Determination and measurement of factors which influence propensity to cycle to work

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Submitted in accordance with the requirements for the degree of Doctor of Philosophy

The University of Leeds Institute for Transport Studies

September 2004

Acknowledgements

Ginette Farrell and John Pickering for assistance with translating reference material from the original German. Dr Charles Lee for assistance in interpreting a model of accident exposure. Ferdinand Crespo de Diu for an introduction to non-linear regression using SPSS and undertaking work leading to a preliminary model. Roy Attwood and the staff at the Centre for Remote Access to Learning at Bolton Institute for assistance in converting digital video images for use on a PC. Angela Rann for performing the fieldwork for the first pilot of the Risk Rating survey. Megan Bradley for providing assistance with the final stages of the fieldwork for the Risk Rating survey. Martin Whitfield of Cycle City Guides, Andrew Smith of Transport for London and John Dinunzio of the London Cycle Network Plus team for assistance with data on bicycle and bus infrastructure.

Kate, Jimmy and Joseph Parkin who have humoured my interest in cycling throughout the period of study. Dr Mark Wardman and Matthew Page who have consistently provided stimulating and constructive criticism throughout.

Thank you.

Abstract

2.89% of the UK population cycled for the journey to work as measured by the census in 2001. This percentage is similar to the percentage from the 1991 census and indicates a levelling off in the decline that had been seen in the previous two decades in bicycle use for the journey to work, but does not demonstrate any increase in line with policy aspirations.

Choice is a complex issue and related to a wide range of factors including socio-economic variables and the nature of transport infrastructure and the physical geography of an area. As well as the rational and measurable factors, there are many much more complex and subtle factors including the influences of culture and social norms. Changes to behaviour probably take an extended period of time and require a range of conditions to be appropriate before a positive choice can be made.

Waldman (1977) undertook the last countrywide aggregate study of the variation in use of the bicycle for the journey to work, but a number of the variables he constructed were measured inappropriately, not the least of which was his measure for "danger", which he recommended for further study. It is widely considered that perception of risk from motor traffic is a reason why many people do not currently use the bicycle. This is only one measurable attribute and European bicycle planners consider network coherence, directness, attractiveness and comfort as other equally important issues when designing schemes to promote bicycle use. This research has used primary data collected on perceptions of risk. The particular contribution of the research is in the development of a methodology for the determination of perception of risk for a whole journey, including routes and junctions, and the extension of this methodology to create a measure for risk at an area wide level.

Measures that have been found to be significant in relation to the use of the bicycle for the journey to work are car ownership, socio-economic classification, ethnicity, distance to work, condition of the highway pavement, highway network density and population density, hilliness, rainfall and mean temperature. In addition the length of bicycle lane, length of bus lane and length of traffic free route have also been found to be important in so far as it influences the perception of risk, which in turn influences the level of bicycle use. The length of route that is signed has also been found to be important. In a sample of four districts for which appropriate data is available, a seven fold increase in route length with cycle facilities, or signed route, would create conditions suitable for an increase in cycle use for the journey to work by a factor of the order of two. An elimination of highways with negative residual life would create conditions suitable for an increase of 10% in the number of bicycle trips for the journey to work.

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Chapter 1 Research objectives and history of cycling

1.1 Introduction

This chapter provides an introduction to the reason for the research and briefly states its aim and objectives. A context for the research is established through a historical review of cycling. The chapter concludes with a summary of the structure of the document.

1.2 Research aim and objectives

The research described in this thesis measures factors that determine cycle use and, using these measures, estimates models of the proportion of journeys to work that are made by bicycle in England and Wales.

Quantitative assessment of cycling trip making was first undertaken by Waldman (1977) who set out to test the assertion that considerably more people would make journeys by bicycle if they could do so safely. The study considered 195 districts in England with the dependent variable defined as the proportion of people who live and work in an area who reported riding a bicycle as their major mode of travel to work in the 1966 census.

The range of cycling in the selected districts was from 0% to 50%. Independent variables thought to be most influential were hilliness, rainfall, trip-lengths, accident risk, availability of alternatives, lifestyle factors and wind. Wind was thought to be important but a measure was not available and it was therefore not modelled. The accessibility of alternative modes was not modelled but income and socio-economic group were modelled.

Waldman demonstrated that the joint effect of hilliness and danger had the most influence on the proportion cycling and he recommended that further work should be undertaken on the measurement of accident risk related to traffic conditions.

The determination of a measure for the perception of risk has constituted a major part of the research effort reported in this thesis. A video based survey of 144 respondents has resulted in a model to predict the perception of risk. This estimated measure for risk has been used in the main analysis of the variation in cycle use for the journey to work taken from the 2001 census. The principal model in the main analysis is based at ward level for all wards in England and Wales and does not include the variable for risk from the respondent survey, but includes variables for other determining factors. A further model is based on a sub-set of wards for England and Wales and does include the variable for risk from the respondent survey as well as other determining factors.

The aim of this research is:

to construct a model of the proportion of journeys to work for English and Welsh electoral wards that are by bicycle using relevant person, transport and other physical factors as explanatory variables.

The objectives of the research which support this aim are stated as follows:

- The determination of factors that influence whether or not the bicycle is chosen as a mode for the journey to work.
- The derivation of an appropriate measure for the identified factors, particularly the perception of risk.
- The analysis of the relative importance of the measured factors within an appropriately formulated choice model.
- The estimation of different potential levels of cycle proportion for the journey to work based on different levels of the determining factors, particularly perception of risk.

The reasons and full justification for alighting on this aim and these objectives arise out of the evaluation of the literature review and full argument is presented in Chapter 5. The estimation of variations in cycle mode choice proportion for the journey to work based on variations in the determining variables is contrasted with the erstwhile policy aspirations identified in the National Cycling Strategy (DfT, 1996) and Ten Year Transport Plan (DfT[1], 2000a). Present policy in the White Paper of Summer 2004 (DfT, 2004a) suggests that local plans and targets are set for increased cycle use and would rely for their setting on a realistic estimation of potential increases in cycle use. The value of the research reported here lies in the potential for assisting practitioners in understanding better the relative importance of the factors which determine whether or not the bicycle is chosen as a mode and hence potentially allowing for a better targeting of resources for the promotion of cycling at a local level.

