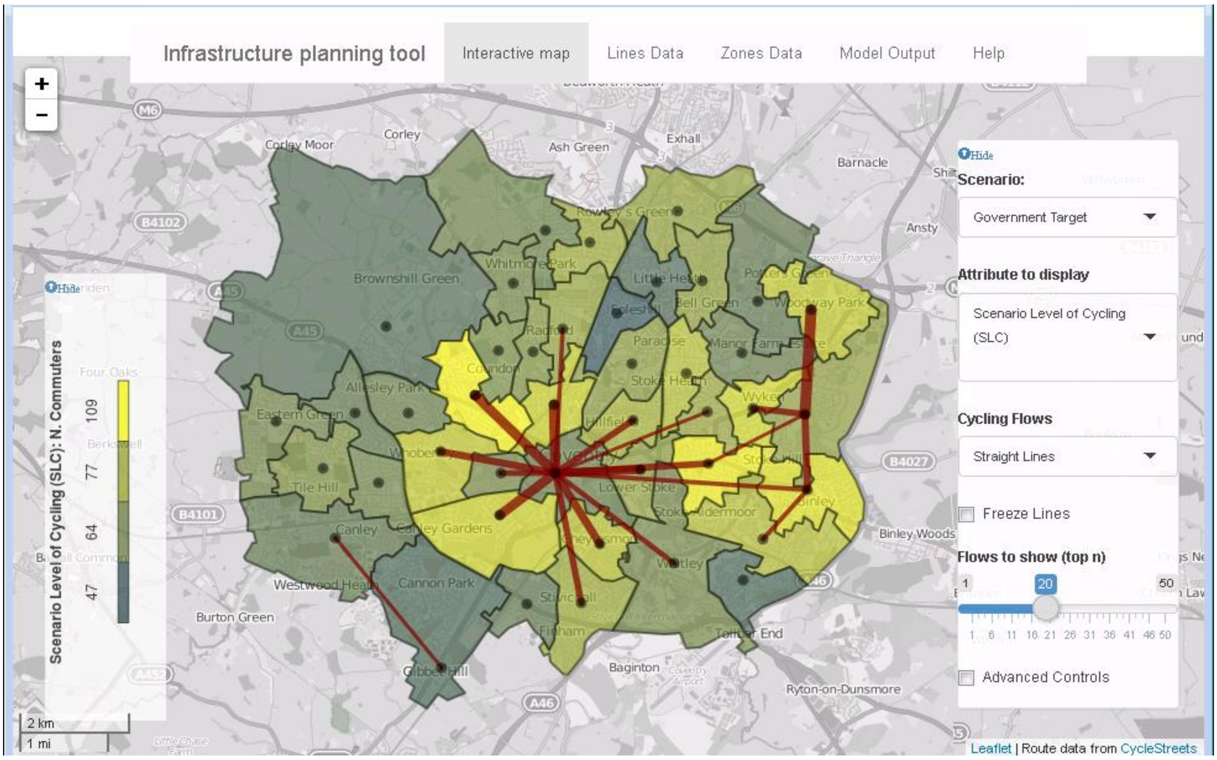

Figure 4: Model output illustrating the geographic distribution of cycling uptake for Coventry, by area and highest 20 flows.

The primary interface to the model is through the 'Interactive map' tab. This has been created using Shiny[iv]. This provides a range of options for interacting with the model's outputs and for displaying different types of model output via a number of 'widgets', defined by Shiny, which allow the user to interact with the graphical display of the model output. These widgets are moveable and 'dockable', allowing the user to focus on the aspects of the map of most interest.

The widgets are:

1. The 'Scenario' widget, which allows users to select which scenario to represent
2. The 'Attribute' dropdown menu, which allows users to focus on the expected potential rate of cycling or increase current levels.
3. 'Cycling Flows', which allows the user to view key flows as direct desire lines or as cyclist-optimised routes allocated to the road network via the CycleStreets.net Application Programming Interface (API).
4. The 'Freeze Lines' button, which allows the lines to move with the current map zoom or to stay fixed for zooming-in to the map.
5. 'Flows to show', which allows the user to focus on specific set of routes or take a more strategic view of the study area with up to 50 lines (this can be increased in Stage 2).

[iv] The internet tool uses Shiny Server (see http://shiny.rstudio.com/), a web application designed to work with the statistical software R (http://www.r-project.org/).

Additional controls are revealed with an additional button for setting the basemap (allowing the user to quickly see the current cycling network from Open Street Map) and displaying flow data separately from zone data.

Additional tabs provide further information to users. These are:

- 'Lines Data and Zone Data', allowing users to see the raw data underlying the model, focusing on the zones and lines currently under investigation.
- 'Help', a tab providing instruction to new users of the tool. In Stage 2 of the project a video and interactive elements will be added to assist with training and to make the tool more accessible.
- 'Model Output', a tab under development that will contain key information about the study area. This will allow local transport planners to compare their area quantitatively with England averages. Critically, this final tab will also present results such as the local distance decay parameters and the extent to which hilliness seems to be a deterrent.

5.0 Review of evidence on cycling infrastructure and uptake

This forms part of Workpackage 1 and summarises the work described in Appendix 4

This review provides evidence about the infrastructural interventions that should be prioritised on key desire lines, such as routes identified through the National Propensity to Cycle Tool. Academic and other evidence was reviewed rapidly and iteratively, focusing on how different types of cycling infrastructure are associated with uptake.

There is good evidence that what people say would most encourage them to cycle is being able to ride completely away from motor traffic (i.e. 'Greenway' routes, such as the Bristol to Bath cycle path where virtually all the route is completely away from motor traffic, with grade separated junctions inherited from the railway). Other strongly preferred routes include those with substantial physical separation along roads (e.g. with hedge or kerb separation), and on very quiet streets with little or no motor traffic.

The evidence base related to behaviour change is weaker. This is partly because cycling interventions in many countries have traditionally not been rigorously evaluated. In addition, many cycling interventions in low-cycling contexts have been relatively limited. Rather than building the most preferred infrastructural types identified here, often the focus has been on smaller-scale changes involving paint and signage which, according to the preference evidence, are much less likely to show substantial changes in uptake.

However, evaluation methods and interventions are both changing, and correspondingly the evidence base is beginning to improve. This is the case for example in the United States, where cities have invested in higher-quality 'protected' or 'green' cycle lanes, with associated studies of impacts. In England, higher quality interventions are being planned and implemented, with more substantial evaluation, for example in London related to Superhighways, mini-Hollands and other schemes. Evidence is starting to emerge that such high-quality routes along key desire lines (e.g. the Cambridge Busway Cycleway) can demonstrably increase cycling uptake.

Therefore, the review suggests building routes that correspond to stated preferences, particularly given evidence from the Rapid Evidence Assessment described below, that under-represented groups may have particularly strong preferences for separation from motor traffic. We need to move towards making evaluation and monitoring results publicly available in a form that is easy to access and to use in reviews and in planning. This should include both summaries of findings and the data on which conclusions are based. More in-depth robust evaluation of specific interventions is also needed, especially using longitudinal methods with adequate controls to track changes in behaviour over time.

The evidence highlights the need to prioritise routes that meet demand, to improve wider networks and to ensure there are good connections to new pieces of infrastructure. Some impressive results have been achieved from infrastructure-focused interventions and programmes; including in England as part of the Cycling Demonstration Town programme. However, the evidence suggests that building small amounts of infrastructure in isolation, where a wider cycle network remains poor and cycling levels are low, may have relatively little effect. In building new infrastructure, it is important to follow desire lines and where needed improve the quality of the surrounding cycle network.

6.0 Rapid Evidence Assessment: How Age and Gender Affect Cycle Infrastructure Preferences

This forms part of Workpackage 1 and summarises the work described in Appendix 5.

The Rapid Evidence Assessment (REA) is a systematic review that examines and synthesises the evidence for age and gender differences in cycle infrastructure preferences. It focuses on views about cycling infrastructure and routes that keep cyclists away from motorised traffic, shown in the literature review to be generally preferred. The REA complements the accompanying review of cycling interventions and uptake summarised above. It looks at under-represented groups within UK cycling (specifically women and older people, who represent the majority of the English population, and the majority of cyclists in countries such as The Netherlands) exploring whether, and how, their infrastructural preferences vary from those expressed by men and younger adults.

The academic and policy literature was systematically searched to find studies on cycle route infrastructure preferences, which reported on findings in relation to age or gender. After several rounds of exclusion the evidence base consisted of 56 studies. Fifty-one of the 56 studies examined preferences in relation to gender, with 33 covering age (older versus younger adults) and only four studies investigating preferences related to child cycling.

While men and women both prefer cycling environments which keep riders away from motor traffic, women's preferences are stronger. Forty-one studies provided evidence as to whether preferences for separation from motor traffic differed by gender. Of these, 24 reported statistically significant evidence that women expressed stronger preferences for segregation from motor vehicles than did men. The remaining 17 studies reported no statistically significant differences in gender preferences. No studies reported that men had stronger preferences than women for greater segregation from motor vehicles. Studies with larger sample sizes were more likely to find a difference in preferences by gender.

We regard this as good evidence of women's stronger preferences for greater segregation from motor vehicles. However, this must be seen within the context of what were often similar overall hierarchies of preference across genders. That is, rather than expressing different preferences, women express the same preferences but more strongly. Four-fifths (19/24) of those studies that reported gender differences in preferences highlighted overall similarity in preferences across genders, even if specific differences in strength (for example, women and men choosing fully separated cycle tracks as the preferred option, but women rating them most highly) were found.

Fewer studies, only 25, reported on age in relation to preferences around segregation from motor vehicles. Findings here were less consistent than for gender. While nine studies found that older people expressed stronger preferences for separation from motor vehicles, 13 found no differences, and three reported that older people had less strong preferences for separation from motor vehicles than did younger people. Nearly nine in ten (22/25) of all studies covering the impact of age on preferences for separated infrastructure highlighted overall similarity in preferences across age groups, even if specific differences were found one way or the other.

While the evidence on age is more mixed, it provides some support for the hypothesis that older people have less tolerance of riding in mixed traffic than younger people. The evidence is likely to be weakened by selection bias, given many studies mostly or only include cyclists. Older cyclists will disproportionately include the small minority of people who have been cycling for many years, and so will be skewed towards those who are satisfied with or at least tolerant of current cycling conditions. The gap in risk tolerance between older cyclists and older non-cyclists is thus likely to be larger than the gap in risk tolerance between younger cyclists and younger non-cyclists, confounding results.

There is ample evidence that motor traffic forms a major barrier to child cycling, yet surprisingly little evidence exploring exactly what kind of infrastructure would meet the needs of parents and children. What does exist suggests strongly that riding away from motor traffic becomes more important. The failure to study and build for child cycling may contribute to the gender inequalities in cycling in low-cycling countries, given women's higher likelihood of making escort trips.

This review supports building for the preferences of under-represented groups. The evidence suggests that such groups have particularly strong preferences for infrastructure separated from motor traffic either through physical barriers, or through route-level separation (e.g. Greenway-type routes, kerb segregation on main roads, streets with very low levels of motor traffic).

These are preferences that are not qualitatively different from preferences expressed by younger adults and men. Rather they are stronger, so building for under-represented groups represents a form of inclusive design that can cater for a broad range of cyclists. Hence the evidence does not support a 'dual networks' approach, but rather suggests that these kinds of segregated routes are attractive for the majority of potential cyclists. This means that such routes should be built with the understanding that they are not 'only' for women, children, and older people, but also for men and younger adults. This has implications for capacity, design speed, and location planning, and stakeholder involvement.

7.0 Inequalities Review

This forms part of Workpackage 1 and summarises the work described in Appendix 6

The Inequalities Review explores how we might draw upon the broader transport literature to define and address inequalities in access to cycling. Although so far cycling has been marginalised within work on transport inequalities, the transport literature does provide useful frameworks that can be adapted to study cycling and inequality. Increasing and diversifying cycling could contribute to the reduction of inequalities in other areas, such as access to services. The Inequalities Appendix explores how conceptualising cycling as a transport service can help identify barriers and solutions. Dimensions of cycling inequality are proposed, with implications and recommendations outlined in the following table

Table 1: Summary of six broad types of exclusion and principles for solving these

EXCLUSIONS	SOLUTIONS
1. Area-based exclusion implies that a local area lacks the route infrastructure to support local cycle trips, affecting those living in the area or wishing to travel through it.	1. Install high quality dense local network of cycle routes.
2. Destination-based exclusion is more specific, affecting people if activity destinations are not accessible via high-quality routes available when needed. For example, people who work in a city's centre may have good cycle routes to work, but those working in a suburban business park do not.	2. Strategic network planning linking trip attractors, identifying and incorporating range of potentially cycled trips.
3. Capability or Distance-based exclusion: distances are prohibitively long for cycling to necessary facilities within an area, or for a particular group. Willingness or ability to cycle longer distances declines faster for some groups than others: as for many exclusions, everyone is affected to some extent but this is not evenly distributed across social groups.	3. Reduce effective distances; ensure land-use planning system helps create cycleable distances to facilities for all; support e-bikes, park and cycle/cycling and public transport for longer trips
4. Risk-based exclusion: some groups are disproportionately affected by risk (both physical and social) that are associated with cycling in countries such as the UK: a. Motor traffic risks: while people are put off cycling by having to share with busy motor traffic, some groups are more risk averse than others. b. Personal safety risks: differentially affecting people who are more concerned about/vulnerable to such risks c. Risk of social stigma: cycling remains stigmatised, with	4. Increasing participation through focusing on the needs and preferences of those users who are most intolerant of risk. This implies an inclusive approach in infrastructure design and network planning, alongside work on specific stigma barriers, ensuring that promotional and educational

barriers heightened for some groups (e.g. poverty stigma for low income people, sports stigma for teenage women)	material does not inadvertently reinforce stigma.
5. Obstacle-based exclusion affects people using non-standard cycles and/or who are unable easily to walk or carry their cycle (and/or cargo).	5. Planning that maximises cycling by building to accommodate diverse physical capabilities and types of cycle. It must not be assumed that all cyclists can dismount and walk with their cycles, for example.
6. Cost-based exclusion: people are unable to afford cycle purchase or hire.	6. Subsidised access or ownership for lower-income groups, and/or where cycles are more expensive: such as cargo bikes, e-bikes, hand-cycles, children's cycles which need regular replacement.

8.0 Spatial Microsimulation (SMS) Feasibility Study

This forms part of Workpackage 5 and summarises the work described in Appendix 7.

Spatial microsimulation (SMS) is a mathematical technique used to tackle transport simulation problems by generating individual level data. SMS will be central to our approach in Version 2, Stage 2. In Stage 1 we have generated the synthetic population for Manchester, and made the methodological innovation of allocating individuals to Census flows data.

In essence SMS produces a synthetic population of individuals at a small area level and, with our methodological developments, for commuting flows that closely resembles the real underlying data. To build this population it uses as a source local aggregate data, e.g. the number of individuals by age, by sex, and by commuting mode. This can be combined with individual level data produced at a higher level of geography, e.g. National Travel Survey (NTS) data for an English region. For NPCT Stage 1 the sources are 2011 Census commuters and their travelling flows, with special emphasis on cyclists.

The advantage of the SMS population is that it explains real behaviours and responses to scenarios much better than aggregate data. In Stage 2 we will use SMS for creating the second version of the NPCT for England. Our main goal in Stage 1 has therefore been to prove the *feasibility* of using SMS on a larger geographical scale, combined with multiple data sources.

To prove the feasibility we have to overcome diverse technical challenges on areas such as:

- Data availability and confidentiality
- Consistent merging of data from used sources (Census, Nat. Travel Survey,…)
- Extension of the microsimulation technique to flows allocation

The tests undertaken have proven successful and provide now a robust basis for undertaking Stage 2.

In Stage 2 the data sampled from NTS, passed through an SMS process, will combine the current commuting trips, already in the web model, with non-commuting and education trips, offering the most comprehensive picture of transport nationwide.

The work done for the DfT cycling propensity project has followed 2 main lines:

1. Microsimulation: generating the synthetic populations in full for Manchester, and in part for Coventry & Norwich.
2. Flow Allocation: allocating individuals to the known commuting trips, obtained from the Census 2011 flow files.

Both lines are needed to prove the feasibility of microsimulation and the flow allocation method, beyond the requirements of Stage 1, thus allowing for more complex scenarios and a better simulation.

Of these (2) represents the key breakthrough over previous SMS approaches: we can now allocate individuals to commuting flows, and not just to areas.

Because of data availability restrictions, both lines of work have been set at MSOA level. Line 1) has the potential to be easily extended to lower geographical levels (e.g. Lower Super Output Areas- LSOAs, Output Areas- OAs, and Workplace Zones- WZs[v]) or to different variables sets; line 2) could also be extended to lower geographies, making some compromises re accuracy and depending on data availability.

Line 1) has already provided detailed information on the [Age-Sex-Mode of transport] variables for Manchester city, plus Ethnicity-Socioeconomic status, and potentially others, which in Stage 2 can prove revealing to understand cycling propensities and to simulation of differential response towards different interventions.

Line 2) has been used to allocate individuals to commuting flows between two MSOAs of a city. This level can trivially be extended out of the city as well, for example to a whole county. Once we have the cyclists' traits, the individuals in the flow can be studied as separate entities, and scenarios applied to them.

Since these traits are not available in the Census flow data, a new technique has been built to fill this gap. It relies on a combination of probability and algorithmics and can highly improve the outcome both in terms of realism and detail of the resulting scenarios.

We believe that the detail provided by Flow Allocation will allow us to further discriminate cycling interventions by demographics, targeting these interventions more effectively. Understanding the potential for change from interventions such as a campaign that is aimed

[v] LSOA: Lower Super Output Area (1000 to 3000 residents), OA: Output Area (100 to 625 residents), WZ: Workplace Zone, a working population rather than resident population unit of geography.

at younger people with low socioeconomic status, or older women, becomes more feasible by knowing the real demographics of the population.

The basis of the allocation technique is to build the city flows incrementally so that they match 2 constraints:

a) The flow specific figures.
b) The total city aggregates (e.g. % of younger female cycling, or of older men not cycling; % of middle aged car users,…. or almost any combination of the variables)

In practical terms, this means that for each flow we get a solution that minimises the error and is as close as it gets to the real population figures. The SMS generated population can then be used as the input for multiple scenarios using the Propensities to Cycle described in Appendix 8.

9.0 Propensities to Cycle

This forms part of Workpackage 4 and summarises the work described in Appendix 8.

These analyses examine current cycling behaviour in England, using National Travel Survey data. They focus on individual, household and geographical predictors of the likelihood of cycling trips of different lengths. The English patterns are compared with those found in Dutch National Travel Survey data, the nation with the highest rates of cycling.

These analyses are not intended to provide a comprehensive examination of cycling behaviour, but to provide an evidence base for our proposed use of spatial microsimulation in Stage 2. As explained in Section 7, microsimulation will allow us to allocate commute and non-commute trips to members of our synthetic individual population. For commute trips we will also be able to represent flows (based on Census flow data) but for non-commute trips we will only be able to represent trip origins.

The analysis summarised here represents the first stage of this process, providing information about the likelihood that trips made by different individuals are cycled. Differences in cycling propensity (for example, by age and gender) provide a rationale for stratifying within the microsimulation model.

The discussion below provides examples of key differences in propensity to cycle, in relation to trip distance, trip purpose, and various geographic and demographic factors. These differences will be used within our microsimulation model to develop and document scenarios sensitive to these differences, and what happens if they change.

9.1 Mode share, and patterning by age, sex and purpose

In England, 1.9% of trips recorded in the National Travel Survey between 2008 and 2012 were made by bicycle. Around this overall figure there is considerable variation according to age, sex, purpose (e.g. commuting/non-commuting) and, to a lesser extent, urban-rural status, see Figure 5. The highest proportion is among males aged 40-49 in urban areas, who cycle 6.5% of commuting trips. The lowest proportion is among females in rural areas, who at all ages make under 1% of non-commuting trips by bicycle.

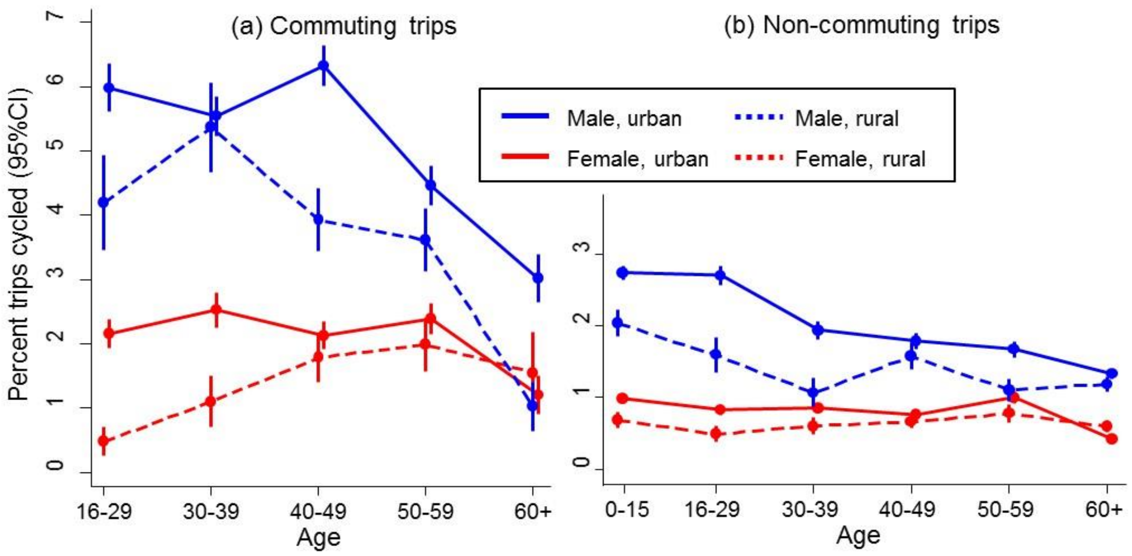

Figure 5: Proportion of (a) commuting and (b) non-commuting trips made by bicycle in England, by age, sex and urban/rural status.

Equivalent figures in the Netherlands are far higher, with 26.7% of all trips are cycled. The Netherlands also differs from England in having smaller differences between age and sex groups (which are for sex in the opposite direction) and between men's commuting and non-commuting cycle trip rates, see Figure 6.

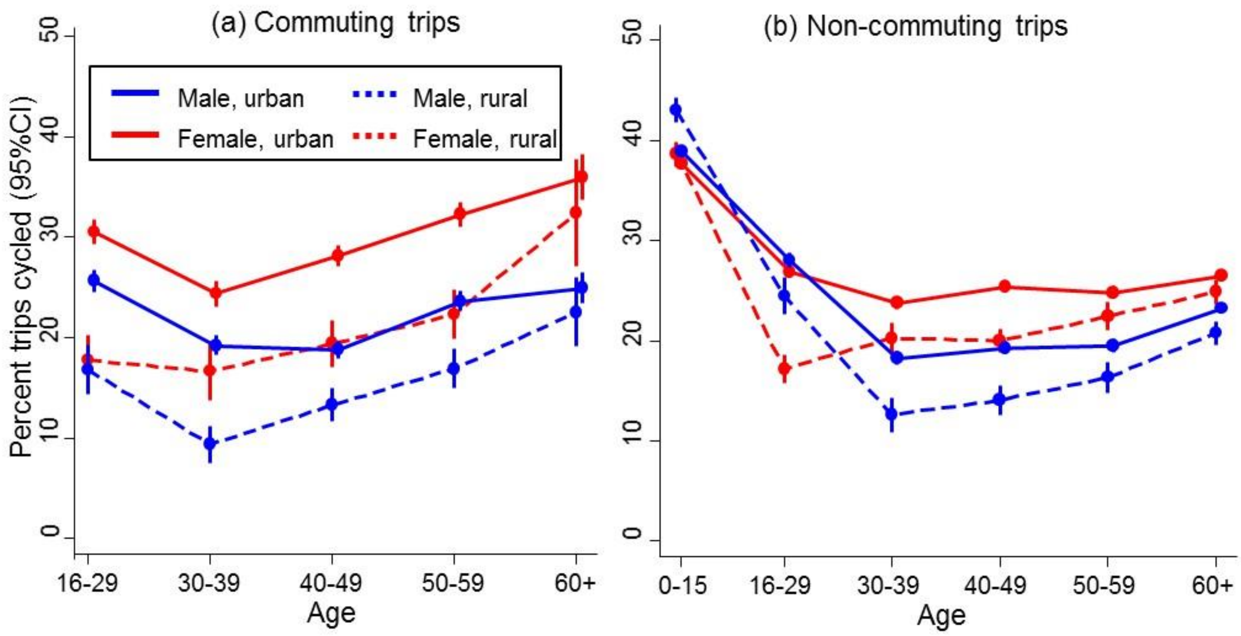

Figure 6: Proportion of (a) commuting and (b) non-commuting trips made by bicycle in the Netherlands, by age, sex and urban/rural status

9.2 Probability of cycling a trip as a function of distance

The probability of cycling a trip declines rapidly with increasing trip distance. In England, the rate of this decline is generally steeper for females than for males, as illustrated Figure 7, Part A. The rate of this decline with distance is also generally steeper for older adults and for children than for younger adults, and for commute trips than for non-commute trips. No large differences are seen by urban-rural status.

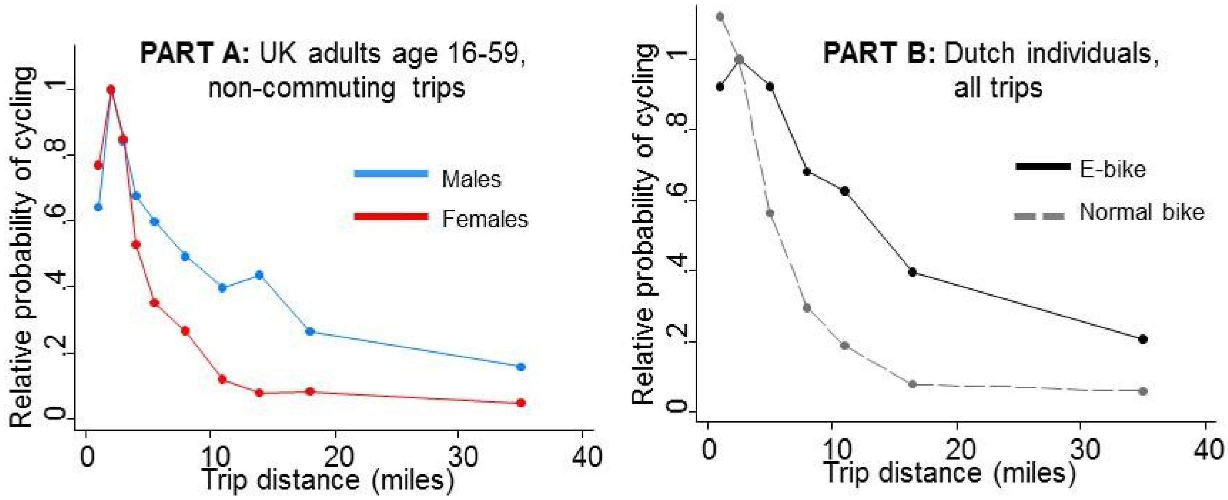

Figure 7: Probability of cycling longer trips relative to the probability of cycling a trip <1.5 miles. Shown A) for males versus females among younger adults in the UK, and B) for e-bikes versus normal bikes among individuals in the Netherlands

Based on these observations, and as distance is a key determinant of cycling, we plan to stratify into the following groups when estimating 'propensity to cycle' a given trip in the proposed microsimulation model:

Male, age 0-15 years, all trips	Female, age 0-15 years, all trips
Male, age 16-59 years, commute trips	Female, age 16-59 years, commute trips
Male, age 16-59 years, non-commute trips	Female, age 16-59 years, non-commute trips
Male, age 60+ years, all trips	Female, age 60+ years, all trips

Using data from the Netherlands, we have also characterised the distance decay function for trips made by electric bicycles ('e-bikes'). Unsurprisingly, distance decay for these trips is less steep than for other bicycle trips (Figure 7, Part B).

9.3 Other individual, household and geographic characteristics as predictors of cycling

For each of the eight stratified groups listed above, we examined how additional individual, household and geographic characteristics affected the probability that a given trip is cycled. We found that ethnicity and household car ownership were particularly strong predictors, even after adjusting for factors such as urban/rural status and socio-economic position. Lower rates of cycling were observed among non-white children and adults, and among adults with more cars in their household. For example, white men aged 16-59 made 6.0% of their commute trips and 2.3% of non-commute trips by bicycle, as opposed to 2.2% and 1.3% for non-White men aged 16-59. We therefore decided to use ethnicity and household car ownership alongside age and sex as key characteristics in the microsimulation model.

9.4 Development of a methodological basis for microsimulation modelling

Alongside analysis of how broader trip purposes and distances vary by group, these new analyses of cycling propensities form the basis for us to develop the microsimulation model. We have information about (a) distributions of trips by distance and purpose, in relation to the factors described above, and (b) propensities to cycle commute or non-commute trips by distance, again in relation to the factors described above.

This provides the potential to create sophisticated scenarios in Stage 2. For example, in modelling potential origins and/or routes of new cycle trips made as uptake increases, we will be able to study the impact of changes in relative propensities by age and gender. One way of doing this is using Dutch data, adjusted for hilliness which is greater in England than The Netherlands. This 'Go Dutch' scenario provides a real life example of what might happen to age and gender disparities in cycling propensity, given a substantial increase in cycling. Worked examples of this and other possible scenarios are provided in Appendix 8.

10.0 Transport and Health Assessment Tool (THAT)

This summarises the work described in Appendix 9 and forms part of Workpackage 2.

THAT model is a web tool that allows the user to generate scenarios based on reallocating trips to walking and cycling and to visualise the health and carbon reduction benefits for these scenarios.

THAT model has been used by Transport for London in 2014 to create and test different scenarios and their health effects in London. It has also been presented at academic conferences and to policy makers.

For this project we have run new scenarios using THAT model to look at the impacts of mode shift to cycling across a range of outcomes. We have trialled the methods for deciding which trips could be shifted, and based on this and feedback from stakeholders we have undertaken analysis of the strengths and weaknesses of the modelling approach and software used.

The key points from the development and testing of THAT model include:

- The demonstrated ability to create a practically useful model based on individual level trip data that could be run with minimum input from the development team
- The limitations of the Analytica software for creating flexible web interfaces
- The desire for geographically localised results
- The burden on the user creating rules based on each trip distance band
- The desire for additional variables, most notably socioeconomic status and ethnicity
- The desire for greater data visualisation, including of baseline data

These findings have been used to inform the development of the Co-Benefits Model described below.

11.0 Co-Benefits Model and Data Visualisation Tool

This summarises the work described in Appendix 10 and forms part of Workpackage 3.

Cycling has the potential impact to benefit multiple societal outcomes. The largest societal benefits are likely to come from improved population through increasing physical activity. However the importance of other impacts should not be downplayed. These potential benefits include faster travel times for users and for others (through reduced congestion), lower road traffic danger, lower urban air pollution, cost savings, lower greenhouse gas emissions, increased journey reliability, and greater choice about travel options. The relative size of these different impacts will depend on *who* is taking up cycling and *which trips* are cycled.

The purpose of the CBM is to indicate how impacts across a wide range of outcomes and population groups can be assessed through modelling the uptake of cycling using individual level data. We also have produced an early prototype tool for visualisation of the results from the CBM **http://geo8.webarch.net/cbm/**

In the CBM we take trips from the NTS previously not cycled and model the impacts on a range of outcomes if they were cycled. We do this by assuming that some non-cyclists take up cycling and have the same distance based propensity to cycle as current cyclists. To model the take up of cycling we simulated both scenarios in which current gender and age inequities persist and in which they are overcome. We have also developed scenarios based in which we assume that the increase in cycling is from e-bike users, with different levels of physical activity and propensity to cycle trips of different distances.

11.1 Data sources

The main data source is the National Travel Survey 2012 (NTS), used for trip data and personal characteristics. NTS includes detailed data for Great Britain, both for the trip itself and the individual performing the trip. We have only analysed results for adults aged 18 to 85 years. In addition we use the Health Survey of England 2012 (HSE) for non-travel physical activity and the Netherland Travel Survey 2012 for the probability of using e-bikes.

11.2 Generation of scenarios

The CBM simulation relies on creating *multiple scenarios* by changing four core parameters. Every new scenario is generated by a combination of the parameters described below.

Key	Concept	Values	Meaning
CM	Cycling multiplier	1, 2, 4, 8, 16, 32, 64	Multiplies the odds of being a cyclist by a given number
TDR	Total Distance Reduction	1, 0.9, 0.8, 0.7	Reduces the distance travelled by a factor. This assumes a shift towards shorter trips with more localised living
Equity	Gender equity	Yes / No (1,0)	Assumes that probability of becoming a cyclist is equal for men and women and for younger and older adults
E-bike	E-bike use	Yes / No (1,0)	Assumes increase in cycling is from people becoming e-bike users, who then use a mixture of e-bikes and regular bikes

11.3 Rules for switching a trip to cycling

To generate new cycling trips, we apply a two-step process:

Step 1: Probabilities of becoming a cyclist

In the non-equity scenario, we assume that the current age and specific probability of being a cyclist (defined as having a cycle trip in the last week) is increased by the Cycling Multiplier (CM). If we assume cycling grows in an equitable manner, *male and female probabilities of cycling* are the same, and there are also no differences by age.

Step 2: Probabilities of cycling a trip

If the individual is now a cyclist, then each trip is assigned a probability of being cycled and longer trips have lower probabilities of being cycled.

Thus for a scenario (CM 64, TDR 1, equity 1, e-bikes 1), we would increase the odds of becoming a cyclist by 64 (CM 64), assuming that everyone in the population has equal chance of becoming a cyclist (equity 1), we would use unchanged trip distances from the NTS (TDR 1), and we would assume all the new cyclists had access to e-bikes (e-bikes 1) and used them for some of their cycling trips (with a greater chance of using them the longer the trip).

This 2-step method mimics *real life situations* more realistically than other strategies previously used, as cycling trips are effectively clustered at the individual level. Further development of the model could change the probabilities that cyclist cycle trips, as even amongst existing UK cyclists there may be trips they would like to cycle but that they do not cycle at the moment.

Finally, if the trip is now cycled, all its variables (e.g. travel times, total physical activity) are recalculated.

11.4 Physical activity and health impact

We are interested in physical activity from two areas, active travel and other – considered as one broad category. For active travelling modes (walking or cycling trips), we calculate the Marginal Metabolic Equivalent hours per week (MMETh).

Using HSE we can also calculate the physical activity spent by individuals in non-travel activities. Individuals are matched from NTS against a pool of individuals from HSE, using age, sex, and socio-economic status.

Changes in physical activity can then be used in assessing impact of risk of premature mortality. Health outcomes are calculated using the methods designed as part of the Integrated Transport and Health Impact Modelling Tool (ITHIM) approach that we have developed at the Centre for Diet and Activity Research (CEDAR). From this we calculate population impact fractions and apply a comparative risk assessment approach to age and gender specific disease burden data from the World Health Organization. The main health outcome calculated is change in years of life lost (YLLs) due to premature mortality.

11.5 Analysis of results

The CBM model produces 112 scenarios and, for each of these scenarios, multiple outcomes for the whole population and specific subgroups. In this report we are only able to focus on a few results and have chosen to mainly present results from the scenarios with cycling multiplier 64 (CM 64), without trip distance reduction (TDR 1).

In addition to the report listed in the deliverables, we have created a prototype web tool that allows users to visualise results from the baseline NTS and under each of the scenarios, see Figure 8 below.

Because we are using individual level data from the NTS, we have the ability to drill down by a wide range of socio-demographic factors e.g. age, gender, socio-economic group, car ownership, ethnicity, and income. This illustrates what can be achieved with the NPCT in Stage 2 when we introduce the microsimulation data.

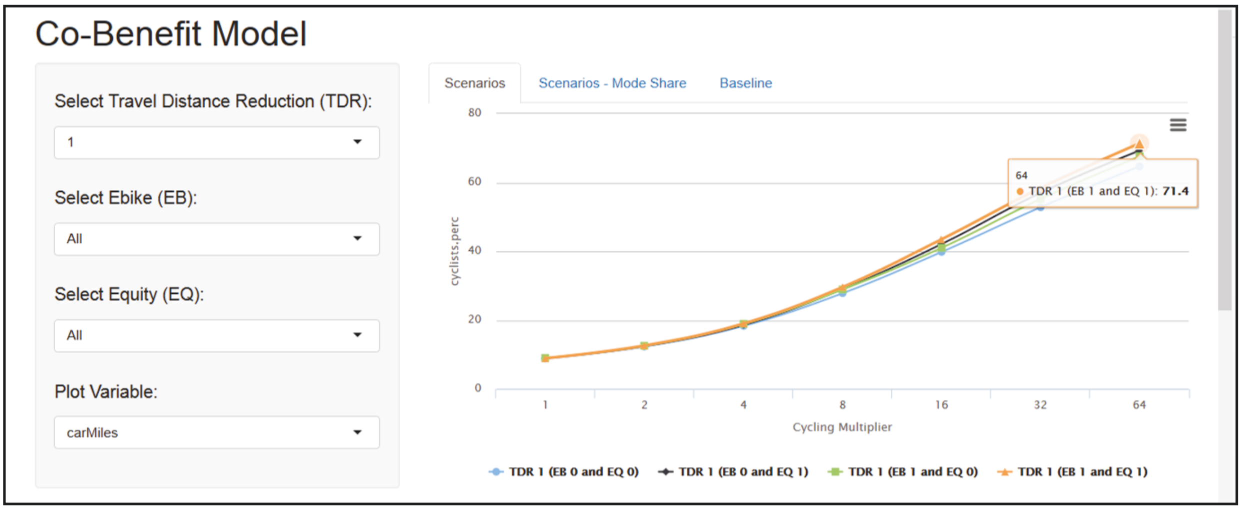

Figure 8: Illustrative figure from the Co-benefits Model web interface http://geo8.webach.net/cbm/

11.6 Results

In the most optimistic traditional bike scenario (CM 64, equity 1) we found a much higher percentage of the population achieving recommended levels of physical activity (up from 45% to 66%), with the disease burden for the UK population reduced by up to 390 thousand YLLs in a single accounting year (6%). This scenario would also see the cycling mode share reach 20% and cycling replace up to 8% of car miles.

In this scenario the mode share for cars would fall from 68% to 52%. Of the new cycle trips approximately 60% would come from cars and 30% from walking. The mode switch ratios were relatively stable across different scenarios.

Mean travel times increased by around 10-15% per trip switched but in around 40% of cases travel times fell (with e-bikes travel times increased by around 5%, and nearly half of trips were faster). It should be noted that these travel time changes are for those making the switch; reduced congestion could also speed up other road users.

If we assumed that the increase in cycling was mostly from e-bikes then we would see a greater replacement of car miles (11% vs 8%) and a higher cycling mode share (26% made-up of 19% e-bikes + 7% traditional bikes). The health impacts were smaller but still substantial, 320 thousand YLLs. Interestingly only with e-bikes do we see a mode share equal to that currently seen in the Netherlands (27% mainly traditional but also including some e-bikes).

Impacts varied across population subgroups, in part depending on the trip patterns of each group. For example, total miles cycled was higher for white compared with non-white populations, reflecting the higher trip rate among the white population. The same was true for non-car owners. These differences might arise from starting from current trips patterns rather than desired trips. This was supported by our finding that time savings were much more common for those without car access. Future work could include differences in take up between car and non-car owners as suggested in Section 9 above.

11.7 Discussion and Conclusions

The work undertaken in the CBM provides valuable evidence in itself, is extendable into a useful policy tool, and lays the basis for what can be incorporated in Version 2 of the NPCT.

If people in the UK who do not currently have cycling trips had the same propensity to cycle as those who do, then their potential increase in physical activity and corresponding reductions in diseases associated with physical inactivity would be considerable.

The reductions in car distance and emissions from transport are more substantial than some previous studies in the area have suggested. Even greater benefits might be possible if we simulated the potential to replace car trips with multi-modal rail and cycling journeys.

Our results indicate that, for a given increase in the propensity to cycle, the health benefits of a switch to e-bikes would be smaller, while the carbon benefits would be larger. This is not surprising but this study may be the first to quantify these impacts.

The CBM approach has the potential to be extended in many ways. The rules could be made more sophisticated, e.g. the probabilities for switching mode could be sensitive to relative trip times or trip purposes. The range of outcomes could be increased and some modelled in more detail, e.g. inclusion of specific diseases and injury risks, and the greenhouse gas emissions modelling could be more sophisticated by taking account of trip speed. The interface could also be developed to provide a comprehensive tool to analyse the data from the NTS (and the simulated NTS + HSE).

This study has shown the potential of modelling uptake of cycling using individual travel survey data and providing a user interface to interact with the data.

12.0 National level analysis: preliminary results

We have undertaken preliminary analysis of the potential for cycling increase across different areas covering all of England. This analysis, like the flow-model of cycling uptake (see Section 4), was based on commuting data from the 2011 Census.

The results for the Cycling Delivery Plan scenario (CDP), aggregated to the level of Highways authorities, are displayed below (Figure 9).

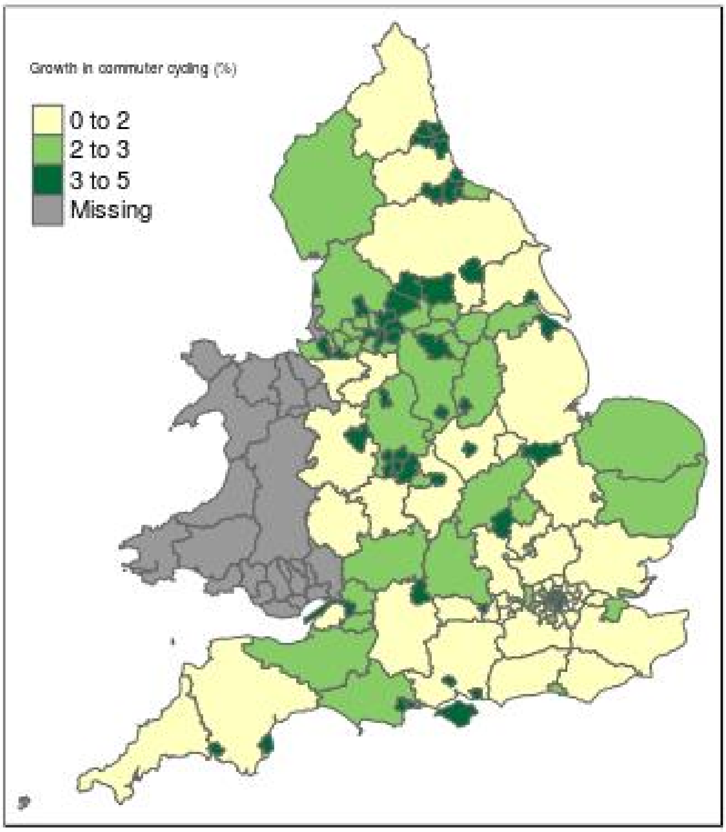

Figure 9: Potential growth in cycle commuters in percentage points across highway authorities in England.

The method used to identify these areas with high unmet cycling potential was the same as that used in the flow-model but without using local origin-destination data. Instead we used data on the proportion of trips by distance band, and applied to each band the probability of cycling trips of that distance. Thus the areas shaded in darker green in Figure 1 are those that have the highest potential to increase the cycle modal share among commuters based on the area's distribution of commute trip distances.

In Stage 2 we will complete the analysis by:

- Inclusion of non-work trips from the National Travel Survey
- Inclusion of hilliness as a predictor of cycling potential

This will be of use to the DfT for developing a nationwide Cycling and Walking Investment Strategy (CWIS). The results of the national level analysis will help inform the decision of where investment is likely to be most cost-effective in the early and later stages of CWIS.

13.0 Stage 2 of the NPCT Project

The models developed, analysis undertaken, and evidence synthesised in Stage 1 provide a robust basis for implementing and rolling out the NPCT in Stage 2. In the past five months, our dedicated team of experts has produced a high quality, fully operational prototype. User testing has indicated the demand and range of potential use cases for the tool.

For Stage 2 we will roll-out the NPCT in two versions. Version 1 will be an aggregate version, similar to the current prototype. Then later in Stage 2 this will be replaced with Version 2, utilising full microsimulation. This two-stage approach allows the very real benefits of the NPCT to be realised in the short term, while allowing us to bring the even greater benefits that will be possible with full microsimulation on stream soon after.

The feedback from the workshops and user testing highlights the valuable insights that can be generated using the simpler aggregate model but also the even greater potential from the individual level microsimulation approach. We envisage that the aggregate model will be rolled-out around eight months after the start of Stage 2 and that the microsimulation model will be rolled-out 12 months later.

The key features of Version 1 will be a fully operational web based propensity to cycle model for the whole of England. With this interactive tool local authority transport planners will be able to investigate which small areas and routes have the greatest cycle commuting potential under a range of assumptions. At the broader level regional and national planners will be able to investigate which towns and cities have the greatest potential. The tool will be WebTag compatible, including health economic savings estimated using the World Health Organization HEAT approach.

Version 2 will be released a year later, in 2017. It will come with significantly improved functionality allowing the user to interrogate results on a much more detailed population. Using synthetic microsimulation population will enable investigation of more results across multiple population subgroups. For example age, gender, ethnicity, car ownership that we have shown to be important determinant of cycling propensity (see Section 9). Key features of Version 2 will be estimation of non-commuting cycling potential at an area level and the inclusion of education trips at a route and area level. More advanced health impact modelling methods will be used, allowing estimation of impacts on mortality and morbidity across different subgroups. Other outcomes will include which mode cycling trips are coming from and the associated change in greenhouse gas emissions.

At the same time as developing Version 1 we will extend the web-interface for the CBM and undertake user testing on this. The CBM will be available as a stand-alone product, as with the NPCT available through an open source licence. The CBM will be usable both to model scenarios and to analyse data from the NTS. User testing of the CBM will inform development of the results interface for Version 2 of the NPCT.

13.1 Use of the NPCT

User testing with local authority transport planners and other key stake holders in London, Manchester, and Newcastle suggested that the tool could be used in multiple ways. Chief among these were uses related to:

i. Planning where to target future infrastructure improvement
ii. Communication to decision makers and visually representing routes
iii. Bid and proposal writing,
iv. As an input for other tools

v. To sense check estimates of demand provided in other ways, to challenge or confirm existing assumptions/understandings.

Overall planning was the most commonly mentioned, but many people included more than one suggestion. These range of uses go with a range of users, and already in the NPCT Prototype we have created advanced features, to satisfy those users who want to go deeper but are not intrusive to those less experienced who wish to use the more basic functions.

Our plans for user testing, training and post-launch evaluation are well under way. We have developing mailing lists of interested users from stakeholder organisations across the country. We plan to hold up to ten events during Stages II and III, plus associated non-event feedback gathering, which will include:

(a) User testing events where Version 1 and 2 will be tested in locations across the UK prior to launch, similar to our already held user testing events

(b) The development of case study material that can be used for training and to assist users post-launch; this material will be user tested at and outside events

(c) Post-launch evaluation of the tool conducted through a short online survey of stakeholders

A key question that has arisen in Stage 1 is the extent to which we are modelling cycling propensity vs cycling potential. In other words, are we looking for quick wins in the near market (high 'propensity') or are we looking for where, based on the urban form and trip distances, the greatest potential exists (high 'potential'). In the near term people are more likely to take up cycling if they match the demographics of those who currently cycle and in areas with already above average cycling. However, in the longer term there may be much greater potential to increase cycling among groups currently less likely to cycle (e.g. women and older people make more short trips). In some cases this will also translate into greater potential to improve health, for example from getting older people on bikes, as shown using the CBM (see Section 11). The NPCT will be designed so that with Version 2 the user can look at both.

13.2 Version 1

For Version 1 we will first add two strongly requested user features, aggregation of cycling flows on specific routes and health impact modelling using the HEAT tool approach. The aggregation of cycling flows from multiple MSOAs on to specific routes is a way of representing that cycling flows will combine at certain key points. Providing the information on where the combinations produce the highest flow provides more valuable information for planning than just looking at flows between any two zones alone.

Inclusion of the HEAT tool calculation will enable WebTag compliant outputs, in which the economic case can be included based on the statistical value of a life. We will also add video and interactive elements to assist with training and to make the tool more accessible. This will be followed by extensive user testing with local authorities, regional planning authorities, DfT, and cycling organisations. The model will then be refined in the light of this feedback and then rolled out, that is made freely available on a website and with open source code, covering the whole of England.

New features planned for Version 1 include:

- 'Headline stats' section at beginning of model output tab saying 'Under 'Go Dutch' xx% of commuters would cycle, compared with xx% of commuters under the ‘Go Dutch’ scenario nationally’
- ‘Heatmap' view of propensity to cycle 'desire lines', potentially with different 'bandwidth' options
- Results tab, illustrating model output (e.g. extra cyclists, HEAT output, with economic benefits allocated to routes)
- 'Quadrant view', showing only top n lines in specific quadrants of the city
- 'Select flows' functionality, allowing selection of specific origins/destinations or both
- A scenario based on the Get Britain Cycling recommendations.

13.3 Version 2

Based on Stage 2 starting in autumn 2015, Version 2 will be launched in early summer 2017. The final year of the project will consist of website maintenance and support and evaluation.

For Version 2 we will generate a synthetic individual level population covering the whole of England. When completed and after user testing, the Spatial Microsimulation Model will supersede the Aggregate Model. Propensities to Cycle will be included based on the Stage 1 analysis. The data will be at the smaller area level, most likely LSOA and LSOA to Workplace Zone. An additional education layer will be included based on travel to school data.

We will integrate non-commuting travel data from the National Travel Survey, producing best estimates at a small area level of other travel patterns. The data will be rich and allow detailed interrogation by users with extensive data visualisation. Here we will draw on the lessons learned from the CBM and THAT model.

Previous work using the National Travel Survey has indicated that, at a population level, the proportion of commuters using cycling as their ‘usual, main commute mode’ is reasonably well correlated with the proportion of total travel time in an area that is accounted for by cycling (r=0.77) [vi]. In other words, populations in which a larger proportion of commuters cycle to work tend also to be populations in which cycling accounts for a larger proportion of

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[vi] Goodman, A. (2013). Walking, Cycling and Driving to Work in the English and Welsh 2011 census: Trends, Socio-Economic Patterning and Relevance to Travel Behaviour in General. *PLOS ONE*, 8 (8), e71790. Available from: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0071790

all travel. This gives some confidence that areas defined as high-cycling based on commute modal share will also be high-cycling for other types of trips. We will also calibrate estimates at the Local Authority level using the Active People Survey.

This strong correlation between levels of commute and non-commute cycling will be useful for Stage 2, as it provides some justification for assigning non-commute cycling trips to local populations based on their commuting trip patterns. However, our analysis shows that areas differ substantially in the proportion of commuters among the population (and hence the ratio at area level between commute and non-commute trips), depending on factors such as employment levels, student population, and age structure. For variation by age see Figure 10.

This means that those areas with highest commuter cycling potential under a given scenario may not be the same areas as those with highest non-commuter cycling potential.

Note also that the correlation between commuter and non-commuter cycling at population level may not apply at route level – the routes that individuals might use when cycling to work are likely to over-represent commuting corridors between residential and business areas, and may not be the same routes that people use in making other trip types, such as shopping trips or trips to visit friends. This is one (of many) reasons why the route allocation on NPCT will be only one of multiple pieces of evidence that transport planners should draw on in deciding where to build infrastructure.

In Stage 2, extending NPCT to include non-commuting trips will not only make the model more comprehensive but also more inclusive. This is because commuting is a type of trip disproportionately made by younger as opposed to older adults, and by men as opposed to women:

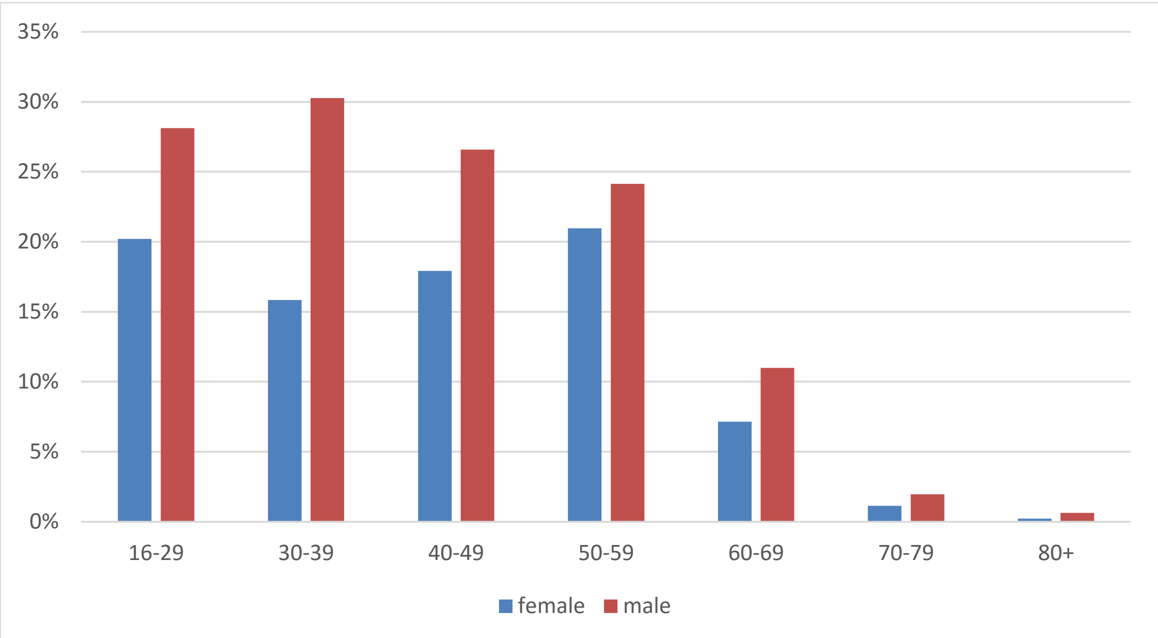

Figure 10: Proportion of all trips made for commuting purposes for adults in England

The commute is also, by definition, a type of trip that is only made by those in work, and therefore excludes some disadvantaged groups such as the unemployed and those unable to work because of disability. As such, a model that only examined propensity to cycle for commuting trips would disproportionately be seeking to facilitate cycling among relatively-advantaged younger men, a group that is already over-represented among cyclists. By contrast, incorporating other trip types will help to give greater consideration to the cycling potential of trips by a wider range of individuals.

A far wider range of scenarios will be testable, in this case building on the Rapid Evidence Reviews. In particular the user will be able to investigate how cycling uptake might vary if we assume current propensities by age, gender, ethnicity, car ownership and region are maintained or if they are overcome. Rather than using an area level propensity based on average characteristics e.g. as in the Mosaic approach, we will use individual level data combined with area level characteristics. This approach will enable us to explain a large proportion of variation in behaviour, whilst recognising that areas are not homogenous but include heterogeneous individuals with different propensities.

The user will be able to choose in detail both where the greatest short term wins will be realisable and where the longer term potential is highest. It will enable estimation of *who* is cycling under different scenarios and what this means in terms of health, greenhouse gas emissions, and equity.

The users will be able to look at outcomes as a series of tables, similar to the currently available Census tables. For example a table could consist of the number of cycle commuters by socio-economic status, age, ethnicity, gender, or car ownership under a range of scenarios. At higher levels of geography more results will be available. Although the data presented will be aggregated, to ensure data confidentiality, the analysis behind it will be at the individual level so far more combinations of results will be realisable than if we were starting with aggregated data.

Again building on the CBM and THAT model we will integrate a more sophisticated health impact modelling approach that will allow calculation of demographic specific changes in disease burdens across a range of conditions affected by physical inactivity. Diseases will include ischemic heart disease, stroke, type 2 diabetes, colon cancer, breast cancer, lung cancer, depression, and dementia. These models will be populated with the best evidence from a series of dose response meta-analyses the MRC Epidemiology Unit are currently conducting.

In conclusion, the development and testing of the prototype NPCT and the complementary workpackages have demonstrated both the feasibility and the demand for a NPCT.

14.0 Stages 2 and 3 Gantt Chart

	Oct-Dec 2015	Jan-Mar 2016	Apr-June 2016	July-Sept 2016	Oct-Dec 2016	Jan-Mar 2017	Apr-June 2017	July-Sept 2017	Oct 2017-Sept 2018
Version 1									
National Model									
Adding features (aggregated flows, buffered zones, visualisation at different levels, Improving hilliness)									
Adding features HEAT									
Additional scenarios (e-bikes)									
Extension to all of England									
User testing									
Modification following user testing									
Training and post launch evaluation									
Co-Benefits model (other health outcomes, CO_2 and webtool)									
Co-Benefits model user testing									
Version 2									
Generating and testing MS population									
Implementation into webtool									
Additional scenarios									
Education layer									
Inclusion of NTS									
ITHIM health calculation									
User testing									
Modification following user testing									
England roll out									
Training and post launch evaluation									
Maintenance and updating									
Stage 3: Pathways to National Objective									

The work laid out for Stage 2 is ambitious but realistic and will put a fit for purpose model in the hands of practitioners backed by a wealth of in-depth evidence and research.

There are further steps that could be taken with the work but that are not realisable within the budget, see Section 16. The costs will be front loaded such that around half the budget will spent in year 1, around one third in year 2, and one sixth in year 3.

15.0 Risks and Risk Mitigation

All projects come with risks. Producing a fit for purpose propensity to cycle tool that covers the whole of England and is publicly available is an ambitious undertaking. That we can achieve this goal is evidenced by our success in producing a robust prototype in six months that has stood up well under user testing. We have gone beyond the requirements to develop this for three cities and have a process in place that allows comparatively rapid deployment for multiple areas. Further evidence is provided by our having concurrently developed the methodology required for the more advanced microsimulation approach.

15.1 Scalability

During Stage 1 we have monitored demands on server capability (e.g. during our user testing events) and have researched options for scaling up server capacity to allow roll-out of the NPCT and reasonable levels of simultaneous use. We have obtained quotes for technical support and are confident of our ability to create a resilient system supporting national roll-out. See Appendix 11 for more details.

15.2 Data access

Building the models requires access to data, including requesting access to bespoke and restricted data, as well as freely available data. We have requested access to a number of additional ONS tables, which will allow us to more accurately populate our micro-simulation model. So far we have already purchased more detailed tables at the LSOA level. We are still in discussion with the Census teams on more detailed flow data. It is possible that not all of these will be made available to us, due to confidentiality concerns. In this case we will be able to use Census datasets already provided, which will be acceptably accurate for our purposes. The work conducted for the SMS feasibility study has demonstrated that even with the data already available we can produce an accurate population with multiple characteristics at the LSOA to LSOA flow level.

For the proposed education layer we will need to access data from the National Pupil Database 2010-11, which has data on pupil postcodes, schools, and mode of travel. As with the additional Census tables, it is not guaranteed that we will be able to access this data in the form we would ideally like, and we may have to make compromises based on this. In the worst-case scenario that it proves impossible to operationalise an education layer, alternative functionalities could be prioritised instead (for example, looking at trips to transport interchanges).

15.3 Data management and data security

Our team has extensive data management expertise and is used to dealing with 'big data' type problems. The lead institution is the MRC Epidemiology Unit which has considerable experience in handling large, sensitive and complex data sets. All secure data will be stored at the MRC Epidemiology Unit. No sensitive data will be placed on the server.

Version 1 of the model is based on Census data at sufficient levels of aggregation such that there is no sensitive or potentially disclosive data on the server.

In Version 2 we will be creating a realistic microsimulation population that, in many cases, for some characteristics will closely match the 'real' population in 2011 of England. This, therefore, creates a greater challenge for data security. This challenge will be met by ensuring the individual level data generated is not stored on the server. Instead we will generate summary tables, similar to those currently provided by the Census, for each scenario and these will be stored on the server. This will also considerably reduce the amount of data that needs to be placed on the server.

We will also apply various thresholds to make sure the summary tables we generate do not include potentially disclosive data. We plan to apply stricter rules than those currently applied by the Census disclosure team when we are displaying data that is close to real or baseline synthetic data; for variables that are model generated (e.g. switch to cycling) the need for caution is lower.

16.0 Stage 3: Pathways to Implementation

This report will collate information from Stage 2 to consider the policy implications of the findings and set out a range of options for achieving the Government's cycle ambition. This will include central material from the NPCT and associated co-benefits modelling, as well as updating and expanding reviews from Stage 1, and conducting a new online survey to enhance understanding of what practitioners see as the key local/national policies that could support our achieving the national cycling ambition.

In Stage 1 we have developed and (in our case study cities) implemented scenarios that have explored the different implications of building for the near market versus building for the kind of cycling demographic we see in high-cycling countries. As we build upon this work in Stage 2, we will be able to take both a local and a national view of these choices. In a local context, we can ask what the different implications are of building routes to cater for different groups of potential cyclists: for example, building for a different commuter market may imply catering for different origin-destination pairs than if one were to attempt to attract more people who are similar to already existing cyclists.

At a national level, we will be able to identify particularly promising areas under different scenarios. For example, there may be areas with many short trips made by under-represented groups (e.g. women, older people), where building transformative infrastructure might unlock substantial suppressed cycling potential. These areas might not be identified without our tool.

The report will cover these issues, highlighting and contrasting specific local case studies where the tool has informed approaches to investment and planning. It will discuss implications of different strategies for co-benefits, which may include: travel time benefits, health benefits, decongestion benefits, carbon benefits, and increases in access to mobility and facilities.

The report will update and summarise reviews already conducted in Stage 1, which have provided evidence about the type of infrastructure which can attract different market segments. This will be built upon to provide recommendations for building for areas without a tradition of cycling, and for under-represented groups. The case studies already mentioned can provide specific local illustrations, as well as broader examples of location specific interventions. An online survey of built environment practitioners will contribute to recommendations about national changes that may be needed to support this local activity.

Proposed structure of report:

- Discussion of broader issues involved in realising our cycling ambition, drawing on Stage 1 reviews, updating these and summarising for a broad policy audience.
- Summary of results of national survey of built environment practitioners on barriers to planning for cycling, and national/local changes that could enable these.
- Discussion of investment options in relations to co-benefits and specific strategies/targets; informed by our co-benefits model, examples will be drawn from this.
- Examples of how the tool has been used to develop location specific investment plans; this material can also be used as training/guidance for other areas.
- Specific recommendations about how places with low levels of cycling and/or targeting under-represented groups might grow cycling substantially within a decade.
- Recommendations for national policy interventions needed to support local transport authorities seeking to make the change.

17.0 Future work

The two versions of the NPCT that we envisage will provide a robust and transparent basis for transport planners to support evidence based decision making. The tool will go considerably beyond the armoury that decision makers currently have at their disposal. However, we recognise that there is always more than can be done in any one project. In this section we highlight what we consider the most significant additional steps that could be taken.

1) Modelling of multimodal trips.

The NPCT focuses on trips that can be cycled all the way. Currently the vast majority of cycle trips are cycle all the way trips. Thus it makes sense to start with these trips. However, the potential for multimodal cycle trips is still significant, particularly in rail commuter belts. Multimodal cycle trips have the advantage of allowing physical activity to become part of longer journeys that could not realistically be cycled all the way.

Multimodal trips are harder to model than all the way trips. Different combinations of multimodal cycle trips are possible with the most important likely to be multimodal train plus cycle. The easiest trips to model would be existing rail trips where the train is currently accessed by a non cycle mode. In areas of the country in which there is substantial rail commuting estimates of this potential would be significant. A more difficult question is the potential for replacing existing car journeys with rail plus cycle. Whilst challenging we believe that credible estimates are possible and answering this question could bring bigger benefits where longer distance car travel is the norm. Replacing these longer car journeys could bring substantial benefits in terms of greenhouse gas emissions as well as additional health outcomes.

2) Scaling up for other nations in UK
The NPCT is being created for England, while the CBM also covers Scotland and Wales. Further work could extend the tool to cover the other constituent countries of the United Kingdom. For a large part the work would be quickly extendable to these countries due to the generalisable nature of the methods developed and the similarities in the data available. However, in each case some additional work will be required around data harmonisation, initial propensity parameterisation and developing the tool to fit with the needs of local stakeholders.

3) Locally detailed versions
Using generalisable methods allows the creation of a national useful model with a transparent method. However, specific areas and regions could take the approach further using local data. In some cases, e.g. London, more densely sampled additional travel survey data is available and this could be used to improve estimates of non-commuting flow and locally parameterised estimates on propensities. In other cases more detailed work could focus on the attractiveness of destinations to provide estimates of transport demand and corresponding cycling potential.

4) Impact of policies
The NPCT is designed to answer the question if cycling increased, in which areas, on which routes and amongst which groups would the impacts be greatest. It is not designed to predict what the effect of an intervention might be on cycling rates, although we do envisage providing data that will help with this question. The data to answer this question remains limited, although members of the research team are involved in other research projects taking this forward. Incorporation of methods for estimating the impact of policies, whilst recognising the considerable uncertainty that such estimates would come with, could be a further development of the NPCT.

5) Inclusion of new big data sources to estimate flows
Flows for all trips, not only commuting trips, could be estimated based on new data sources. The most promising of these would be mobile phone data. This data would not inform on mode or trip purpose but offers by far the most potential for estimating total flows between areas.

6) Improved linkage to other transport models.

For example, TRICS[vii]/TRAVL provides data on likely trip generation from different types of development. This could be used to predict overall flows to particular destinations, such as a shopping centre or a new housing development. Our cycling potential analysis could then be applied to these flows. Another option would be to link up with local transport models which contain local origin-destination information. Unfortunately there is no such national model available and the local models will typically be commercially restricted and not open source.

7) Road traffic injury risk
Cycling poses low risk to other road users but cyclists typically face higher risks than they would if they travelled by car, with the possible exception of young men. Mode shift could reduce the risk cyclists face as there would be fewer cars on the road. Putting in better infrastructure could also reduce risks. Risks vary substantially by age, gender and location. Estimating local risks is difficult because of small numbers of events. Producing small area estimates on baseline and scenario risks would require research including literature reviews, data analysis, model development and model calibration. The ITHIM model developed by CEDAR and the associated calibrations conducted for Metropolitan Planning Organisations conducted in the USA could form the basis for this work.

18.0 Stages 2 and 3 Academic Team members

Dr James Woodcock – Research Lead

James leads the Public Health Modelling Group within CEDAR http://www.cedar.iph.cam.ac.uk/people/leads/james-woodcock/ James is a Medical Research Council Population Health Scientist fellow and Principal Investigator on an Economic and Social Research Council (ESRC) study using agent based modelling to understand propensity to cycle. He is Principal Investigator on a project for Public Health England creating a microsimulation model England to evaluate the 'Health Checks' Programme. He has been awarded Engineering and Physical Sciences Research Council (EPSRC) funding to collaborate with Transport for Greater Manchester on a bespoke cycling propensity model. James has extensive experience managing systematic reviews for governmental, third sector, and commercial clients. James has led development of the ITHIM and THAT health impact models. These models are used globally in both academic research and in transport practice http://www.cedar.iph.cam.ac.uk/research/modelling/ithim/ . He is also on the expert core group for the World Health Organization HEAT tool.

Dr Rachel Aldred – Co-Investigator

Rachel is a Senior Lecturer in Transport at the University of Westminster's Department of Planning and Transport. She specialises in research on cycling and has published many articles in key journals. By training a qualitative sociologist she now collects, analyses and re-

[vii] See http://www.trics.org/ and http://travl.org/homepage.aspx

analyses qualitative and quantitative transport data. She led the ESRC seminar series 'Modelling on the Move' (focusing on transport modelling) and has recently had work funded by British Cycling, TfL, and the Arts and Humanities Research Council. Rachel has given evidence on cycling to the London Assembly (twice) and the All-Party Parliamentary Cycling Inquiry. She has been invited to speak at many relevant conferences and meetings including TfL's Highway Assignment Modelling Forum. http://scholar.google.co.uk/citations?user=jycgGvsAAAAJ&hl=en

Dr Anna Goodman – Co-Investigator

Anna is a Lecturer at the London School of Hygiene and Tropical Medicine, and has expertise in the use of secondary data to understand cycling behaviour. This expertise is core to two grants on which she is Principle Investigator: a Fellowship funded by the National Institute for Health Research (NIHR) on socio-economic inequalities in walking and cycling; and an ESRC Secondary Data Analysis grant to evaluate DfT's Bikeability scheme. Anna has collaborated with CEDAR for 5 years. Anna has experience collaborating with DfT including in relation to evaluations of the Cycling Demonstration Towns, Bikeability, and the Local Sustainable Transport Fund. http://researchonline.lshtm.ac.uk/view/creators/106408.html

Dr Robin Lovelace – Co-Investigator

Robin is an Environmental Scientist and quantitative geographer. Robin's expertise includes modelling modal shift, spatial data analysis and GIS. Through a recent 1 month placement at the $20+ million Australian Urban Research Infrastructure Network, Robin has direct experience with development and deployment of governmental online planning tools. Robin is Research Fellow on the newly formed Consumer Data Research Centre at the Leeds' Institute for Data Analytics. Working for the National Centre for Research Methods, Robin teaches data visualisation and spatial microsimulation methods. Robin's skill-set combines computing (e.g. online interactive visualisation), data analysis and multi-disciplinary collaboration. http://www.geog.leeds.ac.uk/people/r.lovelace

Alvaro Ullrich – Data manager and programmer

Alvaro has extensive experience in data handling and analysis, on an assorted range of platforms. Recent relevance experience includes:

- **Multiple Imputation** using NTS and Health Survey for England data
- **Spatial microsimulation:** refining methods to produce a model including commuting routes for Cambridgeshire County Council
- **Handling of spatial data:** analysis of 900 GPS files, using R scripts to automate the mapping
- **Data cleaning:** using Structured Query Language (SQL) and R to deal with missing values, data entry errors, and anonymisation.
- **Relational databases:** experience with SQL-based languages including Postgres and SQLite.
- **Bespoke web tools** to display study results (GoActive study).
- **Shiny:** building and deploying apps.

Ali Abbas- Researcher and programmer

Ali is an experienced programmer with expertise in R, Java, and Netlogo and at developing apps with Shiny. He has worked extensively with microsimulation models including social network models, agent based models, and other models representing individual variation in propensity to cycle.

Dr Nikolai Berkoff – Programmer

Nikolai is a freelance web developer and consultant, with experience working on a number of complex, innovative and high-volume website applications in a commercial programming environment. He mainly programs in Ruby, but also is expert in Go, R and JavaScript. Nikolai has a Ph.D. in mathematics and adopts a strongly analytic approach to programming. Nikolai has previous experience hosting web servers; and as part of the NPCT project team leads on server administration and technically challenging aspects of the tool's online interface.

19.0 Authorship and contributors

The work presented in the report was a team effort, led by the academic team (James Woodcock, Rachel Aldred, Anna Goodman, and Robin Lovelace) and Alvaro Ullrich. James Woodcock led on workpackages 2, 3, 6; Anna Goodman led on workpackage 4; Rachel Aldred led on workpackage 1; and Robin Lovelace led on workpackages 5 and 7, with Alvaro Ullrich leading on the microsimulation section of workpackage 5.

In addition contributors to each section were Ali Abbas (Appendix 10), Nikolai Berkoff (Appendices 3 and 11), Bridget Elliott (Appendix 5), David Fell (Summary Report), Eva Heinen (Appendices 4 and 8), Geoff King (Appendix 4 & Summary Report), Tim Knight (Appendix 4), Rick Prins (Appendix 8), Marko Tainio (Appendix 9), and Alvaro Ullrich (Appendix 10).

Appendix 1 Policy and Practice: context and implications

Contents

Summary

- Meeting ambitious cycling targets such as those set out by the Get Britain Cycling (GBC) report requires increasing the demographic diversity of cycling uptake.
- Identifying potentially cycleable journeys under a range of scenarios, through the National Propensity to Cycle Tool (NPCT), will enable local and national policy makers to better prioritise and plan for those new cycle trips.
- Routes and areas with high unmet potential for increased cycling should be the focus of targeted interventions informed by local contexts.
- Direct routes for all cyclists are important. Under-represented groups will be more put-off by detours.
- Cycle paths physically separated from busy roads are crucial for widening the demographic appeal of cycling
- The concepts of cycling accessibility and exclusion help explain and measure current barriers to cycling and the extent to which planned infrastructure will overcome these.

Cycling Ambition

Government policy aims to increase cycling, which has risen year-on-year since 2008 but still remains far below that by some other European countries (DfT, 2015). There is high potential for cycling to grow in England due to the large number of short trips made by motorised modes. In areas with strong cycling policies and good infrastructure, around a third (or more) of such trips are made by bicycle. It is possible to achieve such a level of cycling here with the right investment and policy mix; the NPCT model helps show where new infrastructure could have the greatest benefits. The graph below compares the share of short trips (<=3 miles) made by cycle in the UK versus the Netherlands: around half (51%) of all trips in the UK National Travel Survey are <= 3 miles.

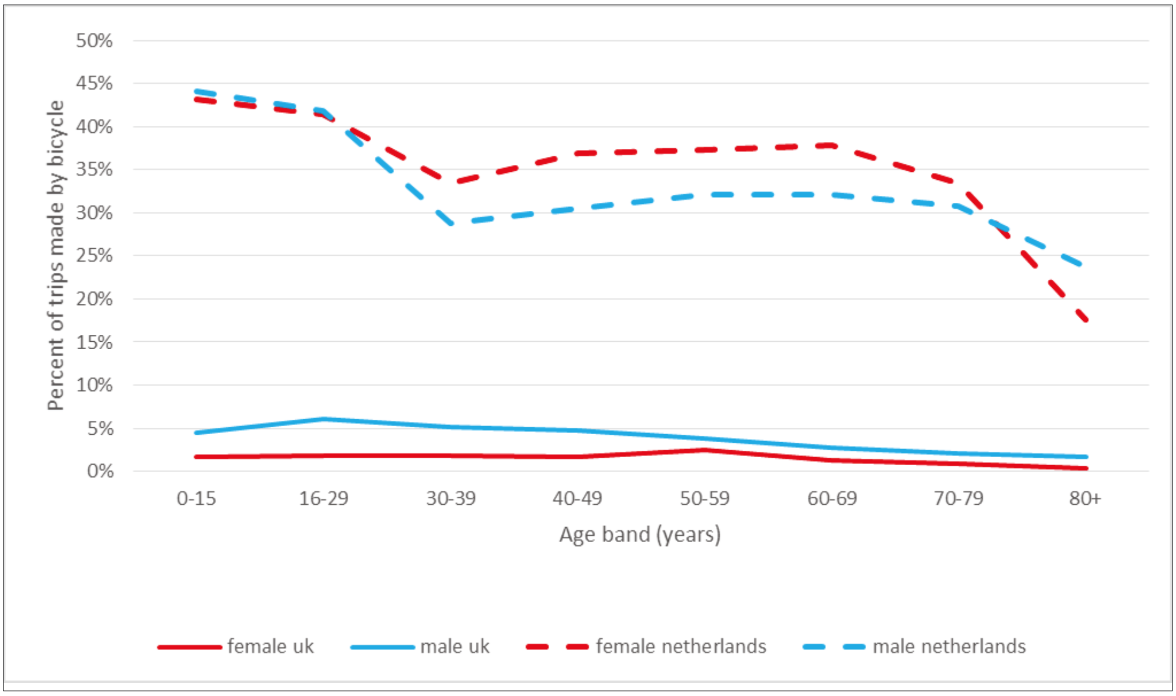

Figure 1: Percentage of trips bv age made by bicycle UK and the Netherlands

The national English picture shows particularly low cycling rates amongst older adults and women. However, where cycling is higher (including in English cities with higher cycling levels) there is greater equity in cycling. In Cambridge City, for example, around one in four commuters aged over 65 travel to work by cycle. This is similar to rates of cycling amongst young adults. Cambridge also bucks the national trend, in terms of cycling to school. 14.7% of state-funded secondary pupils cycle to school in Cambridge County Council, compared with an English average of 3.0%[i]. In cities such as Amsterdam and Copenhagen cargo cycles carrying children and goods are a common sight. This, combined with the growth of 'all ability cycling' means that infrastructure and policy should cater for greater diversity of both cycles and cyclists. This will help cycling become a normal and natural mode of transport for all groups.

There is a clear need to plan for different future user groups. Steps to help meet this need include:

(a) Within local transport authorities, planning direct, high-quality and high-capacity priority routes for cycle networks. For longer-term impact the geographical location of these strategic routes should be decided based on potential rather than currently cycled trips.

(b) A greater strategic overview of cycling investment and outcomes, considering the potential for cycling to grow in different localities across the country in the short and long term.

(c) A focus on the infrastructural/route environment needs and preferences of a more diverse demographic, likely to use a more diverse range of cycles, including e.g. tricycles and cargo cycles.

[i] Based on School Census data for 2010-11

The National Potential to Cycle Tool (NPCT) primarily helps to address (a) and (b), by identifying places, corridors and routes that might be cycled under different uptake scenarios. Combining Census and National Travel Survey data allows us to model route-based and area-based propensities for commuting trips, but will restrict us to area-based propensities for non-commuting trips. This is a limitation of available data. Commuting trips only make up 16% of all trips (19% by distance), but levels of cycle commuting provide a reasonable (but not precise) proxy for overall levels of cycling.

However, focusing only on commuting inherently tends to prioritise trips made by men and younger adults, who are most likely to commute. This limitation can be addressed to some extent by the integration of other data sources into the NPCT model and/or local knowledge of the destinations (current and future) driving demand for short-distance trips. Modelled data on area propensities for non-commute trips might be used at a local level to plan for non-commute flows, as policy-makers decide to prioritise investment based on their assessment of destinations that people are likely to visit for non-commute trips (for example, local shopping centres or high streets). Because the NPCT model is open source it will be possible for suitably equipped organisations to take the code and produce more detailed local versions tailored to local needs.

The NPCT methodology will assist in (c) as it is not limited to planning for existing cyclists. By projecting route-specific rates under various scenarios of change the NPCT can explore a range of possible futures. For example 'where would people ride if cycle commuting were to double tomorrow?' and 'how would the spatial distribution of cycling trips change if gender equality in cycle commuting were reached?' The method provides a glimpse into potential cycling futures where cycling is a mainstream mass transport mode, which will necessitate much greater investment to ensure demographic diversity.

The reviews conducted in Phase 1 of the project complement the tool by addressing (c), through

(i) a review of literature on infrastructure and uptake

(ii) a systematic focus on how and if preferences for infrastructure differ by age and gender

(iii) developing a framework for understanding and tackling inequalities, and diversifying cycling

Encouraging Demographic Diversity in Cycling

Infrastructural interventions

The literature review in Appendix 4 highlights international evidence around cycling uptake. This evidence is limited by: the lack of appropriate monitoring and data dissemination associated with specific policy interventions; the quality and availability of research on long-term impacts following an intervention; and by the quality and availability of interventions. Nevertheless, there is now a growing consensus about what constitutes good cycle infrastructure and conditions for cycling, and emerging evidence from specific cities such as Cambridge (England) and Portland (USA) that such infrastructure can increase uptake.

One important characteristic of good cycle infrastructure is its separation from motor traffic where speeds or volumes are high. This can be done in a range of ways:

1) High-quality segregation on busy roads

2) Routes through parks and other green space

3) The reduction or elimination of through motor traffic on residential streets allowing safer and more comfortable sharing, for example using the concept of 'filtered permeability'.

The separation of cyclists from motor traffic has multiple benefits. Increased safety and perceived safety are often highlighted. Potentially just as critical in low-cycling countries, the visibility of high-quality provision for cycling along key corridors can counteract the perception that cycling is a marginal form of transport. This last benefit can help to overcome cultural barriers to cycling among a range of groups. This includes the perception that cycling is a low-status mode, a particular problem for some low-income groups.

Evidence on infrastructure and uptake suggests that building isolated pieces of infrastructure that do not connect key origins and destinations or link with a surrounding network is likely to have limited results. This highlights the importance of identifying at city and regional levels the key areas, corridors and routes with strong potential for cycling. Where main road routes are identified for new segregated infrastructure, the potential to identify key 'feeding areas' for the new route – including the origins of non-commute trips, likely to be much more numerous than commute trips – can help policy-makers prioritise broader network improvements.

By offering a range of scenarios the non-prescriptive nature of the tool is clear. Its ability to identify areas, 'desire lines' and specific routes allocated to the road network will help local transport authorities across the country to improve provision for existing and future cyclists.

Differences by age and gender

The evidence assessment in Appendix 5 further shows that there is strong evidence that women tend to express stronger preferences than do men for segregation from motor traffic. This is the case from a range of country contexts and for studies that do *and* do not include non-cyclists. For example, if only painted lanes are provided, the proportion of women saying they would be willing to cycle using such provision is typically lower than men.

Stated preference evidence clearly has limitations. However, here it is corroborated by evidence from 'revealed preference' studies including from London Cycle Hire trips, which show that women tend to choose quieter routes than do men. In addition, evidence from the US found an association between increased infrastructure provision and uptake of cycling among women, which was not the case for men (Camp, 2013). Considering this evidence together strongly suggests that the absence of such separation, in addition to intimidating behaviour by motorised vehicle users, should be considered to be part of the reason for women's lower cycling rates in countries such as the UK.

In terms of age, Appendix 5 shows that while the evidence is less clear, it is likely that older people (age categories vary, but might typically mean those over 55) have a higher preference than younger people for segregation from motor traffic. The evidence is likely to be more mixed partly because of selection bias. Where studies consist only or mostly of cyclists, older participants will be those who have continued to cycle for many years, and are thus likely to be disproportionately satisfied with current cycling conditions, compared with their peers. However, on balance the evidence still suggests a greater preference for separation on the part of older people.

Finally, evidence on child cycling is limited; research has only recently started into children's and adults' infrastructural preferences related to child cycling. However, what is starting to emerge is that very good infrastructure with high levels of segregation from motor traffic is necessary for high levels of child cycling. This has implications for gender equity too, as women are more likely than men to be travelling with children.

Directness and distance

The work done as part of the NPCT modelling has identified that distance decay curves differ by age and gender, in both England and The Netherlands. Hence it is likely that even in a higher-cycling England, women and older people's propensity to cycle would still decline more steeply than men's and younger people's. This has implications for infrastructure provision and cycle routing: a less direct route that effectively increases distance is likely to reduce the potential for women and older people to cycle at a disproportionately high rate.

As discussed above, if a direct route is to be introduced along a busy road, then it will need to have high quality infrastructure introduced with a high level of separation in order for women, older people and children to be attracted to use it. By contrast, a longer route through quiet, traffic calmed residential streets may also provide a preferred route type for these groups, but will reduce potential uptake through the increased distance that must be travelled to reach a given destination. See Appendix 3, on the flow-level model, for an example of such a potential route in Manchester.

Broader evidence shows that women and older people have in general higher levels of concern about personal safety than men and younger people. This concern will be particularly salient during the hours of darkness, which include many evening commuting trips in winter. It may also affect travel decisions during the interpeak, when women and older people are more likely to be travelling than are men and younger people. Routes particularly affected may include some lower-trafficked Greenways and residential road routes, for example through estates. Women are more likely to work part time than men, making it more important that cycle infrastructure (e.g. restrictions on through motor traffic) is operational all day and not only at traditional peak times.

Improving Cycling Accessibility

The NPCT will provide authorities with the ability to prioritise and plan investments along particular corridors based on the best available evidence on travel behaviour. One way of understanding the NPCT approach is in terms of building improvements in cycling accessibility. Conceptually, this approach draws on ways of understanding public transport accessibility. For public transport, measures exist that tell us how easily and quickly people at a location can (a) access public transport and (b) access a range of specific services. If a new bus service is planned, it is then in theory possible to calculate the change in accessibility for people living within a certain area.

Similarly for cycling, we can imagine a similar concept. Where planners compare ‘fastest’ and ‘quiet’ routes, e.g. those generated by the CycleStreets.net, this could provide a first approximation of ‘distance penalty’ for safer cycling. It is a first approximation because ‘quiet’ routes may not be sufficiently quiet, or may have other problems such as poor surfacing (increasing the time penalty) or poor lighting along off-road sections. Here we understand ‘effective distance’ as being the actual distance someone must travel if using a route of acceptable quality. Policy could work towards a Level of Service (LOS) criterion, based on relevant guidance or standards applied to potential route sections. Where LOS is consistently improved along a particular corridor, this could, as with public transport, be used to calculate the change in the population for whom a given destination is accessible by cycle within a given time.

Where a specific route is under consideration, the increase in cycling distance needed to achieve an acceptable LOS could also be complemented with reference to distance decay functions calculated for the National Propensity to Cycle (NPC) team. This could help to measure the extent to which a new route, which might for example cut distance to cycle a particular trip at an acceptable LOS (as with the Bath Two Tunnels Greenway, which makes a major difference in this regard), makes the trip accessible to a wider demographic with steeper distance decay functions. A related insight provided by the NPCT method is that the ‘quietness diversion factor’ (QDF) should be as low as possible: the safest route to cycle should also be the most direct (see Appendix 3).

References

Camp, A. (2013*) Closing the Bicycling Gender Gap*, Master of Community and Regional Planning (MCRP) Terminal Project, University of Oregon, https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/12935/Camp_Terminal_Project_CRP_4%2026.pdf?sequence=1

Department for Transport (2015). *The government response to the draft cycling delivery plan consultation*. London: Department for Transport. Available from https://www.gov.uk/government/speeches/the-government-response-to-the-draft-cycling-delivery-plan-consultation

Appendix 2 User Testing Summary Report

Contents

Key points

User testing of the tool has included three well attended half day sessions with formal feedback forms, which were held in London and Manchester (with invited attendees) and a session held as part of the Newcastle Cycle City Active City event held at the end of June 2015. Sample quotes from stakeholders are included at the start of this report. We have discussed this structured material in meetings and intend to use the material to guide work in Stages 2-3, also putting in place a larger programme of user testing to ensure maximum relevance and usability for practitioners as we prepare for national roll-out.

The Newcastle event demonstrated the wide appeal of the tool. It attracted 35 practitioners to what was an optional session before the main conference, running alongside two other optional events. All attending wanted to be kept informed about the tool. People came from a wider range of geographical areas (from the Department for Regional Development Northern Ireland to Surrey County Council) and had a range of roles, from strategic programme managers and experienced consultants to interns and early career staff, and were working for government, NGOs and private sector organisations.

The user testing has helped us think about what people want from the tool and what we can do to help ensure that practitioners have the resources and expertise to use (and potentially develop) it. We were pleased to see that people have very much liked the look and idea of the National Propensity to Cycle Tool (NPCT). People said they liked the presentation of the tool, said that it was easy and intuitive, appreciated the map detail and the potential to visualise cycling potential. We were alerted to potential misunderstandings, which will help us guard against these and develop case studies highlighting ways to use the tool.

Feedback helped us to understand how people might use the NPCT. Users suggested that the tool could be used (i) to help present business cases to the Department for Transport (DfT), for bid and proposal writing, including through demonstrating benefits of cycling (ii) communication to members and decision makers, including communicating that there is a demand for cycling, and visually representing routes (iii) in planning where to target future infrastructure improvement, to prioritise routes, to influence design of road schemes, and to justify cycling investment, (iv) as an input for other tools e.g. Transport for London (TfL) modelling, (v) to sense check estimates of demand provided in other ways, to challenge or confirm existing assumptions/understandings.

People liked the fact that the tool is academic led, and felt this would help provide high quality, credible evidence to inform strategy development. There has been discussion about how simple or self-explanatory it should be, and this is something we will monitor and continue to discuss within the team. One question asked was: ‘Are we aiming at something that doesn’t need an instruction manual?’ Stakeholders discussed who would be the intended audience, and the merits of providing a ‘pro’ version with advanced functionality. There was also the expressed need to have something that can be used by officers to communicate with members about strategic cycle planning.

People suggested there will be a need for training and written materials, which we have been developing in the form of ‘help text’. During Stages 2 and 3, we will be developing closer relationships with some authorities, and this may lead to further documentation providing examples of applying the tool and of using in within a policy context. Different authorities and organisations have different priorities, for example, maximising speedy take-up of cycling versus maximising health benefits. There is interest in concentrating on more deprived areas where people have fewer other transportation options, as well as in planning to reduce carbon emissions or congestion (which might imply concentrating efforts on different types of area).

The lively and engaged discussions at these three more formal user testing events, as well as at additional shorter demonstrations and presentations, have illustrated the level of interest in the tool. We look forward to continuing to involve users and learn from their policy and practice needs and interests.

Some broad issues raised

- People really liked the look and idea of the tool, and were engaged and animated in intense and complex debates while using it. However, some struggled to understand it, with implications for training and materials.
- The sessions raised questions about what to prioritise – e.g. functions / outputs / users / interface / data inclusion / route modelling / scenario builder
- There are multiple uses for the tool, with five distinct ways people said they might use it – each has different implications.
- How does the tool's map-based interface work as an output, including alongside other types of outputs – content and formats (e.g. potential for downloading CSV files via a dashboard)?
- Aggregating flows to allocate to roads was strongly supported; there was also support for including cycling facilities, health impacts of scenarios, cycle count data, social data (of various kinds), and to a lesser extent collision and air pollution data.
- There is a trade-off between simplicity and complexity; raising questions about how much data to include and which users to aim at.
- How much do we want to start getting into route details and – relatedly – how much do we want to start duplicating traditional transport modelling functions?
- How much can we provide for non-commute trips, and (actual/potential) mixed-mode trips?
- Can we do anything in relation to new developments and the potential for cycle infrastructure to enable better access to jobs (a key aim of Local Enterprise Partnerships)?

London and Manchester

At London and Manchester we had a dedicated event with half a day allocated to the user testing and reasonable small groups; we were therefore able to collect detailed feedback sheets as well as making notes on the day. These events were relatively early on in Stage 1, so participants were shown an early version of the prototype and some comments have already been addressed.

Likes and dislikes

People said they liked the presentation of the tool, said that it was easy and intuitive, appreciated the map detail and the potential to visualise cycling potential.

People found some of the terms (e.g. observed level of cycling) and the scale/units confusing. Some people thought the centroids were misleading or too small and that the 'freeze lines' feature could lead to users not realising data was being excluded (as an alternative one user suggested the ability to point and click to select areas to be included).

Options and Information

Seven out of 10 people who responded said that there weren't enough options (two 'About Right', one 'Too Many'), with a majority also asking for more information. One person said they wanted data including value of time, health costs, journey time effects on other modes, and planned cycle networks. Another suggested a 'scenario builder' function allowing the user to select, combine and split factors.

Features

Seventeen out of 20 people who answered the question about existing cycling facilities thought showing these would be very useful (three 'Maybes'). One person highlighted the need for these to show quality e.g. distinguish between a high quality separated cycle track and a narrow painted lane.

One person queried whether we would have all cycle rights of way included in the dataset, e.g. byways, bridleways and cycle tracks, which are all on Ordnance Survey.

Thirteen out of 20 who answered the question about health impacts thought this would be very useful (seven 'Maybes'). Fewer, eight out of 20, thought air pollution data would be very useful (11 'Maybes', one 'No'.) Five out of 19 said collision data would be very useful (12 'Maybes', two 'Nos' of whom one said it could be 'positively unhelpful'.)

Ten out of 17 said that social data would be very useful (seven 'Maybes'). People said this would be information about age (3), gender splits, location of universities/colleges/residences, deprivation/Index of Multiple Deprivation (IMD)/income/occupational mix (4), housing type/density, population density, land use, ethnicity.

Twelve out of 16 said that cycle count data would be very useful (one specified for validation) and four out of 12 said it 'maybe' be useful.

Other suggestions included cycle propensity data from outside the city boundaries, trip purposes, hilliness, output matrices which could be inputted to traditional transport models and journey time savings (using Google traffic delays) which could generate a monetised journey time benefit.

Only five people answered the question about routing cycle trips aggregated from origin-destination (OD) pairs as this was only asked in Manchester; four out of five said this would be very useful (one 'Maybe'). (Discussions in London suggested that this would be a useful feature).

Results

Map-based

People suggested providing map-based information showing: changes in cycle flow, an area wide view, flows on links (including summing flows from different O-D pairs to give an overall flow for a route link), using line density to represent different things, observed cycle count data, heat maps.

People suggested using ward- or Lower Super Output Area (LSOA)-level data.

There was also the suggestion of providing shapefiles which authorities could then use in other GIS analysis.

Non map-based (e.g. downloads)

In terms of non-map based information, people suggested: data on cycle miles per person, before and after comparisons, an output that explained the data for a non-technical audience, being able to download the underlying data, health and economic outputs, downloadable matrices (which could be used in business cases), numbers and demographics of cyclists, results from neighbouring authorities, and the calculation of Webtag outputs e.g. health benefits, noise, journey quality, decongestion.

Other results

Comments made by several participants here (and in other sections) suggested they wanted us to be able to calculate cycling uptake under specific investment scenarios, which relates more to the purpose of the tool than specific results.