1.3 A brief history of cycling

McGurn (1999) records that cycling's antecedence lies with the two-wheeled running machine of Baron von Drais. Mainly due to the French media, the idea caught on across Europe in the year 1818, but was the preserve of the aristocracy. The Baron had little success in protecting his extensive applications for patents across Europe and this helped the machine's development. In England, Denis Johnson showed the entrepreneurial skills lacked by the Baron and was able to

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[1] Prior to 2002 the Department for Transport, DfT, existed as the DETR, Department of Environment Transport and the Regions and prior to 1997 it existed as the DoT, Department of Transport. References are noted throughout the thesis as "DfT"

construct in large quantities machines that became known as "dandy-horses" or "hobby-horses", the latter name of course remaining in jocular parlance today. McGurn notes that while the Mayor of Haarlem in The Netherlands rode a version of the hobby-horse, the authorities in Milan banned the machines by civic order: perhaps an early reflection of cultural differences still evident today between Northern and Southern Europe. The "craze" reached a height in the mid-1820s but the limitations of the machine were as much to do with the state of the roads and footways as the technology of the machine itself. The state of the roads assisted in the development of large-scale railways powered by steam engines financed by powerful interests. Mechanical developments to the bicycle, then known as a velocipede, on the other hand were left to amateur mechanics vying for the significant breakthrough in human powered propulsion and control. Kirkpatrick Macmillan a blacksmith from Thornhill near Dumfries in Scotland is credited with the development of propulsion by treadle connected to the rear wheel and it is claimed that in 1842 he rode the last 40 miles into Glasgow in five hours. Note that his speed is very comparable with modern day touring speeds!

Mirroring modern antipathies, McGurn quotes a Parisian journalist in the 21st March 1868 issue of *Once a Week* "Paris is just now afflicted with a serious nuisance ...velocipedes, machines like the ghosts of departed spiders, on which horrible boys and detestable men career about the streets and boulevards". It was in France and particularly Paris where velocipeding became a very fashionable pastime with royal support and this was due mainly to the mass production of machines begun by Michaux and enhanced by the capital of the Olivier brothers. Strong views, both for and against, the health and safety of velocipeding were expressed and nothing seems to have changed to date.

Ritchie (1975) notes that in Great Britain in the 1860s and 1870s by-laws concerning the use of the bicycle varied between jurisdictions with the bicycle itself having uncertain legal status. It was not until the 1878 Highway Act that the bicycle and its use were legally defined.

Ingenious developments began when industrial companies used their skills in machining to refine the science and technology of velocipedes, notably sewing machine companies in Coventry and lace making factories in Nottingham. Large front wheels developed which allowed for greater speed and length of journey, but at the expense of coming a "cropper" over the handlebar. Significant improvement to the ride quality occurred with the development from traditional cart-wheel design (with an iron ring shrunk onto a wooden rim) to tensioned spokes meeting the hub tangentially and overlapping with adjacent spokes. High-wheelers, later known as penny-farthings, had their hey-day in the 1870s and were the preserve, as most sport was, of the upper classes attracted by the adventure. Clubs, exclusively of men in militaristic uniforms, developed across the country ostensibly for the pursuit of rides into the country but often only as social clubs. Machines with chains driving the rear wheel were developed in the 1880s which allowed for smaller front wheels and removed the safety problems of high-wheelers. These "safeties" hailed a new era in the use of the bicycle. The technology allowed for the parallel development of tricycles which became the preserve of the upper middle classes and quite distinct from the more sporting ethos of the bicycle clubs. Smaller wheels were not as comfortable as larger wheels but this problem was overcome by the pneumatic bicycle tyre patented by John Dunlop in 1888. It is interesting to note that by 1905 the tyre had become so widespread that Sir Arthur Conan Doyle describes Sherlock Holmes as being familiar with forty-two different impressions left by tyres (Conan Doyle,1905).

The bicycle introduced a new-found freedom for those able to afford it, not least amongst women for whom fashion still, however, dictated inappropriate clothing. Cycling became linked with emancipation and the movement for "rational" dress championed by Lady Harberton (Ritchie, 1975).

The expression of mobility was often not tolerated by the authorities. The French, accommodated cyclists whereas in Germany the authorities closed many roads to cyclists and otherwise insisted on restrictions such as riding in a single file a set distance apart.

By the middle 1890s cycling was very popular in Britain and France with about a million cyclists in each country. Germany had around a half a million cyclists while estimates in the USA ranged from 2 to 4 million. The Cyclists' Touring Club (CTC, NB a list of abbreviations is provided in Appendix A) in Great Britain had 60,000 male and 20,000 female members (Wigglesworth, 1996) which compares with 54,400 in February 2004 and 50,000 in December 1999 (CTC, 2000 and CTC, 2004). Some of this popularity could have been as a result of the patronage of royalty, Queen Victoria having purchased two tricycles in 1881 (Bijker, 1995).

The vogue extended to the upper middle classes and the aristocracy with many fashionable London parks being the venues. Lady Colin Campbell suggested it was "unfitting for women to expose themselves to the dangers of London traffic" and in so saying is perhaps reflecting present day traumas about the juxtaposition of cyclists and traffic.

In addition to the middle classes, the working classes found that the new-found means of transport increased their horizons substantially. These wider horizons, coupled with artificial light and the widening literacy rates, increased the proportion of the working population able to avail themselves of further educational opportunities. Working class cycling was linked in the minds of its participants to the struggle for greater democratic representation in Germany in the 1890s. The movement was repressed by the Government but was able to spawn a chain of co-operatively run cycle factories and shops. The counterpart in Britain was the Clarion Cycling Club born out of the Clarion movement linked to the newspaper of that name. It espoused fellowship and fresh air mixed with a radical utopianism. "Meets" were arranged annually, originally in South Derbyshire as a central point between the majority of local groups which were emerging in the industrialised towns of the North (Pye, 1995). The club developed its own peculiar dress code and language of communication, most prominent members having pseudonyms, and propagated socialism through open-air meetings and leaflet distribution. There was tension between those who saw the club's prime raison d'être as the propagation of socialist doctrine and those who believed their principles would show through their "comradely confraternity".