How the tool would be used

Users suggested that the tool could be used (i) to help present business cases to DfT, for bid and proposal writing, including through demonstrating benefits of cycling (ii) communication to members and decision makers, including communicating that there is a demand for cycling, and visually representing routes (iii) in planning where to target future infrastructure improvement, to prioritise routes, to influence design of road schemes, and to justify cycling investment, (iv) as an input for other tools e.g. TfL modelling, (v) to sense check estimates of demand provided in other ways, to challenge or confirm existing assumptions/understandings.

Overall (iii) – planning where to target cycling infrastructure investment- was the most commonly mentioned but many people included more than one suggestion.

One feature

People were asked to recommend one feature (a couple recommended more than one). Suggestions were:

The ability to switch on/off different parts of the network for routing (e.g. A roads), aggregations from multiple Medium Super Output Areas (MSOAs) to provide figures for an overall flow for a specific link, replacing the 'baseline' with scenarios focused on growth (several people mentioned this, and also that there might already have been growth since 2011), using LSOA instead of MSOA data, incorporating journey purposes, giving comparative journey times by different modes, making the model Greater Manchester-wide, providing estimates of cycling travel time, inclusion of IMD data, providing figures on the shift from different modes, scenarios showing where interventions would have the highest benefit (e.g. in relation to connectivity, economic activity, health health), traffic flow data, and a street view of what 'Go Dutch' would look like and implications for road space reallocation.

Newcastle

At Newcastle the event was held as part of a broader conference (Cycle City Active City) and attracted large numbers, which along with the shorter length of the session limited the feedback we were able to obtain. While generally the uses of the tool were similar to those previously identified, suggestions for what people would like included were somewhat different (partly perhaps because people were shown a more advanced version with enhanced functionality). Comments included the following

- An authority near the Welsh border raised the problem of the tool being limited to England.
- Cross-border trips: to look at trips coming from outside a specific local authority area.
- Cyclist demographics: the idea of being able to download data on who would be cycling under a given scenario.
- Data on deprivation: as above, to target specific groups and to see the extent to which a particular route would provide for deprived areas.
- E-bikes: people in hillier cities were excited by the potential to map what trips might be enabled by uptake of e-bikes, and potentially use this to plan the location of hire e-bikes
- Housing data: including a layer of housing data, which might for example be used to indicate where secure cycle storage might be needed (where many potential cycle trips, and also many flats).
- How the tool related to other tools: this is just one tool, could it be integrated with, for example, Cyclescape (a map-based advocacy tool).
- Including multi-modal trips and trips to interchanges; where commute trips are longer, the ability to cycle to the station might be important rather than the ability to cycle a whole trips.
- Links to other modes, including walking.
- Local data and other open data sources (e.g. Strava) were suggested as complementing the tool.
- Shapefiles or spreadsheets as outputs.
- Suggestions for allowing users to create their own scenarios and potentially bespoke queries via a log-in system (as with Neighbourhood Statistics).
- The focus on commuting was queried.
- The inclusion of cycle infrastructure.
- The inclusion of health data (for similar purposes to deprivation data).

- Training was requested.
- Whether the tool might be used to predict uptake from new developments; and to get a measure of the extent to which cycle infrastructure could open up new job opportunities (i.e. not just serve existing commutes).

Appendix 3 The National Propensity to Cycle Tool: A generalisable flow-level model of cycling uptake for sustainable transport planning

Contents

Introduction

The National Propensity to Cycle Tool (NPCT) is an interactive policy support application for developing transport policies, funded by the UK's Department for Transport (DfT). The NPCT will have data covering England and be used by Local Authority transport planners to prioritise investment in cycling. The tool's main purpose is to help prioritise where to build new strategic cycle routes and related infrastructure at the city level.

This paper describes the model underlying the NPCT and explains some of the decisions that were made relating to the data and methods that it uses. The model is open source and transparent, based on input datasets that are widely available in many countries around the world. The model is implemented in R, a mature language for statistical computing. All of the code has been made available under the MIT license on the GitHub platform.[i]

The research was funded by the UK's Department for Transport and this paper focuses on Stage 1 of the work. In 'Stage 2' we will extend the model to the entirety of England. Key lessons were learned during Stage 1 and, where applicable, these are discussed in relation to future plans. Although the original model was developed for England, the NPCT methodology has the potential to assist with the design of transport policy in many settings. The present paper reports results from 3 case study or 'pilot' cities which acted as a 'proof of concept' for the Department of Transport: Coventry, Manchester and Norwich. The method is described in a generalisable way so it is applicable to any city or region where the appropriate datasets are available. The 'generalisability' of the method is important due to the momentum behind cycling in cities across the world. Planning support tools such as the NPCT can help the associated investment to be spent effectively, yielding more efficient targeting of resources.

The model operates at the flow-level and, by aggregating data from these flows, at the level of geographic zones. A 'flow' in this context constitutes an origin-destination pair: the place where a trip begins and the destination where it ends. Flows therefore represent 'desire lines', typically connecting residential origins with workplace, educational or other destinations. The model takes the current rate of cycling and other variables per flow and uses this to simulate what the rate of cycling per flow could be under various futures. It is important to note that the models do not include the effects on cycling rates of specific policies, such as a particular piece of new infrastructure (although further work could explore adding such capability). Instead, the models allow estimation of where new cycling trips are most likely to be generated given specific overall increases in cycling, such as a target level of cycling (typically measured as a proportion of all trips) being met. The 'Cycling Delivery Plan' scenario, for example, assumes a doubling in the level of cycling, this being the proposed target of the Government’s draft Cycling Delivery Plan (DfT, 2014). The Cycling Delivery Plan scenario translates this doubling into a change in cycling at the flow level. Specifically, the future rate of cycling is simulated at a high

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[i]See github.com/npct/pct.

level of geographical resolution: per flow line and per small administrative zone. The model can answer the question: if cycling increases overall by this amount nationally or regionally, how could this plausibly come about at the local level? More specifically: along which routes would the new cycle[ii] trips plausibly occur?

The model operates 'under the hood' in the NPCT online interface. This means that the output of the NPCT is simply a visualisation of the model's pre-calculated outputs. Rather than interacting with the code that drives the model directly, users interact with visualisations of the model output. This makes the user interface more accessible. The user is not required to perform any of the model set-up for the model to run, but can access all of the underlying code through the project's online code repository.[iii] Thus practitioners can further develop the model if they have the skills and time to do so, for example to add new explanatory variables specific to the local area. We plan to encourage a user community to build up around the tool and to create new versions for specific applications in Stage 2 of the project. This could involve running training sessions for transport planners with programming experience.

Data

The basic model requires only two sets of input data (although more refined versions benefit from many additional datasets):

- *Flow data* estimating the rate of movement between different places. Ideally these datasets should include a breakdown of trips by mode of travel, as this enables regression models. We used flow data disaggregated by mode for England although, by estimating parameters from other data, it would also be possible to estimate cycling potential in cases where no break-down by mode is possible. Flow data are available from various sources, including: flows derived from mobile telephone service providers (Smoreda et al., 2013); public transport data; household travel surveys (Transport for New South Wales, 2014); and census data on home and work locations (Rae, 2009). We used Census 2011 data in the first instance due to their comprehensive coverage of the population, high geographic resolution and assurances surrounding data quality. Official datasets are available for commuting trips and in some cases education trips. In cases where no census data are available (e.g. in relation to shopping trips), some combination of the aforementioned alternative sources such as those derived from mobile telephones may be able to provide a reasonable approximation of real world travel . Flow data are generally provided as a 'flow matrix' (with rows representing origins and columns destinations) or a longer table of origin-destination pairs.

[ii]We use the term 'cycle' instead of 'bicycle' to include trips made by tricycles, quadricycles and hand cycles.

[iii]See github.com/npct/pct.

- *Geographical data* that provide the coordinates corresponding to the trip origins and destinations present in the flow data. At a bare minimum, this means the centroids of each zone in the study area, preferably weighted by population and/or work location. In addition to this, geographic variables could also include additional features of the urban environment that affect cyclists, such as hilliness or number of nodes on the public transport network.

The flow model described in this paper can work for anywhere that has access to such data. To link the two datasets together, *zone ids* are needed in both datasets. To ease the process of combining *flow* data and geographical *point* data, an R function called `gFlow2Lines()` was created.[iv] Table 1, Table 2 and Fig. 1 illustrate the two input datasets along with the single output, namely a set of geographically defined lines with attributes for each flow in both directions (labelled flowlines).

Table 1 Sample of the 'flow' input dataset, representing the number of people who commute from locations within and between administrative zones (MSOAs)

	Area.of.residence	Area.of.workplace	All	Bicycle
920573	E02002361	E02002361	109	2
920575	E02002361	E02002363	38	0
920578	E02002361	E02002367	10	0
920582	E02002361	E02002371	44	3
920587	E02002361	E02002377	34	0
920591	E02002361	E02002382	7	0

Table 2 Sample of the 'cents' input dataset, representing the geographical location of the population-weighted centroids of Medium Super Output Areas (MSOA) zones described in Table 1.

	geo_code	MSOA11NM	coords.x1	coords.x2
1708	E02002384	Leeds 055	-1.546463	53.80952
1712	E02002382	Leeds 053	-1.511861	53.81161
1805	E02002393	Leeds 064	-1.524205	53.80410

[iv]The source code of `gFlow2Lines()` has been made available online, as part of an R package for sustainable transport planning, **stplanr**. See github.com/Robinlovelace/stplanr/.

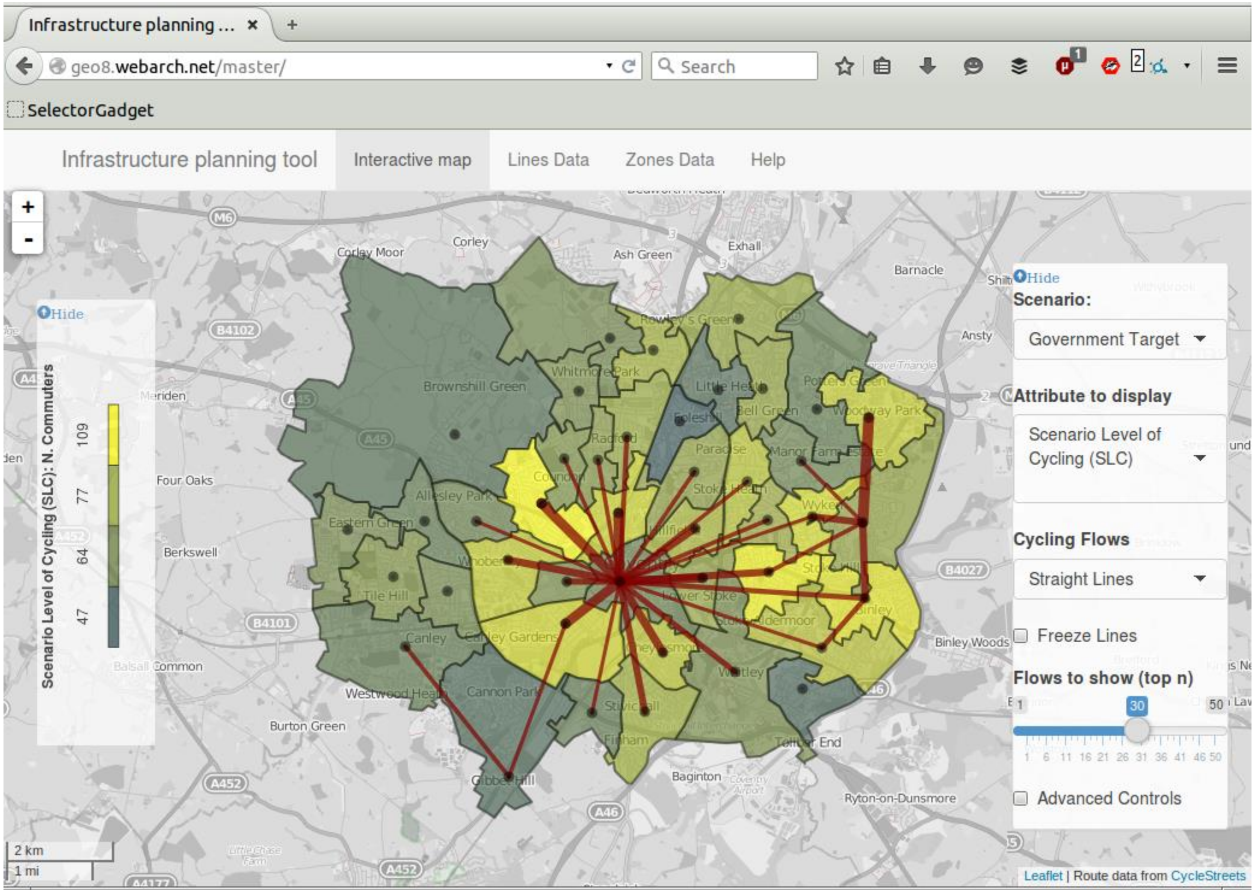

Figure 1 Illustration of 'flow data' converted into geographical lines between origin and destination pairs for Coventry. Width represents the total number of trips. Note the use of population-weighted (as opposed to geographic) centroids used for the point of departure and destination.

Although the details may differ,[v] the basic structure of flow data is likely to be applicable in many settings. The model for England described in this paper uses the following open datasets:

- `wu03ew_v2.csv`, a 104 MB (12 MB compressed) comma-delimited text file of flows between unique origin destination pairs, disaggregated by mode (see Table 2). Note that this is a square table, which was loaded as a `data.frame` in R. Note the origin and destination codes in some rows are the same, indicating *intra-zone* flow, meaning trips which begin and end in the same zone, as is the case in the top row of Table 2. In summary, this dataset describes the overall pattern of travel behaviour in a region (for commuting in this case) in terms of 'desire lines' between hundreds of geographically dispersed origins and destinations.

[v]For example, categories used to disaggregate flow by vehicle mode, trip type and socio-demographic group will vary depending on the data source. Flow data from some sources (e.g. anonymised mobile phone records) will not typically have any categories and simply report total flow.

- `cents.geojson`, representing population-weighted centroids of local administrative zones. For Stage 1 of the NPCT we used MSOAs as both origins and destinations. MSOAs are a geographic unit used for the release of statistical data (average population around 7,800 people). Other geographic levels can be used.

In Stage 2 of the project we plan to explore using Lower Super Output Areas (LSOAs, average population of around 1,600) as the origins and potentially Workplace Zones (WZ) as the destinations. Using different geographic units for the origins and destinations would have two advantages: the centroids will is better-matched to actual workplace destinations and the direction of travel is clearer. The centroid data can either be extracted from boundary data (which finds the geographic centroid) or, if available, a population-weighted centroid dataset can be used. However, it may not be possible to get the cross-tabbed needed to model LSOA to WZ flows. England has a population-weighted centroid dataset and this was used for the NPCT model as the aim is to model population flows.[vi] In summary this dataset shows the user where people live, an important determinant of whether they will benefit from new infrastructure in their local area.

Method

Loading data for local government areas

To ensure reproducibility and enable deployment of the model outside the original case study cities, a systematic data loading method was developed. The computational work to load the various datasets was developed in a series of modular scripts that were subsequently integrated into a single script: `load.Rmd`. This approach ensures that each component of the data (e.g. flow data, administrative zones, topography data) can be loaded separately but that there is a single 'master' script to bring together all the diverse data sources.[vii]. The majority of the loading scripts will only need to be run once; for the case study cities, all open-access datasets that were created this way were saved in a separate folder: github.com/npct/pct-data.

It is possible to run the model for the whole England at once but as the end user is interacting via a map this could mean overloading the user and the computer. Therefore for pragmatic reasons we decided to divide-up England into regions; and have tried, where possible, to operate at the level at which funding is allocated and at which planners work, to ensure the results are compatible with previous transport plans.

Using only one regional geographic level can also have disadvantages, for example hindering the creation of inter-regional plans and a potentially detrimental reduction of emphasis on

[vi]The centroids were loaded in the model from a small (1.7 MB) human-readable text file stored in the open data format GeoJSON. This file was originally downloaded as a Shapefile under the UK's Open Government Licence. The license was accessed from nationalarchives.gov.uk in March 2015.

[vii]See github.com/npct/pct/tree/master/loading-data for a full list of the loading scripts used for the NPCT.

'edge zones' that straddle two or more regions. To overcome this issue it is worth considering using more than one regional geography, as well as considering running at least one version of the model at the national level. Another solution to the problem of 'edge zones' is to create buffers around the regions, which we have already implemented in the prototype for Stage 1 (as discussed below). We plan to test each of these options in Stage 2, and ask practitioners for feedback on the advantages and disadvantages of each.

In Britain, transport decisions (such as where to build new cycle routes) are often made at the local level (Gaffron, 2003). At present, this primarily means at the level of local Highway Authorities, which generally have the same boundaries as County and Unitary Authorities (CUAs). There are 152 CUAs in England (some of which are illustrated in Fig. 2). We recommend these CUAs as the regional unit for Stage 2 of the project.[viii]

As well as CUA level an increasing proportion of transport funding in England is also being allocated to Local Enterprise Partnerships (LEPs) and Combined Authorities (CAs) which are larger than, and often overlapping with, CUAs. Based on these insights, and feedback from practitioners, our recommendation for Stage 2 is to build the NPCT for every CUA in the nation and for selected LEPs and CAs where strategic cycling plans are being planned. These suggestions may change based on feedback from the Department for Transport.

We will also explore the possibility of running the model at the national level. This would involve setting appropriate selection criteria to filter-out the majority of origin-destination pairs to avoid exceeding computational resources. The demarcation of regional boundaries is deemed useful for focusing on one region at a time.

Stage 1 of the NPCT project focused instead on smaller administrative units: Local Authority Districts (LADs). There are 324 LADs across England. For the case study towns of Manchester and Coventry, the choice between CUA and LAD levels made no difference as LADs and CUAs have the same boundaries for these areas. For Norwich, however, the LAD is much smaller than the CUA and is less practical for strategic transport planning at the MSOA level (Fig. 2). For this reason we implemented a buffer selection methodology to expand the scope of the selection, as described in the next section. Before describing the buffer selection method, it is worth briefly considering some of the other regional geographies that could be used: Travel to Work Areas (TTWAs), which could be applicable in many contexts and Local Enterprise Partnerships (LEPs) which are specific to the UK context.

TTWAs are 'commuting watersheds' that correspond to cohesive regions, the centres of which are known employment centres (Coombes and Bond, 2008). Versions of the NPCT model developed for more scientific purposes would benefit from using TTWAs as the regional geography for local scenario development and visualisation.

[viii]Some work is required to ensure the compatibility of pre 2011 and post 2011 codes.

Figure 2 Local Authority District (LAD, above) and County and Unitary Authority (CUA, below) levels of transport planning. These are potential regional units for the National Propensity to Cycle Tool

Variable zone and flowline selection criteria

Flow-routes are where the origin-destination pair is mapped onto the current travel network using the fastest cycling route possible. Flow-routes are used in the model but calculating them for the travel routes possible between all origin-destination pairs requires significant computational resources. For our NPCT Stage 1 model, the route allocation algorithm, implemented 'in the cloud' by CycleStreets.net (an online routing service for planning cycle trips), is the major bottle-neck at present in terms of computational time. In order to make the model scalable and flexible, it may be desirable that only a sub-sample of flow-lines should be processed within the model. We therefore sought to reduce the number of flows whilst retaining the overall travel pattern. The most straightforward way to do this is to only include flows that are used by a minimum number of commuters. Because the distribution of number of commuters per flow is highly skewed by high numbers of commuters using a few major 'commuter corridors', a high proportion of commuters can be represented by a relatively small proportion of flow lines. In Manchester, for example, the top 15% of flow lines (those used by 30+ commuters) account for almost 70% of commuters. This is a parameter that can be adjusted to reach a reasonable balance between comprehensive coverage on the one hand and being fast to save and load on the other. Setting the maximum Euclidean distance is another way to reduce the number of flow lines, and this can be done in conjunction with setting a maximum number of commuters. We used a maximum value of 15 km Euclidean distance, based on the knowledge that this typically translates to a road distance of over 20km. This distance is not feasible for most people to cycle on a daily basis. This is evidenced by our analysis of National Travel Survey data (see Appendix 8). A related issue is the selection of flow lines to illustrate. At present the tool select all lines completely encapsulated in the current zoom extent. Future work could explore allowing alternative ways of selecting lines, such as via polygons of origins, destinations, or both.

Although flow-lines are the unit of analysis for running the model, zones are the basic unit of visualisation of the results over geographic space. This is largely because the number of flow-lines processed in the model is such that they cannot all be effectively visualised on a single map. It is very hard to interpret a map showing more than around 50 flow-lines simultaneously. Our use of simultaneously displayed zonal data helps solve this problem, by averaging results across a surface. The aggregation of bi-directional lines into overall flow both was (a novel feature of our methodology) also simplifies the visualisation of lines for users.

In our model testing, we found that there often seemed to be too few 'MSOA' zones per Local Authority 'LAD' region to gain a comprehensive understanding of the travel system. This would be solved by using larger regional units to split the MSOAs into groups for visualisation, as planned for Stage 2. An alternative is to create buffers around each region, from which additional zones are sampled. This sampling of additional zones within a buffer could be triggered if the number of zones falls below some threshold. We set this threshold to 60 for Manchester (which contains 57 MSOAs) so that zones would be selected outside the long and thin LAD shape. This protocol increases the sample size by including all zones whose population-weighted centroid lies inside the buffer.

This led to the selection of additional zones outside Manchester's long and thin LAD shape. Implementing this procedure involved creating a parameter, `buff_dist`, which represents the distance buffer around the LAD in question from which the additional zones are sampled. This approach has the additional advantage of preventing breaks in continuity (and zero flows) between different regions in the model.

The Model Output tab

Users can view a summary of the model, including the subsetting criteria mentioned above, without going through all the underlying code. This is can be done via the 'Model Output' tab (Fig. 3). This feature of the user interface serves three purposes: to avoid 'hiding' the underlying model from users; to encourage modifications and enhancements to the code; and to ensure transparency. The tab was added in response to feedback during the user testing sessions, during which a number of transport planners requested further information about the model. The output tab also communicates the results of the model, including through key statistics, diagnostic plots and model-results on a per-region basis. This means that a different summary document is provided depending on which local authority the user is currently exploring.

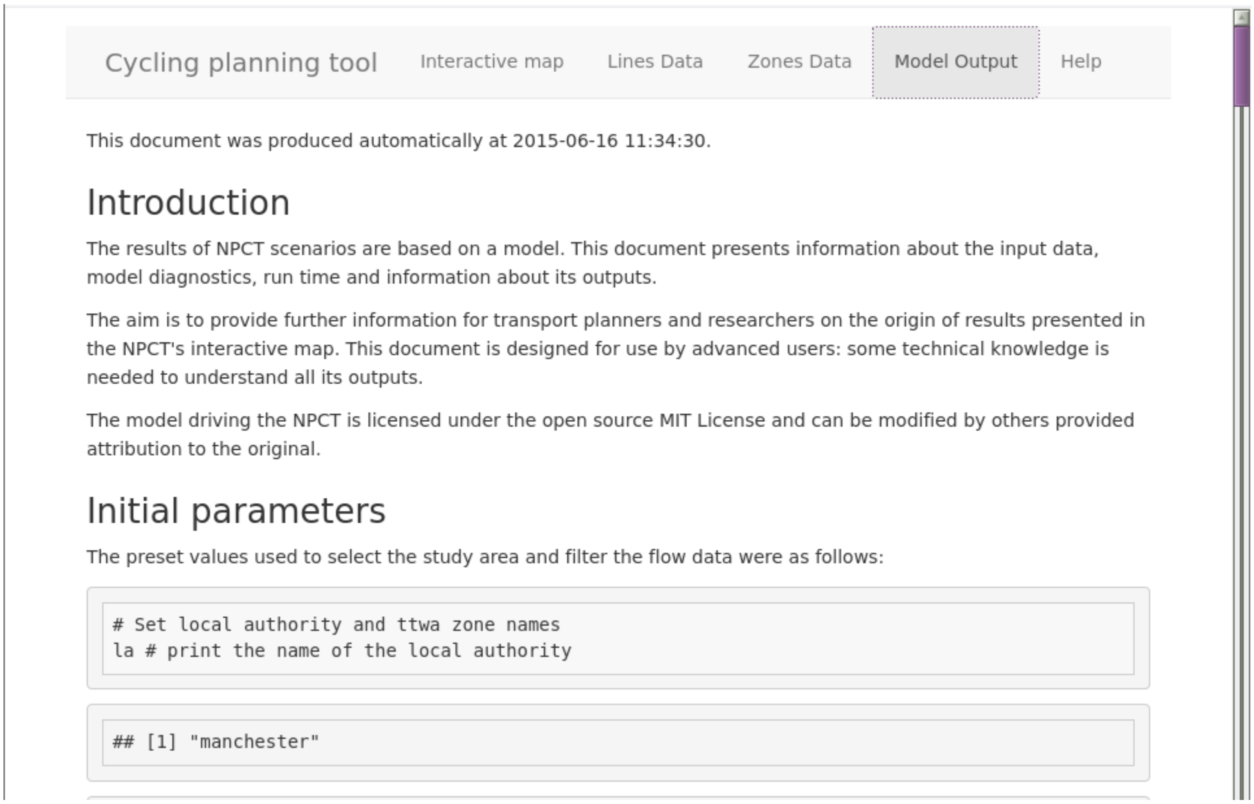

Figure 3 The Output Tab of the National Propensity to Cycle Tool

Modelling distance decay

So far we have described the input data and ways of processing, selecting and subsetting different geographical objects (primarily lines, representing flows and polygons, representing administrative zones) for the NPCT. Yet the greatest value of the NPCT lies in its ability to represent different scenarios of change. Illustrations of how the number of cyclists using different 'desire lines' along each flow could shift in the future were described as 'very useful' for transport planning during user testing. In addition, the visualisation of different scenarios enables 'visioning', an activity that has great potential to improve transport planning for sustainability (Tight et al., 2011).

For all scenarios (except *gender equality*) a regression model was used to estimate the potential rate of cycling at the flow level. Place of home and work are geographical variables with a high degree of inertia, so we assumed these would remain constant under all scenarios. An exciting future direction of this research would involve shift work and home locations, for example to reflect a more localised economy. This could provide insight into the impact of changing travel demand patterns on the potential rate of active travel in different areas. This section describes the regression model and how it was used to generate geographically-specific scenarios of transport futures.

The regression model operates at the *flow* level and seeks to explain the current level of cycling. It does so using Ordinary Least Squares (OLS) to optimize a number of model parameters linking the *explanatory variables* described above to the *dependent variable*: the proportion of trips made by cycling per flow (pcycle). Central to the model is *distance decay*, which describes the (non-linear) relationship between the distance of a trip and the probability of it being made by cycling. After trying various functional forms on various flow datasets, we found that the distance decay curve displayed in Fig. 4, and variations thereof, seemed to fit the data well.

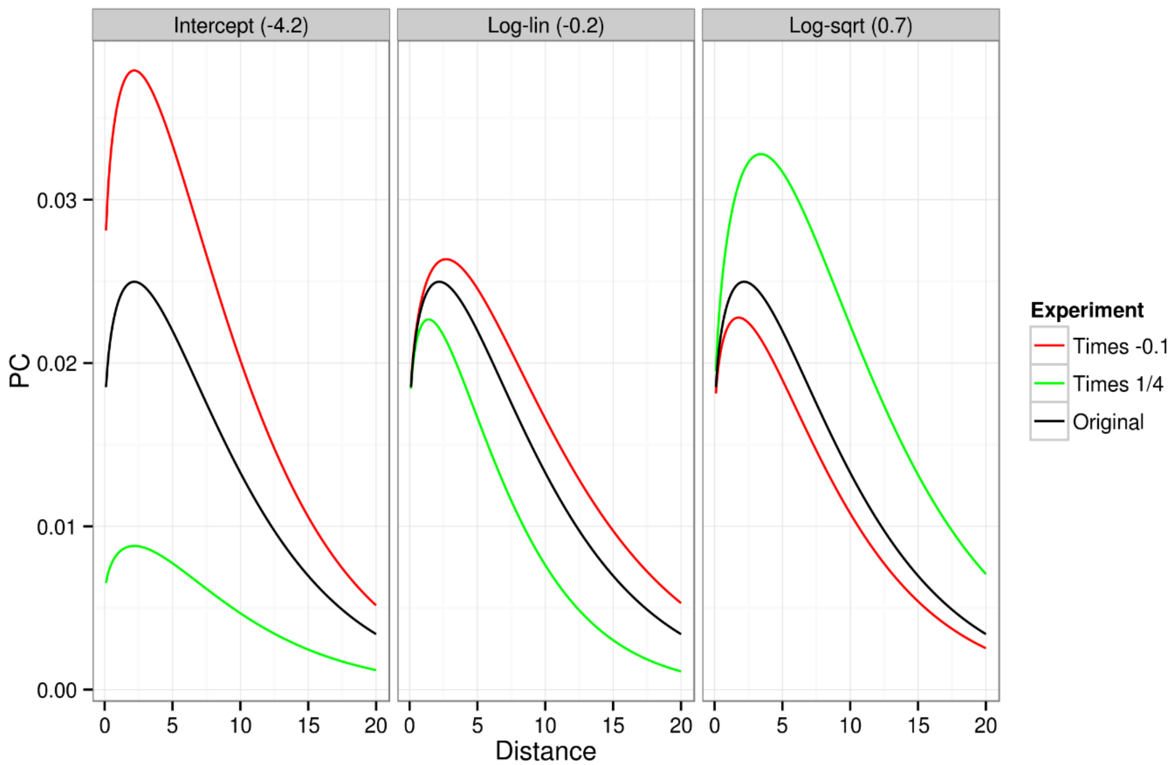

Figure 4 The distance decay curve resulting from the log-square-root function. The green lines represent increases of 0.25 times original parameter values (obtained by running the model on data from the 2011 Census for Manchester) and the red lines represent -0.1 times the original value.

The gradual decline of pcycle with increasing distance results in a 'long tail' distribution, typical of exponential decay. Thus we estimated the log of pcycle rather than pcycle directly. Also, to avoid estimates that are above 1 or below zero, we applied a *logit link* to the model to improve model fit. Including hilliness as a dependent variable, the final model formula was as follows:

$$\mathrm{pcycle} \approx \alpha + \beta_1 X1 + \beta_2 X1^{0.5} + \theta X2$$

where X1 is distance (km, route distance) and X2 is the hilliness (described below) per flow. α represents the intercept (the rate of cycling very short trips), β_1 and β_2 represent the rate of distance decay and θ represents the impact of hilliness on cycling. A 'quasipoisson' general linear model was used to implement this formula using the base R function `glm`, which predicts $\log(\text{pcycle})$ to account for the aforementioned exponential decay.[ix]

Model scenarios

Once the input data has been processed and subsetted to the area of interest, it is passed to a regression model. The dependent variable is the percentage of trips currently made by cycling (*pcycle*). This is calculated as the number of cycle commutes from the flow data (*OLC*) divided by the total flow by all modes per flow (tflow). In the model output, this is visualised as number of cyclists.

The explanatory variables predicting the percentage of trips made by cycling included the route distance of each flow and hilliness. By aggregating the origins of all flows, the model also estimates the proportion of commuters cycling to work among inhabitants in each area. Aggregating by destination would also allow an estimate of the number incoming cyclists per work destination, which would be useful for assessing features such as new cycling parking. In descending order of importance (in the UK context), the factors implemented in NPCT in Stage 1 were:

- Distance between origins and destinations. This was calculated in the first instance as Euclidean (straight line) distance for filtering purposes using the **rgeos** package. An estimate of route distance was then assigned to each flow using the CycleStreets.net API.[x]
- Hilliness of zones and routes. Hilliness is a continuous variable in our model designed to capture the extent to which vertical gradient along cycled routes is a disincentive to cycling. There are various ways to represent this information, ranging from the simple (e.g. the vertical displacement between origin and destination) to the complex (e.g. total amount of climb along the route network in both directions). In Stage 1 we started with a simple approach to demonstrate the importance of hilliness. This involved converting open digital elevation model (DEM) data from the National Aeronautics and Space Administration (NASA) into a measure of gradient and then aggregating this to the level of administrative zones.[xi] To allocate this area-based hilliness metric to flows, we calculated

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[ix]See github.com/npct/pct/blob/master/models/aggregate-model.R..

[x]To implement this functionality in a generalisable way a custom function, `route_cyclestreet()`, was written for the R package **stplanr**.

[xi]The average gradient of the administrative zones was data from the Shuttle Radar Topography Mission (SRTM), collected by NASA and provided for public download by the Consultative Group on International Agricultural Research (CGIAR - see http://srtm.csi.cgiar.org/). "Version 4" of the dataset was used. At the equator, this has a resolution of 90m. Across the UK, the average resolution of the raster, converted to the OSGB1936 Coordinate Reference System (CRS) is 56.5 m along the east-west axis 92.6 m along the north-south axis. To convert the elevation data into a gradient in degrees for each raster cell the function 'terrain' from R's 'raster' package was used which implements the algorithm of Horn (1981). To geographically aggregate these values to find the average gradient per LSOA zone the function 'extract' was used, also from the raster package.

the average hilliness of origin and destination. This method has the disadvantage that it becomes far less accurate for longer journeys spanning many intermediate zones and is also less accurate for origin or destination zones with considerable internal variation in hilliness. We plan to refine this method in Stage 2.

For Stage 2 we will explore using additional explanatory variables to predict cycling more accurately and to differentiate more finely between different types of area.

One interesting preliminary finding is that analysis of the commuting data suggests that the difference in distance between the quieter and fast route along the flow line is a strong predictor of the rate of cycling. Directness of the route would increase cycling due to the distance decay function. Interestingly the effects seems to be stronger than would be expected from the increase in distance alone. One possibility to explain this is that people are put off cycling if they feel they unduly have to go out of their way to access quieter routes.

This can be quantified in various ways, for example via the 'quietness diversion factor' (qdf), the ratio between the 'quietest' and the 'fastest' route calculated by CycleStreets.net ($\mathrm{qdf} = \mathrm{d_{fast}}/\mathrm{d_{quiet}}$). The inclusion of this variable per flow creates an opportunity to estimate the short-term impacts of new or improved cycle provision, up to the standard of a current average quieter route but along a more direct route. By setting qdf to 1 (i.e. setting $\mathrm{d_{quiet}} = \mathrm{d_{fast}}$), the increase in the number of cyclists using upgraded routes can be estimated. An example in which the length of a quiet route is much further than the fastest route (i.e. $\mathrm{qdf} > 1.2$) is provided at the end of this paper, in Fig. 9. Note that qdf is different than circuity (q), the diversion from straight-line (Euclidean) distance as it approximates represents *how much further* one must travel to use a quiet path. Where qdf is low, this means that the quiet routes are also the most direct, which will likely encourage new cyclists.

Note that *total number of cycle trips* is not an explanatory variable on its own. This is because the dependent variable includes cycling by using the *proportion* of those who cycle. This measure, labelled pcycle, is robust to large variations in the absolute flow by all modes.

Cycling Delivery Plan

The Cycling Delivery Plan scenario (*cdp*) is based on the government's proposed target to double cycling in England, from 0.8 billion stages currently to 1.6 billion stages by 2025 (DfT 2014). Assuming increases in population offset the national trend towards lower trip rates,[xii] achieving the draft Cycling Delivery Plan's proposed target would result in a doubling in the

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[xii]Increases in population would mean the *proportion* of trips by cycle would not need to double for the *absolute number* of trips to double. However, the rate of trips overall (measured in the number of trips per person per year by any mode for any purpose) is on a long-term downward trajectory which more than offsets the impact of population growth. See (F. Crawford and Lovelace 2015) for a detailed discussion of this issue. The authors could not find evidence about how this trend was accounted for by the DfT in scenarios from the National Transport Model (NTM) or elsewhere.

proportion of trips made by cycling nationwide. DfT (2014) does not investigate the geographic distribution of potential cycling uptake in their publication of the scenario, and so we made our own assumptions about this (see next paragraph) and investigated their implications. The *cdp* scenario should help transport planners identify where new demand for cycling is likely to be greatest.

In line with the target set out in the draft Cycling Delivery Plan, the *cdp* scenario seeks to approximate the geographic distribution of growth in cycling under a scenario of doubling in cycling. In our implementation of this scenario, cycling does not double in all areas. Places that have high average commute distances or that already have a rate of cycling above the national average will see cycling increase less than two-fold; areas with a below average current rate of cycling but high potential based on the number of short commute trips will see cycling increase more than two-fold. The same logic applies to flows: origin-destination pairs that are close together but with a currently low rate of cycling tend to see the greatest increase in cycling under the *cdp* scenario.

At the heart of the *cdp* scenario is a regression model at the national level (labelled natmod) estimating the current proportion of trips by cycle by (*pcycle*). Route distance and hilliness at the national level were the explanatory variables in Stage 1, although as explained above additional variables could easily added. The resulting national distance decay curve is then applied locally. The additional number of cyclists for each flow is calculated by multiplying the proportion expected for the distance of the flow nationally. The new rate of cycling ($\mathrm{pcycle(cdp)}$) is the current rate of cycling plus this model-based estimate:

$$\mathrm{pcycle(cdp)} = (\mathrm{pcycle} + \mathrm{pcycle(natmod)})$$

where pcycle is the proportion of commuters who cycle per flow in the 2011 Census and $\mathrm{pcycle(natmod)}$ is the proportion of commuters expected to cycle based on the national-level regression model. The sum of these values is multiplied by tflow, the total number of commuters all modes, to convert the proportion into a number of cyclists, i.e.:

$$\mathrm{SLC(cdp)} = (\mathrm{pcycle} + \mathrm{pcycle(natmod)}) * \mathrm{tflow}$$

An example of this scenario for illustrative purposes is as follows. Based on a representative sample of flows in the UK, among those making trips with a 'fastest route' distance of between 4 and 5 km, the proportion who used a cycle as their main mode is 5.0%. Under the 'national doubling' assumption of the *cdp* scenario, this implies that the total increase in the proportion of cyclists in this distance band is 5.0% --- i.e. $\mathrm{pcycle(natmod)} = 0.05$. In the case study city of Manchester, the proportion of commuters travelling four to five kilometres to work, who used a cycle as their main mode, was 4.6% ($\mathrm{pcycle} = 4.6$).

All else being equal (specifically, assuming average hilliness in Manchester is equal to the national average), the number percent of commuters cycling to work in this case under the Cycling Delivery Plan scenario ($\mathrm{SLC(cdp)}$) would be 4.6% + 5.0% = 9.6%. The total number of commuters cycling to work in Manchester ($\mathrm{SLC(cdp)}$) would thus be 9.6% multiplied by tflow, i.e. the proportion cycling multiplied by the total number of commuters.

Note that this does not mean that *all* flows in Manchester between four and five kilometres would be projected to have a 9.6% proportion of cycle commuters in the *cdp* scenario. The initial level of cycling (*pcycle*) will vary widely: a flow with an exceptionally high initial rate of cycling, for example pcycle = 30%, would end up with a projected rate of cycling of 35% ($\mathrm{pcycle(cdp)}$ = 35%). Likewise, a flow of 4.5 km that has no cycling currently would be projected to reach 5%.

The approach here assumes that cycling potential against a given national increase is always a positive number. This applies even in the areas in which cycling is currently substantially above what would be expected given trip distances and hilliness we model an increase in cycling. The larger the increase in cycling the less the baseline matters compared with the potential. By contrast, the larger the current rate of cycling, the less important is the scenario in influencing the projected total flow.

This implementation of the *cdp* is in line with findings from Sloman et al. (2014) that suggest building in areas with a high current rate of cycling will further increase the rate of cycling (Sloman et al., 2014). The method also links to the discussion of 'propensity' vs 'potential' to cycle: the former relates to short-term responses, based on demographic, social and cultural likelihood of cycling. Some areas are comparatively prone to cycle, whereas others are averse to cycling. Under our implementation of the *cdp* scenario, these 'low propensity' areas would still have a lower than expected rate of cycling based on national trends. In the longer-term 'Go Dutch' scenario, it is simply the potential rate of cycling that determines the rate of flow, and the current rate of cycling has no bearing on the estimates.

The next scenario to be discussed is *Gender Equality*. In this scenario cycling tends to grow much more in areas that already have a high rate of cycling. Thus this scenario is more about a shift in current propensity than the long-term potential levels of cycling described in *Go Dutch* and *Ebike* scenarios. In the long-run, it would be hoped that inter-group differences in the rate of cycling tend to zero as the rate of cycling increases. In the Netherlands cycling is almost equally common among males, females, and people of different socio-economic status.

Gender equality

The Gender Equality scenario (*gendereq*) is a relatively simple modification of an existing scenario. For the purposes of explanation, we will use the *observed level of cycling* (*OLC*) in the 2011 Census as the basis of the scenario. However, it is possible to apply the *gendereq* method to any scenario, as described towards the end of this section.

The Cycling Delivery Plan scenario (*cdp*) makes no assumption about the future gender split in cycling. On average in England around three-quarters of cycle commuters are male, although this varies substantially. *gendereq*, by contrast, is based on the assumption that gender equality is reached in cycling. Specifically, the scenario assumes that in each flow the proportion of females cycling is the same as the proportion of males. A prerequisite is a model-based estimate of the number of male and female cyclists between origin and destinations for the observed data. This involves splitting the number of cyclists projected by the model, the *Scenario-based Level of Cycling*, into male ($\mathrm{SLC_m}$) and female ($\mathrm{SLC_f}$) components:

$$\mathrm{SLC} = \mathrm{SLC_m} + \mathrm{SLC_f}$$

More males cycle than females in every Local Authority in the country (Fig. 5). For this reason, the *gendereq* scenario is based on the assumption that the rate of cycling amongst females increases to match the rate of cycling amongst males, rather than vice versa. Under *gendereq* $\mathrm{SLC_m}$ remains constant. The challenge is to find the value of $\mathrm{SLC_f}$ such that the proportion of females cycling under the gender equity scenario ('$\mathrm{pcycle(gendereq)_f}$') becomes equal to the observed proportion of males cycling ($\mathrm{pmale_{cyclist}}$). Note that this is not as simple as $\mathrm{SLC_f} = \mathrm{SLC_m}$, as the absolute number of female and male cyclists will also depend on the gender split of the total commuting population within each flow.[xiii] It is the *proportion* of males and females per flow who cycle that becomes equal, as follows.

$$\mathrm{pcycle(gendereq)_f} = \mathrm{pcycle_m}$$

$$\frac{\mathrm{SLC(gendereq)_f}}{\mathrm{tflow_f}} = \frac{\mathrm{OLC_m}}{\mathrm{tflow_m}}$$

$$\mathrm{SLC(gendereq)_f} = \mathrm{tflow_f} * \frac{\mathrm{OLC_m}}{\mathrm{tflow_m}}$$

$\mathrm{OLC_m}$ is the observed number of males cycling (in the 2011 Census in this case), $\mathrm{SLC(gendereq)_f}$ is number of females cycling in the gender equality scenario, and $\mathrm{tflow_m}$ and $\mathrm{tflow_f}$ are the total numbers of males and females in the flow respectively.

$\mathrm{tflow_m}$ and $\mathrm{tflow_f}$ are both available at the flow level in the 2011 Census, as is the total number of cyclists (OLC). The proportion of cyclists who are male in each flow ($\mathrm{pmale_(cyclist)}$) is not available in the published 2011 datasets (although we intend to commission such tables for Stage 2). The smallest level at which the gender breakdown of cyclists is currently available is the zone level ('$\mathrm{pmale_{cyclist}(zone)}$'), and we assume that all flows have this same proportion of male cyclists. This allows the estimation the number of males cycling as $\mathrm{OLC_m} = \mathrm{OLC} * \mathrm{pmale_{cyclist}(zone)}$, so that

$$\mathrm{SLC(gendereq)_f} = \mathrm{OLC} * \mathrm{pmale_{cyclist}(zone)} * \frac{\mathrm{tflow_f}}{\mathrm{tflow_m}}$$

and therefore the total flow for gender equality $\mathrm{SLC(gendereq)}$ would be

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[xiii]To illustrate this point, consider a flow in which there are more female than male commuters. In this case, the number of female cyclists would exceed the number of male cyclists in the *gendereq* scenario.

$$\mathrm{SLC(gendereq)} = \mathrm{OLC_m} + \mathrm{SLC(gendereq)_f}$$

$$\mathrm{SLC(gendereq)} = \mathrm{OLC} * \mathrm{pmale_{cyclist}(zone)} * (1 + \frac{\mathrm{tflow_f}}{\mathrm{tflow_m}})$$

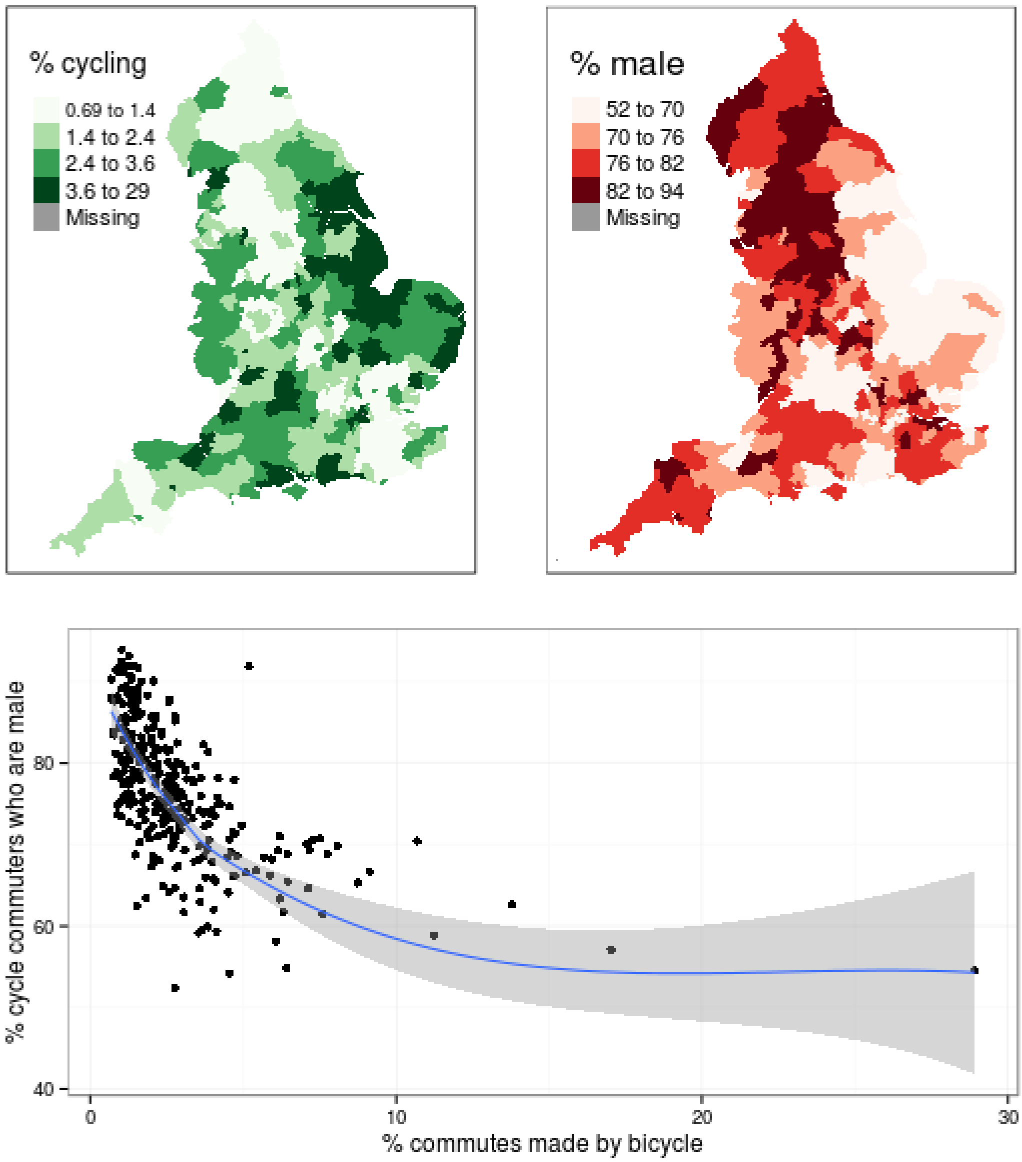

Figure 5 Cycling and the gender balance of cycling in England. The choropleth maps illustrate the spatial distribution of the two variables. The scatter plot illustrates the relationship between the two variables cycle commuting (x axis) against the proportion of commuter cyclists who are male (y axis) for all 326 Local Authorities (including Districts) in the UK.

To illustrate how this method works in practice, imagine a flow in which 5 from a total of 50 people commute by cycle ($\mathrm{tflow} = 50; \mathrm{OLC} = 5$). 30 of the total trips in the flow are made by males ($\mathrm{tflow_m} = 30$) and 20 by females ($\mathrm{tflow_f} = 20$). In addition, 70% of commuter cycling in the wider zone is by males ($\mathrm{pmale_{cyclist}(zone)} = 0.70$). This means that an estimated $5 *$

$0.70 = 3.5$ cycle commuters are male ($\mathrm{OLC_m} = 3.5$) and 1.5 are female ($\mathrm{OLC_f} = 1.5$). These are not whole numbers but represent the average number expected in many flows with the same characteristics.

Applying the formulae presented on the previous page:

$$\mathrm{SLC(gendereq)_f} = \mathrm{OLC} * \mathrm{pmale_{cyclists}zone} * (1 + \frac{\mathrm{tflow_f}}{\mathrm{tflow_m}})$$

$$\mathrm{SLC(gendereq)} = 5 * 0.70 * (1 + \frac{20}{30}) = 5.83$$

The increase from 5 cyclists to 5.83 represents an increase of 17% from the observed rate of cycling in total numbers of cyclists. All of these extra 0.83 cyclists are female, giving a new total of 1.5 + 0.83 = 2.33 female cyclists (and still 3.5 male cyclists). Gender equality in cycling has been reached, such that an estimated 11.7 % of commute trips are made by cycling among both men (3.5/30) and women (2.33 / 20).

Go Dutch

The 'Go Dutch' scenario represents the rate of cycling that would occur if people had the same propensity to cycle as the Dutch do, for trips of the same length. It is important to note that this is not a 'top down' scenario in which the national level of cycling is set to levels found in the Netherlands. The scenario is 'bottom up' because the proportion of trips being cycled is set per flow and the end result for any particular region depends on the local distribution of trip distances. Although the Dutch currently cycle far more frequently than the English for short trips, their propensity to cycle still drops rapidly with distance, with relatively few utility trips being made beyond around 15 km.

Based on these insights, the essence of the 'Go Dutch' scenario (henceforth simply *dutch*) is the application of distance decay parameters found in the Netherlands to each flow in the study area. In Stage 2 we plan to refine this by also factoring in average differences in hilliness levels between England and the Netherlands, drawing on the work presented in Appendix 8.

Electric cycles

The purpose of this scenario is to demonstrate the increased rate of cycling that is possible due the electric cycles (hence the scenario name, *ebike*). This is the most ambitious of the scenarios presented in this paper and it builds on 'Go Dutch', with Dutch model parameters.

In Stage 1 this scenario is not fully implemented, and the results are merely illustrative. At present, the results are based on the decision to increase by a small amount the β_1 distance decay parameter, which corresponds to distance as a linear term. Specifically, we increased this value by 0.025, as we found this to be sufficiently small to avoid generating an implausibly high rate of cycling but sufficiently large to create a noticeable effect. This allows us to illustrate the type of output that will be possible in this model. In Stage 2 we will implement the model fully by basing the changes to the distance decay parameters on real data from the Dutch National

Travel Survey. Analysis of the influence of ebikes on propensity to cycle (of people using both using ebikes and conventional bicycles) bikes in the Netherlands has was conducted as part of the Co-benefits model. See Appendix 10.

Results

To demonstrate how the scenarios work in practice and to provide an overview of the results, Fig. 6 illustrates the observed level of cycling (OLC, from the 2011 Census) and the scenario-based level of cycling in two Local Authorities (Manchester and Norwich). Note that while Manchester has a much higher total number of trips than Norwich, the proportion of those trips that are made by cycling is lower. There is noticeable distance decay of for all modes of transport, especially for cycle trips in Norwich, where cycle trips above 7.5 km observed from 2011 census data are comparatively rare.

Note that although Manchester and Norwich have very different initial levels of cycling, the final level estimated from the *dutch* and *ebike* scenarios are similar, reflecting local trip distributions and overriding the initial rate of cycling. Note also that the *cdp* scenario in Manchester has a considerably higher rate of cycling than the *gendereq* scenario, whereas in Norwich these scenarios are very similar. This is because Manchester is starting from a lower baseline, so a doubling nationwide results in a relatively high absolute increase in cycling locally. In Norwich, by contrast, the current rate of cycling is considerably greater than the national average, so the *cdp* scenario represents less than a doubling in cycling.

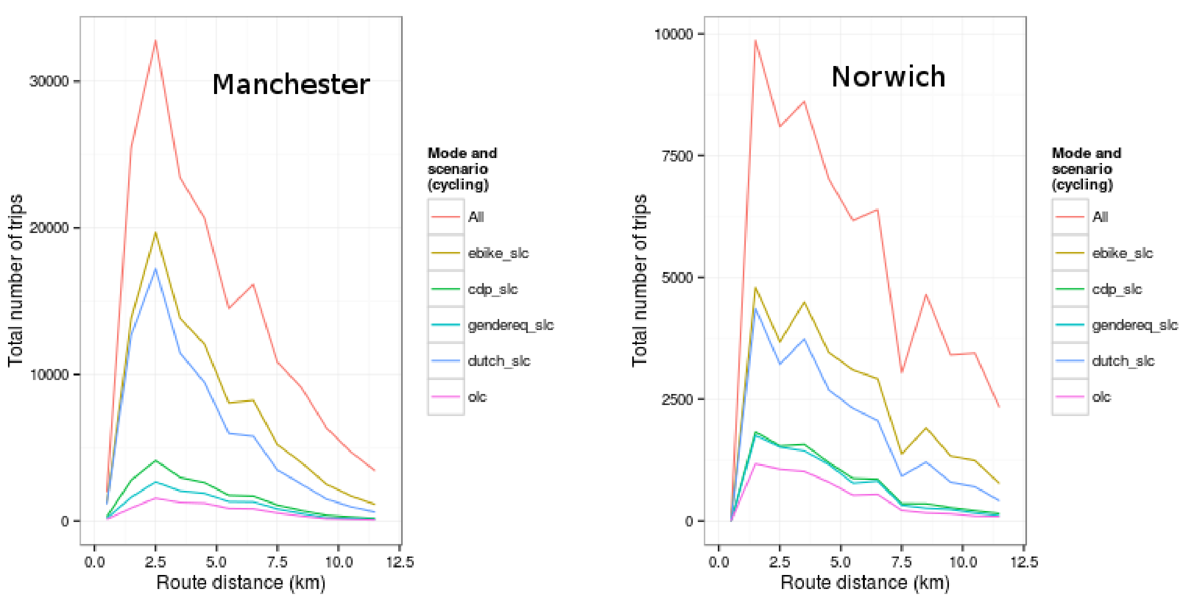

Figure 6 Results of observed and scenario-based levels of cycling from NPCT model runs for Manchester (left) and Norwich (right).

The difference between the spatial distribution in cycling potential between the shorter-term Cycling Delivery Plan (*cdp*) and longer-term Go Dutch (*dutch*) scenarios is illustrated in Fig. 7.

Note that the top 20 flows in Norwich under *cdp* assumptions is dominated by the current rate of cycling, whereas under *dutch* assumptions, the distribution shifts to flows that are more representative of short-distance flows in across the city overall. In both cases the flows are focused around Norwich city centre: the region has a mono-centric regional economy, making trips beyond around five kilometres from the centre much less likely to be made by cycling.

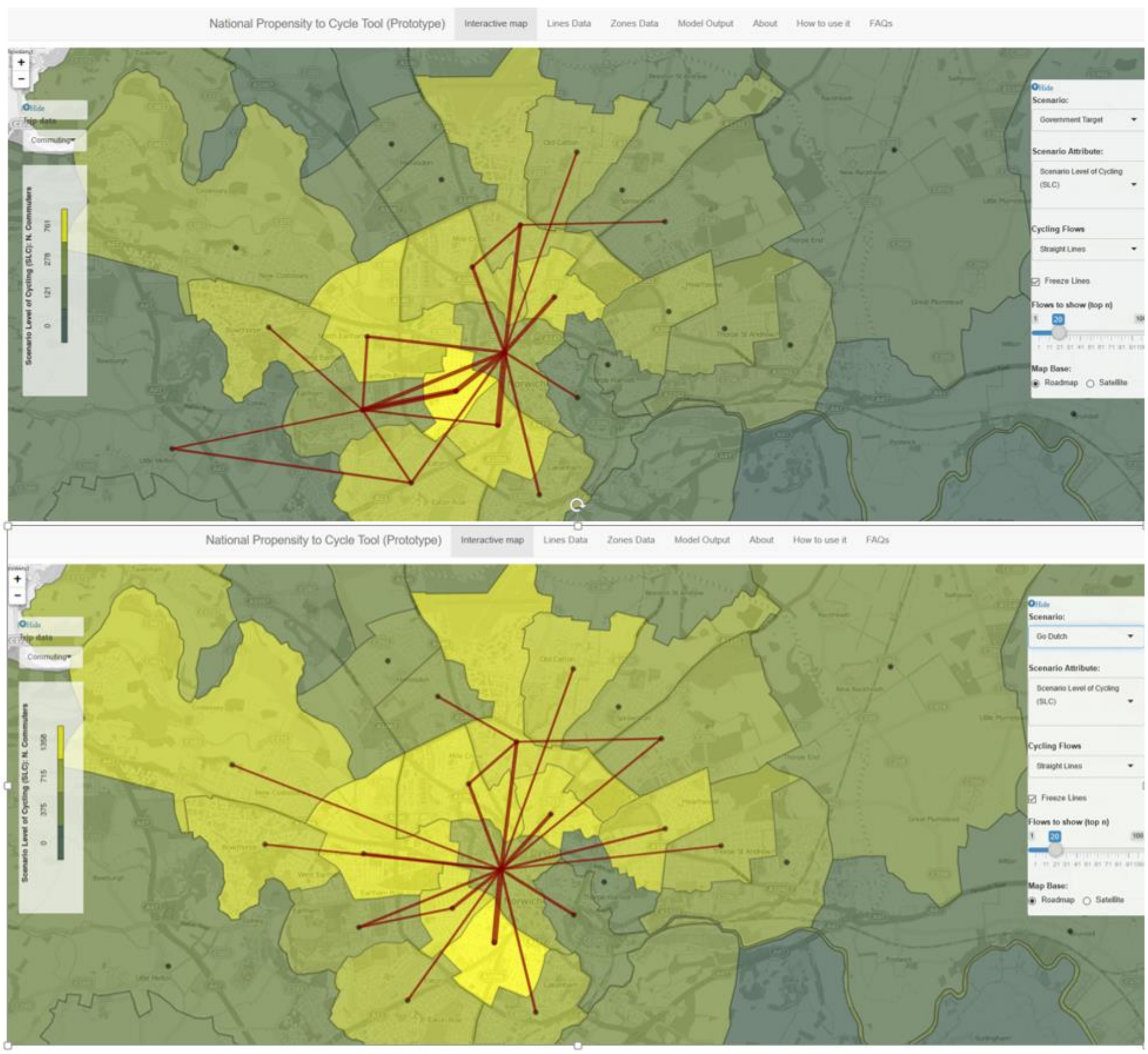

Figure 7 Model output illustrating the top 20 most cycled flows in Norwich under Cycling Delivery Plan and Go Dutch scenarios.

The equivalent results are shown for Manchester in Fig. 8. This shows that Manchester has a poly-centric structure, favouring the construction of cycle routes between the various sub-centres, not just in radial routes to a single centre. Note in both scenarios the large increase in the level of cycling in between *cdp* (which represents only a doubling nationwide) and *dutch* scenarios (which represents a more ambitious plan for cycling uptake).

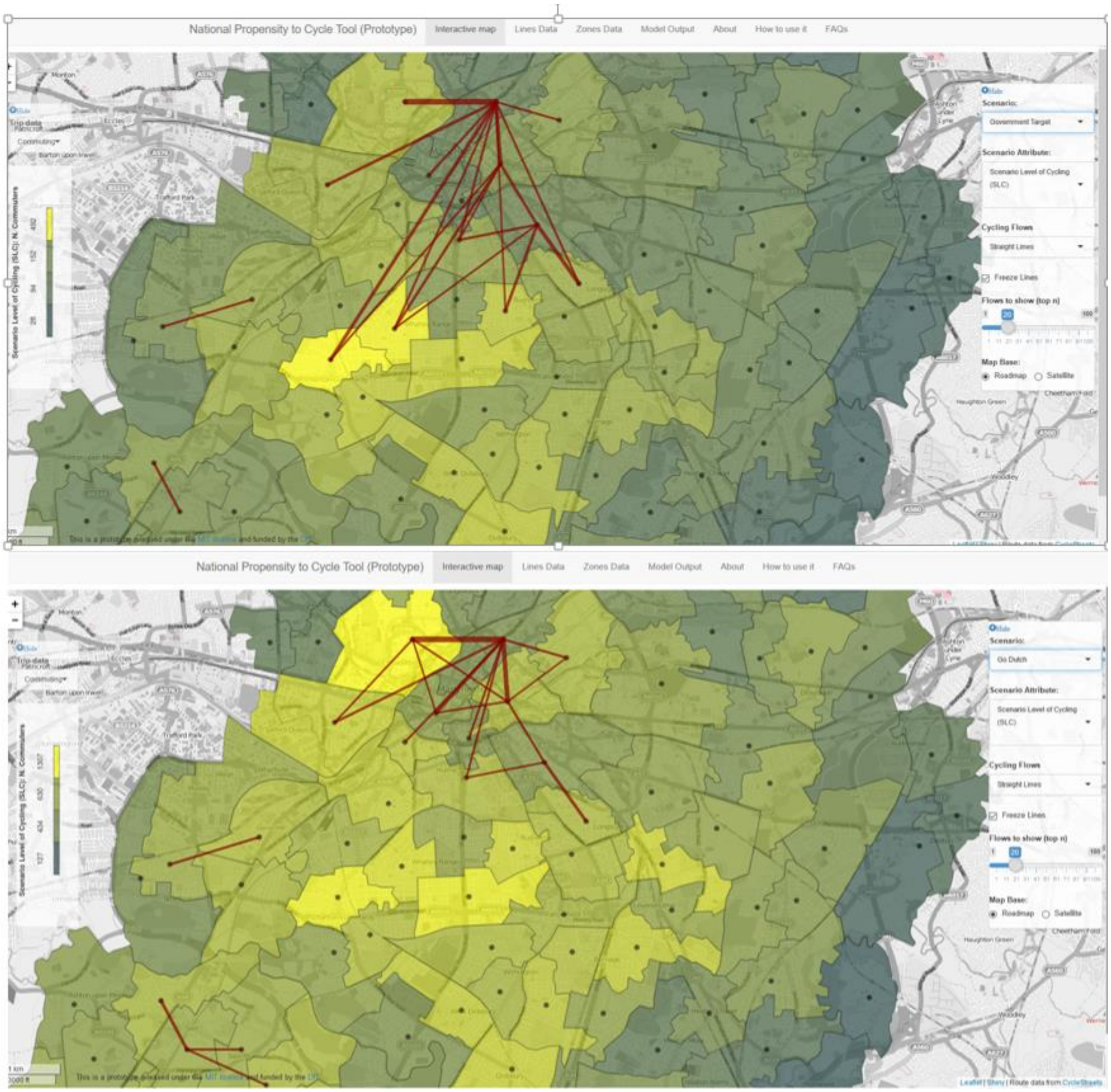

Figure 8 Model output illustrating the top 20 most cycled flows in Manchester under Cycling Delivery Plan and Go Dutch scenarios.

To illustrate the importance of the difference between the 'fastest' and 'quietest' routes calculated by CycleStreets.net for our model, Fig. 9 illustrates the route with the highest cycling potential under the *cdp* scenario. The 'quietest' route is substantially further, with a distance of 2.8 km (as shown by clicking on the line). The 'fastest' route is more direct (with a route distance of 2.3 km) but it passes along Trinity Way (the A6042), a busy dual carriage way. Dutch evidence suggests that cyclists will not divert to a route which is more than about 1.4 to 1.5 times the length of the 'crow-flies' Euclidean distance (defined as q above), and that the target "for cycle provision should be 1.2".[xiv] This suggests that high quality cycle infrastructure along

[xiv]Reference: 'Design manual for bicycle traffic', CROW, 2007.

the Trinity Way route would be much better used by commuters than an alternative quiet route that diverges greatly from the shortest path. The decline in cycling propensity with distance supports this approach. The faster decline for women and older people combined with their greater preference for protected infrastructure indicates the importance of providing direct and safe routes to encourage cycling amongst groups who currently cycle the least.

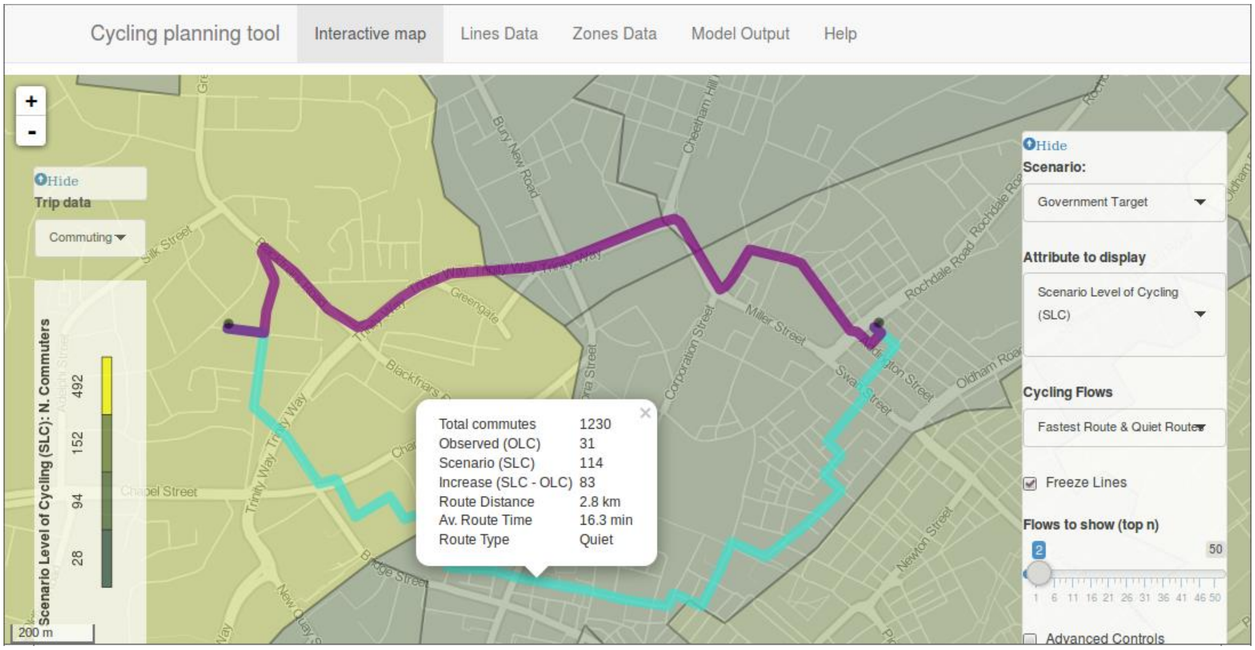

Figure 9 Close-up of the 'fastest' and 'quietest' routes from CycleStreets.net of the flow with highest cycling potential under the cdp scenario in Manchester.

Discussion

The flexibility of the approach outlined in this paper ensures that it can be used in many different contexts. Because the underlying methods and computer code are transparent and open source, it is possible to use the NPCT as a foundation for further work. This flexibility has been demonstrated by the tool's ability to be deployed in any Local Authority (or other administrative area) in England for a range of cycling scenarios, with wide-ranging results that can be presented in many ways. The results demonstrate the utility of the tool for the cost-effective allocation of investment and local targeting of policies within a single country or region. Potential applications go far beyond re-running the model for different cities in the same country. Potential extensions of the model include:

- Deployment of the tool and underlying flow model in different countries. This would depend on having appropriate flow data. As indicated above, the datasets required for the NPCT are increasingly available, from a range of sources.
- Inter-regional and international comparisons of model results. This could help answer long-standing questions such as: "do areas with the highest cycling potential receive the

greatest amount of cycling investment?" and "is there a strong link between a country's propensity to cycle and actual rates of cycling?"

- The extension of the model to cover variation by demographic groups and breakdown by currently dominant mode to enable more targeted cycling policies.
- The addition of additional purposes of trips in the model. An 'education layer' would be our recommendation to prioritise in this area, based on the location of schools, and data on travel to school patterns from the Department of Education. (Note we would need to formally request data for this.) This could inform the construction of off-road 'cycle to school' networks.
- The extension of the tool to enable the estimation of cycling demand following new developments, such as high-density housing or a new school.

Because the model is open source, others are free to take the tool and modify it for their own needs. We will actively encourage practitioners to modify the scenarios, input data and display of the results to suit local contexts. This could help to visualise city-level targets for the proportion cycling by a certain year, for example, which will vary considerably from place to place. It is hoped that an active user community will build up around the tool. This could enable transport planners to decide on and create the precise set of online tools that are that are most useful for their work.

It is likely that future work will focus on enabling practitioners to add new features that have not been considered in this paper. After all, the people who best understand the requirements of transport planners (and other users of the tool), are the 'end users' themselves. By reducing the barriers to entry into the creation and visualisation of evidence-based scenarios about change in travel behaviour, the NPCT methodology can empower transport decision-makers across England and beyond to supplement their own understandings of where need for new infrastructure is greatest. By indicating where investment could be most cost-effective, the NPCT methodology and interactive planning tool will also help to build business cases for further investment and policy change. Careful allocation of resources is critical for creating highly cost-effective interventions. Such targeted interventions are critical to ensure a long-term transition away from the private car and towards a more sustainable and healthy transport system.

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References

Coombes, M., and Bond, S. (2008). *Travel-to-Work Areas: the 2007 review*. Office for National Statistics, UK. Available from: http://scholar.google.com/scholar?hl=en\&btnG=Search\&q=intitle:Travel-to-Work+Areas:+the+2007+review\#0

DfT. (2014). *Cycling Delivery Plan: Draft (October)*. Department for Transport. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/364791/141015_Cycling_Delivery_Plan.pdf

Gaffron, P. (2003). The implementation of walking and cycling policies in British local authorities. *Transport Policy,* 10 (3), pp.235–44. Available from: http://www.sciencedirect.com/science/article/pii/S0967070X03000246?np=y

Rae, A. (2009). From spatial interaction data to spatial interaction information? Geovisualisation and spatial structures of migration from the 2001 UK census. *Computers, Environment and Urban Systems,* 33 (3). pp.161–78. Available from: https://mediamapping.wikischolars.columbia.edu/file/view/Rae+-+2009+-+From+spatial+interaction+data+to+spatial+interacti.pdf

Sloman, L., Taylor, I., Wilson, A., King, N., Goodwin, P., Anable, J., Davison, S., Crawford, M., Cope, A., and Adcock, S. (2014). *Finding the optimum: revenue/capital investment balance for sustainable travel*. Department for Transport. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/416797/finding-the-balance-sustainable-travel.pdf

Smoreda, Z., Olteanu-Raimond, A-M., and Couronné, T. (2013). Spatiotemporal data from mobile phones for personal mobility assessment. *Transport Survey Methods: Best Practice for Decision Making*. Emerald Group Publishing, London.

Tight, M., Timms, P., Banister, D., Bowmaker, J., Copas, J., Day, A., Drinkwater, D., et al. (2011). Visions for a walking and cycling focussed urban transport system. *Journal of Transport Geography,* 19 (6), pp. 1580–89. Available from: http://www.sciencedirect.com/science/article/pii/S0966692311001268

Transport for NSW. (2014). *Household Travel Survey Report: Sydney 2012/13 (November)*. Available from: http://www.bts.nsw.gov.au/ArticleDocuments/79/r2014-11-hts-summary-report_12-13.pdf.aspx.

Appendix 4 Cycle route infrastructure and cycling uptake: a review

Key Points

- Studies show people tend to express a strong preference for cycling environments with complete or substantial separation from motor traffic.
- The evidence base related to behaviour change is weaker but is growing and suggests that high quality infrastructure can increase cycling uptake.
- The evidence suggests that in building new infrastructure, it is important to follow desire lines and improve the quality of the surrounding cycle network.
- Evaluation and monitoring should be improved, with more rigorous use of routine monitoring alongside high quality studies of specific cases.
- Access to data and evidence should be improved, with evaluation and monitoring results made publically accessible online.

Executive summary

This report provides evidence about the infrastructural interventions that should be prioritised on key desire lines, such as routes identified through the National Propensity to Cycle Tool. It firstly sets out a typology of interventions using categories drawn from recent work on infrastructural preferences. Secondly, using this structure, it summarises evidence on stated preferences and on behaviour change. The evidence base has gaps and limitations, but, this review concludes, a hierarchy of preferences is clear and increasingly evidence on actual behaviour change is emerging.

There is good evidence that what people say would most encourage them to cycle is being able to ride completely away from motor traffic (i.e. ‘Greenway’ routes, such as the Bristol to Bath cycle path where almost the whole route is completely away from motor traffic, with grade separated junctions inherited from the railway). Other strongly preferred routes include those with substantial physical separation along roads (e.g. with hedge or kerb separation), and on very quiet streets with little or no motor traffic.

The evidence base related to behaviour change is weaker. This is partly because cycling interventions in many countries have traditionally not been rigorously evaluated. Often the only data available are count data, which unless done at an area level cannot separate new from diverted uptake; and the monitoring data are not made routinely available. In addition, cycling interventions in low-cycling contexts have often in the past been limited. Rather than building the most preferred infrastructural types identified here, often the focus has been on smaller-scale changes such as signage or Advanced Stop Line (“bike boxes”). Such interventions are – according to the preference evidence – much less likely to show substantial changes in uptake.

However, evaluation methods and interventions are both changing, and the evidence base is beginning to improve. This is the case for example in the United States, where cities have

invested in higher-quality ‘protected’ or ‘green’ cycle lanes, with associated studies of their impacts. Similarly in England, higher quality interventions are being planned and implemented, with more substantial evaluation, for example in London related to Superhighways, mini-Hollands and other borough schemes. Evidence is starting to emerge that high-quality routes along key desire lines can demonstrably increase cycling uptake.

Therefore, our recommendations support building routes that correspond to stated preferences, particularly given evidence from the Rapid Evidence Assessment (REA) on differences by age and gender, suggesting under-represented groups have particularly strong preferences for separation from motor traffic. Evaluation of such interventions needs to be more robustly conducted, using for example longitudinal methods to track changes in behaviour over time. We also need to move towards a situation where all evaluation and monitoring results (for example, those conducted as part of Sustrans interventions, or by local authorities) are routinely made publically available in a form that is easy to access and to use in reviews and in planning. This should include both summaries of findings and the data on which conclusions are based.

The evidence highlights the need to prioritise routes that meet demand, to improve wider networks and ensure there are good connections to new pieces of infrastructure. Some impressive results have been achieved from infrastructure-focused interventions and programmes; including in England as part of the Cycling Demonstration Town programme. However, the evidence suggests that building small amounts of infrastructure in isolation, where a wider cycle network remains poor and cycling levels are low, may have relatively little effect.

Contents

1.0 Introduction

1.1 Aims

This document reviews and discusses evidence around cycling infrastructure and cycling uptake from a range of countries. It includes both 'stated' and 'revealed' preference evidence, i.e. both what people say they would do and what people who cycle actually do. It forms part of the report for Stage 1 of the National Propensity to Cycle Tool project (NPCT). The NPCT seeks to identify areas and routes that have high potential for cycling growth under different uptake scenarios. This document complements that work by making recommendations for the types of infrastructural improvements that should be prioritised when planning such routes. The evidence base is still relatively weak for a range of reasons, so the document makes suggestions for improving this.

1.2 About the evidence

This review has been conducted rapidly and iteratively, using academic and web databases and searching for articles cited within a first round of papers accessed. It includes English-language academic and policy material, available online or described within previous reviews. Evidence related to cycle route infrastructure considered broadly is included; this covers both small-scale interventions such as 'traffic calming' and town-level interventions, for example. Evidence needed to have some discussion of impact on uptake, whether related to stated preferences (where people say they would take up cycling) or measured changes in uptake. Non-route infrastructure, such as cycle parking or bicycle hire systems, were not included; nor were promotional interventions.

'Stated preference' evidence tells us about what people say they would like, but may not be an accurate predictor of what they would actually do. To some extent, this is an inherent limitation of the broader policy context making it challenging to conduct studies evaluating the impact of interventions. Many such studies have been conducted within the United States, which has relatively little high quality cycling infrastructure compared with some Northern European countries, and generally has very low levels of cycling. Hence (until recently) US studies measuring changes in uptake have often studied small-scale interventions which are likely to make relatively little difference to cycling, given the broader lack of a high-quality local cycling network.

Rather than examining the impact of a specific intervention, many 'revealed preference' studies examine the routes taken by cyclists and draw conclusions as to the value of specific types of infrastructure found in the local context. Relatedly, studies have modelled the impact of factors on mode share, including within this measures of cycling infrastructure. One problem with these studies is that local street networks are relatively homogenous in terms of the features that people say are important for cycling. For example, in most US, UK and Australian cities, there is little high-quality segregated infrastructure along main roads, so one cannot easily examine its impact on route choice or mode share. By contrast, such cities may have relatively large amounts of signed routes where cyclists share with motor traffic, but the stated preference evidence suggests these are likely to have a relatively low impact on uptake.

The second problem with 'revealed preference' studies affects low-cycling countries in particular: in contexts where only a small minority cycle, it is questionable to what extent their preferences reflect those of the broader population of potential cyclists. This is likely given that 'cycling experience' tends to affect stated preferences, and has arguably weakened the findings of the REA in relation to age. This is because while older people are likely to be less risk tolerant than younger people, those older people who cycle in low-cycling contexts might be *more* risk tolerant than other (younger) cyclists, because on average they will have chosen to continue cycling for longer (selection bias).

Moreover, much 'revealed preference' evidence presented below on the impact of interventions comes from counts of cyclists. Like stated preference studies this can provide evidence for relative preferences for different infrastructure types (although comparing studies can be difficult, because of factors such as the broader route network and the quality of alternative routes, which are often not well reported). However, it can be problematic if taken to imply mode shift, because re-routing may make up a substantial part of any increase. As Pratt et al report (2012: 72):

> 'Most before-and-after evaluation studies [of bicycle lane introduction] report increased bicycle volumes on streets […] In those that also examine off-facility data, however, it becomes apparent that a portion of the demand attracted to bicycle lanes is simply shifted from presumably less desirable routes.'

Within the UK context, there is a further problem related to data availability. While much monitoring and evaluation of routes is carried out, by Sustrans and/or local authorities, the findings and associated datasets are not generally freely available. It would be useful if a central repository existed where organisations and researchers could access case studies and monitoring data.

There are a number of difficulties inherent in evaluating the impact of interventions on cycling rates, and therefore judging which interventions are most likely to increase cycling levels. The evidence presented in the chapters below is context specific and it can be difficult to compare evidence from different settings. The quality of the intervention clearly matters, but so also does its utility in connecting key origins and destinations for potential cyclists. For example, Greenway interventions may be high quality (although not always) in terms of route preferences, but do not necessarily function well as part of a utility cycling network due to their location.

A number of factors beyond the intervention alone will influence take-up (Aldred and Jungnickel 2014). Other cycling infrastructure (or the lack of it), local land-use patterns, cultural and sub-cultural attitudes to cycling, and many other factors may affect take-up (and may be changing while an intervention is introduced). On any given actual or potential cycle trip people would not just use one piece of infrastructure but an entire route, in a broader context within which individuals are affected by signals sent out by policy-makers, media, employers, colleagues, friends and family. Moreover infrastructure as actually implemented and evaluated does not necessarily fit neatly into categorisation systems reflecting what people value in cycling environments (see for example the ambiguous definition of 'bicycle boulevards').

The evidence suggests the existence of a broader high-quality cycle network is important, which may be due both to its specific impact on journeys and its broader cultural impact (by demonstrating that cycling is an important, mainstream transport mode). Where this is poor, network improvements (aligned with evidence presented here) should go alongside specific high profile interventions. In studying effects, we should expect lags (Fuller et al., 2013). Recent work on Sustrans' Connect2 interventions showed that the benefits only start to appear after two years and were not discernible after one year. However, many evaluations only look at short-term effects. Interactional effects and the effect of timing interventions are not well understood but may have a substantial impact on the outcome of investments.

Randomised controlled trials (RCTs) are seen as the gold standard for research study design, helping to overcome some of these difficulties. Often RCTs are not practical, but opportunities where they could be implemented should be sought out. Many 'behaviour change' interventions can be introduced in a randomly staged manner. For example, cycle training could be provided on a randomly staged basis, allowing comparison between individuals who have requested training but not yet received it, and those who have requested training and have already been given it. The unit of randomisation does not have to be the individual person, e.g. where workplace support packages are being provided along a cycle route corridor, some workplaces could be given the support ahead of others, again randomly selected. The key point is that here the randomisation allows us to pinpoint the specific intervention effect. Traditionally the higher-quality evaluations of 'behaviour change' interventions will compare 'before' to 'after', but this does not tell us whether workplaces would have seen a similar increase in cycling (for example) had an intervention not been introduced.

For infrastructural interventions the unit of randomisation would have to be the intervention, not the person, as we cannot randomly allocate people to live or travel along a new cycle route. Randomly staging the introduction of new cycle infrastructure is challenging: it would be difficult to have a sufficient number of sites and to randomly delay the introduction of some infrastructure. However, a good alternative is to view infrastructural interventions as 'natural experiments', providing some of the benefits of the RCT approach. We can for example create longitudinal studies following people over time, as interventions are introduced, providing much better quality data than cross-sectional studies (which may be affected by the changing composition of an area: two years after an intervention may for example coincide with a substantial amount of gentrification) or retrospective studies (asking people to recall behaviour in the past; prone to bias).

There is a strong case for building high quality evaluation into intervention planning, particularly where interventions are potentially transformative and so there is a lack of existing evidence. Increasingly, better quality evidence is becoming available (see, for example, Goodman et al., 2013). In the meantime, much evidence reviewed here is likely to suffer from bias in one or more directions; some more so than others. It is useful to have a sense of the strengths and weaknesses of different methods, and to triangulate by seeking evidence gathered through different methods.

Creating a transformation in cycling requires doing things very differently in a range of ways (from infrastructural planning to the way we think about and represent road users) and many of our modelling tools are poorly equipped to deal with this. However, this is not a recipe for despair, but implies the need to evaluate and learn from interventions as best we can, be willing to accept provisional estimates, and continually update models and guidance.

1.3 Report navigation

The content of this report is divided into two chapters:

- Chapter 2 discusses evidence on the impact of area-level infrastructural interventions, including academic and policy evidence from the UK, US and other European contexts.
- Chapter 3 discusses evidence on specific infrastructural interventions, from a range of contexts. This chapter includes both evidence about stated preferences for specific intervention types, and evidence about their impact. It is organised to reflect the key route characteristics identified as important for cycling preferences.

Chapters 2 and 3 are followed by a summary and a bibliography.

2.0 Area-level infrastructure: findings from research

Countries with the highest levels of cycling have higher quality cycle infrastructure, developed over time to meet the needs of cyclists. Hull and O'Holleran (2014) conducted a benchmarking study for two British and four Dutch cities (where cycling rates were significantly higher). Compared to the Dutch averages for infrastructure quality, they found that the quality of cycling infrastructure was substantially lower in Cambridge (which has the highest levels of cycling in the UK); and lower still in Edinburgh. Within one low-cycling city, Melbourne, Pistoll and Goodman (2014) found cycle infrastructure positively correlated with cycling prevalence, while US studies have found similar results (Pratt et al., 2012). Fraser and Lock (2010: 738) comment that:

> ‘The environmental factors identified as being positively associated with cycling included presence of dedicated cycle routes or paths, separation of cycling from other traffic, high population density, short trip distance, proximity of a cycle path or green space and for children projects promoting ‘safe routes to school’. Negative environmental factors were perceived and objective traffic danger, long trip distance, steep inclines and distance from cycle paths.’

City-level studies have suggested that places that invest in cycling, and support it politically, are able to increase it (Pucher et al., 2010; TfL, 2014). The section below presents some evidence of the impacts of area-based infrastructure before drawing on examples from elsewhere in Europe and from the United States.

2.1 Evidence from the UK

The main evidence for town-level programmes in the UK comes from two evaluations of England’s Cycling City and Towns (initially Cycling Demonstration Towns) programme. In 2005, six English towns were chosen to be Cycling Demonstration Towns and funded to encourage the use of cycling as a means of transport. In 2009 a further 12 towns and cities were awarded money as ‘Cycling Towns’. Towns and cities took different approaches but the majority of money awarded to each was spent on physical infrastructure of various types (Cycling England, undated) though the programme involved a range of disparate interventions, incorporating both infrastructural and promotional elements (roughly equating to £10 per head over a three year period).

Sloman et al (2009; cited in Yang et al) studied the impacts of Cycling Demonstration Towns (2005-2009) and found a relative increase of 27% from cycle counters over four years. The prevalence of cycling for half an hour or more, once a month or more increased by 2.78% (+1.89% if adjusted to the most similar control area). The prevalence of cycling for half an hour or more, 12 times a month or more increased by +0.97% (+1.65% if adjusted to the most similar control area). While relative increases in the report are often high, the absolute figures are often still very low.

Unfortunately, data collected specifically to evaluate the Cycling City and Towns (CCT) programme is unusable[i]; however, Goodman et al (2013, cited in Scheepers et al., 2014) evaluated the programme using Census data. Overall results showed commuter cycling increasing significantly above three possible sets of comparators in the Cycling City and Towns. Goodman et al. (2013: 232) write:

> 'Compared with the matched comparison group, this represented an absolute intervention effect of 0.69 percentage points' (and more compared to national or unfunded comparators).

However, Goodman et.al (2014: 234) also say that:

> 'Although some towns experienced large percentage-point increases or decreases, the average town-level effects were non-significant [because] the significantly positive population-level effects were partly driven by large increases in a few large towns, particularly Bristol and Brighton and Hove.'

This suggests that learning from the Cycling Cities and Towns programme will require consideration of why some towns were relatively successful and others not; likely related both to the programmes implemented there and broader contextual factors.

2.2 Evidence from other European Countries

The three examples below all display positive uptake of cycling following improved cycling infrastructure (sometimes combined with other interventions) in European cities. They include examples which have increased cycling levels from an already very high level, and one (Seville) where cycling had impressive relative growth from a very low base. Experts are undecided as to which is more difficult: however, it is clear that both are possible.

Example 1:
One of the most impressive recent examples is Seville, Spain, where cycling was historically very low. Seville in 2005 committed to the construction of a network of bicycle lanes that by 2010 was over 120 km long, with cycle hire being implemented at the same time. By 2012 there were 72,000 daily journeys being made by bicycle, equivalent to 9% of all mechanized journeys, up from under 2% just five years ago (Castillo-Manzano et al., 2015; Castillo-Manzano and Sanchez-Braza, 2013).
Example 2:
Wilmink and Hartman (1987; cited in Yang et al's 2010 systematic review of interventions to increase cycling) studied improvements to the Delft bicycle network in the Netherlands. Unlike many other examples this is a controlled before-and-after study, and only involves infrastructural provision (not for example including training). They found an increase of 3% in bicycle mode share for trips within the city boundaries (40% rising to 43%) and concluded

[i] The Department for Transport has removed data and reports from its website on the advice of AECOM, the contractor responsible for collecting the baseline data for the CCT evaluation. For further details, see: https://www.gov.uk/government/publications/evaluation-of-the-cycling-city-and-towns-programme

that the bicycle network plan alone had resulted in an increase of 6-8% of total distance travelled by bicycle, depending on the trip purpose. Delft already had very high mode share and reasonably good infrastructure provision in the European context; making the absolute rise of 3% impressive.
Example 3:
The example of Odense is also cited in the review by Yang et al. (2010). They report that: 'The three year Danish National Cycle City project aimed to increase cycling in Odense between 1999 and 2002 through a multifaceted approach that included promotional campaigns and infrastructural measures. A controlled repeat cross sectional study comparing national travel survey data collected in Odense and in nearby towns and cities between 1996-97 and 2002 found an increase in the proportion of all trips made by bicycle in Odense from 22.5% to 24.6% (equating to an estimated net increase of 3.4 percentage points after adjustment for regional trends) and a net increase in the distance cycled of 100 metres per person per day'. Odense already had high levels of cycling, so this, like the Delft results, is impressive.

2.3 Evidence from the USA

Barnes et al. (2006) used US Census data to examine whether any changes in cycle mode share in the Minneapolis-St. Paul, area were related to infrastructure provision (seven new facilities, some on-road, and some off-road). Using a buffer analysis method, they found that cycling in areas close to the new facilities showed cycle commute mode share increased from 1.7% to 2.0% between 1990 and 2000, while the remainder of the region remained constant at 0.2%. All individual facilities showed statistically significant increases in bicycle mode share.

However, infrastructure that is disconnected from a network and/or where publicity is limited may not be associated with higher cycling. Douma and Cleaveland (2008) repeated Barnes et al’s analysis for six other US cities and conclude that the findings are not universally applicable: the pattern was only observed for some of their case studies. They compare the political and policy contexts in the different cities and argue that facilities have only led to a discernible increase in cycle commute mode share where (i) facilities are located along usable commuting routes, (ii) there are good levels of overall network connectivity, and (iii) there is accompanying publicity and promotion. This is a lesson for low-cycling cities seeking to increase cycling: key routes need to be identified while retaining a focus on the quality of the broader network for cycling.

Pucher et al. (2011) have used Census data to explore changes in cycle commuting rates in nine large North American cities, 1990–2009, which had all put in place a variety of infrastructure, programs, although the specific mixes differ. All the cities have seen increases in cycle commuting. Pucher et al. (2011: 464) comment:

> ‘Without exception, the focus of cycling policy in all nine of our North American case study cities has been the expansion and improvement of bikeway facilities, including on-street bike lanes, on-street bike paths (cycle tracks), and off-street bike paths.’

They cite Portland as an exemplar of what can be achieved in a North American context.

Camp (2013) used Census data to explore changes in the gender balance of commuting in US cities, comparing this to changes in the amount of cycle infrastructure. She found that the relationship between change in ridership and change in cycle infrastructure was positive and statistically significant for women, but no evidence of a similar relationship for men. This is supported by TfL (2012) research which found women responding more strongly than men to all proposed interventions, but most strikingly to the most preferred, an off-road cycle track.

2.4 Urban versus rural contexts

There is relatively little quantitative evidence specifically on the demand for rural cycling infrastructure (Laird et al., 2013). However, given the nature of cycling mobility and cycle routes, many journeys may incorporate non-urban contexts, as may infrastructural interventions. For example, some Greenway routes (such as US rail trails) may be partly or predominantly rural; some town-level interventions include routes that connect the town with areas outside its boundaries. Therefore it should not be assumed that the evidence discussed here only relates to urban routes.

Rural roads can be disproportionally dangerous. Research in the UK found that roads in non-built-up areas accounted for only 9% of all cyclist casualties, but almost one half (45%) of all cyclist deaths (Gardner and Gray, 1998). The authors link this, in part, to lack of infrastructure provision in rural areas. This combined with high motor traffic speeds on rural A and B roads increases risks for people cycling, compared to urban areas where even if infrastructure is also lacking, speeds will often be lower. The All Party Parliamentary Cycling Group's 2013 report 'Get Britain Cycling' similarly recognises the danger of cycling outside urban areas.

Hence there is reason to believe that preferences for rural riding may in principle be similar to those for riding in urban areas: in particular, related to protection or separation from fast moving or heavy motor traffic. Some examples of infrastructural interventions in a rural context are given in a report produced by the Transport 2000 Trust (2003; now the Campaign for Better Transport). The City of Copenhagen, mentioned in the report, is currently collaborating with authorities outside the city boundaries in constructing and upgrading a range of Cycle Superhighways enabling speedy and segregated cycling between the city and municipalities generating high numbers of commuting trips.

The Dutch Fietsberaad organisation (2008) has carried out work on specific infrastructural solutions for rural roads, from a starting point that takes a holistic approach and considers the broader function of roads and the extent to which they need to carry large volumes of through motor traffic. In some contexts, Fietsberaad (2008) suggest, planners might want to downgrade the function of a road for motor traffic, to the level at which provision for cycling with lower levels of separation becomes possible. In other contexts, the need to continue supporting high volumes and/or speeds of motor traffic might imply provision of high-quality separated paths away from the road.

3.0 Specific Infrastructure

3.1 Introduction

In the previous chapter examples of the impact of town- or city-wide infrastructural developments were noted. This chapter focuses more specifically on types of infrastructure that could be implemented, and their potential impacts on cycling rates.