There were similar moves towards worker emancipation through bicycle use in Denmark and, as with the invention of many technological artefacts, its use soon generated regulations and restrictions to conserve some degree of propriety. An example is the banning of the use of the bicycle on employers' business by an extraordinary general meeting of the Plumbers Trade Union in 1902 designed to limit what would otherwise be a benefit solely for the employers. Around 1910 cyclists began to use the bridle paths around the lakes in Copenhagen (Danish Road Directorate, 2000). Briese (1993) notes that the primary justification for early separate cycle facilities in Germany was to provide a relatively smooth stable surface to increase rider comfort, convenience and speed and this contrasts with later policy where paths were provided with the main goal of increasing the speed of motor traffic.

Significantly in 1896 the speed limit for the car in the UK was raised from 4mph to 12 mph and this perhaps signalled the beginning of the popularity, at least amongst those who could afford it, of the automobile. The upsurge of car ownership was reflected in the Cyclists' Touring Club's wish in 1906 to seek judicial permission to change its articles of association to embrace motoring as well as cycling. The judge ruled that the club could not protect the cyclist and at the same time espouse the "very people who were a danger to them" (CTC,1953).

Cycles did not develop greatly in technical detail in the 1920s, and by the early 1930s cycling was a significant part of the whole recreation movement that had resonance with the German penchant for outdoor activity. In 1930 the modal split in German cities was generally between 15% and 40% and in Berlin, exceptionally was 60% (Maddox, 2001).

The growth of motoring in the UK led to what was described in Cycling magazine as "carnage on the road". In 1936 there were 1,496 cyclist deaths and 71,193 injured. 31% of all road casualties were cyclists.

The 10th March 1934 edition of Cycling noted that Hore-Belisha, the Minister of Transport, "caters primarily for an age in which none of the leaders of public thought in transport matters are cyclists". Links with the sporting ethos of the Tour de France kept cycling to the forefront of the national psyche in France. In The Netherlands and Denmark cycling remained popular and has been described by McGurn as a "cultural asset" (McGurn, 1999), perhaps embedded in the psyche of North Europeans for reasons similar to those in Germany, that is linked with strong physicality and the outdoor life, but without the militaristic overtones. Despite the carnage, Pye (1995) reports that the Clarion Cycling Club almost doubled its membership to 4,330 in 1934 and this was linked to the fresh air and outdoor exercise movement as opposed to principles linked with the propagation of socialism. Franklin (1999a) notes that there was little specific provision for cyclists in the middle decades of the 20th century, but that where a few cycle tracks that had been provided along trunk roads, research by the Ministry of Transport had found that there was increased danger at every junction where cycle tracks were present.

The rise in car ownership and use in Britain was temporarily halted during the petrol rationing years of the Second World War. In 1960 the Conservative Minister for Transport, Ernest Marples, told the party conference that "we have to rebuild our cities. We have to come to terms with the car". In 1967 he chaired a colloquium on cycling in which he said that he used his bicycle in France but to use it to go round Hyde Park Corner is "to sign your own death warrant".

Developments to bicycles in the 1960s, such as the introduction of small wheels and stylised bicycles for children, marked a passage of the bicycle from workhorse to fashion accessory. Technological developments have continued, particularly influenced from America, and include the development of a wide range of recumbent cycles as well as mountain bikes that sell in larger numbers than any other sort of bicycle.

Cycling has become linked in recent years with "campaigning" particularly for improved conditions of safety for cyclists. Government action has often been limited to statements and publicity campaigns, the effects of which have been negligible. The relentless increase in volumes, speed and acceleration capabilities of motor traffic presents a particular problem to cyclists and much local campaigning has been directed towards the creation of special facilities and routes designed to reduce the perceived hazard of motor traffic. On the other hand campaigners such as Franklin (1999a) disagree with this thrust and note that efficiency and comfort are probably two more important criteria than perceptions of safety.

In contrast with equivocation in the UK, the Dutch Government as early as 1975 began a programme of building and improvement of cycle facilities within the motor traffic carriageway, with routes adjacent to the carriageway and with other routes remote from carriageways.

A useful insight into the thinking of civil engineers regarding cycling is provided by an extended period of correspondence (25th May 2000 to 31st August 2000) in the letters pages of the New Civil Engineer Magazine rebutting and supporting comment in a "debate" article by Roy Aylott, former City Engineer of the City of London Corporation (NCE, 2000). Mr Aylott had the temerity to suggest that "within the cycling community, there is almost total disregard of the highway code and a general lack of discipline". It may not be too far from the truth to imagine that this is a conception held by a large proportion of the population.

Certainly there is much in the history of cycling that demonstrates that it raises significant passion and division amongst the road using community.

1.4 Structure of the thesis

Chapter two presents cycling statistics and describes trends and current cycle use in the UK, setting these against the development of UK transport policies as they have affected cycling. Comparisons with European cycling statistics and policy development are provided. A final section describes measures currently used to promote cycling.

Chapter three comprises a literature review of cycle modelling. This is accomplished by reference first to monitoring studies that reflect and amplify the descriptive statistics introduced in Chapter two. Qualitative studies are then discussed, again comparing to relevant European studies, with particular interest being directed towards cross-cultural issues. The next section reviews the increasing range of quantitative research on mode and route choice. The chapter also includes discussion of the way cycling is incorporated in transport models and methods of evaluation of cycle schemes. It concludes with an evaluation of the studies reviewed so far as they are able to provide an indication of the important factors determining whether or not the bicycle is chosen as a mode.