Evidence from where cyclists currently ride suggests that even those riding in relatively low-cycling contexts, who might be assumed to be relatively risk-tolerant, are willing to divert to use higher-quality infrastructure. Broach et al's (2012) Portland findings in fact indicate a preference hierarchy (given adequate directness) for all utility trips. This hierarchy suggests off-road paths are the most preferred facility type, followed by bicycle boulevards (traffic-calmed residential streets with cycle signage and low levels of motor traffic), then bicycle lanes (which in Portland run generally along arterial roads)[ii] or quiet residential streets, with all those routes preferred to riding on moderately or very busy streets with no facilities.

Similarly, the strong consensus from the stated preference evidence is the preference for higher levels of separation from motor traffic. The Rapid Evidence Assessment on age and gender differences in preferences highlights that (a) research generally finds this preference to be shared across demographic groups, with the possible exception of sub-groups of more committed cyclists in some low-cycling contexts and (b) that the preference is relatively stronger among women and, probably, older people.

Some of the most detailed stated preference research has been carried out for Transport for London (2010, 2012). This is particularly relevant in a UK context as the examples given to participants are more likely to be found here than elsewhere (for example, the concept of bus lanes as cycle infrastructure is relatively unusual). The TfL evidence (including both cyclists and non-cyclists) shows a strong preference for cycling with higher levels of separation from motor traffic, for example, on routes entirely away from roads, segregated tracks, or streets without motor traffic[iii]. It indicates further that changes to motor traffic speeds are of relatively minor importance compared to cycle infrastructure and motor traffic volume. The report states (2010, Report 2, page 46) that in the preference exercise given to participants (cyclists and non-cyclists):

> 'Speed limits on the road of 20mph to 40mph were presented, but this was not a significant influence on choices. On the other hand, the volume of traffic was significant and its influence was equivalent to 40% of a segregated cycle lane.'

Hence, this chapter begins by discussing the evidence related to routes away from motor traffic. This is separated into Greenway routes, completely away from motor traffic (3.2) and on-road but segregated routes (3.3). The chapter continues to consider evidence related to motor traffic reduction and traffic calming (3.4), followed by non-segregated on-road provision (3.5), often implemented in low-cycling countries but found in the stated preference evidence to be relatively undesirable, compared to the solutions discussed in

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[ii] Bicycle tracks alongside main roads were not considered separately.

[iii] This is presumably interpreted by participants as meaning streets with so little motor traffic – e.g. access-only streets, such as cul de sacs – that they would be unlikely to meet one while using the street.

3.2, 3.3 and (probably) 3.4. The final section (3.6) discusses junction improvements, an under-researched area but one which TfL (2010, 2012) and other research has found very important in terms of route barriers to cycling.

3.2 Greenway routes: completely away from motor traffic

Cycling routes without motor traffic are strongly preferred by cyclists in stated preference surveys. This has implications for using the NPCT to highlight potential investment locations as indicated by strong desire lines. If such 'straight line' routes would run through a park, for example, the introduction of a new cycle route through the park could be important in catering for cycling uptake.

TfL's (2010) Cycling Behaviour Survey found that people rated a Greenway-type off-road route as being much safer than cycling on-road with no cycle provision, and also found a substantial stated preference for streets without motor traffic even over streets with 'low traffic'. The survey shows people rated a Greenway-type off-road route as being much safer than cycling on-road with no cycle provision. Segregated lanes next to a road were rated slightly less safe than the Greenway-type route.

The three examples below show that this stated preference is sometimes, but not always, borne out in terms of cycling activity when Greenway or traffic-free routes are provided. The examples also highlight – as, often, do study authors – the limited likely impact of providing a short motor-traffic free facility where the surrounding network is very poor, or providing a route that does access key destinations. By contrast, the material on bridges indicates the potential for high uptake where (a) the surrounding cycle network is more acceptable, potentially through making associated improvements and (b) the route connects important desire lines (as is likely to be the case with urban bridges across a river that divides the city):

Example 1:
Heinen et al's (2015) longitudinal study of the impact of a cycling and walking path alongside the new Cambridge Guided Busway showed that the new infrastructure led to an increase in the share of commuting trips involving active travel and a decrease in the share made entirely by car. Their analysis found that proximity to the busway predicted an increased likelihood of a large increase in the share of commute trips involving any active travel and a large decrease in the share of trips made entirely by car. This is within a context in which cycling is already high, so that many who would be considered 'near market' cyclists in other contexts would be likely to already be cycling.
Example 2:
Burbidge (2008; cited in Scheepers et al's review, 2014) studied changes in trip patterns by residents in West Valley City, Utah before and after construction of one mile of Greenway. She found an increase in car use and no change in cycling, from its already low level (typical of a suburban area in the U.S.) This study involved a small amount of infrastructure, in a relatively poor-quality walking and cycling environment with very high levels of car use.

Example 3:
Jones (2012; cited in Scheepers et al., 2014) provides evidence related to Stafford's new Isabel Trail. Constructed in 2005 this is a 2.5 miles long motor traffic-free cycle and walking route linking suburban areas north east of Stafford with the town centre. Jones used a questionnaire study to compare people living near the route with those living further away and found little evidence of mode shift. This is against a background of very low levels of cycle commuting (1.7% in 2001; 1.6% in 2011).
Example 4:
Goodman et al. (2014) found that two years after new off-road cycling and walking routes were developed, people living nearby increased their total levels of physical activity, compared to those living further away. For people living 1km away from the new routes this meant an average of 45 minutes more active travel per week, compared to those living 4km (2.5 miles) away. This was largely due to recreational walking, however, and the lead study author has suggested that getting mode shift towards transport cycling and walking may need the support of joined-up high quality route networks. It should be noted that this change was not apparent at one year follow-up, and hence, studies which only use one-year follow-up (and some studies use less) may miss lagged effects.

Pratt et al. (2012) report that bridge crossing facilities seem particularly important. The studies that they cover where bridges are motor traffic-free show substantially increased usage, though generally resultant mode shift cannot be estimated. For example, Pratt et al. (2012) cite the Millennium Bridge in York (built in 2001): cycle trips on routes each side of the bridge increased from 220,000 to 290,000 annually, concentrated among utility trips. Further examples of bridge infrastructure constructed for non-motorised users include:

- The Greenway Bridge in Eugene, Oregon, opened in 1978: a survey after construction suggested that 14-18% of weekday users and 28% of Saturday users would not have made their trip by bicycle without the bridge, estimated to equate to a reduction of over 500 car trips per week by bridge users (Pratt et al., 2012).

- McCartney et al. (2012) found a 61.6% increase in cyclists crossing the Glasgow cordon from the South, with a new pedestrian/cycle bridge accounting for almost all of the increase. The 61.6% increase is from a very low base.

The relative popularity of off-road sections of the UK National Cycle Network can be taken to indicate a preference for these types of route. Specific examples based on Sustrans before and after monitoring (DfT, 2014) have indicated increased uptake from interventions including the creation of motor traffic-free routes and link sections; for example the Links to Schools programme. However, for the most part these findings are not reported in a way that would enable their incorporation in reviews such as this (for example, the examples given in DfT 2014 provide little detail on the interventions involved and do not provide contextual information that would enable comparison with broader local changes in cycle usages) and nor is the associated data publically available.

3.3 On-road cycle routes segregated from motor traffic

Where cyclists and non-cyclists have been asked about preferences, studies show people say they would prefer and feel safer on routes involving separate infrastructure on busier roads (e.g. Caulfield et al., 2012; Björklund and Isacsson, 2013; TfL, 2012; Wang et al., 2012; Winters et al., 2012; Winters and Teschke, 2010). A study in Ireland found that tourists said they were willing to increase their cycling time by approximately 100% in order to cycle on a route fully segregated from traffic, rather than along a road without cycling infrastructure (Deenihan and Caulfield, 2015). Respondents in TfL's Cycling Behaviour Survey said they were willing to spend almost double (88% longer) travelling along a route with a segregated cycle lane, compared to a route with no cycle provision.

Growing numbers of studies show cycling rates having increased following provision of segregated cycle lanes or tracks on major roads. In a revealed preference study based in Austin, Texas, Melson et al. (2014) found existing cyclists were significantly affected by both bridge accessibility and by the availability of separated infrastructure on the bridge.

Monsere et al. (2014) have recently written a key report studying the installation of 'protected' cycle routes in five US cities. In some cases, these tracks replaced painted lanes; in other cases, there were no previous facilities at all. Pre- and post-intervention counts showed an average increase of 75% in ridership. While there was substantial variation, the lower percentage gains often represented large absolute increases on already well-used routes. An intercept survey of riders found that 11% of trips were newly generated (ranging from 6% to 23% at individual locations): 10% would have made the trip by another mode and 1% would not have made the trip at all. The rest would have cycled on a different route (24%) or the same route (65%). Over a quarter (26%) of respondents to a resident survey said they were cycling more than two years ago, against 11% who said they were cycling less (63% reported no change).

It is interesting to speculate why the evidence for on-road segregated cycle routes seems stronger than that for Greenway routes, given the latter are usually rated as somewhat or slightly preferable (although both types of route are strongly preferred). Reasons for this apparent divergence are likely to be contextual: broader networks, route suitability for utility trips, and political/cultural factors. For example, the US Greenway evaluated in Burbidge's (2008) study (a) was not part of a wider, high quality cycle network, (b) being only one mile long was unlikely to newly link key utility origins and destinations, and (c) was implemented in the context of high car dependency and extremely low cycle mode share. Moreover, as Greenway routes are often built with leisure trips in mind, although they may effectively separate cyclists from motor traffic, their design, surfacing, maintenance, and lighting may mean they are not suitable for year-round utility travel.

Greenways can also often be built with relatively little impact on other modes. Because of this, they are generally not associated with predicted delays to drivers. Predicted delays associated with the re-allocation of road space tend to lead to large 'costs' when summed over a high number of journeys, even if individual delays are small. Lacking this, Greenway schemes often have very high cost-benefit appraisal ratios, even with relatively little change in cycling ptake. Hence, they can be a relatively easy intervention in political terms. By contrast, implementing high-quality on-road segregated routes has often required substantial political support for cycling, particularly where motor traffic lanes are being removed (as in London's Phase 2 Cycle Superhighways). Thus it is likely that new segregated routes are being built only where contextual conditions are relatively favourable. Moreover, on-road segregated routes tend to be created alongside existing main roads, likely to be key desire lines for potentially cycled trips due to their direct linking of key origins and destinations.

Example 1:
Pratt et al. (2012) report on the trial (now permanent) of creating a segregated cycle track on Vancouver's Burrard Bridge (two mixed-use pavements were replaced by facilities segregating cyclists and pedestrians). Counts showed in the months following the change, cyclist numbers increased by 26% (count-based results) while a survey suggested a doubling of use by those living near the bridge. The net effect for interviewees was a 1% decline in reported incidence of cross-bridge walking in the last month (16% before, 15% after) versus a 9% increase in reports of cycling across (9% before, 18% after).
Example 2:
Pratt et al. (2012) report on a study by Jensen et al. (2007) which found installation of segregated cycle tracks was associated with an 18 to 20% increase in cycle/moped traffic, compared to 5 to 7% for the installation of (non-segregated) cycle lanes.
Example 3:
A study of Portland Bridges found substantial increases in cycling over four city bridges between 1992 and 2011 (from 3560 to 18,257 daily cycle trips in total). During this period, infrastructure was upgraded, with motor traffic free crossings provided at three of the four bridges (Birk et al., 2014), with bridge access routes also improved. Over the 18-year period the increases in cycling on the four bridges ranged from a doubling of trips to a 15-fold increase. Burnside, the bridge with the lowest rise (doubling) had only painted lanes introduced, while the other three bridges saw cycle journeys at least quadrupled. Proportionally, the number of crossings made using Burnside also fell from 26% in 1992 to 12% in 2011.
Example 4:
Goodno et al. (2013) studied changes in counts on 15th Street, Washington before and after the introduction of a segregated two-way cycle track. Two locations along the track showed a before-and-after increase from c. 30 and 60 bicycles per hour peak, to c. 120 and 180. The average city-wide peak hour bicycle changed from c. 65 to c. 90 over the same period. The study notes that some of this increase may be due to diversion.
Example 5:

Thakuriah et al. (2012, cited in Scheepers et al., 2014) reviewed five new pedestrian facilities (which cyclists are legally allowed to use) and three new cycle facilities in Chicago. While they reported low overall usage levels (counting 1487 users in total of all non-motorised modes over a 26 hour period), 30% of cyclists intercepted using these segregated routes had previously made the trip by single-occupancy motor vehicle.

3.4 Motor traffic reduction and traffic calming

Traffic calming

Stated preference surveys (e.g. Broach et al., 2012) have shown traffic calmed residential streets may be preferred to busier roads with painted lanes. TfL's Cycling Behaviour Survey found respondents placed relatively low importance on a lower speed limit (comparing 20mph, 30mph and 40mph) with motor traffic volumes seen as more important.

As with many other elements in this review, studies of traffic calming measures appear to show increased use of these routes, but the extent to which these increases have come from diversion as opposed to 'new' journeys is unclear. For example:

- Pratt et al. (2012) report on studies from the US and Denmark which showed increases in pedestrian and cycle counts after traffic calming, though some of these increases may be due to route diversion.
- Pucher et al. (2010) found that five out of the six studies on traffic calming that they reviewed showed that there were positive results on cycling levels, although 'none rigorously measured the effects on the amount of bicycling'.

Filtered permeability

Filtered permeability (also known as closing streets, or restricting car access) refers to the removal of through motor traffic from a street or area. While stated preference evidence suggests that filtered permeability could substantially increase uptake, there is a lack of revealed preference evidence, due to a lack of evaluations, even relatively non-rigorous ones.

As noted above, TfL's Cycling Behaviour Survey finds a substantial stated preference for streets without motor traffic over streets with 'low traffic'. Similarly, the Children and Cycling survey (Aldred, 2015) finds a street without through motor traffic is as attractive (or more so, depending on the user group) as segregated route types including kerb separation, separation by car parking, and entirely off-road (park) routes.

Most research however does not consider the impact of removing through motor traffic from minor roads. For example, Wardman et al's (2007) influential study only offers one 'minor road' option, that of 'minor roads with no cycle facilities'. This encourages them to define separation from motor traffic along the whole of a journey to work as 'ideal but unachievable'.

However, if we include filtered permeability as representing substantial separation from motor traffic (as per TfL, 2010 and Aldred, 2015), hence a highly desired route type, it is surely not that 'unachievable' to imagine a journey to work that is separated from motor traffic. This could include both filtered (or otherwise very quiet) residential streets and separated infrastructure along major roads. This is the often misunderstood 'Dutch model': while only a minority of roads have segregated tracks, most other roads carry very low levels of through motor traffic as part of a broader holistic approach to multi-modal network functioning.

'Bicycle Boulevards' (sometimes known as 'Neighborhood Greenways')

The term 'bicycle boulevards' is used to denote increased priority for cycling. More specifically, bicycle boulevards are defined in Dill et al. (2014) as residential streets that use traffic calming, diversion, signage, and intersection treatments to reduce the speed and volume of motor vehicles. There is, however, ambiguity in the literature about the extent to which through motor traffic is or should be reduced, discouraged, or removed (or not) in bicycle boulevards. Some bicycle boulevards involve the removal of through motor traffic (filtered permeability) while others do not and are more similar to general traffic calming measures. For example, Walker et al. (2009:72) write that:

> 'Traffic circulation patterns and historic collision histories are very site-specific, as are the design elements and level of treatment chosen for a particular bicycle boulevard. Due to the lack of consistency between sites, it can be difficult to generalise impacts from one design to the next.'

It can be difficult to know (without more detailed contextual information than is often given) what impact a bicycle boulevard (or indeed other traffic calming scheme) has had on motor traffic levels. This ambiguity creates a problem, given the importance of motor traffic levels in the stated preference evidence.

Two studies of bicycle boulevards covered in this review assessed their impact on new journeys:

Example 1:
Dill et al. (2014) studied the impact on physical activity and active transport of installation of new 'bicycle boulevards' in Portland. This longitudinal study could not confirm an increase in physical activity or active transportation among adults with children living near newly installed bicycle boulevards. Potentially, one reason for the lack of impact might be a lack of substantial reduction in motor traffic volumes, if as suggested above this is a key factor. All intervention streets already had low levels of motor traffic (up to 1000-2000 motor vehicles per day; Personal correspondence with Jennifer Dill, 2015). Some sites had other crossing treatments or diverters installed. All interventions included sharrows, signage, speed humps, and "flipped" stop signs removing priority from traffic joining or crossing the bicycle boulevard.
Example 2:
Ciccarelli (2010, cited in Pratt et al. 2012: 85) reports on a bicycle boulevard on Bryant, Palo Alto, where he defines the concept as meaning that '[t]hrough motor traffic is diverted by bicycle-permeable street closures and mandatory-turn devices spaced every half-mile to a mile' alongside bicycle priority at intersections. When the bicycle boulevard treatment was

installed in 1982 on Bryant's Southern segment, motor traffic near two street closures more than halved, while bicycle traffic almost doubled. However, some of this represented diversion from nearby parallel multi-lane roads.

Further evidence on bicycle boulevards includes:

- Khut (2012) found a statistically significant correlation between the presence of bicycle boulevards and cycle commuting rates for Portland neighbourhoods.

- Some revealed preference surveys (e.g. Broach et al., 2012) have suggested cyclists divert routes to use 'bicycle boulevards'.

- Pratt et al. (2012) report on some other evidence showing higher cycle counts after 'bicycle boulevards' were installed (albeit without accounting for diversion).

3.5 Non-segregated on-road provision

Unsegregated cycle lanes generally score higher in terms of stated preferences than similar roads without cycle lanes (Pucher et al., 2010). This was, for example, the case in TfL's Cycling Behaviour Survey, while Deenihan and Caulfield (2015) found that tourists were willing to increase their journey time by 40–50% in order to be able to cycle along a road with a cycle lane rather than a road without cycling facilities. However, these lanes are usually also viewed as less desirable than fully segregated lanes or tracks, often much less so (as in TfL's Cyclist Route Choice Survey).

Studies of unsegregated lanes offer mixed results of their impact:

- Pucher et al. (2010) found mixed evidence from revealed preference and before-and-after studies. Although a number of studies showed increases in cycle counts after painted lanes were installed, only one study examined the amount of diversion, and found that diversion was a substantial influence on changed counts.

- Goodno et al. (2013) studied changes in counts on Pennsylvania Avenue, Washington before and after the introduction of a centre cycle lane. Two locations along the route showed a before-and-after increase from c. 20 to 25 bicycles per hour peak, to c. 170. The average city-wide peak hour bicycle count changed from c. 70 to c. 90 over the same period. Some of this increase may be due to diversion.

- Hunter et al. (2009) examined changes in cycle counts after the introduction of on-road (painted) lanes along main roads in St. Petersburg, Florida. They found that the number of bicycles per day after installation of the bike lanes moved from 9 to 10-11 bicycles per day, suggesting that building low-quality infrastructure in a low-cycling environment made little absolute difference to ridership.

- Pratt et al. (2012) report findings showing cyclists in the US shifting from using sidewalks (footways) to using on-road lanes when these were provided, although this effect was reduced where the lanes were narrow.

In some contexts, limited interventions have been associated with substantial increases in uptake. TfL's (2011) evaluation of London's first two Cycle Superhighway routes showed substantial increases in cycling. One route (CS7) saw an increase of 46% in counted cyclists and another (CS3) saw a rise of 83%. While CS3 contains substantially segregated sections (most of which pre-dates the intervention), CS7 is largely unsegregated (again, with relatively little change in type of provision). The major infrastructural change implemented on both routes is signage; by contrast, second wave Superhighways are including much more substantial engineering changes. These results suggest that in favourable contexts, relatively small changes to routes along key desire lines can help to increase uptake. However, TfL (2011) note that this was concentrated among young men, as might be expected given the findings of the REA.

3.6 Junction improvements

There is substantial evidence that junctions are perceived as problems by existing and potential cyclists, from both stated and revealed preference research. For example, Broach et al's (2009) route choice study using revealed preference data found cyclists in Portland, Oregon preferred to avoid many junction types, likely due both to delays and safety concerns.

Stated preference evidence from London also demonstrates the off-putting impact of complex and difficult junctions. The TfL Route Choice study (2012) found cyclists said they were willing to detour for 7.5 minutes to avoid a right turn at a two lane roundabout or a right turn from a minor to a major road, while in the TfL Cycling Behaviour survey (2010) respondents said they would detour 15 or 16 minutes to avoid lane crossing or a roundabout. In practice people would probably not cycle at all rather than accept such a time penalty; however, the response indicates substantial aversion to problematic junctions.

Smith and Vu (2009) also found that 'there is high user demand for intersection treatments specifically addressing the difficulty of left-turn [NB right-turn in UK] manoeuvres'; half the cyclists they surveyed said they would modify their route if a particularly problematic junction was made safer for such turns, and nearly all the rest said they would consider doing so.

A stated preference survey on preferences for infrastructure while cycling with and without children (Aldred, 2015) similarly suggests unprotected crossings of major roads may be problematic, particularly where children are involved. Indeed, Pratt (2012) report evidence that crossings of major roads is associated with lower levels of active travel among children.

There is little stated or revealed preference evidence about the impact of specific junction improvements (e.g. Advanced Stop Lines, cycle lanes through junctions, segregation through junctions, shared cycle/pedestrian crossings, trixi mirrors, etc.) on cycling uptake, especially in the UK context. A Transport Research Laboratory (TRL) review of literature on two-stage right turns (2013: 39) commented that '[s]ources identified were mostly technical guidance or descriptions of example schemes; no research papers or reports have been found.' Most evidence that does exist focuses on safety, and the collected data often does not allow the drawing of conclusions about changes in uptake.

This is in contrast to the relatively high level of detail used in investigating the impact different types of infrastructure along links, and how this might affect cycling uptake. For example, whereas Wang et al's (2012) study asked respondents in detail about link configurations for different route options (including sharing with pedestrians or buses) only one choice was offered in the case of major junctions: '[a]dvanced stoplines/traffic signal priority for cyclists'.

Where evidence does exist, it generally relates to risk and perceptions of risk, rather than evidence on uptake - although we might expect the two to be related. A TRL report (2003) found most cyclists using several Advanced Stop Lines (ASLs, also known as 'bicycle boxes') installed at junctions in Guildford[iv] thought the ASLs had made them safer. The study did not, however, ask cyclists whether the availability of ASLs affected or would affect their journey choices.

Parkin et al. (2007) similarly investigated perceived risk in relation to intersection types among cyclists and non-cyclists, finding that the presence of a cycle lane[v] made little difference for signalised junctions (a small increase in perceived safety for right turn manoeuvres) and was associated with greater perceived danger for roundabouts.

Below are three relatively rare examples where the impact of new junction or intersection infrastructure have been evaluated in terms of their impact on cycling journeys.

Example 1:
A study by Gårder et al. (1998; reviewed in Pratt, 2012) studied the impact of improving intersection treatments in Gothenburg, Sweden. This involved minor T-intersections, where cyclists would be travelling on a cycle path next to a main road. Previously, cycle paths had ended prior to junctions, leaving cyclists using a painted lane at road level. The improvements involved raising the side road to the level of the cycle paths and parallel pavements, using distinctive paving and red colouring. Bicycle flows on the streets where volumes were measured increased 75% (one side) to 79% (other side) on one street and 100% on the other, compared to 20% at control intersections. There were safety benefits for pedestrians, cycles, and motorists. Other cycle improvements were implemented on a year-by-year basis during this period.
Example 2:
Farley (2014) studied the introduction of Advanced Stop Lines (ASLs) in Portland, Oregon, but focused on interactions and safety. His counts found that cyclist volumes had actually decreased (by an average of 31% per site) at 9 out of 11 sites where ASLs were installed. Across all sites (11) the decline was from a total of 3010 cyclists in a 24-hour period, to 1777. However, the counts were not taken at comparable times of the year: 'before' counts were taken in September (when the "Bike Commuter Challenge" occurs and classes begin at the University) while some of the after data was collected in November or February. On average, Portland's bicycle counts were showing 3.3% annual growth rate in 2012 (Portland

[iv] The Guildford study involved very low levels of cycling e.g. around 10 per hour.
[v] Cycle lanes at signalised intersections do not eliminate conflicts with turning motor vehicles, unlike facilities that separate conflicting traffic streams (e.g. Dutch-style junctions).

Bureau of Transportation, 2013). Two intersections did have similar observation dates: NE Couch St at Grand Ave (64% increase) and SE Gladstone St at Cesar E Chavez Blvd (23% and 20% decline) (Figures from personal correspondence with Will Farley, 2015).
Example 3:
At a junction in Portland, where a 'green scramble' (a separate green signal for cyclists who can then exit the junction in all directions simultaneously; very unusual in the U.S.) was installed in 2004, the numbers of cyclists doubled in two years (IBPI, 2006; Wolfe et al., 2006) and the proportion of cyclists illegally crossing the junction fell from 71.8% to 4.2%.

While the evidence on junction design and cycling uptake is very limited, we know that problematic junctions are a barrier to cycling. Given the broader preference expressed for segregation from motor traffic, and the specific risks posed by mixing at junctions (e.g. left hooks), Dutch best practice could help here: specifically, the separation of cyclists from conflicting streams of motor traffic. This could be achieved through traffic control systems (for example, the 'green scramble' often used in The Netherlands, or signal timings ensuring that cyclists are stopped while turning motor traffic continues and vice versa), or through other methods, for example, Fietsberaad (2011) also suggest restrictions on HGV access and turning movements.

4.0 Summary

In 2010 the evidence base for cycling infrastructure and cycling uptake was described as relatively weak by Yang et al. (2010). Many of these problems persist; some are inherent to the framing of the question while others relate to the limited nature of existing evaluations or a failure to make monitoring results (and data) publically available. However since 2010 more studies have begun to emerge, increasingly involving academics and using more robust methods to investigate uptake.

This report has argued that the stated preference evidence is useful as a means of classifying and prioritising interventions. Stated preference evidence is not good for predicting the amount of uptake; however, the evidence is fairly consistent in terms of what types of cycle route infrastructure is preferred (although further research is needed in some areas, for example where children are concerned or for filtered permeability and other traffic calming measures).

Hence, where infrastructural interventions are being considered, the suggestion is that more preferred infrastructure types be prioritised. This includes Greenway-type routes, routes physically separated from motor traffic, and routes where interactions with motor traffic are likely to be infrequent and occur at very low speeds (e.g. routes with filtered permeability). Evidence not reviewed here suggests that additional promotional and publicity activities, and non-route infrastructure such as workplace facilities and cycle hire, can help in maximising the benefits of new route infrastructure.

The evidence also indicates the importance of building it in the right place: some evidence from lower-cycling contexts such as the US suggests that a one-off intervention involving a small amount of infrastructure without a cycle network may have little or no discernible impact, particularly in the short term. Where interventions are planned in a context where cycling networks are poor, which may often be the case, planners should consider how to improve access (e.g. reducing through motor traffic on residential feeder streets), focusing on where people are likely to access the new infrastructure. The importance of building in the right place is further demonstrated by the fact that bridge crossings (either segregated on-road or new bridges for cyclists and pedestrians) often show relatively high levels of uptake, presumably because rivers form barriers to many cycling desire lines and hence suppressed demand is often high.

What may discourage cycling may not be objective injury risk so much as hostile traffic conditions, such as near misses (Joshi et al., 2001). Aldred and Crosweller (2015) found 'very scary' near misses to be a weekly experience for regular UK cyclists, with deliberate harassment around monthly. Frightening incidents are relatively likely (compared with less frightening incidents) to involve motor vehicles and larger vehicles such as HGVs and buses. Hence separation of cyclists from motor traffic, while not completely preventing the latter from injuring the former (apart from completely separate Greenway routes) may increase uptake by reducing the numbers of specific frightening incidents such as close overtakes, almost half of all 'very scary' incidents.

Interventions should be more robustly evaluated, particularly where high-quality and potentially transformative interventions are being implemented. This will improve the evidence base and improve our chances of implementing those interventions that prove to be successful in other contexts. Evaluation programmes in US cities such as New York and Portland, and in the mini-Holland borough of Waltham Forest, offer examples of what can be done on a relatively limited budget. Results of routine evaluation and monitoring should be made available online to the public, as should the monitoring data, wherever possible (there should be no reason for not releasing before- and after count data, for example). Evaluation should also be used to test the findings of the Rapid Evidence Assessment on preferences by age and gender.

While much can be done by improving evaluation methods and sharing the results and data, higher-quality specific studies should also be supported. These should involve key academics in designing and/or advising on studies, which should include staged RCTs for 'behaviour change' interventions and longitudinal studies following residents over time, before, during and after infrastructure is built. Public health academics should be among those involved given the importance of health benefits in establishing business cases for cycling investment; whereas traditional transport evaluations have not focused on this area.

5.0 References

Aldred, R. (2015). Adults' attitudes towards child cycling: a study of the impact of infrastructure. *European Journal of Transport and Infrastructure Research*, 15, pp.95-115. Available from http://www.tbm.tudelft.nl/fileadmin/Faculteit/TBM/Onderzoek/EJTIR/Back_issues/15.2/TableofContentsvol15issue2.pdf

Aldred, R. and Crosweller, S. (2015). Investigating the rates and impacts of near misses and related incidents among UK cyclists*, Journal of Transport & Health*, In Press, doi:10.1016/j.jth.2015.05.006. Available from http://www.sciencedirect.com/science/article/pii/S2214140515002236

Aldred, R. and Jungnickel, K. (2014). Why culture matters for transport policy: the case of cycling in the UK. *Journal of Transport Geography*, 34, pp.78-87. Available from http://www.sciencedirect.com/science/article/pii/S0966692313002202

Barnes, G., Thompson, K. and Krizek, K. (2006). A longitudinal analysis of the effect of bicycle facilities on commute mode share. *85th Annual Meeting of the Transportation Research Board. Transportation Research Board*, Washington, DC. Available from https://www.hhh.umn.edu/centers/slp/pdf/reports_papers/effect_bike_facilities_mode_share.pdf

Birk, M., Smith, J. and Mead, J. (2014). *A Tale of Portland Bridges, Bicycle Safety Guide and Countermeasure Selection System*, pedbikesafe.org. Available from http://pedbikesafe.org/bikesafe/casestudies_detail.cfm?CS_NUM=106

Björklund, G. and Isacsson, G. (2013). Forecasting the impact of infrastructure on Swedish commuters' cycling behaviour, *Stockholm Centre for Transport Studies*, KTH. Available from http://www.diva-portal.org/smash/get/diva2:677865/FULLTEXT01.pdf

Broach, J., Gliebe, J. and Dill, J. (2009). Development of a multi-class bicyclist route choice model using revealed preference data. Presented at the *12th International Conference on Travel Behavior Research*, Jaipur, India, December 2009. Available from http://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1020&context=usp_fac

Broach, J., Dill, J. and Gliebe, J. (2012). Where do cyclists ride? A route choice model developed with revealed preference GPS data, *Transportation Research Part A: Policy and Practice*, 46(10) pp. 1730–1740. Available from http://www.sciencedirect.com/science/article/pii/S0965856412001164

Burbidge, S.K. (2008). *Evaluating the Impact of Neighborhood Trail Development on Active Travel Behavior and Overall Physical Activity*, PhD Thesis, University of California, Davis. Available from http://escholarship.org/uc/item/5vw10860#page-2

Camp, A. (2013*). Closing the Bicycling Gender Gap*, Master of Community and Regional Planning (MCRP) Terminal Project, University of Oregon. Available from https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/12935/Camp_Terminal_Project_CRP_4%2026.pdf?sequence=1

Castillo-Manzano, J.I. and Sanchez-Braza, A. (2013). Managing a smart bicycle system when demand outstrips supply: the case of the university community in Seville, *Transportation,* 40, pp. 459–477. Available from http://link.springer.com/article/10.1007%2Fs11116-012-9424-7

Castillo-Manzano, J.I., López-Valpuesta, L. and Marchena-Gómez, M. (2015). Seville: A city with two souls, *Cities*, 42, pp. 142–151. Available from http://www.sciencedirect.com/science/article/pii/S0264275114001632

Caulfield, B., Brick, R. and McCarthy, T. (2012). Determining bicycle infrastructure preferences – A case study of Dublin, *Transportation Research Part D: Transport and Environment*, 17(5): 413–417. Available from http://edepositireland.ie/bitstream/handle/2262/68118/TRD-D-11-00237R1.pdf?sequence=1&isAllowed=y

Ciccarelli, J. (2010). *Bryant Street Bicycle Boulevard*. Available from http://pedbikesafe.org/bikesafe/casestudies_detail.cfm?CS_NUM=502

Cycling England (undated). *Making a Cycling Town*. Available from http://webarchive.nationalarchives.gov.uk/20110407094607/http://www.dft.gov.uk/cyclingengland/site/wp-content/uploads/2010/05/making_a_cycling_town_qualitative_report1.pdf

Deenihan, G., and Caulfield, B. (2015). Do tourists value different levels of cycling infrastructure?, *Tourism Management*, 46: 92 – 101. Available from http://edepositireland.ie/handle/2262/70501

Department for Transport (2014). *Claiming the Health Dividend: A summary and discussion of value for money estimates from studies of investment in walking and cycling*, London: Department for Transport. Available from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/371096/claiming_the_health_dividend.pdf

Dill, J., McNeil, N., Broach, J. and Ma, L. (2014). Bicycle boulevards and changes in physical activity and active transportation: Findings from a natural experiment, *Preventive Medicine, 69, pp s74-s78.* Available from: http://dx.doi.org/10.1016/j.ypmed.2014.10.006.

Douma, F. and Cleaveland, F. (2008). *The Impact of Bicycling Facilities on Commute Mode Share*, Minnesota Department of Transportation / Center for Transportation Studies. Available from http://www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=1646

Farley, W.R. (2014). *An Analysis of Bicycle-Vehicle Interactions at Signalized Intersections with Bicycle Boxes*, thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Civil and Environmental Engineering, Portland State University. Available from http://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=2617&context=open_access_etds

Fietsberaad (2008). Fietsberaadpublicatie 16: Fietspad of parallelweg. Utrecht: Fietsberaad. Available from http://www.fietsberaad.nl/?section=publicaties&lang=nl&mode=detail&repository=Fietsberaadpublicatie%2016:%20Fietspad%20of%20parallelweg

Fietsberaad (2011). Publication 19: *Working together for a safe cycling environment*, Otto Boggelen (Fietsberaad), Paul Schepers (I & M), Peter Kroeze and Maja van der Voet (Ligtermoet and Partners). Utrecht: Fietsberaad, http://www.fietsberaad.nl/?section=publicaties&lang=nl&mode=detail&repository=Fietsberaadpublicatie%2019:%20Samen%20werken%20aan%20een%20veilige%20fietsomgeving

Fraser, S.D.S. and Lock, K. (2010). Cycling for transport and public health: a systematic review of the effect of the environment on cycling, *European Journal of Public Health*, 21(6), pp. 738-43. Available from http://eurpub.oxfordjournals.org/content/21/6/738

Fuller, D., Gauvin, L., Kestens, Y., Daniel, M. F., Morency, P. and Drouin, L. (2013). Impact evaluation of a public bicycle share program on cycling: a case example of BIXI in Montreal, Quebec. *American Journal of Public Health*, 103, e85–e92. Available from http://ajph.aphapublications.org/doi/abs/10.2105/AJPH.2012.300917

Gårder, P., Leden, L. and Pulkkinen, U. (1998). *Measuring the Safety Effect of Raised Bicycle Crossings Using a New Research Methodology*, Paper No. 98-1360, Transportation Research Record 1636. Available from http://pure.ltu.se/portal/files/2084241/1636-010.pdf

Garder, G. and Gray, S. (1998). *A preliminary review of rural cycling*. Available from http://trid.trb.org/view.aspx?id=485604

Goodman, A., Panter, J., Sharp, S.J. and Ogilvie, D. (2013). Effectiveness and equity impacts of town-wide cycling initiatives in England: A longitudinal, controlled natural experimental study, *Social Science & Medicine,* 97, pp. 228–237. Available from http://www.sciencedirect.com/science/article/pii/S0277953613004826

Goodman, A., Sahlqvist, S., and Ogilvie, D. (2014). New Walking and Cycling Routes and Increased Physical Activity: One- and 2-Year Findings From the UK iConnect Study. *American Journal of Public Health,* 104, No. 9, pp. e38-e46. Available from http://ajph.aphapublications.org/doi/abs/10.2105/AJPH.2014.302059

Goodno, M., McNeil, N., Parks, J. and Dock, S. (2013). Evaluation of Innovative Bicycle Facilities in Washington, D.C. Submitted for the *TRB 92nd Annual Meeting* (January 2013). Available from http://docs.trb.org/prp/13-0519.pdf

Heinen, E., Panter, J., Mackett, R. and Ogilvie, D. (2015). Changes in mode of travel to work: a natural experimental study of new transport infrastructure, *International Journal of Behavioral Nutrition and Physical Activity,* 12:81. Available from http://www.ijbnpa.org/content/12/1/81

Hull, A. and O'Holleran, C. (2014). Bicycle infrastructure: can good design encourage cycling? *Urban, Planning and Transport Research*, 2:1, pp. 369-406. Available from http://www.tandfonline.com/doi/full/10.1080/21650020.2014.955210#.VH8xT8kYtr8

Hunter, W.H., Srinivasan, R. and Martell, C. (2009). *An examination of bicycle counts and speeds associated with the installation of bike lanes in St. Petersburg*, Florida. University of North Carolina Highway Safety Research Center. Available from http://www.stpete.org/transportation/citytrails/docs/Examination_of_bicycle_counts_and_speeds_associated_with_bike_lanes.pdf

IBPI: Institute for Bicycle and Pedestrian Innovation (2006). *IBPI RESEARCH DIGEST - Bike Scramble Signal at N Interstate & Oregon Portland State University*, Department of Civil and Environmental Engineering, November 30, Submitted to Chris Monsere. Available from http://www.pdx.edu/ibpi/sites/www.pdx.edu.ibpi/files/monsere%20-%20scramble.pdf

Jensen S, Rosenkilde C, Jensen N. (2007*). Road safety and perceived risk of cycle facilities in Copenhagen*. Available from http://www.vehicularcyclist.com/copenhagen1.pdf

Jones, T. (2012). Getting the British back on bicycles—the effects of urban traffic-free paths on everyday cycling, *Transport Policy,* 20, pp. 138–149. Available from http://www.sciencedirect.com/science/article/pii/S0967070X12000157

Joshi, M.S., Senior, V. and Smith, G.P. (2001). A diary study of the risk perceptions of road users Health, *Risk and Society*, 3:3, 261-279. Available from http://www.tandfonline.com/doi/abs/10.1080/13698570120079877#.VIc9nGfyDTo

Khut, R. (2012*). Bicycle boulevards: statistical analysis of the presence of bicycle boulevards and their influence on bicycle-to-work rates in Portland, Oregon*, thesis submitted to the University of Oregon in partial fulfilment of the requirement for the degree of Master of Community and Regional Planning. Available from https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/12961/Khut_oregon_0171N_10585.pdf?sequence=1

Laird, J., Page, M., and Shen, S (2013). The value of dedicated cyclist and pedestrian infrastructure on rural roads. *Transport Policy,* 29, pp. 86–96. Available from http://www.sciencedirect.com/science/article/pii/S0967070X13000553

McCartney, G., Whyte, B., Livingston, M. and Crawford, C. (2012). Building a bridge, transport infrastructure and population characteristics: Explaining active travel into Glasgow, *Transport Policy*, 21, pp. 119-125. Available from http://www.sciencedirect.com/science/article/pii/S0967070X12000467

Melson, C.L., Duthie, J.C. and Boyles, S.D. (2014). Influence of bridge facility attributes on bicycle travel behaviour, *Transportation Letters*, 6(1), pp. 46-54. Available from http://www.maneyonline.com/doi/abs/10.1179/1942787513Y.0000000010

Monsere, C., McNeil, N. and Dill, J. (2011). *Evaluation of Innovative Bicycle Facilities: SW Broadway Cycle Track & SW Stark/Oak Street Buffered Bike Lanes*. FINAL REPORT Prepared for City of Portland Bureau of Transportation, Center for Transportation Studies, Portland State University. Available from http://www.pdx.edu/ibpi/sites/www.pdx.edu.ibpi/files/PSU%20Cycle%20Track%20BBL%20Report%20FINAL_0.pdf

Monsere, C., Dill, J., Clifton, K. and McNeil, N. (2014). *Lessons from the Green Lanes: Evaluating Protected Bike Lanes in the U.S.,* Portland State University. Available from http://trec.pdx.edu/research/project/583/Lessons_from_the_Green_Lanes:_Evaluating_Protected_Bike_Lanes_in_the_U.S._; Main report -

Parkin, J., Wardman, M. and Page, M. (2007). Models of perceived cycling risk and route acceptability, *Accident Analysis and Prevention,* 39: 364–371. Available from http://www.sciencedirect.com/science/article/pii/S0001457506001473

Pistoll, C. and Goodman, A. (2014). The link between socioeconomic position, access to cycling infrastructure and cycling participation rates: An ecological study in Melbourne, Australia, *Journal of Transport & Health,* 1(4), pp. 251–259. Available from http://www.sciencedirect.com/science/article/pii/S2214140514000796

Portland Bureau of Transportation (2013). *Portland Bicycle Count Report 2012*. Available from https://www.portlandoregon.gov/transportation/44671

Pratt, R.H., Evans, J.E. and Levinson, H.S., et al (2012). *Traveler Response to Transportation System Changes*, Chapter 16—Pedestrian and Bicycle Facilities, TCRP REPORT 95 sponsored by the Federal Transit Administration in cooperation with the Transit Development Corporation. Available from http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c16.pdf

Pucher, J., Dill, J. and Handy, S. (2010). Infrastructure, programs, and policies to increase bicycling: An international review, *Preventive Medicine*, 50 S106-S125. Available from http://www.sciencedirect.com/science/article/pii/S0091743509004344

Pucher, J., Buehler, R. and Seinen, M. (2011). Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies, *Transportation Research Part A,* 45, pp. 451–475. Available from http://www.fietsberaad.nl/library/repository/bestanden/TRA960_01April2011.pdf

Scheepers C.E., Wendel-Vos, G.C.W., den Broeder, J.M., van Kempen, E.E.M.M., van Wesemael, P.J.V. and Schuit, A.J. (2014). Shifting from car to active transport: A systematic review of the effectiveness of interventions, *Transportation Research Part A*, 70, pp. 264–280. Available from http://www.sciencedirect.com/science/article/pii/S0965856414002493

Sloman, L., Cavill, N., Cope, A., Muller, L. and Kennedy, A. (2009). *Analysis and synthesis of evidence on the effects of investment in six Cycling Demonstration Towns*: Report for Department for Transport and Cycling England. Available from http://webarchive.nationalarchives.gov.uk/20120607215928/http://www.dft.gov.uk/publications/analysis-synthesis-of-evidence-on-investment-effects-in-six-cycling-demonstration-towns

Smith, A. and Vu, H. (2009). *Volatile Endeavors: Negotiating Left Turns Along the SE Hawthorne Bike Corridor* IBPI RESEARCH DIGEST. Available from http://www.pdx.edu/ibpi/sites/www.pdx.edu.ibpi/files/VuSmith-Digest.pdf

Thakuriah, P., Metaxatos, P., Lin, J., and Jensen, E. (2012). An examination of factors affecting propensities to use bicycle and pedestrian facilities in suburban locations

Transportation Research Part D, 17, pp. 341–348. Available from http://www.sciencedirect.com/science/article/pii/S1361920912000077

Transport 2000 Trust (2003). *Rural Transport Futures* (Summary). Available from http://transportforqualityoflife.com/u/files/RuralTransportFutures_summary%20Sep2003.pdf

Transport for London (2010). *Cycling Behaviour Survey* (three reports). London: Transport for London/Steer Davies Gleave.

Transport for London (2011). *Barclays Cycle Superhighways Evaluation of Pilot Routes 3 and 7*, London: Transport for London. Available from: https://www.whatdotheyknow.com/request/162841/response/402026/attach/3/BCS%20pilot%20evaluation%20report.pdf

Transport for London (2012). *Cycle route choice: Final survey and model report*. London: Transport for London/Steer Davies Gleave. Available from https://www.tfl.gov.uk/cdn/static/cms/documents/understanding-cycle-route-choice.pdf

Transport for London (2014*). International Cycling Infrastructure Best Practice Study*. London: Transport for London. Available from https://www.tfl.gov.uk/cdn/static/cms/documents/international-cycling-infrastructure-best-practice-study.pdf

Transport Research Laboratory (2003). *TRL Report 585: Capacity implications of Advanced Stop Lines for cyclists*. Prepared for Charging and Local Transport Division, Department for Transport, G T Wall, D G Davies and M Crabtree. Berkshire: TRL.

Transport Research Laboratory (2013). *TRL Report PPR717: Cycle Facility Trials Work Stream 6. Literature Review considering ways for cyclists to turn right at signalised junctions*. Berkshire: TRL. Available from http://trl.co.uk/media/399636/ppr717_literature_review_cyclists_turning_right_at_signalised_junctions.pdf

Walker, L., Tresidder, M., Birk, M., Weigand, L. and Dill, J. (2009). *Fundamentals of Bicycle Boulevard Planning & Design*, Initiative for Bicycle and Pedestrian Innovation, Portland State University, CUS-CTS-09-02. Available from http://www.pdx.edu/ibpi/sites/www.pdx.edu.ibpi/files/BicycleBoulevardGuidebook%28optimized%29.pdf

Wang, J.Y.T., Mirza, L., Cheung, A, K, L., Moradi, S. (2012). *Transforming Auckland into a bicycle-friendly city: Understanding factors influencing choices of cyclists and potential cyclists.* Australasian Transport Research Forum. Available from http://www.atrf.info/papers/2012/2012_Wang_Mirza_Cheung_Moradi.pdf

Winters, M. and Teschke, K. (2010). Route preferences among adults in the near market for bicycling: findings of the cycling in cities study. *American Journal of Health Promotion,* 25(1), pp. 40-7. Available from http://ajhpcontents.org/doi/abs/10.4278/ajhp.081006-QUAN-236

Winters, M., Babul, S., Becker, J., Brubacher, J., Chipman, M., Cripton, P., Cusimano, M., Friedman, S., Harris, M., Hunte, G., Monro, M., Reynolds, C., Shen, H., Teschke, K. (2012). Safe Cycling: How Do Risk Perceptions Compare With Observed Risk? *Canadian Journal of Public Health,* 103(Suppl. 3), pp. S42-S47. Available from http://journal.cpha.ca/index.php/cjph/article/view/3200/2668

Wardman, M.R., Tight, M.R. and Page, M. (2007). Factors influencing the propensity to cycle to work. *Transportation Research A*, 41(4), pp. 339-250. Available from http://eprints.whiterose.ac.uk/2448/1/

Wilmink, A. and Hartman, J.B. (1987). *Evaluation of Delft Bicycle Network Plan: final summary report*. Available from http://publicaties.minienm.nl/download-bijlage/7259/evaluation-of-the-delft-bicycle-network-plan-final-summary-report.pdf

Wolfe, M., Fischer, J., Deslauriers, C., Ngai, S. and Bullard, M. (2006). *CE454 Urban Transportation Systems - Fall 2006 Final Report*, Bike Scramble Signal at N Interstate & Oregon, University of Portland. Available from http://www.minneapolismn.gov/www/groups/public/@publicworks/documents/images/wcms1p-093244.pdf

Yang, L., McMinn, A., Griffin, S.J. and Ogilvie, D. (2010). Interventions to promote cycling: systematic review, *BMJ*, 341: c5293. Available from http://www.bmj.com/content/341/bmj.c5293

Appendix 5 Rapid Evidence Assessment: Do cycling infrastructure preferences vary by gender and by age?

Contents

Introduction

This Rapid Evidence Assessment (REA) examines and synthesises the evidence for age and gender differences in cycle infrastructure preferences. It focuses on preferences for cycling infrastructure and routes that keep cyclists away from motorised traffic. The aim is to examine whether under-represented groups within UK cycling (women, older people, children) have infrastructural preferences that vary from those expressed by other groups.

Summary of Key Findings and Recommendations

Forty-one of the 56 studies examined preferences for separation from motor traffic in relation to gender, with 25 covering this in relation to age (adults) and only four studies discussing preferences related to child cycling. Meta-analysis, as routinely conducted for epidemiological studies, is precluded because of the nature of the evidence. Firstly, often there is insufficient information provided; secondly, stated preference studies use different methods of asking about preferences, making it problematic to aggregate findings. One recommendation is therefore for a more complete reporting of findings.

Preferences by Age and Gender: Summary

Men and women both prefer cycling environments which keep riders away from motor traffic, but women's preferences are stronger.

There is good evidence that in general, people prefer cycling away from motor traffic. This evidence is discussed further in the accompanying review of evidence on infrastructure and uptake. That review and the studies analysed here support the assumption in WebTAG[i] that people place higher values on more segregated cycle infrastructure, all else being equal.

There is **good** evidence that women have stronger preferences than do men for cycling away from motor traffic. 58.5% of relevant studies (24) found this, with the remainder (17) reporting no statistically significant differences. No studies reported that *men* expressed stronger preferences for cycling away from motor traffic. Therefore we can conclude that the gender difference in preferences is likely to be real, particularly as studies finding no difference in preferences often had low sample sizes which might have precluded finding a statistically significant effect.

[i] WebTAG refers to the UK Department for Transport's web-based multimodal guidance on appraising transport projects and proposals.

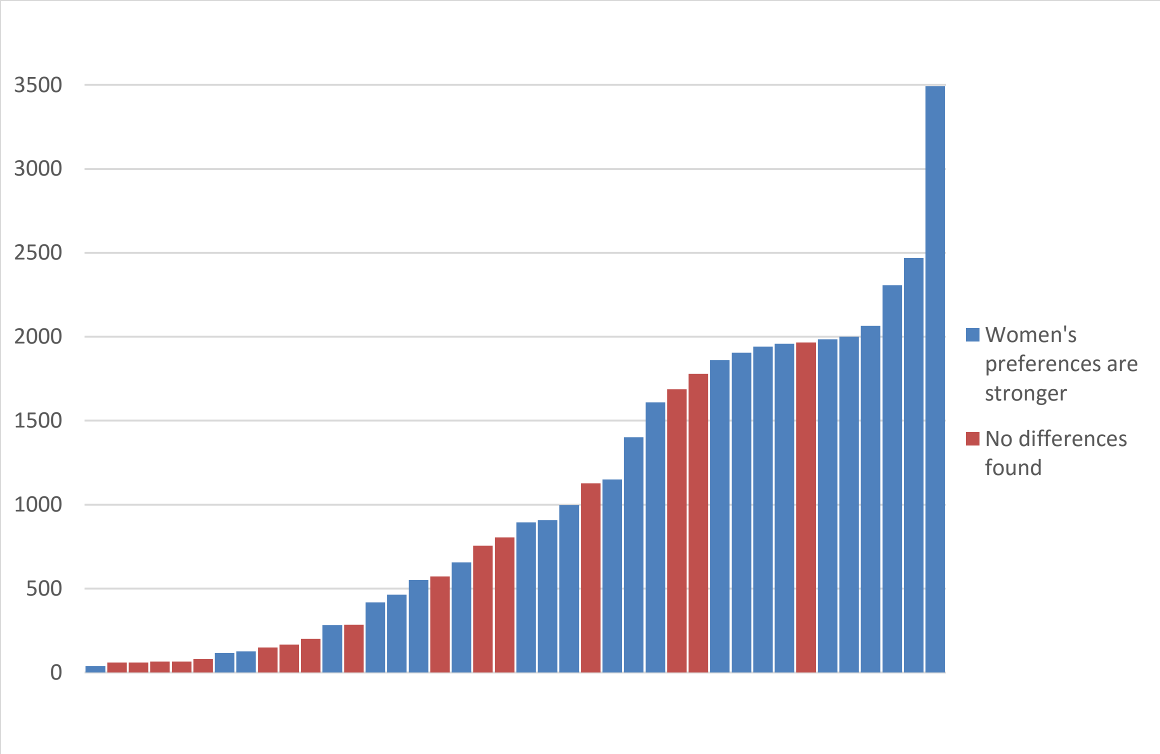

Figure 1 Gender and preferences for separated infrastructure, by sample size (one study with missing sample size excluded)

Some studies suggest older people have stronger preferences for riding away from motor traffic, but the evidence is less clear.

There is **less strong evidence** on the impact of age on preferences, although it does broadly indicate a similar relationship to that found in relation to gender. 36.0% of studies (9) reported some evidence that older people seek greater separation from motor traffic, with 52.0% (13) reporting no differences, and 12.0% (3 studies) reporting some evidence in the opposite direction. While the evidence here is more mixed, we believe it provides some support for the hypothesis that older people have less tolerance of riding in mixed traffic than do younger people. Selection bias may weaken the evidence here where studies only or mostly comprise cyclists. Older cyclists will disproportionately include people who have been cycling for many years, and therefore will be skewed towards those who are satisfied with cycling conditions. Thus it may be particularly true among older age groups that the preferences of cyclists are not a good indication of the preferences of non-cyclists.

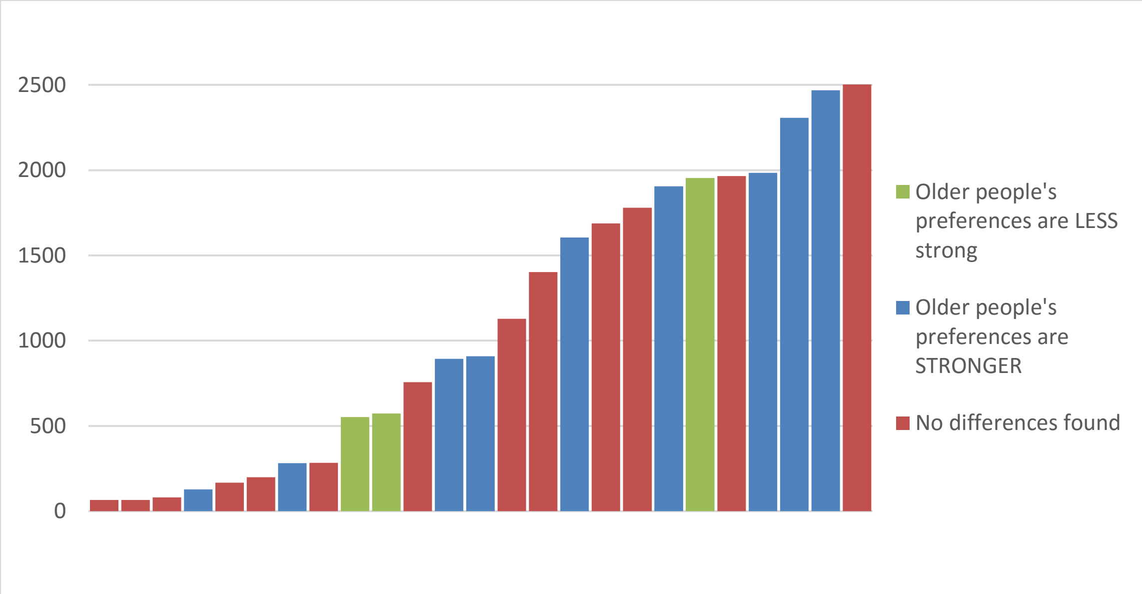

Figure 2 Age and preferences for separated infrastructure, by sample size

There is relatively little evidence on how adult preferences change where children are involved (or children's own preferences), but what exists suggests strongly that riding away from motor traffic becomes more important.

Future Research

More complete reporting of study findings would aid future reviews. It would also be useful for future stated preference studies to consider including some harmonised questionnaire module, allowing reviewers to aggregate results across studies, which is particularly important where sample sizes are small. This is frequently done in epidemiological reviews.

More specifically, the evidence on gender differences in preferences is strong and unlikely to need further detailed investigation. Older people's infrastructural preferences do merit further investigation: there were relatively few studies and definitions of 'older' were very disparate. While searching the literature we found two useful recent papers focusing on this (Velasco et al., 2015; Winters et al., 2014) but unfortunately these did not compare the expressed preferences with those of younger people, so we could not include them here.

Given that those with greater cycling experience tend to be more tolerant of mixing with motor traffic, it is important to seek the views of older cyclists whose preferences are more likely to be representative of their broader demographic. This could include those who currently cycle only occasionally, non-cyclists and those with lower levels of cycling experience, and those cycling within higher-cycling country or city contexts.

More research on cycling with children should be conducted. There is ample evidence that motor traffic forms a major barrier to child cycling, yet surprisingly little detailed investigation of what kind of infrastructure would meet the needs of parents and children. The failure to study and build for child cycling may contribute to the gender inequalities in cycling in low-cycling countries, given women's higher likelihood of making escort trips.

Infrastructural Recommendations

This review supports building for the preferences of under-represented groups. The evidence suggests that such under-represented groups have particularly strong preferences for infrastructure that is separated from motor traffic either through physical barriers, or through route-level separation (e.g. Greenway-type routes or streets with very low levels of motor traffic).

The evidence suggests these preferences that are not qualitatively different from preferences expressed by younger adults and men. Rather these preferences are <u>stronger</u>, so building for under-represented groups represents a form of inclusive design that can cater for a broad range of cyclists.

The evidence does not support a 'dual networks' approach, but rather suggests that these kinds of segregated routes are attractive for the majority of potential cyclists. This means that such routes should be built with the understanding that they are not 'only' for women, children, and older people, but also for men and younger adults. This has implications for capacity, design speed, and location planning, and stakeholder involvement.

Building inclusive infrastructure is particularly important given evidence that some other barriers to cycling may be stronger for under-represented groups (Damant-Sirois et al., 2015; van Bekkum, 2011; Daley et al., 2007; Finch et al., 1985; Steinbach et al., 2011; Bergstroem and Magnusson, 2003). For example, women may have stronger concerns than men about safety from crime (social safety). Focusing on the needs and preferences of under-represented groups should be sensitive to these issues and, for example, take account of social safety concerns in planning routes.

Rationale

Literature

A policy concern to diversify cycling has been accompanied by a growth in the academic literature. Aldred et al. (2015) explored the extent to which increasing cycle commuting (between 2001 and 2011) had been associated with greater age and gender diversity in England and Wales, the results suggesting that greater cycling has not yet been associated with an increase in diversity.

Authors have discussed the extent to which existing cycling environments may be experienced differently by different groups (Habib et al., 2014). There is increased concern to develop standards for active travel infrastructure that are more welcoming to a range of groups (e.g. Oxley et al., 2005). Asadi-Shekari et al. (2013) identify a lack of attention to the needs of older people, children and disabled people in Non-Motorised User Levels of Service calculations. They describe this as affecting pedestrians, not cyclists; yet related issues may arise for cycling, whether due to different levels of risk tolerance, perceived comfort, physical capability or other variables.

In The Netherlands the organisation Fietsberaad has commented (2007) that while an ageing Dutch population will mean a higher mode share for cycling (Harms et al., 2014), it will generate new challenges for design, for example necessitating wider cycle tracks. TfL (e.g. 2014) has begun to consider issues around designing for disabled cyclists and different types of cycle (e.g. hand-cycles).

A number of authors have suggested that women and other under-represented groups may show greater aversion to motor traffic than do groups dominating existing cycling in countries like the UK (Davies et al., 1997; Chataway et al., 2014). If so, this could be an important part of the explanation for the observed inequalities in cycling, especially given that in higher-cycling countries, with better cycling infrastructure, there is much greater gender and age equity (Aldred et al., 2015).

Implications

A number of evidence reviews, including the literature review in this report, have covered the kinds of cycling infrastructure and interventions that are likely (or not) to increase uptake. However, as yet no systematic review has focused specifically on gender and age differences in preferences or tolerance for different types of cycling infrastructure or environments. Given policy goals of diversifying cycling, this is an important gap in the literature and one where some literature has suggested there may be relevant differences.

There are three possible outcomes of the review. Firstly, we might find that the views of under-represented groups are broadly similar to those of groups dominating current cycling in countries such as the UK. Secondly, the two groups' views might differ fundamentally: for example, one group preferring separated cycle routes and another preferring integration with traffic. Thirdly, preferences might lie in the same direction, but with differences in strength or emphasis: for example, both groups preferring separation from motor traffic, but under-represented groups having a markedly stronger or markedly weaker preference.

These three situations imply different policy prescriptions. The first implies that building infrastructure to cater for current preferences should be sufficient to attract new cyclists from all groups. The second suggests potentially a 'dual network' strategy, with different infrastructure types developed for different social groups. The third suggests a different strategy; targeting infrastructure design towards groups with the strongest preferences, and thereby creating infrastructure that is intended to cater for all.

Methods

Research Questions

How do expressed preferences/tolerances for different types of cycle route environments/ infrastructure vary by age and by gender?

In particular, is it true that women and older people tend to have stronger preferences for more segregated/motor traffic free environments than do men and younger people?

In order to answer these research questions, a Rapid Evidence Assessment (REA) was undertaken to find and review literature relevant to how cycling infrastructure preferences vary between age and gender. The following search strategy was utilised to capture and synthesise the relevant literature.

Search terms

The facets of the research question were identified using the PICO model- which stands for Population, Intervention, Comparison, and Outcome- and used to determine key search terms. The search terms used are detailed in Table 1 and a more comprehensive outline of searches carried out for each source (and number of records retrieved) is available at the end of this section.

Table 1 Key search terms used

P terms: bike$ OR bicycle$ OR bicycling OR bicyclist$ OR cycle OR cyclist$ OR cycling OR “active travel” OR “active transport” OR “non-motorised modes” OR “non-motorised transport” OR “non-motorized modes” OR “non-motorized transport” AND **I terms:** infrastructure OR track$ OR lane$ OR “off-road” OR “off-street” OR “on-road” OR “on-street” OR junction$ OR box OR ASL OR “traffic calming” OR “traffic reduction” OR “traffic removal” OR boulevard$ OR filter* OR “road closure” OR greenway$ OR residential OR segregat* OR protected OR painted OR path$ OR facility OR facilities AND **C terms:** sex OR gender$ OR age* OR children OR men OR women OR male$ OR female$ OR older OR younger OR elderly AND

O terms: prefer* OR choice$ OR choosing OR decision$ OR attitud* OR view* OR willing*

Databases and websites searched

A number of databases and websites were searched using the above terms to retrieve relevant online material and the results downloaded to Mendeley, software used to manage references. In order to guide the searches, a number of include/ exclude criteria regarding relevance, setting, quality, date, format and language were determined, as outlined in Table 2.

Table 2 Inclusion and Exclusion Criteria for relevance, setting, quality, date, format, language

	Include in Rapid Evidence Assessment	Exclude
Relevance	Evidence relating to stated preferences (what people say about their preferences, and/or how a particular intervention might change their behaviour) Evidence that specifically relates to route infrastructure preferences (defined broadly as including e.g. lighting and maintenance as well as type of road infrastructure)	Evidence related to observed behaviour Evidence on views about other policies, e.g. financial incentives Views about barriers to cycling (as opposed to views about infrastructure types).
Setting	Any country	
Quality	Peer reviewed academic literature; government-commissioned literature; grey literature, i.e. working papers, NGO, think-tank and consultant reports	Unreferenced, non-traceable web reports
Date of research	Published in the last 25 years	Published more than 25 years ago (unless a key reference frequently cited in more recent sources)
Format	Available electronically	Only available in print form / electronic version no longer available and cannot be sourced from author/ stakeholders
Language	English only	Non-English

Databases

The following databases were searched, yielding 936 peer-reviewed journal papers, and the citations for each downloaded to Mendeley. The TRID database was clearly the most relevant, and so we did not narrow the search criteria by making one of the search terms ‘title-only’, unlike for the other sources (which often yielded many irrelevant results otherwise).

- EBSCO (Business Source Complete, EconLit, Greenfile, Medline) (*170 results*)
- Web of Science (*121 results*)
- ProQuest Dissertations & Theses: UK & Ireland (*21 results*)
- PubMed (41 results)
- TRID (573 results)
- ARRB Knowledge Base (*10 results*)

Three databases that were originally proposed for searching (REPEC, Scopus and International Transport Forum) were excluded from the searches due to access limitations.

Websites

The following websites were searched using Google’s advanced search facility so as to ensure a consistent search approach.

- Danish Transport Research Institute- www.transport.dtu.dk/english
- National Highway Traffic Safety Administration (USA) - www.nhtsa.dot.gov
- New York City Department of Transportation- www.nyc.gov/html/dot/html/home/home.shtml
- OpenSIGLE-http://opensigle.inist.fr
- Pedestrian and Bicycle Information Center- www.bicyclinginfo.org/
- Portland Department of Transportation-www.portlandoregon.gov/transportation/
- Swedish Transport Administration- www.trafikverket.se
- Transport Canada- www.tc.gov
- Transport for London-www.tfl.gov.uk
- Transport Research Laboratory (UK) - www.trl.co.uk
- UK Department for Transport-www.gov.uk/government/organisations/department-for-transport

Websites which were originally proposed for searching but subsequently excluded due to lack of relevant references, access limitations, or being covered by a previously searched source, included:

- Australian Transport Safety Bureau- www.atsb.gov.au
- Cochrane Collaboration Library- http://www.cochranelibrary.com/
- Fietsberaad (Dutch library of national cycling expertise) - http://www.fietsberaad.nl/
- Institute of Transportation Engineers- www.ite.org/
- National Institute for Health and Clinical Excellence- www.nice.org.uk/
- Transportation Research Board (included in TRID)- www.trb.org/Main/Home.aspx
- US Department of Transport (included in TRID)- www.dot.gov/

Due to the large number of results retrieved for some websites (in some cases, within the hundreds and thousands), a decision was made to include for each only the first twenty PDF documents produced by the search. On examining these, some were clearly irrelevant (e.g. primarily about motorcycling) and so only those that had some potential relevance were imported into Mendeley.

The website searches were complemented by a Google Scholar search, which searched the abstracts of any publications added in the past year, due to the limits of Google Scholar functionality. The Google Scholar search was however helpful for accessing publications that due to their newness might not yet have appeared in indexing databases.

The web searches yielded a total of 176 additional publications, after duplicates were removed.

Finally, in addition to the systematic searching of the websites and databases described above, the lead reviewer was aware of five particularly pertinent additional publications (including one that remains unpublished, and two unpublished at that time) through her knowledge of the subject area. These were included in the review.

Screening of evidence

Three rounds of screening were carried out to filter the evidence captured in the website and database searches.

Screening Round 1: The searches of the databases and online resources together captured **1117** separate publications (after removing duplicates) and the citations for each were uploaded into Mendeley. Most of these included full abstracts. The first round of screening was carried out, based on a quick review of the titles only and removed any material which a) did not have anything to do with riding bicycles at all (despite matching search terms, which might for example refer to chemical cycling) b) was only concerned with sport cycling/ indoor exercise cycling/ round the world cycle trips or c) focused on the mechanics of bicycle design/ the structure of the bicycle industry.

BE carried out the initial screening for Round 1. RA checked all decisions and adjusted the codes inclusively (i.e. to minimise unnecessary exclusions). **153** documents were excluded.

Screening Round 2: The second round of screening involved a review of the titles and abstracts for each of the **964** remaining publications. Publications not excluded from the study at this stage included those where the reviewer thought that there may be some attempt to measure expressed preferences for different types of cycle infrastructure or environment, regardless of whether age /gender contrasts were apparent at this stage. Examples of material excluded from the study at this stage included a) where a source related only to bicycle related injuries (rather than, for example, perceptions of safety) b) where a source was clearly reporting only actual cycling behaviour (e.g. where people go) and not expressed preferences (what people say) and c) where a source related only to attitudes to/use of safety clothing e.g. bicycle helmets.

BE carried out the initial screening for Round 2. RA checked all decisions and adjusted the codes inclusively (i.e. to minimise unnecessary exclusions). **662** documents were excluded.

Screening Round 3: We then reviewed the titles, abstracts, and (in just under 50% of cases) full text of the remaining **302** publications and tagging them with either 'Exclude3' or 'Include3'. Within 'Exclude3', evidence was excluded on the basis of the following reasons/ codes listed below.

BE carried out the initial screening for Round 3, following which RA independently reviewed all sources. In 146 cases, this also involved rapid reading of full text sources, where there was disagreement or uncertainty about whether to include the source, provided it was available online. This additional full text reading was done primarily to minimise the extent to which some papers might be missed due to the abstract not reporting having examined differences by age and gender.

- not a publication including information about preferences for different route characteristics. This excluded studies where, for example, the research only looked at preferences for hire bicycle availability. It also excluded publications where the research reported focused on correlations between cycling levels and beliefs about the cycling environment (e.g. that there were enough cycle lanes, or whether people feel cycling is safe). (110 sources)
- where the publication seemed to cover relevant ground but where there was no information about any differences or lack of differences by age or by gender (65 sources)
- 'Other3' i.e. where there were issues with the source (e.g. full text not in English, source was a presentation not a paper or report) (15 sources)

Screening Round 3 led to the removal of **190** sources.

Appraisal and synthesis of evidence

Following the three rounds of screening, there were **112** papers remaining. To assist with the appraisal and synthesis stages, the PDFs or full-text for each citation (where not already obtained as part of Round 3) were sourced and uploaded to Mendeley. For some citations, this involved contacting authors to obtain a copy of the document. Despite undertaking this process, there were still 17 publications in total which had to be excluded from the study as they could not be obtained. A total of **95** publications were therefore included in the appraisal. Concomitant with the appraisal was a final screening stage in which 32 publications were found not to contain information on preferences by age and/or gender, and a further 1 – a narrative review – was excluded because it did not report any additional studies with enough detail to be included in the appraisal.

Therefore, the final appraisal stage comprised **62** publications.

The appraisal stage involved reviewing the full text of each publication for any comparisons of stated infrastructure preferences by age or gender. Details of any findings were recorded in an Excel spreadsheet, along with information about:

- Country of study
- Population characteristics

- Sample size
- Whether non-cyclists were included
- The quality of the sample on a 1-4 scale
- A brief description of what situations were presented to participants
- How the situations were communicated to participants, e.g. in words only, images, video
- A rating on a 1-3 scale of how specific these situations were (e.g. images of a range of different infrastructural types, or statement relating to 'cycle lane present')
- Whether preferences were discussed by gender
- Whether preferences were discussed in relation to age (amongst adults)
- Whether preferences were discussed in relation to children
- A brief description of the findings, focusing on reported differences or similarities in cycle route infrastructure preferences by age and gender.

Following this final stage of screening and appraisal, there were 56 separate studies found to report age and/or gender differences with regards to cycling infrastructure preferences which were included in the synthesis. This is lower than the list of publications; because for six studies multiple papers – often reporting different aspects of the study – had been included in the appraisal.

Tables were created to summarise the findings of these 56 studies with respect to differences and similarities between i) females versus males; ii) older adults versus younger adults; and iii) children versus adults. The achievement of statistical significance as reported by study authors was used to identify differences.

Analysis was then carried out in Excel and SPSS to explore both the headline findings (similarities and differences in preferences) and the extent to which these were associated with factors such as sample size or whether non-cyclists were included. Tables and images from this analysis are included below in the Findings.

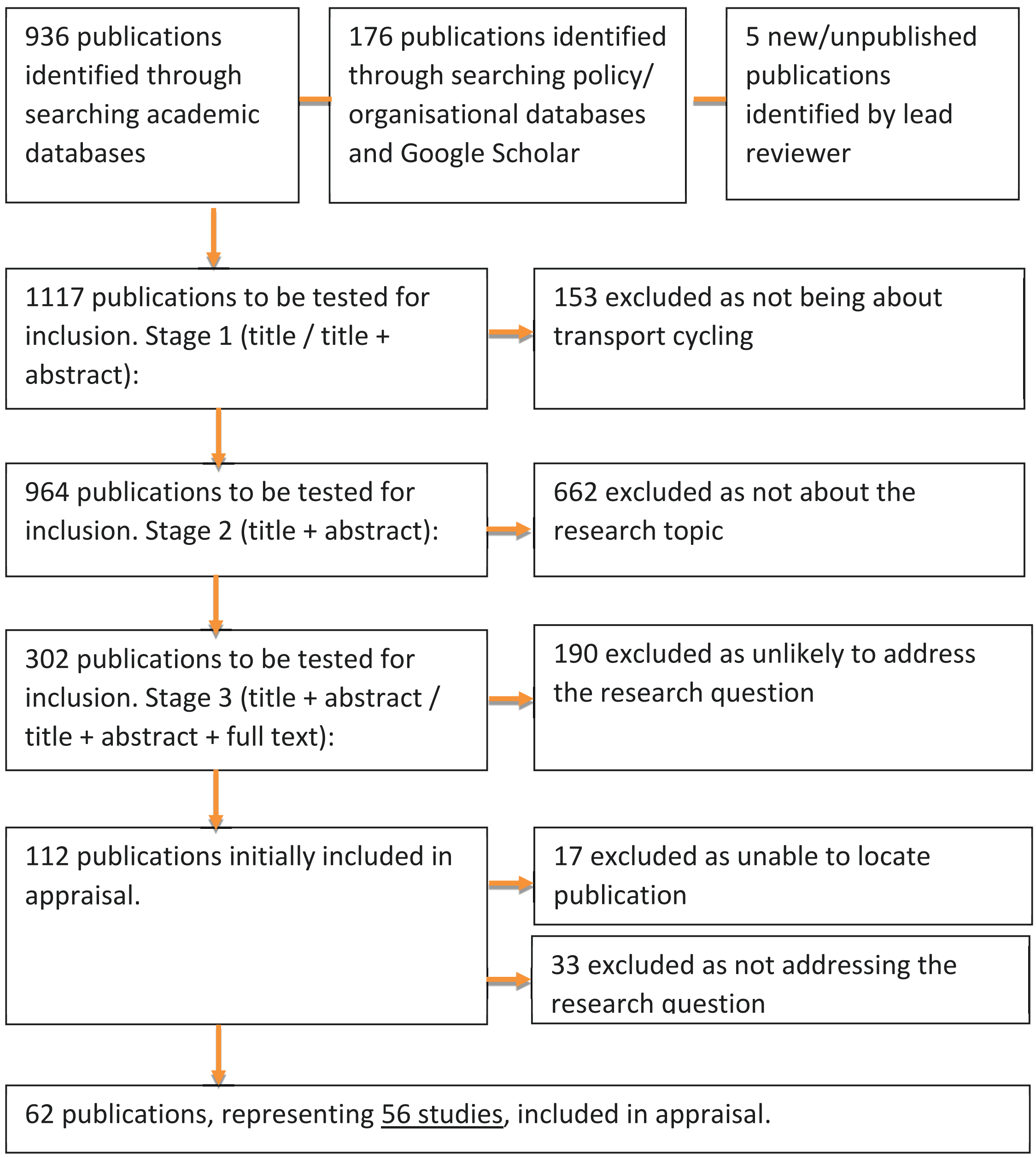

Figure 3 Summary of evidence management strategy

Findings

About the reviewed studies

In reporting studies here we are in some cases combining findings reported from publications which were reporting the same study (e.g. Wardman et al., 2001; and Wardman et al., 2007), but with additional information gleaned from the different papers. Hence the number of reviewed studies (56) is smaller than the number of reviewed papers (62). These 56 studies reported having looked for age and/or gender differences in cycling infrastructure preferences.

Country of origin

A third of all studies were conducted in the United States. The UK was second with 8 (plus one study that covered the UK alongside Sweden and the Netherlands), followed by Belgium and Canada (four each). Overall, 39 of the 56 studies could be characterised as having been carried out only in high-income countries with low cycling rates (such as the US, UK, and Canada). Relatively few studies were carried out in middle-income countries and/or countries with higher cycling rates.

Table 3 Reviewed studies' country of origin

Country	Number of studies	Percentage of studies
US	19	33.9%
UK	8	14.3%
Belgium	4	7.1%
Canada	4	7.1%
Ireland	3	5.4%
Sweden	3	5.4%
China	2	3.6%
Denmark	2	3.6%
India	2	3.6%
New Zealand	2	3.6%
Australia	1	1.8%
Australia/Denmark	1	1.8%
Brazil	1	1.8%
Spain	1	1.8%
Sweden/Netherlands	1	1.8%

Taiwan	1	1.8%
The Netherlands	1	1.8%
Grand Total	56	100.0%

Study size and populations

More specific details are contained within the table listing all papers. However, here we summarise some basic characteristics of the studies. Firstly, the sample size varied considerably; the smallest study had only 35 participants; nine had 80 or fewer. Some studies might thus not be sufficiently powered to detect gender or age differences unless these were very large. Moreover, the gender issue is magnified where populations are drawn from existing cyclists (or even, in one study, 'avid cyclists') as in these populations there is likely to be a gender imbalance and relatively few women.

Table 4 Sample size of reviewed studies

Sample size	Number of studies	Percentage of studies
Under 200	15	26.8%
200+	40	71.4%
Missing	1	1.8%
Grand Total	56	100.0%

Three-fifths of the studies included both cyclists and non-cyclists, although the relative balance varied greatly; studies focusing on cycling generally tend to over-represent cyclists, and this effect is magnified where non-random sampling is used. A little over one-third only sampled cyclists, while one study only sampled non-cyclists.

Table 5 Study population of reviewed studies

Study composition	Number of studies	Percentage of studies
Only cyclists	22	39.3%
At least some non-cyclists	34	60.7%
Grand Total	56	100.0%

Coverage of gender and age

Fifty-one of the 56 studies examined preferences in relation to gender, with 33 covering age (older versus younger adults) and only four studies discussing preferences related to child cycling. Because of the small number of studies covering child cycling, this aspect of the findings are not summarised here and a separate narrative section discusses child cycling.

Methodology of included reports

Sampling methods varied widely; from household survey samples to convenience samples of cyclists attending specific rides. Study sampling methods were rated on a scale of one to four, with four representing a high-quality representative sample survey (perhaps carried out as part of a national travel survey) and one representing a small convenience sample, obtained through means such as contacting cycle touring clubs (for example). Studies with higher quality sampling methods will have a better chance of being representative of a potential cycling population. However, in many cases, convenience sampling is used (as is common for much stated preference research) and only around a quarter of studies were judged as having the highest quality sampling methods.

Table 6 Sampling method quality of reviewed studies

Sample quality	Number of studies	Percentage of studies
1 (lowest)	7	12.5%
2	28	50.0%
3	7	12.5%
4 (highest)	13	23.2%
Insufficient information	1	1.8%
Grand Total	56	100.0%

While all studies involved collecting quantitative data on expressed preferences, various study methods were used to elicit these.

The most common elicitation method was simply to give (using a paper questionnaire, on the phone, in person, or via the Internet) a verbal or text-based description of a particular infrastructure type (e.g. “painted lane”). The participant would then be asked to rate the infrastructure type, although the type of rating would depend on the type of survey. In surveys carried out within the framework and assumptions of cost-benefit analysis, the person will usually be asked to compare different combinations of infrastructure scenarios and time, for example a long route on an off-road track versus a short, direct route on a busy road. This allows the construction of a utility metric establishing the extent to which people trade off infrastructure preferences against time. However, not all studies employed this utilitarian approach. Some, for example, asked people to say whether they would feel comfortable or safe cycling on a particular type of infrastructure, or to rank infrastructural types against each other (without a time trade-off).

The second most common type of elicitation method relied on images, either real pictures of infrastructure or computer-generated images. This accompanied questions about the desirability of the infrastructure type, as with studies using text-based elicitation. A less common method included reference to existing infrastructure; for example, a study that stopped people in a series of sampled cycle lanes and asked them their opinions about the infrastructure they were using in relation to other types of infrastructure. In other cases researchers showed participants videos of particular examples of infrastructure types, then asked them about their preferences.

Table 7 Elicitation methods of reviewed studies

Method	Number of studies	Percentage of studies
Description (only)	27	48.2%
Existing	8	14.3%
Images	16	28.6%
Video	5	8.9%
Grand Total	56	100.0%

Finally, the table below summarises the situational specificity found across the studies. Nearly half were very general (e.g. asking about 'cycle lanes') while one in five were very specific, for example testing different levels and/or types of segregation.

Table 8 Situational specificity of reviewed studies

Situational specificity	Number of studies	Percentage of studies
1 (lowest)	26	46.4%
2	19	33.9%
3 (highest)	11	19.6%
Grand Total	56	100.0%

Infrastructural Preferences

Here findings are discussed in relation to preferences for greater separation from motor vehicles, a key theme within the literature on preferences more broadly (see literature review, Appendix 4) and also within the studies reviewed here. In some cases other types of difference or similarity by infrastructural preference were discussed in relation to age and gender, and these other differences are listed separately in the study summary table (e.g. different or similar perceptions of risk at roundabouts).

Findings: gender and preferences for greater segregation from motor vehicles

Method	Number of studies	Percentage of studies
Women's preferences are stronger	24	58.5%
No differences between men and women	17	41.5%
Men's preferences are stronger	0	0.0%

Total	41	100.0%

Forty-one studies provided evidence as to whether preferences for separation from motor traffic differed by gender. Of these, 58.5% (n=24) said that women expressed stronger preferences for segregation from motor vehicles than did men. As mentioned above, studies tend to find a stronger preference for separation from motor traffic among respondents. So a difference here might for example relate to a higher value being placed on 'existence of a cycle lane', or to a bigger gap between the value placed on complete separation from motor traffic compared to the presence of a painted lane.

41.5% of studies (n=18) reported that there were no statistically significant differences in gender preferences, while none of the studies reported that men had stronger preferences than women for greater segregation from motor vehicles.

We regard this as strong evidence of women's stronger preferences for greater segregation from motor vehicles. However, this must be seen within the context of what were often similar overall types of preference; often there were very similar hierarchies of preference across genders, but with women expressing stronger preferences for the generally more highly ranked infrastructure and route types. Four-fifths of studies that found differences in preferences between men and women (n=19/24) also highlighted an overall similarity in preferences across genders.

Table 9 Prevalence of gender differences in reviewed studies

Findings: age and greater segregation from motor vehicles

Fewer studies, only 25, reported on age in relation to preferences for greater segregation from motor vehicles. Findings here were less strikingly consistent than for gender. One reason for this is perhaps a lack of consistency over what counts as 'older'. While some studies used age in years as an independent variable within linear regression, others used very different cut-offs in comparing groups. These varied from comparing those younger versus older than 20 years to comparing those younger versus older than 70 years, with many different cut-offs in between (e.g. younger versus older than 45 years). One problem here then is that any relationship between age and preference may be obscured by the lack of consistent categories and definitions.

Table 10 Prevalence of age differences in reviewed studies

Method	Number of studies	Percentage of studies
Older people's preferences are stronger	9	36.0%
No differences	13	52.0%
Younger people's preferences are stronger	3	12.0%
Total	25	100.0%

While nine studies (36.0% of those reporting on preferences for greater segregation and age) found that older people expressed stronger preferences for separation from motor vehicles, 13 (52.0%) found no differences, and three (12.0%) reported that older people had less strong preferences for separation from motor vehicles than did younger people.

Nearly nine out of ten (22/25) of studies covering older people's preferences highlighted overall similarity in preferences across age groups, even if specific differences were found.

How findings varied by study type

This section explores how findings vary by study type, although our ability to make comparisons is limited by small numbers, particularly for age, hence most comparisons here are made by gender. One issue is sample size. As indicated in the harvest plot in the summary, a higher proportion of studies with a larger sample size showed a statistically significant gender difference. This also held for age although the numbers of studies are small. It seems likely that some of the smaller studies were not powered to detect the kinds of differences found in larger studies, although due to limited information being reported it is difficult to confirm this.

Table 11 Findings of stronger segregation preferences by age or gender

	Women		Older Adults	
Method	Number	Percentage	Number	Percentage
Sample <200	3/10	30.0%	1/5	20.0%
Sample ≥200	21/30	70.0%	8/20	40.0%
All studies	24/40	60.0%	9/25	36.0%

Table excludes one study missing information on sample size; p=0.025 for gender differences (numbers too small to credibly test for age differences)

When comparing sample quality (which took into account the sampling method as well as sample size) a similar pattern was found (p=0.019). For studies with the highest quality sampling (generally large, random household surveys, some conducted as part of national travel surveys) 72.7% (n=8/11) found gender differences; this was even higher at 100% (n=7/7) for studies with medium-high quality sampling. By contrast only 47.1% (n=8/17) of medium quality surveys found a difference, and this dropped to 20% (n=1/5) among the lowest quality surveys (which typically involved a very limited sample, often students or members of a local cycling club, with small numbers).

Another comparison could be made in terms of how specific questions are about segregated infrastructure. While this comparison is not statistically significant, 77.8% (n=7/9) of studies providing a high level of specificity found a gender difference. This was lower for studies with medium or low specificity (53.8% and 52.6% respectively).

Studies containing only non-cyclists had very similar results to other studies in terms of gender differences. However, there was an interesting difference in comparing studies in low-cycling countries only. For those countries, 70.0% (n=21/30) of studies reporting on preferences for separated infrastructure found differences, while for those where some or all participants lived in medium- or high-cycling countries, only 27.3% (n=3/11) found differences.

It is unclear why this should be the case, and there are relatively few studies from medium- and high-cycling countries. One explanation might be that where cycling is less gendered men are more willing to admit to preferences for cycling away from motor traffic; another might be that people in high-cycling countries interpret scenarios differently (for example, in terms of assumptions about traffic flows) from those in low-cycling countries.

However, given that low-cycling countries could be assumed to be more relevant to the UK, the stronger evidence for these countries supports the case made here about gender differences and preferences for separated infrastructure. When considering only low-cycling country studies with sample sizes of 200 or more, 81.8% (n=18/22) which reported on this found gender differences in preferences.

Findings: other differences

Other differences in preferences were referred to in the studies, and are listed below.

Gender

One notable difference found in several studies (dell'Olio et al., 2014; Ma et al., 2014; Ma and Dill, 2015; Sener et al., 2010) involved women tending to rate their neighbourhoods as less cycle-friendly than men, suggesting that for a given level of cycle infrastructure or cycle-friendliness women are likely to be less satisfied than men. This would fit with the stronger preferences for separated infrastructure discussed above. There was some evidence that personal safety concerns might be stronger for women than for men (Bergström, 2000; Gardner, 1998; Majumdar et al., 2015).

Studies that included weather conditions tended to find that these were more of a barrier for women than men, and that improving winter maintenance treatments might be particularly important for women (Akar et al., 2013a, 2013; Bergström, 2000; Miranda-Moreno et al., 2013; Ryley, 2015). There was some indication that potentially women might find junctions more off-putting than men (Brick et al., 2012; Moller et al., 2008; Twaddle et al., 2011). Finally, carrying everyday items such as shopping was mentioned in two studies (Akar et al., 2013a, 2013b; Twaddle et al., 2011). While apparently not an infrastructural issue, the need to carry items potentially has implications for infrastructure, given the desirability to counteract the 'cargo effect' by creating routes that avoid hills or unnecessary detours. (The 'cargo effect' refers to the fact that cargo cycles have specific width and turning circle requirements, and so cargo cycle riders have to choose routes that accommodate these requirements).

Age

For age, as with the segregation discussion, findings were less clear-cut than for gender. For example, some studies find that older people rate the cycling environment more highly than younger people, with some finding the opposite. There are likely to be confounding effects. People start cycling young (in low-cycling places) and so older cyclists usually have more experience; moreover, people tend to stop cycling in middle age (in low-cycling places) so older cyclists must be particularly keen and enthusiastic.

The table below highlights some of the additional findings related to age and infrastructure (considered broadly); it can be seen that they are quite diverse.

Table 12 Other differences found in the reviewed studies

Citation key	Age-related differences
Antonakos et al 1995	• With regards to recreational cycling preferences, age was positively correlated with importance placed on road surface quality and scenery and negatively correlated with few stops along a route in the choice of a recreational cycling route.
Bernhoft et al 2008	• A higher proportion of younger cyclists found it dangerous to cycle, where there were parked cars, to ride straight on, when there were right turning vehicles, or to turn left (i.e. right in the UK). These situations were acknowledged as dangerous by the older group, but to a somewhat lesser extent. • A higher proportion of the younger group found it important that the route for cycling was fast and direct. A smooth surface for cycling was more important for the younger group.
Hughes et al 1997	• Apparent reduction in sensitivity to risk on the part of the younger cyclist (i.e. under 20 years old).
Lawson et al 2013	• Older people were more likely to deem the cycling network as safer than the relatively younger population.
Ma et al 2014/Ma and Dill 2015	• Age was negatively associated with perceptions of the bicycling environment. Older people (55 and over) are nearly three times more likely as younger people to perceive a 'high bikeable' environment as low.
Miranda-Moreno et al 2013	• The likelihood of winter cycling increases with age to a maximum point, after which increasing age reduces the probably of winter cycling.
Moller et al 2008	• Perception of accident risk at roundabouts was found to decrease with age (p=0.02).

Parkin et al 2007	• The young and older people were found to perceive junctions as adding more risk than for those in the middle years of life (aged 35–44).Young people and older people generally considered cycling less acceptable than those in the age band 35–44 years.
Sener et al 2010	• Young bicyclists perceived the bicycle facilities in their community to be better than did older bicyclists.
Stinson et al 2003	• Older individuals, who are likely to be more comfort-conscious, had a stronger preference for smooth riding surfaces. They disliked major intersections more than younger individuals.
Twaddle et al 2011	• There is a difference in the type of safety concern expressed by older and younger females. Younger females are unsure about the route to take, while older females are more concerned with feeling unsafe riding on the road.
Westerdijk 1990	• Younger subjects tended to give higher importance to distance. Here 'distance' refers to choosing to take a shorter and more direct route.

Findings: children

Only four studies were found that referred to preferences for infrastructure involving children. Of these only two, Aldred (2015) and Ghekiere et al. (2015) fully met the inclusion criteria. The former compared adults' preferences for infrastructure while riding alone, to preferences for riding with or by children. The latter compared adults' preferences for child cycling with the children's own preferences. The other two studies, Chang and Chang (2008) and Ghekiere et al. (2014) have been included here despite their lower relevance, given the very small amount of material available. Chang and Chang (2008) asks about children's confidence to cycle in different traffic situations (which could be seen as something of a proxy for infrastructure preferences), while Ghekiere et al. (2014) is a small scale qualitative study with children and parents, which does not directly attempt comparisons.

All four papers highlight the need to address concerns about motor traffic, and in particular, Aldred (2015) and Ghekiere et al. (2014, 2015) find an expressed preference for greater separation from motorised traffic when child cycling is involved. This goes beyond barrier separation and also covers issues such as, in Aldred (2015), protection at crossings and reduction in rat-running, and in Ghekiere et al. (2014, 2015), the need for wide and even cycle paths.

Chang and Chang's findings (2008) have some differences of emphasis, partly due to methodological differences. While the other three studies used images and also or only explored adults' perceptions of cycle infrastructure (which may ultimately determine whether children can cycle or not), Chang and Chang (2008) asked 13-15 year olds questions such as 'Can you safely ride your bike when crossing intersections with fast-moving traffic?'

to judge their abilities and perceptions of difficulties. Respondents were therefore not asked about 'good' infrastructure but rather about situations seen as potentially problematic. Hence Chang and Chang do not, unlike the other sources, also explore the characteristics of high-quality infrastructure. They do however comment that 'the installation of cycling lanes would circumvent the vast majority of the issues that students perceived as leading to difficulty in cycling to school' (Chang and Chang, 2008: 129).

Narrative review: children

Concerns about motor traffic were found to play an important role in the cycling infrastructure preferences of both adults and children. When parents in a study by Ghekiere et al. (2014) were asked which environmental factors were most likely to influence them to allow their child to cycle for transport, traffic safety was almost always cited as the most important barrier. Another study by Ghekiere et al. (2015) similarly found that speed limit and degree of separation from motorised traffic were, for parents, the most important factors in allowing their child to cycle. Traffic safety was considered to be an important factor by children as well, however environmental elements such as evenness of the cycle path and speed limit of the street were also found to be at least equally important to them (Ghekiere et al., 2014; Ghekiere et al., 2015).

Given the importance placed on traffic safety, it is not surprising that adults and children were generally found to express preferences for cycling environments with higher level of separation from motor traffic. Ghekiere et al 2014. found that children and parents were more comfortable when there were cycle facilities, separated from the road by parked cars, a small hedge, a shoulder or when the cycle path was a bit higher than the road. Aldred (2015) found similar preferences for separation from motor traffic, with the four most popular cycling environments (for cycling by 'most people', carrying a child, with an eight year old, or by a twelve-year old) being segregation by kerb, segregation by car parking, shared park routes, and filtered streets. In the study by Ghekiere et al. (2015), children and their parents preferred streets with cycle paths separated from the road by a hedge, rather than a kerb or no separation (although for parents a kerb was considered as good an alternative as a hedge for separating their children from passing motorised traffic).

Further evidence on adult and children's preference for separation from motor traffic is evident in the study by Aldred (2015) which found that shared bus lanes and mandatory (paint-based) cycle lanes were only seen as safe for cycling with an eight-year-old by a quarter and a third of respondents, respectively. Further, 85% of respondents stated they would be happy crossing over a busier road as part of a cycle route compared to fewer than 30% saying that they thought the crossing would be suitable for a solo twelve-year-old or an accompanied 8-year-old (Aldred, 2015). By contrast, school children surveyed in Chang and Chang (2008) stated that crossing intersections and dealing with cars occupying road shoulders were low difficulty and easy to overcome. Students cycling to school perceived the most difficult conditions as being the presence of trucks and heavy traffic (Chang and Chang, 2008).

The preference for cycling facilities with higher levels of separation from motor traffic was matched, unsurprisingly given the stated importance of safety from traffic, by a preference for cycling environments with lower traffic density and speed. Ghekiere et al. (2014) found that both parents and children agreed that chicanes, speed bumps and speed limitations were helpful in slowing down the traffic. However, children said that chicanes are sometimes problematic since some cars cut corners and drive very close to them.

Beyond traffic volume/speed and separation from motor traffic, Ghekiere et al. (2014) highlighted a number of insights into children's cycling environment preferences (and how they compare to adults) at a more detailed scale. For example, children and parents indicated that wider cycle paths were more enjoyable to cycle, so that children could cycle next to each other. Parents stated that it was especially important to have a wide cycle path, since young children may still have difficulties cycling on a straight line.

The type of surface and evenness of the cycle path was mentioned by parents and children as being important in order to cycle comfortably. Children did not like unevenness in cycle paths due to fear of falling, and were afraid of falling when cycling on certain surfaces, e.g. gutters with a slippery surface or tramways. This is in contrast to the study by Chang and Chang (2008) which found that children did not rate narrow shoulder width, uneven pavement, and cycling on shared roads as being of significant difficulty for cycling to school. This study also found gender differences between school children in terms of stated levels of comfort and perceived safety, with boys indicating they felt they had better cycling ability than girls, being more likely to say they felt safe riding a bike with trucks on the road, or riding around parked cars.

In Ghekiere et al. (2014), street crossings and roundabouts were mentioned by parents as difficult traffic situations which are not always understood by children. Parents disliked their child having to cross roads, especially when it was unclear where cyclists needed to cross. Children found it less enjoyable when they often had to get off their bicycle at a crossing or intersection to press the traffic lights button or wait at zebra crossings. A further consideration noted by Ghekiere et al. (2014) was the visibility impact of car parking and obstructing vegetation at intersections (due to children cycling at a lower height and being less visible for other road users). Finally, a preference for closed street settings with higher residential densities was found for parents in Ghekiere et al. (2015) and thought to reflect parental concerns about social control and 'stranger danger'. Children by contrast were found to have preferences for cycling in open street settings, which may be explained by a preference for aesthetic features rather than safety issues.

Findings: summary

The findings demonstrate clear differences in preferences by gender, in terms of separation from motor traffic. This is against a broader background of similarity, in that men also tend to rate more separated facilities more highly, but women have stronger preferences for these. While not all studies find gender differences, those that did not were often small: among larger studies (200 or more participants), 70% (n=21/30) find stronger preferences in women. There are no studies citing women having *less strong* preferences than men for separation from motor traffic.

By age, the picture is less clear. Around half the studies find no differences by age, with just over a third finding that older people do have stronger preferences for separation from motor traffic. Several studies, however (12%) find that younger people have stronger preferences for separation. On balance, it looks as if older people do often have stronger preferences for separation, however it is not as clear as the evidence in relation to gender. More research is needed here but in the meantime it seems that age-friendly cycling environments should aim for higher levels of separation from motor traffic, which should also be suitable for younger adults and for children.Studies highlight some other differences. Although numbers are small, some studies suggest that women may be more likely to be affected by several other barriers, such as the need to carry items, winter conditions, hills, and concerns about personal safety (see also Heinen et al., 2010; Damant-Sirois et al., 2015). This highlights the need to create cycling environments that minimise the impact of winter conditions, are inclusive of a range of cycles, are direct and ideally avoid hills, and are well lit and overlooked. Studies referred to these and other differences by age, but, because of the relatively limited amount of literature it is hard to draw general conclusions.

Literature on child cycling and infrastructure preferences is limited, but what literature does exist suggests that people believe that greater separation from motor traffic is also needed to facilitate child cycling and cycling with children.

Limitations

The major limitation of this review is that it only focuses on evidence about what people say they prefer. Evidence on 'revealed preferences' by contrast might tell us, for example, whether older cyclists systematically choose different routes, compared with younger cyclists. While including such evidence was considered, it was decided that it would compromise the rapidity and focus of the search process. Additionally, 'revealed preference' evidence has the drawback of by definition only covering existing cyclists (and often only regular cyclists) whereas studies reviewed here include preferences expressed by regular cyclists, occasional cyclists, and non-cyclists.

Despite this limitation, we considered that a review of expressed preferences by age and gender was useful. Such a review has not previously been conducted, and yet, synthesising the evidence in this area can shed light on a commonly hypothesised pathway leading to inequalities in cycling – that different groups have different views on cycling in a specific infrastructural context. Here the evidence can both tell us whether there are systematic differences in this respect, and the nature of such differences. This provides useful information for planners, policy-makers and designers in seeking to build inclusive cycling environments that work for all.

Conclusion

The findings here support a focus on the infrastructural needs and preferences of under-represented groups, including (although not necessarily limited to) older people, women, children and those cycling with children or making decisions about child cycling. Younger people, men, and those travelling without children do also generally prefer separation from motor traffic, although these preferences seem to be somewhat less strong than those expressed by under-represented groups.

One factor involved may be that 'committed cyclists' (Pooley et al., 2013), who are more motor traffic tolerant than other groups, may be disproportionately found among younger men. For example, Winters et al. (2010) report an overall general similarity of preferences across demographic groups, albeit with some variation in strengths. They comment that only 79 respondents were 'very likely' to choose to ride on major streets with parked cars. Winters et al. call this group 'a unique subpopulation', disproportionately likely to be male, regular cyclists, aged 25-34, and without children. When comparing preferences, the greater presence of this group among men and younger respondents may contribute to the differences found here.

The take-home point for policy is thus a need to do more to involve under-represented groups in cycle planning, and to conduct further study of preferences related to older people and cycling with and by children in particular. There is a need for both traditional and innovative research to be more inclusive. Many valuable studies (e.g. Walker et al., 2014) continue to focus on the experience of the male cycle commuter. However, including the viewpoints and experiences of retired people, parents from diverse communities, and disabled commuters (for example) may be crucially important for improving and diversifying cycling experiences and uptake.

The fact that older people in lower-cycling countries have probably spent some time becoming used to conditions that others find off-putting is a methodological concern here, so innovative methods (for example, those used by Ghekiere et al., 2014, 2015, involving go-alongs and discussions using images from these) may help in establishing more realistic levels of required infrastructure than might be obtained through more traditional stated preference methods. Within more traditional research, there needs to be more standardisation of questions about infrastructure preferences, to better enable study comparisons. Reporting standards could be improved; for example, there was generally insufficient information to check study power.

Reviewed Papers

Akar, G., Fischer, N., Namgung, M. (2013a). Bicycling Choice and Gender Case Study: The Ohio State University. *International Journal of Sustainable Transportation,* 7, pp.347–365. doi:10.1080/15568318.2012.673694

Akar, G., Fischer, N., Namgung, M. (2013b). Why women bicycle less? Case Study: The Ohio State University. *International Journal of Sustainable Transportation,* 7, pp.347–365.

Aldred, R. (2015). Adults' attitudes towards child cycling: a study of the impact of infrastructure. *European Journal of Transport and Infrastructure Research,* 15, pp.92–115.

Antonakos L, C. (1995). Environmental and travel preferences of cyclists. *Transportation Research Part A: Policy and Practice,* 29, pp.85. doi:10.1016/0965-8564(95)90300-3

Berggren, M., Graves, A., Pickus, H. Hand Wirtis, L. (2012). *The 20s Bikeway: Clinton to Steele*. Available from https://www.portlandoregon.gov/transportation/article/466646

Bergström, A. (2000). *Winter maintenance service levels on cycleways*. Royal Institute of Technology, Stockholm, Sweden.

Bernhoft, I.M., Carstensen, G. (2008). Preferences and behaviour of pedestrians and cyclists by age and gender. *Transportation Research Part F: Traffic Psychology and Behaviour*, 11, pp.83–95. doi:10.1016/j.trf.2007.08.004

Börjesson, M., Eliasson, J. (2012). The value of time and external benefits in bicycle appraisal. *Transportation Research Part A: Policy and Practice*, 46, pp.673–683. doi:10.1016/j.tra.2012.01.006

Brick, E., McCarthy, O., Caulfield, B. (2012). Bicycle Infrastructure Preferences–a Case Study of Dublin, in: *Transportation Research Board 91st Annual Meeting of the Transportation Research Board.*

Caulfield, B. (2015). Do tourists value different levels of cycling infrastructure? *Tourism Management,* 46, pp.92–101.

Chang, H.-W., Chang, H.-L. (2008). Students' Perceptions of Difficulties in Cycling to School in Urban and Suburban Taiwan. *Transportation Research Record: Journal of the Transportation Research Board*, 2060, pp.123–130. doi:10.3141/2060-14

Chataway, E.S., Kaplan, S., Nielsen, T.A.S., Prato, C.G. (2014). Safety perceptions and reported behavior related to cycling in mixed traffic: A comparison between Brisbane and Copenhagen. *Transportation Research Part F: Traffic Psychology and Behaviour,* 23, pp.32–43. doi:10.1016/j.trf.2013.12.021

dell'Olio, L., Ibeas, A., Bordagaray, M., Ortúzar, J.D.D. (2014). Modeling the Effects of Pro Bicycle Infrastructure and Policies Toward Sustainable Urban Mobility. *Journal of Urban Planning and Development*, 140, 04014001. doi:10.1061/(ASCE)UP.1943-5444.0000190

Dickinson, J.E., Kingham, S., Copsey, S., Pearlman Hougie, D.J. (2003). Employer travel plans, cycling and gender: will travel plan measures improve the outlook for cycling to work in the UK? *Transportation Research Part D: Transport and Environment*, 8, pp.53–67.

Dill, J., Goddard, T., Monsere M, C., McNeil, N. (2015). Can Protected Bike Lanes Help Close the Gender Gap in Cycling? Lessons from Five Cities. *TRB 94th Annual Meeting Compendium of Papers*. Available from http://docs.trb.org/prp/15-3481.pdf

Dill, J., McNeil, N. (2012). Four Types of Cyclists? Examination of Typology for Better Understanding of Bicycling Behavior and Potential. *Transportation Research Record,* 2387, pp. 129-138, doi:10.3141/2387-15

Emond, C.R., Tang, W., Handy, S.L. (2009). Explaining Gender Difference in Bicycling Behavior. *Transportation Research Record: Journal of the Transportation Research Board*, 2125, pp.16–25. doi:10.3141/2125-03

Gardner, G. (1998). *Transport implications of leisure cycling*. Transport Research Laboratory, Berkshire. Available from http://www.trl.co.uk/reports-publications/trl-reports/transport-planning/report/?reportid=2508

Ghekiere, A., Van Cauwenberg, J., de Geus, B., Clarys, P., Cardon, G., Salmon, J., De Bourdeaudhuij, I., Deforche, B. (2014). Critical Environmental Factors for Transportation Cycling in Children: A Qualitative Study Using Bike-Along Interviews. *PLoS ONE*, 9, e106696. doi:10.1371/journal.pone.0106696

Ghekiere, A., Van Cauwenberg, J., Mertens, L., Clarys, P., de Geus, B., Cardon, G., Nasar, J., Salmon, J., De Bourdeaudhuij, I., Deforche, B. (2015). Assessing cycling-friendly environments for children: are micro-environmental factors equally important across different street settings? *The International Journal of Behavioral Nutrition and Physical Activity*, 12, pp.54.

Heesch, K.C., Sahlqvist, S., Garrard, J. (2012). Gender differences in recreational and transport cycling: a cross-sectional mixed-methods comparison of cycling patterns, motivators, and constraints. *International Journal of Behavioral Nutrition and Physical Activity*, 9, pp.106. doi:10.1186/1479-5868-9-106

Heinen, E., van Wee, B., Maat, K. (2010). Commuting by Bicycle: An Overview of the Literature. *Transport Reviews,* 30, pp.59–96. doi:10.1080/01441640903187001

Hughes, R.G., Harkey, D.L. (1997). Cyclists' perception of risk in a virtual environment: Effects of lane conditions, traffic speed, and traffic volume. In: *Traffic Congestion and Traffic Safety in the 21st Century: Challenges, Innovations, and Opportunities*, pp. 132-138. Available from http://trid.trb.org/view.aspx?id=576013

Hunt, J.D., Abraham, J.E. (2007). Influences on bicycle use. *Transportation,* 34, pp.453–470. doi:10.1007/s11116-006-9109-1

Krizek, K. (2006). Two Approaches to Valuing Some of Bicycle Facilities' Presumed Benefits: Propose a session for the 2007 National Planning Conference in the City of Brotherly Love. *Journal of the American Planning Association,* 72, pp.309–320. doi:10.1080/01944360608976753

Krizek, K.J., Johnson, P.J., Tilahun, N. (2005). Gender Differences in Bicycling Behavior and Facility Preferences. In: *Transportation Research Board Conference Proceedings*. Transportation Research Board, pp. 31–40.

Landis, B., Vattikuti, V., Brannick, M. (1997). Real-Time Human Perceptions: Toward a Bicycle Level of Service. *Transportation Research Record*, 1578, pp.119–126. doi:10.3141/1578-15

Landis, B., Vattikuti, V., Ottenberg, R., Petritsch, T., Guttenplan, M., Crider, L. (2003). Intersection Level of Service for the Bicycle Through Movement. *Transportation Research Record*, 1828, pp.101–106. doi:10.3141/1828-12

Lawson, A.R., Pakrashi, V., Ghosh, B., Szeto, W.Y. (2013). Perception of safety of cyclists in Dublin City. *Accident Analysis and Prevention*, 50, pp.499–511. doi:10.1016/j.aap.2012.05.029

Li, Z., Wang, W., Liu, P., Schneider, R., Ragland, D.R. (2012). Investigating Bicyclists' Perception of Comfort on Physically Separated Bicycle Paths in Nanjing, China. *Transportation Research Record,* 2317, pp.76–84. doi:10.3141/2317-10

Lusk, A.C., Wen, X., Zhou, L. (2014). Gender and used/preferred differences of bicycle routes, parking, intersection signals, and bicycle type: Professional middle class preferences in Hangzhou, China. *Journal of Transport and Health*, 1, pp.124–133. doi:10.1016/j.jth.2014.04.001

Ma, L., Dill, J. (2015). Do People's Perceptions of Neighborhood Bikeability Match "Reality"? In: *94th Annual Meeting of the Transportation Research Board TRB*. Available from http://docs.trb.org/prp/15-5739.pdf

Ma, L., Dill, J., Mohr, C. (2014). The objective versus the perceived environment: what matters for bicycling? *Transportation*, 41, pp 1135–1152.

Majumda, B., B., Mitra, S., Pareekh, P. (2015). Methodological Framework to Obtain Key Factors Influencing Choice of Bicycle as a Mode. In: *94th Annual Meeting of the Transportation Research Board TRB*. Available from http://trid.trb.org/view.aspx?id=1339467

Mertens, L., Van Holle, V., De Bourdeaudhuij, I., Deforche, B., Salmon, J., Nasar, J., Van de Weghe, N., Van Dyck, D., Van Cauwenberg, J. (2014). The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: a study using manipulated photographs. *International Journal of Behavioral Nutrition & Physical Activity*, 11, n.p. doi:10.1186/s12966-014-0088-x

Miranda-Moreno, L.F., Nosal, T., Kho, C. 2013. If we clear them, will they come ? A study to identify determinants of winter bicycling in two cold Canadian cities. In: *92nd Annual Meeting of the Transportation Research Board*. Available from http://docs.trb.org/prp/13-3153.pdf

Misra, A., Watkins, K., Le Dantec A, C. (2015). Socio-demographic Influence on Rider Type Self Classification with respect to Bicycling. In: *94th Annual Meeting of the Transportation Research Board TRB*. Available from http://trid.trb.org/view.aspx?id=1339455

Møller, M., Hels, T. (2008). Cyclists' perception of risk in roundabouts. *Accident Analysis and Prevention*, 40, pp.1055–1062. doi:10.1016/j.aap.2007.10.013

Parkin, J., Wardman, M., Page, M. (2007). Models of perceived cycling risk and route acceptability. *Accident Analysis and Prevention,* 39, pp.364–371. doi:10.1016/j.aap.2006.08.007

Petritsch, T., Landis, B.W., Huang, H.F., McLeod, P.S., Lamb, D., Farah, W., Guttenplan, M. (2008). Bicycle Level of Service for Arterials. *Transportation Research Record,* 2031, pp.34–42. doi:10.3141/2031-05

Petritsch, T. a., Ozkul, S., McLeod, P., Landis, B., McLeod, D. (2011). Quantifying Bicyclists' Perceptions of Shared-Use Paths Adjacent to the Roadway. *Transportation Research Record: Journal of the Transportation Research Board,* 2198, pp.124–132. doi:10.3141/2198-14

Ryley, T. (2006). Estimating Cycling Demand for the Journey to Work or Study in West Edinburgh, Scotland. *Transportation Research Record,* 1982, pp.187–193. doi:10.3141/1982-24

Ryley, T.J. (2005). *A study of individual travel behaviour in Edinburgh, to assess the propensity to use non-motorised modes*. Napier University (United Kingdom), Ann Arbor.

Sallis, J.F., Conway, T.L., Dillon, L.I., Frank, L.D., Adams, M. a., Cain, K.L., Saelens, B.E. (2013). Environmental and demographic correlates of bicycling. *Preventive Medicine,* 57, pp.456–460. doi:10.1016/j.ypmed.2013.06.014

Sanders, R.L. (2014). Roadway Design Preferences Among Drivers and Bicyclists in the Bay Area. In: *TRB Annual Meeting Compendium of Papers*. pp. 1–18.

Segadilha, A.B.P., Sanches, S. da P. (2014). Identification of Factors that Influence Cyclistś Route Choice. *Procedia-Social and Behavioral* … 160, pp.372–380.

Sener, I.N., Eluru, N., Bhat, C.R. (2010). Who Are Bicyclists? Why and How Much Are They Bicycling? *Transportation Research Record: Journal of the Transportation Research Board,* 2134, pp.63–72. doi:10.3141/2134-08

Steer Davies Gleave, 2012. *Cycle route choice study*. Transport for London, London.

Steer Davies Gleave, 2010a. *Cycling Behaviour Survey Analysis 2*. Transport for London, London.

Steer Davies Gleave, 2010b. *Cycle Behaviour Survey Analysis 3*. Transport for London, London.

Stinson, M., Bhat, C. (2003). Commuter Bicyclist Route Choice: Analysis Using a Stated Preference Survey. *Transportation Research Record,* 1828, pp.107–115. doi:10.3141/1828-13

Tilahun, N.Y., Levinson, D.M., Krizek, K.J. (2007). Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. *Transportation Research Part A: Policy and Practice*, 41, pp.287–301. doi:10.1016/j.tra.2006.09.007

Tin Tin, S., Woodward, A., Thornley, S., Langley, J., Rodgers, A., Ameratunga, S. (2010). Cyclists' attitudes toward policies encouraging bicycle travel: Findings from the Taupo Bicycle Study in New Zealand. *Health Promotion International*, 25, pp.54–62. doi:10.1093/heapro/dap041

Tiwari, G. (2014). Planning and Designing Transport Systems to Ensure Safe Travel for Women. *International Transport Forum Discussion Paper*, No. 2014-04, Available from http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DP201404.pdf

Twaddle, H., Hall, F., Bracic, B. (2011). Latent Bicycle Commuting Demand and Effects of Gender on Commuter Cycling and Accident Rates. *Transportation Research Record: Journal of the Transportation Research Board*, 2190, pp.28–36. doi:10.3141/2190-04

Van Holle, V., Van Cauwenberg, J., Deforche, B., Goubert, L., Maes, L., Nasar, J., Van de Weghe, N., Salmon, J., De Bourdeaudhuij, I. (2014). Environmental invitingness for transport-related cycling in middle-aged adults: a proof of concept study using photographs. *Transportation Research Part A: Policy and Practice*, 69, pp.432–446. doi:10.1016/j.tra.2014.09.009

Vliet, J. (2014). *How many wheels will it be today? An exploratory research into variables useful for modeling bicycle mode choice with a discrete choice model*. MSc Thesis, University of Twente, Enschede. Available from http://essay.utwente.nl/65179/

Wahlgren, L., Schantz, P. (2011). Bikeability and methodological issues using the active commuting route environment scale (ACRES) in a metropolitan setting. *BMC Medical Research Methodology*, 11, 6. doi:10.1186/1471-2288-11-6

Wardman, M., Tight, M., Page, M. (2007). Factors influencing the propensity\nto cycle to work. *Transportation Research A,* 41, pp.339–359.

Wardman, M. ; Nash, C. ; Tight, M. (2001). *Cycling and urban mode choice*. Published Proceedings of the World Conference on Transport Research, Seoul, Korea.

Westerdijk, P.K. (1990). *Pedestrian and Pedal Cyclist Route Choice Criteria*. Working Paper. Institute of Transport Studies, University of Leeds, Leeds. Available from http://eprints.whiterose.ac.uk/2257/

Winters, M., Teschke, K. (2010). Route preferences among adults in the near market for bicycling: Findings of the cycling in cities study. *American Journal of Health Promotion*, 25, pp.40–47. doi:10.4278/ajhp.081006-QUAN-236

Wooliscroft, B., Ganglmair-Wooliscroft, A. (2014). Improving conditions for potential New Zealand cyclists: An application of conjoint analysis. *Transportation Research Part A: Policy and Practice*, 69, pp. 11–19.

Additional works cited

Asadi-Shekari, Z., Moeinaddini, M., Zaly Shah, M. (2013). Non-motorised Level of Service: Addressing Challenges in Pedestrian and Bicycle Level of Service. *Transport Reviews*, 33, pp.166–194. doi:10.1080/01441647.2013.775613

Van Bekkum, Elizabeth, J. (2011). *Understanding and encouraging cycle commuting in workplace setting: a psychological perspective*. The University of Edinburgh (United Kingdom), Ann Arbor.

Bergström, A., Magnusson, R. (2003). Potential of transferring car trips to bicycle during winter. *Transportation Research Part A: Policy and Practice*, 37, pp.649–666. doi:10.1016/S0965-8564(03)00012-0

Daley, M., Rissel, C., Lloyd, B. (2007). All dressed up and nowhere to go? A qualitative research study of the barriers and enablers to cycling in inner Sydney. *Road and Transport Research*, 16, pp.42–52.

Damant-Sirois, G., El-Geneidy M, A. (2015). Who cycles more? Determining cycling frequency through a segmentation approach in Montreal, Canada. *Transportation Research Part A: Policy and Practice*, 77, pp.113-125.

Davies, D.G., Halliday, M.E., Mayes, M., Pocock, R.L. (1997). *Attitudes to cycling: a qualitative and conceptual framework*. Berkshire: TRL.

Fietsberaad. (2007). Fietsberaad Publication 11b. *The effect of the increase in the number of immigrants and aging on bicycle use*, Otto Boggelen (Fietsberaad) and Robert Jones (Goudappel Coffeng). Utrecht, Fietsberaad.

Finch, H., Morgan, J.M. (1985). *Attitudes To Cycling*, TRRL Research Report. Berkshire.

Habib, K.N., Mann, J., Mahmoud, M., Weiss, A. (2014). Synopsis of bicycle demand in the City of Toronto: Investigating the effects of perception, consciousness and comfortability on the purpose of biking and bike ownership. *Transportation Research Part A: Policy and Practice*, 70, pp.67–80. doi:10.1016/j.tra.2014.09.012

Harms, L., Bertolini, L. and te Brömmelstroet, M. (2014). Spatial and social variations in cycling patterns in a mature cycling country exploring differences and trends. *Journal of Transport & Health*, 1(4), pp.232–242

Oxley A, J., Corben F, B., Charlton L, J., Fildes N, B., Rothengatter A, J. (2005). Creating a Safe Environment for Older Cyclists: Lessons Learnt from a Review of Worlds Best Practice Measures. p. 12p.

Pooley, C.G., Horton, D., Scheldeman, G., Mullen, C., Jones, T., Tight, M., Jopson, A., Chisholm, A. (2013). Policies for promoting walking and cycling in England: A view from the street. *Transport Policy,* 27, pp.66–72. doi:10.1016/j.tranpol.2013.01.003

Steinbach, R., Green, J., Datta, J., Edwards, P. (2011). Cycling and the city: A case study of how gendered, ethnic and class identities can shape healthy transport choices. *Social Science and Medicine*, 72, 1123–1130. doi:10.1016/j.socscimed.2011.01.033

Transport for London. (2014). *London Cycling Design Standards*. London: TfL. Available from: https://tfl.gov.uk/corporate/publications-and-reports/cycling

Velasco, L., Rojo, M., Gonzalo-Orden, H., Diez, J.M. (2015). Safety issues with elderly cyclists and barriers to cycling. *Proceedings of the ICE - Municipal Engineer,* 68, 87–95. doi:http://dx.doi.org/10.1680/muen.14.00003

Walker, I., Garrard, I., Jowitt, F. (2014). The influence of a bicycle commuter's appearance on drivers' overtaking proximities: an on-road test of bicyclist stereotypes, high-visibility clothing and safety aids in the United Kingdom. *Accident Analysis and Prevention,* 64, pp.69–77. doi:10.1016/j.aap.2013.11.007

Winters, M., Sims-Gould, J., Franke, T., McKay, H. (2014). "I grew up on a bike": Cycling and older adults. *Journal of Transport & Health*, 2, pp.58–67.

Further Protocol Details

Revised search terms, March 2015

P terms: bike$ OR bicycle$ OR bicycling OR bicyclist$ OR cycle OR cyclist$ OR cycling OR "active travel" OR "active transport" OR "non-motorised modes" OR "non-motorised transport" OR "non-motorized modes" OR "non-motorized transport" OR ride* OR riding (NOT "life-cycle" OR "life-cycles" OR "menstrual-cycle" OR "menstrual-cycles" OR "menstrual-cycling" OR "cycle-phase" OR "regulated-cycle" OR "ulster-cycle" OR "amadis-cycle" OR "earthquake-cycle" OR "world-cycles" OR "christi-cycles" OR "cardiac-cycle" OR "reproduction-cycle" OR "reproductive-cycle" OR "aging-cycle" OR "sexual-cycle" OR "water-cycle" OR "seasonal-cycle" OR "cell-cycle" OR "night-cycle" OR "day-cycle" OR "isotopes-cycle" OR "hormonal-cycle" OR "vicious-cycle" OR "sea-level cycle" OR "feeding-cycle" OR "estrous-cycle" OR "estrus-cycle" OR "second-cycle" OR "hidden-cycle" OR "the-cycle" OR "cycle-of" OR "business-cycle" OR "business-cycles" OR "astrand-cycle" OR "Krebs-cycle" OR "poverty-disease-cycle" OR "career-cycle" OR "extended-cycle" OR "fuel-cycle" OR "treatment-cycle" OR "gait-cycle" OR "modelling cycle" OR "production-cycle") AND **I terms:** infrastructure OR track$ OR lane$ OR "off-road" OR "off-street" OR "on-road" OR "on-street" OR junction$ OR box OR ASL OR "traffic calming" OR "traffic reduction" OR "traffic removal" OR boulevard$ OR filter* OR "road closure" OR greenway$ OR residential OR segregat* OR protected OR painted OR path$ OR facility OR facilities AND C terms: sex OR gender$ OR age* OR children OR men OR women OR male$ OR female$ OR older OR younger OR elderly AND **O terms:** prefer* OR choice$ OR choosing OR decision$ OR attitud* OR view* OR willing*

Summary of literature searches for DfT REA, March 2015

Resources (in order searched)	Description	Date searched	Search terms	No. of records retrieved
EBSCO (Business Source Complete, EconLit, Greenfile, Medline)	Business Source Complete- over 10,000 full text journals covering all areas of business. EconLit-Index of journal	12 March	TI (bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR "active travel" OR "active transport" OR "non-motorised modes" OR "non-motorised transport" OR "non-motorized modes" OR "non-motorized	2

	articles, books and working papers in all areas of economics. Greenfile- Index to journal articles on all aspects of human impact to the environment. Medline- Index of journal articles covering a range of medical topics relating to research, clinical practice, policy, and health care services.		transport”) NOT TI (see above) AND TI (sex OR gender OR age* OR children OR men OR women OR male OR female OR older OR younger OR elderly) AND TI (prefer* OR choice OR choosing OR decision OR attitud* OR view* OR willing*)	
			TI (bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR “active travel” OR “active transport” OR “non-motorised modes” OR “non-motorised transport” OR “non-motorized modes” OR “non-motorized transport”) NOT TI (see above) AND TI (infrastructure OR track OR lane OR “off-road” OR “off-street” OR “on-road” OR “on-street” OR junction OR box OR ASL OR “traffic calming” OR “traffic reduction” OR “traffic removal” OR boulevard OR filter* OR “road closure” OR greenway OR residential OR segregat* OR protected OR painted OR path OR facility OR facilities) AND TI (prefer* OR choice OR choosing OR decision OR attitud* OR view* OR willing*)	5
			TI (bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR “active travel” OR “active transport” OR “non-motorised modes” OR “non-motorised transport” OR “non-motorized modes” OR “non-motorized transport”) NOT TI (see above) AND TI (infrastructure OR track OR lane OR “off-road” OR “off-street” OR “on-road” OR “on-street” OR junction OR box OR ASL OR “traffic calming” OR “traffic reduction” OR “traffic removal” OR boulevard OR filter* OR “road closure” OR greenway OR residential OR segregat* OR protected OR painted OR path OR facility OR facilities)	2

			AND TI (sex OR gender OR age* OR children OR men OR women OR male OR female OR older OR younger OR elderly)	
			TI (bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR “active travel” OR “active transport” OR “non-motorised modes” OR “non-motorised transport” OR “non-motorized modes” OR “non-motorized transport”) NOT TI (see above) AND AB (sex OR gender OR age* OR children OR men OR women OR male OR female OR older OR younger OR elderly) AND AB (prefer* OR choice OR choosing OR decision OR attitud* OR view* OR willing*)	47
			TI (bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR “active travel” OR “active transport” OR “non-motorised modes” OR “non-motorised transport” OR “non-motorized modes” OR “non-motorized transport”) NOT TI (see above) AND AB (infrastructure OR track OR lane OR “off-road” OR “off-street” OR “on-road” OR “on-street” OR junction OR box OR ASL OR “traffic calming” OR “traffic reduction” OR “traffic removal” OR boulevard OR filter* OR “road closure” OR greenway OR residential OR segregat* OR protected OR painted OR path OR facility OR facilities) AND AB (sex OR gender OR age* OR children OR men OR women OR male OR female OR older OR younger OR elderly)	78
			TI (bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR “active travel” OR “active transport” OR “non-motorised modes” OR “non-motorised	103

			transport” OR “non-motorized modes” OR “non-motorized transport”) NOT TI (see above) AND AB (infrastructure OR track OR lane OR “off-road” OR “off-street” OR “on-road” OR “on-street” OR junction OR box OR ASL OR “traffic calming” OR “traffic reduction” OR “traffic removal” OR boulevard OR filter* OR “road closure” OR greenway OR residential OR segregat* OR protected OR painted OR path OR facility OR facilities) AND AB (prefer* OR choice OR choosing OR decision OR attitud* OR view* OR willing*) Total records (without duplicates)	 170
Web of Science	Indexes of journal articles and more, including Web of Science (Science Citation Index, Social Sciences Citation Index, Arts & Humanities Citation Index), ISI Proceedings, MEDLINE and Journal Citation Reports.		(bike$ OR bicycle$ OR bicycling OR bicyclist*OR cycle OR cyclist* OR cycling OR active travel OR active transport OR non-motorised modes OR non-motorised transport OR non-motorized modes OR non-motorized transport) NOT TOPIC: (see above) AND TOPIC: (infrastructure OR track$ OR lane$ OR “off-road” OR “off-street” OR “on-road” OR “on-street” OR junction$ OR box OR ASL OR “traffic calming” OR “traffic reduction” OR “traffic removal” OR boulevard$ OR filter* OR “road closure” OR greenway$ OR residential OR segregat* OR protected OR painted OR path$ OR facility OR facilities) AND TOPIC: (sex OR gender$ OR age OR children OR men OR women OR male OR female OR older OR younger OR elderly) AND TOPIC: (prefer* OR choice* OR choosing OR decision OR attitud* OR view* OR willing*)	121
ProQuest Dissertations &	A comprehensive listing of theses with abstracts accepted for higher		ti(bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR "active travel" OR "active transport" OR "non-motorised	8

Theses - UK and Ireland	degrees by universities in the United Kingdom and Ireland since 1716. Links to full-text where available online.		modes" OR "non-motorised transport" OR "non-motorized modes" OR "non-motorized transport") AND ab(sex OR gender OR age OR children OR men OR women OR male OR female OR older OR younger OR elderly) AND ab(prefer* OR choice OR choosing OR decision OR attitude* OR view* OR willing*) NOT ti,ab(see above)	4
			ti(bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR "active travel" OR "active transport" OR "non-motorised modes" OR "non-motorised transport" OR "non-motorized modes" OR "non-motorized transport") AND ab(infrastructure OR track OR lane OR "off-road" OR "off-street" OR "on-road" OR "on-street" OR junction OR box OR ASL OR "traffic calming" OR "traffic reduction" OR "traffic removal" OR boulevard OR filter* OR "road closure" OR greenway OR residential OR segregat* OR protected OR painted OR path OR facility OR facilities) AND ab(sex OR gender OR age OR children OR men OR women OR male OR female OR older OR younger OR elderly) NOT ti,ab(see above)	11
			ti(bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR "active travel" OR "active transport" OR "non-motorised modes" OR "non-motorised transport" OR "non-motorized modes" OR "non-motorized transport") AND ab(infrastructure OR track OR lane OR "off-road" OR "off-street" OR "on-road" OR "on-street" OR junction OR box OR ASL OR "traffic calming" OR "traffic reduction" OR "traffic removal" OR boulevard OR filter* OR "road	10

			closure" OR greenway OR residential OR segregat* OR protected OR painted OR path OR facility OR facilities) AND ab(prefer* OR choice OR choosing OR decision OR attitude* OR view* OR willing*) NOT ti,ab(see above) ti(bike OR bicycle OR bicycling OR bicyclist OR cycle OR cyclist OR cycling OR "active travel" OR "active transport" OR "non-motorised modes" OR "non-motorised transport" OR "non-motorized modes" OR "non-motorized transport") AND ab,ft(sex OR gender OR age OR children OR men OR women OR male OR female OR older OR younger OR elderly) AND ab,ft(prefer* OR choice OR choosing OR decision OR attitude* OR view* OR willing*) NOT ti,ab,ft(see above) Total records (without duplicates)	 10 21
PubMed	300,000+ references are added annually from 3,000+ international journals. Equivalent to INDEX MEDICUS. References with abstracts to biomedical literature including research and clinical practice, administration, policy issues and health care services.		(((((bike[Title] OR bikes[Title] OR bicycle[Title] OR bicycles[Title] OR bicycling[Title] OR bicyclist*[Title] OR cycle[Title] OR cyclist*[Title] OR cycling[Title] OR “active travel”[Title] OR “active transport”[Title] OR “non-motorised modes”[Title] OR “non-motorised transport”[Title] OR “non-motorized modes”[Title] OR “non-motorized transport”[Title])) NOT (see above)) AND (infrastructure[Title/Abstract] OR track[Title/Abstract] OR tracks[Title/Abstract] OR lane[Title/Abstract] OR lanes[Title/Abstract] OR “off-road”[Title/Abstract] OR “off-street”[Title/Abstract] OR “on-road”[Title/Abstract] OR “on-street”[Title/Abstract] OR junction[Title/Abstract] OR junctions[Title/Abstract] OR box[Title/Abstract] OR	

			"ASL"[Title/Abstract] OR “traffic calming”[Title/Abstract] OR “traffic reduction”[Title/Abstract] OR “traffic removal”[Title/Abstract] OR boulevard[Title/Abstract] OR boulevards[Title/Abstract] OR filter*[Title/Abstract] OR “road closure”[Title/Abstract] OR greenway[Title/Abstract] OR greenways[Title/Abstract] OR residential[Title/Abstract] OR segregat*[Title/Abstract] OR protected[Title/Abstract] OR painted[Title/Abstract] OR path[Title/Abstract] OR paths[Title/Abstract] OR facility[Title/Abstract] OR facilities[Title/Abstract])) AND (sex[Title/Abstract] OR gender[Title/Abstract] OR genders[Title/Abstract] OR age[Title/Abstract] OR aged[Title/Abstract] OR ages[Title/Abstract] OR child*[Title/Abstract] OR men[Title/Abstract] OR women[Title/Abstract] OR male[Title/Abstract] OR males[Title/Abstract] OR female[Title/Abstract] OR females[Title/Abstract] OR older[Title/Abstract] OR younger[Title/Abstract] OR elderly[Title/Abstract])) AND (prefer*[Title/Abstract] OR choice[Title/Abstract] OR choices[Title/Abstract] OR choosing[Title/Abstract] OR decision[Title/Abstract] OR decisions[Title/Abstract] OR attitud*[Title/Abstract] OR view*[Title/Abstract] OR willing*[Title/Abstract]) Filters: Publication date from 1990/01/01 to 2015/12/31	
			Total records (without duplicates)	41

TRID	TRID is a newly integrated database that combines the records from TRB's Transportation Research Information Services (TRIS) Database and the OECD's Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database. TRID provides access to over 900,000 records of transportation research worldwide.		You searched with subject: Pedestrians and Bicyclists and with index term: Bicycle facilities, Bikeways, Bicycle commuting, Bicycle lanes, Bicycle travel, Sidewalks, Traffic calming, Infrastructure, Filters, Greenways, Segregation (Aggregates), Facilities, Environment and with result type: Articles and papers with keywords containing prefer* OR choice* OR choosing OR decision* OR attitud* OR view* OR willing* and with title containing bike* OR bicycle* OR bicycling OR bicyclist* OR bicyclists' OR cycle OR cyclists OR cycling OR "active travel" OR "active transport" OR "non-motorised modes" OR "non-motorised transport" OR "non-motorized modes" OR "non-motorized transport" OR ride* OR riding between dates 1990 – 2015 You searched with subject: Pedestrians and Bicyclists and with index term: Bicycle facilities, Bikeways, Bicycle commuting, Bicycle lanes, Bicycle travel, Sidewalks, Traffic calming, Infrastructure, Filters, Greenways, Segregation (Aggregates), Facilities, Environment and with result type: Articles and papers with keywords containing sex OR gender* OR age* OR child* OR men OR women OR male* OR female* OR older OR younger OR elderly and with title containing bike* OR bicycle* OR bicycling OR bicyclist* OR bicyclists' OR cycle OR cyclists OR cycling OR "active travel" OR "active transport" OR "non-motorised modes" OR "non-motorised transport" OR "non-motorized modes" OR "non-motorized transport" OR ride* OR riding between dates 1990 - 2015 Total records (without duplicates)	573

ARRB Knowledge Base			P and C terms and P and O terms Total records (without duplicates)	 10

Summary of grey literature searches for DfT REA, March 2015

Resources (in order searched)	Description	Date searched	Search terms	No. of records retrieved (first 2 pages or 20 pdfs imported to Mendeley)
Danish Transport Research Institute	www.transport.dtu.dk	20 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR attitude OR view OR willing) site:www.transport.dtu.dk filetype:ashx	27
Department for Transport (UK)	www.gov.uk	23 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR attitude OR view OR willing) site:www.gov.uk filetype:pdf	3,340
New York City Department of Transportation	www.nyc.gov	23 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR attitude OR view OR willing) site:www.nyc.gov filetype:pdf	2,820
National Highway Traffic Safety Administration	www.nhtsa.dot.gov	23 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR	47

			attitude OR view OR willing) site:www.nhtsa.dot.gov filetype:pdf	
Pedestrian and Bicycle Information Centre	www.bicyclinginfo.org	20 March	(bike OR bicycle OR bicycling OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR attitude OR view OR willing) site:www.bicyclinginfo.org filetype:pdf	2
Portland Department of Transportation	www.portlandoregon.gov/transportation	23 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR attitude OR view OR willing) site:www.portlandoregon.gov/transportation	572
Swedish Transport Administration	www.trafikverket.se	20 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR attitude OR view OR willing) site:http://www.trafikverket.se filetype:pdf	24
TC- Transport Canada	www.tc.gc.ca	20 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR	54

			attitude OR view OR willing) site:www.tc.gc.ca filetype:pdf	
Transport for London	www.tfl.gov.uk	20 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR attitude OR view OR willing) site:www.tfl.gov.uk filetype:pdf	806
TRL- Transport Research Laboratory (UK)	www.trl.co.uk	23 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger OR elderly) (prefer OR choice OR decision OR attitude OR view OR willing) site:www.trl.co.uk filetype:pdf	807
Google scholar (last year)		20 March	(bike OR bicycle OR bicycles OR cyclist OR cycling OR "active transport" OR "active travel" OR "non-motorised modes") (sex OR gender OR age OR child OR male OR female OR older OR younger) (preference OR choice OR decision OR attitude OR view OR willing) Articles added in the last year, sorted by date (searching abstracts)	117
OpenSigle	www.opengrey.eu	23 March	(bike OR bicycle OR bicycling OR bicyclist OR cycling OR cyclist OR "active transport" OR "active travel" OR "non-motorised modes") AND (sex OR gender OR age OR child OR prefer OR choice OR decision OR attitude OR view OR willing) discipline:(05V - Urban planning, rural planning, transport planning, countryside conservation)	13

Table Synthesis of Studies

Study characteristics

Citationkey	Country	Population	Sample Size	Sample type	Sample method	Sample quality	Situations
Akar2013/Akaretal2013	US	Ohio State University students, faculty, staff	2000	Both (cyclists and non-cyclists)	Random sample of students and staff at Ohio State University were emailed a survey link. The survey link was also posted on the University's traffic and parking webpage.	3	Lack of bike lanes, paths and trails' as impediment to biking

Aldred 2015	UK	Mostly cyclists in UK. Similarities and differences here refer to adults' views about cycling with and by children at various ages, and vs. cycling solo.	1958	Both	Convenience sample obtained by circulating a link to an online questionnaire survey amongst a range of online networks (including two national cycling organisations) and cyclists on three busy commuter cyclist routes and on several organised rides in London.	2	10 scenarios with varying quality infrastructure/interactions with motor traffic

Antonakoset al1995	US	552 cyclists at four recreational bike tours in Michigan	552	Cyclists	Convenience sample of cyclists at four recreational bicycle tours in Michigan. Recreational bike tours were chosen for their opportunity to survey a large group of cyclists at a single location. Surveys were distributed where large crowds of cyclists were expected to assemble such as planned rest stops.	2	Asked to rate 6 'corridor types' (e.g. 'bike lane', wide curb lane, bike path', 'trail') alongside route characteristics including 'smooth pavement', 'scenery', 'safety'
Berggrenetal 2012	US	Portland cyclists	39	Cyclists	Convenience sample of intercepted cyclists using a segment of a bikeway in Portland, US. The segment was one of eight which together made up the '20s Bikeway' study area examined by Masters students at Portland State University.	1	Asked to rate (a) street characteristics, e.g. 'low traffic', 'avoids hills', and (b) bicycle infrastructure alternatives, e.g. 'bike sharrows', 'cycle track', 'bike box'

Bergström2000	Sweden	122 people at two workplace locations in Linköping	122	Cyclists	Convenience sample of 122 cyclists stopped at two workplaces	2	In relation to winter maintenance, cyclists asked to rate condition of road surface e.g. slipperiness.
Bernhoftetal 2008	Denmark	Pedestrians and cyclists aged 40-49 and 70+ in two provincial cities in Denmark	1905	Both	Purposeful sample of pedestrians and cyclists aged 40-49 and 70+. Questionnaire was sent to 850 older people and 850 people aged 40–49 in each of two provincial cities in Denmark during 2001. The respondents were randomly selected from addresses within a well-defined area of the cities.	4	Asked to rate 'conditions of importance' for well-being as a cyclist and for cycle route choice (factors included cycle paths, smooth surface, signalised crossing)

Borjessonetal2012	Sweden	Cyclists in Stockholm	756	Cyclists	Convenience sample of intercepted cyclists in Stockholm. The survey was handed out to cyclists during peak hours (7–10 and 15–18) at signalized intersections in the city center and on the roads leading to the city center, together with prepaid response envelopes.	2	Asked to compare bike path vs street in terms of utility

Bricketal2012	Ireland	Cyclists and non-cyclists in Dublin	1941	Both	1,941 people employed in businesses participating in the Smarter Travel Workplaces initiative managed by the Irish National Transport Authority. The businesses are all located within an 8km (5 miles) radius of the city centre. Not stated how respondents contacted/chosen for inclusion.	3	Asked to make trade-off between different infrastructure situations and trip times; situations include bus/cycle lanes, parks/quiet residential streets (combined option), on road cycle lane, off road cycle track.

Caulfield2015	Ireland	Tourists at two locations in Dublin	282	Both	Convenience sample of tourists intercepted at two locations in Dublin, Ireland. Dublin city (and the two intercept locations) were chosen for their proximity to a number of key tourist attractions and their potential to attract a large representative sample of tourists.	2	Asked to choose between options including time, weather, gradient, and infrastructure; infrastructure included three choices: road without cycle infrastructure, road with cycle lanes, cycleway fully segregated from traffic.
Changetal2008	Taiwan	Students and parents at Taiwan schools in urban and suburban areas	1610	Both	Random sampling led to the choice of two junior high schools to determine cycling difficulties and the abilities of students 13 to 15 years old. Not stated how students were recruited.	3	Asked to judge whether they could safely ride their bicycle in a range of situations including e.g. with trucks on the road, with heavy traffic on the road, when turning to the left (right in UK)

Chatawayetal2014	Australia/Denmark	Cyclists targeted through university networks and cycling forums in Brisbane and Copenhagen. Fliers left on bikes in Copenhagen to advertise survey	894	Cyclists	Convenience sample of cyclists in Brisbane (Australia) as an emerging cycling city, and Copenhagen (Denmark) as an established cycling city. The two cities were chosen based on their similarities in terms of population numbers and density in the core, economic status, bicycle infrastructure and prevelance of promotional campaigns and programs to encourage cycling aqnd differences in the bicycle mode share of commuting trips. The survey was administered among cyclists in the two cities through university networks and cyclist forums.	2	Asked to agree/disagree with range of questions on preferences and cycling behaviour, including most relevantly 'use other modes when no segregated paths'

dell'Olioetal2014	Spain	117 self classified potential bike users in Santander	117	Non-cyclists	Household travel survey used to identify and conduct SP survey of potential bicycle users in the city of Santander (Spain).	2	People asked about conditions needed to enable bike trips, including related to weather, lack of slopes, and presence of cycle paths.
Dickinsonetal2003	UK	Employees at three organisations in Hertfordshire	2065	Both	Employees at three companies in Hertfordshire, UK. The settlements in which the organisations were based were all characteristic of Hertfordshire where there are no major cities. Questionnaires were attached to employees' payslips and distributed over the autumn, winter and spring 1998/99.	4	Asked what measures would help reduce use of car (inc more cycle paths, more cycle facilities as options) and 'if you lived near enough to cycle, what would encourage you to cycle to work' inc 'improved cycle paths on way to work', 'less traffic'.

Dilletal2012	US	Residents in Portland	908	Both	Random phone survey of adults in the Portland region that included both land-line and mobile phone numbers; data were weighted to better reflect the population. Adults	4	Categorisation of people based on 'comfort and interest' (No way no how, interested but concerned, enthused and confident, strong and fearless) - based on criteria including how comfortable would feel cycling on non-residential streets with or without bike lanes. While detailed questions on facility types are not broken down by gender, the four-way classification is, providing information on gender and age differences

Dilletal2015	US	Cyclists and residents in five large US cities (Cyclists and non cyclists)	3494	Both	Convenience sampling of cyclists intercepted on nine new protected bike lanes in five large U.S. cities: Austin, TX; Chicago, IL; 27 Portland, OR; San Francisco, CA; and Washington, D.C (all of which participated in the inaugural 28 "Green Lane Project" sponsored by People for Bikes) and random sample of household addresses within a specific boundary (up to a quarter mile) of each study facility.	4	Questions about views on recently installed protected lanes; stated preference question asks about feelings of comfort on different types of cycling environment including 'path or trail separate from the street' and 'commercial street, two lanes of traffic in each direction, traffic speeds of 35 mph, on-street car parking' under three conditions - no bikeway, striped bikeway, physically separated bikeway.

Emondetal2009	US	Random sample of residents in six small cities in the US	657	Both	Random sample of residents in six different communities were each mailed a letter that invited them to participate in the on-line survey. Davis, (California) and five communities that were similar to Davis with respect to size, topography, and weather but differ from Davis with respect to bicycle infrastructure and culture were selected for the survey. Davis was chosen as the relevant model because of its high level of bicycling, not only encouraged by its flat terrain, moderate weather, and large university, but also supported by a city council that has invested in bicycle infrastructure.	4	Asked about cycling comfort levels for different cycling environments: off-street path, quiet street, two lane local street with and without bike lane, four lane local street with and without bike lane

Gardner1998	UK	Leisure cyclists, non-cyclists and utility cyclists in different areas of England	500	Both	Short face-to-face survey interviews with convenience sample intercepted at three locations chosen to give a range of cyclist types; complemented with (a) short survey interviews with non-cyclists living near one of the sites (not specified how recruited) and (b) in-depth interviews with selected cyclists.	2	In quantitative survey, asked about (a) whether people would cycle on different types of road, with and without a cycle lane and (b) facilities thought likely to encourage utility cycling (including more parking, more cycle routes). Qualitative interviewees asked to discuss improvements needed to encourage utility cycling.

Ghekiereetal 2014	Belgium	35 children aged 10 to 12 years old in (semi-)urban areas in Flanders. Similarities and differences refer to parents vs. childrens' views on child cycling.	70	Cyclists	Purposeful convenience sample of 35 children (10-12 years of age) and one of their parents residing in (semi-) urban areas. Participants were recruited by face-to-face contact or by telephone until theoretical saturation. The aim was to include both regular and non-regular cyclists and both boys and girls.	2	Short survey questionnaire (not stated preferences) plus (a) bike-along interviews where children and parents, riding in front of researcher, spoke about experiences in relation to the cycling environment (while being recorded) and (b) discussions with children and parents based on these recordings.

Ghekiereetal 2015	Belgium	305 fifth and sixth grade children and their parents from twelve randomly selected primary schools in Flanders, Belgium. Here differences and similarities refer to children's vs. parental preferences about child cyclin	305	Both	Twenty randomly chosen primary schools located across Flanders (Belgium) were contacted by telephone and asked to participate in the study; twelve schools agreed to participate. Pupils from 5th and 6th grade in each school received an invitation letter for their parents to give consent for them to participate in the study (parents themselves were also invited to participate separately). Children were assisted by researchers in completing the online questionnaire.	4	Manipulated photographs used with e.g. different levels of segregation (paint, kerb, hedge)

Heeschetal2012	Australia	Adult cyclists in Queensland who were members of Bicycle Queensland (BQ) club	1862	Cyclists	Convenience sample of adult cyclists in Queensland who were members of Bicycle Queensland (BQ) club, a state-wide community organization that promotes recreational and transport cycling, organizes community bike rides for all levels of cycling ability and advocates for better cycling facilities and improved safety. As found for Australian cyclists more broadly, most members cycle only for recreation, with less than half cycling for transport.BQ sent email invitations, with a link to the survey, to the 'primary members' of member households, to encourage all adult BQ members of the household to participate.	2	Respondents were asked (a) what types of cycling facilities they had used in the past week and (b) what types of cycling facilities they preferred to use (off-road / on-road designated cycle lane / on-road). Qualitative data was also gathered and coded, through the use of an open-ended survey question.

Hughesetal1997	US	Twenty-three (23) casual and 12 experienced cyclists	35	Cyclists	Twenty-three (23) casual and 12 experienced cyclists served as subjects for the study.' - not stated how recruited.	1	Casual and experienced bicyclists were immersed in a ‘virtual’ or computer-generated simulation of a two-lane roadway environment in order to elicit ratings of the perceived risk associated with various lane conditions as well as different vehicle speeds and volumes. Ratings were made under cyclist, driver, and roadside viewing conditions. Ratings were elicited of the perceived risk associated with the traffic speed, traffic volume, and curb lane characteristics of 16 different test conditions representing two levels of traffic speed, two levels of traffic volume, and four curb lane configurations (none involving separation).

Huntetal2007	Canada	Cyclists in Edmonton	1,128.00	Cyclists	Convenience sample of cyclists throughout the Edmonton area. Questionnaire forms were handed to cyclists or attached to parked bicycles throughout the Edmonton area. The investigation was to support the development of a sub-model which could contribute to a larger modelling effort concerning all passenger travel in Edmonton.	2	Stated preference experiment including a range of factors (e.g. bike parking). Hunt and Abraham state (page 458) that 'The 'in mixed traffic', 'bike lane' and 'bike path' categories for cycling facility were adopted in this work, in part to be consistent with previous work and with designations in Edmonton; but also because it was felt that more detailed categorisations would be too unwieldy given the survey method chosen.'

Krizeketal2005	US	Secondary data from five surveys: two were SP surveys, one of 'current and potential cyclists' and one of current cyclists, in Minnesota (292 and 127 people) - the second survey is also reported in Krizek 2006	419	Both	Two stated-preference datasets were used. For the Minnesota Department of Transportation Statewide Omnibus survey, data were originally collected by a telephone survey from a random sample of Minnesota residents 18 years or older. The second stated-preference data set was a computer- based adaptive stated-preference (ASP) survey administered by Tilahun et al. whose sample was composed of civil service employees from the University of Minnesota, aged 18 years or older, who reported using a bicycle in the past year (n = 127, 85 women and 42 men). Sampling method not stated.	3	In the Omnibus survey, participants were asked to rate importance of range of amenities and facilities, including on-road bicycle lanes, separate bicycle paths, and a connected system of bicycle routes. Each respondent was presented with nine scenarios comparing two facilities for four sets of travel times, with the choice experiment adapting in response to the respondent's choices.

Landisetal1997	US	150 cyclists aged 13+ in Tampa, Florida	150	Cyclists	Convenience sampling of cyclists recruited using a broad-based, area-wide, multimedia approach that included newspaper notices and articles, radio announcements, direct mailings by numerous organi- zations and businesses, and brochure-registration form distribution. The nearly 150 bicyclists who completed the course represented a good cross section of age, gender, experience level, and geographic origin. Due to the potential hazards of riding in urban-area motor vehicle traffic, children younger than age 13 were not allowed to participate in the study. The gender split of the study group was 47 percent female and 53 percent male. The researchers also sought participant diversity in both	2	Participants rode an on-road course (with different lane widths, bicycle-facility types, and striping conditions) during busy traffic conditions and filled in response cards along the way rating different sections. The width of outside motor vehicle through-lanes ranged from 3.05 to 4.88 m (10 to 16 ft). Striped bike lanes and paved shoulders ranged from nonexistent to 1.83-m (6-ft) wide.

					geographic origins and cycling experience, or skill level. Accordingly, the study test course was located in Tampa, Florida, a metropolitan area with significant in-migration. There was a considerable range of cycling experience among the participants.		

Landisetal2003	US	60 cyclists aged 13+ in Orlando, Florida	59	Cyclists	Convenience sampling of Florida cyclists solicited through newspaper notices and registration displays at bike shops, colleges, trailheads, and public buildings.	1	2002 "Ride for Science" using planned course through existing intersections; participants evaluated on the 6-point scale how well they were served (how comfortable or safe they felt) as they traveled through each intersection.

Lawsonetal2013	Ireland	Cyclists, who regularly cycled in Dublin within the previous 12 months, 1954 responses	1954	Cyclists	Convenience sampling of existing cyclists, who regularly cycled in Dublin within the previous 12 months. The questionnaire was distributed among major Irish and multi-national companies, major universities in Dublin, governmental departments and through word of mouth. The questionnaire was also available on-line; the link to which was circulated via e-mail, posts on cycle club and group web- sites, cycling forums, and posts on social networking web-sites. Hardcopies of the questionnaire were available from local cycle repair shops and from the authors, upon request.	2	Survey designed to create model predicting whether a participant believes that cycling is safer than driving in Dublin city; independent variables on which information was collected include safety behaviour and facility preferences.

Lietal2012	China	805 cyclists in the metropolitan area of Nanjing	805	Cyclists	Convenience sample of intercepted cyclists at selected segments of separated bicycle paths in the Metropolitan area of Nanjing, China. The research team selected 29 segments of separated bicycle paths that covered a wide range of path widths and diverse environmental conditions. The investigators distributed the questionnaires to bicyclists near them. Assuming the arrival of bicycles follows a random process, the sampling of bicyclists in this study was supposed to be random.	2	Cyclists were asked to rate on a 1-5 scale from “it is terrible” to “it is excellent” the path they were using in terms of comfort and how favourably they viewed using the facility.

Lusketal2014	China	1150 adults in Hangzhou	1150	Both	Convenience sample of adults who were reached through the middle school students in their family. 32 middle schools (students 14–15 years of age) in Hangzhou were provided with information about the study, objective, and research plan, and 12 schools replied they would like to be included in the study. Researchers selected 8 schools from 4 districts (2 schools from 1 district each). From these schools, 3–4 classes with approximately 150 students each were randomly chosen. Each student took a questionnaire to be filled out by an adult in their family, and the signed consent forms plus the completed survey were returned by the student.	3	Cyclists in the study (around half) were asked to say what % of their time they spent riding on cycle tracks, on shared-use paths, or on painted cycle lanes (next to car parking or not), or on road, and which they preferred.

Maetal2014/ Ma et al 2015	US	Random phone survey of 902 adults in Portland, Oregon region	902	Both	Random phone survey of adults in the Portland, Oregon region. The sample included both land-line and mobile phone numbers to help reduce sample bias.	4	For perception of bikeability, the authors included the following indicators in the factor analysis: (1) “There are off-street bike trails or paved paths in or near my neighborhood that are easy to get to”; (2) “There are bike lanes that are easy to get to”; (3) “There are quiet streets, without bike lanes, that are easy to get to on a bike”; (4) “There is so much traffic along nearby streets that it would make it difficult or unpleasant to bike”; (5) “Many of the places I need to get to regularly are within biking distance of my home”; (6) “How satisfied are you with your neighborhood design in terms of bike safety”. The first five items are scored using a five-point Likert scale from strongly disagree to strongly agree, the last

							item is 30 scored using a five-point Likert scale from very dissatisfied to very satisfied.

Majumdaret al2015	India	Residents of two small Indian cities	1687	Both	Convenience sample of commuters (all mode types) using a travel intercept survey in two small Indian cities.	2	Focus is on 18 factors identified as potential motivators or deterrents to cycling; these include the presence of motor vehicles and on-street parking, road width and road evenness. Participants were asked whether these were barriers to them cycling.

Mertensetal 2014	Belgiu m	66 Flemish middle-aged adults (45–64 years) living in an urban (>600 inhabitants/km2) or semi-urban (300–600 inhabi- tants/km2) municipality in the region of Flanders or the Brussels Capital Region	66	Both	By purposeful convenience sampling, 66 Flemish middle-aged adults (45–64 years), stratified by gender, were recruited. Only middle-aged adults living in an urban or semi-urban municipality in the region of Flanders or the Brussels Capital Region were eligible. The recruitment areas were chosen because average trip distance corresponds with a 10-minutes cycle trip and participants were required to imagine such trips in the measurement protocol. Furthermore, the participants had to be physically able to cycle for 30 minutes and only one person per household could participate.	2	Two sets of manipulated photographs were used. Factors manipulated included in set A: 'traffic level', 'traffic calming', 'the evenness of the cycle path', 'general upkeep' and 'vegetation'. The additional three environmental factors manipulated in set B were: 'separation between cycle path and motorized traffic', 'separation between cycle path and sidewalk' and 'width of the cycle path' (Figure 2). The 'separation between cycle path and motorized traffic' was manipulated by whether or not a hedge was present between these two, while the manipulation of the 'separation between cycle path and sidewalk' was done by the presence or absence of bollards between the two. Finally, the width of the cycle path

							was manipulated by depicting a narrow or wide cycle path.

Mirandaetal 2013	Canada	Adults in Ottawa and Montreal- 1194 respondents	1194	Both	Convenience sampling of cyclists and non-cyclists in Ottawa and Montreal, recruited through local newspapers, blogs, mailing lists for bike organizations, social networking sites, and email forwards. The vast majority are regular cyclists, but not all.	2	Survey included questions about perceptions of level of comfort on factors that can affect winter cycling: - Surface conditions, Weather conditions, Road related factors, Winter maintenance perceptions.

Misraetal2015	US	127 users of the Cycle Atlanta smartphone application	127	Cyclists	Convenience sample of users of the Cycle Atlanta samrtphone application. The survey was sent to current application users via email addresses.	2	Categorisation of people based on 'comfort and interest' (No way no how, interested but concerned, enthused and confident, strong and fearless) with addition of 'comfortable but cautious' to differentiate between people who are willing to bicycle more than their present level if there is adequate safe infrastructure and those who may not bicycle more even if there is infrastructure.

Molleretal2008	Denmark	1019 cyclists aged 18-85 in Denmark	1019	Cyclists	Convenience sample of cyclists intercepted at five Danish roundabouts. The roundabouts were selected based on the following three criteria: (1) design feature, (2) traffic volume and (3) location. The goal was to select roundabouts with and without cycle facilities and roundabouts that were as similar as possible when considering the three selection criteria. Cyclists younger than 18 years old and cyclists riding so fast that trying to stop them would create a dangerous situation were not asked to participate.	2	Five Danish roundabouts of which two had cycle facilities and three did not. Numbers of cars and cyclists, and roundabout configurations, varied. Data were collected using interviewer administered questionnaires with mostly closed questions. Participants were asked to rate perceived risk in different situations at the roundabout under question e.g. car circulating, cyclist leaving roundabout.

Parkinetal2007	UK	144 cyclist and non-cyclists from Bolton Metropolitan Borough Council, the University of Bolton and BoltonRoyal Hospital	144	Both	Convenience sample drawn from employees of Bolton Metropolitan Borough Council, the University of Bolton and Bolton Royal Hospital between January and July 2002.	2	Respondents were asked to rate risk on ten thirty-second clips shown to them at work on their laptop computer. This included busier and quieter roads with and without cycle lanes, and a cycle facility on the footway.
Petritschetal 2008	US	63 cyclist of varying abilities aged 20-71 in Florida	63	Cyclists	Convenience sample of cyclists recruited through broad media outreach	1	Data collected from participants at the Florida Ride for Science 2005, which included a broad spectrum of arterial- and collector- type roadways typically found in U.S. metropolitan areas.

Petritschetal 2011	US	80 cyclists at the Video Ride for Science 2009 event in Tampa, Florida	80	Cyclists	Convenience sample of cyclists recruited through local bicycle advocacy groups, the Tampa Bay Cycle bicycling promotion campaign, and informational boards	1	Participants viewed video segments showing 22 unique segments with varying types of off-road provision usually alongside roads with varying levels of motor traffic speed and volume, grading each from A to F.
Ryley2005/Ryley 2006	UK	Cyclists and non-cyclists in West Edinburgh	997	Both	Random sample of households on three streets or subareas within four chosen postcode sectors at regular distances from the centre of Edinburgh	4	Included a stated preference experiment with factors including facilities en route and facilities at the workplace

Sallisetal2013	US	1780 adults aged 20–65 recruited from the Seattle, Washington and Baltimore, Maryland regions	1780	Both	Random sample within purposively sampled neighbourhoods. 32 neighbourhoods were selected based on varying levels of income and bikeability, in the Seattle, Washington and Baltimore, Maryland regions. Participants were recruited from the selected neighborhoods, with study eligibility established by age (20–65 years), not living in a group establishment, ability to walk, and capacity to complete surveys in English. Participants were contacted for recruitment by mail and telephone in random order within study neighborhoods (balanced by quadrant).	4	Participants were asked about self-projected change (difference score) in bicycling frequency if they thought riding was safe from cars.

Sanders2014	US	463 non-bicycling drivers, bicycling drivers, and non-driving bicyclists in the San Francisco Bay Area	463	Both	An online survey link was emailed to 1,176 people who had previously participated in research on the Bay Area FasTRAK toll tag and “casual carpooling” across the Bay Bridge, and who had agreed to participate in future research.	2	The roadway design preference aspect was optional, resulting in a subsample of 225 cycling respondents and 263 driving respondents. For this aspect of the survey, respondents were asked to indicate their comfort or discomfort on a series of 8 multi-lane, commercial roadway designs while 1) driving near bicyclists, and 2) bicycling near motorized traffic. They were told to “assume that the car traffic is traveling 25-30 mph. Comfort was rated on a seven-part Likert scale, with a neutral option and the modifiers “somewhat”, “moderately”, and “very” comfortable or uncomfortable. The respondents were presented with eight photos of a multi-lane, commercial street, seven of

							which had been manipulated through Adobe Photoshop to show a variation on the original roadway design. Modifications included various types of cycle lane and separation (e.g. by post, by paint) and presence of car parking inside or outside the bike lane.

Segadilhaeta l2014	Brazil	65 cyclists that use the bicycle for commuting in a medium-sized Brazilian city (São Carlos, SP)	65	Cyclists	Convenience sample of frequent bicycle users (that use this mode of transport for commuting).	1	Participants asked to score factors influencing route choice e.g. number of trucks in the flow of vehicles, number of buses in the flow of vehicles, traffic speeds.

Seneretal2010	US	1605 cyclists across more than 100 cities in Texas	1605	Cyclists	Convenience sample of cyclists invited to particpate in an online survey. The survey was administered through a web site hosted by The University of Texas at Austin. The authors contacted the administrators of several bicycle groups and bicycle forums in Texas cities (such as Austin, Dallas, Houston, El Paso, Waco, Lubbock, Tyler, and College Station), and asked them to forward the information to their members. The survey link was also e-mailed to student groups in Texas universities. Further, information about the survey was disseminated to media outlets in Austin (including newspapers and television channels). Moreover, the survey information was also circulated with the help of	2	Two specific dimensions of bicyclists' travel perceptions were considered: 1) bicyclists' overall quality perception in terms of bicycle facilities, and 2) bicyclists' safety perception from the standpoint of traffic crashes. For the first dimension, bicyclists were asked to evaluate the quality of bicycle facilities in their community by providing a rating on a 4-point ordered scale - "very inadequate", "inadequate", "satisfactory" and "excellent". For the second dimension, respondents were asked to provide their responses on another 4-point ordered scale - "very dangerous", "somewhat dangerous", "somewhat safe" and "very safe". Respondents were also asked about the presence of different kinds of cycle

					metropolitan planning organizations and Texas Department of Transportation offices.		route facilities along their cycle commute.

SteerDaviesGleave2010a/ SteerDaviesGleave2010b	UK	Cyclists and non-cyclists in London	1985	Both	Londoners enrolled in Research Now's online panel, with weighting to match the London population profile	4	Three stated preference exercises, with focus on switching trips to cycling; including asking participants to rate different route facility types, and to trade these off against different factors such as time.
SteerDaviesGleave2012	UK	2307 cyclists in London	2307	Cyclists	Cyclists recruited from a combination of sources: Research Now's panel of respondents; people who have expressed an interest in cycling within TfL's customer database, and TfL's database of Barclay's cycle hire users.	3	Questions about influences on cycle route choice, involving stated preference exercise with trade-offs, and questions about broader willingness to change route for a safer facility.

Stinsonetal2003	US	3,145 individuals in the United States (mostly avid bicyclists who use computers)	3145	Cyclists	Convenience sample of cyclists recruited through various means: an announcement of the survey was sent to about 25 bicycling-related listserves across the U.S. and three non-bicycling-related e-mail lists in Austin. In addition, a link was posted on another bicyclist-oriented website (http://www.massbike.org) and announcements were placed in widely read electronic newsletters (Adventure Cycling's Bike Bits and the League of American Bicyclists' BikeLeague [sic] News). Scattered distribution from individuals subscribing to these sources likely occurred as well.	2	Stated preference experiment including a range of link and junction characteristics (e.g. numbers of stops, existence of on-road or off-road separation, quality of surface).

Tilahunetal2007/Krizek 2006	US	167 employees from the University of Minnesota, excluding students and faculty.	167	Both	Invitations were sent out to 2500 employees from the University of Minnesota, excluding students and faculty, randomly selected from an employee database, aking people to participate in a computer based survey about their commute to work and offering $15 for participation.	2	Stated preference experience with five different 'facility' options displayed; off-street facility and four on-street options (no bike lane with and without parking, painted bike lane without parking, and painted bike lane on the outside of car parking)

Tintinetal2010	New Zealand	2469 cyclists, aged 16 years or over, who had enrolled in the 2006 Wattyl Lake Taupo Cycle Challenge	2469	Cyclists	Convenience sample of cyclists who were involved in the 2006 Wattyl Lake Taupo Cycle Challenge. Cylists who provided email addresses when enrolling in the 2006 Wattyl Lake Taupo Cycle Challenge (New Zealand's largest mass cycling event) were invited to particpate in the questionnaire	3	Participants were asked to rate the importance of specified factors that would encourage them to cycle more often—more bicycle lanes (adjacent but not separated from motorized traffic), more bicycle paths (separated from motorized traffic), bike friendly public transport, reduced vehicle speed and better cycle security in public places—and factors that would encourage them to cycle to work more often—rising costs of petrol, rising costs of car parking, fewer car parks, fewer difficult intersections, bikes designed to commute and access to shower facilities at work. The response options were: 'extremely important'; 'very important'; 'important'; 'somewhat important'; 'not

							very important'; and 'not important at all'.

Tiwari2014	India	Review reporting survey of current bicyclists and potential bicyclist in Pune, India.	#NULL!	Both	Not stated	-99	Participants asked to rate the importance of variables for a safe bicycle route including presence of different types of cycle facility.

Twaddleetal 2011	Canada	Staff and students at University of Calgary, particularly potential or current cyclists	1128	Both	Staff and students at University of Calgary. An invitation to complete the survey was sent to the student body via an e-mail from the registrar's office. News articles about the survey containing a link to it were posted on the main University of Calgary webpage, the Office of Sustainability's webpage, Bowcycle's website, the campus Bike Root's webpage, and in the university's online magazine. In addition, sixty-five posters were placed on bulletin boards around campus, and waterproof posters were placed at 10 of the major bike racks on campus. Business cards containing an invitation to the bicy- cle survey webpage were taped to the handlebars of bicycles parked on campus on two	2	Participants asked to identify three of a selection of route improvements and other changes that would encourage them to cycle.

					warm days when bicycle ridership was high.		

VanHolleetal 2014	Belgium	59 middle-aged adults living in urban or semi-urban areas across Flanders and the Brussels Capital region	59	Both	Fifty-nine middle-aged adults (45–64 y), stratified by gender (29 men, 30 women), were recruited: specifically, relatives and acquaintances of the research team were invited for participation in the study. Snowball sampling was used to recruit additional participants.	1	Participants asked to compare two photos at a time (which had already been ranked by experts in terms of factors including openness of view, cycle path width, presence of vegetation) and to state which one they would ride along to get to a friend's house, assuming distances were the same. Participants were also asked to rate invitingness of different segments on an 11-point Likert scale.

Vliet2014	The Netherlands	200 respondents from various parts of The Netherlands; mixed recruitment methods	200	Both	Convenience sample of cyclists and non cyclists recruited using company contacts of Goudappel Coffeng, flyering, municipalities in Noord-Brabant and the author's own network.	2	Stated preference survey incorporating for each scenario, one of three pictures depicting a street, of various quality with regard to cycling.

Wahlgrenetal2011	Sweden	Commuters aged at least 20 years old; living in Stockholm County, excluding the municipality of Norrtälje; and walking and/or cycling the whole way to one's place of work or study at least once a year	1379	Both	Convenience sample of cyclists and non cyclists recruiteed through advertisements in two large morning newspapers or intercepted on the street while they were walking or bicycling into or in the inner urban area of Greater Stockholm, Sweden. These participants were used for representativity comparisons with advertisement-recruited participants.	2	Participants asked to rate their cycle route environments according to the Active Commuting Route Environment Scale (ACRES); this was then compared to expert ratings of the suburban versus urban environments.

Wardmanetal2001/Wardman et al 2007	UK	1996 commuters in four English cities, having screened out the 60% judged never likely to contemplate cycling	1966	Both	Surveys were conducted in Autumn 1998 in Leicester, Norwich, York and Hull, using a specially conducted survey involving participants enrolled in the National Travel Survey	4	Stated preference experiment covering a range of variables, including the provision of cycleways, segregated on-road cycle lanes and unsegregated on-road cycle lanes.

Westerdijk1990	UK/Sweden/Netherlands	284 cyclists and pedestrians aged 20+ in 3 countries (50 subjects in Great Britain, 121 in Sweden and 113 in the Netherlands)	284	Both	Convenience sample of pedestrians in the UK, and pedestrians and cyclists in Sweden and the Netherlands. Generally, subjects were asked to volunteer for the experiment using announcements in local newspapers and posters in public buildings. However, in Sweden the subjects were chosen from a subject database.	2	For the cycling aspect, participants were asked to rate the importance of seven variables to them, and to rate the quality of each on their route. The variables were: Distance, Number of junctions with traffic lights, Number of junctions without traffic lights, Pleasantness, Attractions, Quality of the road surface ,Traffic safety and Gradient.

Wintersetal2010	Canada	1402 adult current and potential cyclists, i.e., the ‘‘near market’’ for cycling in Vancouver, Canada	1402	Both	The study was conducted in three waves distributed throughout 2006, with the focus on travel patterns in the preceding 4 months. In each wave a random sample of names was selected from the telephone book and each was sent an introductory letter. In the second and third waves this was complemented by random digit dialing to increase recruitment.	4	The survey included 16 different route types and used photos illustrating the infrastructure types, for example, major streets with bike symbols and parked cars, residential streets, cycle path next to major road with barrier separation.

Wooliscroftetal2014	New Zealand	573 residents of New Zealand aged 18+	573	Both	Random sample of the New Zealand population aged 18 years and older, using a commercially acquired database.	4	Participants asked whether they would cycle given various combinations of factors, including petrol prices and driver attitudes: the cycle facility attribute being 'cycle lane available'

Detailed information about study findings

Details about stated gender differences

Citation key	Country of origin	Population characteristics	Differences	Similarities	Cited literature
Akar2013/Akaretal2013	US	Ohio State University students, faculty, staff	• Females are more likely than males to self-identify as a ‘beginner cyclist who prefers to stick to the bike trails, paths and/or sidewalks’ while substantially more males identified	• The ratio of females choosing ‘‘I live too far’’ as a reason for not biking to campus was higher than males (45% of females indicated they live too far compared to 36%	• Literature cited suggested female cyclists prefer off-road bike paths, and are turned off by heavy congestion and risky high speed automobile traffic

		themselves as an 'advanced, confident cyclist who is comfortable riding in most traffic situations'. • Percentage of female students who chose 'vehicular traffic', 'extreme weather conditions', 'need to change clothes/carry things', and 'lack of bicycle lanes/paths/ trails' as barriers to bicycling were significantly higher than that of the male students. • Although almost all of the male bicyclists indicated that they feel safe (96%) this percentage is lower for women (71%), so if a woman is cycling this does not necessarily mean she is feeling safe.	males), however, analysis results revealed that there were no statistically significant differences in commuting distances among males and females (6.07 miles for women and 5.98 miles for men). • The difference between the ratios of male and female students choosing distance as a deterrent was not statistically significant. Almost equal ratios of male:female faculty and staff members chose 'need to change clothes/carry things' and lack of cycle infrastructure as barriers to cycling.	(Anderson 2008; Baker 2009; Brown 2004; Emond et al. 2009; Garrard et al. 2009).

Aldred2015	UK	Mostly cyclists in UK (but not exclusively)	• Females indicated some greater support for segregation than males. In particular, the following levels of agreement were found when respondents were asked whether certain cycling environments would be suitable for riding on by a) 'most people' b) on their own c) carrying a child d) with an 8 year old e) by a 12-year old: ➢ Busy roads on own; 68.1% of males against 61.8% of females ➢ Residential rat runs, for most people; 25.4% of males against 32.7% of females ➢ Shared park routes on own; 65.6% of males against 77.0% of females ➢ Shared park routes, for most people; 80.7% of	• For 43 out of 50 situations, there were no significant differences. In particular, there were no significant gender differences for questions related to eight- and twelve-year olds when respondents were asked whether certain cycling environments would be suitable for riding on by a) 'most people' b) on their own c) carrying a child d) with an 8 year old e) by a 12-year old).	• Females have stronger preferences for separation from motor traffic than males (e.g. Beecham and Wood 2014, Garrard et al. 2008, Heesch et al. 2012, Krizek et al. 2006, Steer Davies Gleave 2012, Twaddle et al. 2013 – although see Broach et al. 2012 for an exception).

			males against 85.8% of females ➢ Filtered street, carrying a child; 91.2% of males against 94.8% of females ➢ Armadillo segregation, on own; 88.8% of males against 94.0% of females ➢ Kerb segregation, on own; 82.9% of males against 91.9% of females		
Antonakosetal1995	US	552 cyclists at four recreational bike tours in Michigan	• With regards to commuter cycling preferences, females rated bike lanes and bike paths higher on average, than males. On a scale from 1 (not at all preferred/ not at all important) to 5 (very preferred/ extremely important) females rated bike lanes and bike paths at 4.2 and 4.1 respectively on average compared to 3.9 and 3.6 respectively on average for males). Females and	• The hierarchy of “corridor type” preferences was similar with regards to commuting: males and females both rated bike lanes and wide curb lanes as high preferences. • Preferences for “route characteristic” items other than “safety” e.g. “direct route”, “surface quality”, “traffic speed” showed no statistically significant difference by gender.	

			males both rated traffic safety as high importance, though females gave higher ratings on average than males (4.5 versus 4.1).		
Berggrenetal2012	US	Portland cyclists	• Females had a higher percentage of responding with a rating of ‘much more likely’ over ‘somewhat more likely’ for every given street characteristic by at least nine percent. Street characteristics included: established bike routes; low traffic; crossings at arterials; little on-street parking; direct (no turns or jogs); well-lit; avoids hills; commercial activity. Safety characteristics of a bike route (e.g. marking of the route, low traffic, traffic lights at arterials, etc.) were considered to be more	• Survey data did not indicate large gaps between the preferences of male and female cyclists when combining much and somewhat more likelihood of selecting a route based on a particular characteristic.	

			important to female cyclists. This indicated an important issue in equity and ensuring that bike routes feel safe and accessible to all who may want to use it.
Bergström2000	Sweden	122 people at four major companies in two Swedish cities	• Road condition and darkness were found to be more important to females than to males. • The “brine method” was found to produce a higher level of service than traditional methods for maintaining the test track. There was a tendency for females to be more positive towards the use of brine than males: 56% of females were positive and 22% negative, while 49% of males were positive and 38% negative.

Bernhoftetal2008	Denmark	Pedestrians and cyclists aged 40-49 and 70+ in two provincial cities in Denmark	• A significantly higher proportion of females than males, both among the older respondents (p = 0.0032) and the younger respondents (p = 0.0029) found cycle paths important for their comfort when cycling. • In the younger group, a significantly higher proportion of females than males would choose a route with cycle path (p = 0.0131) and signalized crossings (p = 0.0257), whereas a significantly higher proportion of males would choose the fastest route (p = 0.0004).	The presence of cycle paths was the most important route attribute for both men and women, among older and younger age groups.
Borjessonetal2012	Sweden	Cyclists in Stockholm		• Males and females were found to place equal value on the different route types, e.g. cycling time spent on street (or on a cycle

				path). This was in contrast to the coefficients in the national Swedish travel model reported, where women had higher values of time for cycling (i.e. less likely to prefer cycling) and which included all people rather than only cyclists.
Bricketal 2012	Ireland	Cyclists and non-cyclists in Dublin	• Females had a greater preference for 'greenways' and 'off road cycle lanes'. • Females had a greater preference for shorter trip times. • Females had a greater preference for fewer junctions. • Males had a greater preference for light cycle traffic along the route, compared to females	The preferences for cycle route choice overall show very little difference when comparing the estimated male and female coefficients: ordering of route types was the same for both – off-road cycle lane, then Greenway, then on-road cycle lane, then shared bus lane, then no facilities.

Caulfield2015	Ireland	Tourists at two locations in Dublin	• Male tourists-were more likely to choose a road without cycling facilities, while female tourists were more likely to choose a road with cycle lanes or a segregated from traffic cycling facility.	• Female tourists were very unlikely to select to use a road without any cycling facilities.
Changetal2008	Taiwan	Students and parents at Taiwan schools in urban and suburban areas	• Boys said that they had higher levels of 'cycling ability' than did girls in terms of willingness to ride a bike with trucks on the road, or to ride around parked cars (indicating differences in comfort/perceived safety).	
Chatawayetal2014	Australia / Denmark	Cyclists targeted through university networks and cycling forums in Brisbane and Copenhagen. Fliers left on bikes in	• Male cyclists were linked to lower fear of traffic (measured through a range of questions about cycling situations) in comparison with female cyclists.	

		Copenhagen to advertise survey			
dell'Olioetal2014	Spain	117 self classified potential bike users in Santander	• Females gave more importance to travel time by bicycle. • When considering the existing network of cycle paths, women appear to be more critical than men, placing more value than males on the existence of adequate and safe paths. • This implies that even where similarities are found in relation to, for example, 'existence of an adequate cycle path', the interpretation of this statement may be gendered.	The influence of 'existence of an adequate cycle path' in the mode choice model was not affected by gender.	
Dickinsonetal2003	UK	Employees at three organisations in Hertfordshire	• Cycle paths were popular amongst both males and females but particularly the group of females who lived near	• Cycle paths were popular amongst both males and females.	• Cycle safety may be more of an issue for females. • Personal security issues for females encourage car use.

			enough to cycle and had access to a cycle.		
Dilletal2012	US	Residents in Portland	• Females (and older adults) were underrepresented among the more confident adults and those who cycled for transportation.		• The barriers preventing females from cycling for transportation must be better understood if cycling rates are to increase significantly. Research indicates that common barriers include concerns about traffic, different attitudes towards bicycling, and complex travel patterns, including transporting passengers (e.g. children and older parents).
Dilletal2015	US	Cyclists and residents in five large US cities	• On several measures of safety and comfort, female cyclists using protected bike lanes did	• Both males and female intercepted cyclists overwhelmingly felt that protected bike	• Females consistently rate traffic concerns, aggressive driving, and personal

	(Cyclists and non cyclists)	have significantly more positive associations with the protected lanes than males did. For example: ➢ Females were more likely to agree that the new protected bikeways were safer than other bikeways in the city (93% of females vs. 87% of males). ➢ Females were more likely to state that how comfortable they felt when bicycling on the street had increased a lot (66% or females vs. 58% of males) ➢ Females were more likely to strongly agree that they would go out of their way to ride on the street with the protected lane compared to other streets.	lanes increased their safety while riding in them. • There were no gender differences found amongst intercepted cyclists in relation to the following statements about protected bike lanes: ➢ The buffer section with parked cars makes me feel safe (only asked on lanes with such buffers) ➢ The lane is wide enough for me to ride comfortably ➢ The lane is wide enough for one bicyclist to pass another ➢ The lane is wide enough for two people to comfortably ride side-by-side ➢ The lane makes it clear where cars can be and	security among their significant travel-related concerns. • Females have been shown to ride more cautiously than men and to choose their routes to avoid “hidden dangers” to personal safety. • Females are less likely to prefer off-street paths than males. • Females consistently favour, both in stated and revealed preferences, dedicated bicycle facilities and lower volume streets • Females are more likely than men to prefer maximum separation from automobile traffic. • Females are more likely than males to

	➢ Females were significantly more likely to say that they had increased their overall amount of cycling a lot because of the protected lanes • Among the intercepted bicyclists, females were slightly more comfortable than males on paths or trails separated from the street and less comfortable on commercial streets without bike lanes. In contrast, among the survey of residents, females were less comfortable than males in every environment. However, gender differences in the resident survey can be attributed to the residents who said they do not make trips on	where the designated bicycle lanes are ➢ The buffer effectively separates bikes from cars ➢ The buffer does a good job of protecting bikes from cars ➢ The lanes makes drivers and bicyclists more predictable ➢ The lane makes it clear where pedestrians and bicyclists should be ➢ The lane design effectively separates bicyclists from pedestrians • Amongst the intercepted cyclists, there were few gender differences with regards to the design of facilities, including features such as lane width and most buffer designs (although female cyclists were	tolerate a travel-time trade-off to access lower-stress routes.

bicycle. When the analysis is done with only residents who make some or most of their commute or other trips on bicycle, there were only gender differences on the street without a bike lane.

- For potential female bicyclists (surveyed as part of the residential group), protected lanes increased stated comfort levels significantly, though females still reported lower comfort levels than males.
- The survey of residents revealed that females generally feel less comfortable than males bicycling on roadways, though the addition of some physical separation to a striped bike lane, does increase stated levels of comfort. Among

slightly more comfortable than males with the 2-3 foot buffer with plastic flexposts and the painted buffer with parked cars).

the residents who were interested in bicycling more for transportation, 87% of the females and 82% of the males agreed they would be more likely to ride a bicycle if motor vehicles and bicycles were physically separated by a barrier.

- Where there are differences between males and females, it is sometimes because female levels of agreement are stronger than men's. For example, a larger share of females (58% vs. 48% of males) strongly agreed that the buffers with the plastic flexposts made them feel safe, while there was no significant difference in the shares that somewhat agreed. Similarly, females were

			more likely to state that the usefulness of the street to getting to places they want to go had increased a lot (51% of females vs. 40% of males), though more males than females said that it had increased somewhat (35% or males vs. 27% of females).		
Emondet al2009	US	Random sample of residents in six small cities in the US	• Feeling comfortable using bicycle facilities was the strongest positive influence on female bicycle use. Although males experienced approximately as much discomfort on average as females on facilities not separated from heavier traffic, they were also more likely to report that they would ride on them anyway, in contrast to females who	Males experienced approximately as much discomfort on average as females on facilities not separated from heavier traffic.	• Females are less comfortable with traffic at all levels of experience. • Females are more likely than males to prefer bicycling separated from vehicular traffic by on-road lanes designated for bicycle use or off-road paths.

			indicated that they would not.		
Gardner1998	UK	Leisure cyclists, non-cyclists and utility cyclists in different areas of England	• More males than females were willing to cycle alone, with some female respondents indicating that they did not feel safe if the cycle lanes were too isolated, and that they would not cycle in parks or the countryside on their own.	67% of all cyclists and 72% of leisure cyclists wanted more cycle routes (but no gender similarity or difference reported).	
Heeschetal2012	Australia	Adult cyclists in Queensland who were members of Bicycle Queensland (BQ) club	• For transport cycling, females were less likely than males to prefer cycling on the road (p=0.020). • For recreational cycling, females were less likely than males to prefer cycling on-road (p<0.001), but more likely to prefer cycling off-road (p<0.001). • Top constraints for at least half of the males	• For transport cycling, few males or females preferred to cycle on the road but preferred cycling on routes separated from motorists. • On-road routes were even less preferred for transport cycling than recreational cycling by both males and females.	• Issues of safety, comfort and accessibility to destinations appear to be more important to female overall travel behaviour than to males travel behaviour.

and females were perceived environmental factors, namely traffic and aggression from motorists, with females significantly more likely than males to report these constraints. Of transport-only and recreation-only cyclists, female recreation-only cyclists were the group with the most respondents reporting these constraints, and male transport-only cyclists were the group with the fewest respondents reporting them.

- Although few males or females preferred to cycle on the road, more males and females were cycling off road than would prefer to do so. This may be explained by the qualitative data which suggested that people were cycling on off-road paths as the on-road routes were extremely hostile or did not allow for cycling on them. However, the off-road routes were often detours, poor quality and shared with other users such as pedestrians, thereby negatively affecting preferences for off-road routes. Further, qualitative findings showed that may people wanted to ride alongside roads but

				separate from motorists and pedestrians.
Krizek 2006	US	Bicycle commuters in Minneapolis and St. Paul		• Overall, gender was not found to be a statistically significant factor in route choice (at the 0.05 level). The following factor almost reached statistical significance: the tendency to choose longer routes, which were also perceived as safer (p = 0.07, women higher than men).
Krizeketa l2005	US	Secondary data from five surveys: two were SP surveys, one of 'current and potential cyclists' and one of current cyclists, in Minnesota	• Both males and females were willing to travel longer for an off-road facility, followed by a facility with bicycle lane and no on-street parking. However, females were willing to travel more additional minutes than men for a preferred facility. Assuming a 20 minute	• Male and female cyclists were relatively similar in the proportion who valued specific types of bicycle facilities such as on-road bicycle lanes, separate bicycle paths, and a connected system of bicycle routes.

commute, males were willing to divert 5.43 fewer minutes than females for any facility compared in the survey.

- In general, females demonstrated a stronger preference for safer forms of cycling infrastructure.

- Both males and females were willing to travel longer for an off-road facility, followed by a facility with bicycle lane and no on-street parking.
- Gender differences in relation to rating paved shoulders and lighting on bicycle paths as “very important” to commuting by bicycle did not reach statistical significance although percentages of women agreeing were higher for both. Conversely, higher proportions of men than women cited information about commuting and about cycle routes as “very important” although again this was not statistically significant.

Landisetal1997	US	150 cyclists aged 13+ in Tampa, Florida		• There was no significant difference found in the mean bicycle quality-of-service scores for females versus that of males.
Landisetal2003	US	60 cyclists aged 13+ in Orlando, Florida		• There was no gender difference found between the mean bicycle quality-of-service scores for females versus that of males (among the factors considered through BLOS were pavement surface condition and width for bicycling).
Lawsonetal2013	Ireland	Cyclists, who regularly cycled in Dublin within the previous 12 months, 1954 responses		• Those men who prefer cycling on urban roads, and those women who prefer bus lanes, also had higher tendencies than others to describe cycling as being as safe as or safer than driving in Dublin city.

				• For both genders, cyclists who preferred to use roads with no cycling facilities had a higher change of describing cycling to be as safe as or safer than did others.
Lietal2012	China	805 cyclists in the metropolitan area of Nanjing		• Male and female bicyclists did not perceive different levels of comfort on the physically separated bicycle path sections studied.
Lusketal2014	China	1150 adults in Hangzhou	• The difference between males and females preferring to use the road (i.e share with motorists) was statistically significant with females preferring to use the road even less (5.3% male, 3.0% female) (P=0.000). • Females preferred to use segregated cycle tracks even more than males	• Few males and females in the whole study population preferred to use the road (i.e share with motorists). • Preference for bicycling on segregated cycle tracks in the study population was almost double in both genders, compared to all other types of route i.e sharing road with

			(53.9% men, 60.2% women) (P=0.004). • The study population highly preferred to use (separated) bicycle signals with a statistically significant difference of females preferring bicycle signals more (63.7% males, 69.1% females) (P=0.009). • Both bicyclists and non-bicyclists preferred the bicycle signals with the difference being statistically significant (63.7% males, 69.1% females) (P=0.009).	motorists, sharing path with pedestrians, paint-only bike lane with or without cars parking beside lane.	
Maetal2014	US	Random phone survey of 902 adults in Portland, Oregon region	• Older age, being female, and owning more vehicles was found to be negatively associated with perceptions of the bicycling environment.		• Ball et al. (2008) found that mismatches between perceived and objectively-measured environments were more frequent among females who were younger, older,

					lower-income, less active, using fewer facilities, and living in the neighbourhood for less than 2 years.
Maetal2015	US	Random phone survey of 902 adults in Portland, Oregon region	• Females with children were more likely to perceive their relatively high bikeable neighbourhoods as low bikeable, than males with children. The odds ratio of females with children perceiving their high bikeable neighbourhood as low bikeable was 2.344, compared to 0.199 for males without children.		
Majumdaretal2015	India	Residents of two small Indian cities	• Significant gender differences were found for the following factors/ statements for both samples:	• No significant gender differences were found for the following factors/ statements for both samples: ➢ I will not cycle because on-street parking,	

			➢ I will not cycle because the road is not adequately wide • Significant gender differences were found for the following factors/ statements for one of the samples: ➢ I will not bicycle because the routes are poorly lit and visibility is low in night time. ➢ I will not cycle because of safety hazard associated	illegal pedestrian crossing and partial access control make cycling difficult especially at the kerb side. ➢ I will not cycle because presence of other motorised vehicles makes it difficult for bicycle commuters especially in peak hours.	
Mertensetal2014	Belgium	66 Flemish middle-aged adults (45–64 years) living in an urban (>600 inhabitants/km2) or semi-urban (300–600 inhabi-tants/km2) municipality in		• No moderating effects of gender or age were found when exploring environmental factors related to the invitingness for transportation cycling e.g. traffic level and calming, evenness of the cycle path, general upkeep, vegetation,	

		the region of Flanders or the Brussels Capital Region		traffic level, level of separation, width of the cycle path. Small sample size noted.	
Mirandaetal2013	Canada	Adults in Ottawa and Montreal- 1194 respondents	• Gender and age were found to have a significant effect on winter cycling in certain instances, for example, of the respondents surveyed in Ottawa, males were around 15%-23% more likely to report cycling in the winter than females. Similarly, in Montreal, males were 9% more likely to say they cycle in winter, although this was observed to have a significant effect in only one of the models.		
Misraetal2015	US	127 users of the Cycle Atlanta smartphone application	• Gender was found to have a significant influence on rider type self-categorisation and the following trends	• While average scores for individual conditions and facilities are mostly similar across rider types, the	• Gender and age has a demonstrated effect on an individual's attitude towards safety,

			were found to be statistically significant: ➢ Male cyclists were more likely to categorise themselves as ‘strong and fearless’ than the female cyclists; ➢ Male cyclists were more likely to categorise themselves as ‘enthused and confident’ than female riders; ➢ Females were more likely to classify themselves as ‘comfortable but cautious’ than male riders.	scores have a higher standard deviation across the comfortable but cautious rider type indicating a higher variability of preferences for that group of riders. • Riders across all cyclist types prefer dedicated cycling facilities and are opposed to high speed traffic and high volume traffic, with little variation based on the classification of the cyclist.	comfort, and confidence. Studies on the effect of gender on confidence show that females are much less likely to undertake risky tasks and more likely to report themselves to be less confident than their male counterparts even when performing identical tasks. • Literature suggests that route and facility type preferences should vary across rider demographics (and therefore rider types).
Molleretal2008	Denmark	1019 cyclists aged 18-85 in Denmark	• Females were found to have a higher level of		

			perceived risk at roundabouts.
Parkinetal2007	UK	144 cyclist and non-cyclists from Bolton Metropolitan Borough Council, the University of Bolton and BoltonRoyal Hospital	• Males generally considered cycling more acceptable than females. This was determined using a model that considered the probability of whether a cycling route would be regarded as acceptable or not in various journey situations. • A number of models were estimated that included person type variables and interactions between person type variables and journey variables. While these did show some significant effects, they were often at the expense of the main effects becoming non-significant.