Chapter four reviews literature concerned with cycling from a traffic engineering point of view and considers "level of service" models and safety. Literature is reviewed that attempts to determine cyclists' perception of risk from particular physical and traffic conditions.

The evaluation of relevant research in the field of cycle modelling and engineering leads into discussion of the research opportunities in **Chapter five**. It is in this chapter that the thesis, research aim and objectives are stated and the methodology outlined. The methodology comprises a video based survey to determine perception of risk to cyclists in different cycling circumstances with the aim of producing an area wide measure for risk. This area wide measure for risk may then be used with other socio-economic, transport and physical factor data to build a model of the variation in proportion using the cycle for the journey to work from the 2001 UK census.

Chapter six identifies the data to be included in the analysis and their sources and seeks to satisfy the first objective of the research (identifying the factors determining whether or not the bicycle is chosen as a mode for the journey to work) and the second objective of the research (determining appropriate measurements for the identified factors which determine cycle mode choice). The factors are split into three classes and comprise census data (socio-economic, ethnic and distance to workplace factors), physical factors (hilliness and weather) and transport factors (highway network nature). The data described in chapter six is secondary data, but with manipulations necessary to make it appropriate for use in this research.

Chapter seven presents the detailed methodology and descriptive statistics from the respondent survey to measure perception of risk. The data described in chapter seven is all primary data. Chapters eight and nine expand on the analysis to develop a measure for risk aggregated to the district level. **Chapter 8** presents a comprehensive analysis of the data to develop Risk Ratings for different circumstances and uses non-linear regression analysis as a tool. **Chapter nine** uses the logit binary choice model to develop a measure for risk across an area based on "threshold of acceptability". Results from this analysis are carried forward into the main model of variation in cycle use.

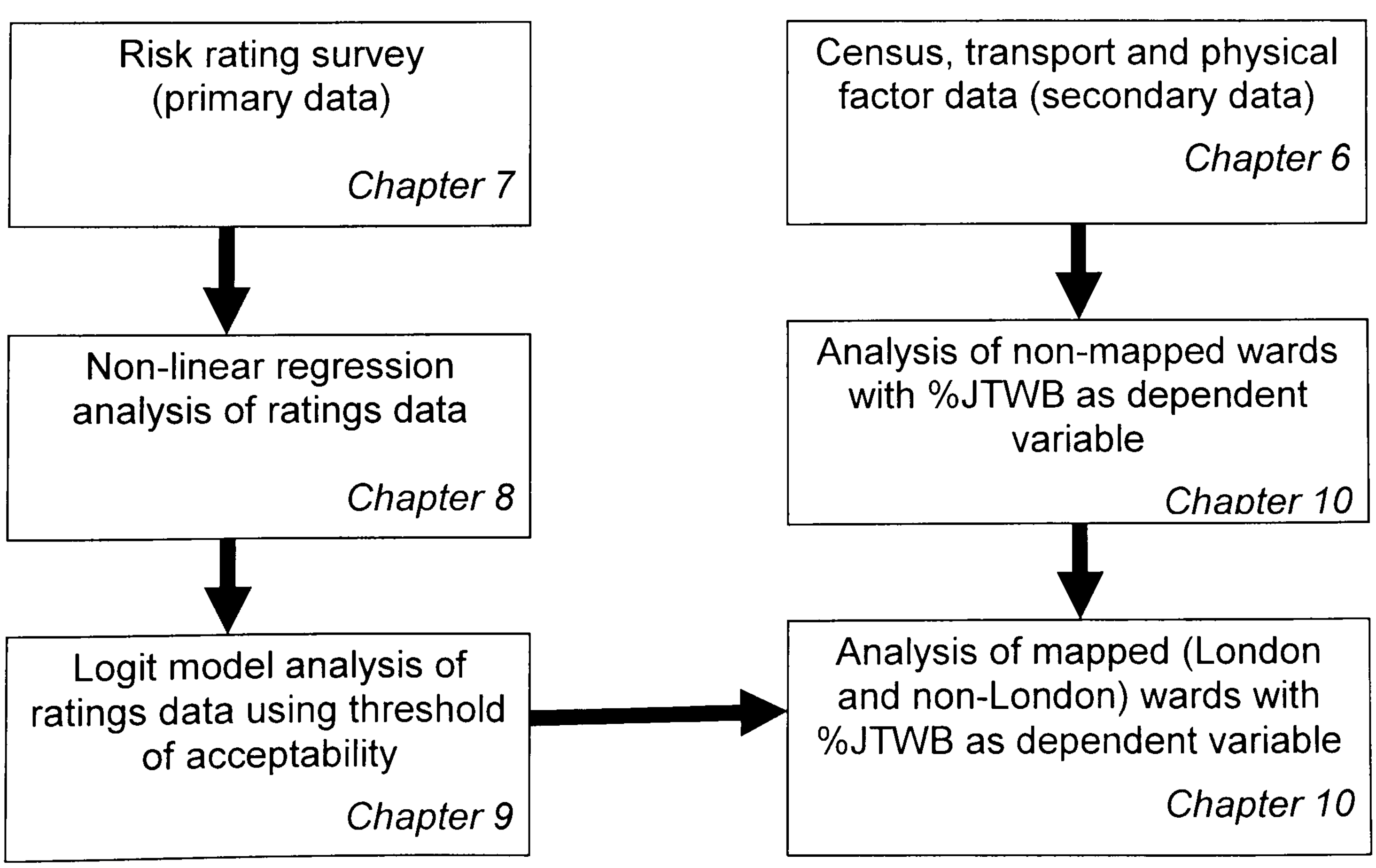
Chapter ten describes the analysis undertaken in which the third objective of the research, analysis of the relative importance of the factors, is satisfied. Three models are reported: one for England and Wales where no specific data on cycle infrastructure is available, one for England and Wales where mapping data on cycle infrastructure is available and one for London where mapping data on cycle infrastructure is available. This is again accomplished using a non-linear regression model. Where available, infrastructure data is used to create a "probability of acceptability" of cycling using the results from the primary data survey reported in Chapter 9.

Chapter eleven describes the use of the model in the forecasting of cycle mode choice proportion for the journey to work based on adjustments to significant determining factors; hence satisfying the fourth objective of the research.

Chapter twelve presents an evaluation of the overall contribution of the research with conclusions and recommendations for further research.

Figure 1.1 below summarises the data collection and analytical processes undertaken as part of the research and described in Chapters 6 to 10.

Figure 1.1 Data collection and analytical process summary



Note: %JTWB stands for percentage mode share for the bicycle for the journey to work

Chapter 2 Cycling use and accident statistics, policy and promotion

2.1 Structure of the chapter

This chapter begins, in Section 2.2, with a presentation of cycling use statistics, taken in most part from the 2001 census in the UK and deduces some broad reasons for the evident variation in cycle use across the country. It also provides some European comparative data. Section 2.3 provides data on cycling and accidents before presenting a chronology of UK policy development as it relates to cycling in Section 2.4. Section 2.5 compares policies in relation to cycling across Europe. A review of methods used to promote cycling is provided in Section 2.6.

The purpose the Chapter 2 is to set the context for cycling in the UK and hence the context for the research. Subsequently Chapters 3 and 4 will provide comprehensive treatment of subject matter that is introduced in Chapter 2. Further development of material first introduced in Chapter 2 is most evident in the following areas:

- Some monitoring data is presented with cycling use statistics, but a comprehensive treatment of monitoring studies is presented in Section 3.2
- Accident data is presented in Chapter 2, but detailed assessment of safety studies is contained in Sections 4.3 and 4.4.
- Engineering measures to promote cycling are summarised in Chapter 2, but discussion of traffic engineering research is provided in Chapter 4.

A summary of salient findings is presented in Section 2.7 and, for ease of reference, a summary table based on the reference sources quoted in Chapter 2 is presented in Appendix B.

2.2 Cycling use statistics

2.2.1 Transport bulletin and National Travel Survey data

Before discussing census data it is worth summarising data on cycle use from other sources to understand the context and limitations of census data.

The Transport Statistics Bulletin for Quarter 1 in 2003 (DfT, 2003a) indicates that pedal cycles comprised 1% of road traffic in 2002. Table 2.1 indicates the index of estimated pedal cycle traffic since 1993 in billion vehicle kilometres.

Table 2.1 Pedal cycle traffic in Great Britain 1993 to 2002

	All motor vehicles	Pedal cycles
Estimated traffic in 1993 (billion vehicle kilometres)	412.2	4.0
1993	100.0	100.0
1994	102.2	100.2
1995	104.2	103.3
1996	107.0	101.7
1997	109.2	101.8
1998	111.5	98.7
1999	113.2	101.6
2000	113.2	103.7
2001	115.0	105.5
2002	117.9	110.0

It would appear that there has been an unprecedented rise in cycle traffic in the year from 2001 (4.2 bn. cycle kms.) to 2002 (4.4 bn. cycle kms.) with the Summer months (2002 Q2 index 108.9 and 2002 Q3 index 114.9) having the greatest volume of cycle traffic. Previous estimates of the volume of cycle traffic in earlier bulletins had shown a decrease from 4.5 billion vehicle kilometres (1993) to 4.0 billion vehicle kilometres (2001). The present bulletin does not fully explain the reversal of this trend, but it may be linked with increased detailed study of traffic counts on minor roads and the division of roads into 22 rather than 7 categories for analysis. The low point of 98.7 in 1998 is not explained either.

The National Travel Survey (DfT, 2002a) shows a declining trend in use of the bicycle both in terms of the average distance travelled and the number of trips per person as shown in Table 2.2.

Table 2.2 National Travel Survey average trips and mileage by bicycle

	Average distance travelled (miles) per person per year (bicycle / all modes[1])	Average number of trips per person per year	Average trip length (bicycle / all modes[1])
1975/76	51 / 4740	30	1.7 / 5.1
1985/86	44 / 5317	25	1.8 / 5.2
1989/91	41 / 6475	21	1.9 / 5.9
1992/94	38 / 6439	18	2.0 / 6.1
1996/98	38 / 6728	16	2.3 / 6.4
1999/2001	39 / 6815	16	2.5 / 6.7

Notes

1 All modes average distance travelled and average trip length taken from TSGB (2003)

While the all modes average distance travelled has risen by 44%, the average distance travelled by bicycle has declined by 24%. Average bicycle trip length has risen by 47% over the period 1975/76 to 1999/2001 (Cf. 31% increase for all modes), perhaps because of decreasing use of the bicycle for very low distance journeys, or because only a "hard-core" of cyclists is left. The latest bulletin on cycling statistics in England (DfT, 2003b) and Great Britain (DfT, 2003c) reports bicycle travel as the number of stages per person per year, where a trip consists of one or more stages and a new stage is defined when there is a change in the form of transport or when there is a change in vehicle requiring a separate ticket. Table 2.3 indicates a year by year breakdown of bicycle travel for England.

Table 2.3 Bicycle travel in England

	Average distance travelled (miles) per person per year	Bicycle stages per person per year	Average bicycle stage distance (miles)
1996	41	19	2.2
1997	43	19	2.2
1998	37	16	2.4
1999	45	18	2.5
2000	41	18	2.3
2001	38	15	2.5

Assuming a population of 58 million, it may be noted in passing that the National Travel Survey (NTS) average distance travelled per person of 38 miles per year for 2001 would imply 3.5 bn cycle kilometres compared with the traffic bulletin estimate of 4.2 bn cycle kilometres for the same year. On the basis that some of the travel identified in the NTS may have been undertaken on non-highway routes, this discrepancy is perhaps all the more noteworthy.

It is also worth noting the consistent changes with time for groups of years in Table 2.2, but the less certain direction implied by the figures in Table 2.3. The additional year to year detail available from the expanded NTS is not robust for minority activities such as cycling and concern had been expressed that the NTS is missing some cycling journeys. In order to investigate this issue, additional probing questions were asked in the April 1997 survey (Jackson, undated) and the concern was not substantiated.