Petritschetal2008	US	63 cyclist of varying abilities aged 20-71 in Florida	• In this bicycle level of service study of arterial roadway environments, females graded roadways worse overall than males did (3.51 vs. 3.24, p=0.043). The roadways included in the study consisted of a variety of facility configurations (including with or without bike lanes) and traffic conditions.		
Petritschetal2011	US	80 cyclists at the Ride for Science 2009 event in Tampa, Florida		•No statistically significant grading difference was found between genders in this bicycle level of service study of paths adjacent to roadways. Several different facility types were included in the study: shared lanes, designated bike lanes, paved shoulders, side paths and independent	

				alignment of shared use paths.	
Ryley2005	UK	Cyclists and non-cyclists in West Edinburgh	• A higher proportion of females than males agreed that more money should be spent on on-road cycle lanes, safety fears are more likely to prevent them from cycling, and that Edinburgh is too hilly and too wet for cycling.		
Ryley2006	UK	Cyclists and non-cyclists in West Edinburgh	• The t-value for females (model coefficient) for 'facilities on route' was found to be higher than that for males.		
Sallisetal2013	US	1780 adults aged 20–65 recruited from the Seattle, Washington and Baltimore, Maryland regions		• The study found a lack of any association between gender and the stated projected increase in cycling if safety from cars was improved.	
Sanders2014	US	263 non-bicycling drivers,	• Female respondents were significantly less	• Barrier-separated bicycle lanes were	• Literature cited suggested a strong

		bicycling drivers, and non-driving bicyclists in the San Francisco Bay Area	comfortable (p ≤ 0.001) then males bicycling on designs involving sharing with motor traffic.	found to be popular among potential and current cyclists, irrespective of gender, age, and cycling frequencies.	preference amongst females for separated bicycle facilities. • A study cited suggested that the presence of a bicycle lane has a much greater impact on the odds of choosing the higher quality facility than the elimination of on-street parking or the presence of an off-road facility. The tendency to choose the higher quality facility was magnified among females.
Segadilhaetal2014	Brazil	65 cyclists that use the bicycle for commuting in a medium-sized Brazilian		• No statistically significant gender differences were found in the attribution of factors influencing cyclist route choice.	• Larsen and El-Geneidy (2010) found that there was not a statistically significant

	city (São Carlos, SP)		Small sample size and composition – 80% male – may have affected this result. • Eighteen factors concerning the roadway environment were included in the study, including factors related to characteristics of the roads (e.g width, direction of flow, type and quality of pavement, street slope, permission for parking on right hand side of street, traffic volume and speed, number of truck and busses in the flow of vehicles, and presence of trees), as well as factors related to the trip (e.g travel time), factors related to the route as a whole (e.g number of stop signs, traffic lights and	difference between males and females with respect to preference for use of bike paths and lanes. • Garrard et al. (2008) found that the percentage of females who prefer to use cycling infrastructure is statistically higher than that of males (50.7 % and 41.7 %, respectively). • The sensitivity to additional distances varies according to experience (more experienced cyclists are less willing to sacrifice their time in order to ride on more comfortable routes) and by gender (females are more sensitive to

				intersections, and having to go through roundabouts), and factors relating to the environment (e.g security and street lighting).	longer trips than males). • Sener et al (2008) found that for many cyclists (mostly male and experienced) a large number of crossings has a negative influence on route choice (note that the authors do not mention what they consider to be a large number of intersections).
Seneretal2010	US	1605 cyclists across more than 100 cities in Texas	• Male bicyclists perceived the bicycle facilities in their community to be better than did female bicyclists.		
SteerDaviesGleave2010a	UK	Cyclists and non-cyclists in London	• Although values placed on different attributes (e.g cycle lanes, junction types) were found to be broadly similar for males and females, females	• Males and females both had stronger preferences for segregated cycle lanes (compared to no cycle lane or non-segregated	

			gave ‘No traffic on the road’, ‘Segregated cycle lane’ and ‘Junction types’ higher ranks, while ‘Unsegregated cycle lane’ and ‘Secure cycle parking’ were lower down the list compared to males.	cycle lanes) and no traffic (compared to low volume of traffic on the road).	
SteerDaviesGleave2010b	UK	Cyclists and non-cyclists in London	• On average, females rated the absence of cycle lanes or clearly marked cycle lanes as more unsafe than males did. For example, the mean safety score given for ‘no cycle lanes’ varied between 7.3 and 7.8 for different female age groups, compared to 6.5 to 7.1 for different male age groups (on a scale of 1 to 10 where 1 equals ‘completely safe’ and 10 equals ‘completely unsafe).	Both women and men, in all age groups, felt that “cycle lane away from road” and “cycle lane kerb separated” were the safest type of infrastructure, ahead of a road with a “clearly marked cycle lane” or “no cycle lane”.	
SteerDaviesGleave2012	UK	2307 cyclists in London	• There was a significant difference in the level of	• Generally, “route choice considerations”	

confidence between male and female respondents, with 79% of male respondents saying they felt confident enough to cycle on all roads, compared to only 50% of female respondents.

- Females were much more likely to prefer safer routes, away from other traffic, and away from difficult junctions. The average score for “Safety is the most important consideration when choosing a cycle route” for females was 0.89, compared to 0.53 for males (based on a five point scale from strongly agree (+2) to strongly disagree (-2)).
- In general female respondents were slightly more likely to rate each junction as less

were in the same direction (i.e. mean score was >0 rather than <0, where >0 indicates agreement and >0 disagreement with the statement).

- This included “I choose to travel on roads with less traffic” and “I would prefer cycling in a cycle lane which is separate from the traffic even if it meant a longer journey”.
- Three of the “route choice considerations” had results in different directions by gender, however differences were small (close to 0 for both) and it was unclear if they would be statistically significant. These were “sometimes I choose longer or more challenging routes in

			safe than male respondents and were more prepared to detour. • Though male respondents also agreed on average that they would avoid a route if they had to negotiate a number of difficult junctions, they were less certain that they would avoid that particular route (0.66 compared to 1.04 for females). • Female cyclists were slightly more willing to change their route in order to use a dedicated on-road cycle lane (56% of females said they would change their route, compared to 48% of males).	order to improve my fitness" (men marginally agree, women marginally disagree), "All that matters when I cycle is finding a direct route" (men marginally agree, women marginally disagree) and "the quality of signage and cycle markings has no influence on which route I take". • There was no variation between male and female cyclists in terms of willingness to consider changing routes to use a cycle superhighway.	
Tilahunetal2007	US	167 employees from the University of Minnesota,		• Gender was not found to be significant at the 0.05 level for probability of choosing	

		excluding students and faculty.		a higher quality route. The following factor almost reached statistical significance: females had a higher tendency to choose the facilities that were perceived safer (better quality) than men (p-value = 0.073).	
Tintinetal2010	New Zealand	2469 cyclists, aged 16 years or over, who had enrolled in the 2006 Wattyl Lake Taupo Cycle Challenge	• In a study of the perceived importance of factors that would encourage bicycle travel, female cyclists were more likely to report the importance of all factors (e.g bicycle lanes, more bicycle paths, better bicycle security in public places, reduced vehicle speed and bike friendly public transport). • Female cyclists were more likely to report the importance of all factors when considering what would be most likely to	• Men and women both rated bicycle lanes and bicycle paths highly as factors that would encourage them to cycle (with both rating lanes higher than paths)	• In earlier US surveys, more than four-fifths of respondents supported zoning regulations favouring walking or bicycle paths with greater odds observed among female respondents.

			encourage them to cycle to work (factors included rising cost of petrol, rising cost of car parking, fewer car parks, fewer difficult intersections, bike designed to commute, and access to shower facilities at work).		
Tiwari2014	India	Review including report of survey of current bicyclists and potential bicyclist in Pune, India.	• . Females attached lower weights to intersections and other barriers as compared to males. Females also gave higher weight to personal security aspects, informal land use presence and formal land use mix. This further emphasizes the importance of personal security for women.	• Preferences of females and males for bicycle routes showed similar trends except a few variables; differences look extremely slight.	
Twaddleetal2011	Canada	Staff and students at University of	• Females were more concerned than males about safety issues	• There was no significant difference by gender in the	• Females tend to place a high value on safety, are more

	Calgary, particularly potential or current cyclists	associated with cycling. Significant differences were found for the following four statements: ‘I do not know a safe route’, ‘I feel unsafe riding on roads’, ‘I cannot carry my daily items’, ‘I would have to fix my hair’. • Males were more likely than females to indicate a desire for wide curb lanes.	selection of any of the on-route improvements. Females were found to share similar facility preferences with males with high proportions of both genders indicating a desire for bicycle lanes, more pathways, and more direct bicycle routes. Twaddle et al note that this contradicts other research suggesting women have higher preference for off-road tracks than on-road lanes, and that the on-road lane preference runs contrary to provision in Calgary where routes are marked on-road but generally do not provide separate lanes. • Although more pathways was the	risk averse than males, and often favour transportation modes that pose the least risk. • The facilities that females are using, and those they prefer to use, have been topics of disagreement. Garrard et al. found that females, more than males, prefer to use bicycle paths that are separated from automotive traffic. Aultman-Hall found no significant difference between males and females in facility preferences. In another study, Garrard et al. found that “females were more likely to use

second most requested improvement, the number of requests by female for more pathways was less than half of the number requesting more bicycle lanes. This finding suggests that females do not appear to have a strong preference for off-road bicycle paths and have an equally strong desire for bicycle lanes as males do.

- Considering that the top three selections by both males and females pertain to the connectivity of the network, the availability of bicycle facilities, and the directness of route, the type of infrastructure may not be as important as the

on-road bike lanes than off-road paths, but showed similar preferences for these two types of bicycle facility. Males were also more likely to use on-road bike lanes than off-road paths, but, unlike females, they expressed a greater preference for on- road lanes". Aultman-Hall found that commuter cyclists, both males and females, generally use the shortest route or a slight variation from this route. The respondents to Aultman-Hall's survey used path-ways and trails less often than the proportion that was

				existence of a facility. Females, as much as males, seemed to desire a fast, easy route to their destination. Males and females were also similar in the low importance they placed on signage, with the option of more signs ranking as the least cited improvement.	identified in the computer-identified shortest path. Krizek et al. found that females are more sensitive to low-quality cycling facilities than males are. They are more likely than males to rate lighting on bike paths and paved shoulders on roads as very important. Similarly, they are more likely than males to cite the lack of pathways and poor road conditions as key cycling problems.
VanHolleetal2014	Belgium	59 middle-aged adults living in urban or semi-urban areas across Flanders	• For observed characteristics included in the ‘choice task’: ‘‘evenness of the cycle path’’, ‘‘presence of new elements’’, ‘‘presence of historic elements’’ and	• Moderating effects of gender on the association between the environmental characteristics and proportion of environmental	• Krizek et al. (2005) observed that safety-related characteristics were stronger predictors of transportation cycling in females

	and the Brussels Capital region	''safety for crossing the street'', associations with proportion of invitingness for transportation cycling were only found in females, while results were not significant in males.	invitingness for transportation cycling were absent in the final model for the choice task as well as the cognitive task. Bivariate predictors of invitingness for transportation cycling, measured through both tasks included: vegetation, openness of view, cycle path separation type, and cycle path width. • The results of the choice task and cognitive responses were considered somewhat surprising, with 'presence of vegetation'' the only significant predictor of the environment's invitingness to cycle for transportation (and little evidence for	than in males. Such characteristics included presence of paved shoulders and sufficient lighting on bicycle paths. In contrast, studying three countries, Van Dyck et al. (2012) found that aesthetics and safety from crime were positively related to cycling for transportation in males, while results were non-significant in females.

			separation/ segregation found).	
Vliet2014	The Netherlands	200 respondents from various parts of The Netherlands; mixed recruitment methods	• Gender (and age) was not found to be a significant factor in bicycle mode choice for short-distance commuting. • Noted that 'while the results mostly agree with earlier Dutch research, they do not agree with foreign research. It becomes clear that the view of cycling and the cycling environment in The Netherlands is very different from that abroad.'	• There is a difference in bicycle usage with respect to gender (Rietveld & Daniel, 2004; Rodríguez & Joo, 2004), but not in countries with high rates of cycling (Pucher & Buehler, 2008).
Wahlgrenetal2011	Sweden	Commuters aged at least 20 years old; living in Stockholm County, excluding the municipality of Norrtälje; and	• Males and females both showed preferences for cycling in suburban route environments than inner urban route environments due to factors such as exhaust	

		walking and/or cycling the whole way to one's place of work or study at least once a year			fumes, noise and congestion of all types of vehicles. In contrast, inner urban route environments were preferred for the item greenery.
Wardmanetal2007	UK	1996 commuters in four English cities, having screened out the 60% judged never likely to contemplate cycling			• No interaction effect between cycling-specific variables and gender or age was found.
Westerdijk1990	UK/Sweden/Netherlands	284 cyclists and pedestrians aged 20+ in 3 countries (50 subjects in	• Only the importance of the attribute, distance, was different for the age and gender groups. Male subjects tended to give		• Distance, pleasantness and traffic safety were the most important attributes for pedal cyclists,

		Great Britain, 121 in Sweden and 113 in the Netherlands)	higher importance to distance (as did younger subjects). Here ‘distance’ refers to choosing to take a shorter and more direct route.	however there were few differences found in the importance of attribute weights between male and female subjects (attributes included distance, junctions with traffic lights, junctions without lights, pleasantness, attractions, quality of the road surface, traffic safety, and gradient).	
Wintersetal2010	Canada	1402 adult current and potential cyclists, i.e., the ‘‘near market’’ for cycling in Vancouver, Canada	• Females scored the low preference routes even lower than males (e.g. Major city streets with parked cars, major city streets with no parked cars, rural roads with no paved shoulder, rural roads with paved shoulder, major city streets with bike symbols and parked cars, major city streets with	• There were virtually no differences in mean scores between males and females for the six most preferred route types (paved-off street paths for bikes only, paved off-street multiuse paths, unpaved off-street multiuse paths, cycle path next to major street separated by barrier, residential	

			bike lanes and parked cars). • The two least preferred route types were major streets with no facilities, with or without parking (16% likely to choose). Only 79 respondents were ''very likely'' to choose to ride on major streets with parked cars. They represented a unique subpopulation: 22.6% were regular cyclists (vs. 8.1% in the overall sample), and they were mainly male (66.5%), aged 25 to 34, with a lower likelihood of having children (22.3% vs. 46.8%).	streets marked as bike routes with traffic calming, residential streets marked as bike routes).	
Wooliscroftetal2014	New Zealand	573 residents of New Zealand aged 18+		• There was no statistical difference in the average part-worth rating of attributes for gender (attributes included availability of cycle lanes, petrol	

				price, driver attitudes, and facilities at work).	

Details about stated age differences (adults)

Citation key	Country of origin	Population characteristics	Differences	Similarities	Cited literature
Antonakosetal 1995	US	552 cyclists at four recreational bike tours in Michigan	• With regards to recreational cycling preferences, cycling experience and age were negatively associated with preference for bike paths, sidewalks, dirt roads, and trails for recreational cycling. Age was positively correlated with importance placed on road surface quality and scenery and negatively correlated with few stops along a route in the choice of a recreational cycling route. • With regards to commuting cycling preferences, age and cycling experience was	• Age was not associated with concerns about traffic and safety.	

			negatively correlated with preference for bike paths, sidewalks, and dirt trails for commuting. Age was positively correlated with consideration of convenience for errands in the choice of a commuting bike route.		
Bernhoftetal2008	Denmark	Pedestrians and cyclists aged 40-49 and 70+ in two provincial cities in Denmark	• Both the older and younger cyclists felt the presence of cycle paths was the most important factor in their level of comfort – over 80% of both groups mentioned this, although a significantly higher proportion of the older than the younger group stated this ($p < 0.0001$). • Older respondents appreciated cycle paths significantly more than the younger respondents did. To a larger extent they felt that it was dangerous to cross the road where these facilities were missing.	• Both the older and younger cyclists felt that the presence of cycle paths was most important for their comfort.	

- A higher proportion of younger cyclists found it dangerous to cycle, where there were parked cars, or to ride straight on, when there were right turning vehicles. These situations were also acknowledged as dangerous by the older group, but to a somewhat lesser extent.
- A higher proportion of the younger group found it important that the route for cycling was fast and direct.
- The amount of traffic was not as important for the younger group as it was for the older group ($p < 0.0001$).
- A smooth surface for cycling was more important for the younger group ($p < 0.0001$).
- 49% of the older respondents found it dangerous to turn left [i.e. what would be right in UK],

			as opposed to 36% of the younger respondents (<0.0001).		
Borjessonetal2012	Sweden	Cyclists in Stockholm		• The marginal utilities of time and money were not found to be significantly dependent on age.	
Caulfield2015	Ireland	Tourists at two locations in Dublin	• Younger tourists are more likely to choose a road without any cycle infrastructure. More mature tourists would have a higher preference for a fully segregated facility, over a cycle lane.		
Chatawayetal2014	Australia / Denmark	Cyclists targeted through university networks and cycling forums in Brisbane and Copenhagen. Fliers	• Older cyclists were more averse to riding in mixed traffic.		

		left on bikes in Copenhagen to advertise survey			
Dilletal 2012	US	Residents in Portland	• Older adults (and females) are underrepresented among the more confident adults and those who currently cycle for transportation.		
Heinen etal2010	The Netherlands	n/a (non-systematic review)	• Inexperienced cyclists, women and younger cyclists tend to consider bicycle facilities to be more important (Stinson and Bhat, 2003; Krizek et al., 2004; Stinson and Bhat, 2005; Garrard et al., 2008). • Older people, females and experienced cyclists attach more importance to a smooth surface (Bergström and Magnussen, 2003; Stinson and Bhat, 2003, 2005).		• Inexperienced cyclists, women and younger cyclists tend to consider bicycle facilities to be more important (Stinson and Bhat, 2003; Krizek et al., 2004; Stinson and Bhat, 2005; Garrard et al., 2008). • Older people, females and experienced cyclists attach more importance to a smooth surface (Bergström and

					Magnussen, 2003; Stinson and Bhat, 2003, 2005).
Hughes etal1997	US	Twenty-three (23) casual and 12 experienced cyclists	• Apparent reduction in sensitivity to risk on the part of the younger cyclist (i.e under 20 years old).		
Huntetal2007	Canada	Cyclists in Edmonton	• There were indications that older people had less of an aversion to riding in mixed traffic and that the very young had less of an aversion to riding on paths, but these indications were weak statistically and the corresponding models did not display any better goodness-of-fit.	• There were indications that older people had less of an aversion to riding in mixed traffic and that the very young had less of an aversion to riding on paths, but these indications were weak statistically and the corresponding models did not display any better goodness-of-fit.	
Lawson etal2013	Ireland	Cyclists, who regularly cycled in Dublin within the previous	• The probability of describing cycling as safer than or as safe as driving grew with age. Consequently, older people were more likely to deem		

		12 months, 1954 responses	the cycling network as safer than the relatively younger population. • Older female cyclists tended to perceive cycling to be safer than the younger ones.
Lietal2012	China	805 cyclists in the metropolitan area of Nanjing	• Bicyclists more than 30 years old perceived less comfort than younger bicyclists. Bicyclists less than 30 years old were 10% more comfortable on average across all facilities studied than those more than 30 years old.
Maetal 2014	US	Random phone survey of 902 adults in Portland, Oregon region	• Age, being female, and owning more vehicles was found to be negatively associated with perceptions of the bicycling environment.
Maetal 2015	US	Random phone survey of 902 adults in Portland,	• Compared with people aged 18 to 34, middle aged (35-54) people are less likely to hold low perceptions in 'high

		Oregon region	bikeable' neighborhoods; by contrast, older people (55 and over) are nearly three times more likely to perceive 'high bikeable' environment as low.	
Majumdaretal 2015	India	Residents of two small Indian cities		• No significant age differences were found for the following factors/ statements for both samples: ➢ I will not cycle because the road is not adequately wide ➢ I will not cycle because on-street parking, illegal pedestrian crossing and partial access control make cycling difficult especially at the kerb side. ➢ I will not cycle because presence of other motorised vehicles makes it difficult for bicycle commuters

					especially in peak hours. ➢ I will not cycle because the routes are poorly lit and visibility is low in night time. ➢ I will not cycle because of safety hazard associated	
Merten setal20 14	Belgium	66 Flemish middle-aged adults (45–64 years) living in an urban (>600 inhabitants /km2) or semi-urban (300–600 inhabi-tants/km2) municipalit y [30] in the region of Flanders or the			• No moderating effects of gender or age were found when exploring environmental factors related to the invitingness for transportation cycling e.g. traffic level and calming, evenness of the cycle path, general upkeep, vegetation, traffic level, level of separation, width of the cycle path.	

		Brussels Capital Region			
Mirandaetal2013	Canada	Adults in Ottawa and Montreal-1194 respondents	• Gender and age were found to have a significant effect on winter cycling in certain instances, for example, the findings indicated that the likelihood of winter cycling increases with age to a maximum point, after which increasing age reduces the probably of winter cycling.		
Misraetal2015	US	127 users of the Cycle Atlanta smartphone application	• Age was found to have a significant influence on rider type self-categorisation and the following trends were found to be statistically significant: ➢ Older people were less likely to categorise themselves as 'strong and fearless' ➢ With increasing age people are more likely to group themselves into less	• While average scores for individual conditions and facilities are mostly similar across rider types, the scores have a higher standard deviation across the comfortable but cautious rider type indicating a higher variability of preferences for that group of riders.	• The gender difference in perception of risk and confidence increases with increasing age although the level of gap is decreasing over time.

			confident groups as the marginal increase is higher in the 'comfortable but cautious' group than the 'enthused and confident' group	• Riders across all cyclist types prefer dedicated cycling facilities and are opposed to high speed traffic and high volume traffic, with little variation based on the classification of the cyclist.
Mollere tal2008	Denamrk	1019 cyclists aged 18-85 in Denmark	• Perception of accident risk at roundabouts was found to decrease with age (p=0.02).	
Parkine tal2007	UK	144 cyclist and non-cyclists from Bolton Metropolitan Borough Council, the University of Bolton and Bolton	• The young and older people were found to perceive junctions as adding more risk than for those in the middle years of life (aged 35–44). • Young people and older people generally considered cycling less acceptable than those in the age band 35–44 years. This was determined using a model that considered	

		Royal Hospital	the probability of whether a cycling route would be regarded as acceptable or not in various journey situations.	
Petritsch et al 2008	US	63 cyclist of varying abilities aged 20-71 in Florida	• In this bicycle level of service study of arterial roadway environments, participants who were 40 years or older perceived the roadways as worse overall than younger participants (with an average grade of 3.48 for people aged over 40 versus 3.04 for people aged 20 to 39, a statistical difference of p=0.002). The roadways included in the study consisted of a variety of facility configurations (including with or without bike lanes) and traffic conditions.	
Petritsch et al 2011	US	80 cyclists at the Ride for Science 2009 event		• No statistically significant grading difference was found between age groups in this bicycle level of

		in Tampa, Florida		service study of shared use paths adjacent to roadways. Several different facility types were included in the study: shared lanes, designated bike lanes, paved shoulders, side paths and independent alignment of shared use paths.
Ryley2005	UK	Cyclists and non-cyclists in West Edinburgh	• There was more agreement than disagreement for an increase in spending to improve cycle lanes in Edinburgh, both on-road and off-road, particularly amongst younger respondents (individuals aged 18-24 were 55% agreement for on-road, 78% agreement for off-road).	
Salliset al2013	US	1780 adults aged 20–65 recruited from the Seattle,		• The study found a lack of any association between age and the stated projected increase in cycling if

		Washington and Baltimore, Maryland regions		safety from cars was improved.
Segadilhaetal2014	Brazil	65 cyclists that use the bicycle for commuting in a medium-sized Brazilian city (São Carlos, SP)		• No statistically significant age differences were found in the attribution of factors influencing cyclist route choice. Eighteen factors concerning the roadway environment were included in the study, including factors related to characteristics of the roads (e.g width, direction of flow, type and quality of pavement, street slope, permission for parking on right hand side of street, traffic volume and speed, number of truck and busses in the flow of vehicles, and

				presence of trees), as well as factors related to the trip (e.g travel time), factors related to the route as a whole (e.g number of stop signs, traffic lights and intersections, and having to go through roundabouts), and factors relating to the environment (e.g security and street lighting).
Seneret al2010	US	1605 cyclists across more than 100 cities in Texas	• Young bicyclists (aged 18-24 years of age) had the most positive perception of safety from traffic crashes. • Young bicyclists perceived the bicycle facilities in their community to be better than did older bicyclists. • The effects of bicycle facilities along the commute route in this study reflected a substantial improvement in perception of safety from	• There was no statistically significant difference in safety perception found among individuals of different ages beyond 24 years.

			traffic crashes in the presence of bicycle lanes, particularly for individuals who were 65 years of age or older.		
SteerDaviesGleave2010b	UK	Cyclists and non-cyclists in London	• For females, perceptions of safety generally decrease with age, although overall there is little difference in the scores given until reaching the 55-64 and 65+ age groups, where safety declines for most of the attributes. • For males, the middle-aged group generally state that cycling is safer compared to the scores given by the other age groups (except no cycle lane and kerb separated cycle lane). The youngest males tend to rate the cards as less safe than those in other age groups, although not to the same extent as the oldest group do.	• Men and women of all ages had similar infrastructural preferences, on average, when comparing kerb-segregated and off-road lanes (the two most preferred infrastructure types), clearly marked cycle lanes (less preferred) and no cycle infrastructure (least preferred).	

SteerDaviesGleave2012	UK	2307 cyclists in London	• Those aged 55 or over, and those aged under 35 were more likely to choose to cycle on safer routes with less traffic (or in a cycle lane separating them from the traffic). • There was much greater willingness to change route for parks and green spaces amongst the over 55s. Overall 67% of over 55s said they would change their route, compared to 58% of 35-54 year olds, and 47% of under 35s. • At junctions, older respondents reported feeling less safe than younger ones and were more prepared to detour, although differences were slight. • All age groups were found to have a preference for cycling on routes with more cyclists. However, over 55s were the most likely to	• Willingness to change route for a dedicated on-road cycle lane differed little by age group, unlike for parks and green spaces.	

			want to cycle on routes with a higher volume of other cyclists and those under 35 were the least likely. • The willingness to consider changing routes to use a cycle superhighway increases slightly with age.		
Stinson etal2003	US	3,145 individuals in Texas (mostly avid bicyclists who use computers)	• Older respondents associated a higher disutility for routes with car parking; however, as in the case of roadway class (i.e whether the road was residential, a minor arterial, or major arterial), the impact of age was small. • Older individuals had a marginally higher preference for wide right-hand (near-side) lanes. • Older individuals, who are likely to be more comfort-conscious, had a stronger preference for smooth riding surfaces.	• For practical purposes, the differential preference for residential streets (compared to minor arterials) is a non-issue (even for a bicyclist who is 100 years old, the magnitude on the minor arterial coefficient drops just from -0.77 to -0.69. • In the overall, however, the variations in sensitivity to the link-level and route-level factors across individuals are rather marginal compared to	• Older cyclists are more sensitive to comfort and traffic condition than younger cyclists, and older individuals are less sensitive to route travel time.

			• Older individuals disliked major intersections more than younger individuals.	the main effects of these factors.	
Tilahun etal2007	US	167 employees from the University of Minnesota, excluding students and faculty.		• Age was not found to be significant at the 0.05 level for probability of choosing a higher quality route.	
Tintinet al2010	New Zealand	2469 cyclists, aged 16 years or over, who had enrolled in the 2006 Wattyl Lake Taupo Cycle Challenge	• People over 35 years in age (particularly the over 50s) were more likely to report the importance of ‘more bicycle paths’ when considering factors that would encourage them to cycle more (other factors included in the survey were more bicycle lanes, bike friendly public transport, reduced vehicle speed, and better security in public places).		

			• Younger cyclists were more likely to report the importance of ‘rising fuel costs’ when considering factors that would be most likely to encourage them to cycle to work (other factors included in the survey were rising cost of car parking, fewer car parks, fewer difficult intersections, bike designed to commute, and access to shower facilities at work).	
Twaddleetal2011	Canada	Staff and students at University of Calgary, particularly potential or current cyclists	• Although all females are likely to indicate that safety concerns prevent them from commuting by bicycle, there is a difference in the type of safety concern expressed by older and younger females. Younger females are unsure about the route to take, while older females are more concerned with feeling unsafe riding on the road.	

			• Both male and female younger cyclists are more likely than older cyclists to state that their commute is too far. Twaddle et al note that this could be because they are students living with parents.	
Vliet2014	The Netherlands	200 respondents from various parts of The Netherlands; mixed recruitment methods		• Age (and gender) was not found to be a significant factor in bicycle mode choice for short-distance commuting.
Wardmanetal2001	UK	1996 commuters in four English cities, having screened out the 60% judged never likely		• No age effect apparent.

		to contemplate cycling			
Wardmanetal2007	UK	1996 commuters in four English cities, having screened out the 60% judged never likely to contemplate cycling		• No interaction effect between cycling-specific variables and gender or age was found.	
Westerdijk1990	UK/Sweden/The Netherlands	284 cyclists and pedestrians aged 20+ in 3 countries (50 subjects in Great Britain, 121 in Sweden and 113 in the	• Only the importance of the attribute distance was different for the age and gender groups. Younger subjects tended to give higher importance to distance (as did male subjects). Here 'distance' refers to choosing to take a shorter and more direct route.	• Distance, pleasantness and traffic safety were the most important attributes for pedal cyclists, however there were almost no differences found in the importance of attribute weights between different age groups	

		Netherlands)		(attributes included distance, junctions with traffic lights, junctions without lights, pleasantness, attractions, quality of the road surface, traffic safety, and gradient).
Winters etal2010	Canada	1402 adult current and potential cyclists, i.e., the ‘‘near market’’ for cycling in Vancouver, Canada	• The two least preferred route types were major streets with no facilities, with or without car parking (16% likely to choose). Only 79 respondents were ‘‘very likely’’ to choose to ride on major streets with parked cars. They represented a unique subpopulation: 22.6% were regular cyclists (vs. 8.1% in the overall sample), and they were mainly male (66.5%), aged 25 to 34, with a lower likelihood of having children (22.3% vs. 46.8%).	Age was not in general a significant predictor of route choice preferences.

Woolisc roftetal 2014	New Zealand	573 residents of New Zealand aged 18+	• Age had some impact on the average part-worth of three attribute levels: the availability of cycle lanes, a petrol price of \$2.10 and helpful drivers. Older respondents (over 50 years) assign them less utility than young respondents (ANOVA, $p < 0.05$).	• Most results showed no significant differences by demographic group.	

Details about age differences (children)

Citation key	Country of origin	Population characteristics	Differences	Similarities	Cited literature
Aldred 2015	UK	Mostly cyclists in UK. Similarities and differences here refer to adults' views about cycling with and by children at various ages, and vs. cycling solo.	• There was consensus over suitable cycling environments for twelve year olds, followed by cycling with eight year olds. • Respondents felt that shared use park routes were highly suitable for children and 'most people'	• Considering all scenarios (e.g cycling by 'most people', cycling on own, with an eight year old, or by a twelve-year old) the four most popular cycling environments were segregation by kerb, segregation by car parking, shared	• Literature cited suggested that riding with a child appears to influence route choice (e.g avoiding streets with lots of traffic , minimizing distance and riding on a path or trail) (Dill and Gliebe, 2008) • Literature cited suggested that children and parents feel more comfortable when there are cycle

	but not ideal for themselves. • Shared bus lanes and mandatory (paint-based) cycle lanes were only seen as safe for cycling with an eight-year-old by a quarter and a third of respondents, respectively. • While 85% of respondents said they would be happy crossing over a busier road as part of a cycle route under 30% said that they thought the crossing would be suitable for a solo twelve-year-old or an accompanied 8-year-old. • A combination of through motor traffic and parked cars restricting visibility and manoeuvring in	park routes, and filtered streets.	facilities, separated from the road and that cycle lanes on the road are viewed less favourably than separated cycle tracks (Ghekiere et al 2014)

			residential streets were thought to be hostile cycling environments for children.		
Ghekiereetal 2014	Belgium	35 children aged 10 to 12 years old in (semi-)urban areas in Flanders. Similarities and differences refer to parents vs. childrens' views on child cycling.	• When parents were asked which environmental factors were most likely to influence them to allow their child to cycle for transport, traffic safety was almost always cited as the most important barrier. Children also extensively discussed traffic, but they mentioned that other environmental elements were at least equally important to them. • Parents and children agreed that chicanes, speed bumps and speed limitations	• Both parents and children indicated that it was more comfortable to cycle in streets with low traffic density. • Parents and children agreed that streets with speed limitations were more inviting to cycle. • Children and parents felt more comfortable when there were cycle facilities, separated from the road by parked cars, a small hedge, a shoulder or when the cycle path was a bit higher than the road. Parents were a bit critical about parked cars, because of	• Cycling on busy roads, having to cross many roads, high traffic density, parental concern about stranger danger and having no safe place to cross are negatively related to cycling for transport in children. Positive associations of the presence of recreation facilities, cycle store facilities, pedestrian crossings, cycling along a quiet route, walkway quality, and walkability are identified.

were helpful in slowing down the traffic. However, children also said that chicanes are sometimes problematic since some cars cut corners and they drive very close to them.

- Children were afraid of falling when cycling on certain surfaces, e.g. gutters with a slippery surface or tramways, especially in bad weather conditions.
- Parents stated that it was especially important to have a wide cycle path, since children of that age may still have difficulties cycling on a straight line.
- Crossings and roundabouts were

the possibility of doors suddenly opening. Cycle lanes on the road were viewed less favourably than separated cycle tracks.

- Children and parents indicated that wider cycle paths were more enjoyable to cycle, so that children could cycle next to each other. When no cycle path was present, parents and children mentioned the importance of wide street lanes such that cars can easily pass. Also, bollards next to the cycle path or curbs of sidewalks were seen as making it difficult to move aside when cars need to pass.
- The type of surface and evenness of the cycle path was

	mentioned by parents as difficult traffic situations which are not always understood by children. Children found it difficult to maintain an overview when cars are coming from different streets. Some parents said that it was easier for their child to cross by dismounting their bicycle and walking. Other parents mentioned that their child was able to handle these difficulties, but the child just needs to be very alert. Bicycle tunnels and traffic lights were seen as good solutions to avoid difficulties in crossing junctions or roundabouts.	mentioned by parents and children as being important in order to cycle comfortably. • Children did not like unevenness in the cycle paths, because these vibrations were thought to damage their bicycle or make them fall and hurt themselves. Parents were also concerned about the fact that their child may not have seen these holes and therefore, the child may be surprised and fall. • Parents found a lack of legible road line markings a major issue that makes it unclear where cyclists have to ride. Making cycling facilities clearly visible and understandable by road signatures or	

- Parents disliked their child having to cross roads, especially when it was unclear where cyclists needed to cross. Designated places to cross, such as crosswalks or bike boxes, were therefore viewed favourably, since these infrastructures made cars alert of the presence of cyclists.
- Children found it less enjoyable when they often had to get off their bicycle such as needing to press the traffic lights button or wait at zebra crossings.
- Children cycle at a lower height and are less visible for other road users and have a more limited view of

colours were elements suggested by children and parents to facilitate legibility. For example, the sudden disappearance of road markings of the cycle path was disliked.

			the traffic situation compared with adults. It was therefore considered that cars should not be allowed to park at intersections and obstructing vegetation should be removed.		
Changetal2 008	Taiwan	Students and parents at Taiwan schools in urban and suburban areas. Differences reported relate to gender differences among children.	• Boys said they had better cycling ability than girls, in terms of – for example – confidence feeling safe riding a bike with trucks on the road, or to ride around parked cars (indicating differences in comfort/perceived safety).	• Students cycling to school perceived the most difficult conditions as being the presence of trucks, heavy traffic, and rainy and windy conditions. • Darkness, cars occupying the shoulder, making left turns, and crossing intersections were considered low difficulty and easy to overcome. • Narrow shoulder width, uneven pavement, and cycling on shared roads	

				were not rated as being of significant difficulty.	
Ghekiereetal2015	Belgium	305 fifth and sixth grade children and their parents from twelve randomly selected primary schools in Flanders, Belgium. Here differences and similarities refer to children's vs. parental preferences about child cycling.	• For children, evenness of the cycle path and the speed limit of the street were the most important attributes, while for parents it was the speed limit and degree of separation from motorised traffic that were the most important factors to prefer a street to let their child cycle along. • For parents, a curb was considered as good an alternative as a hedge for separating their children from passing motorised traffic during a cycle trip. In contrast, children's lower preference for	• Children and their parents preferred the street with a cycle path separated from the road by a hedge, rather than a curb or no separation (although for parents a curb was considered as good an alternative as a hedge for separating their children from passing motorised traffic during a cycle trip).	• Parental safety concerns (in terms of speed limit and degree of separation from motorised traffic) play an important role in their street preference. Safety should therefore be considered as the key priority for strategies to increase children's cycling. • Children focus more on evenness compared to their parents as children experience this difficulties more extensively

a curb may be due to perceived difficulties in accessing the cycle track over the curb.

- No parental preference was observed for an open or a half open street setting. Some parents may have preferred a higher residential density to let their child cycle, because of social control and stranger danger. In contrast, children preferred to cycle in open street settings, which may be explained by the preference of natural elements over building environments and thus preference for aesthetic features rather than safety issues.

	• Children's choices focused more on the evenness of the cycle path across all different street settings, while their parents' choices focused more on the separation between the cycle path and traffic. Evenness of the cycle path may be important for children as an uneven cycling path may hamper cycling, making cycling less pleasant.	

Appendix 6 Defining and Addressing Inequalities in Access to Cycling

Contents

This Appendix explores how we might draw upon the broader transport literature to define and address inequalities in access to cycling. Although cycling has been marginalised within work on transport inequalities, the transport literature provides useful frameworks that can be adapted to study cycling and inequality.

We draw here in particular on the approach developed in work on access to public transport. This involves a focus on understanding inequalities in access to cycling, and relatedly disparities in the extent to which people can access destinations by cycle. This relates to the National Propensity to Cycle Tool (NPCT) goal of exploring where cycle trips might be made in the future, by foregrounding the question: to what extent can people *now* get places by cycle, and if not, why not?

Highlights

- Academic work on transport inequalities has had little to say about cycling, even though use of cycling is currently highly unequal
- Increasing and diversifying cycling could help reduce inequalities in other areas, such as access to services
- Conceptualising cycling as a transport service, borrowing from work on public transport, can help identify barriers and solutions
- Dimensions of cycling inequality are outlined, with implications and recommendations
- This can help local decision-makers develop cycling strategies that identify and address access disparities, including then using the NPCT to identify potential routes

Cycling is highly unequal in the UK, and gender- and age-based inequalities persist even where cycling increased between 2001 and 2011 (Aldred et al., 2015). However, in contexts where cycling levels have been high for some time, participation in cycling is relatively gender-equal, and cycling remains high or even increases (as a proportion of trips) across older ages. This is the case in The Netherlands (see Appendix 8: Propensities to Cycle).

So while in the UK cycling is often thought of as an activity for younger men, this is culturally specific and can be changed. Rather than seeing cycling as something *by definition* unsuitable for groups that currently have lower cycling levels, it should be seen as potentially a highly inclusive mode. Cycling is more affordable than most modes, and – being a non-weight-bearing form of exercise – can sometimes be easier than walking; some disabled people cannot walk easily but can cycle. Where cycling is or becomes a mass mode it can be particularly important for people who otherwise have poor access to transport for a range of reasons.

This section therefore seeks to develop an approach to understanding cycling inequalities in terms of people's ability to travel and access key destinations by cycle. It outlines a range of types of exclusion from cycling, including those related to routes and networks, various types of risk, capability, and distance, and suggests ways of addressing these. It puts forward ideas for how we can use data collection, standards, policy and investment to increase cycling equity.

Table 1 Summary of six types of exclusions and strategies for addressing these

EXCLUSIONS	SOLUTIONS
1. Area-based exclusion implies that a local area lacks the route infrastructure to support local cycle trips, affecting those living in the area or wishing to travel through it.	1. Install high quality dense local network of cycle routes.
2. Destination-based exclusion is more specific, affecting people if activity destinations are not accessible via high-quality routes available when needed. For example, people who work in a city's centre may have good cycle routes to work, but those working in a suburban business park do not.	2. Strategic network planning linking trip attractors, identifying and incorporating range of potentially cycled trips.
3. Capability or Distance-based exclusion: distances are prohibitively long for cycling to necessary facilities within an area, or for a particular group. Ability to cycle longer distances declines faster for some groups than others: as for many exclusions, everyone is affected to some extent but this is not evenly distributed.	3. Reduce effective distances; ensure land-use planning system helps create cycleable distances to facilities for all; support e-bikes, park and cycle/cycling and public transport for longer trips
4. Risk-based exclusion. Some groups are disproportionately affected by risks (both physical and social) associated with cycling in countries such as the UK: a. Motor traffic risks: while people generally are deterred from cycling by having to share with busy motor traffic, some groups are more risk averse than others. b. Personal safety risks: differentially affecting people who are more concerned about/vulnerable to such risks 4c. Risk of social stigma: cycling remains stigmatised, with barriers heightened for some groups (e.g. poverty stigma for low income people, sports-related stigma for teenage women)	4. Increasing participation through focusing on needs and preferences of those users who are most intolerant of risk. This implies an inclusive approach in infrastructure design and network planning, alongside work on specific stigma barriers, ensuring that promotional and educational material does not inadvertently reinforce stigma.
5. Obstacle-based exclusions affect people using non-standard cycles and/or who are unable easily to walk or carry their cycle (and/or cargo).	5. Planning that maximises cycling by building to accommodate diverse physical capabilities and types of cycle.

	It must not be assumed that all cyclists can dismount and walk with their cycles, for example.
6. Cost-based exclusion: people are unable to afford cycle purchase or hire.	6. Subsidised access or ownership for lower-income groups, and/or where cycles are more expensive: such as cargo bikes, e-bikes, handcycles, children's cycles which need regular replacement.

Conceptualising Transport Inequalities

What does 'transport inequality' mean? This sub-section first briefly outlines some approaches to transport inequality, covering social exclusion, mobility and accessibility, justice and rights-based approaches. It is argued that all are potentially relevant to cycling, although in general cycling has been little discussed within any of them.

Transport and Social Exclusion

In the UK, much work has focused on transport's relationship with, and contribution to, social exclusion. An influential piece by Lucas (2012: 106) covers its history, explaining that people writing from this perspective:

'are less interested in the fact that there is no transport available to people per se but rather the *consequences of this in terms of their (in)ability to access key life-enhancing opportunities*, such as employment, education, health and their supporting social networks.'

The point then is not a right to any form of mobility in itself, but a right to access goods and services that improve people's lives. The answer to some exclusions might not mean improving access to personal transport at all. Other solutions might include improving internet accessibility, changes to land-use planning, or subsidising grocery deliveries for low-income households.

Kenyon et al's (2003) definition of transport inclusion, cited by Lucas (2012: 108), highlights the context as broader social expectations around personal mobility levels:

'[P]eople are prevented from participating in the economic, political and social life of the community because of reduced accessibility to opportunities, services and social networks, due in whole or part to insufficient mobility in a society and environment built around the assumption of high mobility.'

This definition highlights the need to look more broadly at what is required to participate effectively in a given society, rather than only focusing at those who are excluded. The broader social context might include land-use patterns shaping the types of journey people need to make and the choices that are available to them, or social norms meaning that the use of active modes is associated with poverty and low social status.

Accessibility or Mobility?

An accessibility-focused framing is often contrasted to framing the question as being about a 'right to mobility', with the latter approach being more narrowly focussed on people's ability to access and/or use *particular modes of transport*.

A 'right to mobility' has been established in some countries. Since 1982 in France, the law has enshrined the right of users to transportation and the freedom of mode choice, generally understood as meaning a right to public transport. Within academic work, literature on older people's driving cessation implies a right to car-based mobility, recommending efforts to prolong driving mobility in the older population. For example, Choi et al. (2012) express concern that women and ethnic minority drivers are stopping driving before male and white drivers.

In practice, however, there is substantial overlap between approaches focusing on a right to access and those focusing on a right to mobility. The French 'right to mobility' has led to the development of public transport subsidies[i] created with social and economic goals in mind, for example enabling unemployed people to access work. Similarly research seeking to delay older people's driving cessation does so because of the concern that stopping driving will have negative impacts on older people's health and well-being, including social connectivity, rather than being simply promoting the right to drive (see also Audrey and Langford, 2014 on young people's access to cars).

Recent critical work on the value of time has highlighted that people value leaving the house and may specifically value time spent travelling. There would then be negative implications of reducing travel time to zero, a goal suggested by a view of transport as *only* 'derived demand' for services (Aldred, 2013). This does suggest that as well as providing access to services, mobility may have direct value; for example, providing health and social benefits intrinsic to time spent using a specific mode.

Inequalities and different modes

It has been argued (Aldred, 2012) that the three 'pillars of sustainability' (economic, social, environment) have tended to segue into associations with modes. Thus economic sustainability has become associated with car and air transport, social sustainability with public transport, and environmental sustainability with walking and cycling.

This has helped to marginalise cycling within the field of transport inequalities, which is frequently framed in terms of socio-economic disadvantage and social exclusion. Much relevant academic and policy literature has relatively little to say about inequalities in access to cycling, or how cycling could contribute to poverty reduction: see for example Titheridge et al's (2014) recent review on transport and poverty. Debates around transport inequalities are much more likely to focus on improving access to public transport; or sometimes, for example in the US or rural UK context, improving access to cars.

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[i] For an example, see http://www.uclg-cisdp.org/en/observatory/free-public-transport

Within the field of transport inequalities, walking is treated somewhat differently to public or private motorised transport. Firstly, it is covered in work on land-use and neighbourhood characteristics, which focuses on distance to facilities (e.g. Cerin et al., 2007) and how this differs by area. This can be used to establish whether different communities are equally able to access key services on foot, or whether distance acts as a barrier. In the United States for example there is a well-established literature examining problems faced by low-income communities living in 'food deserts' and lacking the transport to access fresh food.

Secondly, there is a substantial literature on designing pedestrian infrastructure that works for a range of users, particularly older and disabled pedestrians. Policy-focused discussion of inclusive walking environments can be found in guidance, for example, TfL's (2014) *Accessible London*, which states (page 56) that '[w]alking routes should […] be welcoming to all, should not present barriers to their use, and be clear and navigable.' Tools have been developed to explore the extent to which different user groups can in fact navigate walking routes.

Similarly, tools have been developed to measure access *to* public transport and access *by* public transport. The former as with TfL's PTAL (Public Transport Accessibility Level) system would focus on access to bus routes (for example), while the latter, as with TfL's TIM time mapping system, would look at a particular service or destination type, such as an employment zone or retail centre, and examine how quickly people in different locations could reach it by bus[ii]. There is still relatively little work mapping access to services more broadly, incorporating access to non-geographically based services (internet shopping) as well as geographically-based services.

Justice and Rights

A contrasting framing of transport and inequality comes from the United States, in the form of an environmental justice approach. This perspective highlights environmental 'bads' and how those most exposed often do least to cause the 'bads' and benefit little from them (see e.g. Mitchell and Dorling, 2003 on air quality and car ownership).

Mullen et al's (2014) recent piece considers government has a duty to redress these inequalities and provide for walking and cycling, and potentially a duty on individuals to walk and cycle, as it reduces risk to others. This, like some other justice-based approaches (see e.g. Davis, 1993) highlights something often stated in other literature but less often discussed in depth: the relational nature of mobility, where enabling one person's mobility has implications for the lives and mobilities of others. For example, as Mullen et al. (2014) suggest, someone switching from driving to cycling may reduce the risk posed to others through a range of pathways: including not directly emitting air pollutants, posing a lower risk to other road users, and the 'safety in numbers' effect.

Relational approaches offer insight into, and options for, the allocation of road space and resources, a difficult challenge for transport planners. Where provision for different modes and users conflicts, how should space be prioritised? Different approaches have been used,

[ii] See https://tfl.gov.uk/info-for/urban-planning-and-construction/planning-with-webcat

from the development of broader mode-based 'hierarchies of users' to street-specific hierarchies such as those promoted in 'Link and Place' (Jones et al., 2008), which first categorise a street in relation to movement and place-based functions. It is important to remember that many people use, or could use, a range of modes. For example, a measure that makes it harder for someone to access a shop by car may potentially make it easier for them to access it as a pedestrian or cyclist, and vice versa.

A contrasting justice-based approach draws on Sen's work on capabilities and functioning (e.g. Walker, 2013). This highlights the need for people to have what Sen calls 'substantive opportunities'; thus focusing not on utility or wealth but on people’s ability 'to function in the lives they choose for themselves' (Davoudi and Brooks, 2014: 2690). Sen's approach has similarities with access-focused perspectives, in highlighting the social context: what people are attempting to use mobility *for*. The approach used here borrows more from Sen than from relational justice-based approaches, although both may be helpful for developing our knowledge of transport inequalities in relation to cycling.

Where is Cycling in Transport Inequality?

While a range of barriers are covered in the literature on accessibility to transport and destinations, three already mentioned above are among the most frequently discussed:

(a) exclusion based on distance to jobs or services: this literature often analyses land-use patterns, seen as inherently limiting take-up of active modes, although usually the focus is walking.

(b) exclusion based on inability to afford transport. The focus is usually car or public transport, with active travel often seen as unproblematic due to its relatively low cost for the individual.

(c) exclusion based on lack of, or inaccessibility of, transport. This covers for example availability of bus services, or accessibility of walking environments to all users; cycling is relatively rarely covered.

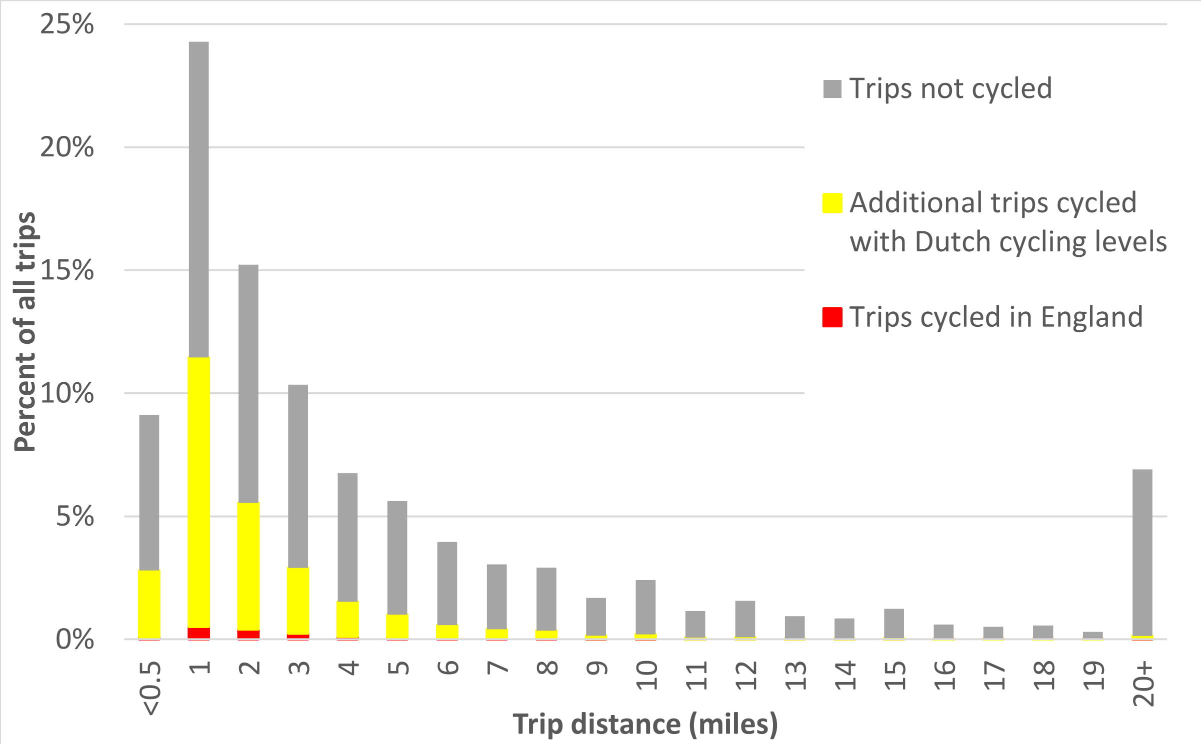
Other forms of exclusion, such as fear-based exclusion (Church et al., 2000), are seen as relatively marginal within work on transport and inequalities. However, given that many surveys have found motor traffic danger to be the major barrier to cycling (e.g. TfL, 2012), this and other marginalised types of exclusion are covered in our conceptualisation of inequalities in access to cycling.

Distance-based exclusions

Exclusion based on distance to jobs and services is particularly pertinent to walking and cycling. As our research in Appendix 8 quantifies, propensity to use active travel modes declines as distance increases. However, in low cycling contexts distance based exclusion is not the main barrier to cycling. Pucher and Dijkstra (2003) note that ‘[e]ven in the sprawling metropolitan areas of the USA, 41% of all trips in 2001 were shorter than 2 miles’. In a context in which many people feel confident to walk but not to cycle the greater range enabled by cycling can overcome distance-based barriers that block trips being made on foot.

The graph below illustrates the limited extent to which distance forms a barrier to cycling. It can be seen that there are large numbers of short trips currently made in England, which would be cycled in The Netherlands.

Figure 1: Number of trips by distance and proportion cycled UK vs Netherlands



Thus in currently low-cycling contexts, land use/distance is not likely to be the major barrier to cycling: whereas in higher-cycling countries, the focus is turning to distance limitations and means of overcoming this, for example through higher quality direct cycleways or through e-bikes (see Appendix 8: Propensities to Cycle). Likewise, it does not seem to be the case that fixed topographical factors pose one the major limiting factors on cycling levels. For example, hilliness is a deterrent to cycling and can be thought of as being closely related to distance in that it effectively acts to increase perceived distance. Our hilliness analysis shows that were England as flat at The Netherlands, with other propensities to cycle unchanged, English cycling rates would increase to only around 2.9% (Appendix 8), still sit near the bottom of the European league.

Therefore, in England the starting point should be that many trips lie well within reasonable cycling distances on suitable terrain. It should also be recognised that distance and hilliness are not independent of infrastructure planning, and that decisions are made in relation to other mode choices. Cycle routes can be more or less direct than corresponding routes for cars; and can involve more or fewer stops. Infrastructure can affect the impact of hilliness, in the best case bypassing hills[iii], in other cases creating them (e.g. through steep overpasses or even bridges with steps).

[iii] See http://www.twotunnels.org.uk/index.html

Differences between groups in distance tolerance and/or physical capability to cycle longer distances do not necessarily imply inequalities in use, because people in different groups make different trips. Our analysis of Dutch and English travel surveys shows that while (a) older people and women have steeper distance decay functions than do men, (b) cycling mode share can still be highest among women and at older ages in places like the Netherlands where infrastructural, cultural and policy environments are highly conducive to cycling. The trip characteristics of women and older people tend to be more cycling-friendly, precisely because they are shorter distances than trips made by younger men. However, our analysis shows that the discrepancy in cycling levels between England and The Netherlands is precisely at its widest for older people and for women.

Affordability-based exclusions

There is limited work on cost-based exclusions from cycling. The bicycle's cheapness can even at times work to its *disadvantage*, associating it with poverty (Law and Karnilowicz, 2014).

Goodman and Cheshire (2014) analysed the impact of expanding the coverage and soon after increasing user charges for the London Cycle Hire system. The expansion of the system, alongside increasing take-up by residents of poorer areas in the original cycle hire area, led to the proportion of trips by registered users from 'highly-deprived areas' rising from 6% to 12%. However, a doubling of prices may have then disproportionately discouraged casual-use trips among residents of poorer areas. The authors conclude that lower-income communities can and do use hire bikes, but these must be affordable relative to other modes.

Within policy communities, some initiatives address affordability, usually in relation to disadvantaged groups. The 'Earn a Bike' scheme in Bristol provide subsidised cycles and training in cycle maintenance to marginalised groups including unemployed refugees and those on probation[iv], while a scheme in Hackney loans a cycle to residents for a month for £10[v]. These provide an alternative to the better known national 'Cycle to Work' scheme, which subsidises cycle purchase for those in work, and thus excludes those without work by definition, and many in poorer paid or more casual employment. There is little academic work analysing and evaluating the impact of such schemes. However, Van Kloof et al. (2014) discuss a scheme in The Netherlands providing bicycle lessons to ethnic minority women; commenting that access to a bicycle 'seems to be problematic' with most participants starting and ending the course saying that they wanted to buy a bicycle.

Like distance-based exclusions, affordability-based exclusions may not currently be the major issue for cycling access. However, the issue still needs addressing, particularly in relation to more expensive cycles. While a basic hybrid bicycle can be bought for around £250, an electric-assist cargo cycle for transporting children may cost ten times as much. Similarly, adapted and specialist cycles for disabled people may be expensive. This form of exclusion could be addressed through keeping cycle hire prices low, ensuring that not only

[iv] See http://www.thebristolbikeproject.org/our-workshops/earn-a-bike/

[v] See http://www.hackney.gov.uk/cycle-loan.htm#.VaAOYvlViko

people in better-paid jobs benefit from subsidised cycles, and providing additional support for people needing more expensive cycles. Affordability-based exclusion is also a reason to minimise the perceived need for expensive accessories.

Service-based exclusions

A very few studies have looked at access to cycling facilities in relation to inequalities (e.g. Pistoll and Goodman's 2014 Melbourne study; the Goodman and Cheshire study discussed above, in relation to hire bikes). Some mode choice studies (e.g. Parkin et al., 2007; Downward and Rasciute, 2015) include access to cycle facilities within regression modelling, often finding a statistically significant but small impact on cycling. However, a lack both of facilities and data remain a problem. In Parkin's and Downward and Rascuite's studies, the variable used is the length of NCN (National Cycle Network) routes within a local authority area; while elsewhere 'length of cycle lane' has been used. However, it is now recognised (e.g. GLA 2013) that many route sections that 'count' under these metrics are unsuitable to enable mass access to cycling.

In developing better metrics to measure cycling environments, we can learn from methods and tools used for walking environments, such as Achuthan et al. (2010) on measuring walkability for different social groups. As such better metrics for cycling environments become available, we will increasingly have data and capacity to calculate what proportion of local road networks are suitable for cycling by, say, a 'competent twelve-year old'[vi]. This opens the door to reconceptualising access to cycling drawing on the approaches used in tools measuring access to public transport services and on those used to establish the inclusiveness of walking environments. An approach to cycling that incorporates the needs of different social groups has started to appear, but the TfL guidance Accessible London (2014) remains unusual in specifically referencing the needs of disabled cyclists; albeit without the broader inclusive language it uses for walking.

Access to cycling as a transport service

This section explores what it would mean to focus on access to cycling and hence to destinations, learning from the ways that writers have conceptualised inequalities in access to public transport and to walking environments. Cycling has historically not been seen as being based on a distinct system of provision (Aldred, 2012), so understanding it in relation to inequalities and disparities has not been easy. Instead, 'access to cycling' is generally conceptualised in an individualistic manner: it is thought of as access to an individual possession, as with a car, rather than as access to a service, as with public transport.

But the car analogy is incorrect and blocks our understanding of access to cycling. Ownership of a car facilitates access to the road network, given the right to legally drive, the money to pay for fuel and other costs. However, cycle ownership does not provide the same unproblematic access to the road network. Most of the UK population say they would not feel safe cycling on Britain's roads, and revealed behaviour bears out the stated preference for separation from motor traffic. Only one-third of Britain's National Cycle Network (NCN)

[vi]Often cited as the 'design user' of specified cycle routes

is motor traffic-free, but this portion carries 85% of cycle traffic. This is despite much of the motor traffic-free network being unsuitable for year-round utility riding, for example surfacing that becomes muddy in winter and lack of lighting.

Establishing Access to Cycling

By way of a comparison with access to public transport we might ask:

- Is the possession of a bus pass sufficient to meet someone's mobility needs, if bus services are infrequent and unreliable?
- Does living in a particular local authority area count as having 'access to bus transport' if the area has a bus service, but the nearest stop is more than 20 minutes' walk away?
- Do people have access if the services do not allow disabled or pushchair access?

All these questions have analogies in terms of cycling provision.

Tools such as PTAL, TIM and Accession have been developed to help measure quality of bus service and contribute to land-use and transport planning, alongside legal requirements for buses to reach certain accessibility standards. These tools are not perfect, but provide a conceptual starting point for thinking about access to cycling, alongside new assessment tools such as those found in the London Cycling Design Standards (LCDS) and the Welsh Active Travel Act Guidance.

For example, if provision of a good cycling service was taken as attaining a score of 70%[vii] or more in the LCDS Cycling Level of Service (CLOS) tool, then this could be operationalised through the following questions:

(i) At an area level measure the proportion of the network achieving 70% CLOS.
(ii) At an origin or destination level map the locations from where one can access the origin or destination within 30 minutes, using routes that consistently score 70% CLOS.
(iii) At a route level measure proximity of addresses within an area to a cycle route scoring 70% CLOS.
(iv) At an individual level ask how many of an individual's trip purposes can be realised by bike, given the requirement to achieve 70% CLOS and a distance based constraint.

For (iv) in particular, we might want to change the CLOS requirement based on the individual characteristics. The Rapid Evidence Assessment included within this report discusses the different preferences evidenced by gender and, to a lesser extent, age. Women, older people, children and those travelling with children tend to ask for higher levels of protection from motorised traffic. Newer tools such as CLOS are aligned with this, in that a higher score is likely to translate to a greater likelihood of meeting these groups' higher standards. They also often reference the existence of physical barriers, which can prevent disabled people and others from accessing routes (e.g. commonly installed anti-motorcycle barriers).

[vii] The specific figure is somewhat arbitrary and used as an example only.

Using this approach, we can move beyond thinking about cycle accessibility as simply meaning personal access to a cycle, and possession of the skills to ride it. The table below explores specific forms of exclusion from cycling, foregrounding but not limited to issues directly related to route infrastructure. This borrows from the useful typology in Church et al. (2000, cited in Lucas 2012). Church et al. outline seven forms of exclusion – physical barriers, geographical exclusion, distance from facilities, economic exclusion, time-based exclusion, fear-based exclusion, and exclusion by security or space management. Table 2 below shows how these concepts, largely developed with motorised modes in mind, can be usefully applied to barriers to cycling.

Table 2 Summary of six types of exclusion and key principles for solving these

Dimension (Church et al 2000 factor)	Explanation	Impacts (existing)	Suggested response	Impacts (of improvements)
Areas ("geographical Exclusion")	An area lacks the infrastructure to support local cycle trips; primarily route infrastructure but potentially also including access to cycle hire.	People in an area are excluded from cycling for everyday trips; particularly problematic in areas with low car ownership / lack of public transport.	Provision of high quality cycle infrastructure.	Mobility and access can become more equal as those excluded from other modes (e.g. unable to drive, lacking public transport) gain access to cycling.
Destinations ("exclusion from facilities")	The cycle network fails to connect key destinations, by contrast with primary motoring routes.	Inequalities might involve the provision of routes connecting commuter but not shopping or educational destinations; or routes that connect some commuter destinations but not others.	Cycle route planning needs to focus on key origins and destinations, ensuring these are connected.	Ability in particular for people with lower mobility resources to access jobs, services etc., reducing social exclusion.
Capability / Distance ("exclusion from facilities"; "time-based exclusion")	As distance increases, propensity to cycle falls. However, this is more acute for some groups e.g. women, children and older people, partly due to physical capability.	Where cycle network routes are longer (and/or hillier) than equivalent routes by other modes, this disproportionately discourages women, children and older	Utility cycle routes must prioritise directness to maximise take-up and accessibility, particularly where targeted journeys are made by women, older people, etc. Other measures to make routes faster include junction	Reducing distance on cycle routes by comparison with routes prioritised for non-active modes.

		people from making a given length of trip by cycle.	priority, improved surfaces, electric assist cycles. In the longer term, land-use planning can be used to help create cycleable distances to facilities for all.	
Risk (largely, but not limited to "fear-based exclusion")	(i) While people generally prefer greater separation from motor traffic, groups have different average levels of tolerance to motor traffic risk. (ii) The transport literature indicates some groups (e.g. women, older people) have greater concerns for social safety while travelling. (iii) If cycling (as in UK) is still a stigmatised activity, and cycling stigma differentially affects different social groups.	(i) Lower-quality infrastructure (e.g. painted lanes on busy roads) disproportionately excludes groups with lower levels of risk tolerance, such as women. (ii) Routes where social safety is a problem at times, which may be the case where there is little active surveillance, for example.	(i)Planners need to be mindful of the fact that lower infrastructural standards will disproportionately exclude these groups. (ii)Routes need to be perceived as also being safe from crime at night and when there are fewer cyclists on the roads. (iii) Cycling needs to be mainstreamed and seen as socially valuable, to counter stigma; planning and promotion of new infrastructure can also be targeted at specific groups.	Providing higher-quality infrastructure that (i) does not requires high levels of risk tolerance and (ii) is socially safe can increase mobility choice and reduce access inequalities (e.g. women have lower levels of access to cars than do men, so gain more mobility benefits from cycle access).
Obstacles ("physical exclusion", also	Physical barriers on cycle routes disproportionately exclude some groups;	Many barriers (e.g. steps, gates, bollards) disproportionately exclude people using	Infrastructure standards need to take account of a range of different cycle types and cyclist ability. Existing and	Reduction in inequalities in mobility and access. Potential to contribute to

potentially "space exclusion")	banning cycling in e.g. pedestrianised town centres excludes those unable to dismount.	non-standard cycles (disabled people, those carrying children or cargo) and those less fit or able.	planned cycle routes should be audited in relation to these barriers being mindful of equalities legislation (in UK, the Equality Act 2010).	reductions in health inequalities (e.g. among disabled people, older people on low incomes).
Cost ("economic exclusion")	People are financially excluded by personal transport costs such as purchasing a bicycle or cycle hire membership.	While not the major factor in access to cycling, this may make people in lower income groups less likely to cycle – particularly where extensive 'safety gear' is seen as necessary.	Potential to use targeted schemes (e.g. cycle loan programmes, subsidising cargo cycle access) and/or broaden existing subsidy schemes. Consider equity issues in charging for cycle hire, and in the provision of schemes that only target securely employed workers (e.g. in UK, Cycle to Work).	Increase in mobility and access for those with currently limited transport choices.

The table above focuses on the benefits of using cycling to increase mobility and access, so foregrounds increasing access for those experiencing lower mobility or access problems in other areas. However, substantial benefits also arise from transferring trips from car to cycle. Achieving this mode shift from the car is more traditionally seen as the main goal of cycling policy. While people who currently drive are on average less excluded and perhaps in less 'need' of cycling, if this group does shift modes then benefits arise from reducing their impact on others, including cutting CO_2 emissions and reducing road danger. Building on the methods developed during stage 1 of the NPCT with the microsimulation model we will be able to indicate how changing the trip patterns of different groups would differentially impact on health, environmental and equity outcomes.

None of the pathways that lead to exclusion from cycling are independent of each other and it is important to understand how they can reinforce each other. Many affect groups protected under the 2010 Equality Act; while no challenge has yet been brought in relation to cycling, it is possible given previous challenges related to pedestrian provision (failure to provide tactile paving).

For example:

(i) if key routes with high quality provision only connect commuter destinations, this can exclude retired people and those outside the workforce; as well as those with 'non-standard' commutes. This could be a double burden for women who are more likely to be dropping off children on route to work *and* are particularly put off by poor infrastructure. Use of the NPCT needs to be cognisant of the data limitations involved; for example incorporating local knowledge about non-commute trips.

(ii) if a sufficiently segregated route is available, but increases distances to destinations, women and older people will be disadvantaged. Again these groups are doubly excluded as they are likely to have both stronger preferences for short routes *and* for high quality infrastructure.

(iii) if a route has low levels of social safety, this will disproportionately affect those who make trips at quieter and off-peak times; such as those working part-time. This might happen where a route runs through a park which is dark and quiet at night, or through a residential housing area that is relatively deserted. Women are both more likely to work part-time than men, and more likely to be excluded by social safety concerns.

The table below shows that trip timings differ systematically by age and gender: so, if we are trying to increase trips among women and older people, it is particularly important to ensure routes are equally safe, welcoming and usable at interpeak times.

Table 3 Trip timings – how they vary by age and gender

	Peak (7-10am, 4-7pm)	Interpeak (10am-4pm)	Other times (7pm-7am)	All times of day

Gender	Female	41%	47%	12%	100%
	Male	42%	42%	16%	100%
	Both sexes	42%	45%	14%	100%
Age	0-15	45%	48%	8%	100%
	16-29	45%	36%	20%	100%
	30-39	46%	39%	15%	100%
	40-49	45%	39%	16%	100%
	50-59	42%	42%	16%	100%
	60-69	34%	54%	12%	100%
	70-79	29%	63%	8%	100%
	80+	26%	68%	6%	100%
	All ages	42%	45%	14%	100%

How data, standards, and planning can help reduce disparities in access and outcomes

Finally, Table 4 below highlights the need to develop our data, our design standards, and our planning processes to incorporate the points made above.

Table 4 Data, standards, and planning recommendations

Recommendation	Explanation
We need data on the extent to which existing roads and other infrastructure reach the standards needed to enable mass cycling. This goes beyond presence of a recognised route or 'cycle lane'.	Without this, it is very hard to establish the extent of infrastructure-based exclusion from cycling, and to compare this by area, by trip type, by destination or by social group.
Infrastructural standards should encompass a range of different cycle types and cyclists, prioritising under-represented groups with lower risk tolerance. Standards should include social safety and the need for 24-7-365 provision.	As well as route quality, route directness is particularly important for women and older people whose cycling levels will decline sharply if journey lengths increase.
Planning for increasing cycling needs to focus on key origins and destinations, prioritising alignments where there is substantial potential for increased uptake.	This should be sensitive to how trip types, origins and destinations vary systematically by age, gender and other factors.

References

Achuthan, A., Titheridge, Mackett, R.L. (2010) Mapping accessibility differences for the whole journey and for socially excluded groups of people, *Journal of Maps* 6(1), pp.220-229. DOI:10.4113/jom.2010.1077

Aldred, R. (2012). Governing transport from welfare state to hollow state: The case of cycling in the UK. *Transport Policy*, 23, pp.95–102. doi:10.1016/j.tranpol.2012.05.012

Aldred, R. (2013). The Commute. In: *Routledge Handbook of Mobilities*, eds. Adey, P., Bissell, D., Hannam, K., Merriman, P., Sheller, M. London: Routledge, pp. 450-459.

Aldred, R. (2013a) Incompetent or Too Competent? Negotiating Everyday Cycling Identities in a Motor Dominated Society, *Mobilities,* 8(2), pp. 252-271, DOI:10.1080/17450101.2012.696342

Aldred, R., Woodcock, J. and Goodman, A. (2015) Does More Cycling Mean More Diversity in Cycling? *Transport Reviews*, available online before print, DOI:10.1080/01441647.2015.1014451

Audrey, S., Langford, R. (2014). Dying to get out: young drivers, safety and social inequity. *Injury Prevention*, 20, pp. 1–6.

Cerin, E., Leslie, E., du Toit, L., Owen, N., Frank, L.D. (2007) Destinations that matter: Associations with walking for transport, *Health & Place*, 13(3), pp. 713–724.

Choi, M., Mezuk, B., Lohman C, M., Rebok W, G. (2013). Gender and racial disparities in driving cessation among older adults. *Journal of Aging and Health,* 25, pp.147S–162S.

Church, A., Frost, M., Sullivan, K. (2000) Transport and Social Exclusion in London. *Transport Policy*, 7, pp.195–205.

Davis, R. (1993). *Death on the Streets: Cars and the Mythology of Road Safety*. Hawes: Leading Edge Press.

Davoudi, S., Brooks, E. (2014). When Does Unequal Become Unfair? Judging claims of environmental injustice. *Environment & Planning A,* 46, pp.2686–2702.

Downward, P. and Rascuite, S. (2015) Assessing the impact of the National Cycle Network and physical activity lifestyle on cycling behaviour in England. *Transportation Research Part A: Policy and Practice*, 78, pp.425–437

Greater London Authority (2013). *The Mayor's Vision for Cycling in London*. London: TfL.

Goodman, A., Cheshire, J. (2014). Inequalities in the London bicycle sharing system revisited: impacts of extending the scheme to poorer areas but then doubling prices. *Journal of Transport Geography*, 2014, pp.272–279. doi:10.1016/j.jtrangeo.2014.04.004

Jones, P., Boujenko, N. and Marshall, S. (2008). *Link and Place: A Guide to Street Planning and Design*. London: Landor Publishing

Kenyon, K., Lyons, G., Rafferty, J. (2003). Transport and social exclusion: Investigating the possibility of promoting social exclusion through virtual mobility. *Journal of Transport Geography*, 10, pp.207–219.

Law, S.F., Karnilowicz, W. (2014). “In Our Country it”s Just Poor People who Ride a Bike’: Place, Displacement and Cycling in Australia. *Journal of Community & Applied Social Psychology* n/a–n/a. doi:10.1002/casp.2215

Lucas, K. (2012). Transport and social exclusion: Where are we now? *Transport Policy*, 20, pp.105–113.

Mitchell, G., Dorling, D. (2003). An environmental justice analysis of British air quality. *Environment & Planning A,* 35, pp.909–929.

Mullen, C., Tight, M., Whiteing, A., Jopson, A. (2014). Knowing their place on the roads: What would equality mean for walking and cycling? *Transportation Research Part A: Policy & Practice,* 61, pp.238–248. doi:10.1016/j.tra.2014.01.009

Parkin, J., Wardman, M., Page, M., (2007). Estimation of the determinants of bicycle mode share for the journey to work using census data. *Transportation*, 35, pp.93–109. doi:10.1007/s11116-007-9137-5

Pistoll, C., Goodman, A. (2014). The Link between Socioeconomic Position, Access to Cycling Infrastructure and Cycling Participation Rates: An Ecological Study in Melbourne, Australia. *Journal of Transport & Health*, 1, pp.251–259.

Pucher, J., Dijkstra, L. (2003). Promoting Safe Walking and Cycling to Improve Public Health: Lessons From The Netherlands and Germany. *American Journal of Public Health*, 93, pp.1509–1516. doi:10.2105/AJPH.93.9.1509

Titheridge, H., Christie, N., Mackett, R., Hernández, D.O., Ye, R. (2014). Transport and Poverty: a review of the evidence. Joseph Rowntree Foundation

Transport for London (2012) Attitudes to Cycling. London: TfL

Transport for London (2014). Accessible London: achieving an inclusive environment. Supplementary Planning Guidance. London, TfL. Available from https://www.london.gov.uk/sites/default/files/Accessible%20London%202014_4.pdf

Van Kloof, A., Bastiaanssen, B., Martens, K. (2014) Bicycle lessons, activity participation and empowerment, *Case Studies on Transport Policy*, 2(2), pp.89–95.

Walker, G. (2013). Inequality, Sustainability and Capability: locating justice in social practice. In Shove, E. and Spurling, N., eds. *Sustainable Practices: Social Theory and Climate Change*. London: Routledge, pp. 181-196

Appendix 7: Spatial Microsimulation applied to Propensity to Cycling

Contents

Introduction: the case for using Microsimulation

The National Propensity to Cycle Web Tool (NPCT) developed for the NPCT project describes current cycling propensity for England, and possible evolution of cycling uptake under different scenarios.

The web tool that supports NPCT has been designed to analyse and explain who cycles, to where, and what distances are covered; it also may help to picture how certain factors like hilliness can affect the outcome.

NPCT relies on a range of different data sources. One of them is the 2011 Census commuting flows, which give a broad picture of current cycling commuting rates. Census 2011 flows datasets include the number of trips between different census geographies, made by bicycle or by other means of transport.

The approach followed has been to combine flows, scenarios and distance decay functions (DDF) to understand how trip commutes would change under different assumptions. A limitation of the aggregate modelling approach currently used is that it does not provide information about the individuals performing the trips.

Why is this important? As the distance decay functions charts below illustrate, information about individuals is relevant for the outcome of a given scenario. We see stratification (strong, in some cases) by factors like age, gender, area type, or even purpose of the trip. In other words, not all people face the same constraints, or cycle in the same ways.

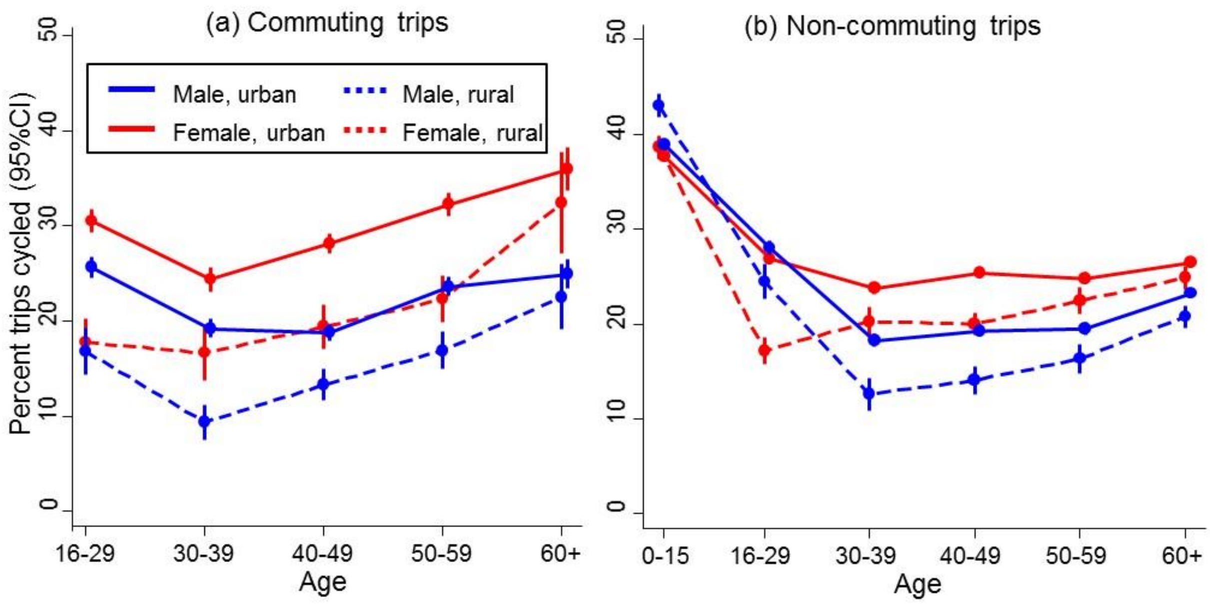


Figure 1 Distance Decay Functions for commuting and non-commuting trips, by age-sex-type of trip (Dutch Travel survey)

Therefore, knowing extra information about the population can be of interest for planners envisaging interventions focused on concrete measures to improve cycling, or targeting specific population groups.

Even without variation in response there will be variation in outcome based on the different trips that different groups make.

Heterogeneity in the population matters as health, carbon, and transport related benefits will differ according to *who* is changing *which* trips.

One way to achieve this *granularity* is to extend the level of detail of individual information. However, datasets such as the National Travel Survey, used in the Co-Benefits Model (CBM), only cover a very small percentage of the population and thus do not directly provide robust estimates at the small area level.

In Stage 2 Version 2 having extra information about the individuals would allow us to extend the aggregate model to more complex scenarios, to apply more precise DDFs, resulting in more accurate estimates.

In Stage 2 Version 2 we plan to extend the three cities analyses to a nationwide analysis, and to enlarge the key variables to cover new individual variables, like ethnicity and car ownership, that would join age, sex and mode of transport allowing a better picture of transport.

Data sources in Stage 1

The Propensity to Cycle Tool flows are sourced and analysed directly from Census flow data, at Medium Super Output Area (MSOA) level (dataset WU03UK_msoa). The original flows are displayed in the web, offering several simulated scenarios on the right hand of the screen.

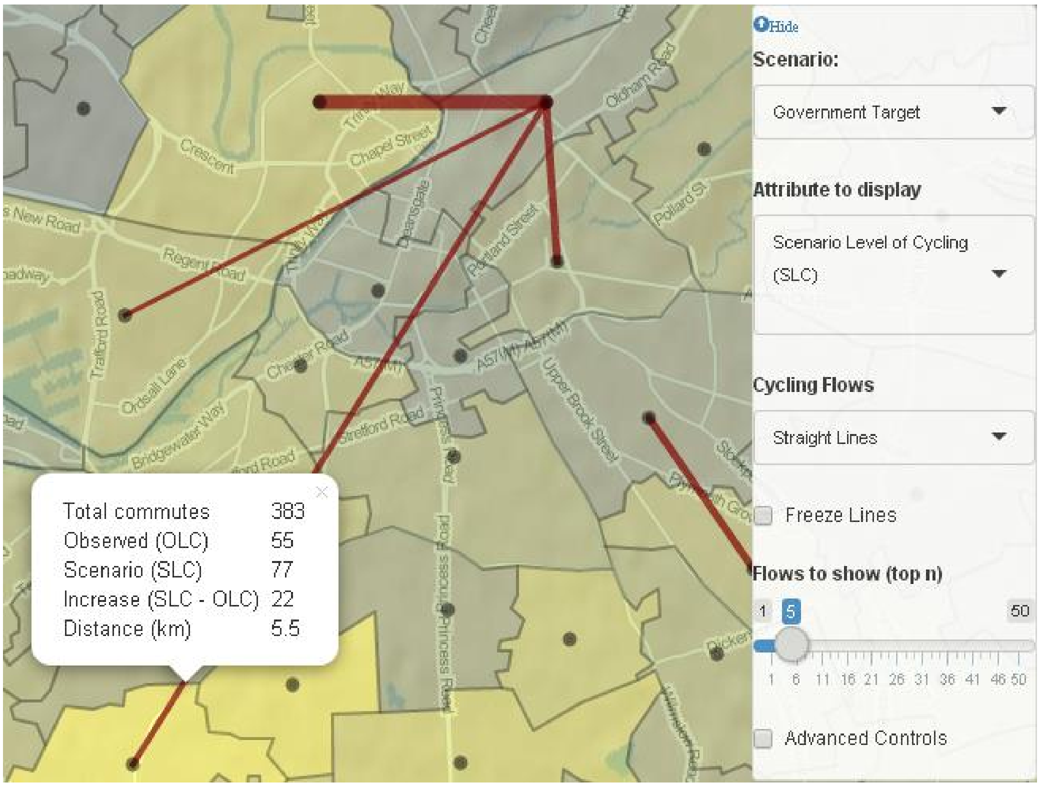


Figure 2 NPCT web tool, detail of five flows in Manchester city

We refer to this as the *aggregate model*, meaning that the map flows show aggregates (383 commutes, 55 cyclists); the map flows don't hold combined information on other additional variables. This aggregate approach will be the one adopted in Version 1 of the national model.

For Stage 2 Version 2 we intend to extend the model by using Spatial Microsimulation (SMS) generated populations. This would mean having the breakdown of these 55 cyclists by extra variables like: Age-Sex-Ethnicity-Car Ownership, or any other which we consider of interest (see Appendix 8).

Data approach for Stage 2

The table below describes some of the changes we plan for Stage 2 distinguishing Versions 1 and 2 of the model, from the point of view of the data sources used.

Table 1 Comparison of data features in Stage 1 and Stage 2

Version 1	Version 2
Nationwide (England)	Nationwide (England)
Trips detail level: Local (=only commuting with origin & destination in the city displayed)	Trips detail level: Probably county level (=trips with origin/destination in the county displayed)
Target Variables: [Mode of transport] =cycling, with partial processing of age &	Target Variables: [Age-Sex-Mode of transport

sex	(Cycling) + Ethnicity-Car ownership]
Sources: • Census 2011 (only commuting trips)	• Sources: Census 2011 (commuting trips) + Non-commuting trips (Nat. Travel Survey, NTS): shopping, leisure trips, friends….. + Education related trips (schools) + Non-travel physical activity (Health Survey for England) + Additional area level estimates of non-commuter cycling (Active People Survey)
Aggregate model: Trips displayed on web tool based on 1 variable + predefined scenarios	Aggregate model + Microsimulation model: Trips on web tool based on up to five variables, microsimulated model + user-defined scenarios results
Results come from processed *actual* data	Results come from processed actual data + Microsimulation & probabilistic model + Derived variables

This means the web tool for Version 2 could provide more sophisticated scenarios, depicting a still more accurate model of transport in wider areas of the country by using data from different sources of trips (commuting from Census, leisure and non-work related activities from the National Travel Survey, and other activities such as primary and secondary education), with overall better predictive capabilities.

National Travel Survey. Non-commuting trips

The current design of the NPCT web tool displays *commuting trips* flow information, but we do not yet have information on non-commuting trips. To be able to consider non-commuting trips, we will combine the power of microsimulation techniques with the detail offered by the National Travel Survey.

The National Travel Survey (NTS) is a yearly household survey covering regular, up-to-date data on personal travel, that monitor changes in travel behaviour over time. It contains nine separate datasets and over 1000 variables, with tabulated results for years 2002-2013. The available variables cover areas like:

- Household: address, public transport, household vehicle access
- Individual: age, sex, marital status, SeS information
- Vehicle: type, registration, parking, mileage
- Trips: date and time, mode, purpose, origin and destination

- Trip stages: mode, distance, duration, costs

The NPCT team is already familiar with NTS datasets, as they have been the main source used for the Co-Benefits model (see Appendix 10), and team members have worked extensively with them on other projects. Being nationwide, NTS suits our Version 2 goal of acting as a seed population for *non-commuting trips*, using [trip purpose] as a filter variable.

With the non-commuting trips extracted and regionally allocated, we plan to use the SMS technique to sample non-commuting trips and represent them locally, with a maximum degree of accuracy.

Candidate variables for matching will include commuting mode (for those with commuting trips), age, gender, car-ownership and ethnicity. We will also include area level variables, e.g. region and level of urbanisation. For those without commuting trips it will be important to ensure that people in higher cycling areas have a greater propensity to cycle their non-commuting trips. The analysis we have undertaken on NTS allows us to estimate how non-commuting cycling rates correspond to commuting rates. We will also be able to calibrate the model with data from the Active People Survey that provides addition Local Authority level estimates of cycling participation.

Previous work using the NTS has indicated that, at a population level, the proportion of commuters using cycling as their 'usual, main commute mode' is reasonably well correlated with the proportion of total travel time in an area that is accounted for by cycling (r=0.77; Goodman, 2013). In other words, populations in which a larger proportion of commuters cycle to work tend also to be populations in which cycling accounts for a larger proportion of all travel. This gives some confidence that areas defined as high-cycling based on commute modal share will also be high-cycling for other types of trips.

This strong correlation between levels of commute and non-commute cycling will be useful for Stage 2, as it provides some justification for assigning non-commute cycling trips to local populations based on their commuting trip patterns. However, our analysis shows that areas differ substantially in the proportion of commuters among the population (and hence the ratio at area level between commute and non-commute trips), depending on factors such as employment levels, student population, and age structure. This means that those areas with highest commuter cycling potential under a given scenario may not be the same areas as those with highest non-commuter cycling potential. Thus our incorporation of non-commuting trips may highlight different areas for investment.

Note also that the correlation between commuter and non-commuter cycling at population level may not apply at route level – the routes that individuals might use when cycling to work are likely to over-represent commuting corridors between residential and business areas, and may not be the same routes that people use in making other trip types, such as shopping trips or trips to visit friends. This is one (of many) reasons why the route allocation on NPCT will be only one of multiple pieces of evidence that transport planners should draw on in deciding where to build infrastructure.

In summary the combined data will be rich and allow detailed interrogation by users with extensive data visualisation. Here we will draw on the lessons learned from the CBM and Transport and Health Assessment Tool (THAT). Thus the user will be able to see in detail estimated baseline and scenario patterns of travel and physical activity for their population broken down across multiple subgroups.

Spatial Microsimulation: Concept

Spatial Microsimulation (SMS) is an analytical technique used in simulation, with wide applications to different areas, including transport problems. Its unique feature is that it can generate populations of individuals that can be allocated and displayed on a map at a small area level.

SMS uses as a source local aggregate data, e.g.

- Number of individuals by age band
- Number of individuals by sex
- Number of individuals by mode of transport used for commuting

These aggregates are always expressed at a geographical level of detail (e.g. country, city, MSOA), that constrains the detail of the resulting SMS population.

To match those aggregates, SMS uses a sample population, or *seed.* This population is then cloned, and its components (e.g. persons, households, other) are weighted , to match the constraints. Re the seed population, two main options exist:

1. Option 1: Using as seed a combination of categories of the target variables.
2. Option 2: Using as seed an existing survey. This survey can even be from an area having nothing in common with the geographical targeted SMS level, although the closer the match the more reliable will be the results.

Option 1 has been preferred to generate some of the city populations for NPCT in Stage 1. Option 2 will be incorporated and used in NPCT project Stage 2, as described for the NTS survey in the previous section.

The result is that by 'putting the individuals in a map', the SMS population explains real behaviours and responses to scenarios better than the confounded aggregates.

NPCT lines of work in Microsimulation

For Stage 1 our main goal has been to prove the feasibility of applying microsimulation in Stage 2. To prove this, we have generated the synthetic population for Manchester, and made the methodological innovation of allocating individual to Census flows data.

Two main lines of work involving SMS have been followed in Stage 1:

1. **SPATIAL MICROSIMULATION:** the first line is focused on generating the populations living in the three case study cities (Manchester, Coventry, & Norwich), at MSOA

level. The synthetic population for Manchester with three variables has been created, and the method to extend this to additional variables, not initially available in the aggregates sources, has been tested with successful results.

The basic source variables used have been [AGE-SEX-MODE OF TRANSPORT], as they explain a large proportion of variation in cycling. Of the several techniques available for microsimulation, we have followed IPF (Iterative Proportional Fitting), developed by one of the members of the academic team, as it is reliable and well tested (Lovelace et al., 2014).

In Stage 2 we plan to complete the IPF population with variables Ethnicity-Car Access, considering the possibility of adding into the mix other extra variables, if they prove useful at explaining cycling trips.

2. **FLOW ALLOCATION:** the second line of work refers to the allocation of individuals to the existing commuting flows.
   Census data has a granular detail of the populations of the three cities, but only at the city level; on the other hand, the individuals making up the flows do not have a high level of detail. This is to say that the Census office provides either *high* categorical detail + *low* geographical detail; or *low* categorical detail + *high* level of geographical detail, due to confidentiality issues.

   To overcome this limitation, we have developed a probabilistic method that reconstructs the features of commuter flows, so that they match the city aggregates. The method has been tested for the city of Manchester with the three key variables mentioned; it can also easily target larger or smaller areas.

   For Stage 2, the combination of the IPF microsimulation technique and the flow allocation method has proven the feasibility of using them nationwide, using further variables as a workable option.

Spatial Microsimulation illustration (SMS)

Number of variables

To illustrate the SMS technique, we will explore an example using the Manchester Census data, for a specific area (the first lower layer Super Output Area of the city: Manchester-001A).

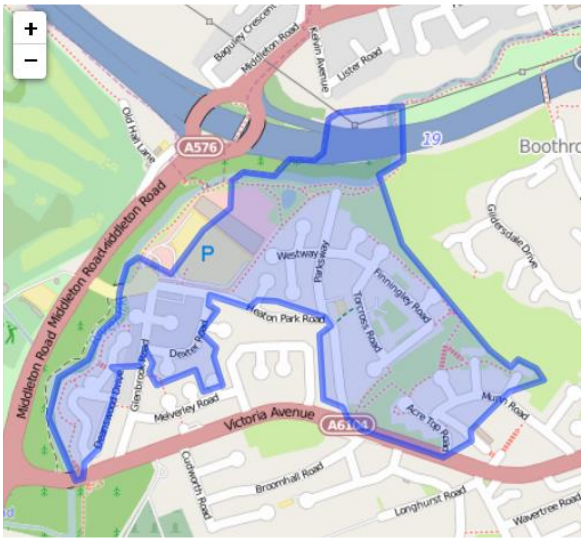


Figure 3 Detail of LSOA- Manchester 001A, located northwest of the city

The Office of National Statistics offers public access to all datasets for this area. The table below summarises the single aggregates, for the three variables of interest for cycling propensity (age-sex-mode of transport):

Table 2 Tabulation of 3 single variables for Manchester 001A (Census 2011)

Manchester 001A											
Age bands	16-24	25-34	35-49	50-64	65+						
549	76	107	202	154	10						
Sex	Males	Females									
549	254	295									
Trans port mode	Home	Undergr.	Train	Bus	Taxi	Bike	Car/ van	Passe nger	Bicy cle	Wa lk	Other
549	9	23	4	106	6	7	302	41	9	40	2

We can see the categories per variables, and therefore derive that the total number of categories for a hypothetical individual living in Manchester-001A:

5 (age) x 2 (sex) x 11 (transport) = 110 combinations

Of the 110 theoretical combination, an educated guess would probably say that some combinations (e.g: Female | 35-49 | Car-van driver) are much more usual than others (Male | 65plus | Bicycle).

Essentially what the SMS technique does is to provide, for this area, a maximum-likelihood solution for all the 110 basic individual types, or combinations. The resulting population will be a dataset with the structure:

Table 3 Format of Synthetic Population file, using Microsimulation, for Manchester 001A

Age	Sex	Mode	Total
16-25	M	Home	0
16-25	F	Home	1
……	……	……	……
35-49	M	Car/van	123
……	……	……	……
65+	F	Other	1

that is, a dataset containing all possible combinations of variables, for the individuals living there, and a total. This is the condensed format of the solution, with a maximum of 110 records (as some combinations may not exist).

If we prefer the expanded format, we will have a file with 549 records; one per individual living in the target Lower Super Output Area (LSOA)[i].

The SMS technique would allow us to estimate, for example, how many of the nine cyclists living in Manchester-001A are males or females, or how many fall into each age band.

Geographic level of application

The IPF technique used is generalisable to any geographic level (large or small areas), or to multiple areas, like the LSOA in a city, the wards in a city or the counties in a country. The only imperative requirement is to have access to the aggregates, for the target areas, and that they have consistent categories.

It can also be used, directly or not, for a larger number of variables (age-sex-mode-ethnicity-car ownership….), or even with combinations of cross and non cross-tabbed variables as source (age ~ sex + mode ~ sex), as we will see very soon. In this last case the main concern is compatibility between conflicting variables.

It is important to remember that the IPF technique does NOT provide *the solution* to the population problem, but just *one solution* amongst many possible.

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[i] A Census unit of geography with between one and three thousand people.

Iterative Proportional Fitting (IPF). Accuracy & variable correlations

Since the SMS technique only provides a solution, a relevant question would be: How *accurate* the IPF solution is, compared to the actual population?

There are multiple factors involved in the accuracy of the result, that go beyond the scope of this appendix; but a key one is the *internal correlations* between variables. For example, the use of certain transport modes may not be correlated, others may have moderate correlations on one variable (working at home, to var. 'Sex'), and finally others present strong correlations between two or more variables (cycling, to sex and age).

Therefore the correlation happens at variable level (like mode of transport, to age/sex), but may be relevant only on some categories (cycling) and not in others (bus).

Cycling correlations

We know, for example, that cycling in the UK is currently skewed towards men, by a factor of three to one compared to women. If we use single variables as a source, IPF would produce a certain error when estimating combinations like 'males who cycle' (i.e, it would underestimate the number of men, and overestimate for women).

This inadequacy can be easily solved by using *crosstab variables* as a source for IPF. Crosstab variables show the internal correlations between two or more variables; in theory, we could even think of using multi crosstabs, showing the correlation between *all* variables in a problem, if data was available.

Crosstabs variables approach

To compare crosstabs with single variables, we present a case study using our three key variables (age, sex, mode of transport) for the city of Manchester.

We have limited the example to a specific category per variable: [AGE BAND] =25-34, [SEX]=Female, [MODE OF TRANSPORT]= Cycling

SINGLE VARIABLES (whole Manchester):

FEMALES= 99,769 | CYCLISTS = 8708 | AGE (25-34) = 73,259

CROSSTAB DATA: for the female subgroup, the cross-tabbed data are shown in the table below.

Table 4 Three-variable crosstabs, filtered for female entries, city level (Manchester)

Age	sex	mode	total		age	sex	mode	total
a25	female	car	14303		a16	female	train	966
a35	female	car	14265		a25	female	bicycle	857
a25	female	bus	7864		a35	female	bicycle	687

a16	female	bus	7612		a35	female	train	662
a50	female	car	6604		a65	female	car	598
a35	female	bus	6085		a16	female	home	536
a25	female	walk	4918		a35	female	other	443
a16	female	car	4722		a65	female	bus	417
a35	female	walk	4150		a16	female	bicycle	406
a16	female	walk	3760		a25	female	other	333
a50	female	bus	3542		a65	female	walk	297
a50	female	walk	2372		a50	female	other	253
a35	female	home	2264		a50	female	bicycle	252
a25	female	home	1683		a50	female	train	248
a25	female	pass	1572		a65	female	home	240
a25	female	train	1506		a16	female	other	232
a35	female	pass	1371		a65	female	pass	136
a16	female	pass	1234		a65	female	other	38
a50	female	home	1196		a65	female	train	38
a50	female	pass	1088		a65	female	bicycle	19

We observe then that cycling only appears on the second half of the table. Still, we know the exact number of female cyclists in this category:

FEMALE + CYCLIST + AGED 25-34 = 857 individuals

If we consider the three categories as completely independent probability events, we would obtain an expected number of cyclist of 1,384; still way off the real 857.

Even by applying Bayes probability, the chances of deriving the exact number of 857 are tiny. This example illustrates why, whenever possible, for Stage 2 of the Propensity to Cycle project we aim to use crosstab variables that reduce estimation errors to a minimum.

Data Handling Risks in Stage 2

Confidentiality issues

In Version 2 the use of more variables, combined with the SMS technique, will provide a higher level of detail about the individuals living in an area.

Since we will be creating a realistic microsimulation population, in many cases the results will closely match the 'real' population of England. This, therefore, creates a greater challenge for data security. This challenge will be met by ensuring the individual level data generated is not stored on the server. Instead we will generate summary tables, similar to those currently provided by the Census, for each scenario and these will be stored on the server.

For NPCT Stage 2, two main considerations arise in the field of data protection:

1. Clearly establishing what data are confidential and cannot be disclosed under any circumstance. Under certain circumstances, a relatively non-confidential variable poses a risk, due to some categories being not frequent, or when combined with other variables, allowing reverse identification of individuals.

2. Setting anonymisation rules (like randomisation or small areas swaps) for those variables considered risky.

We will also apply various thresholds to make sure the summary tables and charts generated do not include potentially disclosive data. We plan to apply stricter rules than those currently applied by the Census when displaying data that is close to real or baseline synthetic data; for variables that are model generated (e.g. switch to cycling) the need for caution is lower.

Computability

Processing nationwide data with a higher number of variables will require an increased computing power. This is especially relevant for the calculations involved in the probabilistic model, in the SMS calculation, and in user-defined scenarios.

In Version 2 the majority of the data sources shown in the NPCT tool will be pre-calculated, improving the overall web performance in terms of response speed.

Flows allocation

To break down a flow into its components is equivalent to the problem described previously of comparing aggregates to crosstabs. Most dataset are not geographically detailed enough; when it comes to flows allocation, we need a better technique to fill that gap.

We describe how the flow allocation method can be used as a basis for scenario modelling in the microsimulation model of Stage 2.

For this, we will use two data sources: the three-crosstabs variables source (age~sex~mode), at city level (DC7101EWla), and the commuting flows (WU03UK_msoa).

The goal is that every flow in the city gets allocated, and that the whole allocated set matches the city crosstabs probability distributions.

Flow example

As a worked example, we have taken this line from the Manchester flow files:

Table 5 Detail of flows between 2 Manchester MSOAs (Census 2011)

Orig	dest	all	male	female	a16	a25	a35	a50	a65
E02001046	E02001090	5	2	3	1	1	3	0	0
Orig	dest	home	train	bus	car	pass	bicycle	walk	other
E02001046	E02001090	0	0	2	2	0	0	1	0

It describes commuting flows between two Manchester MSOAs (Manchester 002 >046).

Data availability: ideally, the flow should be allocated using crosstabs as close to its geographic level as possible (e.g. 3-var. MSOA crosstabs for a given MSOA flow). As seen, this level of detail is not available from the Census and we have to use three variable crosstabs at city-level.

Assumptions: to allocate this flow, we will make the assumption that flows tend to follow the aggregates crosstabs at the city level; this is equivalent to say that MSOA internal correlations tend to behave (though in most cases they won't comply with the rule) in the same way that they do generically at the city level.

The flow allocation process can then be summarised in the following calculation steps:

1. PRE-PROCESS SOURCE FILES: (1) crosstab file + (2) city flows file.
2. CALCULATE TYPE PROBABILITIES, per flow
3. ALLOCATE SINGLE TYPES to CROSSTABS for the flow
4. VALIDATION: ADJUST CITY AGGREGATES after allocation (opt.)

Step 1: PRE-PROCESS SOURCE FILES

Two source files are used for allocation: the crosstabs file (reference) and the flows file. Preprocessing simply formats both files with comparable categories. Sorting order for crosstabs is not relevant, but to minimise errors the order in the flows totals file must be ascending (ie. starting with low flow nos.).

The format of the three variable crosstabs file for age~sex~mode, for Manchester city looks like this:

Table 6 Three crosstabs variables in Manchester, ready for flow allocation

age	sex	mode	total
a35	male	Car	19056

a25	male	Car	16931
a25	female	Car	14303
a35	female	Car	14265
a50	male	Car	10486
…	…	…	
…	…	…	…
a25	female	Bus	7864
a25	male	Bus	7825

So it simply lists each of the possible types (80), and its aggregate numbers for the city. The flow file will have the aggregates with origin within the city MSOA, and destination any other MSOA in the country.

Step 2: CALCULATE TYPE PROBABILITIES, per flow

For the 80 possible type combinations of [age-sex & mode, with five, two and eight categories respectively], and for each of the flows (22,083 in Manchester), we calculate a prob. vector, which describes the probabilities per type and per flow. This will give us how likely is each 'type' in the MSOA.

On mathematical notation the 'p' prob vector for the types is:

$$p = \prod_{i}^{t} prop.Ni \,/\, FT^{t-1}$$

where:

- *t* is the number of traits targeted (3)
- *FT* is the flow total (5), or number of individuals
- N_i are the totals for each of the single variables.
- *prop* is the propensity of a type, compared to its probability derived considering its types as independent events

E.g. ignoring propensity, the non-normalised probability of the type [Female | Age 35-49 | Car] is: p= 3.3.2 / $5^{(3-1)}$ = 18/25 = 0.72.

The process must be repeated for all types in the flow and then normalise all probs. The key missing element is then propensity.

The propensity for this type is 1.09, which is equivalent to say that the probability for a female, aged 35-49, of driving a car is ~9% higher, for Manchester, than what you would expect considering its single variables [Female|35-49|Car], as independent probability events. Propensity can be calculated in at least two different ways: one a priori, from the crosstabs table, using the expected probability and comparing it with the real one; and one a posteriori, once the allocation method has been completed (in which case you must use iteration). This second approach would mean running the procedure at least twice, one with an initial estimate and a second with a better match for propensity.

Step 3: ALLOCATE SINGLES

In principle, the probability vector per flow is all you need to allocate types to a flow. A probability vector will have the format:

vprob= 0.005, 0.0043,0, 0 …………… 0.12 (80 values)

that is, it gives a probability, for each of the existing theoretical types, of existing in a given flow.

To allocate the single type you can use a multinomial distribution. However, being random, using a multinomial doesn't guarantee matching the singles, and it does not minimise the proxy errors.

To allocate the flow minimising errors and sticking to single var. aggregates, we eliminate single variables of value 0 and then sort it from lower to higher aggregates, resulting:

Table 7 Detail of flow sorted before the singles allocation starts

orig	Dest	all	a16	a25	walk	bus	car	male	female	a35
E02001046	E02001090	5	1	1	1	2	2	2	3	3

This sorting reduces the allocation error. We will now allocate single variables, one at a time, starting with the lowest (age band 16-25, a16), using a multinomial probability distribution where the probability vector is vprob.

This will result in the a16 individual being allocated to one of the 80 types; for example, a16-female-car.

Now let's recalculate the single variable aggregates. Each individual allocated forces a recalculation of singles totals. E.g, if one individual has been randomly allocated to type [a16-female-car] then totals for categories [a16-female-car] will decrease in one unit.

Table 8 Detail of flow sorted after allocating the first individual

orig	dest	all	a16	a25	walk	bus	car	male	female	a35
E02001046	E02001090	4	0	1	1	2	1	2	2	3

Now there are only four individuals to allocate, and we can proceed to allocate the next minimum, a25, which will follow the same procedure. At the end of this iterative process all the elements in the flow should match the single var. aggregates.

Step 4: VALIDATION and ADJUSTMENTS

Once all the area flows have been allocated, several checks occur. At the geographic level (Manchester city in this case), all the nos. must be accurate: the total population allocated, plus the single aggregates (age-sex-mode) and the crosstab variables. Crosstab variables are the key constraint.

In our experience the level of matching after the first iteration is already very high (~98-99%), so in users may prefer to save time at the minor cost of not achieving a perfect match. However, an additional iteration can then achieve 100% matching for the small number of areas that did not match totally on the first iteration.

One improvement we would intend to implement in Stage 2 for this method is measuring the maximum level of error per flow. Some flows will be totally accurate, while others may have errors that can be quantified, with practical implications highlighted.

Extending flows allocation to other variables

For Stage 2 we plan to extend this method so that it can be used on a larger number of variables. Some of the decisions will depend on the availability of data. For example, if only three-cross tabbed variables are available nationwide, we will develop a method of extending results, by completing the three variables accurate results with a minimal degree of error, to cover five variables.

The two missing variables, which we do not anticipate will be available cross tabbed, are Ethnicity and Car Ownership. Still, these two variables are present in multiple datasets, with internal correlations provided, so there are good prospects of data handling and deriving accurate information.

References

Goodman, A. (2013) Walking, cycling and driving to work in the English and Welsh 2011 census: trends, socio-economic patterning and relevance to travel behaviour in general. *PloS one,* 8 (8), e71790.

Lovelace, R, Ballas,D., Watson, M. (2014). A Spatial Microsimulation Approach for the Analysis of Commuter Patterns: From Individual to Regional Levels. *Journal of Transport Geography*, 34. pp.282–96. doi:10.1016/j.jtrangeo.2013.07.008.

Appendix 8 Descriptive analysis of the UK and Dutch National Travel Surveys, examining propensities to cycle

Contents

Summary

- In England, 1.7% of trips recorded in the National Travel Survey between 2008 and 2012 were made by bicycle. Around this overall figure there is considerable variation according to age, sex, purpose (e.g. commuting/non-commuting) and, to a lesser extent, urban-rural status. The highest proportion is among males aged 40-49 in urban areas, who cycle 6.4% of commuting trips. The lowest proportion is among females in rural ages, who at all ages make under 1% of non-commuting trips by bicycle. Equivalent figures in the Netherlands are far higher, with 26.7% of all trips are cycled. The Netherlands also differs from the England in having smaller differences between age and sex groups.

- The probability of cycling a trip declines rapidly with increasing trip distance. In England, the rate of this decline is generally steeper for older adults and for children than for younger adults; for females than for males; and for commute trips than for non-commute trips. No large differences are seen by urban-rural status. Based on these observations, and given that distance is a key determinant of cycling, we stratify into the following groups when estimating 'propensity to cycle':
    1. Male, age 0-15 years, all trips
    2. Male, age 16-59 years, commute trips
    3. Male, age 16-59 years, non-commute trips
    4. Male, age 60+ years, all trips
    5. Female, age 0-15 years, all trips
    6. Female, age 16-59 years, commute trips
    7. Female, age 16-59 years, non-commute trips
    8. Female, age 60+ years, all trips

  Using data from the Netherlands, we also characterise the distance decay function for trips made by electric bicycles ('e-bikes'). Unsurprisingly, distance decay for these trips is less steep than for other bicycle trips.

- For each of our eight stratified groups, we examined how additional individual, household and geographic characteristics affected the probability that a given trip is cycled. We found that ethnicity and household car ownership were particularly strong predictors, with lower rates of cycling observed among non-White people and among those with more cars in their household. We therefore decided to use ethnicity and household car ownership alongside age and sex as key characteristics in the microsimulation model (see Appendix 7).

- We developed a flexible approach to modelling scenarios. This approach assumes that the current distribution of trips in England by distance and purpose remains unchanged, as does the current patterning of trips by factors such as ethnicity, car ownership and hilliness. This approach allows the underlying propensity to cycle to vary in line with

scenarios involving one or more of the following types of alteration: 1) increase in national cycle mode share; 2) increased age and/or gender equity of cycling; 3) 'Go Dutch' scenarios in which English propensities to cycle become similar to those in the Netherlands (taking into account the dampening effect of higher levels of hilliness in England). We show how this approach can form the basis for scenario modelling in the microsimulation model (see Appendix 7).

Purpose of this Appendix

The analyses presented in this Appendix examine current cycling behaviour in the UK, with a particular focus on the individual, household and geographical predictors of cycling trips of different lengths. Dutch National Travel Survey data is presented in places in order to compare English cycling patterns with a Western European nation with high rates of cycling.

These analyses are not intended to provide a comprehensive examination of cycling behaviour. Instead they aim to inform the creation of a spatial microsimulation model of propensity to cycle in Phase II. Specifically, the work presented in this Appendix aims to:

1) Provide background information that can contextualise the model and the scenarios.

2) Document decisions regarding how to estimate 'propensity to cycle' in the model

3) To describe the modelling process that uses National Travel Survey data to estimate the propensity to cycle a given trip in the current English population, and to model how these propensities would change under alternative scenarios.

Data sources

UK National Travel Survey, 2008-2012

The UK National Travel Survey (NTS) is a continuous, nationally-representative household survey. It has an annual sample size of around 8300 households, 7000 of which are from the study region of England. In recent years, the proportion of target households completing the survey has been around 60%. This Appendix uses NTS data from 2008 to 2012 to ensure the findings reflect recent travel patterns. All members of participating households complete personal questionnaires. In addition, participants complete one-week travel diaries on the trips they make during that week. A number of details of these trips are recorded, including duration, distance, mode and purpose for all 'stages' of most trips. Trips are defined as a one-way journey from an origin to a destination; stages are the components of trips made by a single mode. In the vast majority of cases (96% of trips), there is only one stage per trip and the rate of cycling rarely changes between trips and stages.

The purpose of a trip is generally classified in terms of the main reason the person went to the destination site, unless the destination is their home in which case the reason for being at the origin site is used (e.g. both home-to-work and work-to-home are counted as 'commuting'). If a chained series of trips is made, then these are broken up into single trips and coded separately (e.g. a mother dropping off her child at school and then going to work would be counted as making an 'escort education' trip followed by a 'commute' trip).

In addition to the standard individual, household and area variables present in the NTS, we used data merging to assign three further geographical variables to the Lower Super Output Area (LSOA) of every household. These were: the prevalence of cycling to work among commuters in the 2011 census; the 2010 Index of Multiple Deprivation score (income deprivation subdomain); and the average hilliness derived using remote sensing data from NASA[i].

Dutch National Travel Survey, 2010-2013.

The Dutch travel survey (Onderzoek Verplaatsingen in Nederland, or OViN) is a rolling nationally-representative individual survey that includes a travel diary of one day. It has been conducted in its current form every year since 2010, collecting data on around 50,000 residents of the Netherlands per year (response rate 55%). Data are collected by a variety of methods: internet questionnaire, interviewed over phone and face-to-face interview during home visits. As in the UK NTS, both trips from work to home and from home to work are counted as 'commuting'. In 2013, for the first time, the Dutch NTS asked about 'e-bikes' (electric bikes) as a separate mode.

Methods of analysing National Travel Survey data

We aimed to derive formulae that could characterise the current 'propensity to cycle' for any given trip. The propensity to cycle refers to the probability that a particular trip would be cycled given the characteristics of the trip (including trip distance), the person making the trip, and the area in which the trip was made. This measure of current propensity to cycle (Observed Level of Cycling, or OLC) is then manipulated to generate modelled propensities under a range of alternative scenarios (Scenario Level of Cycling, or SLC).

Section 1: Descriptive analysis of probability of cycling according to key characteristics

In the UK NTS analysis we defined cycling trips as those for which cycling was the main mode, i.e. the mode used to travel the longest stage by distance. In the first section of this Appendix we present the overall probability of making a trip by cycling according to the three key variables of (a) sex, (b) age and (c) urban-rural status. Here and subsequently we stratified *a priori* between commuting and non-commuting trips, because the local-level models presented in subsequent Appendices and in Phase II also model commuting and non-commuting trips separately. For comparison, we present equivalent analyses using Dutch NTS data.[ii]

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[i] Calculated using elevation data from the Shuttle Radar Topography Mission ['Version 4' dataset], available at http://srtm.csi.cgiar.org/. Across the UK, the average resolution of the raster is 56.5m east-west and 92.6 m north-south. We converted the elevation data into a gradient in degrees for each raster cell (using R's 'raster' package), and then aggregated these to generate the average per LSOA.

[ii] In the Dutch NTS is that trip 'main modes' are classified according to a fixed hierarchy of modes, such that all trips involving both cycling and a motorised transport mode are given the motorised mode as the 'main' mode (e.g. a trip involving both cycling and a train journey is automatically given the main mode 'train'). Trips involving both cycling and walking are automatically given the main mode 'cycling'. In practice, this makes very little difference compared to the UK's distance-based approach as very few trips involving cycling and a motorised mode have the longest distance travelled by bicycle. Similarly, very few trips involving both cycling and walking have the longest distance travelled by walking.

Section 2: Characterising the shape of the distance decay of cycling across different groups

In the second section of the Appendix, we examined how the probability of making a trip by cycling changed as a function of trip distance, or the 'distance decay' of cycling. We created graphs to plot this distance decay and compare the shape across different groups, again defined in terms of sex, age, urban-rural status and trip purpose. If the observed distance decay shape differed systematically between groups – for example, if the probability of cycling declined faster in women than in men at increasing trip distances – then we proposed stratifying according to that characteristic. We singled out distance for this particularly detailed examination as a predictor variable because it has such an important effect on propensity to cycle.

Once we had determined the relevant stratified groups in the UK data, we present the equivalent Dutch distance decay functions for comparison. We also present Dutch distance decay functions for e-bikes (pooling people of all ages and both sexes to increase the number of observations).

Sections 3 and 4: Approach to modelling propensity to cycle, and application to scenarios

In this section we outline the flexible modelling process that we use in order to model scenarios in which the underlying propensities to cycle are altered. Specifically, we allowed these underlying propensities to be altered in one or more of the following ways:

- National mode share increase: The overall national model share of cycling in England is assumed to increase to a given target value (e.g. 5%).
- Increased age and/or gender equity: Females and/or older people in England become more similar to young males.
- 'Go Dutch': Individuals in England become more similar to their counterparts in the Netherlands. In 'Go Dutch' scenarios, we allowed for the fact that England is a hillier country and that hilliness tends to lower the propensity to cycle.

These types of changes can be made either separately or in combination, for example one can combine a mode share increase with increased age and/or gender equity. Finally, in section 4 we show how this modelling process is applied to our selected Phase 1 scenarios.

Statistical methods

In most analyses, we use trips as our units of analysis. In order to account for the clustering of trips within individuals, we used robust standard errors when calculating confidence intervals. This takes account of the fact that the trips in our datasets are not independent observation but instead a given individual will tend to make many trips of the same type.

We used the weights provided by the UK NTS to take account of 1) differing response rates by factors such as age and sex, and 2) the fact that short walk trips were only recorded on the final day of the diary. We likewise used the trip-level weights provided by the Dutch NTS.

We excluded from all analyses trips with missing data on trip length or mode (0.2% of trips in the UK NTS, 0% in the Dutch NTS). We also excluded individuals with missing data on one or more of the individual, household or geographical variables examined (0.1% of individuals in the UK, 0.6% in the Dutch NTS).

Results, Section 1: Probability of cycling according to key characteristics

In total, 1.7% of trips in England were cycled. **Error! Reference source not found.** shows how this proportion varied by age, sex, urban/rural status and trip purpose. For all age groups under age 60, three things were consistently observed. First, commuting trips were more likely to be cycled than non-commuting trips. Second, men were more likely to cycle than women. Third, trips in urban areas were generally more likely to be cycled than trips in rural areas. By contrast, for adults aged 60 years or more, these differences grew smaller or disappeared.

Cycling levels showed more marked age variation in men than in women. Specifically, cycling levels in men were relatively high until age 49 for cycle commuting and until age 29 for non-cycle commuting, and declined thereafter. An apparently different pattern was seen in women, with cycling levels being relatively flat across the age range (p=0.12 for interaction between age and sex for commuting trips and p=0.06 for non-commuting trips).

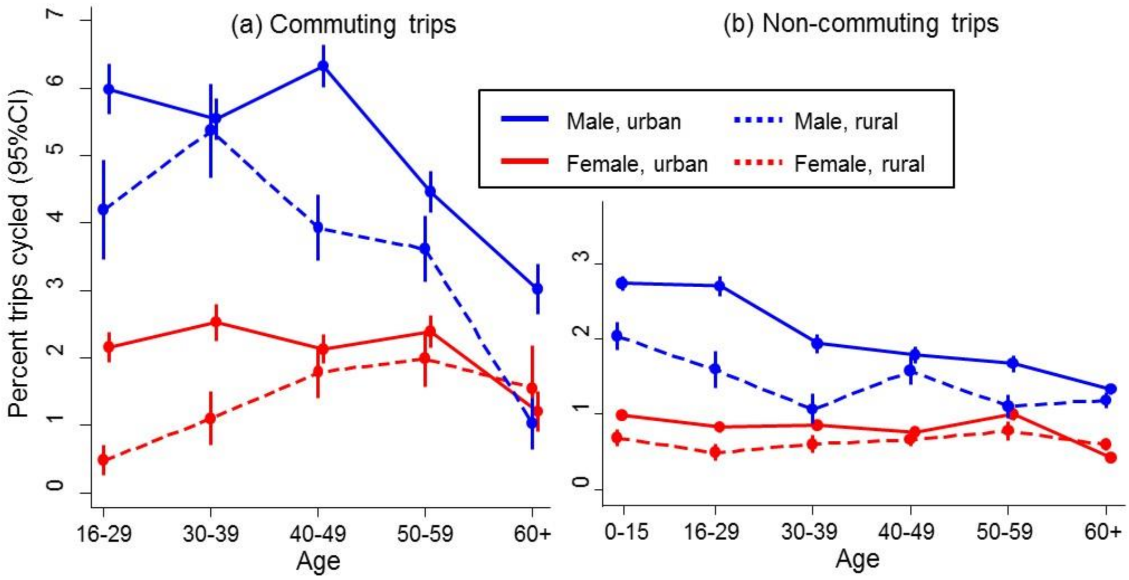

Figure 1: Proportion of (a) commuting and (b) non-commuting trips made by bicycle in England, by age, sex and urban/rural status

In the Netherlands, the overall proportion of trips cycled was 26.7%, more than ten times the rate in England. The Netherlands also differed from England in the distribution of these trips by age, sex and purpose (

). In particular, the overall proportion of trips cycled by women was consistently higher than the proportion cycled by men, and trip rates remained high into old age. There was also little difference in the proportion of trips cycled according to purpose. The main point of similarity was that, as in England, trips in the Netherlands were generally somewhat more likely to be cycled in urban areas than in rural areas.[iii]

[iii] 'Urban' status defined as 'somewhat urbanised' ['weinig stedelijk'] areas and above, corresponding to 84% of Dutch participants. This is similar to the proportion of 80% of English participants defined as living in urban areas.

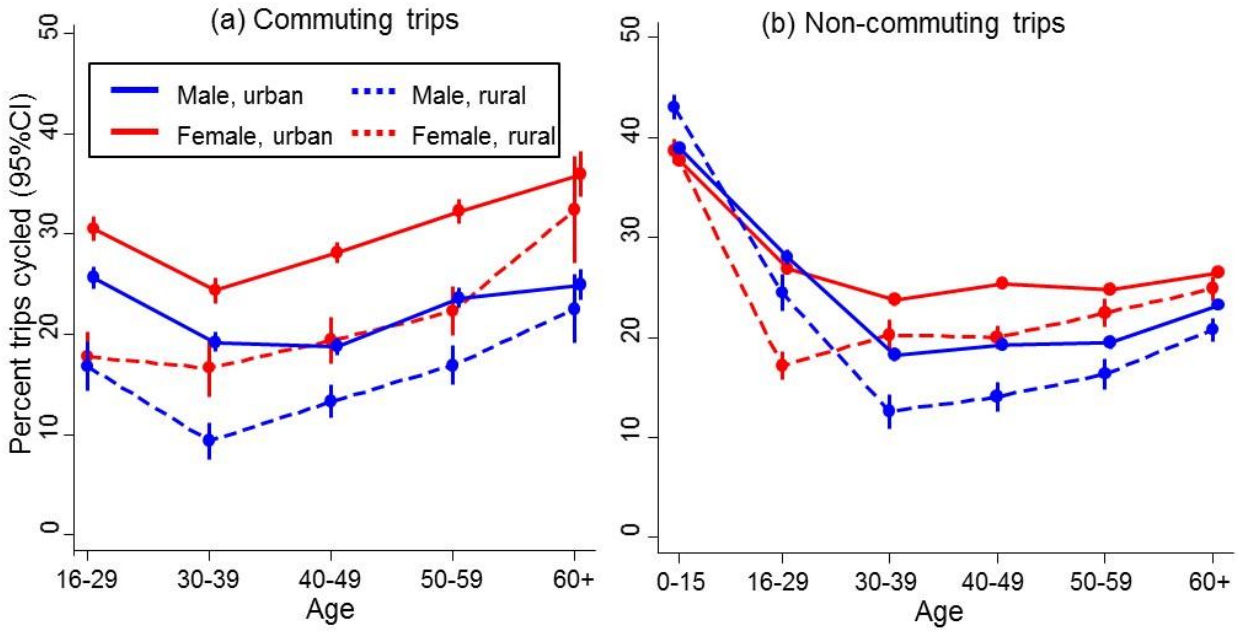

Figure 2: Proportion of (a) commuting and (b) non-commuting trips made by bicycle in the Netherlands, by age, sex and urban/rural status

Results, Section 2: Characterising distance decay across groups

Table 1 shows the eight groups into which we ultimately decided to stratify people, based on variation in the shape of distance decay. In the remainder of this section we describe the reasons for selecting these groups.

Table 1: Stratified groups ultimately selected, based on variation in distance decay functions

Group	Sex	Age	Trip purpose
1	Male	0-15 years	All trips
2	Male	16-59 years	Commute
3	Male	16-59 years	Non-commute
4	Male	60+ years	All trips
5	Female	0-15 years	All trips
6	Female	16-59 years	Commute
7	Female	16-59 years	Non-commute
8	Female	60+ years	All trips

Decision to stratify by age

Error! Reference source not found. shows the probability of cycling a trip for different age/sex/purpose combinations in the English NTS, relative to the probability of cycling a trip of two miles. **Error! Reference source not found.** shows that the probability of cycling a trip declines faster among older adults than among younger adults with increased distance, and that this decline is even steeper for children. These results illustrate the importance of stratifying by age. Note that the decision to stratify adults at a single cut-point of 60 years of age was based upon exploratory analyses that revealed low inter-group variation amongst age groups younger than 60.

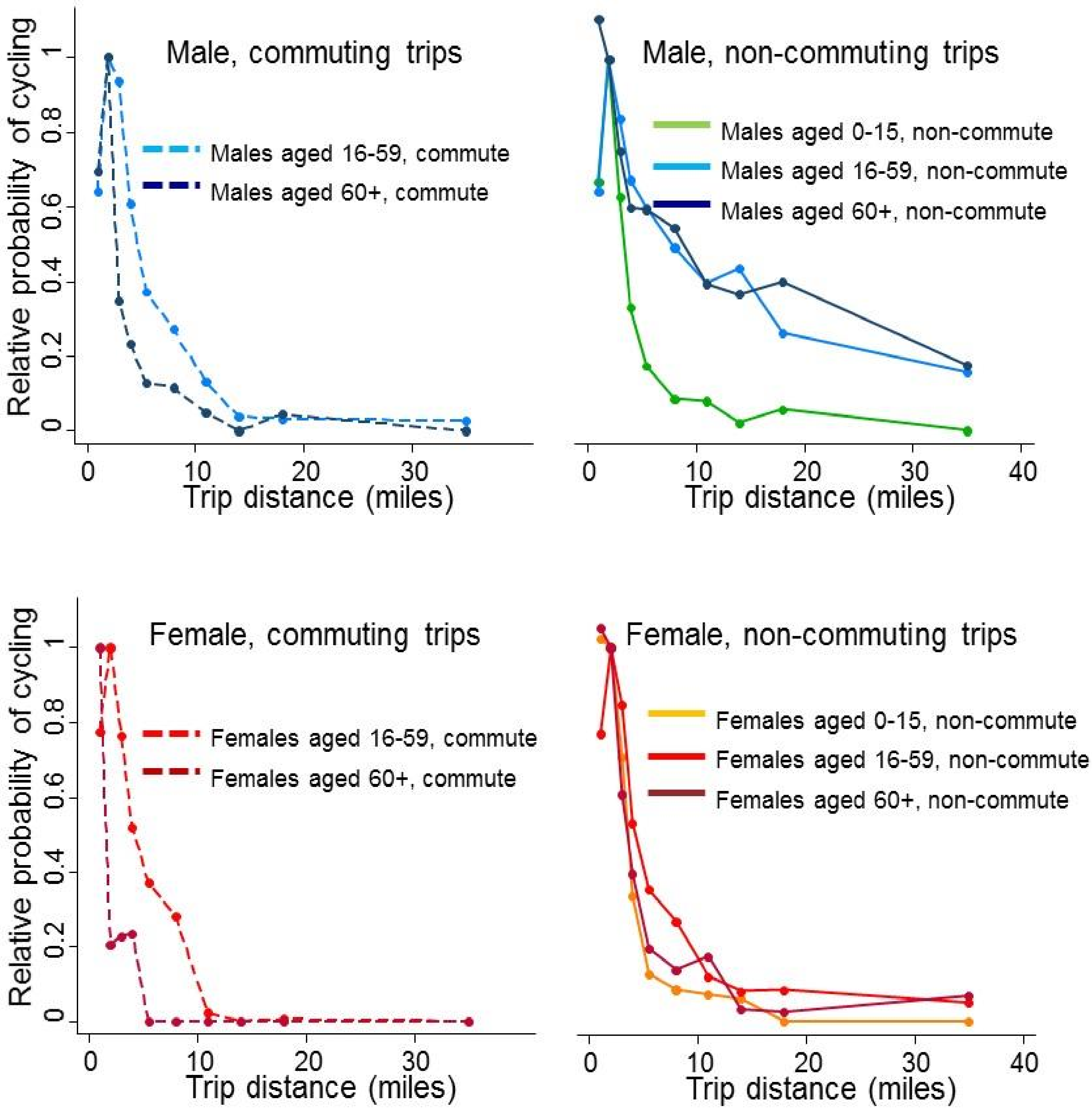

Figure 3: Relative probability of cycling for different age groups, stratified by purpose and sex.

Decision to stratify by sex

Stratification by sex is justified because distance decay is generally steeper for females than males (

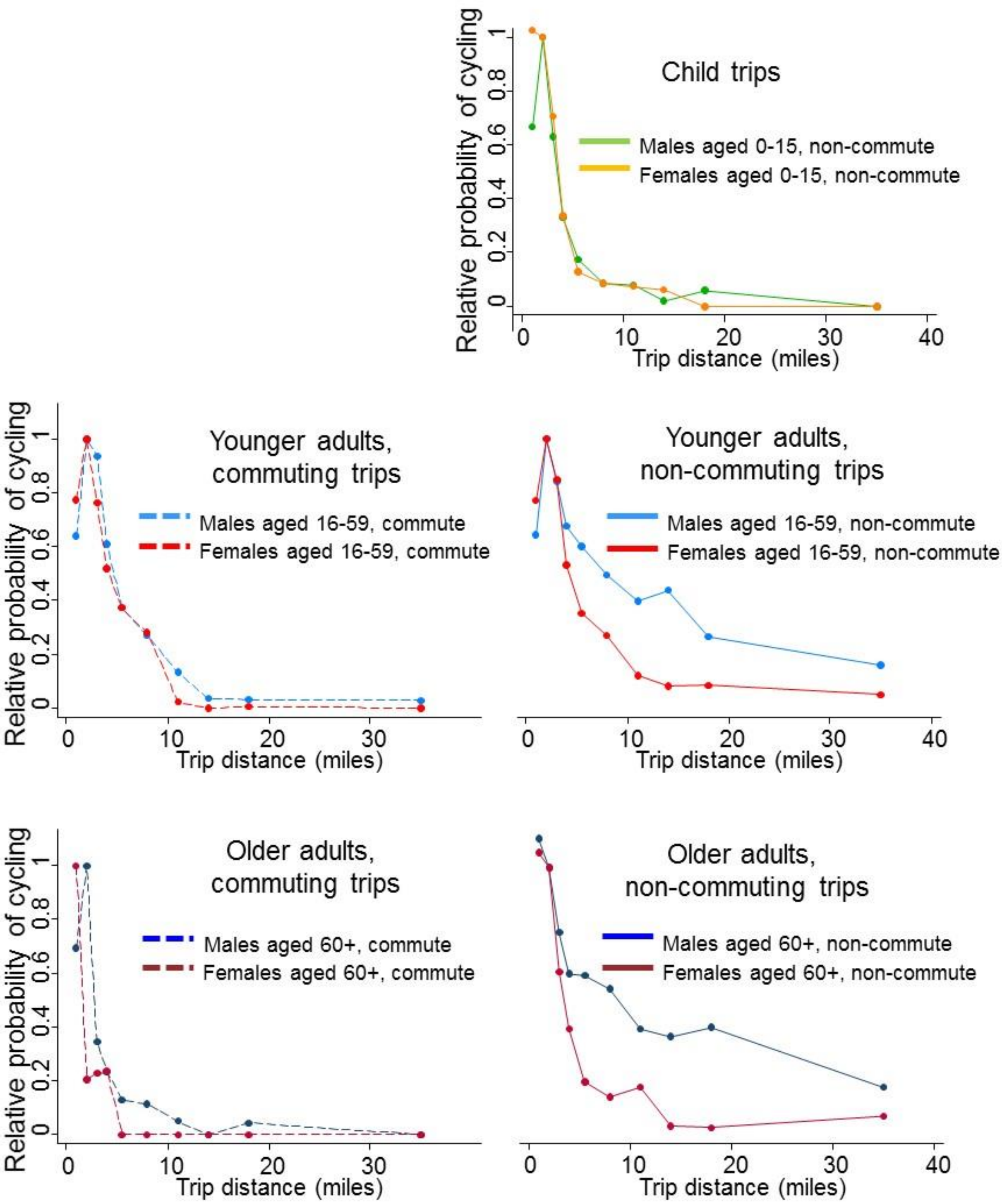

Figure 4). Note that the lines in

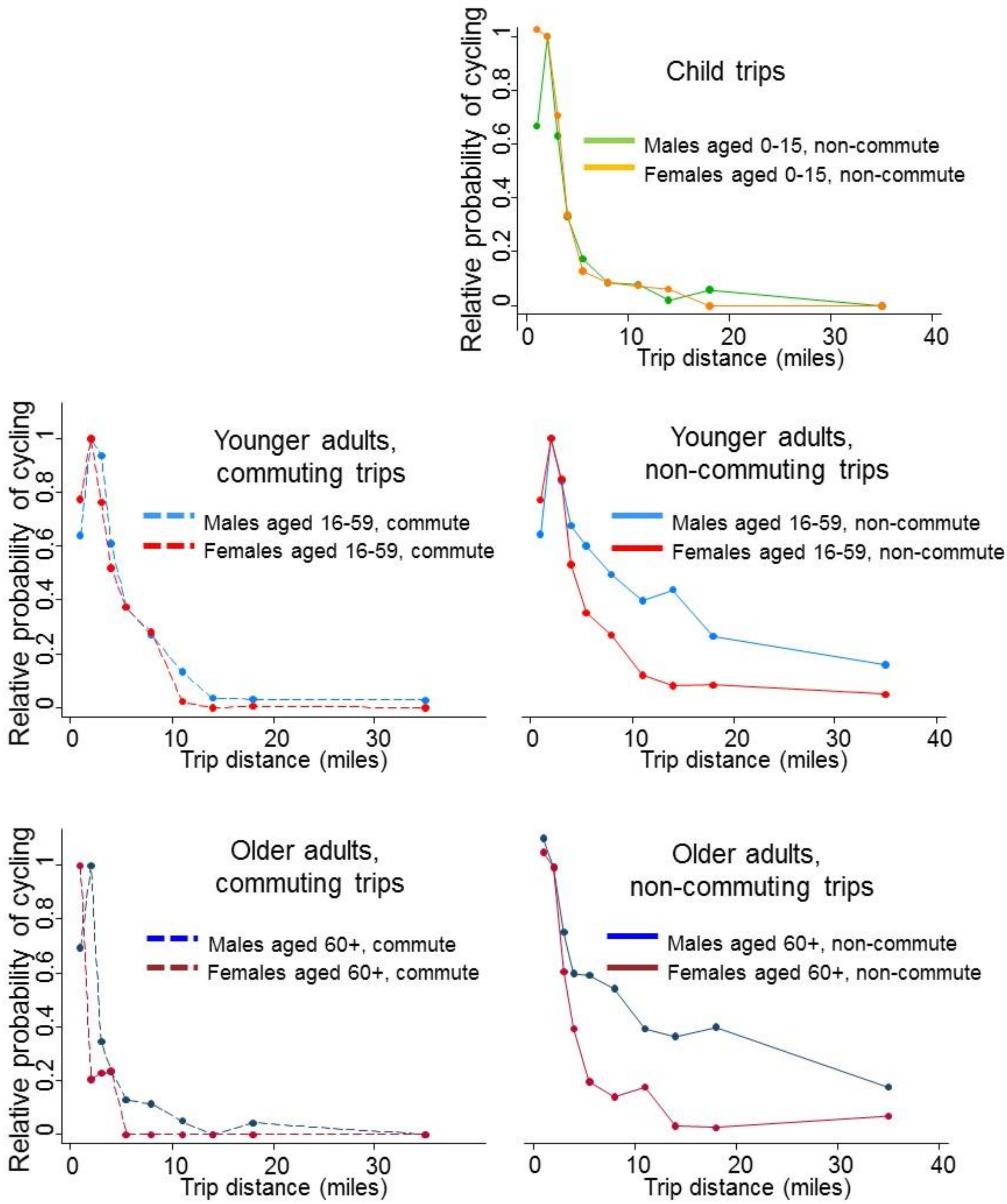

Figure 4 all have an identical counterpart in Error! Reference source not found. but that these lines are now presented paired according to sex rather than paired according to age.

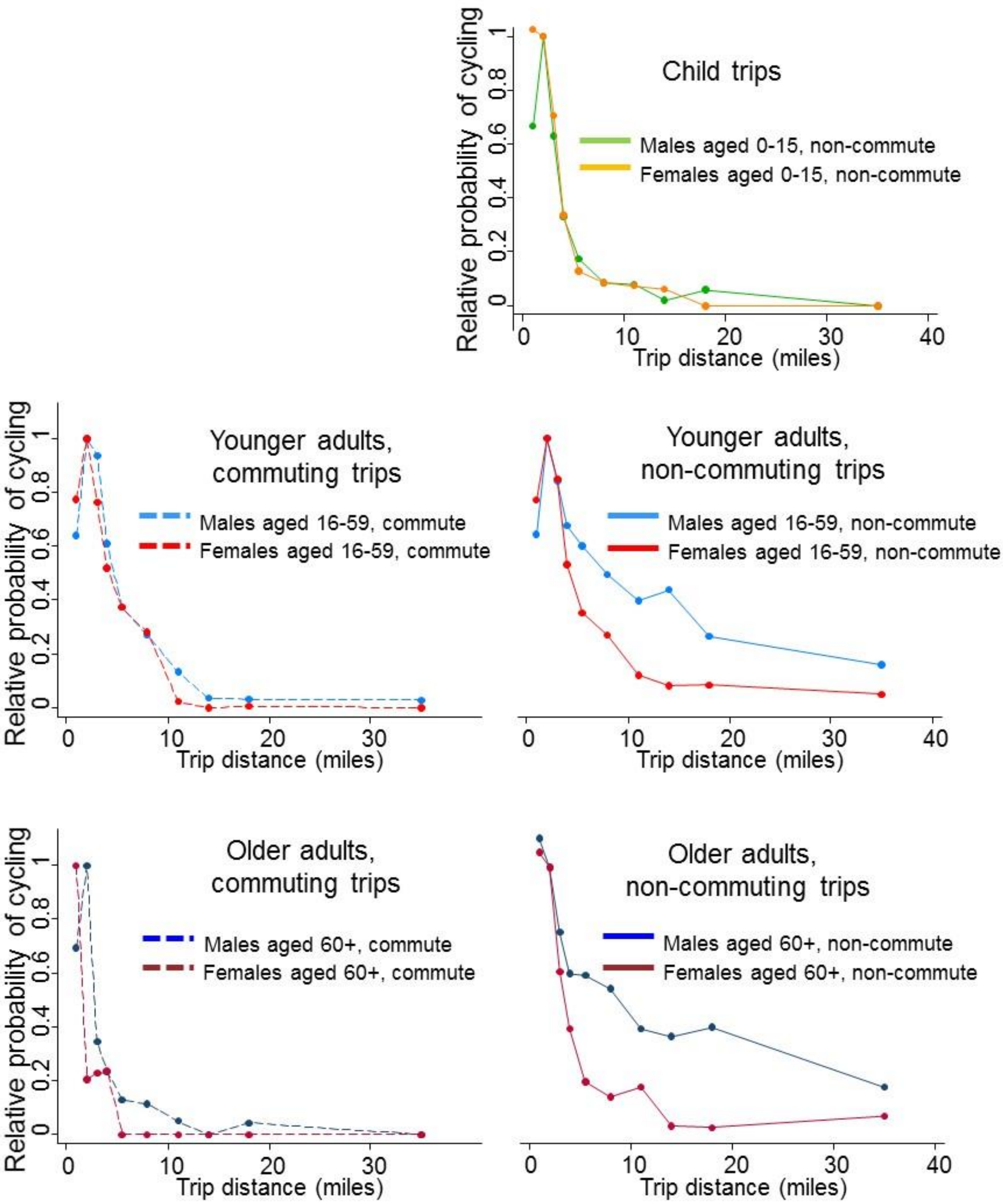

Figure 4: Relative probability of cycling for males vs. females, stratified by age and purpose.

Decision to stratify by purpose

Stratification by trip purpose did not prove feasible for older males and older females, because these people make few commuting trips. Also, cycling trips are far less common amongst the elderly, making regression by age/sex/mode impossible for these age groups because of ‘empty cells’. For example, between 2008 and 2012, no cycle commute trip was reported by a non-white male or female aged 60 years or more. This explains our decision to combine commuting and non-commuting trips for the oldest age group (Table 1).

We nevertheless decided to stratify by trip purpose in adults aged 16-59 because, at least in males, the distance decay function was steeper for commuting than for non-commuting trips, (

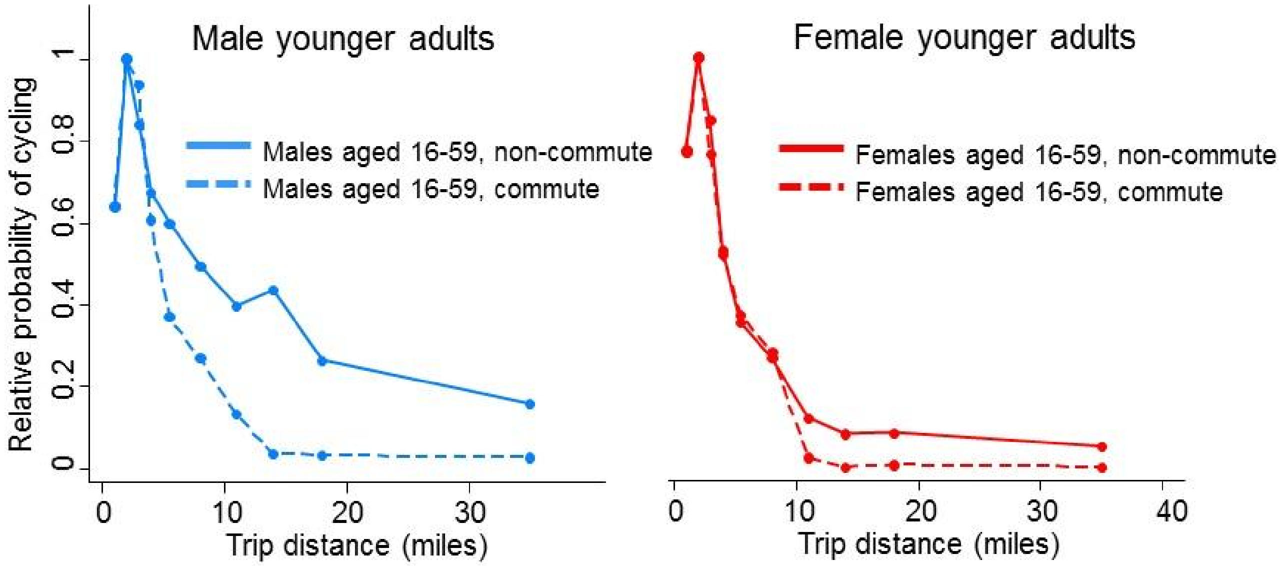

Figure 5).

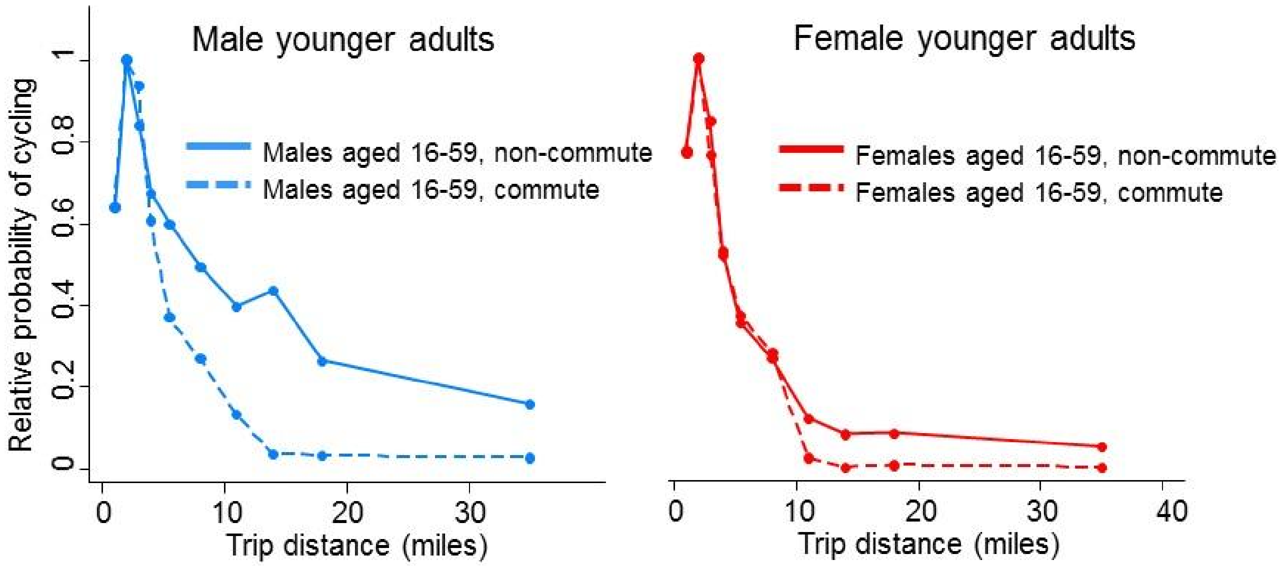

Figure 5: Relative probability of cycling for commuting vs. non-commuting trips in adults aged 16-59, stratified by sex

Decision not to stratify by urban-rural status

After stratifying by age, sex and purpose, the shape of the distance decay function was similar according to urban-rural status. It was therefore not considered necessary to stratify by this characteristic: particularly as doing so would risk having insufficient power for some analyses. Instead urban-rural status is adjusted for as a covariate in the regression models fitted in the next section.

Comparison of distance decay functions between England and the Netherlands

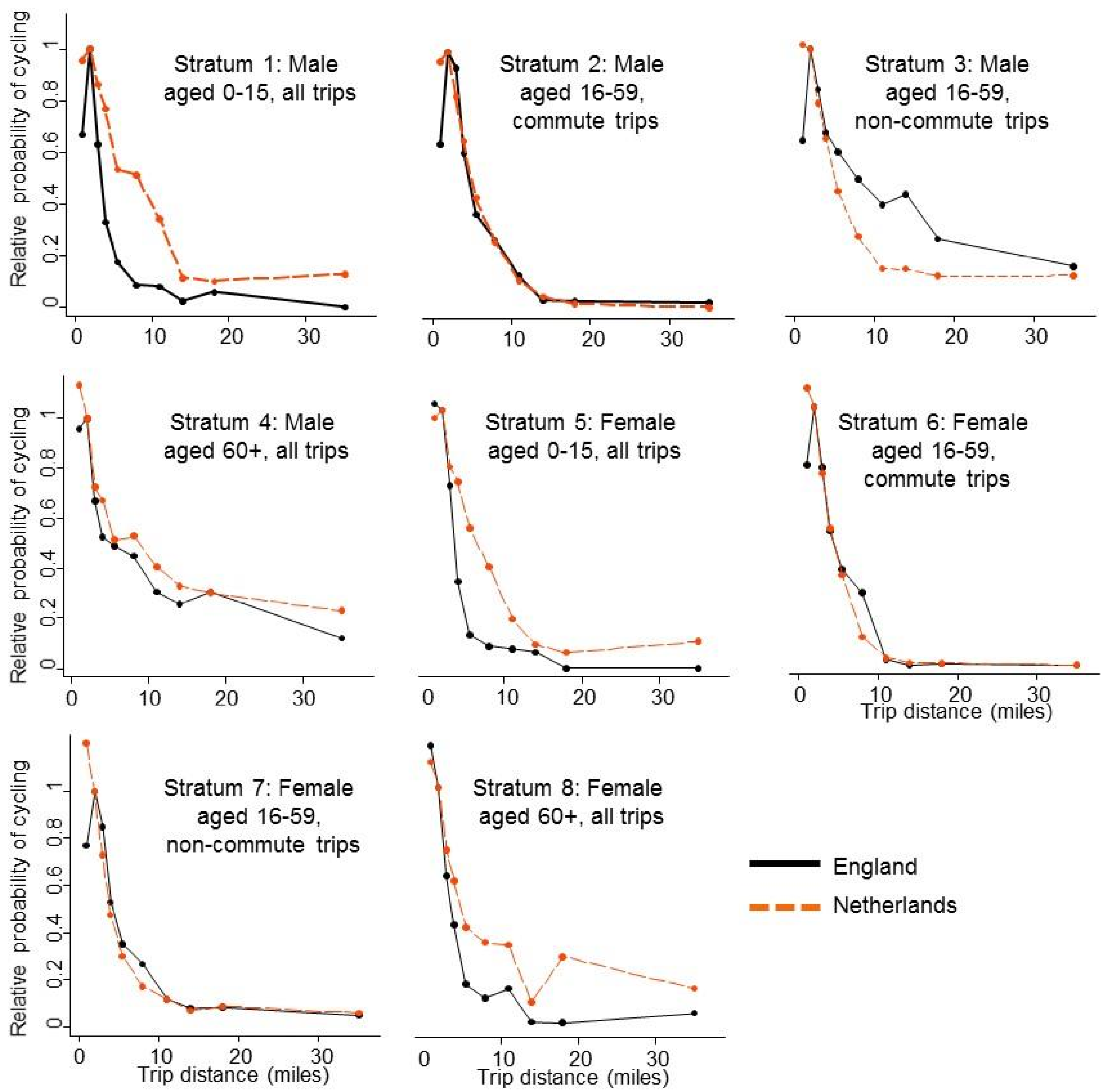

Figure 6 compares the shape of distance decay between England and the Netherlands in our eight strata. As this shows, for children of both sexes, the distance decay function declines less steeply in the Netherlands than in England. The same is true among older males, but not females. By contrast, in adults aged 16-59 the distance decay functions were generally similar, or were in fact less steep in England than in the Netherlands for non-commute trips among males.

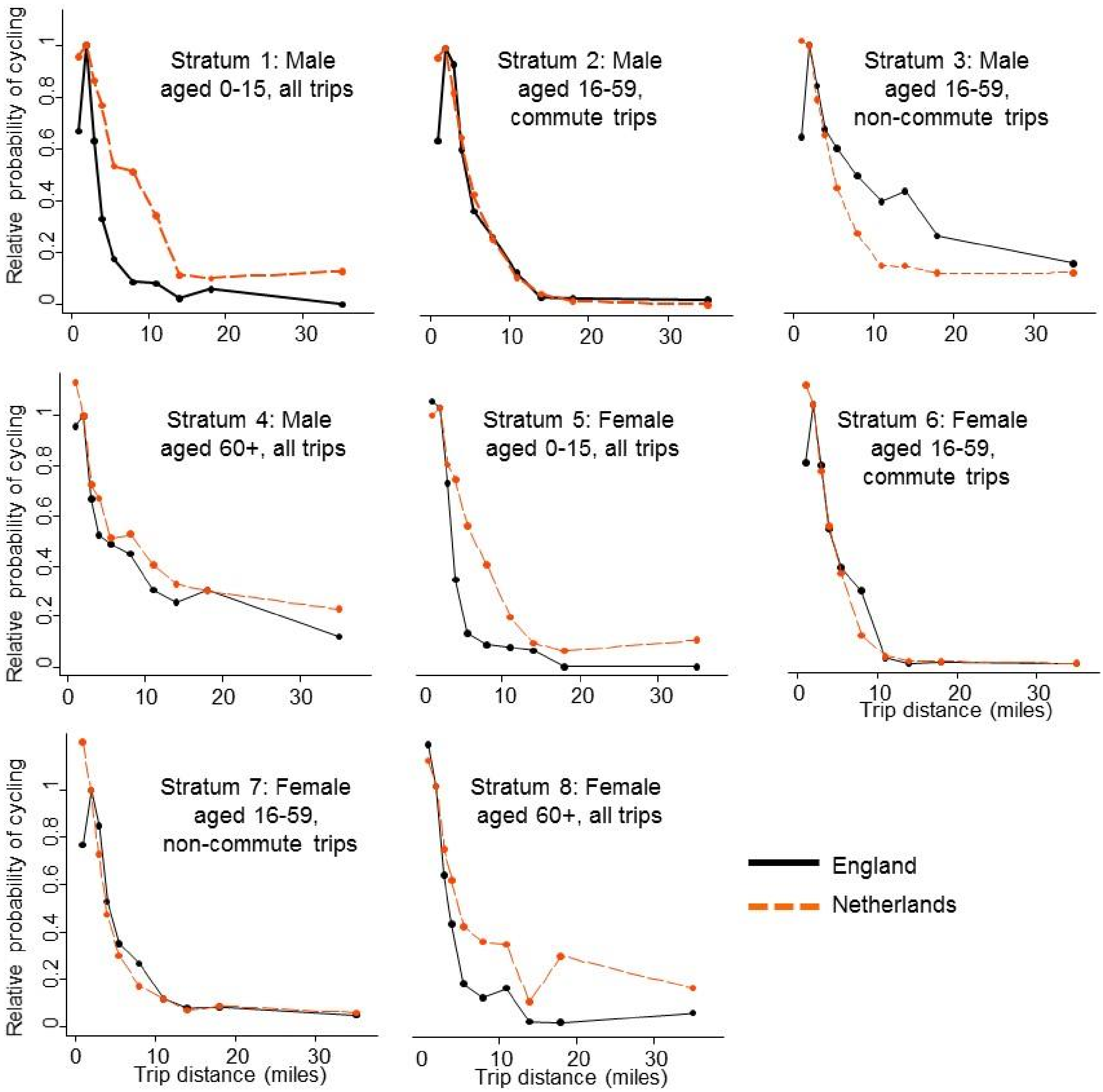

Figure 6: Distance decay functions in England and in the Netherlands, across eight strata.

Distance decay for e-bikes

Finally,

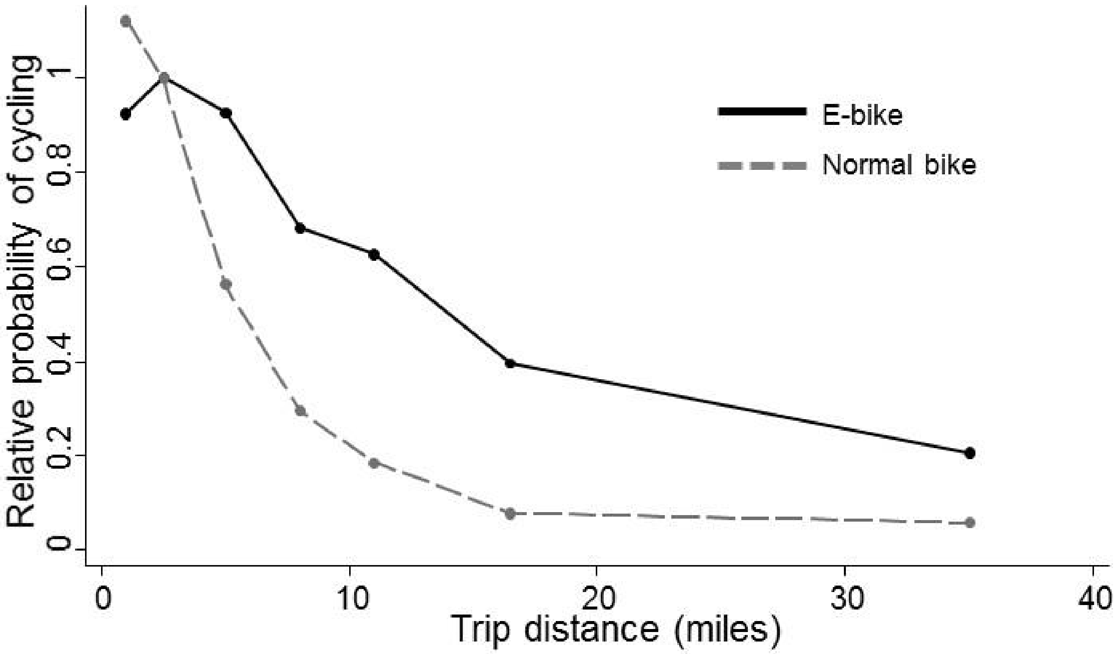

Figure 7 compares distance decay functions between normal bikes and e-bikes in the Netherlands in 2013 (the only year in which e-bikes were distinguished). As expected, distance decay is much flatter for e-bikes– i.e. longer distance has relatively less of a deterrent effect on using an e-bike than a normal bike.

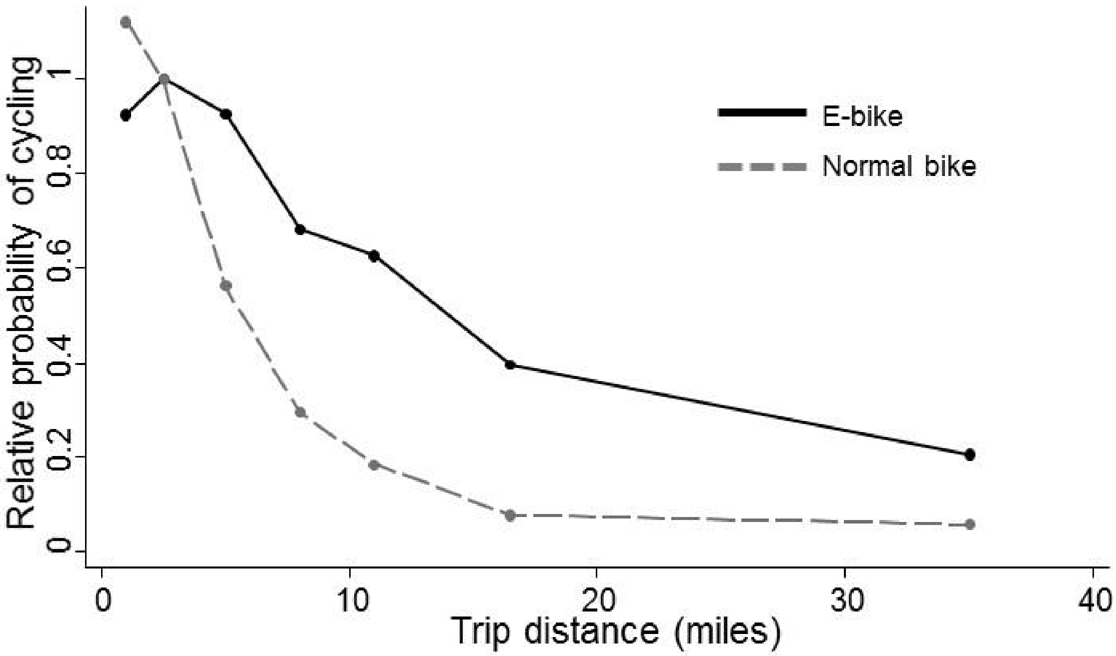

Figure 7: Distance decay functions for e-bikes and normal bikes across all trips, Netherlands 2013.

In 2013 e-bikes constituted 7.6% of all cycle trips in the Netherlands among individuals aged 12 or older (individuals aged under 12 were not asked whether a cycle trip was made by electric bike or not). This proportion was very low among children aged 12-15 (<0.5%); relatively low among adults aged 15-59 (range 2.0%-6.8%); and higher among older adults

(8.5% among older males for commute trips, 20.8% among older males for non-commute trips, and 25.3% among older females across all trip types). This pattern therefore does not match particularly well to the strata in which the distance decay function declines less steeply in the Netherlands than in England (

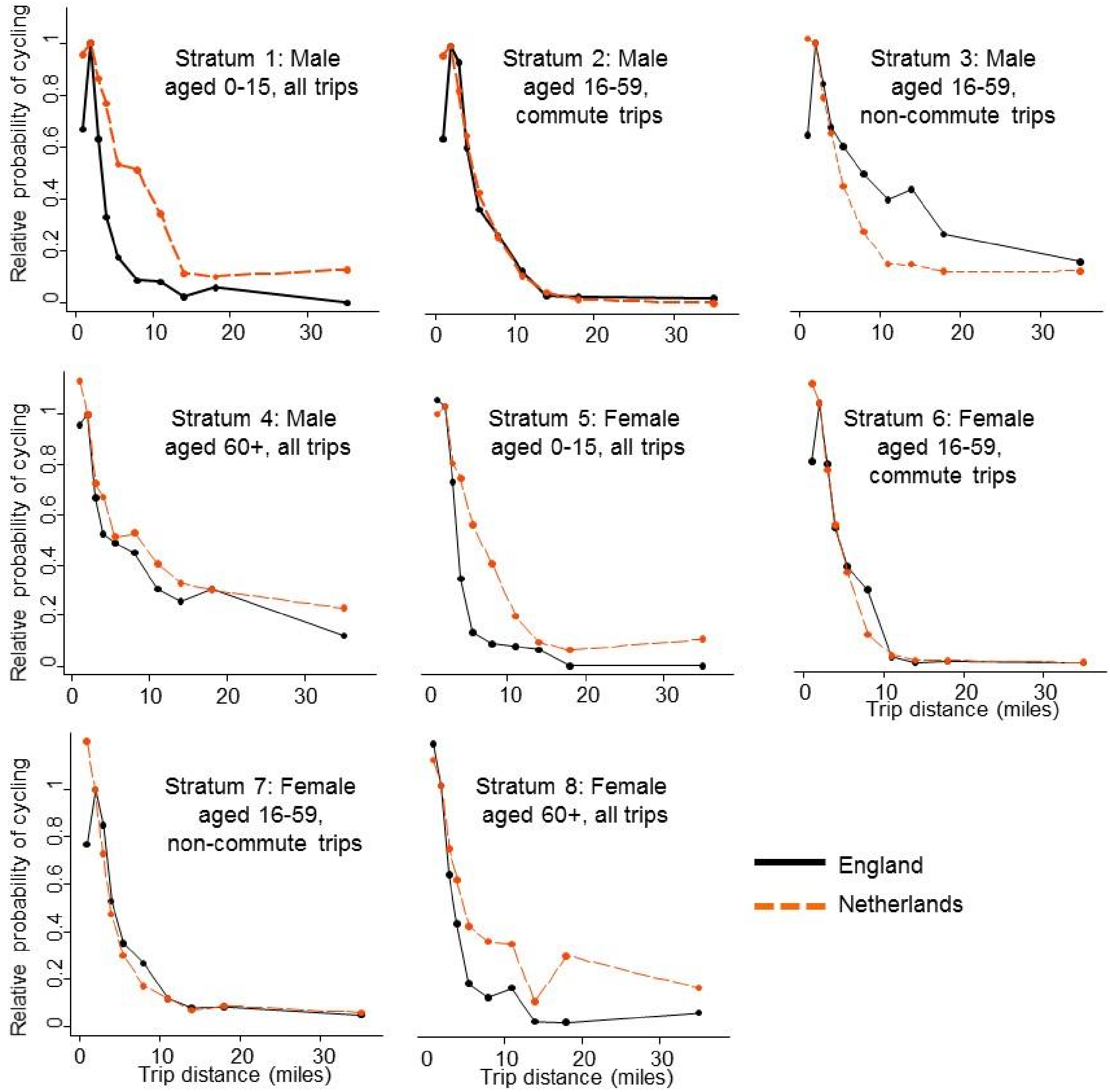

Figure 6), suggesting that a higher prevalence of e-bikes is not the main reason for this observed difference.

In Stage 1, we used these results in relation to e-bikes as part of the creation of our co-benefits model (see Appendix 10). With regard to our scenario modelling, e-bikes are implicitly present in the 'Go Dutch' scenario, given the relatively higher prevalence of e-bike use in the Netherlands (8% as opposed to an estimated <1% in England). They also represent one plausible mechanism whereby age disparities in cycling rates might be reduced, by allowing older people to cycle longer distances.

Results, Section 3: Approach to modelling propensity to cycle

Decision to model the distance decay function as a linear term plus square root term

After experimenting with a number of functional forms, we decided to enter distance into logit regression models as a linear term plus a square-root term (see page 24 for equations describing this formula). This modelling approach proved to fit the data almost as well as models based on a larger number of powers (e.g. based on five powers: linear term plus square root term plus square term plus cubed root term plus cube term). This approach also avoided possible concerns related to over-fitting.

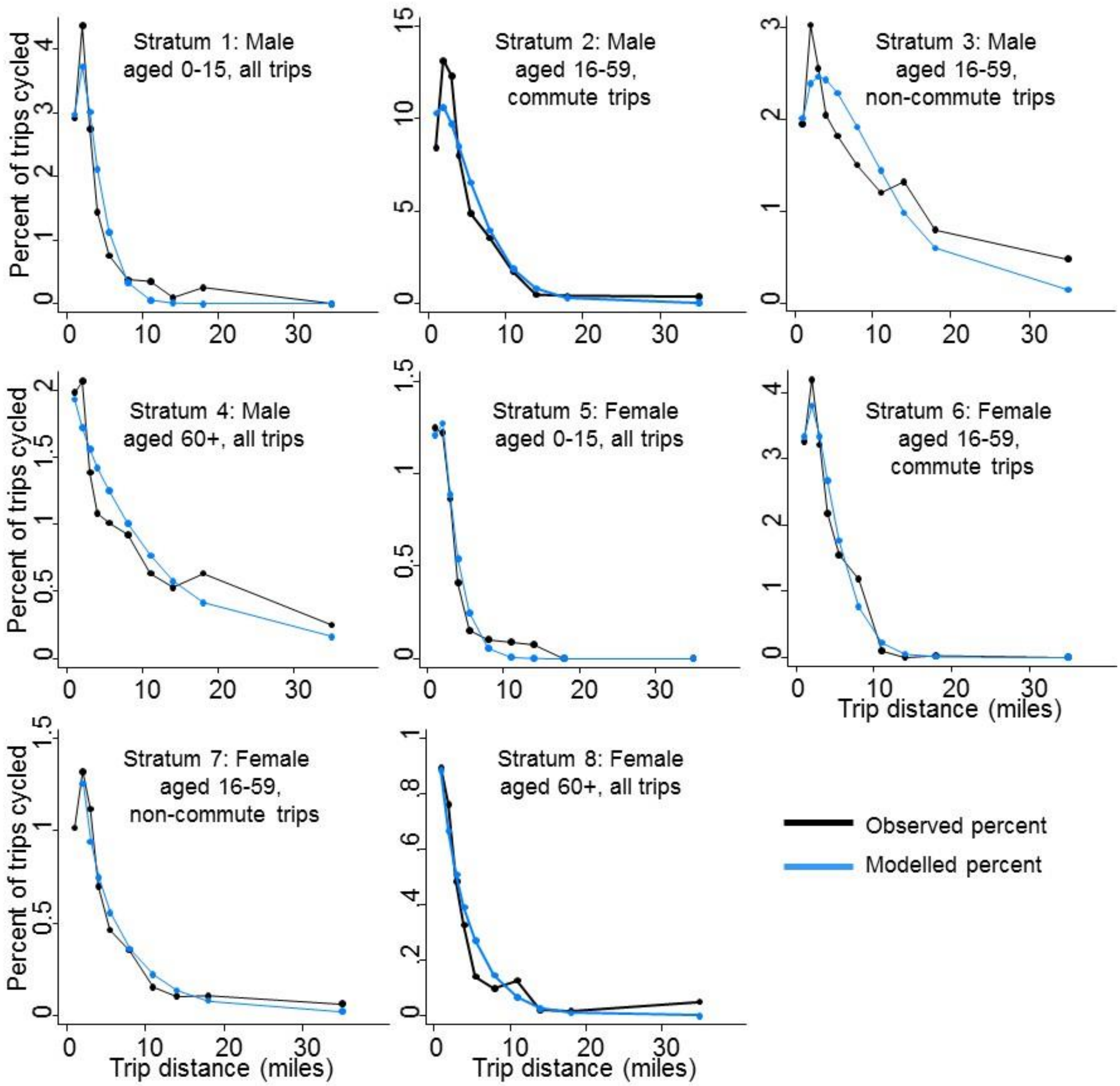

Figure 8 presents the comparison between the modelled and the raw data, after fitting separate regression models for each of our eight strata.

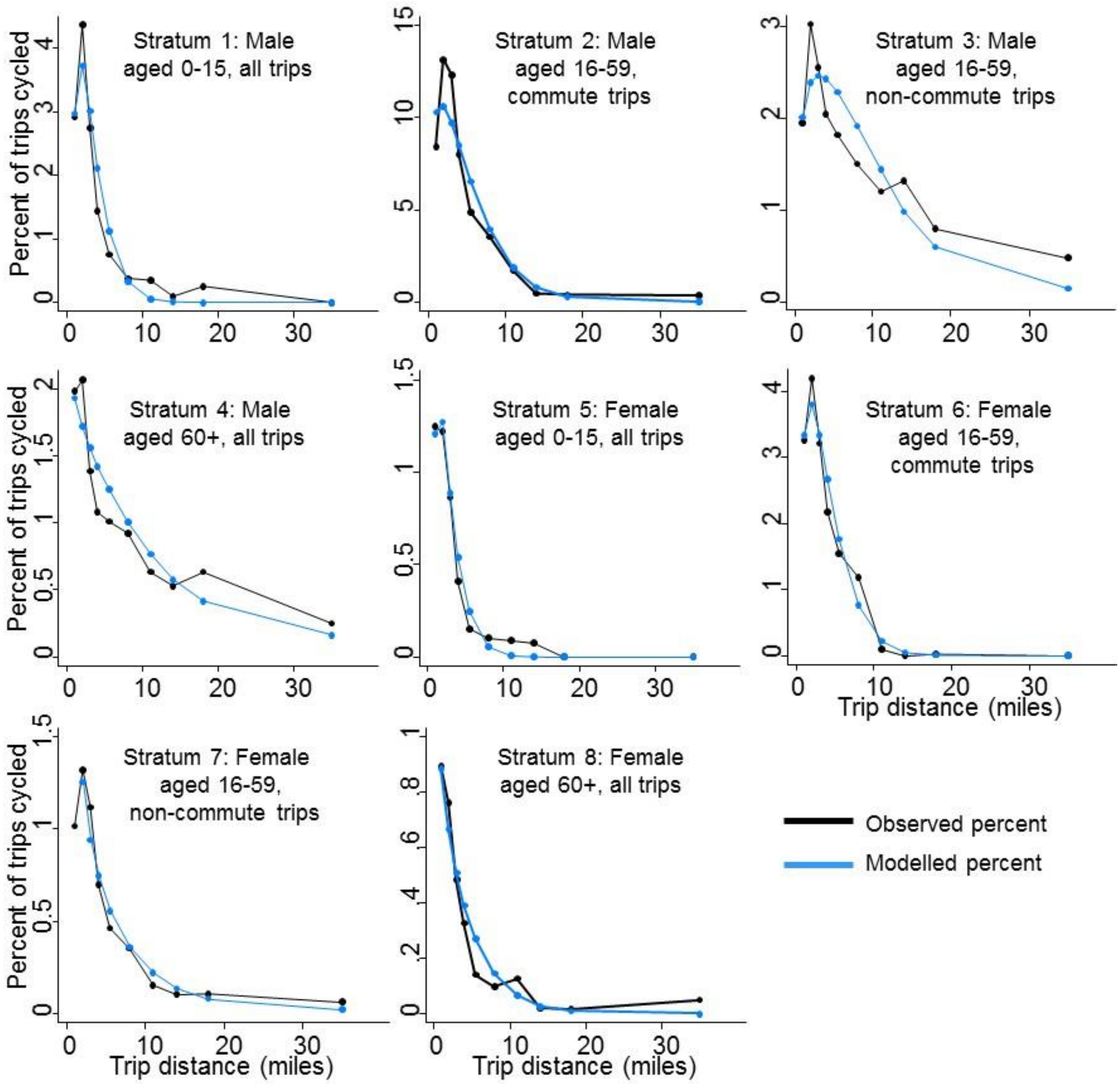

Figure 8: Modelled versus observed data across eight strata

Approach to scenario modelling: what we changed, and what we kept the same

The distance decay functions in

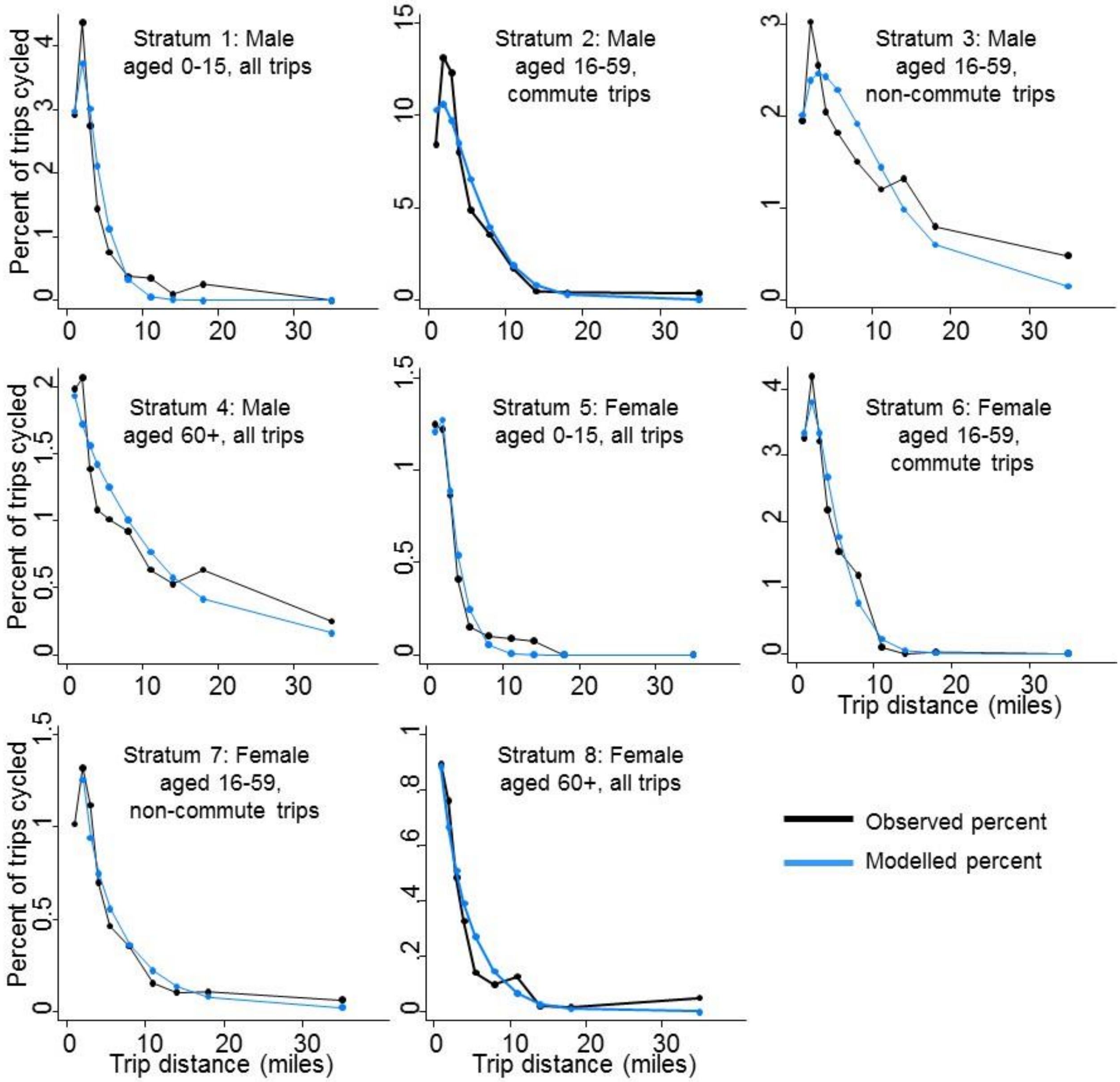

Figure 8 capture propensities to cycle in the current English population, i.e. in the baseline condition. The curves shown in

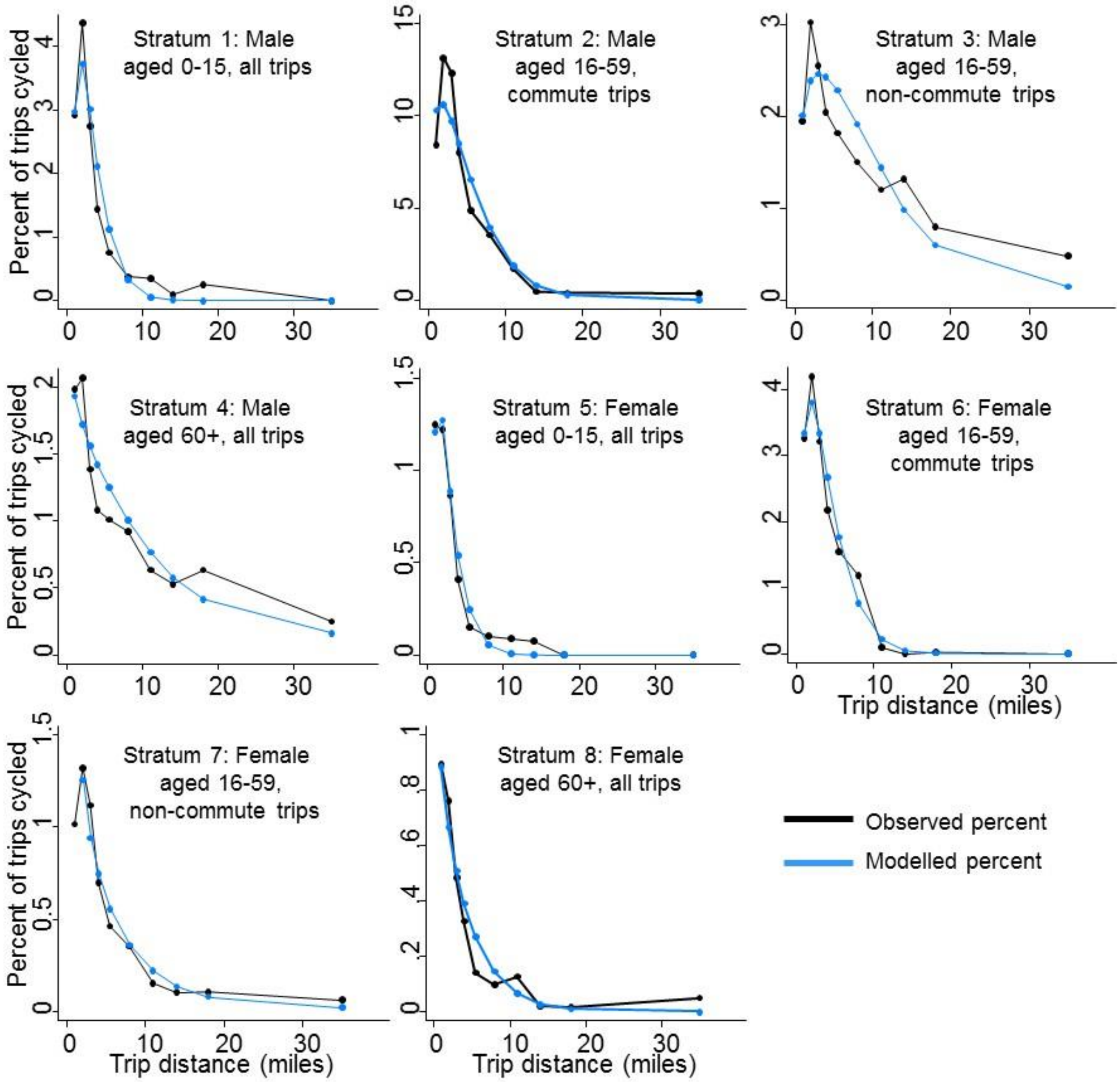

Figure 8, and the functions they represent, capture the average propensity to cycle a particular trip, given trip distance, trip purpose, age and sex. These averages can be further refined to generate more detailed baseline propensities by taking into account the modifying influence of other characteristics such as car ownership. For example, in England around a tenth of commute trips are three miles long among adult women aged 16-59 (stratum 6). The overall proportion of such trips that are cycled is 3.2%. When applied to specific trips, this average baseline propensity of 3.2% can be further refined by taking into account whether the woman has a car, as the propensity to cycle between young adult women with no car versus with one or more cars varies more than two-fold (6.7% vs. 2.5%).

We sought to model scenarios in which the English pattern of trip types and distances was retained (e.g. three miles remained the distance of a tenth of commute trips by young adult women). We also retained the English pattern of baseline propensities (e.g. the two-fold difference according to household car ownership remained in place among young adult women). What we sought to vary was the average propensity for a trip to be cycled (e.g. we sought to vary the point estimate of 3.2%). We did this in line with scenarios in which one or more of the following types of alteration can be made:

- **National mode share increase**: The overall national model share of cycling in England is assumed to increase to a given target value (e.g. 5%). All baseline propensities are uniformly scaled by a given multiplier in order to achieve this target. To ensure that propensities never exceed 100%, the scaling factor is derived from, and applied to, odds not proportions.
- **Increased age and gender equity**: Females in England acquire an average propensity to cycle that is closer to, or equal to, the propensity of males in England of the same age (increased gender equity). Older adults acquire an average propensity to cycle that is closer to, or equal to, the equivalent group of younger adults (increased age equity). If the propensity of older adults and females is fully equalised with that of younger males, this represents 'complete' age and gender equity.
- **'Go Dutch'**: Individuals in England acquire the average propensity to cycle that is closer to, or equal to, the propensity of the equivalent group in the Netherlands. When estimating the propensity of the equivalent group in the Netherlands, we reduced the observed Dutch values somewhat to take account of the fact that England is a hillier country and therefore inherently subject to lower propensities to cycle than the Netherlands. In other words, we sought to retain the reality of English topography even when modelling what it would mean to 'Go Dutch' in terms of cycling infrastructure and cycling culture.

These types of alternation represent scenario 'building blocks', with a particular scenario reflecting the combination of one or more of these types of changes.

Developing a flexible basis for modelling alternative scenarios

We sought to develop a flexible approach that would easily allow a range of scenarios to be modelled. We did this in a three-stage modelling process, outlined below and described more fully in the remainder of this section:

Stage 1: Generate detailed baseline propensities to cycle. We assigned each trip a propensity to be cycled in the current English population (baseline condition). This propensity is calculated with respect to a detailed set of characteristics, including trip, individual, household and geographical factors. The formulae needed to generate these 'detailed baseline propensities to cycle' are derived using multivariable logit regression models, and are derived separately for each of the eight strata in England.

Stage 2: Generate and apply stratum-specific propensity scaling factors *for each scenario*

1. Derive distance decay formulae describing the average propensity for a trip to be cycled in the baseline condition, based only on trip distance. These formulae are derived separately for all eight strata in England, using logit regression models.

Assign an ‘average baseline propensity to cycle’ to each trip by applying the relevant distance decay formula. For example, this would involve applying the ‘England stratum 6’ formula to a commute trip in England by a woman aged 16-59.

2. Repeat step 2a using data from the Netherlands to derive Dutch distance decay formulae. Modify these formulae to reduce the value of the propensities generated, in line with the estimated influence of topography upon English versus Dutch cycling levels. This represents an attempt to estimate what the average propensity to cycle would be if Dutch cycling culture and infrastructure were transferred to a country as hilly as England.
3. For each trip, select and apply distance decay formulae that will model average propensity to cycle under a given scenario. For example, consider a three mile commute trip made by a woman in England. In an ‘increased gender equity’ scenario, the propensity to cycle this trip would be calculated by taking a weighted average of the propensities for young women making commute trips in England and young men making commute trips in England. In a ‘Go Dutch’ scenario, the propensity to cycle would be calculated using the distance decay formula derived for young women making commute trips in the Netherlands. These estimated average propensities to cycle a given trip under a given scenario are called the ‘average scenario propensities’.
4. For each trip, calculate a propensity scaling factor for the scenario in question, by taking the average scenario propensity and dividing it by the average baseline propensity. Apply this propensity scaling factor to the detailed baseline propensities, as calculated in Stage 1. To ensure that propensities never exceed 100%, the scaling factor is derived from, and applied to, odds not proportions.

Stage 3: If applicable, apply a national mode share scaling factor to all strata to achieve a target scenario mode share. If the scenario in question involves a ‘target’ mode share, this final stage calculates the discrepancy between this target mode share and the mode share modelled at the end of Stage 2. All propensities would be increased by a constant scaling factor, such that the target mode share is achieved. As in Stage 2, the scaling factor is derived from, and applied to, odds not proportions, in order to ensure that propensities never exceed 100%.

Stage 1: Generate detailed baseline propensities to cycle

Example output from logit regression models

For each of the eight strata in England we fit a logit model at the trip level. The outcome was binary: whether the trip was cycled or made by another mode. Factors operating at the trip, individual, household and geographical levels were used as the predictor variables. Table 2 shows the output of one such the multivariable logit regression model for adult females making commute trips (stratum number 6). The equivalent tables for all eight stratum are shown in Supplementary Material 1.