The cycling bulletin notes that in 1999/2001 46% of bicycle journeys for men and 35% for women were for journey to work and business, indicating that the majority of cycling activity is for reasons other than the journey to work. (Note that Sharp (1990) reports that 90% of men and 67% of women can cycle). The bulletin also notes that the Labour Force Survey of Autumn 2001 indicated that 3% of those who travelled to work did so by bicycle.

Other relevant data at a national level includes Sustrans' monitoring of non-National Cycle Network routes and National Cycle Network routes that show a 2-3% and 13% rise respectively for the year 2001 to 2002 (Surveyor, 2003). On a sample of 22 Sustrans routes across the UK it was found that the average length of trips for "functional purposes" was 10 kilometres and for "recreational purposes" was 25 kilometres, although the variation from route to route in the sample was large (Cope et al., 2003).

An analysis of census data from the years 1981, 1991 and 2001 is then against a backdrop of:

- apparently increasing cycle traffic in the decade to 2001;
- variation in cycle traffic being seasonal, with flows picking up in the second quarter of the year, i.e. from April at the time when the census is undertaken;

- a declining trend in the average number of trips per person per year by bicycle up until the 1980s, but then an apparent levelling off;
- cycle traffic for the journey to work comprising less than half of all cycle journeys by trip purpose; and
- the Labour Force Survey in 2001 indicating a journey to work proportion for the bicycle of 3%.

2.2.2 Census data

Overall and regional comparisons

Table 2.4 summarises overall proportions of cycling for the journey to work by bicycle for England, Scotland and Wales and for Great Britain for the years 1981, 1991 and 2001 from census data. Note that the percentages are calculated based on the number of persons making a journey to work (and in the case of Scotland for those aged over 16 making a journey to study), that is to say that persons who work from home are deducted from the denominator in the calculation. The relevant census question asks for the mode of transport that forms the longest part of the journey to work by distance. Hence, as it is likely that a public transport leg of a journey is longer than a cycle leg, the census does not include as "cycle journeys to work" journeys where a stage of the journey is made by bicycle.

Table 2.4 Overall comparisons 1981, 1991 and 2001

	1981	1991	2001
England	4.11%	3.21%	3.11%
Wales	1.59%	1.41%	1.53%
Scotland	1.44%	1.36%	1.53%[1]
Great Britain	3.76%	2.97%	2.89%

Notes

1 All figures calculated by removing those who work or study mainly from home. Hence in the case of the Scottish data the percentage differs slightly from that quoted in KS15 (ONS, 2003a).

The decline of 0.9% points in the percentage cycling to work in England in the decade to 1991 appears to have been arrested in the subsequent decade with only a 0.1% point decline evident. For Great Britain the 0.79% points decline to 1991 has levelled off with a decline of only 0.08% points to 2001.

The increases in the percentage in Scotland and Wales are also reflected in the English regions of the North East, London and to a small extent the South West shown in Table 2.5. It should be noted that the base figure for persons travelling to work in England has risen consistently in each census year. In Wales, however, the number of journeys to work in the 2001 census was 1,070,933, compared with the 1991 figure of 1,087,400. It would appear that within the 16,467 journeys that did not take place in Wales in 2001 compared with 1991, a disproportionate number were undertaken by modes other than the bicycle.

Table 2.5 shows comparisons across the three census years by Government region for England. The source of the 1981 and the 1991 data is the Census Dissemination Unit website that allows for machine readable data to be downloaded and the data available is based on a cross-tabulation of travel to work and socio-economic group based on a 10% sample (CDU, 2003). The 2001 data comes from the Office of National Statistics (ONS, 2003b).

Table 2.5 English regional comparisons

		1981 (10% sample)	**1991 (10% sample)**	**2001**
North East	JTW	101,750	97,594	953,660
	Cycle JTW	2,026	1,527	16,786
	% cyclists	1.99%	1.56%	1.76%
North West	JTW	275,036	275,055	2,657,546
	Cycle JTW	8,714	7,263	65,961
	% cyclists	3.17%	2.64%	2.48%
Yorkshire and Humberside	JTW	193,180	200,883	1,998,658
	Cycle JTW	7,686	6,936	63,384
	% cyclists	3.98%	3.45%	3.17%
East Midlands	JTW	158,375	174,710	1,744,420
	Cycle JTW	7,521	6,637	62,644
	% cyclists	4.75%	3.80%	3.59%
West Midlands	JTW	209,321	220,851	2,125,744
	Cycle JTW	7,117	5,529	52,545
	% cyclists	3.40%	2.50%	2.47%
East	JTW	202,668	231,997	2,335,893
	Cycle JTW	14,227	11,382	100,193
	% cyclists	7.02%	4.91%	4.29%
London	JTW	298,270	282,644	3,033,199
	Cycle JTW	7,308	5,783	77,330
	% cyclists	2.45%	2.05%	2.55%
South East	JTW	297,774	344,768	3,502,454
	Cycle JTW	15,587	12,674	119,315
	% cyclists	5.23%	3.68%	3.41%
South West	JTW	166,145	200,603	2,034,699
	Cycle JTW	8,015	7,470	76,430
	% cyclists	4.82%	3.72%	3.76%

Notes

1 JTW is journeys to work

The East of England, which is drier and flatter than the rest of England remains the region with the largest proportion of people that use the bicycle for the journey to work. The South West is the region with the next highest proportion and this may be characterised by early Springs and warm Summers despite being relatively wet. The large declines in the East of England (2.11% points) and South East of England (1.55% points) in the decade to 1991 have stabilised in both of these regions for the decade to 2001. This stabilisation of decline in the regions with the larger proportions that cycle for the journey to work is, perhaps, a further symptom of the "bottoming out" of the decline in cycle use.

District comparisons

As counties are generally geographically non-homogenous, the analyst is immediately coaxed towards the greater detail offered by the data at the level of the 354 districts in England and the 22 unitary authorities in Wales[1]. Table 2.6 shows the rank ordering of cycle use for the journey to work by district based on the 1981 census for the 26 English districts with cycle journey to work percentages greater than 10%.