Table 2: Predictors of cycling for commute trips among females aged 16-59 (stratum 6) in England

Variable	Level	Log-odds	95% CI of log-odds
Constant		-2.764	(-3.607, -1.921)
Distance (miles)	Linear term	-0.424	(-0.569, -0.279)
	Square root term	1.141	(0.566, 1.717)
Age	16-29 years	0	NA
	30-39 years	0.176	(-0.093, 0.445)
	40-49 years	0.360	(0.108, 0.612)
	50-59 years	-0.034	(-0.319, 0.251)
Ethnicity	White	0	NA
	Non-white	-1.271	(-1.663, -0.878)
Household income	Fifth 1 (poorest)	0	NA
	Fifth 2	-0.254	(-0.620, 0.112)
	Fifth 3	-0.259	(-0.592, 0.074)
	Fifth 4	-0.230	(-0.568, 0.108)
	Fifth 5 (richest)	-0.164	(-0.526, 0.199)
No. cars/vans in household	0	0	NA
	1	-0.500	(-0.754, -0.246)
	2	-1.244	(-1.550, -0.938)
	3+	-1.718	(-2.184, -1.252)
Urban/rural	Rural	0	NA
	Urban	-0.163	(-0.438, 0.113)
LSOA income deprivation	Fifth 1 (poorest)	0	NA
	Fifth 2	-0.144	(-0.425, 0.136)
	Fifth 3	0.171	(-0.106, 0.447)
	Fifth 4	0.342	(0.003, 0.682)
	Fifth 5 (richest)	0.255	(-0.038, 0.548)
LSOA prevalence commute cycling	Change per percentage point	0.111	(0.088, 0.135)

LSOA hilliness	Change per decile, relative to England	-0.064	(-0.098, -0.030)
Region	North East	0	NA
	North West	0.446	(-0.081, 0.974)
	Yorkshire & Humber	0.322	(-0.240, 0.883)
	East Midlands	0.782	(0.234, 1.330)
	West Midlands	0.765	(0.213, 1.317)
	East of England	0.572	(0.027, 1.116)
	London	0.367	(-0.195, 0.930)
	South East	0.768	(0.251, 1.285)
	South West	0.917	(0.385, 1.449)

CI: Confidence interval. LSOA: Lower Super Output Area

The results of these eight regression models are of substantive interest because they reveal the independent effects of a range of predictors of cycling. The results are also of methodological importance because they provide the basis for estimating detailed baseline propensities to cycle at the trip level. In the following pages, we consider both of these facets in turn

Substantive findings: ethnicity and household car ownership are strong predictors of cycling

In the mutually adjusted model shown in Table 2, the strongest individual or household predictors of not cycling are non-White ethnicity and higher car ownership. This pattern was observed for all eight strata in the case of ethnicity, and for all adult strata in the case of car ownership. This is illustrated in the forest plots shown in

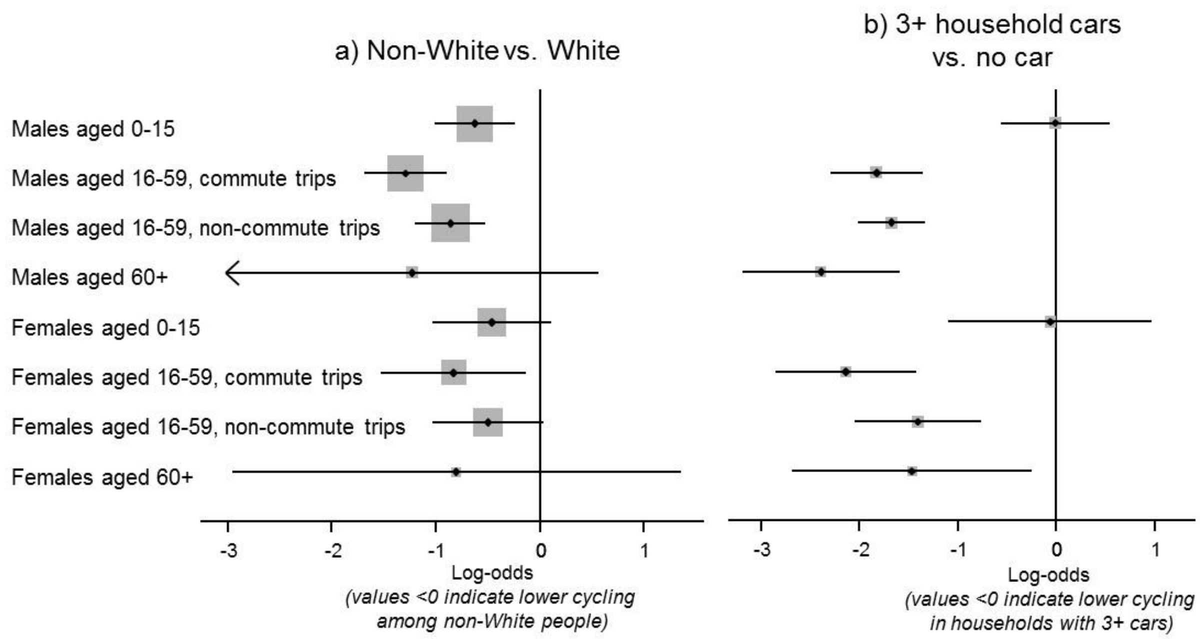

Figure 9, which present the log-odds coefficient for these predictor variables in each of the eight models.

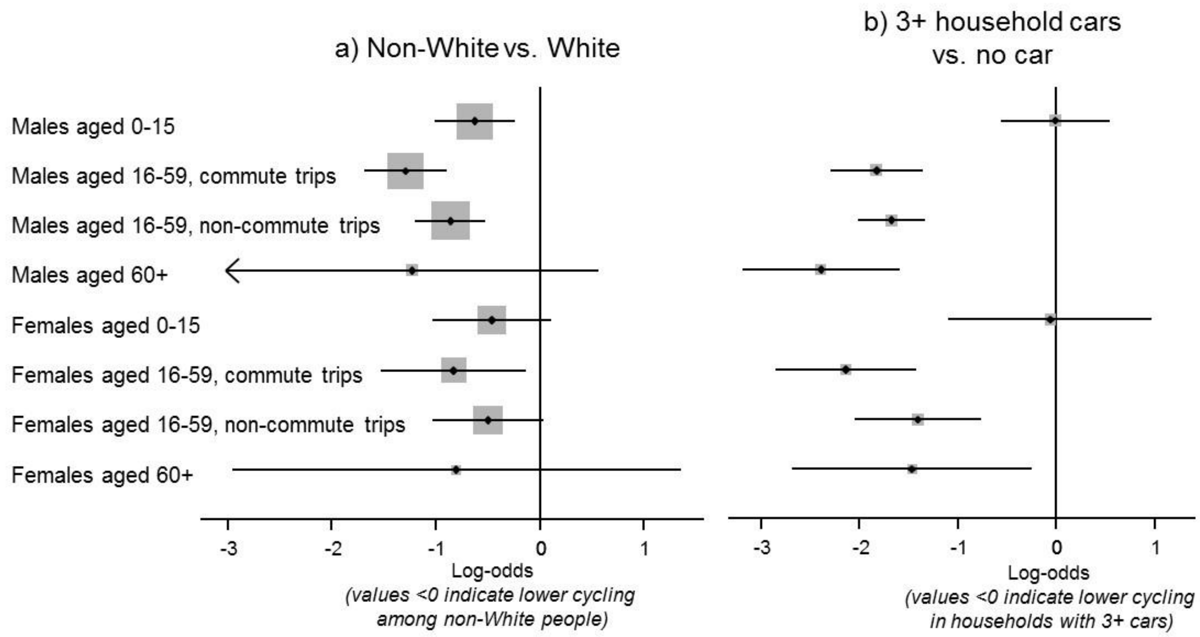

Figure 9: Forest plot showing the log-odds for a) non-white ethnicity, and b) for car ownership across the eight strata.

Based on this finding, we decided to include ethnicity and household car ownership alongside age and sex as key characteristics of the 'seed population' in our microsimulation model (see Appendix 7). Note that the important geographical characteristics (e.g. hilliness and region) are automatically included as characteristics of the seed population of the microsimulation model, as these can be assigned at the area level.

Methodological contribution: estimating detailed baseline propensities to cycle

The log-odds associated with the multiple parameters shown in Table 2 can be used to predict the propensity to cycle for a given trip. Specifically, the predicted probability of a trip being cycled is given by the formula:

$$\text{pcycle} \quad = \quad \exp(b_0 + b_1X_1 + b_2X_2\ldots)/\ (1 + \exp(b_0 + b_1X_1 + b_2X_2\ldots))$$

Where 'pcycle' is the probability that a trip is cycled, and '$b_0 + b_1X_1 + b_2X_2\ldots$' is generated by the linear combination of the parameters above. Box 1 presents a simplified worked example indicating how these parameters can be combined to estimate propensity to cycle.

Box 1: Worked example, Stage 1

To illustrate how the log-odds parameters are used, consider the smaller regression model shown in Table 3. In this table, each parameter is labelled X_1, X_2 etc, and each regression term is labelled b_0. b_1, b_2 etc.

Table 3: Predictors of cycling for commute trips among females aged 16-59 in England, worked example

Variable	Level		Log-odds	
Constant			-4.47	[b_0]
Distance	Linear term	[X_1]	-0.71	[b_1]
(miles)	Square root term	[X_2]	1.76	[b_2]
Age	16-29 years	[X_3]	0	[b_3]
	30-39 years	[X_4]	0.28	[b_4]
	40-49 years	[X_5]	-0.02	[b_5]
	50-59 years	[X_6]	0.05	[b_6]
Ethnicity	White	[X_7]	0	[b_7]
	Non-white	[X_8]	-0.52	[b_8]
Urban/rural	Rural	[X_9]	0	[b_9]
	Urban	[X_{10}]	0.16	[b_{10}]

This means that, for example, a commute trip of 3 miles made by a 30-39 year old white woman in an urban area would have the following $b_0 + b_1X_1 + b_2X_2$ … equation[iv]:

= -4.47 + [-0.71*(3) + 1.76*(3^0.5)] + [0.28] + [0] + [0.16]

= -3.112

The detailed baseline propensity of cycling trip that would therefore be:

pcycle = exp(-3.112)/(1 + exp(-3.112))

= 0.043

= **4.3%**

An equivalent approach, with a larger number of parameters, can similarly be used to translate the log-odds shown in Table 2 into detailed baseline propensities to cycle.

Stage 2: Generate and apply stratum-specific propensity scaling factors for the scenario in question

Stage 2a: Use distance decay formulae to create ‘average baseline’ propensities in England

For each of the eight strata in England, we fit a logit model at the trip level in which the only predictor variable in the model was distance, entered as a linear plus square-root term. Two examples of such a model are given in Table 4 (see Supplementary Material 2 for all models).

Table 4: Distance decay function for cycle commute trips by A) men and B) women aged 16-59

Variable	Level	Log-odds men (stratum 2)	Log-odds women (stratum 6)
Constant		-2.676	-4.320
Distance (miles)	Linear term Square root term	-0.412 0.963	-0.712 1.773

The average propensity of a trip being cycled is again given by the formula:

$$pcycle = \exp(b_0 + b_1X_1 + b_2X_2) / (1 + \exp(b_0 + b_1X_1 + b_2X_2))$$

Where X_1 in this case is equal to distance, and X_2 to the square root of distance. As such, an alternative way to present the log-odds parameters shown for males in Table 4 is as the distance decay formula:

pcycle = exp(-2.676 - 0.412*[Distance] + 0.963*[Squareroot_Distance]) / (1 + exp(-2.676 - 0.412*[Distance] + 0.963*[Squareroot_Distance])

A worked example based on Table 4 is shown in Box 2.

Box 2: Worked example, Stage 2a

Average baseline propensity of a man aged 16-59 in England making a 3 mile commute trip:

$$\text{pcycle} = \exp(b_0 + b_1X_1 + b_2X_2) / (1 + \exp(b_0 + b_1X_1 + b_2X_2))$$

$$= \exp(-2.676 + (-0.412 * 3) + (0.963 * (3^{\wedge 0.5}))) \;/\; (1 + \exp(-2.676 + (-0.412 * 3) + (0.963 * (3^{\wedge 0.5}))))$$

$$= \exp(-2.244) / (1 + \exp(-2.244))$$

$$= 0.096$$

= **9.6%**

Average baseline propensity of a woman aged 16-59 in England making a 3 mile commute trip:

$$\text{pcycle} = \exp(b_0 + b_1X_1 + b_2X_2) / (1 + \exp(b_0 + b_1X_1 + b_2X_2))$$

$$= \exp(-4.320 + (-0.712 * 3) + (1.773 * (3^{\wedge 0.5}))) \;/\; (1 + \exp(-4.320 + (-0.712 * 3) + (1.773 * (3^{\wedge 0.5}))))$$

$$= \exp(-3.385) / (1 + \exp(-3.385))$$

$$= 0.033$$

= **3.3%** [Note that this is somewhat lower than the detailed baseline propensity generated in Box 1, reflecting the fact that within stratum 6, cycling propensities are higher than average among women aged 30-39, among white women and in urban areas]

Stage 2b: Use distance decay formulae to create 'average hilliness-adjusted baseline' propensities in the Netherlands

We repeated the process shown in Stage 2a using data from the Netherlands. Specifically, we again fit logit regression models at the trip level for all eight strata, entering distance as a linear plus square-root term. Two examples of such a model are given in Table 5 (see Supplementary Material 2 for all models).

Table 5: Distance decay function for cycle commute trips by A) men and B) women aged 16-59

Variable	Level	Log-odds men (stratum 2)	Log-odds women (stratum 6)
Constant		-0.416	-0.753
Distance (miles)	Linear term Square root term	-0.445 0.770	-1.008 2.069

We then modified the average propensities generated by distance decay formulae in line with the fact that the average level of hilliness in the Netherlands is much lower than in England: 80% of people in the Netherlands live in neighbourhoods that would fall within the bottom 20% of Lower Super Output Areas in England, and 96% fall within the bottom 50%.[v] Hilliness is an important determinant of cycling levels in England, as shown in

[v] These 'Neighbourhoods' are created by Statistics Netherlands and have an average population of 1424 people (610 households). They are therefore of a similar average size to Lower Super Output Areas, which are designed to contain approximately 1500 individuals. The Statistics Netherlands neighbourhoods vary considerably in size, however, and so we weighted by population when making comparisons to the distribution of LSOAs in England.

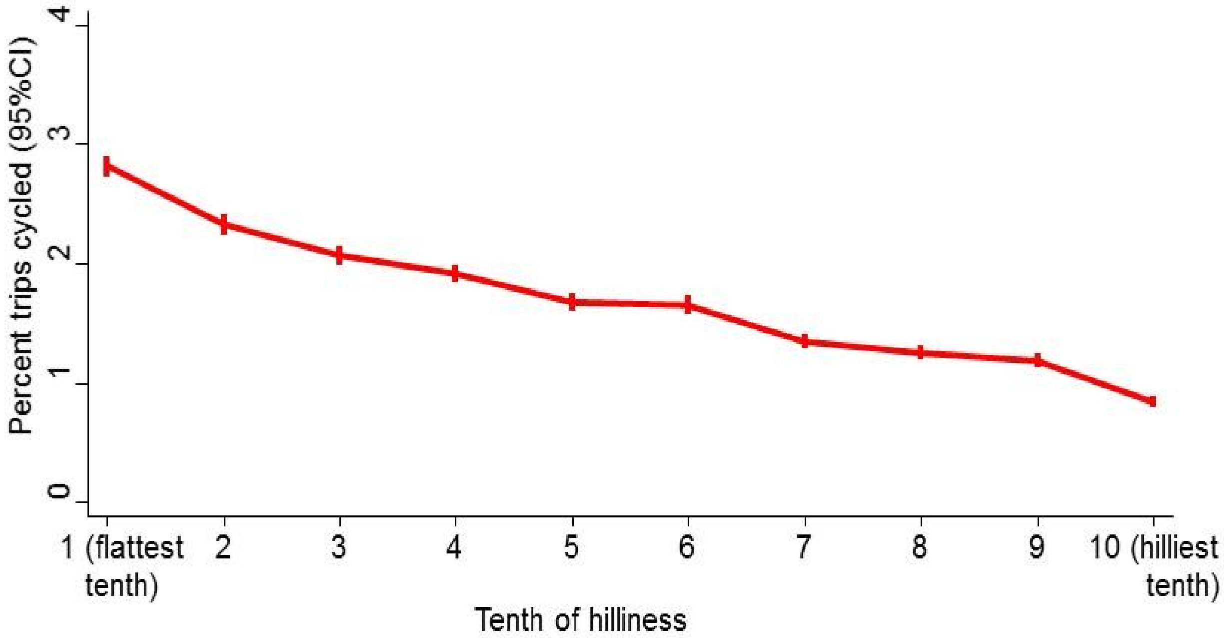

Figure 10. Although

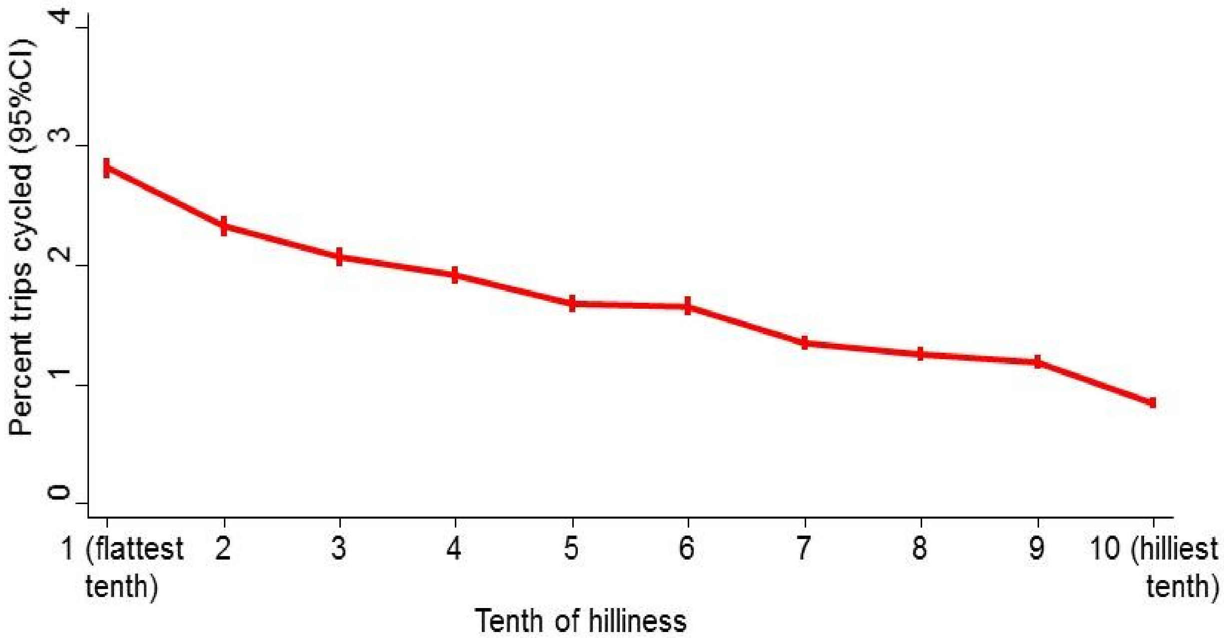

Figure 10 are not adjusted for potential geographical confounders, such as the possibility that hilly areas of England tend to be in rural areas where trip distances are longer, adjusting for such factors makes very little difference (e.g. the univariable log-odds for cycling commute trips among females aged 16-59 is -0.08442 per decile increase in hilliness; in a model adjusting for trip distance, urban/rural status and region of England this changes to -0.08591 per decile increase).

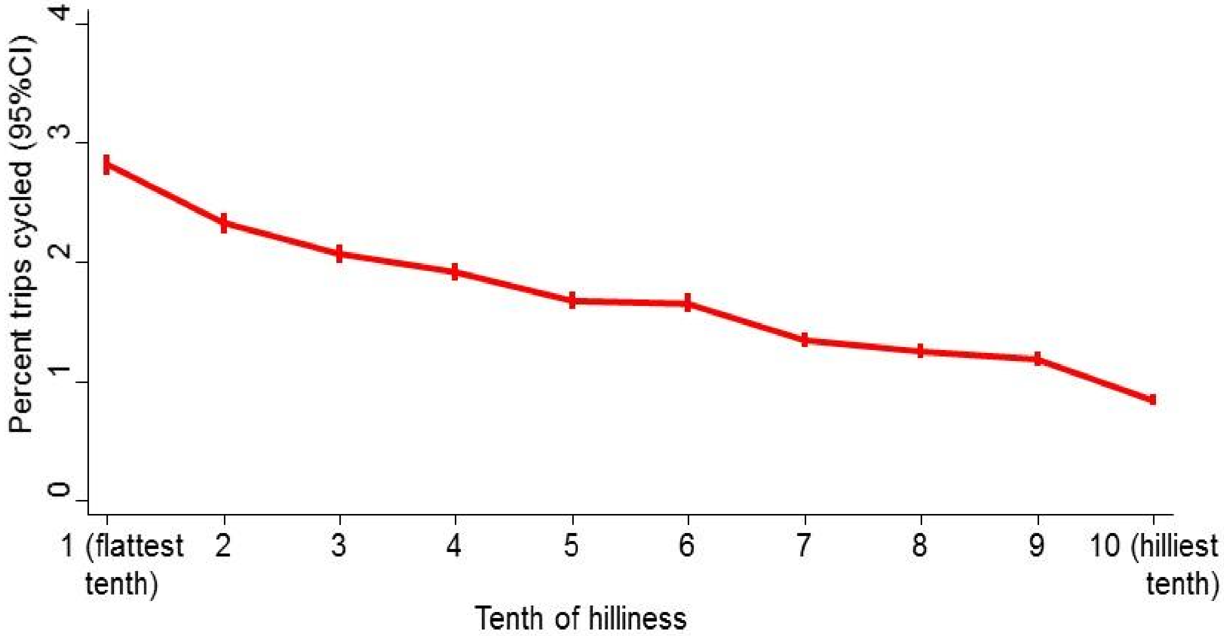

Figure 10: Proportion of all trips cycled in England (combining all age groups and genders), according to twentieth of hilliness

If one weights the percentages shown in

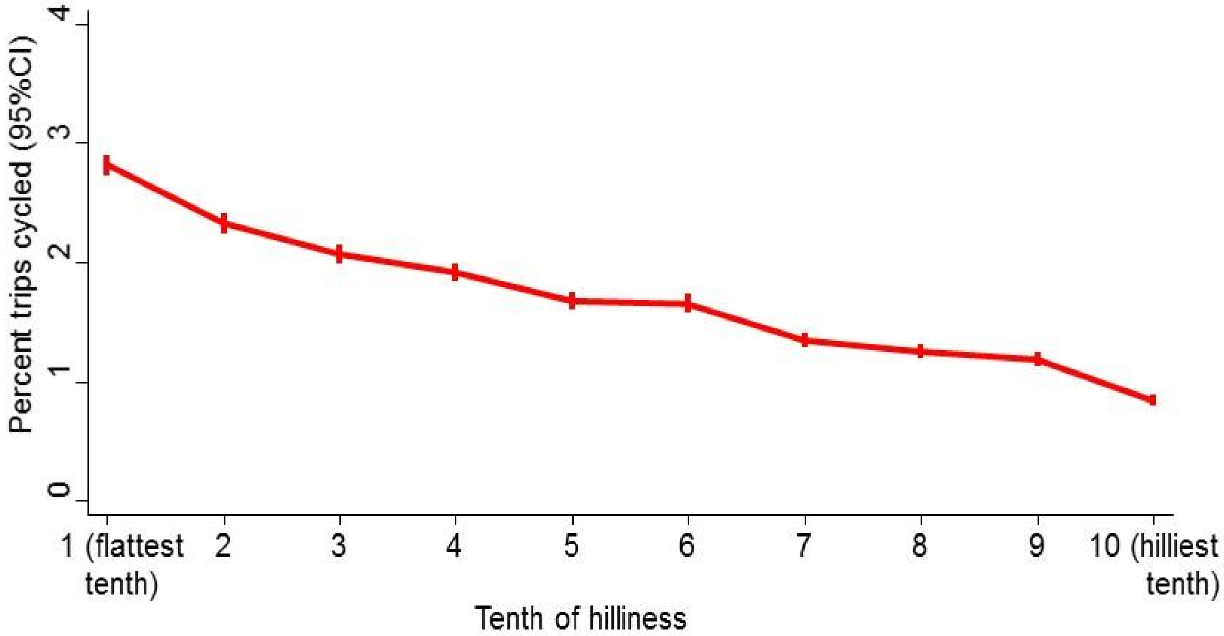

Figure 10 by the hilliness distribution observed in the Netherlands, one gets an expected national cycle mode share of 2.6% in England, as opposed to the observed national mode share of 1.7%. This suggests that if England had the same level of hilliness as the Netherlands, cycling levels would be approximately 2.6/1.7 = 1.53 times higher. Conversely, it suggests that if the Netherlands had the same hilliness level as England, cycling levels would be 1/1.53 = 0.65 times lower.

We therefore multiplied all Dutch propensities to cycle by 0.65 when modelling scenarios for England, to capture the fact that average cycling propensities are likely to be inherently lower in more hilly England than in the Netherlands. In other words, we sought to model what the propensities to cycle would be expected to be if England was the same as the Netherlands in terms of infrastructure and cycling culture, but retained its topography. This involved using the equation:

$$\text{pcycle} = 0.65 * [\exp(b_0 + b_1X_1 + b_2X_2)/ (1 + \exp(b_0 + b_1X_1 + b_2X_2))]$$

An application of this formula is shown to in the worked example in Box 3. .

Box 3: Worked example, Stage 2b

Average hilliness-adjusted baseline propensity of a woman aged 16-59 in the Netherlands making a 3 mile commute trip:

$$\text{pcycle} = 0.65 * [\exp(b_0 + b_1X_1 + b_2X_2)/ (1 + \exp(b_0 + b_1X_1 + b_2X_2))]$$

$$= 0.65 * [\exp(-0.753 + (-1.008 * 3) + (2.069 * (3^{\wedge 0.5}))) /$$

$$(1 + \exp(-0.753 + (-1.008 * 3) + (2.069 * (3^{\wedge 0.5}))))]$$

$$= 0.65 * [\exp(-0.193)/ (1 + \exp(-0.193))]$$

$$= 0.65 * 0.452$$

$$= 0.294$$

= **29.4%**

Stage 2c: Model average propensity to cycle under a given scenario

In some scenarios we examine what would happen if a given group (e.g. women aged 16-59 in England making commute trips) became more like another target group (e.g. more like men aged 16-59 in England making commute trips, or more like women aged 16-59 in the Netherlands making commute trips).

Using the distance decay formulae derived in Stage 2a and Stage 2b, one can derive the average propensity to cycle a trip of a given length for all these groups. One can then combine these to create an average propensity to cycle for a particular scenario. This is done using the following formula:

Average scenario propensity = [PropensityTarget * %transfer]

+ [PropensityOriginal * (1 - %transfer)]

Where 'PropensityOriginal' is the propensity to cycle a trip of a given distance in the original group (e.g. women aged 16-59 in England), 'PropensityTarget' is the propensity to cycle a trip of the same distance in the target group (e.g. men aged 16-59 in England). '%transfer' is a variable that takes a value between zero and one, corresponding to the degree to which the original group is assumed to become like the target group. A value of 'zero' is equivalent to the original group remaining unchanged, a value of 'one' is equivalent to the original group becoming indistinguishable from the target group.

Box 4 shows examples of the application of this approach to two scenarios: an 'increased gender equity' scenario (involving a partial shift from an original to a target group), and a 'Go Dutch' scenario (involving a complete shift from an original to a target group).

Box 4: Worked example, Stage 2c

Relevant previously calculated:

- 9.6%: Average baseline propensity for 3-mile commute trips by males aged 16-59 in England [Stage 2a, see Box 2]
- 3.3%: Average baseline propensity for 3-mile commute trips by females aged 16-59 in England [Stage 2a, see Box 2]
- 29.4% : Average hilliness-adjusted baseline propensity for 3-mile commute trips by females aged 16-59 in the Netherlands [Stage 2b, see Box 3]

<u>Example 1: 'Increased gender equity' scenario</u>. 30% of female commute trips among 16-59 year olds are assumed to acquire the distance decay formula of the equivalent male trips in England

Average scenario propensity = [PropensityTarget * %transfer]

+ [PropensityOriginal * (1 - %transfer)]

= [9.6% * 0.3] + [3.3% * (1 – 0.3)]

= <u>5.2%</u>

<u>Example 2: 'Go Dutch' scenario</u>. 100% of female commute trips among 16-59 year olds are assumed to acquire the distance decay formula of the equivalent female trips in the Netherlands

Average scenario propensity = [29.4 * 1] + [3.3% * (1 – 1)]

= <u>**29.4%**</u>

Stage 2d: Calculate and apply a propensity scaling factor for the scenario in question

For a given trip in a given scenario, the average baseline propensity is calculated using the relevant distance decay formula, as described in Stage 2a. The average scenario propensity is calculated using the weighted average of one or more distance decay formulae, as described in Stage 2c. The 'propensity scaling factor' is calculated by taking the average scenario value and dividing it by the average baseline value. This is then applied to the detailed baseline propensities, as calculated in Stage 1, to generate the 'detailed scenario propensity'.

To ensure that propensities never exceed 100%, the scaling factor is derived from, and applied to, odds not proportions. The calculation process is therefore as follows[vi], with a worked example in Box 5:

[Average baseline odds] = [Average baseline propensity] / (1 – [Average baseline propensity])

[Average scenario odds] = [Average scenario propensity] / (1 – [Average scenario propensity])

[Propensity scaling factor] = [Average scenario odds] / [Average baseline odds]

[Detailed baseline odds] = [Detailed baseline propensity] / (1 – [Detailed baseline propensity])

[Detailed scenario odds, Stage 2d] = [Detailed baseline odds] * [Propensity scaling factor]

[Detailed scenario propensity, Stage 2d] = [Detailed scenario odds] / (1+ [Detailed scenario odds])

[vi] Odds are calculated as (probability)/(1- probability) . Probability is calculated as (odds)/(1 + odds). Odds are always larger than probabilities, but the difference is small for values close to zero.

Box 5: Worked example, Stage 2d

Relevant previously calculated:

- 4.3%: Detailed baseline propensity for 3-mile commute trips by white females aged 30-39 in urban areas England [Stage 1, Box 1]
- 3.3%: Average baseline propensity for 3-mile commute trips by females aged 16-59 in England [Stage 2a, Box 2]
- 5.2%: Average scenario propensity for 3-mile commute trips by females aged 16-59 in England under an 'increased gender equity' scenario [Stage 2c, Box 4]
- 29.4%: Average scenario propensity for 3-mile commute trips by females aged 16-59 in England under an 'Go Dutch' scenario [Stage 2c, Box 4]

Application of propensity scaling factor to the 'increased gender equity' scenario

- [Average baseline odds] = [3.3%] / (1 – [3.3%]) = 0.0341
- [Average scenario odds] = [5.2%] / (1 – [5.2%]) = 0.0549
- [Propensity scaling factor] = [0.0549] / [0.0341] = 1.610
- [Detailed baseline odds] = [4.3%] / (1 – [4.3%]) = 0.0449
- [Detailed scenario odds, Stage 2d] = [0.0449] * [1.610] = 0.0723
- [Detailed scenario propensity, Stage 2d] = [0.0723] / (1 + [0.0723]) = 0.0674 = **6.7%**

Thus **6.7%** is the estimated propensity to cycle for a 3-mile commute trip by a white female aged 30-39 in urban area in England, under this 'increased gender equity' scenario

Application of propensity scaling factor to the 'Go Dutch' scenario

- [Average baseline odds] = [3.3%] / (1 – [3.3%]) = 0.0341
- [Average scenario odds] = [29.4%] / (1 – [29.4%]) = 0.4164
- [Propensity scaling factor] = [0.4164] / [0.0341] = 12.211
- [Detailed baseline odds] = [4.3%] / (1 – [4.3%]) = 0.0449
- [Detailed scenario odds, Stage 2d] = [0.0449] * [12.211] = 0.5483
- [Detailed scenario propensity, Stage 2d] = [0.5483] / (1 + [0.5483]) = 0.3541 = **35.4%**

Thus **35.4%** is the estimated propensity to cycle for a 3-mile commute trip by a white female aged 30-39 in urban area in England, under this 'Go Dutch' scenario

Stage 3: If applicable, apply a national mode share scaling factor to all strata to achieve a target scenario mode share

In some scenarios, we seek to model propensities solely in terms of changing socio-demographic patterns – for example, 'cycling becomes more gender equitable in England' or 'England 'goes Dutch' with respect to cycling propensities'. In such scenarios, the detailed scenario propensities generated at the end of Stage 2d are the final propensities used in the model.

In other scenarios, we additionally or alternatively seek to model propensities such that the scenario as a whole generates a target national mode share. Examples would include, 'cycle mode share in England doubles' or 'cycle mode share in England increases five-fold, and there is also increased gender equity'. For these latter scenarios, we need to go through a third Stage in which all Stage 2d detailed scenario propensities in all strata are scaled up or down by a uniform national mode-share scaling factor, in order to give the desired target mode share. As in Stage 2d, odds not proportions are used to calculate the scaling factor in order ensure that propensities never exceed 100%,.

The method for calculating and applying the national mode-share scaling factor is as follows, with a worked example provided in Box **6**.

[Cycle mode share, Stage 2d] = overall mode share of cycling across all trips, based on the values of the [Detailed scenario propensities, Stage 2d]

[Cycle mode odds, Stage 2d] = [Cycle mode share, Stage 2d] / (1 - [Cycle mode share, Stage 2d])

[Cycle mode odds, target] = [Cycle mode share, target] / (1 - [Cycle mode share, target])

[Mode-share scaling factor] = [Cycle mode odds, target] / [Cycle mode odds, Stage 2d]

[Detailed scenario odds, Stage 3] = [Detailed scenario odds, Stage 2d]

* [Mode-share scaling factor]

[Detailed scenario propensity, Stage 3] = [Detailed scenario odds, Stage 3]

/ (1 + [Detailed scenario odds, Stage 3])

Box 6: Worked example, Stage 3

Relevant previously calculated:

- 0.072: Detailed scenario odds (Stage 2d) for 3-mile commute trips by white females aged 30-39 in urban areas England, under a scenario of increased gender equity [Stage 2d, Box 5]

Example scenario: a scenario assuming both 'increased gender equity' and also that the total national mode share will increase five-fold. Given that the baseline overall mode share for cycling in England is 1.7%, this implies a target mode share of 8.5%.

After applying to all strata of females the procedure shown in Box 5, one can derive [Detailed scenario propensities, Stage 2d] for all trips. The national mode share based on these Stage 2d propensities is approximately 2.0%. Given this, one can then proceed as follows:

[Cycle mode odds, Stage 2d]	= [2.0%] / (1 - [2.0%])	= 0.0204
[Cycle mode odds, target]	= [8.5%] / (1 - [8.5%])	= 0.0929
[Mode-share scaling factor]	= [0.0929] / [0.0204]	= 4.552
[Detailed scenario odds, Stage 3]	= [0.072] * [4.552]	= 0.328
[Detailed scenario propensity, Stage 3]	= [0.328] / (1 + [0.328])	= 0.247 = **24.7%**

Thus **24.7%** is the estimated propensity to cycle for a 3-mile commute trip by a white female aged 30-39 in urban area in England, under this scenario of 'increased gender equity plus 5-fold mode share increase'.

Results, Section 4: Application of modelling approach to selected scenarios

Generic 'Scenario statement'

The scenario modelling approach described in the previous section provides a flexible basis for generating scenarios which involve one or more of the following elements:

1. An increase in the national mode share of cycling
2. Increased gender and/or age equity of cycling
3. 'Go Dutch': English cycling propensities becoming more like, or the same as, Dutch propensities

One way to describe the scenario generated by a particular combination of alterations is to make the appropriate substitutions in the generic Scenario statement in Box 7. In this generic statement, the first section (involving stratum-specific manipulations) corresponds to Stage 2c and 2d of the modelling process. The second section (involving a target national mode share) corresponds to Stage 3 of the modelling process.

Box 7: Generic Scenario statement

- In Stratum 1 in England: [all average propensities are unchanged] OR [__% of trips are given the same average propensity as **Stratum ___** in **England / the Netherlands]**

- In Stratum 2 in England: [all average propensities are unchanged] OR [__% of trips are given the same average propensity as **Stratum ___** in **England / the Netherlands]**

- In Stratum 3 in England: [all average propensities are unchanged] OR [__% of trips are given the same average propensity as **Stratum ___** in **England / the Netherlands]**

- In Stratum 4 in England: [all average propensities are unchanged] OR [[__% of commute trips are given the same average propensity as **Stratum ___** in **England / the Netherlands**] AND/OR [___.___% of non-commute trips are given the same average propensity as **Stratum ___** in **England / the Netherlands**]].

- In Stratum 5 in England: [all average propensities are unchanged] OR [__% of trips are given the same average propensity as **Stratum ___** in **England / the Netherlands]**

- In Stratum 6 in England: [all average propensities are unchanged] OR [__% of trips are given the same average propensity as **Stratum ___** in **England / the Netherlands]**

- In Stratum 7 in England: [all average propensities are unchanged] OR [__% of trips are given the same average propensity as **Stratum ___** in **England / the Netherlands]**

- In Stratum 8 in England: [all average propensities are unchanged] OR [[__% of commute trips are given the same average propensity as **Stratum ___** in **England / the Netherlands**] AND/OR [___.___% of non-commute trips are given the same average propensity as **Stratum ___** in **England / the Netherlands**]].

AND THEN

- Overall national mode share is: [not otherwise manipulated] OR [increased by a factor of ___.___]

Application of 'Scenario statements' to Stage 1 scenarios

Below we characterise the six scenarios that we selected to model in Stage 1 in terms of such Scenario statements. In Stage 1 we focus on commute trips. We do not make changes to Strata 1, 3, 5 or 7, and these four strata are therefore omitted from the scenario statements. Note, however, that non-commute trips form part of strata 4 and 8. In these strata, both commute and non-commute trips were used to define the distance decay functions for older adults (modelling Stage 2a), but only the commute trips are then altered when modelling alternative scenarios (modelling Stage 2c and 2d).

Scenario 1: Model the current average propensity to cycle commute trips in each region of England (the 'baseline' condition)

- In Stratum 2 in England: all average propensities are unchanged
- In Stratum 4 in England: all average propensities are unchanged
- In Stratum 6 in England: all average propensities are unchanged
- In Stratum 8 in England: all average propensities are unchanged

AND THEN

- Overall national mode share is: not otherwise manipulated

Scenario 2a: Small increase in commuter cycling to twice the current level: no change in socio-demographic distribution of commuter cycling

- In Stratum 2 in England: all average propensities are unchanged
- In Stratum 4 in England: all average propensities are unchanged
- In Stratum 6 in England: all average propensities are unchanged
- In Stratum 8 in England: all average propensities are unchanged

AND THEN

- Overall national mode share is: increased by a factor of **2** .

Scenario 2b: Small increase in commuter cycling to twice the current level, achieved in the context of partial equalising of commuter cycling levels by both age and gender

- In Stratum 2 in England: all average propensities are unchanged
- In Stratum 4 in England: **30%** of commute trips are given the same average propensity as
  Stratum 2 in England
- In Stratum 6 in England: **30%** of trips are given the same average propensity as **Stratum**
  2 in England
- In Stratum 8 in England: **30%** of commute trips are given the same average propensity as
  Stratum 2 in England

AND THEN

- Overall national mode share is: increased by a factor of **2**.

Scenario 3a: Medium increase in commuter cycling to five times the current level: no change in socio-demographic distribution of commuter cycling

- In Stratum 2 in England: all average propensities are unchanged
- In Stratum 4 in England: all average propensities are unchanged
- In Stratum 6 in England: all average propensities are unchanged
- In Stratum 8 in England: all average propensities are unchanged

AND THEN

- Overall national mode share is: increased by a factor of **5**.

Scenario 3b: Medium increase in commuter cycling to five times the current level, achieved in the context of partial equalising of commuter cycling levels by both age and gender

- In Stratum 2 in England: all average propensities are unchanged
- In Stratum 4 in England: **30%** of commute trips are given the same average propensity as
  Stratum 2 in England
- In Stratum 6 in England: **30%** of trips are given the same average propensity as **Stratum**
  2 in England
- In Stratum 8 in England: **30%** of commute trips are given the same average propensity as
  Stratum 2 in England

AND THEN

- Overall national mode share is: increased by a factor of **5**.

Scenario 4: Large increase in cycling to the levels seen in the Netherlands

- In Stratum 2 in England: **100%** of trips are given the same average propensity as Stratum 2 in the Netherlands
- In Stratum 4 in England: **100%** of commute trips are given the same average propensity
  as Stratum 4 in the Netherlands
- In Stratum 6 in England: **100%** of trips are given the same average propensity as Stratum 6 in the Netherlands
- In Stratum 8 in England: **100%** of commute trips are given the same average propensity
  as Stratum 8 in the Netherlands

AND THEN

- Overall national mode share is: not otherwise manipulated

Conclusion

Sections 1 and 2 of this Appendix have described the differences in the probability of cycling a trip according to age, gender, trip purpose and trip distance. They have also compared England and the Netherlands in these respects, examined the role of hilliness in determining propensity to cycle, and examined the effect of e-bike use on the willingness to cycle longer trips. In doing so, these analyses provide a backdrop to applying and interpreting the various scenarios planned for NPCT in Stage 2, as well as informing other decisions such as the decision to characterise local populations based on car ownership and ethnicity in the Spatial Microsimulation model.

This Appendix has also set out a process whereby, in Stage 2, propensities to cycle can be defined and manipulated at the individual level in the microsimulation model. By applying this methodology in Stage 2, we will be able to build an NPCT version that harnesses the strengths of microsimulation, and that also allows for a more customised range of scenarios than are available in the present prototype.

Supplementary material 1: Logit regression models used to generate detailed baseline propensities to cycle in modelling Stage 1, for the eight strata in England

Table 6: Predictors of cycling for trips among males aged 0-15 (stratum 1) in England

Variable	Level	Log-odds	95%CI of log-odds
Constant		-4.967	(-5.710, -4.224)
Distance (miles)	Linear term	-1.062	(-1.382, -0.741)
	Square root term	2.586	(1.724, 3.447)
Ethnicity	White	0	
	Non-white	-0.642	(-1.020, -0.263)
Household income	Fifth 1 (poorest)	0	
	Fifth 2	0.157	(-0.147, 0.461)
	Fifth 3	-0.096	(-0.416, 0.223)
	Fifth 4	-0.065	(-0.376, 0.247)
	Fifth 5 (richest)	-0.611	(-0.954, -0.267)
No. cars/vans in household	0	0	
	1	0.009	(-0.322, 0.339)
	2	0.191	(-0.169, 0.551)
	3+	0.176	(-0.366, 0.719)
Urban/rural	Rural	0	
	Urban	0.043	(-0.219, 0.304)
LSOA income deprivation	Fifth 1 (poorest)	0	
	Fifth 2	0.241	(-0.116, 0.598)
	Fifth 3	0.353	(-0.009, 0.715)
	Fifth 4	0.105	(-0.258, 0.468)
	Fifth 5 (richest)	0.534	(0.175, 0.893)
LSOA prevalence commute cycling	Change per percentage point	0.091	(0.064, 0.117)

LSOA hilliness	Change per decile, relative to England	-0.082	(-0.118, -0.047)
Region	North East	0	
	North West	-0.143	(-0.671, 0.384)
	Yorkshire & Humber	-0.273	(-0.853, 0.307)
	East Midlands	0.143	(-0.427, 0.713)
	West Midlands	-0.161	(-0.754, 0.431)
	East of England	0.416	(-0.122, 0.954)
	London	-0.436	(-1.011, 0.140)
	South East	0.181	(-0.355, 0.716)
	South West	0.176	(-0.369, 0.722)

Table 7: Predictors of cycling for commute trips among males aged 16-59 (stratum 2) in England

Variable	Level	Log-odds	95%CI of log-odds
Constant		-2.764	(-3.607, -1.921)
Distance (miles)	Linear term	-0.424	(-0.569, -0.279)
	Square root term	1.141	(0.566, 1.717)
Age	16-29 years	0	
	30-39 years	0.176	(-0.093, 0.445)
	40-49 years	0.360	(0.108, 0.612)
	50-59 years	-0.034	(-0.319, 0.251)
Ethnicity	White	0	
	Non-white	-1.271	(-1.663, -0.878)
Household income	Fifth 1 (poorest)	0	
	Fifth 2	-0.254	(-0.620, 0.112)
	Fifth 3	-0.259	(-0.592, 0.074)
	Fifth 4	-0.230	(-0.568, 0.108)
	Fifth 5 (richest)	-0.164	(-0.526, 0.199)
No. cars/vans in household	0	0	
	1	-0.500	(-0.754, -0.246)
	2	-1.244	(-1.550, -0.938)
	3+	-1.718	(-2.184, -1.252)
Urban/rural	Rural	0	
	Urban	-0.163	(-0.438, 0.113)
LSOA income deprivation	Fifth 1 (poorest)	0	
	Fifth 2	-0.144	(-0.425, 0.136)
	Fifth 3	0.171	(-0.106, 0.447)
	Fifth 4	0.342	(0.003, 0.682)
	Fifth 5 (richest)	0.255	(-0.038, 0.548)

LSOA prevalence commute cycling	Change per percentage point	0.111	(0.088, 0.135)
LSOA hilliness	Change per decile, relative to England	-0.064	(-0.098, -0.030)
Region	North East	0	
	North West	0.446	(-0.081, 0.974)
	Yorkshire & Humber	0.322	(-0.240, 0.883)
	East Midlands	0.782	(0.234, 1.330)
	West Midlands	0.765	(0.213, 1.317)
	East of England	0.572	(0.027, 1.116)
	London	0.367	(-0.195, 0.930)
	South East	0.768	(0.251, 1.285)
	South West	0.917	(0.385, 1.449)

Table 8: Predictors of cycling for non-commute trips among males aged 16-59 (stratum 3) in England

Variable	Level	Log-odds	95%CI of log-odds
Constant		-3.974	(-4.498, -3.449)
Distance (miles)	Linear term	-0.199	(-0.252, -0.146)
	Square root term	0.837	(0.611, 1.063)
Age	16-29 years	0	
	30-39 years	-0.248	(-0.469, -0.027)
	40-49 years	-0.197	(-0.414, 0.021)
	50-59 years	-0.319	(-0.561, -0.077)
Ethnicity	White	0	
	Non-white	-0.845	(-1.184, -0.506)
Household income	Fifth 1 (poorest)	0	
	Fifth 2	-0.049	(-0.325, 0.227)
	Fifth 3	-0.398	(-0.674, -0.121)
	Fifth 4	-0.171	(-0.440, 0.097)
	Fifth 5 (richest)	-0.147	(-0.424, 0.131)
No. cars/vans in household	0	0	
	1	-0.776	(-1.016, -0.536)
	2	-1.256	(-1.521, -0.991)
	3+	-1.538	(-1.884, -1.192)
Urban/rural	Rural	0	
	Urban	-0.014	(-0.221, 0.194)
LSOA income deprivation	Fifth 1 (poorest)	0	
	Fifth 2	0.238	(-0.027, 0.502)
	Fifth 3	0.090	(-0.182, 0.362)
	Fifth 4	0.241	(-0.027, 0.508)
	Fifth 5 (richest)	0.506	(0.226, 0.786)

LSOA prevalence commute cycling	Change per percentage point	0.105	(0.088, 0.121)
LSOA hilliness	Change per decile, relative to England	-0.038	(-0.067, -0.010)
Region	North East	0	
	North West	0.033	(-0.363, 0.428)
	Yorkshire & Humber	0.242	(-0.179, 0.664)
	East Midlands	0.406	(-0.040, 0.852)
	West Midlands	0.156	(-0.260, 0.572)
	East of England	0.375	(-0.043, 0.792)
	London	0.082	(-0.327, 0.492)
	South East	0.483	(0.089, 0.877)
	South West	0.375	(-0.032, 0.783)

Table 9: Predictors of cycling for trips among males aged 60+ (stratum 4) in England

Variable	Level	Log-odds	95%CI of log-odds
Constant		-2.546	(-3.616, -1.475)
Distance (miles)	Linear term	-0.125	(-0.221, -0.029)
	Square root term	0.220	(-0.184, 0.624)
Age	60-69 years	0	
	70-79 years	-0.457	(-0.764, -0.150)
	80+ years	-0.972	(-1.464, -0.480)
Ethnicity	White	0	
	Non-white	-1.203	(-3.035, 0.629)
Household income	Fifth 1 (poorest)	0	
	Fifth 2	-0.506	(-0.923, -0.088)
	Fifth 3	-0.189	(-0.603, 0.226)
	Fifth 4	-0.370	(-0.791, 0.050)
	Fifth 5 (richest)	0.086	(-0.383, 0.555)
No. cars/vans in household	0	0	
	1	-1.196	(-1.589, -0.804)
	2	-1.532	(-2.007, -1.056)
	3+	-2.259	(-3.059, -1.459)
Urban/rural	Rural	0	
	Urban	-0.210	(-0.541, 0.120)
LSOA income deprivation	Fifth 1 (poorest)	0	
	Fifth 2	0.085	(-0.426, 0.596)
	Fifth 3	0.183	(-0.388, 0.755)
	Fifth 4	0.343	(-0.147, 0.834)
	Fifth 5 (richest)	0.630	(0.140, 1.120)
LSOA prevalence	Change per percentage point	0.110	(0.073, 0.146)

commute cycling			
LSOA hilliness	Change per decile, relative to England	-0.103	(-0.150, -0.056)
Region	North East	0	
	North West	-0.379	(-1.187, 0.428)
	Yorkshire & Humber	0.078	(-0.739, 0.896)
	East Midlands	0.000	(-0.900, 0.901)
	West Midlands	-0.226	(-1.083, 0.632)
	East of England	0.116	(-0.729, 0.961)
	London	-0.355	(-1.252, 0.542)
	South East	0.217	(-0.585, 1.020)
	South West	0.539	(-0.277, 1.354)

Table 10: Predictors of cycling for trips among females aged 0-15 (stratum 5) in England

Variable	Level	Log-odds	95%CI of log-odds
Constant		-5.439	(-6.534, -4.343)
Distance (miles)	Linear term	-1.127	(-1.645, -0.609)
	Square root term	2.384	(1.069, 3.699)
Ethnicity	White	0	
	Non-white	-0.431	(-1.000, 0.137)
Household income	Fifth 1 (poorest)	0	
	Fifth 2	0.105	(-0.437, 0.647)
	Fifth 3	0.048	(-0.544, 0.641)
	Fifth 4	0.000	(-0.574, 0.574)
	Fifth 5 (richest)	-0.361	(-1.019, 0.296)
No. cars/vans in household	0	0	
	1	0.317	(-0.304, 0.937)
	2	-0.191	(-0.903, 0.521)
	3+	0.154	(-0.926, 1.233)
Urban/rural	Rural	0	
	Urban	0.074	(-0.342, 0.490)
LSOA income deprivation	Fifth 1 (poorest)	0	
	Fifth 2	0.637	(0.031, 1.243)
	Fifth 3	0.322	(-0.227, 0.871)
	Fifth 4	1.089	(0.506, 1.673)
	Fifth 5 (richest)	1.305	(0.708, 1.901)
LSOA prevalence commute cycling	Change per percentage point	0.083	(0.037, 0.130)

LSOA hilliness	Change per decile, relative to England	-0.148	(-0.219, -0.078)
Region	North East	0	
	North West	-1.173	(-2.126, -0.219)
	Yorkshire & Humber	-0.801	(-1.799, 0.197)
	East Midlands	-0.462	(-1.394, 0.471)
	West Midlands	-0.102	(-1.002, 0.798)
	East of England	-0.258	(-1.162, 0.645)
	London	-1.044	(-1.980, -0.109)
	South East	-0.229	(-1.126, 0.668)
	South West	-0.558	(-1.453, 0.337)

Table 11: Predictors of cycling for commute trips among females aged 16-59 (stratum 6) in England

Variable	Level	Log-odds	95%CI of log-odds
Constant		-5.255	(-6.573, -3.938)
Distance (miles)	Linear term	-0.666	(-0.924, -0.409)
	Square root term	1.689	(0.778, 2.601)
Age	16-29 years	0	
	30-39 years	0.147	(-0.282, 0.575)
	40-49 years	0.134	(-0.267, 0.535)
	50-59 years	0.195	(-0.217, 0.608)
Ethnicity	White	0	
	Non-white	-0.800	(-1.497, -0.103)
Household income	Fifth 1 (poorest)	0	
	Fifth 2	-0.231	(-0.792, 0.331)
	Fifth 3	-0.241	(-0.755, 0.273)
	Fifth 4	0.128	(-0.402, 0.658)
	Fifth 5 (richest)	0.219	(-0.303, 0.742)
No. cars/vans in household	0	0	
	1	-0.450	(-0.818, -0.082)
	2	-1.478	(-1.945, -1.012)
	3+	-2.043	(-2.756, -1.330)
Urban/rural	Rural	0	
	Urban	-0.319	(-0.745, 0.108)
LSOA income deprivation	Fifth 1 (poorest)	0	
	Fifth 2	-0.035	(-0.513, 0.444)
	Fifth 3	-0.291	(-0.803, 0.222)
	Fifth 4	0.156	(-0.303, 0.615)
	Fifth 5 (richest)	0.447	(-0.053, 0.946)

LSOA prevalence commute cycling	Change per percentage point	0.130	(0.100, 0.160)
LSOA hilliness	Change per decile, relative to England	-0.035	(-0.092, 0.021)
Region	North East	0	
	North West	1.463	(0.507, 2.419)
	Yorkshire & Humber	1.494	(0.452, 2.536)
	East Midlands	1.560	(0.542, 2.578)
	West Midlands	1.233	(0.189, 2.277)
	East of England	1.421	(0.412, 2.431)
	London	1.400	(0.444, 2.356)
	South East	1.673	(0.709, 2.637)
	South West	1.859	(0.885, 2.832)

Table 12: Predictors of cycling for non-commute trips among females aged 16-59 (stratum 7) in England

Variable	Level	Log-odds	95%CI of log-odds
Constant		-6.031	(-6.756, -5.306)
Distance (miles)	Linear term	-0.617	(-0.815, -0.419)
	Square root term	1.762	(1.136, 2.388)
Age	16-29 years	0	
	30-39 years	0.100	(-0.249, 0.449)
	40-49 years	0.098	(-0.195, 0.391)
	50-59 years	0.393	(0.085, 0.700)
Ethnicity	White	0	
	Non-white	-0.507	(-1.039, 0.026)
Household income	Fifth 1 (poorest)	0	
	Fifth 2	0.268	(-0.156, 0.692)
	Fifth 3	0.466	(0.086, 0.845)
	Fifth 4	0.329	(-0.066, 0.724)
	Fifth 5 (richest)	0.514	(0.130, 0.897)
No. cars/vans in household	0	0	
	1	-0.685	(-1.035, -0.335)
	2	-1.196	(-1.589, -0.804)
	3+	-1.258	(-1.902, -0.615)
Urban/rural	Rural	0	
	Urban	-0.383	(-0.668, -0.098)
LSOA income deprivation	Fifth 1 (poorest)	0	
	Fifth 2	0.202	(-0.198, 0.603)
	Fifth 3	-0.124	(-0.520, 0.273)
	Fifth 4	0.365	(-0.024, 0.754)
	Fifth 5 (richest)	0.480	(0.072, 0.888)

LSOA prevalence commute cycling	Change per percentage point	0.131	(0.109, 0.152)
LSOA hilliness	Change per decile, relative to England	-0.089	(-0.130, -0.048)
Region	North East	0	
	North West	0.509	(-0.089, 1.107)
	Yorkshire & Humber	0.473	(-0.131, 1.076)
	East Midlands	0.485	(-0.112, 1.082)
	West Midlands	0.421	(-0.171, 1.014)
	East of England	0.892	(0.304, 1.481)
	London	0.670	(0.082, 1.259)
	South East	1.049	(0.504, 1.594)
	South West	0.939	(0.367, 1.511)

Table 13: Predictors of cycling for trips among females aged 60+ (stratum 8) in England

Variable	Level	Log-odds	95%CI of log-odds
Constant		-4.357	(-5.951, -2.763)
Distance (miles)	Linear term	-0.297	(-0.643, 0.050)
	Square root term	0.151	(-0.932, 1.235)
Age	60-69 years	0	
	70-79 years	-0.606	(-1.151, -0.060)
	80+ years	-1.794	(-2.880, -0.708)
Ethnicity	White	0	
	Non-white	-0.770	(-2.919, 1.379)
Household income	Fifth 1 (poorest)	0	
	Fifth 2	0.118	(-0.503, 0.739)
	Fifth 3	-0.251	(-0.917, 0.416)
	Fifth 4	-0.059	(-0.743, 0.624)
	Fifth 5 (richest)	-0.348	(-1.086, 0.389)
No. cars/vans in household	0	0	
	1	-0.190	(-0.781, 0.402)
	2	-0.296	(-1.005, 0.413)
	3+	-1.343	(-2.540, -0.146)
Urban/rural	Rural	0	
	Urban	-1.101	(-1.605, -0.597)
LSOA income deprivation	Fifth 1 (poorest)	0	
	Fifth 2	0.973	(0.016, 1.931)
	Fifth 3	0.864	(-0.039, 1.766)
	Fifth 4	0.708	(-0.239, 1.655)
	Fifth 5 (richest)	1.020	(0.097, 1.942)
LSOA prevalence	Change per percentage point	0.180	(0.146, 0.213)

commute cycling			
LSOA hilliness	Change per decile, relative to England	-0.168	(-0.247, -0.089)
Region	North East	0	
	North West	-0.708	(-2.398, 0.982)
	Yorkshire & Humber	0.786	(-0.688, 2.260)
	East Midlands	0.269	(-1.218, 1.756)
	West Midlands	-0.124	(-1.761, 1.514)
	East of England	0.220	(-1.233, 1.672)
	London	0.792	(-0.750, 2.334)
	South East	0.306	(-1.141, 1.753)
	South West	0.872	(-0.573, 2.317)

Supplementary material 2: Distance decay functions used to generate average baseline propensities, in modelling Stage 2a and 2b

Parameters used to define average baseline propensities in England (Stage 2a)

Table 14: Log-odds parameters for distance decay functions in males in England

Variable	Level	Log-odds			
		Stratum 1	Stratum 2	Stratum 3	Stratum 4
Constant		-4.855	-2.676	-4.157	-3.847
Distance (miles)	Linear term	-1.078	-0.412	-0.157	-0.084
	Square root term	2.649	0.963	0.521	-0.034

Table 15: Log-odds parameters for distance decay functions in females in England

Variable	Level	Log-odds			
		Stratum 5	Stratum 6	Stratum 7	Stratum 8
Constant		-5.570	-4.320	-5.396	-4.589
Distance (miles)	Linear term	-1.153	-0.712	-0.567	-0.277
	Square root term	2.462	1.773	1.489	0.068

The values in Table 14 and Table 15 were then substituted into the formula:

$$pcycle = \exp(b_0 + b_1X_1 + b_2X_2)/ (1 + \exp(b_0 + b_1X_1 + b_2X_2))$$

where X_1 is the linear term for distance, and X_2 is the term for the square root of distance

Parameters used to define average baseline propensities in the Netherlands (Stage 2b)

Table 16: Log-odds parameters for distance decay functions in males in England

Variable	Level	Log-odds			
		Stratum 1	Stratum 2	Stratum 3	Stratum 4
Constant		-1.241	-0.416	-0.566	-0.554
Distance (miles)	Linear term	-0.603	-0.445	-0.070	-0.028
	Square root term	1.716	0.770	-0.249	-0.297

Table 17: Log-odds parameters for distance decay functions in females in England

Variable	Level	Log-odds			
		Stratum 5	Stratum 6	Stratum 7	Stratum 8
Constant		-1.328	-0.753	-0.789	-0.625
Distance (miles)	Linear term	-0.691	-1.008	-0.406	-0.131
	Square root term	1.852	2.069	0.525	0.018

The values in Table 16 and Table 17 were then substituted into the formula:

$$\text{pcycle} = 0.65 * [\exp(b_0 + b_1X_1 + b_2X_2)/ (1 + \exp(b_0 + b_1X_1 + b_2X_2))]$$

where X_1 is the linear term for distance, and X_2 is the term for the square root of distance. The value of 0.66 is a scaling factor to account for the greater hilliness of England, see Stage 2b.

Appendix 9 Transport Health Assessment Tool (THAT)

Contents

Summary

Transport Health Assessment Tool (THAT) is a web tool that allows the user to generate scenarios based on reallocating existing trips to walking and cycling, and to visualise the health and carbon reduction benefits for these scenarios.

THAT model was used by the Transport for London in 2014 to create and test different scenarios and their health effects in London (Greater London Authority, 2014).

Key points from the development and testing of THAT model include:

- The ability to create a practically useful model based on individual level trip data that could be run with minimum input from the development team
- The limitations of the Analytica software for creating flexible web interfaces
- The desire for geographically localised results
- The burden of creating rules based on each trip distance band
- The desire for additional variables most notably socioeconomic status and ethnicity
- The desire for greater data visualisation, including of baseline data

Background

Transport Health and Assessment Tool (THAT) is integrated assessment of health effects model that simulates the effect of transport scenarios. The simulation allows estimation of the effects that alternative transport scenarios could have on travel modes, public health and CO_2 emissions in London.

The model draws on background trip data from the London Travel Demand Survey (LTDS), and is supplemented with other data sources (Stats19 for injuries; and London Atmospheric Emissions Inventory for PM2.5 and CO_2 emissions). Details of these sources can be found in the References section below.

The model compares a real baseline scenario (actual trips in London) with alternative scenarios that can be created and tweaked by the user. In these scenarios, a part of the trips now carried out by car, bus, underground and other modes are transferred to active modes (walking or cycling). The specific subset of trips transferred to walking/cycling is determined by the user.

Once the scenarios have been defined, THAT runs the simulation, showing as a result the initial baseline scenario compared with the user created scenario(s).

Description of the model

Overview

THAT is a version of the Integrated Transport and Health Impact Modelling Tool (ITHIM): a range of related models and tools developed at The Centre for Diet and Activity Research (CEDAR), University of Cambridge. ITHIM was developed to perform integrated assessment of the health effects of transport scenarios and policies at the urban and national level. The health effects of transport policies are modelled through the changes in physical activity, road traffic injury risk, and exposure to fine particulate matter (PM2.5[i]) air pollution. ITHIM is being used in research and by health and transport professionals to estimate the health impacts of transport scenarios, compare the impact of travel patterns in different places, and model the impact of interventions. The impacts (benefits and harms) are presented as disability adjusted life years (DALYs) to compare across different outcomes. A gain of one DALY is equivalent to a gain of one year of life in good health. For more information from ITHIM see e.g. Woodcock et al. (2009, 2013, 2014) and Maizlish et al. (2013).

THAT is a version of ITHIM with a user interface which allows users to create own transport scenarios. THAT model calculates the changes in the health in London following the changes in travel modes on various scenarios.

Background travel data

Background travel data was obtained from the London Travel Demand Survey (LTDS) and uses 2005-2011 data. LTDS is a continuous household survey of the London area, covering London Boroughs as well as some of the area outside Greater London (Transport for London, 2011). The annual sample size of LTDS is around 8000 households.

From the LTDS travel diaries the background travel data was stratified by:

- Gender;
- Age (eight age bands[ii]);
- Mode (car/taxi, motorcycle, bus/coach/tram, underground, national rail/underground); and
- Distance travelled.

LTDS weighting was not used in the analyses. All trip stages with duration of zero to three minutes (including trips with a total duration of less than three minutes) were excluded.

Data from the National Travel Survey (NTS) was used to create scaling factors which translate one-day data (from LTDS) to estimates of past-week activity.

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[i] Particulate Matter up to 2.5 micrometers in size

[ii] Travel diaries were not completed for children aged 0-4 years, but in all trips the number of accompanying 0-4 year olds is noted. These records of trips made with accompanying 0-4 year olds were therefore used as the basis for defining travel behaviour in each age group. If a trip had one 0-4 year old accompanying, it was counted as one trip in this age group, if there were two 0-4 year olds it was counted as two trips in this age group, etc. If the number of co-resident 0-4 year olds living in the household of the person making the trip were the same as the number of 0-4 year olds on the trip, then it was assumed these corresponded to the same individuals.

User defined scenarios

In THAT, the user interface allows the user to define which of the current trips are transferred to walking or cycling. The trips transferred can be decided based on the:

1. Gender of the person doing the trip;
2. Age of the person (eight age bands);
3. Transport mode from where the trips are transferred to walking or cycling (five categories);
4. Trip length (min. and max. length of the trip); and
5. Percentage of all the trips fulfilling above categories that are transferred to walking/cycling.

If the percentage of trips transferred (as per point five above) is set 100%, all of the trips matching the filters (points one to four) are transferred. If the percentage of trips transferred is set to less than 100%, trips replaced with walking/cycling are decided randomly.

The user interface allows the user to create three different scenarios. In each scenario, the user can allocate trips to walking, cycling or both. For example, 100% of car/taxi trips less than one kilometre could be allocated to walking and 50% of car/taxi trips that are one to three kilometres long could be allocated to cycling in same scenario. Possible overlaps resulting from same trips being allocated to walking and cycling are resolved through first allocating all the trips to walking, and then allocating remaining trips to cycling. See Figure 1 for an example of the user interface.

After the user has defined the scenarios, THAT model calculates the changes in: physical activity; injuries and fatalities; PM2.5 air pollution; and CO_2 emissions in the defined scenarios.

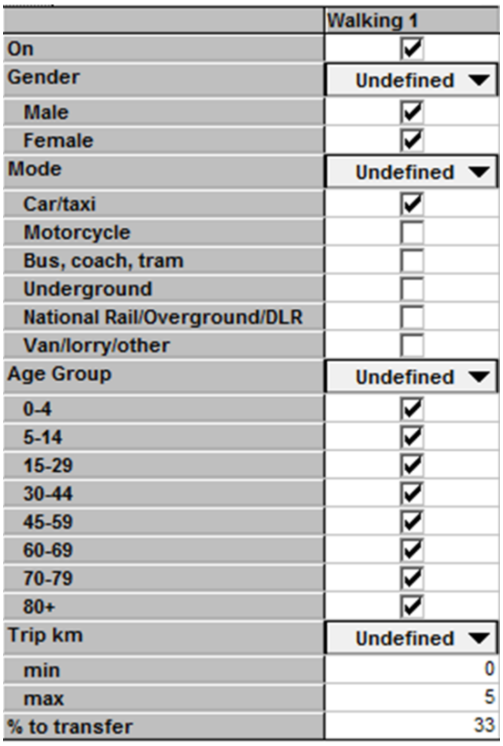

Figure 1: Example of the user interface to create scenarios. In this case user wants to replace 33% of the trips less than 5 km long and currently made with car/taxi with the walking, in all age groups.

Physical activity levels

Increase in physical activity is calculated based on the number and length of the trips replaced by walking and cycling in each scenario. For each replaced trip, duration of the trip (in minutes) is estimated, and the duration data is used to estimate change in physical activity level. Background physical activity data was obtained from Health Survey for England (HSE) 2008[iii].

Physical activity due to walking, cycling and background activities is aggregated to marginal Metabolic Equivalents of Task (METs). METs reflect intensity of different activities and are a useful summary measure of the physical activity. For walking, a value of 2.5 MMETs was used, and for cycling a value of 5.8 MMETs was used. This reflects the intensity differences between walking and cycling[iv].

METs are converted to marginal METs by subtracting 1 MET (intensity of being at rest). This approach therefore only considers the marginal activity over and above what would be done at rest.

[iii] See http://www.hscic.gov.uk/pubs/hse08physicalactivity

[iv] The MMETs rate used for walking are lower than those used in the CBM reflecting different evidence sources providing different estimates. In this case values were taken from https://sites.google.com/site/compendiumofphysicalactivities/

Road Traffic Injuries

Road traffic injuries calculations first estimate current risks for all transport modes in London based on observed travel times and injuries (using Stats19 2005-2011 data). The risks are both for being injured and for injuring other road users. Risks are assumed to vary by gender and age. Following that, the change in injuries is estimated by calculating the changes in travel time in different modes. Each additional travel time is assumed to add a less than linear increase in risk both of being injured and of injuring others. For cycling the non-linear approach is estimated to capture some of the changes in infrastructure and norms between high and low cycling environments.

No changes in speed in injury calculation were assumed. With significant changes in travel modes it is conceivable, for example, that the speed of cars would decrease if amount of car trips increased. Modelling such changes was, however, beyond the scope of THAT.

In all injury calculations it is assumed that non-passenger transport remains the same. A large proportion of cyclist fatalities are the result of being hit by Heavy Goods Vehicles (HGVs). However, we assumed that higher rates of cycling would result in lower risk of fatalities from HGV collisions for each cyclist (using non-linear approach, as described earlier).

Air Pollution (PM2.5)

The air pollution effect for small particular matter PM2.5 includes:

- the changes in background concentrations;
- the differential exposure to PM2.5; and
- ventilation rates whilst travelling by different modes.

The impacts of other policies or changes in the vehicle fleet emissions have not been modelled.

The background PM2.5 emission data was obtained from the London Atmospheric Emissions Inventory[v] . Background annual average PM2.5 concentration (from all sources) was estimated to be 13µg/m^3 , with 28% (approximately 3.6µg/m^3) assumed to be due to local road transport. It was assumed that change in motorised transport in different scenarios would linearly decrease the emission of that transport mode, which would then again linearly decrease the annual average concentration of PM2.5 in London.

The exposure to PM2.5 in the London Underground ('tube') was calculated with different approach. The median concentration of PM2.5 in the tube was assumed to be 200µg/m3 but the tube related PM was assumed to be less harmful than the outdoor PM2.5 due to differences in particle composition.

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[v] See http://www.cleanerairforlondon.org.uk/sites/default/files/LAEI/data-dashboard/GLA_PM25_EmissionsTotalsVehType.pdf

The ventilation rates (breathing rate) between different transport modes were taken into account when estimating the total exposure while being in transport. For the non-transport related time it was assumed that people are exposure to average background concentration of PM2.5.

Air Pollution (CO_2)

CO_2 emissions due to different transport modes were also estimated based on the London Atmospheric Emissions Inventory for CO_2[vi] . The changes in CO_2 emissions were calculated in a similar way to the changes in PM2.5 emissions: first calculating the change in different road transport modes; and then assuming linear decrease in CO_2 emissions following decrease of the distance travelled by different transport modes.

Health calculation

The health effects of physical activity, injuries and PM2.5 air pollution are measured with DALY approach. DALY stands for 'Disability-Adjusted Life Year' and DALY is a commonly used measure of the impact of disease on a population. DALYs are used to measure population health benefits by combining years of healthy life gained by 1) living longer and 2) living in good health (by avoiding disability). One DALY is equivalent to gaining one year of life in perfect health. With the DALY method we can combine different health outcomes, such as injury and premature death due to PM2.5, to a single measure.

Background DALY data was obtained from the Global Burden of Disease year 2000 data for the UK, and adjusted to study area population by using population numbers by age and gender as a proxy.

Modelling approach

THAT was implemented with the Monte Carlo simulation program: Analytica version 5.4[vii]. Uncertainties were propagated through the model with 1000 iterations. The user interface was implemented through the Analytica cloud player platform[viii] , which is developed and maintained by Lumina.

Example scenarios

To illustrate THAT we created three walking and cycling scenarios. In all scenarios 50% of car/taxi trips with specified distance are replaced with walking and/or cycling. Details of the scenarios are in Table 1.

[vi] See http://www.cleanerairforlondon.org.uk/sites/default/files/LAEI/data-dashboard/GLA_CO2_EmissionsTotalsVehType.pdf
[vii] See: www.lumina.com
[viii] See http://www.lumina.com/products/analytica-cloud-player/

Table 1: Definition of example scenarios.

Trips changes	Scenario 1	Scenario 2	Scenario 3
Gender.	Both	Both	Both
Age group.	15-69	15-69	15-69
Trips length (km) replaced.	0-2 km to walking	0-5 km to cycling	0-2 km to walking, 2-5 km to cycling
% of trips replaced	50%	50%	50% 0-2 km, 50% 2-5 km
Mode replaced	Car/taxi	Car/taxi	Car/taxi

The results of these scenarios are shown with set of figures below. Figure 2 shows how the mode share of different transport modes changes due to scenarios. In all scenarios share of car/taxi trips (shown in green) is reduced (when compared to baseline) and the share of walking/cycling trips is increased. The share of other transport modes is the same in all scenarios.

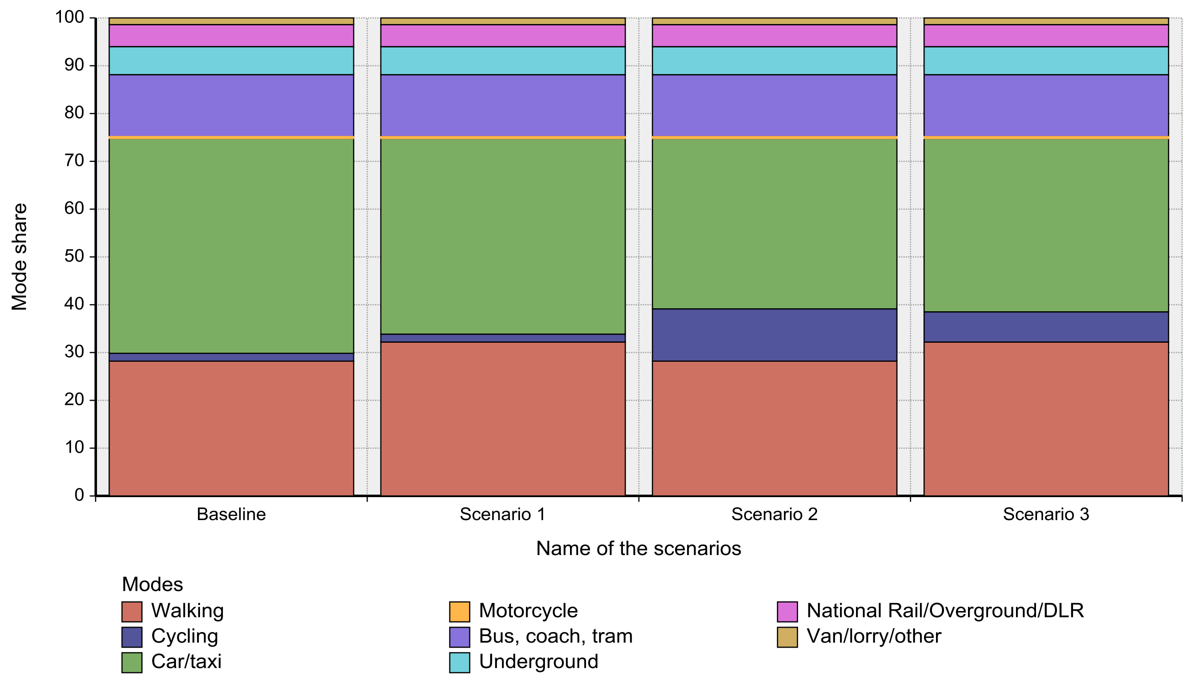

Figure 2: Change in mode share in different scenarios.

Figure 3 shows the overall change in health due to scenarios in comparison to London baseline situation. Scenario 1 was estimated to cause a health gain of 1500 DALYs for both males and females, while scenarios 2 and 3 were estimated to cause a health gain of over 5000 DALYs (negative DALYs are health gains). Figure 4 shows a more detailed snapshot of the results by showing DALY gains and losses through physical activity, injuries and PM2.5 air pollution. In all scenarios health effects are mainly caused by changes in physical activity. Changes in injuries and PM2.5 air pollution were estimated to have a minor health impact.

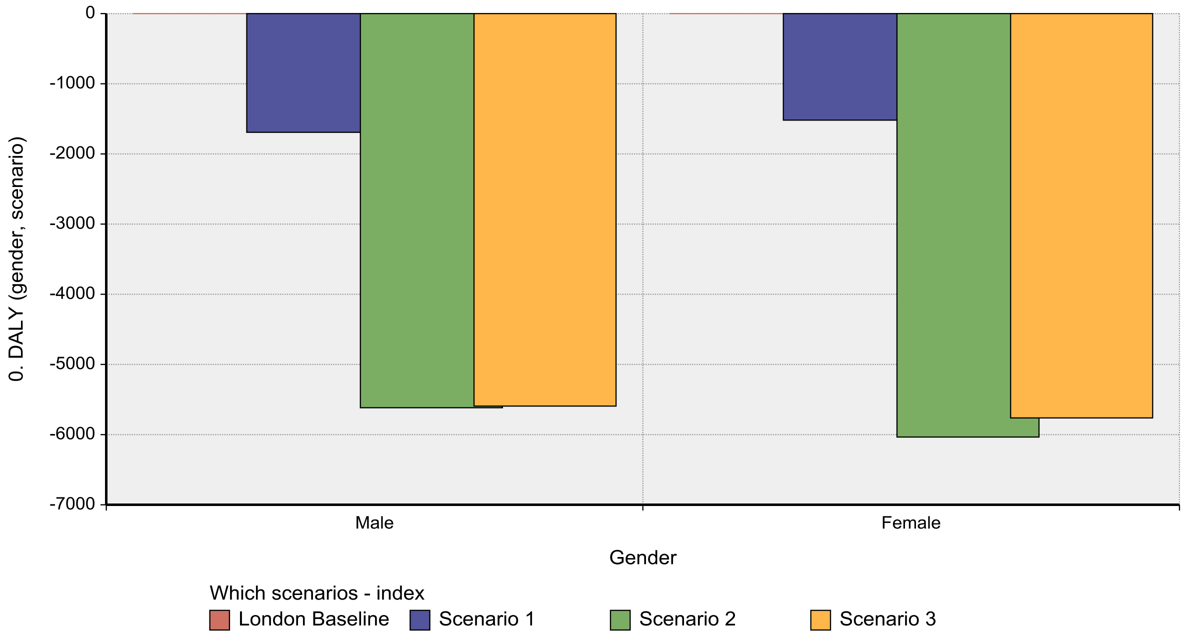

Figure 3: Change in DALYs in different scenarios. Negative values mean health benefits.

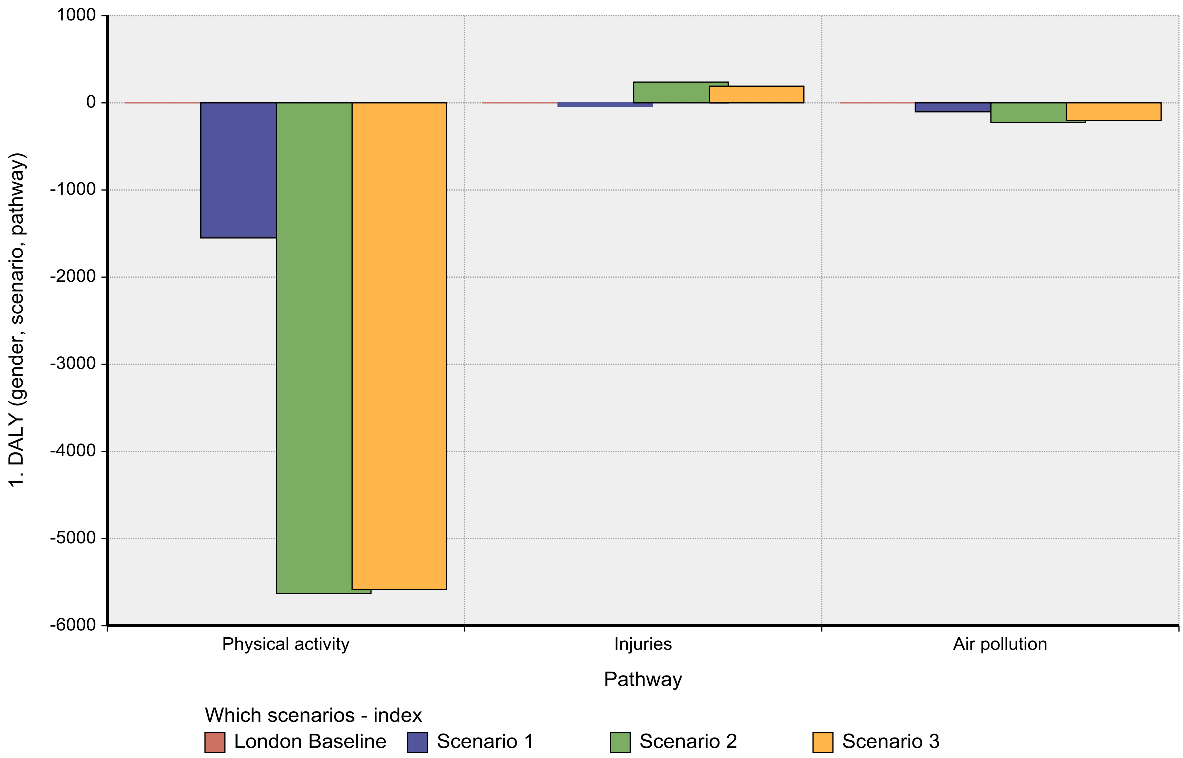

Figure 4: Change in DALYs due to physical activity, injuries and air pollution. Negative values mean health benefits. These results are for males.

Figure 5 shows the changes in CO_2 emissions in comparison to baseline. All three scenarios reduced transport related CO_2 emissions in the study area.

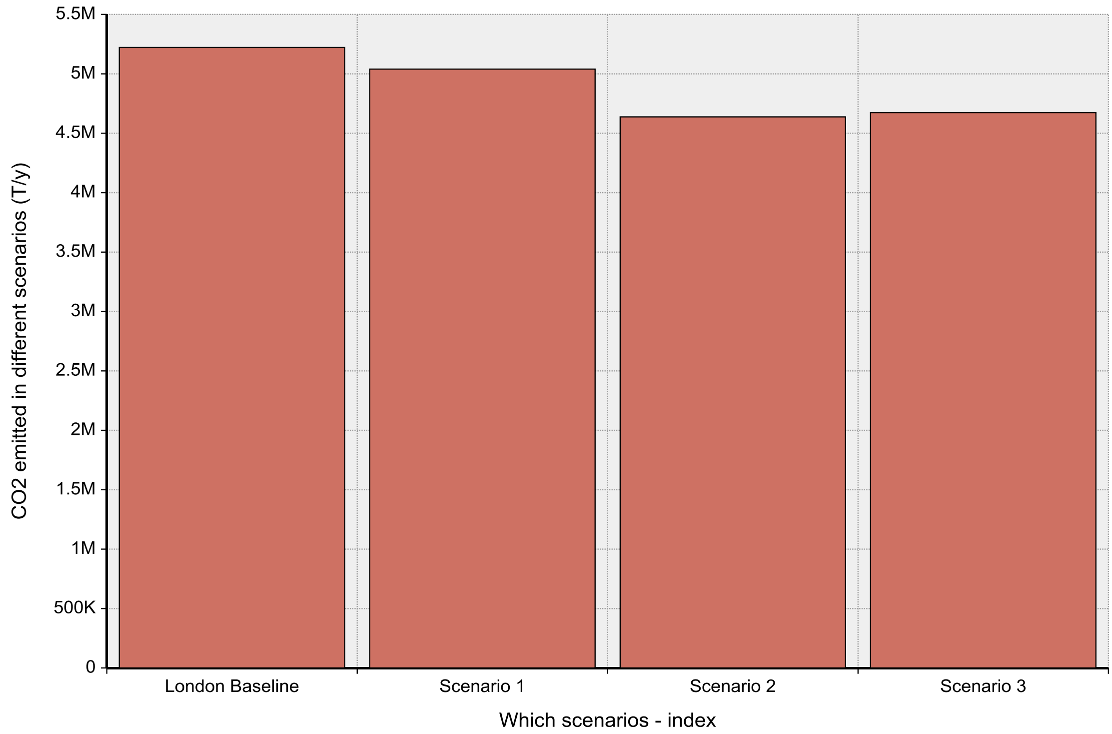

Figure 5: CO_2 emissions from greater London area due to transport in baseline and in different scenarios.

Lessons learned and next steps

THAT model was used by the Transport for London in 2014 to create and test different scenarios and their health effects in London (Greater London Authority, 2014). A graphical user interface allowed Transport for London to run and test various scenarios independently, with minimal support from THAT development team. This highlights the advantage of developing this kind of tool for policy users.

The main challenges in current implementation were related to the Analytica software and the creation of the user interface. The web interface available with Analytica requires purchasing through an annual licence, which costs around £1400. The functionality with the user interface is also limited and only allows a limited selection of styles. Detailed representation of geographical data is not possible, for example. To create our own interface independent of Analytica and then use the Analytica engine would require a licence costing approximately £8000.

In the user testing and discussions with stakeholders there was a clear call for more localised versions of the model. In particular, at the London Borough level, users wanted Borough specific results.

THAT model gives the user the flexibility to create their own scenarios. However, user testing revealed the complexity keeping track of what calculations had been undertaken when many different rules were combined together in one scenario. When generating scenarios based on age, gender, trip distance and mode, the created number of combinations is multiplicative. At the same time, interest was also expressed in adding additional variables e.g. ethnicity and socio-economic status. Without further guidance users struggled as to know which trips they should transfer. This indicated the need for simplifying assumptions about which trips are likely to be transferred to cycling. These assumptions should be based on evidence and should also be flexible, so the user can understand what would happen if things were different. The tool proved to be too complicated for a wide range of potential users and would therefore remain limited to a few expert users.

We recognised a need to develop systems that are more open in terms of code and also that allow more user interaction. For example, an illustration of the current share of trips before creating scenarios, or a graphical creation of scenarios would provide promising new direction for development of user interface.

In conclusion THAT model has shown the potential for putting a sophisticated transport health impact modelling tool into the hands of practitioners. However, it has also shown the limitations of the software used and indicated directions as to how to provide tool(s) that better meets users' needs. In the NPCT project we are acting on these lessons and developing tools, both the NPCT and the CBM, that are suited to wider adoption.

References

Greater London Authority. (2014). *Transport and health in London: The main impacts of London road transport on health*. Available from https://www.london.gov.uk/sites/default/files/Transport%20and%20health%20in%20London_March%202014.pdf

Maizlish, N., Woodcock, J., Co, S., Ostro, B., Fanai, A,. Fairley, D. (2013). Health cobenefits and transportation-related reductions in greenhouse gas emissions in the San Francisco Bay area. *American Journal of Public Health,* 103(4), pp.703-9.

Transport for London. (2011). *Travel in London, Supplementary Report: London Travel Demand Survey (LTDS)*. Available from https://www.tfl.gov.uk/cdn/static/cms/documents/london-travel-demand-survey.pdf

Woodcock, J., Edwards, P., Tonne, C., Armstrong, B,G., Ashiru, O., Banister, D., et al. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet* , 374, pp.1930–1943.

Woodcock, J., Givoni, M., Morgan, A,S. (2013). Health impact modelling of active travel visions for England and Wales using an Integrated Transport and Health Impact Modelling Tool (ITHIM). *PLoS One*, 8; doi:10.1371/journal.pone.0051462.

Woodcock, J., Tainio, M., Cheshire, J., O'Brien, O., Goodman, A. (2014). Health effects of the London bicycle sharing system: health impact modelling study. *BMJ,* 348, pp.425.

Appendix 10: Co-Benefits Model and the Data Visualisation Tool

Contents

Introduction

The Co-Benefits Model (CBM) is a tool aimed at analysing the potential impacts of a progressive switch of trips to cycling as non-cyclists develop the same distance based propensities to cycle as existing cyclists.

The effects of this switch are assessed across multiple domains including health (physical activity levels, mortality rates), transport related CO_2 emissions, transport (trips time and mode shift), and equity (uptake rate of cycling by women, elderly or ethnic minorities).

The CBM uses a microsimulation approach, similar to that planned for Version 2 of the National Propensity to Cycle Tool (NPCT) but using data for the whole population rather than modelled data for local areas. As with the NPCT the CBM uses distance decay probabilities that allow us to model how the probability of cycling varies with the length of the trip. Significantly the CBM is applied to all trip purposes and not just commuting trips. Thus the CBM indicates some of what will be achievable at a local level with the NPCT in Version 2.

The CBM Data Visualisation Travel tool is a prototype web based interface that allows users to both visualise the scenarios from the CBM and baseline data from the National Travel Survey (NTS) and the processed synthetic data we have created building on the NTS. The Data Visualisation Tool is not a project deliverable and thus falls outside the terms of the contract but we are keen to make it available for DfT to use. We will be developing the tool in Stage 2 of the project. We see the tool as both useful in itself for looking at travel survey and scenario data and to inform the development of the NPCT Version 2 results pages.

Most graphs in this report are directly exported from the tool. As with the NPCT Prototype the tool is created in R using Shiny.[i]

Data sources

The main data source used is:

- The **National Travel Survey 2012** (NTS): for trip data

We also use

- The **Health Survey of England 2012** (HSE): for non-travel energy expenditure data
- The **Dutch Travel Survey 2013**: for e-bikes use probabilities

NTS includes detailed data for the UK (excl. Northern Ireland), both for the trip itself and for the individual performing the trip.

Combining three of the nine datasets in NTS, we extract all the relevant information for year 2012, approximately 275,000 trips. This produces an accurate picture on UK personal travelling, and more specifically on:

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[i] The internet tool uses Shiny Server (see http://shiny.rstudio.com/), a web application designed to work with the statistical software R (http://www.r-project.org/).

- NUMBER of TRIP STAGES
- SPEEDS and MODES of TRANSPORT
- TRIP DURATION and EFFECTIVE TIMES in TRAVELLING

- At individual level: AGE, SEX, ETHNICITY, SOCIO-ECONOMIC STATUS, HOUSEHOLD, CAR ACCESS…

Dataflow model

The figure below shows the main stages followed in the CBM.

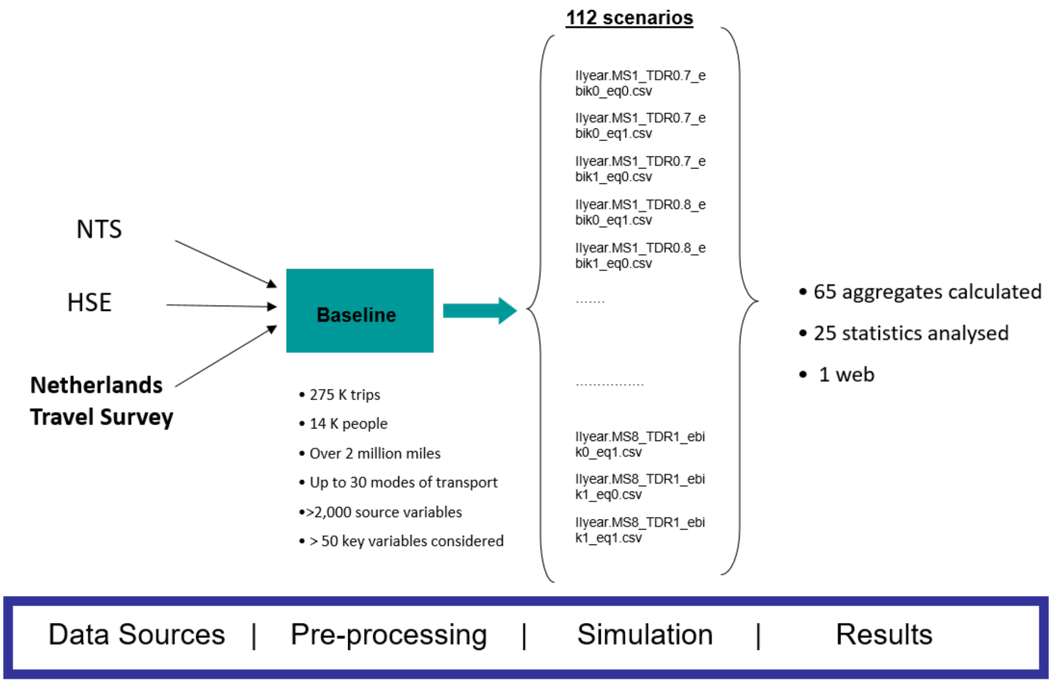

Figure 1: Schematic of main stages in the CBM

Building the Baseline scenario

Variables used

The baseline scenario is used as a seed, to generate the simulated cycling scenarios. It is limited to 2012 trips, performed by people 18 years or older.

People without trips

Individuals without any trips recorded are also taken into account, as they make a relatively important part of the population.

File used: [People_w_NoTrips2012_v3.csv]

Every individual without trips is characterised by [Age-Sex-Ethnicity-Socio economic status (SES)], as well as their total non-travel physical activity.

List of variables used

The variables used in the baseline scenario come from three different NTS datasets. These are listed in the table below.