Table 2.6 Rank ordering of Districts with greater than 10% cycle mode share in 1981

2001 District Name and Code	2001 % cyclists	1991 % cyclists	1981 % cyclists
12UB Cambridge	28.34%	26.06%	27.61%
00FF York UA	13.06%	17.93%	20.98%
38UC Oxford	16.22%	16.26%	20.25%
32UB Boston	11.13%	14.31%	18.91%
42UH Waveney	9.27%	11.54%	16.60%
13UD Crewe and Nantwich	7.58%	11.05%	15.82%
12UD Fenland	7.44%	9.37%	15.36%
00FA Kingston upon Hull; City of UA	12.32%	12.69%	15.07%
24UF Gosport	11.44%	14.45%	14.70%
32UF South Holland	6.46%	8.86%	14.61%
00JA Peterborough UA	8.33%	10.76%	13.83%
36UF Ryedale	5.18%	9.11%	13.06%
33UG Norwich	9.37%	9.75%	12.98%
23UB Cheltenham	7.55%	8.74%	11.94%
00FC North East Lincolnshire UA	8.19%	8.54%	11.84%
40UC Sedgemoor	7.05%	7.95%	11.69%
33UF North Norfolk	5.57%	7.47%	11.33%
32UD Lincoln	7.59%	7.63%	10.87%
33UE King's Lynn and West Norfolk	6.07%	7.73%	10.81%
09UD Bedford	5.05%	6.07%	10.68%
36UH Selby	4.26%	6.53%	10.63%
00FD North Lincolnshire UA	6.08%	7.77%	10.57%
00MR Portsmouth UA	7.59%	8.69%	10.52%
45UC Arun	5.66%	6.72%	10.45%
40UE Taunton Deane	7.45%	8.25%	10.21%
42UD Ipswich	6.13%	7.35%	10.07%

So far as Wales is concerned Cardiff (2.89%) has the highest proportion cycling for the journey to work followed by Denbighshire (2.06%) and The Vale of Glamorgan (2.05%). 14 other unitary authorities in Wales have proportions greater than 1%, with the remaining 5 having proportions less than 1%.

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[1] Some district boundary changes took place between 1981 and 1991, but there have been significant changes in the decade to 2001, principally as a result of the creation of many new unitary authorities in shire county areas and the disappearance of the counties of Humberside and Avon. Discussion at a greater geographical detail in Scotland has not been undertaken.

There is a consistent journey to work proportion by bicycle maintained in Cambridge, but perhaps, with the slight decline to 1991, there is evidence of a mirroring of the national trend of decline through the 1980s. York has significantly declined in mode share for the bicycle for journeys to work and this is related to the larger area that the City of York now covers as a unitary authority. In 1991 there were 4,377 journeys to work in the York City area, in 2001 there were 10,508 journeys to work in the York unitary authority area. These boundary issues are also relevant for North East Lincolnshire (Grimsby), and other districts besides. Oxford would appear to have stabilised after a 3.99% point reduction from 1981 to 1991. The decline in the proportion using the bicycle for the journey to work is generally greater in districts that had higher cycle proportions in 1981 and the range of the percentage point decline is from 2.75% (Kingston-upon-Hull) to 8.24% (Crewe and Nantwich). The ten districts either side of the 1981 English District average of 4.11% show an average decline in proportion cycling for the journey to work of 1.32%, although two districts (North Devon and Exeter) show increases (0.2% points and 0.77% points respectively). At the bottom end of the table, the ten districts with the lowest proportion cycling for the journey to work in 1981 (ranging from 0.00% to 0.56%) showed an average increase in cycling for the journey to work of 0.94% points. Once again the declines, as for the regional data, are more pronounced in areas of higher cycle use confirming a trend of "bottoming out".

Considering the data from the point of view of 2001, Table 2.7 shows the twenty-nine districts with mode shares for the journey to work by bicycle greater than 6%.

Table 2.7 Rank ordering of Districts with greater than 6% cycle mode share in 2001

2001 District Name and Code	2001 % cyclists	1991 % cyclists	1981 % cyclists
12UB Cambridge	28.34%	26.06%	27.61%
38UC Oxford	16.22%	16.26%	20.25%
15UH Isles of Scilly	15.59%	15.04%	6.58%
00FF York UA	13.06%	17.93%	20.98%
00FA Kingston upon Hull; City of UA	12.32%	12.69%	15.07%
24UF Gosport	11.44%	14.45%	14.70%
32UB Boston	11.13%	14.31%	18.91%
33UG Norwich	9.37%	9.75%	12.98%
42UH Waveney	9.27%	11.54%	16.60%
00JA Peterborough UA	8.33%	10.76%	13.83%
00FC North East Lincolnshire UA	8.19%	8.54%	11.84%
12UG South Cambridgeshire	7.59%	7.19%	9.00%
00MR Portsmouth UA	7.59%	8.69%	10.52%
32UD Lincoln	7.59%	7.63%	10.87%
13UD Crewe and Nantwich	7.58%	11.05%	15.82%
23UB Cheltenham	7.55%	8.74%	11.94%
38UE Vale of White Horse	7.52%	8.32%	8.06%
40UE Taunton Deane	7.45%	8.25%	10.21%
12UD Fenland	7.44%	9.37%	15.36%
40UC Sedgemoor	7.05%	7.95%	11.69%
00AM Hackney	6.83%	4.03%	2.56%
23UE Gloucester	6.52%	7.12%	9.74%
32UF South Holland	6.46%	8.86%	14.61%
16UC Barrow-in-Furness	6.35%	9.11%	7.22%
32UE North Kesteven	6.17%	6.43%	7.56%
42UD Ipswich	6.13%	7.35%	10.07%
00FD North Lincolnshire UA	6.08%	7.77%	10.57%
33UE King's Lynn and West Norfolk	6.07%	7.73%	10.81%
42UG Suffolk Coastal	6.04%	6.47%	9.78%

It would appear that the favoured destination for cycle study tours should be the Isles of Scilly, but the percentage is calculated from a low base of journeys to work (975 in 2001, compared with the English district average of 58,000).