Table 1: Variables from NTS used in the CBM

Variable	Description
Age	Age band
Age_B01ID	Age category
Sex	Sex band
Sex_B01ID	Sex category
agesex	Combination of age & sex bands (for processing only)
CarAccess_B01ID	Access to Car
NSSec_B03ID	Socio-economic status
EthGroupTS_B02ID	Ethnicity
IndIncome2002_B02ID	Individual income
HHIncome2002_B02ID	Household Income
HHIncQDS2012_B01ID	Household Income (quintiles, Diary sample)
HHIncQIS2012_B01ID	Household Income (quintiles, Interview sample)
SurveyYear	Year survey was run (2012)
TripID	Trip identifier
DayID	Day identifier
IndividualID	Individual identifier
HouseholdID	Household Identifier
PSUID	PSU Identifier
W5	Weighted travel sample
W5xHH	Weighted travel sample - excluding household weight
TravDay	Day of the week the trip was make
SeriesCall_B01ID	Trip includes series of calls or not
ShortWalkTrip_B01ID	Trip includes short walks
NumStages	No. of stages of the trip
MainMode_B03ID	Main travel mode B03 (28 categories)
MainMode_B04ID	Main travel mode B04 (13 categories)
MainMode_B11ID	Main travel mode B11 (22 categories)
TripTotalTime	Trip total time start to finish
TripTravTime	Trip effective travelling time (e.g. excluding waiting times)
TripDisIncSW	Trip distance incl. short walks (miles)
TripDisExSW	Trip distance excl. short walks (miles)
JJXSC	Number of trips - grossing up short walks and excluding series of calls
JOTXSC	Overall trip time - grossing up short walks and excluding series of calls

JTTXSC	Overall travel time - grossing up short walks and excluding series of calls
JD	Trip distance - grossing up short walks
BAND	Travel distance band (pre-calculated to speed up processing)
WalkDistance	Distance for walked trips
WalkTime	Time for walked trips
Cycled	Boolean: Trip is cycled in baseline (Yes=1, 0=No)
Pcyc	Probability of cycling the trip
Pcyc2	(Not in use)
cyclist	Probability for individual of becoming a potential cyclist
now_cycle	Boolean: Trip is effectively cycled (Yes=1, 0=No)
e-bike	Boolean: Trip is effectively cycled by e-bike (Yes=1, 0=No)
METh	METs used in the trip (only for active modes)
MMETh	MMETs used in the trip (only for active modes)
TripTotalTime1	New trip time (can be the same, or different depending on switch to cycling)
TripTravelTime1	New Trip travel time (temporarily not in use)
mMETs	Marginal METs (MMETh), related to non-travel activities (1 week estimates)

Additional variables calculated from NTS and the other data sets are shown in Table 2 below.

Table 2: Additional variables used in the CBM

Variable	Description
WalkDistance	Distance for walked trips
WalkTime	Time for walked trips
Cycled	Boolean: Trip is cycled in baseline (Yes=1, 0=No)
Pcyc	Probability of cycling the trip
cyclist	Probability for individual of becoming a ‘potential’ cyclist
now_cycle	Boolean: Trip is effectively cycled (Yes=1, 0=No)
e-bike	Boolean: Trip is effectively cycled by e-bike (Yes=1, 0=No)
METh	METs used in the trip (only for active modes)
MMETh	MMETs used in the trip (only for active modes)
TripTotalTime1	New trip time (can be the same, or different depending on switch to cycling)
mMETs	Marginal METs (MMETh), related to non-travel activities (1 week estimates)

Generation of simulated scenarios

The CBM model creates *multiple simulated scenarios* by combining four core parameters described in the table below.

Table 3: Four core parameters used to create CBM scenarios

Key	Concept	Values	Meaning
CM	Cycling multiplier	1, 2, 4, 8, 16, 32, 64	Multiplies the odds of cycling a no. of times
TDR	Total Distance Reduction	1, 0.9, 0.8, 0.7	Reduces the distance travelled by a factor to reflect move to denser living with more local travel
Equity	Equity	Yes / No (1,0)	Assumes Men/Women and older and younger people have the same propensity to take up cycling
E-bike	E-bike use	Yes / No (1,0)	Assumes the new cyclists are e-bike owners

These parameters produce a total of:

7 (CM, range of values) x 4 (TDR range) x 2 (Equity values) x 2 (E-bike values) = 112 scenarios

E.g., the set of values:

CM=16, TDR=0.8, Equity=0, E-bike=1

would describe a scenario with *16 times greater odds* of becoming a cyclist (than in baseline) + an average length of trips *reduced by 20%* (TDR=0.8) + *No gender equity* (men/women/young-elderly behave as in baseline) + *Use of e-bikes* is supposed.

Types of scenarios

The 112 scenarios can be grouped into 4 broad categories:

1. NON EQUITY + PEDAL BICYCLE: this is assuming that some of the inequities in cycling uptake are replicated from the current 'baseline scenario'. Both genders behave differently, as do people in different age bands, and they use only pedal bicycles.
2. EQUITY + PEDAL BICYCLE: probabilities of becoming a cyclist depend on age & sex, and all groups use only pedal bicycles. Equity by age & sex is <u>not</u> applied to cycling speeds or relative probability of cycling longer trips.
3. NON EQUITY + E-BIKES: probabilities of becoming a cyclist depend on age & sex. For those becoming a cyclist, some trips are by pedal bicycles, others use e-bikes. Probabilities of cycling short and longer trips do not vary by age or gender.

4. EQUITY + E-BIKES: probabilities of becoming a cyclist do not depend on age or sex. For those becoming a cyclist, some trips are by pedal bicycles, others use e-bikes[ii].

It would also be possible to test the impact of the continuation of other inequities, e.g. by ethnicity or car ownership; variables shown to be important in our propensity analysis (see Appendix 8).

Rules for switching a trip to cycling

To generate new cycling trips, we apply a 2-step process:

1. STEP 1 (INDIVIDUAL BECOMES a POTENTIAL CYCLIST): each individual is assigned a probability of becoming a cyclist.
2. STEP 2 (a TRIP IS SWITCHED to CYCLING): if the individual is now a cyclist, then each trip is assigned a probability of being cycled (e.g. 30 miles trip has much lower probabilities of being cycled than a 2 mile one).

This two-step method mimics *real life situations* more realistically than other strategies previously used, as cycling trips cluster around people who already cycle. In real life, people starting to cycle greatly increase chances of cycling all their trips.

However, the earlier tested method does have the advantage of allowing that even existing cyclists may not cycle all the trips they would like to, e.g. due to variable infrastructure. Future work could combine the two approaches by allowing both new cyclists to have the same probability of cycling a trip as existing cyclists and by allowing these probabilities to increase.

STEP 1: Probabilities of BECOMING A CYCLIST

Option 1.1: Non-equity scenarios

In the non-equity scenario the probability of becoming a cyclist varies according to age and sex, and matches the probability of **being a cyclist** at baseline. These probabilities were calculated from the NTS for England using data between 2008- 2012. It was possible to calculate the probability of being a cyclist in different ways. We explored different options based on both the trip diary and the reported frequency of regular cycling. Our analysis identified a notable mismatch between the trips recorded in the travel diary and the ‘usual travel behaviour’ reported in the questionnaire data. Specifically, many fewer people recorded a cycling trip in the one-week travel diary data then reported that they usually cycled ‘at least weekly’ in the questionnaire data. We assumed the diary data was more accurate and more appropriate for our purposes

[ii] E-bikes come in different types. Here we are referring to Pedelec or pedal assist bikes the most common type of e-bikes in the Netherlands. To use these bikes pedalling is required at all times but different levels of electric assistance are provided.

and defined a cyclist as someone with at least one cycling trip in the one-week travel diary.

We then assumed that for each scenario the probability of an individual becoming a cyclist was the cycling multiplier * the odds of being a cyclist at baseline for that demographic.

Table 4: Percentage of people with at least one cycling trip in the week diary used to estimate

Male 16-59	Female 16-59	Male 60+	Female 60+
9.4%	3.8%	4.5%	1.5%

Option 1.2: Equity scenarios

With equity=1, the probability of becoming a cyclist is the same across all groups, with no differences by age or sex. This probability is equal to the average overall probability of being a cyclist in the baseline data, which was 5%. Under these scenarios the probability of an individual becoming a cyclist was the cycling multiplier * the odds of being a cyclist at baseline for the whole population.

STEP 2: Probabilities of CYCLING A TRIP

For people becoming cyclists, all their trips are applied a probability function which determines how likely they are of being cycled. Therefore, in CBM, an individual may become a potential cyclist and *still not make any trips* (e.g. because of all his actual trips being over 50km).

The probability of cycling a trip depends on a number of factors:

1. Trip distance
2. Age
3. Sex
4. Whether you use a pedal bike or an e-bike.

Option 2.1: Probabilities of cycling a trip for pedal bicycles

The table below describes the probability (Pcyc) that a trip of a given distance might be cycled by a cyclist. These are derived from the observed probabilities of making a given trip by bicycle among cyclists in the baseline data, i.e. the 2008-2012 NTS[iii]. As outlined above, the definition of being a cyclist was having at least one cycling trip in the diary.

Table 5: Probabilities of cycling trips of different distances by age and gender

[iii] Values were smoothed for some cells to produce more realistic patterns of change.

Distance (miles)	Female 16-59	Female 60+	Male_16-59	Male 60+
<0.5	0.111	0.236	0.074	0.131
0.5 to <1.5	0.268	0.375	0.286	0.349
1.5 to <2.5	0.337	0.317	0.423	0.327
2.5 to <3.5	0.303	0.282	0.43	0.281
3.5 to <4.5	0.231	0.146	0.342	0.236
4.5 to <5.5	0.187	0.146	0.341	0.217
5.5 to <6.5	0.179	0.087	0.302	0.217
6.5 to <9.5	0.147	0.054	0.271	0.195
9.5 to <12.5	0.05	0.063	0.193	0.144
12.5 to <15.5	0.024	0.013	0.154	0.104
15.5 to <20.5	0.028	0.013	0.082	0.082
>20.5	0	0	0	0

Option 2.2: Probabilities of cycling a trip for e-bikes

The e-bike scenarios take into account two facts:

1. E-bikes assist the cyclist to overcome longer distances. The probabilities of cycling a trip reflect this fact.
2. E-bike owners only make some of their trips by e-bike, with other trips undertaken by pedal bikes.

E-bike probabilities of cycling a trip of distance lengths do not distinguish by gender/age bands. That is we assume that older e-bike users are as likely as younger ones to cycle long distances, and similarly by gender. While it is would be expected that e-bikes reduce the variation in how far people are willing to travel by bike this assumption can be investigated in further analysis. The Netherlands travel survey is only a daily not a weekly survey so it was not possible to calculate the probabilities in the same way as we did for England. Instead we calculated the probabilities for e-bike owners. Interestingly we found that e-bike owners did not use e-bikes for all their cycling trips but for the shortest trips also used traditional bikes. It should be noted that the probabilities of cycling short trips are in some cases also higher for Dutch e-bikes owners than for cyclists in England. Further work could investigate the extent to which this is an e-bike specific finding or generally reflects the convenience of cycling in the Netherlands.

Table 6: Probability of cycling trips of different distance for Dutch e-bike owners and probability that the cycle trip is by e-bike.

Distance (miles)	Prob. of cycling the trip by any type of bike	Prob. of the bike used being an e-bike
<0.5	0.342	0.55
0.5 to <1.5	0.463	0.68
1.5 to <2.5	0.427	0.751
2.5 to <3.5	0.358	0.815
3.5 to <4.5	0.294	0.889
4.5 to <5.5	0.294	0.889
5.5 to <6.5	0.252	0.905
6.5 to <9.5	0.219	0.929
9.5 to <12.5	0.199	0.947
12.5 to <15.5	0.159	0.919
15.5 to <20.5	0.159	0.919
30.5 to 40.5	0.127	1
>40.5	0.058	1

Other rules applied to trips

Finally, for each trip we define the following set of rules:

- <u>Trips ALREADY cycled</u> are not randomised, keeping them as cycled.
- <u>Trips NOT yet cycled</u>: we calculate its probability and the model randomly chooses whether they switch to cycling, or not.

Finally, if the trip is now cycled, all its variables (cycling speed for that specific individual, travel times, total energy spent in the trip) are recalculated.

Short walks processing

The NTS survey records short walks (<1 mile) only on one day of the week (the first day of the volunteer's survey, which can fall on any day of the week). This means total walked distance would be under represented unless you apply weighting coefficients to it.

To handle short walks, all trips in the short walks category are replicated *six additional times* so that the totals reflect the real walked distances, times and other measures, as x7. It is recognised that this approach means that person level variation in short walks will reflect daily rather than weekly patterns.

Times and speeds

Trips switched to cycling are recalculated for time and speed. The following table has been derived from NTS data. The trip time lets us recalculate the level of physical activity, depending on the switch being to pedal bike or to e-bike.

Table 7: Speeds for pedal bikes

Age band	Speed (males, mph)	Speed (females, mph)
18-29	11.28	10.46
30-49	10.81	10.07
50-59	10.53	9.82
60-69	9.59	9.01
70 plus	8.82	7.9

Speeds for e-bikes:

For e-bike trips, all age bands and genders have a fixed speed of 11.28 mph (CROW-Fietsberaad, 2013).

Physical Activity

We conceptualise physical activity as coming from two domains, travel (from NTS) and non-travel (from HSE). Travel is represented in detail as this is the domain we are interested in changing. Non-travel is represented more simply and is assumed not to change.

Different types of physical activity, e.g. walking and cycling, have different intensities. We have standardised activities of different intensity as Marginal Metabolic Equivalent (MMET). METs reflect intensity of different activities and are a useful summary measure of the physical activity[iv]. METs are converted to marginal METs by subtracting 1 MET (intensity of being at rest). This approach therefore only considers the marginal activity over and above what would be done at rest.

Combined with the duration of the activity this gives MMET hours (MMETh).

Travel physical activity comes from walking and cycling and, in some scenarios, from e-bikes. Public transport trips often include a walking element and this is recorded in the NTS in the trip stages. To account for this, we allocated the appropriate walking time to each public transport trip in the dataset. When modelling an increase in cycling we also need to account for changes in walking, because some new cycling trips would have previously been walked all the way or as part of a public transport trip. In these cases we subtracted the walking physical activity from the new activity estimates.

The following MMET values were used for each of the three active modes.

[iv] The MMETs rate used for walking are lower than those used in the CBM reflecting different evidence sources providing different estimates. In this case values were taken from https://sites.google.com/site/compendiumofphysicalactivities/

Table 8: Marginal MET rates for active travel modes

Active Travel Mode	MMET rate
Walking	3.6[v]
Cycling	5.4[vi]
E-bikes	3.5

For each individual we summed their MMEThs over all of their trips for baseline and for each scenario. This gives each individual their total weekly travel related physical activity.

Using HSE data, we also calculated the physical activity by individuals from non-travel activities. We excluded work related physical activity to match with the estimates from which the relative risks were derived.

To do this matching the key defining variables used were [Age] – [Sex] & [Socio-economic status].

Each individual is then matched against a single individual from HSE; and their non-travel MMETs is used as the closest estimate. The total physical activity by each individual will then be:

Total MMET = $MMET_1$ (from all trips, from NTS) + $MMET_2$ (from non-travel activities, from HSE)

Combining NTS and HSE we get their total physical activity, so we can measure the impact, in terms of health, of modifying active travel behaviours.

Health impact modelling

The health impact of cycling is calculated using a Comparative Risk Assessment (CRA) approach in the manner developed by the Centre for Diet and Activity Research (CEDAR), as part of the Integrated Transport and Health Impact Modelling Tool (ITHIM) research. The health impact was calculated for age group and gender specific premature mortality, including both premature deaths averted and years of life lost (YLLs)[vii].

Relative Risks for MMETs

[v] Based on personal communication from Dr Jenna Panter based on validation study.
[vi] Based on personal communication from Dr Jenna Panter based on validation study.
[vii] YLLs refer to the burden of premature mortality compared with a full life expectancy for that age. The burden is per 'accounting year', that is it refers to the postponing of deaths that would occur in one year but the extra years then lived will stretch out into the future until the full life expectancy is reached.

Estimates of the impact of different amounts of physical activity on all-cause mortality were taken from a large cohort study. From this study we derived a dose response curve for non-work physical activity measured as MMETh per week, see Figure 2 below. The dose response curve is such that moving from no activity to a small amount produces the largest benefit.

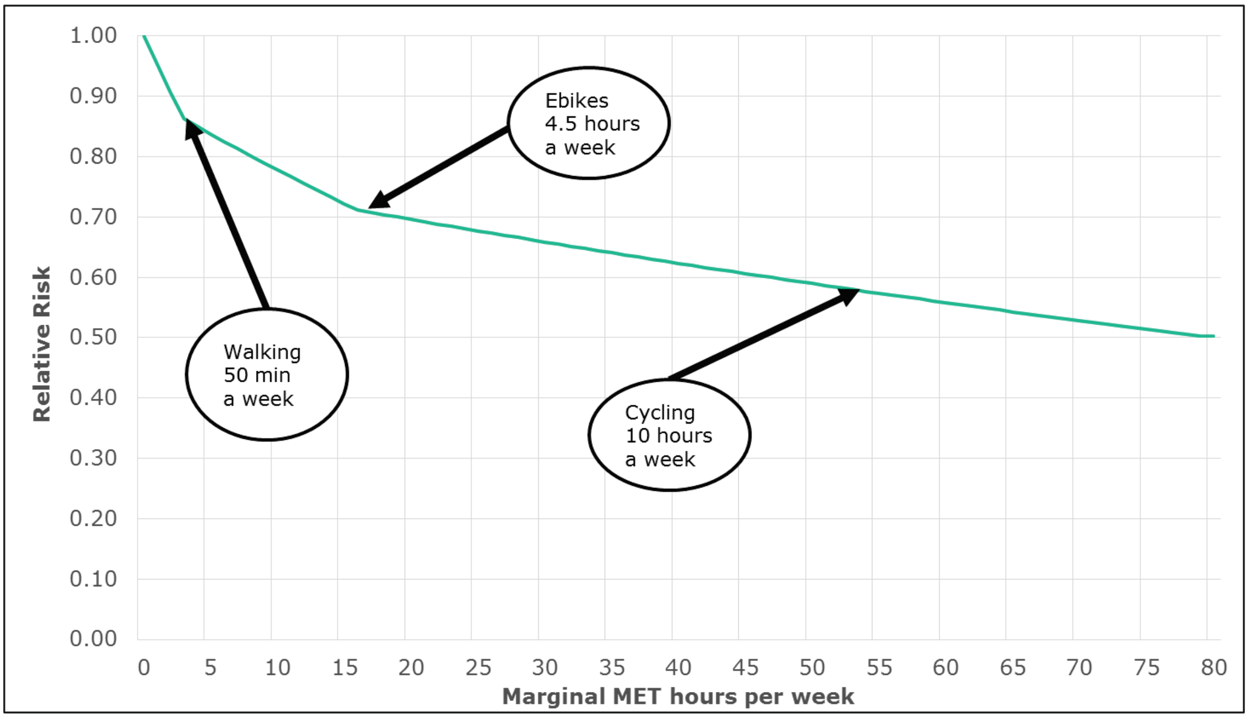

Figure 2: Dose response curve giving the relative risks for all-cause mortality for different physical activity levels (MMETh per week)

Population Impact Fraction

Population Impact Fraction (PIF) is the proportional reduction in population mortality (or disease burden), following a change in exposure to a risk factor. PIF can be represented in the following way.

PIF = $\frac{attribuble\ cases}{total\ cases}$

In other words,

PIF = $\frac{factual\ cases - counterfactual\ cases}{factual\ cases}$

PIF = $\frac{\sum RRb - \sum RRsc}{\sum RRb}$

In our case the exposure is MMETh per week for each individual. Using the dose response curve illustrated in Figure 2 previously we can estimate the relative risk (RR) for a change in exposure for each individual. The results PIF can then be applied to age group and gender specific disease burden data.

Burden of Premature Mortality

Years of life lost and premature deaths are taken from the Global Burden of Disease data for the UK[viii]. These data are presented by gender and for five year age categories. The method used could be extended for morbidity data (years of healthy life lost due to illness or disability) and to disease specific mortality.

To summarise six steps are needed to complete the health calculations:

1. Calculate the individual level of physical activity (MMETh per week).
2. Calculate Relative Risks, for the each individual based on total MMETh (Wen et al 2011).
3. Apply CRA formula – treating each individual as a strata of 1/n

PIF = $\frac{\sum RRb - \sum RRsc}{\sum RRb}$

   Where *RRB* is the baseline relative risk and RRsc is the scenario specific relative risk.

4. PIFs are calculated separately for each age/gender strata
5. PIF * Disease burden) for each age/sex strata
   a. Global Burden of Diseases (GBD) data UK all-cause mortality
6. Sum results over age/sex strata

List of calculated aggregates

The aggregates refer to summary statistics describing values of interest for every one of the scenarios.

The following table describes the list of aggregates derived for each scenario.

Table 9: Aggregate variables derived for each scenario

Variable	Concept
MS	Multiplier of probability of becoming a cyclist
TDR	Total distance reduction
e-bike	e-bike scenario (1) or not (0)
equity	equity scenario (1) or not (0)
carMiles	car Miles total
carMilesR	car Miles reduction
carMiles.pers	car Miles per person
carMilesR.pers	car Miles reduction per person
carMilesCycled	car Miles cycled
milesCycled.pers	Miles cycled per person
milesCycled.male	Miles cycled (by male)
milesCycled.female	Miles cycled (by female)

[viii] Available from http://www.healthdata.org/gbd

milesCycled.white	(by white person)
milesCycled.nonwhite	(by non-white)
milesCycled.caraccess	(by pp. w car access)
milesCycled.noncaraccess	(by pp. w/o car access)
METh	total travel MET
METhincr	MET increase
MMETh	travel MMETh
MMETh.pers	MMETh p.pers
MMEThincr	MMETh increase
CO2.Tm	CO2 emissions (in metric tonnes)
CO2R.perc	CO2 reduction %
CO2.pers	CO2 total p.pers
TripDisIncSW	Total miles (incl. short walks)
TripTotalTime1	Total minutes in all trips
timeSaved.Total.h	Time saved, compared to baseline, in hours
timeSavedCyclists.perc	Ratio of time, for cycled trips, compared to baseline
nocarTrips.people.perc	people w/o car trips, %
nocar.males.perc	males w/o car trips, %
nocar.females.perc	females w/o car trips, %
nocar.white.perc	whites w/o car trips, %
nocar.nonwhite.perc	non-whites w/o car trips, %
nocar.caraccess	people w. car access w/o car trips, %
nocar.noncaraccess	people w/o car access w/o car trips, %
nopeople	no. of individuals in trips file
nocyclists	no. people who now cycles + no. of cyclists in baseline
newcyclists	no. people who now cycle
cyclist.potential	no. people who have become cyclists
cyclists.perc	% cyclists in total popul
cyclists.incr	% cyclists incr. compared to baseline
cyclist.male.perc	% cyclists in males
cyclist.female.perc	% cyclists in females
cyclist.white.perc	% cyclists in white population
cyclist.nonwhite.perc	% cyclists in non-white population
cyclist.caraccess.perc	% cyclists in people w. car access
cyclist.noncaraccess.perc	% cyclists in people without car access
cyclist.nssec1.perc	% cyclists for group with nssec =1
cyclist.nssec2.perc	" =2
cyclist.nssec3.perc	" =3
cyclist.nssec4.perc	" =4
cyclist.nssec5.perc	" =5

trips.nssec1.perc	% trips cycled for people nssec=1
trips.nssec2.perc	" =2
trips.nssec3.perc	" =3
trips.nssec4.perc	" =4
trips.nssec5.perc	" =5
trips.age20.39.perc	% trips cycled, for ages 20-39
trips.age40.59.perc	" 40-59
trips.age60plus.perc	" 60 years old +
nopeopleWithTrips	no. people with trips
People.with.NoTrips	no. people without trips

Car modes & car miles trips

To reduce the number of modes presented we aggregated the modes into fewer categories. We considered car-based trip any trip done in one of the following modes:

- By car or van, as a driver
- By car or van, as a passenger
- By motorcycle
- By taxi or minicab

This corresponds to variable MainMode_B04ID=3,4,5, 12. This approach accurately matches private motorised transport modes.

To define those with and without car access we used the NTS variable CarAccess_B01ID and we coded 5 (driver but no car) and 6 (non-driver and no car) as having no car access. We included non-drivers in households with cars as having car access.

CO_2 emissions

The model calculates emissions of CO_2 in relative to baseline. The calculation has been does in a simple illustrative manner and results will be refined in Stage 2.

We did not include buses as a reduction in bus passengers may not directly lead to a reduction in miles travelled by the bus fleet.

No adjustment has been made for trip speed or possible congestion of the road network. Given the richness of the vehicle data in NTS future work can apply vehicle and speed specific emission factors. As cycling would tend to replace shorter car trips in more congested urban settings our current approach is likely to underestimate the total emission savings.

Definitions of Cyclists

Three different types of cyclists are used in the model:

1. **Potential cyclist:** an individual who, under the assumptions of the model, becomes a cyclist.
2. **Actual cyclist:** an individual who has trips made by cycle in the travel diary.
3. **New cyclist:** an individual who switches at least one of trips to cycling.

For all the cyclists' ratios and percentages, a cyclist is simply an individual of types 2 or 3. That is, for a given scenario, an individual is counted as cyclist if she has performed cycled trips in the baseline, or if she does one or more trips by cycling in the scenario.

List of calculated distributions

As well as aggregates, from the CBM model a list of distributions is derived to shed some light on the potential of the switch to cycling.

The distributions can be classified in four areas, with some of them broke down by age, ethnicity and other parameters:

- **Original mode:** % per mode, indicating where the cycling trips are coming from.
- **Trips share:** % share of total trips, per mode, in a given scenario.
- **Time savings/cost:** histogram of % of trips/total, and how much faster/slower are the cycled trips, compared to the original modes before switching to cycling.

Recategorisation of MainMode_B04ID -> Final mode

For clarity, NTS variable MainMode_B04ID are grouped to a smaller number of modes. Final mode groups some of the categories, while the irrelevant categories (-10, -8) disappear.

Table 10: Recatgorisation of main mode

MainMode_B04ID	Description	Mode final
Value = 1.0	Label = Walk	1
Value = 2.0	Label = Bicycle	2
Value = 3.0	Label = Car/van driver	3
Value = 4.0	Label = Car/van passenger	4
Value = 5.0	Label = Motorcycle	3
Value = 6.0	Label = Other private transport	7
Value = 7.0	Label = Bus in London	5

Value = 8.0	Label = Other local bus	5
Value = 9.0	Label = Non-local bus	5
Value = 10.0	Label = London Underground	6
Value = 11.0	Label = Surface Rail	6
Value = 12.0	Label = Taxi/minicab	4
Value = 13.0	Label = Other public transport	7
Value = -10.0	Label = DEAD	-
Value = -8.0	Label = NA	-

The table below lists the available breakdowns.

Table 11: Detailed results and breakdown by population subgroup

File	Description	Notes
BD_mode.csv	Which mode (%) the cycling trips are coming from- all groups	Only for cycling trips subset
BD_mode.caraccess.csv	" - only people WITH car access	"
BD_mode.noncaraccess.csv	" - only people WITHOUT car access	"
BD_mode-white.csv	" - only white ethnicity	"
BD_mode-nonwhite.csv	" - only non-white ethnicity	"
BD_mode-male.csv	" - males group	"
BD_mode-female.csv	" - females group	"
BD_mode-fastertrips.csv	Which mode the cycling trips are coming from (for trips faster by bicycle)	"
BD_mode-slowertrips.csv	Which mode the cycling trips are coming from- for trips slower by bicycle)	"
BD_share.csv	% - mode share of all trips	All trips considered
BD_share1split.csv	%share of trips, all population, break down e-bikes/pedal bikes	"
BD_share-caraccess.csv	%share of trips for group WITH car access	"
BD_share-noncaraccess.csv	%share of trips for group WITH car access	"

BD_share-caraccess1split.csv	%share of trips for group WITH car access, break down e-bikes/pedal bikes	"
BD_share-noncaraccess1split.csv	%share of trips for group WITH car access, break down e-bikes/pedal bikes	"
BD_timehist.csv	Distribution of times saved in cycled trips	Time bands meaning: 0-8: 0: <50% time 1:50-70, 2: 70-90 3: 90-100 4:100-110 5: 110-130 6: 130-150 7: 150-200 8: >200% time
BD_timehist-female.csv	Time histogram of savings for females	"
BD_timehist-male.csv	Time histogram of saving for males	"

Results

The CBM model derives valuable information from its simulated scenarios. With the large number of results and scenarios we have chosen to focus on a selection of results in this report. In particular we found that Total Distance Reduction (TDR) had relatively limited effect on the take up of cycling and thus we have decided to focus our reporting on the scenarios without a reduction in trip distances (TDR=1).

Most of the results can be browsed on the web[ix]

We plan to add the rest of the results to the web tool early in Stage 2.

Summary

In the most optimistic traditional bike scenario (cycling multiplier 64 with equity) we found a much higher percentage of the population achieving recommended levels of physical activity (up from 45% to 66%), with the disease burden for the UK population reduced by up to 390 thousand YLLs in a single accounting year. This scenario would also see the cycling mode share reach 20% and cycling replace up to 8% of car miles. In this scenario the mode share for cars would fall from 68% to 52%. Of the new cycle trips approximately 60% would come from cars and 30% from walking. The mode switch ratios were relatively stable across different scenarios.

[ix] See http://geo8.webarch.net/cbm/

Mean travel times increased by around 10-15% but in around 40% of cases travel times fell (with e-bikes travel times increased by around 5%, and nearly half of trips were faster). It should be noted that these travel time changes are for those making the switch; reduced congestion could also increase speeds for other road users.

If we assumed that the increase in cycling was mostly from e-bikes then we would see a greater replacement of car miles (11% vs 8%) and a higher cycling mode share (19% e-bikes, 7% traditional bikes). The health impacts were smaller but still substantial, 320 thousand YLLs.

Impacts varied across population subgroups, in part depending on the trip patterns of each group. For example, total miles cycled was higher for white compared with non-white populations, reflecting the higher trip rate among the white population. The same was true for non-car owners. These differences arise, at least in part, from our starting from current trips patterns rather than desired trips.

Baseline Data Visualisation

The functionality of the webtool can be illustrated by starting with the baseline data from the NTS.

Consider first the main mode of travel. In Figure 3 we see the main mode for each journey for both the whole population and for a specific subgroup (white men aged 60-64 in routine occupations). Using the web tool the actual values can be seen in the interface by hovering over any of the bars.

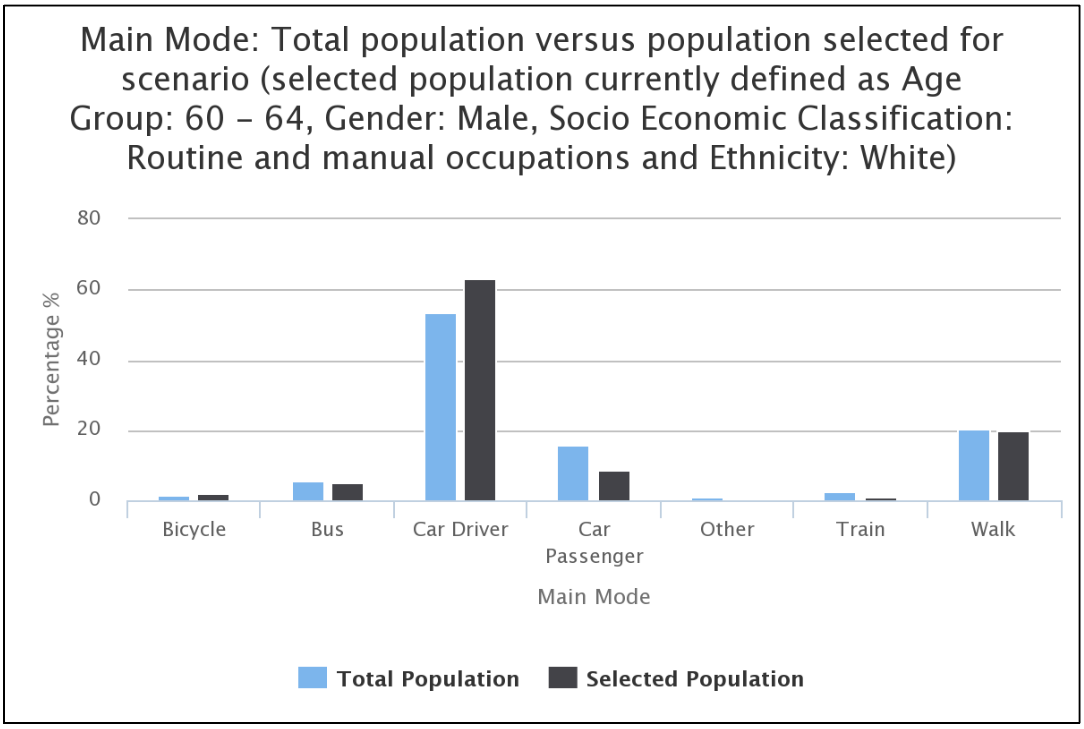

Figure 3: Mode share for whole population and selected subgroup

In addition to visualising the raw data the tool allows users to visualise the data combining physical activity from the synthetic population including both NTS and HSE data. In Figure 4 we see the distribution of MMET hours per week of activity amongst both the whole population and amongst a selected subgroup. The chart also informs us what percentage of the subpopulation are meeting the recommended physical activity guidelines.

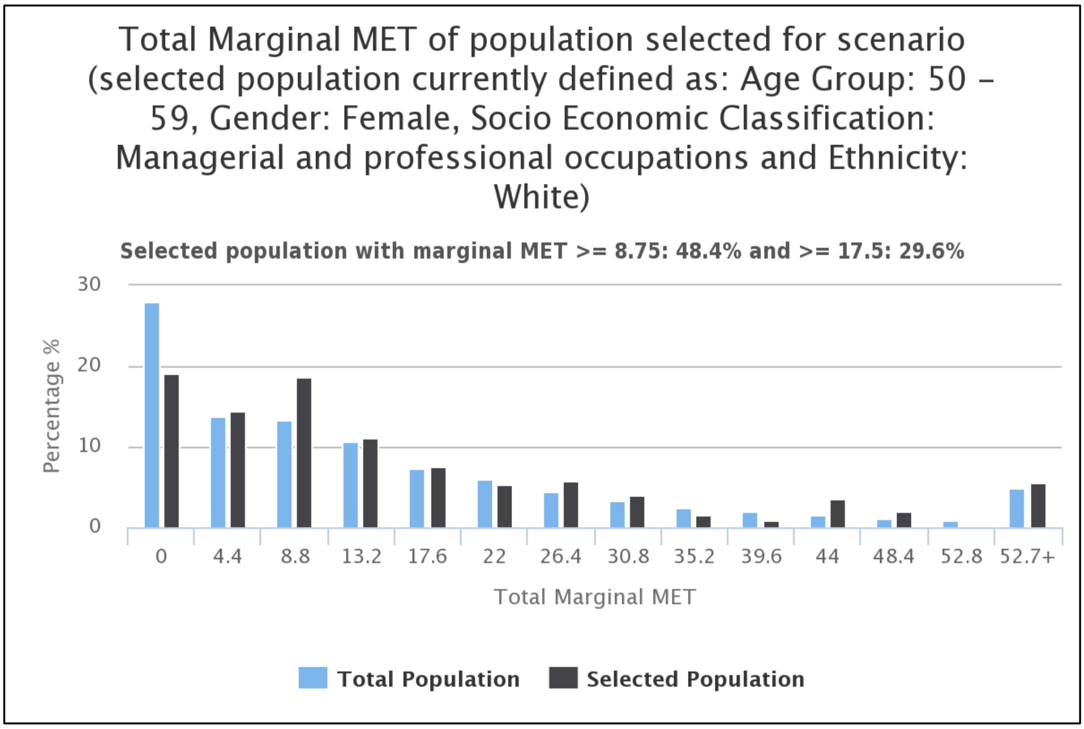

Figure 4: MMETh per week for whole population and selected subgroup

Currently the data can be stratified according to age group, gender, socio-economic group, and ethnic group (white vs non-white). In the future it would be possible to present the data stratified according to any of the far larger number of variables available in the NTS. The present analyses use the least restricted version of the NTS covering 2012. More variables (and finer resolution within a variable such as ethnicity) would be possible using other versions of the dataset, although greater data security would be needed. To overcome the problem of smaller numbers for multiply stratified data multiple years of data could be combined. We also intend to add a feature to allow the users to see the sample size in each case.

Behaviour change and the number of cyclists

In Figure 5 we can see that the values for the number of people with at least one cycle trip increases from 5% at baseline to over 70% in the highest scenario (cycling multiplier 64, equity and e-bikes on)[x]. Both equity and e-bikes tended to increase the number of cyclists but by relatively small amounts.

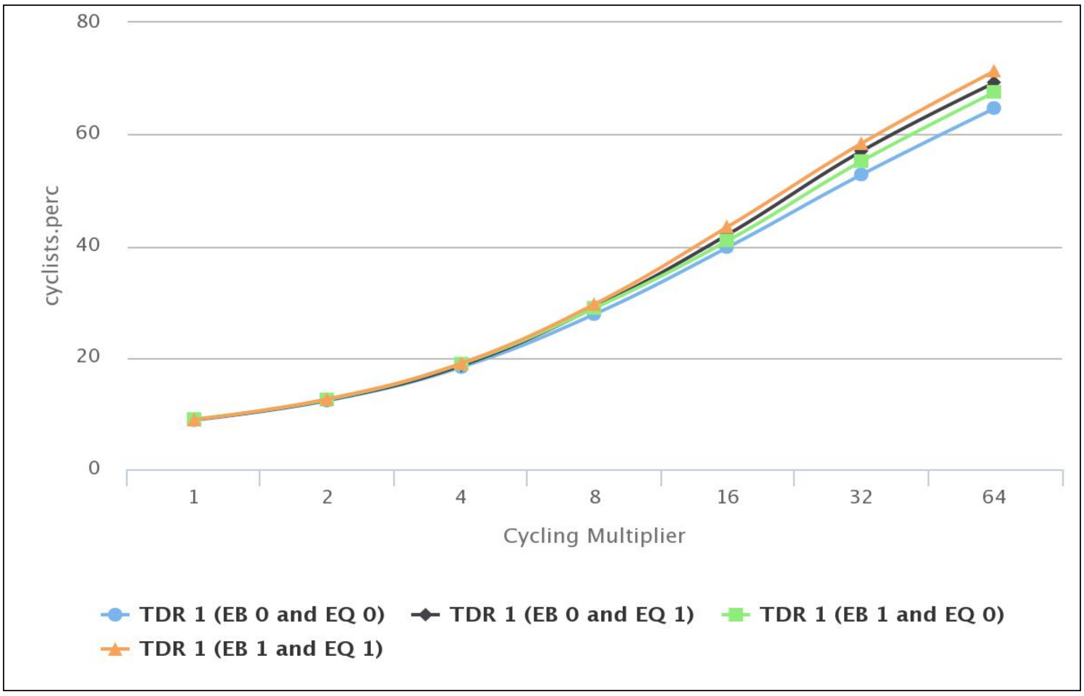

Figure 5: Percentage of population with at least one cycling trip over one week. TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

We found that TDR has a very small effect on the percentage of people with at least one cycle trip (numbers not shown).

When the results are looked at separately by gender the differences are starker, see Figure 6. The percentage of women cycling increases from under 3% to 71.5% in the highest scenario.

[x] It should be noted that in the following figures taken from the interface we are only visualising the Scenarios and the not the baseline numbers. The baseline numbers will be added to the display in Stage 2.

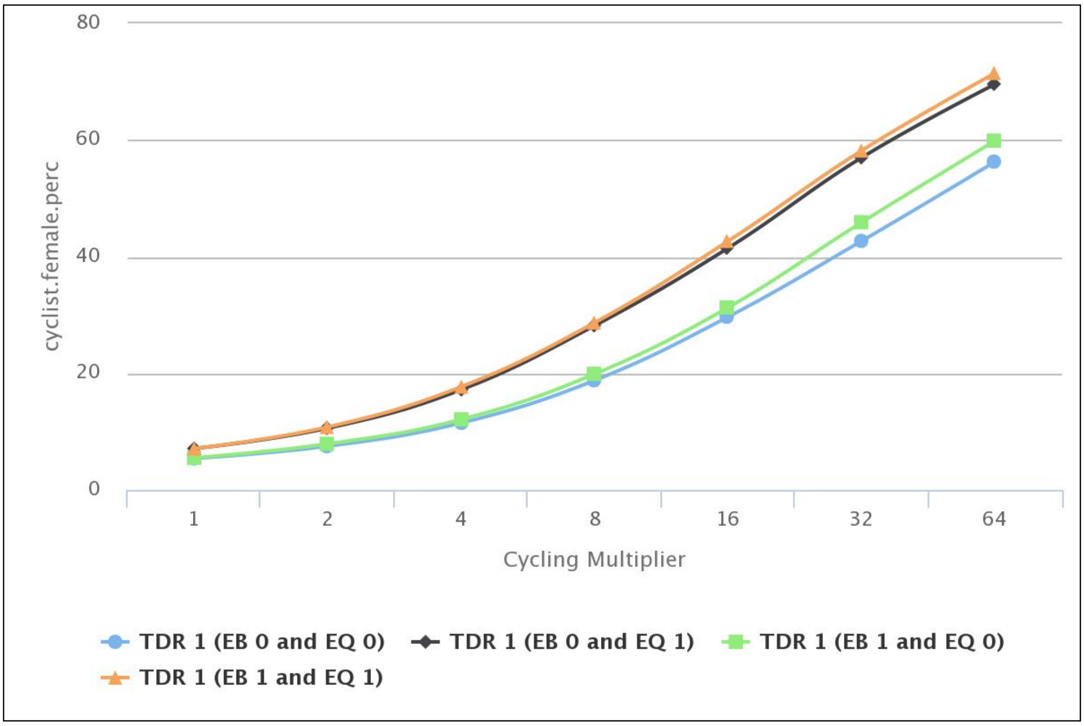

Figure 6: Percentage of women with at least one cycling trip over one week. TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

Data from the NTS shows that non-white people are less likely to cycle than white people. Currently the model does not incorporate differential propensity by ethnicity although this could be included in future versions. Comparing results by ethnicity, white versus non-white, did not result in large changes in the percentage of people with cycling trips under high cycling scenarios (results not shown)

At baseline more cycling rates are higher in people without cars. However, people without cars make fewer trips than those with cars thereby reducing the chance they switch any trip at all to cycling in the model**.** This resulted in a slightly lower percentage of cyclists in the high cycling scenarios, see Figure 7.

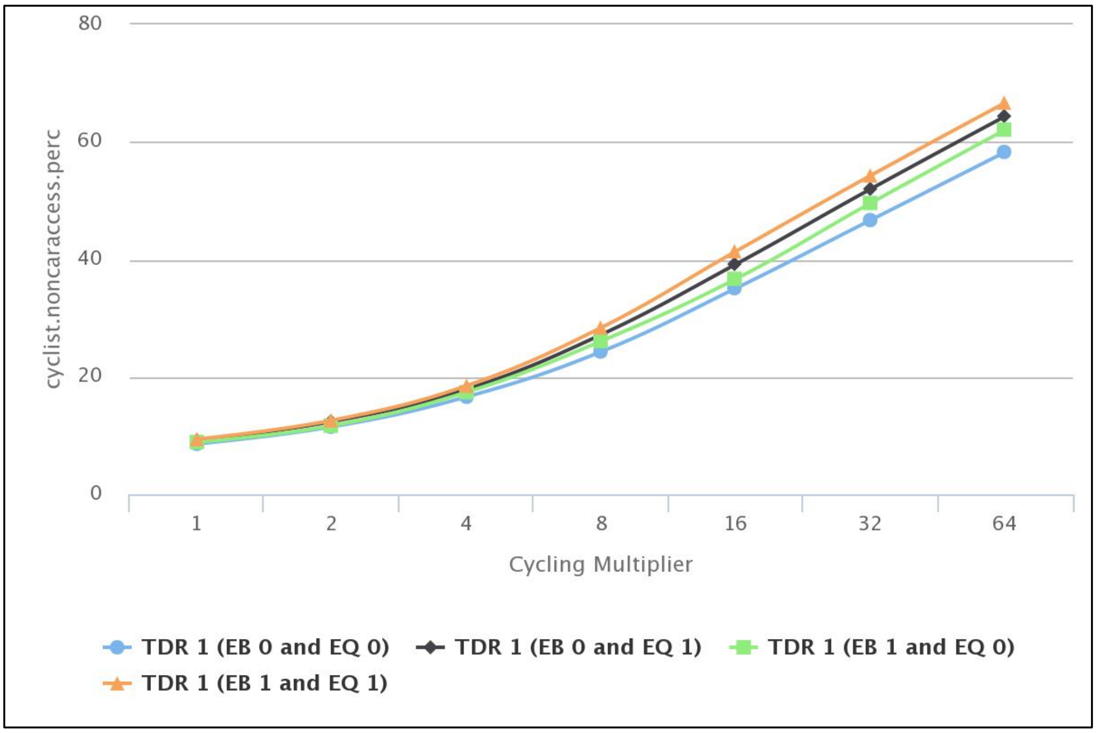

Figure 7: Percentage of people without car access with at least one cycling trip over one week TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

Miles Cycled

For miles cycled there was a large divergence between the scenarios, with e-bikes unsurprisingly producing much higher distance cycled, see Figure 8. Equity also increased distance cycled, particularly in non e-bike scenarios. In the highest scenarios the distance cycled increased to over 15 miles per person per week.

Generally men cycled further than women and white than non-white people under all scenarios but differences were not large. The largest difference was for those without car access and this may in part reflect suppressed demand for trips amongst this group.

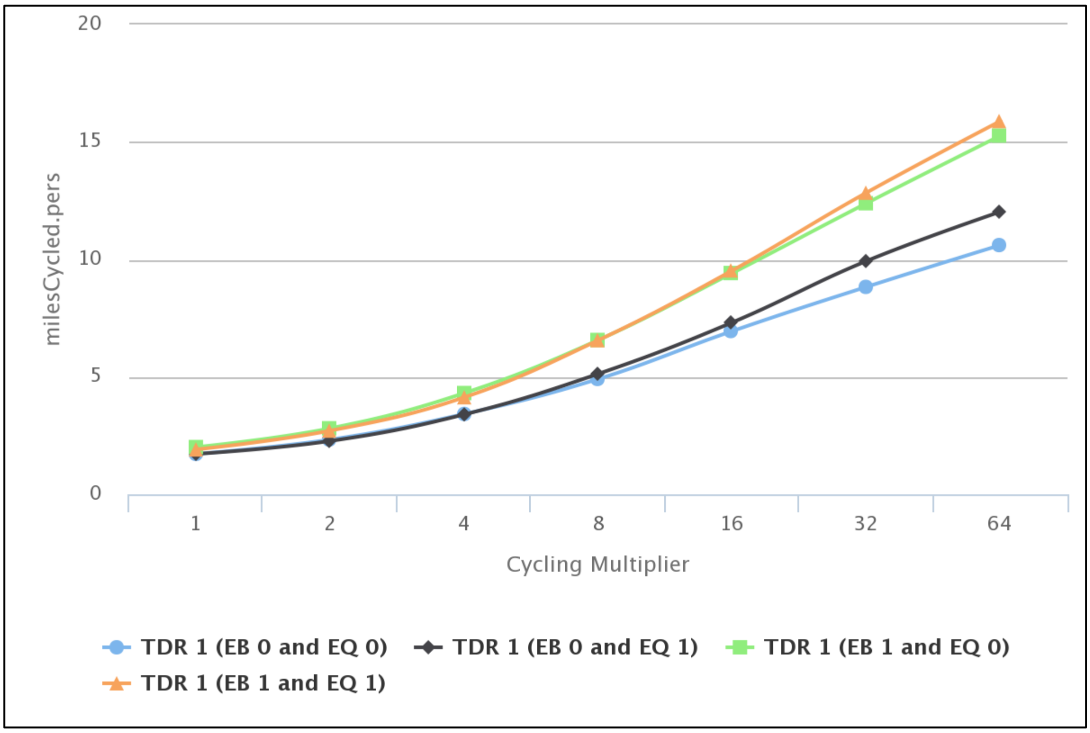

Figure 8: Miles cycled per person per week TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

Physical activity

Physical activity was calculated in different ways, both as mean values and as the percentage of the population achieving recommended levels of activity. Mean MMEThs per week for the population increased from 14 to over 19, see Figure 9. For scenarios including TDR MMETh were lower.

With the increase in cyclists we found a big increase in the number of people meeting physical activity guidelines. The World Health Organisation (2010) recommend at least 2.5 hours per week of moderate activity, we interpreted this as at equivalent to at least 8.75 MMET hours per week. In the highest scenario over 65% of people would achieve the physical activity recommend levels compared with 45% at baseline; see Figure 10. It should be emphasised at this point that this includes both travel physical activity and activity from other domains and that we are not assuming any change in non-travel related physical activity.

The World Health Organization recommends that people should aim to not just achieve the minimum activity levels but ideally to double, equating to 17.5 MMET hour per week. Here the percentages increase from 27% to over 41% with equity on and no use of e-bikes; see Figure 11.

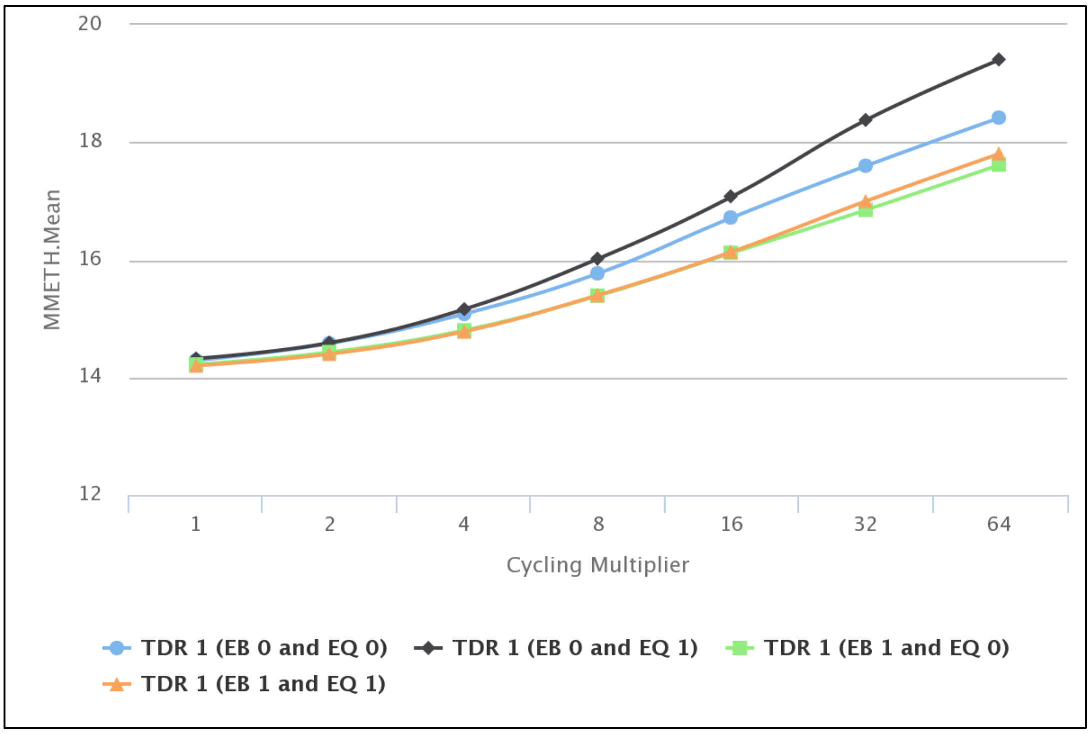

Figure 9: Mean MMETh per week. TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

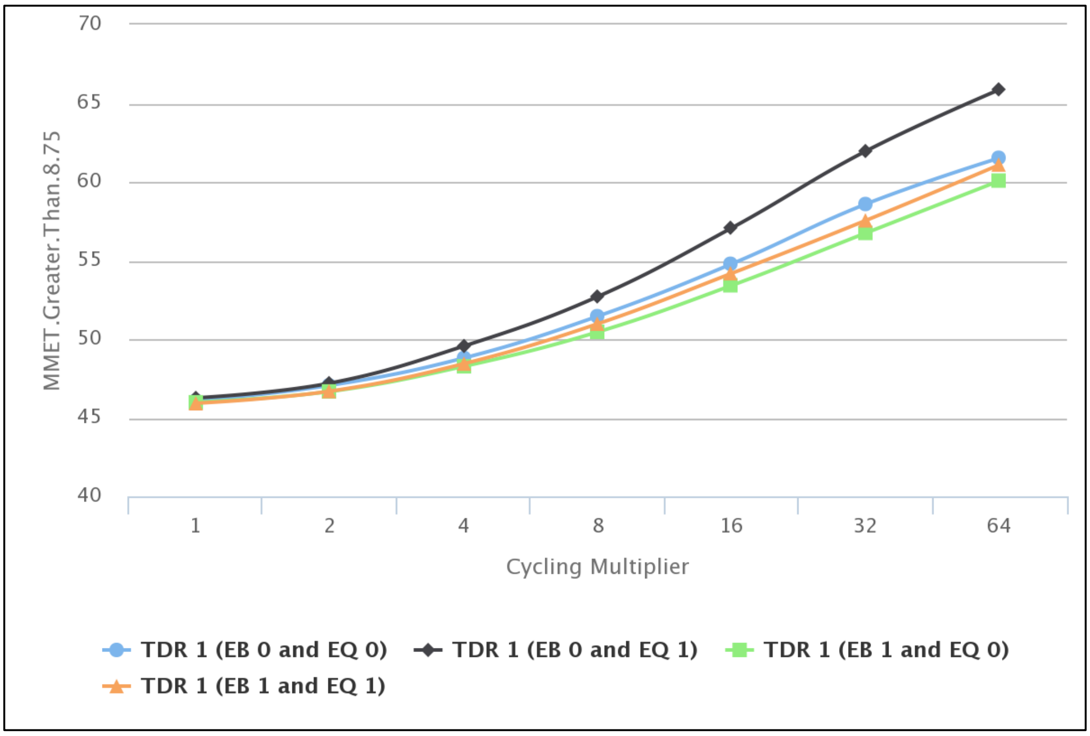

Figure 10: Percentage of population achieving minimum recommended physical activity per week. TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

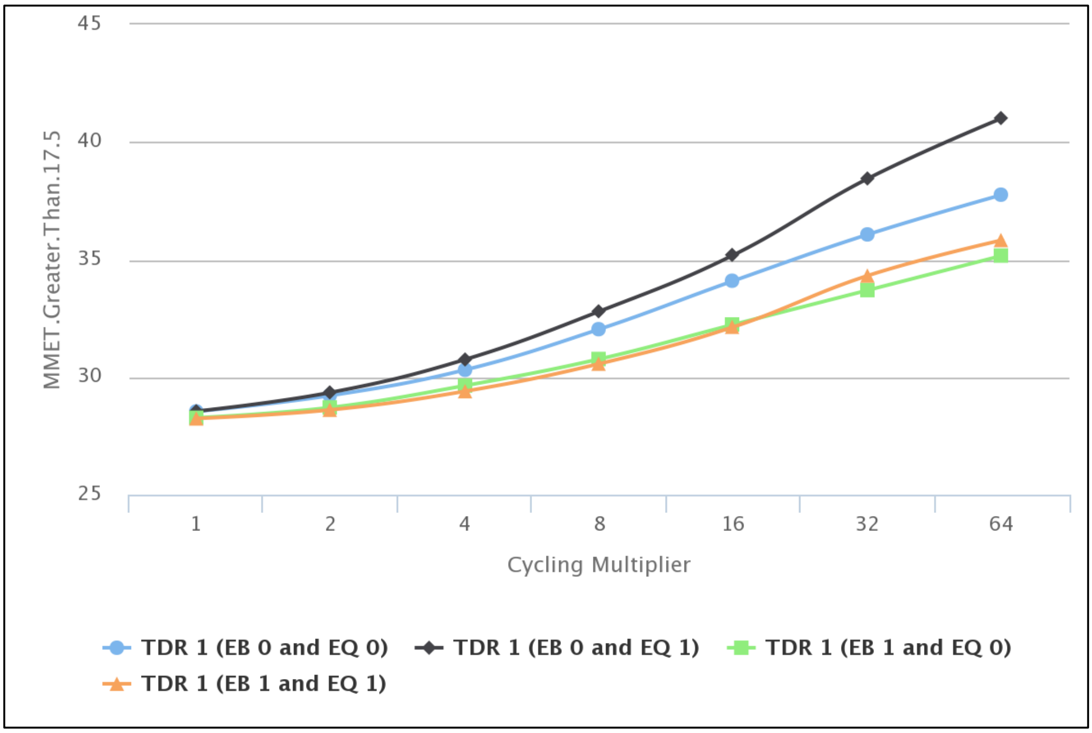

Figure 11: Percentage of people achieving higher recommended physical activity per week. TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

Health outcomes

The increase in physical activity translates into a reduction in the disease burden from physical inactivity. In the most beneficial scenario (cycling multiplier 64, equity on, e-bikes off) the increase in cycling would avert over 6% of premature mortality form people aged 20-84 years, see Figure 12. For a given increase in the probability of being a cyclist equity increased the benefits while e-bikes decreased them.

As absolute numbers, if these changes occurred across the entire United Kingdom population, the benefits would be 390 thousand YLLs in the most beneficial scenario (equity on, e-bikes off), without equity or with e-bikes the benefit would be around 320 thousand YLLs, without equity and with e-bikes the benefit would be just under 300 thousand YLLs.

Unsurprisingly differences between scenarios are even starker for some subgroups, e.g. see Figure 13. For older women equity is the most important issue while e-bikes have a less clear effect, because their impact on this age group on the potential for cycling longer trips is greater than for younger men.

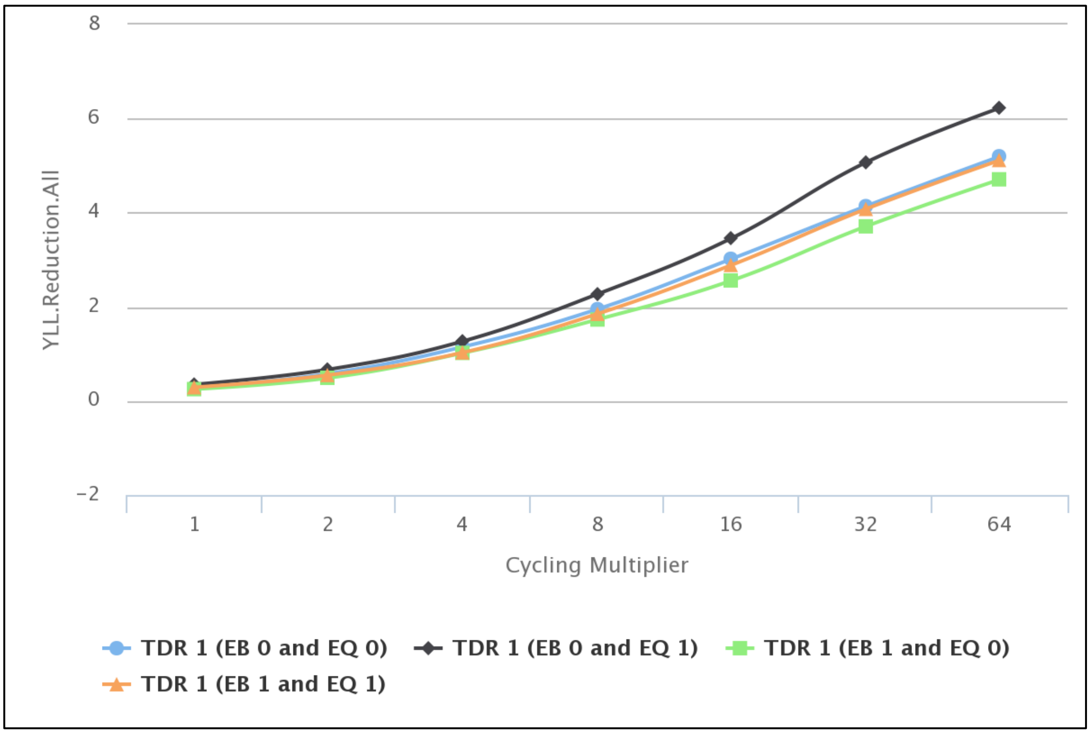

Figure 12: Percentage reduction in burden on premature mortality (YLLs). TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

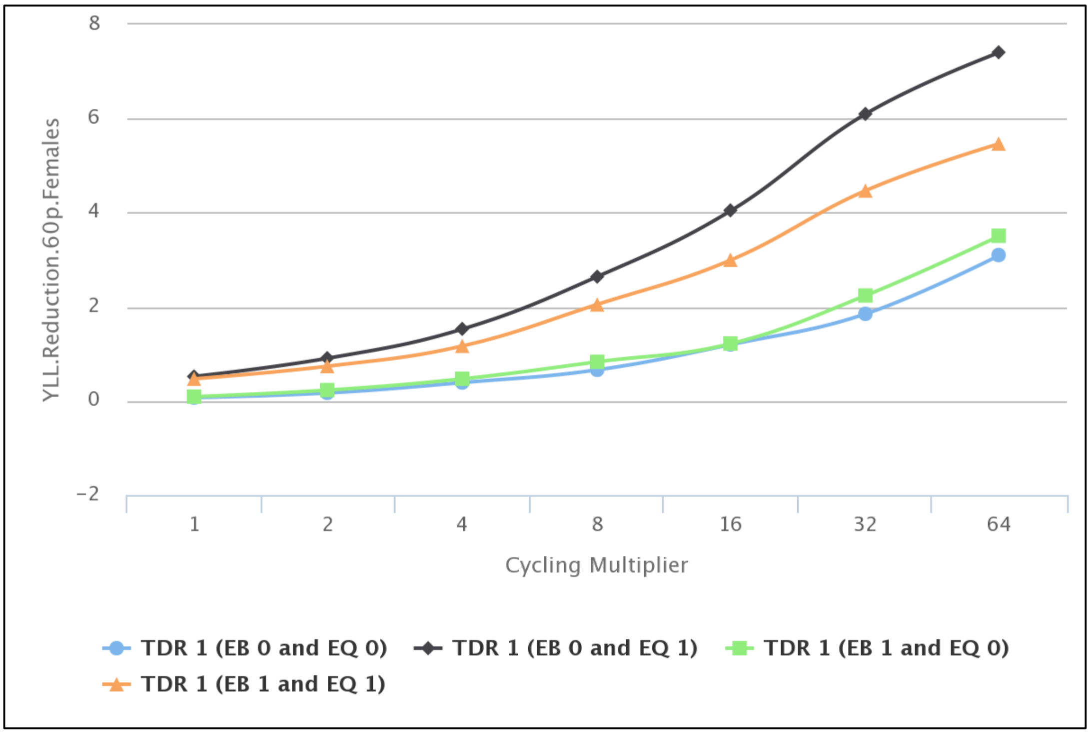

Figure 13: Percentage reduction in burden on premature mortality (YLLs) for older women. TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

Mode share/ which mode trips are coming from

In the tool it is possible to visualise the trip mode share for any of the scenarios. In Figures 14 and 15 the mode shares can been seen for the highest cycling scenarios with and without e-bikes (cycling multiplier 64, equity 1, and e-bikes 1 or 0). In both cases the blue values give the baseline values. The overall mode share for traditional bicycles reaches around 20%, while for cars it falls from over 50% to a little over 40%.

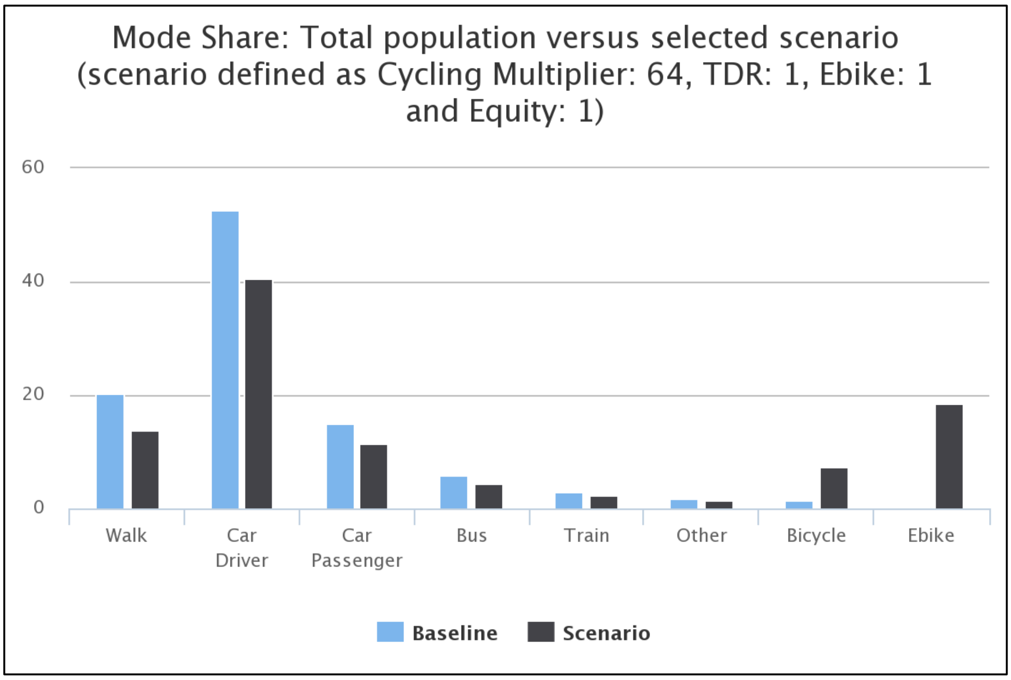

Figure 14 Mode Share baseline compared with e-bike scenario. TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

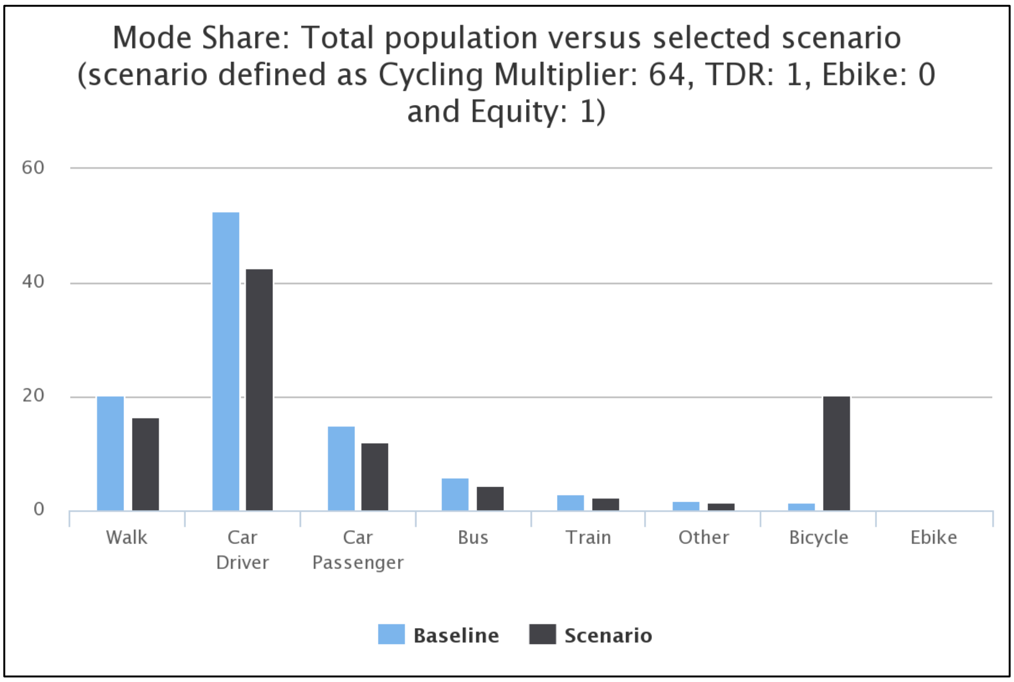

Figure 15 Mode Share baseline compared with traditional bike scenario. TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

It is also possible to look at which mode new cycling trips are coming from. In Figure 16 we see that the majority of new cycling trips were previously driven. However, a substantial minority came from walking. We can also see for people without car access that, unsurprisingly, far fewer were from trips previously as the driver but more surprisingly with a similar number previously as a car passenger. The relative values as to where cycling trips from did not vary substantially with the different cycling multipliers.

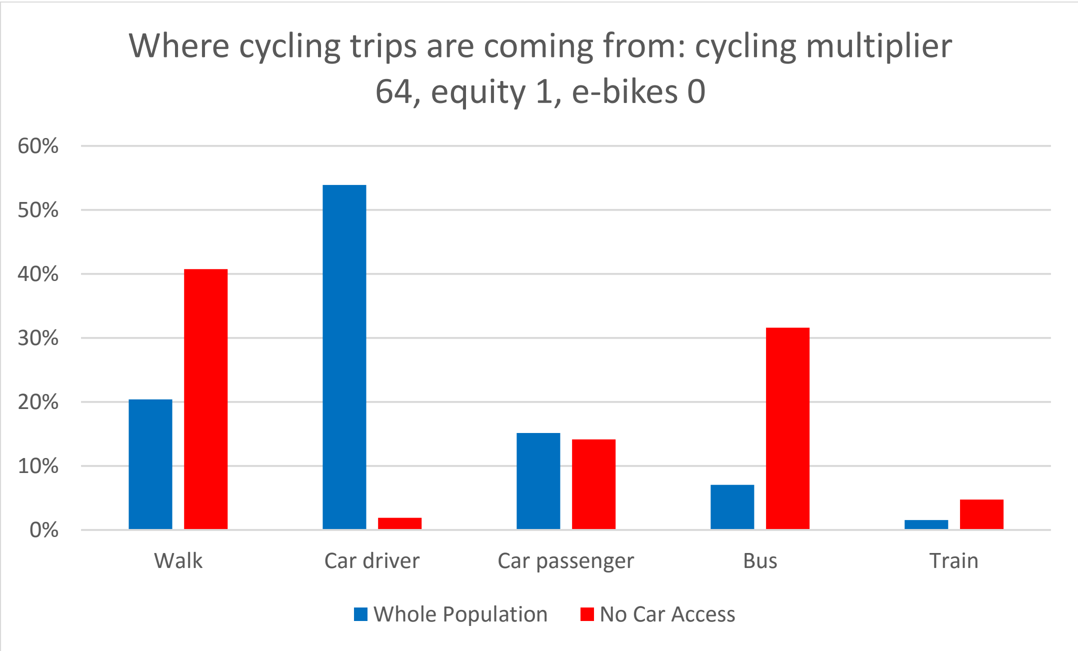

Figure 16: Previous mode for cycling trips comparing whole population versus those without car access

Travel Times

The NTS provides the journey times for all trips. Based on our estimates of cycling speeds we can estimate if a journey would be quicker or slower by bike or e-bike. It should be noted that this approach does not consider how an increase in cycling, as one of the most space efficient modes of transport, could reduce congestion and so speed up traffic for other modes. To do this well would require detailed local analysis. However, some indication of the congestion benefits can be seen by the data provided on where trips are coming from and if as modelled a large number of the trips were previously driven then congestion benefits might be substantial. On the other hand, increasing cycling is likely to require reallocation of road space in favour of cyclists and this may, at least initially, increase congestion for other users.

As can be seen in Figure 17, for 40% of trips newly cycled, journeys were faster, with around half of new cycled trips faster in the e-bikes scenario.

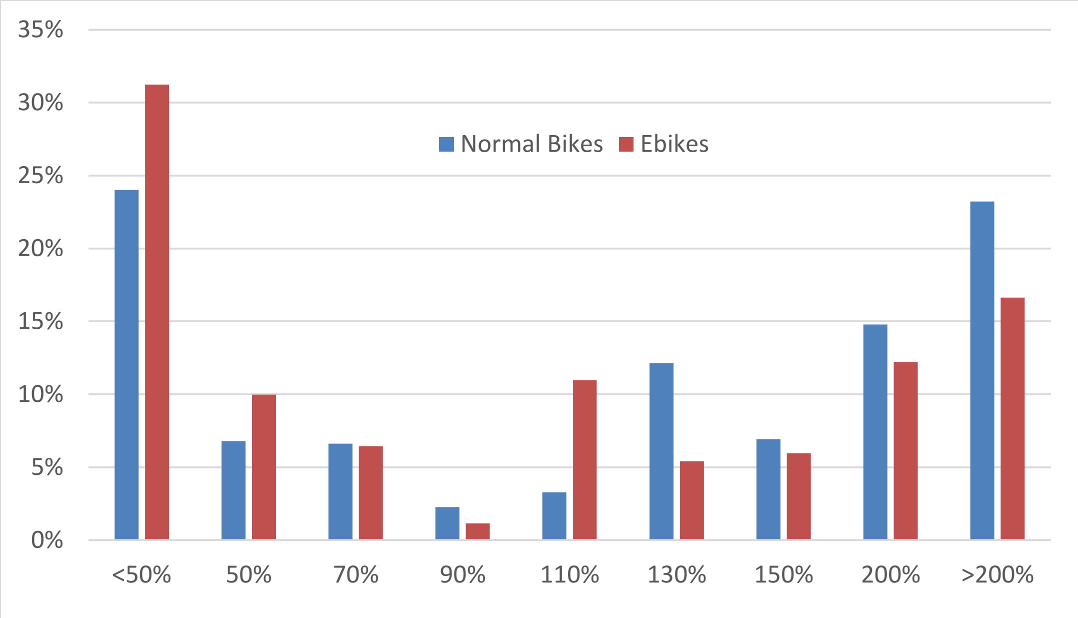

Figure 17: Histogram of relative change in travel times. Scenario Cycling multiplier 64, equity on, e-bikes on/off

There were not substantial differences between men and women, however, for those without car access time savings were much clearer; see Figure 18. This could indicate greater potential for uptake of cycling in those without cars.

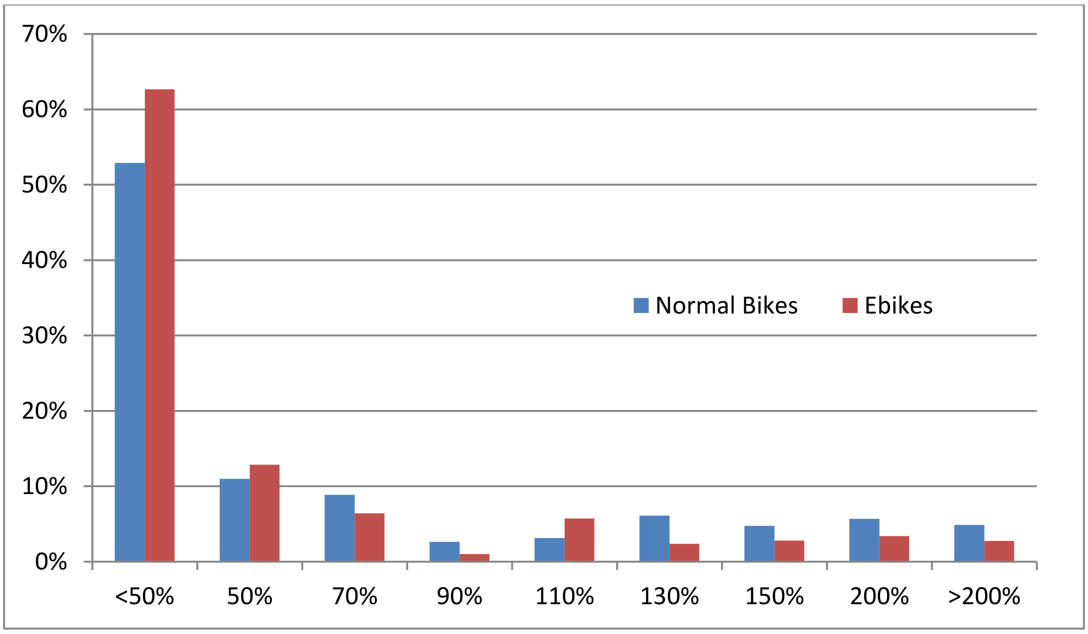

Figure 18: Histogram of relative change in travel times for people without car access. Scenario Cycling multiplier 64, equity on, e-bikes on/off

For some short walking trips we may be overestimating time savings as we have been applying a speed per mile for cycling and not separating this out into a fixed time for parking and unlocking the bike and a variable component per mile.

In Figure 19 we see the subset of trips that are faster by cycling (cycling multiplier 64 and with equity included). Nearly half of these faster trips were previously walked. However, encouragingly over 30% were previously driven (with a higher percentage driven in the e-bikes scenario). This suggests that even if people are more likely to switch to cycling when it speeds up their journey a substantial number of trips would still come from cars.

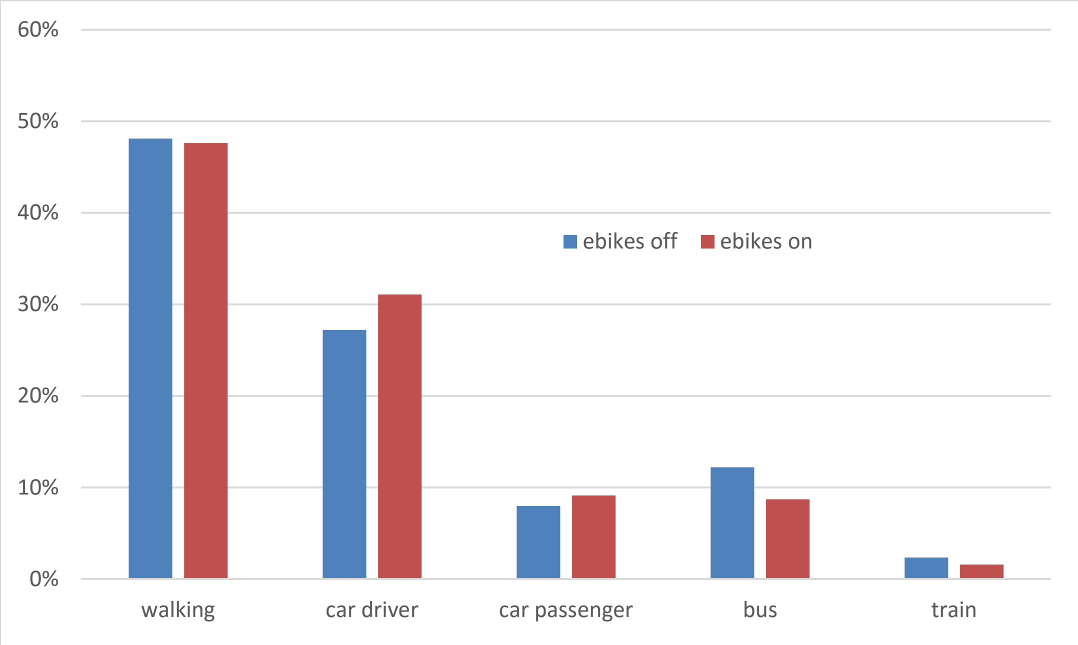

Figure 19: Breakdown of trips that are faster by bike for the Cycling Multiplier 64 with equity scenarios

Change in car miles/ CO2 emissions

If we first look at car driver miles per person (see Figure 20) we see that in the best case (equity on and e-bikes on) distance driven falls by around 12 miles per person per week, a fall of around 11%. With traditional bikes the distance driven is reduced by up to around 9 miles per person per week (8%).

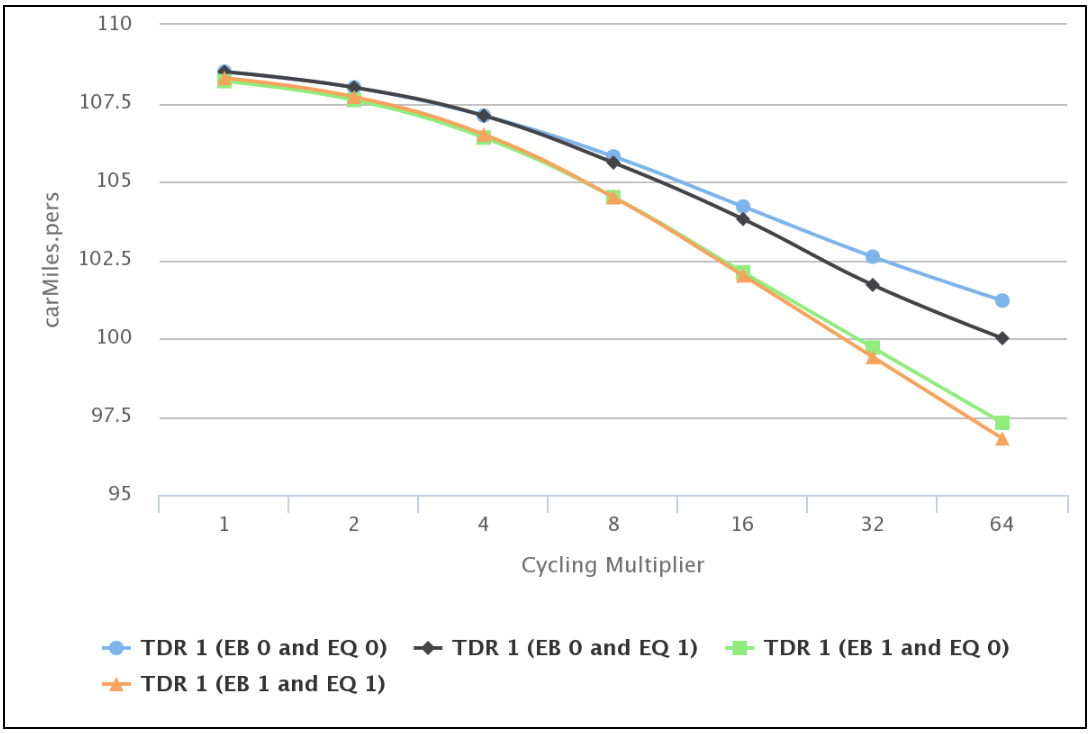

Figure 20: Car miles per person per week. TDR 1= no change in trip distances, EB 1= e-bikes scenario, EQ 1= equity scenario.

Considering next at CO_2 emissions from personal transport (Figure 21) we see a pattern that closely mirrors the change in car miles. With e-bikes up to around 11% of CO2 from private personal travel could be reduced, with normal bikes the reduction could be up to 8%.

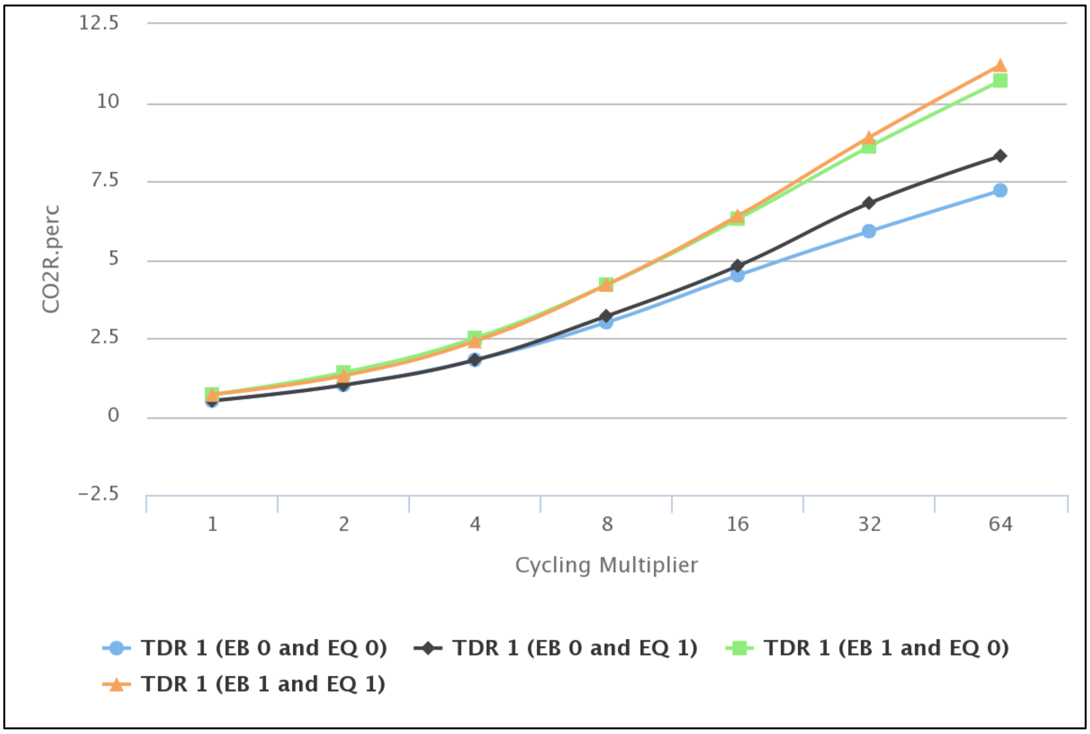

Figure 21. Percentage reduction in CO2 from private personal transport

Discussion

Strengths of analysis and summary of results

Previous studies have modelled the health impact of people in the UK adopting the same average amount of cycling as people in the Netherlands or walking the same amount as people in Switzerland. This study has considerable advantages over this previous work. Firstly it uses UK derived propensities for cycling trips of different distances (only using Dutch data for e-bikes) and secondly it applies these to individual trips. The application to individual trips makes it much clearer which trips would and wouldn't be cycled under different assumptions, and thus allows calculation of a much wider range of outcomes and analysis of results for different subgroups. Thirdly this work is created using open source software and comes with a web tool that allows detailed interrogation of the results.

The study has demonstrated that if non-cyclists had the same propensity to cycle short to medium length trips as existing cyclists there would be considerable benefits in terms of both health and carbon.

Limitations

As with any model the CBM has many limitations. In particular it should be noted that this analysis assumes that current trip numbers continue as they are. Whilst this is a reasonable first approximation in some cases we may be missing suppressed travel demand. This is particularly likely to be the case amongst people without car access. Our estimates of a lower potential in this group may be conservative for a number of reasons. Firstly time savings are greater, amongst this group. Secondly this group has a greater baseline propensity to cycle, which could be represented with differential probabilities as we have done for age and gender. And thirdly this there is evidence from recent empirical studies of higher use of new infrastructure in households without car access (Goodman, 2014). In future work we will consider adjusting the distance based propensities by relative trip lengths to provide a wider range of estimates of which trips are likely to be cycled. In the longer term additional trips could be imputed for groups with less than average trips if there is evidence of suppressed demand.

Other limitations relate to the choice of health outcomes. By focusing on premature mortality we are missing the considerable benefits that might also be achieved by reducing morbidity. On the other hand benefits may be overestimated because we are not modelling injury risks. Although earlier studies have found that benefits from cycling at the population level substantially exceed the harms from injuries. It should also be noted that although injury risks might be higher amongst cyclists[xi] than other

[xi] Potentially injury risks for e-bike users might be higher due to their greater speed, although recent research as part of the Near Miss project actually found fewer near misses for faster cyclists http://www.nearmiss.bike/academic-papers/

road users, fewer cars on the roads would reduce population level risks. Equally for air pollution, cyclists would typically inhale more pollutants but the amount of pollution produced would fall. Considering estimates for CO_2 emission reductions were done with a basic approach not accounting for car speed or variation in vehicles.

Inevitable limitations arise from the data sources. For the traditional bike scenarios we have assumed that new cyclists have the same distance based propensities as current cycling. However, this may underestimate the potential as even current cyclists may not cycle all the trips they would like, e.g. if only some trips have decent routes. The use of Dutch values for e-bikes may not have direct relevance in a UK context but given the limited data from the UK it provides the best approximation of future potential we have. Interestingly in the traditional bike scenario the highest mode achieved (20%) is notably lower than the mode share in the Netherlands (27%), and only with the e-bike scenario do we actually achieve the Dutch mode share.

Although the modelling is probabilistic we have not yet run sensitivity analysis to investigate the uncertainty of our results. Based on previous modelling studies we have a good handle on the variables which are likely to make the greatest contribution to total uncertainty.

Future work

In Stage 2 we plan to develop the CBM in the following ways:

1. increase the realism of the CO_2 calculation (vehicle speeds and types)
2. vary propensities by other factors shown to be important (ethnicity, car ownership)
3. vary propensity to cycle by change in trip duration (lower chance of switching if trip would be slower by bike)
4. include morbidity from specific diseases in addition to mortality
5. introduce a simple injury model
6. analyse further outcomes (e.g. household financial savings)
7. improve the interface both for understanding baseline NTS data and modelled results.

We plan user testing in Stage 2 to further develop the CBM. We are happy to discuss further developments to the approach that could make this more useful in practice.

List of Tables

List of Figures

References

CROW-Fietsberaad. (2013). *Fietsberaadpublicatie 24 Feiten over de elektrische fiets*. Available from: http://www.fietsberaad.nl/?lang=nl&repository=Fietsberaadpublicatie+24+Feiten+over+de+elektrische+fiets

Goodman, A., Sahlqvist, S., Ogilvie, D., and on behalf of the iConnect Consortium. (2014) New Walking and Cycling Routes and Increased Physical Activity: One- and 2-Year Findings From the UK iConnect Study. *American Journal of Public Health*, 104, 9, pp. e38-e46. doi: 10.2105/AJPH.2014.302059

World Health Organisation (2010) *Global recommendations on physical activity for health*. WHO: Switzerland. Available from http://www.who.int/dietphysicalactivity/factsheet_recommendations/en/

Appendix 11: Server Requirements

The internet tool uses Shiny Server[i], a web application designed to work with the statistical software R[ii]. R is used heavily in the statistical and academic community and is fast becoming a tool for analysing Big Data in industry. Shiny is a library for creating interactive web applications using R. In addition we use the leaflet R library, which provides an interface to the Leaflet JavaScript library to build interactive maps.

Licensing

R is released on the GNU (General Public License), we are not modifying the source code and so this has no bearing on the project. Shiny Server Open Source Edition is released under the Open Source AGPL v3 which requires any work based on this to be publicly available, which we already comply with.

Scalability

Shiny Server provides a simple server set-up with minimal configuration. In Stage 1 of the project we were able to create a working server environment in under ten hours and have had very little downtime. The site has had multiple concurrent users and has not experienced any issues.

In scaling up for Stage 2 we would like the tool to be available to as many people as possible. Our tests suggest the current server only slows down when more than ~20 users are intensively using the application simultaneously. Assuming we have a peak load of ~160 users then ~8 servers would be sufficient.

We have approached two companies for technical expertise in creating robust repeatable deployment structure. This structure will mean that if we need to scale up to more machines or add new features then the deployment process creates an identical stable environment. Both companies estimated this would take two to three days. This would involve the NPCT team working on-site so that if future problems developed there would be multiple people who understand the infrastructure. Both companies also offer a managed server package with security updates and general support.

The end system will consist of n identical machines behind a load balancer. When a user navigates to the tool URL the request will be sent to the load balancer which will then transparently send the request on to one of the available machines. The load balancer only runs a very simple process consisting of passing on requests and so is highly unlikely to fail. As there are multiple identical machines, if any one does fail then it would not bring down the whole system. We are looking at managed solutions where the hosting company would apply basic security upgrades and oversight.

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[i] See http://shiny.rstudio.com/
[ii] See http://www.r-project.org/

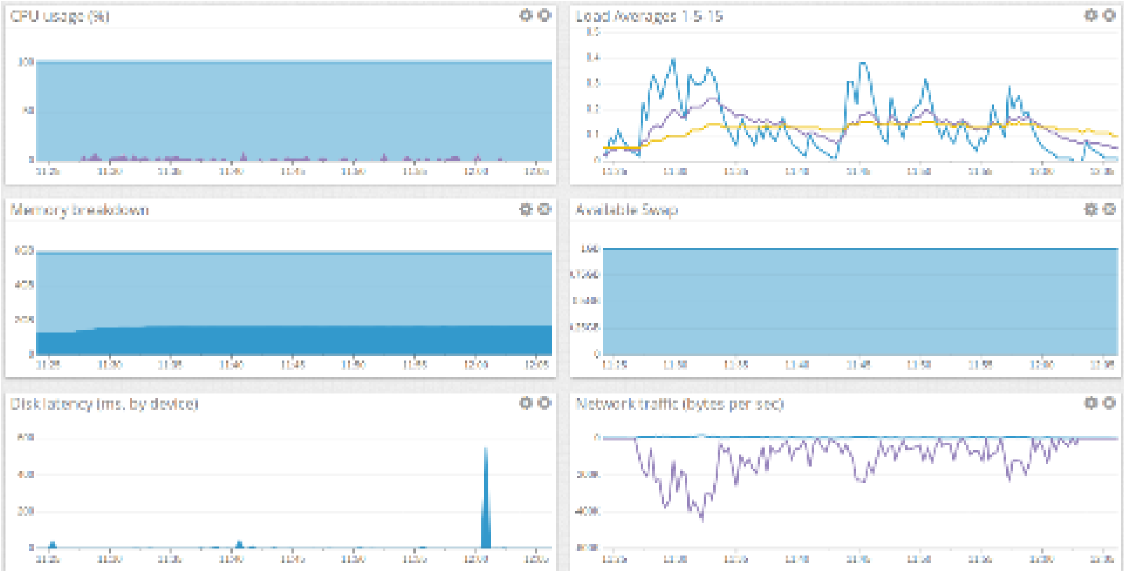

Figure 1: Server metrics from DataDog.

At this point there were ten simultaneous users. CPU usage is low < 10%, also shown in the load averages. Memory usage (RAM) increased only slightly from 1.3Gb to 1.7Gb. Disk latency spikes but Solid State Drives would help reduce latency. Finally on network we were sending 400KB/s which is 1/5th of the current server’s capacity.

Table 1 Costing Estimate

Company	Mythic Beasts	BrightBox	Google
Location	Cambridge	Leeds	?
Set-up Cost (2 days – company)	£800.00	£1,920.00	£1,500.00
Set-up Cost (2 days – NPCT)	£900.00	£800.00	£850.00
Cost per basic machine per year	£250.00	£180.00	£195.00
Management	Yes	No	No
Management cost (by hour)		£500.00	£500.00
Load Balancer	£375.00	£350.40	£307.68
Machine RAM	2GB	1 GB	3.75 GB
No. of machines	8	8	8
Total cost	£4,075.00	£5,010.40	£4,717.68
No. of machines	12	12	12
Total cost	£5,075.00	£5,230.40	£4,997.68