The majority of the districts listed above (fifteen) are located in the drier and flatter East of England. Other notable locations, such as Oxford, Crewe & Nantwich and Barrow-in-Furness, are noted for large employers (either universities or engineering works) that may account for a sub-culture of cycling. South coast towns and towns in the South West (including Cheltenham and Gloucester) are well represented.

Table 2.8 lists districts that have demonstrated increases in cycling of 1% point or more in the decade to 2001.

Table 2.8 Rank ordering of Districts with greater than 1% point increase in cycle mode share from 1991 to 2001

2001 District Name and Code	2001 % cyclists	1991 % cyclists	1981 % cyclists	2001-1991
00AM Hackney	6.83%	4.03%	2.56%	2.81%
12UB Cambridge	28.34%	26.06%	27.61%	2.28%
00HB Bristol; City of UA	4.94%	3.30%	3.21%	1.64%
00AU Islington	5.15%	3.52%	2.59%	1.63%
00MC Reading UA	4.44%	2.83%	3.98%	1.61%
00AN Hammersmith and Fulham	5.21%	3.80%	3.89%	1.41%
00AY Lambeth	4.47%	3.06%	2.49%	1.41%
18UC Exeter	4.84%	3.44%	4.07%	1.40%
00AG Camden	4.10%	2.78%	2.52%	1.32%
39UD Oswestry	2.94%	1.75%	5.94%	1.19%
00ML Brighton and Hove UA	2.97%	1.82%	1.53%	1.15%
00BJ Wandsworth	4.22%	3.07%	3.12%	1.14%
00BE Southwark	3.98%	2.89%	2.21%	1.10%
00FY Nottingham UA	3.93%	2.93%	2.96%	1.00%

The nature of the districts demonstrating increases is somewhat disparate, including county towns, many London boroughs and some new unitary authorities. Noticeably absent are districts in metropolitan counties. It is worth noting that the absolute increase in the number of cycle journeys to work in Hackney from 1991 to 2001 is 2,670, for Cambridge it is 1,848 and for Nottingham it is 891. All of the London boroughs are Inner London boroughs and relatively close to the business and commercial heart of the city. The reasons for increases in these boroughs could be linked with socio-economic changes, distances to work and infrastructure changes being put in place.

Only 6 of the 14 districts showing the greatest increase in percentage points in the decade to 2001 had cycle usage at a level greater than the average (3.21% for England) in 1991. This could imply that other "special factors" are at work rather than that some districts are inherently better, or at least progressively better, places for cycling. The seven London boroughs with increases greater than 1% point are all inner London boroughs. Of the remaining 26 boroughs, 7 demonstrate a decline in cycle use for the journey to work and the largest decline is -0.82% points (Hillingdon). A detailed comparative analysis of the fairly significant differences between London boroughs and any potential causes of these differences could be instructive.

Table 2.9 shows, not unexpectedly, that the vast majority of districts show little if any change in the proportion cycling to work in 2001 compared with 1991.

Table 2.9 Number of English districts in different bands of percentage point change from 1991 to 2001

Percentage point change in proportion cycling for the journey to work 1991 to 2001	Number of English districts in range
-3.0% or a greater decrease	5
-1.0% to less than -3.0%	35
Less than -1.0% to +0.0%	167
0.0%	3
0.0% to less than +1.0%	130
+1.0% or greater increase	14
Total	354

The five districts with a greater than 3.0% decline are York (4.87%), Ryedale in North Yorkshire (3.93%), Crewe and Nantwich in Cheshire (3.47%), Boston in Lincolnshire (3.18%) and Gosport in Hampshire (3.01%). All five districts demonstrated higher than average proportions of cycling for the journey to work in 1991 and appear in Table 2.6. More districts exhibit a decline in the proportion cycling for the journey to work than exhibit an increase.

Concluding remarks

Geographical variation is evident from the census data and perhaps belies physical factors, such as climate and topography, which may affect the use of the bicycle. Other high use areas and areas where there have been high increases in use over the last decade indicate that there could be other infrastructure or socio-economic factors influencing the quantity of cycle use.

Census data shows no great difference in proportion of journeys to work made by bicycle in 2001 as compared with 1991, with the England and Wales average for 2001 being 2.89%. This suggests an arrest in the decline in cycle use for the journey to work that took place during the 1980s. The census data is consistent with the Autumn 2001 Labour Force Survey proportion of 3%.

Fourteen districts (4.0%) in the 2001 census demonstrate percentage point increases in cycling greater than 1% compared with the 1991 census and 7 of these are London boroughs. Notwithstanding London's special nature, a detailed comparative analysis of the fairly significant differences between London boroughs and any potential causes of these differences could indicate the presence of special factors that may be instructive in the further promotion of cycling for the journey to work.

Journeys to work by bicycle form less than half of all journeys by bicycle and hence the census data is representative of changes in cycle use only for a minority of cycle journeys. A further compounding problem is that the census questionnaire asks for mode of transport for the longest stage of the journey to work by distance. Changes in choice of access mode to the main mode of a journey to work are therefore not indicated in the census data.

While the census data shows a stable level of cycle use for the main mode journey to work for 2001 in comparison with 1991, the 1st quarter 2003 transport statistics bulletin demonstrates a

5.5% growth in pedal cycle kilometrage from 1993 to 2001. A significant growth in cycle use is also reported by Sustrans in connection with National Cycle Network Routes for the year 2001 to 2002, confirming a picture of increasing use towards the end the decade to 2001. Contrasting with this is National Travel Survey data which shows a decline in both the average distance travelled per person by bicycle and the number of bicycle stages of a journey made per person per year in the period 1996 to 2001[1].

The findings of Section 2.1.2 have been published in Parkin (2003).

2.2.3 Other use level data

As part of the London Area Transport Survey in 1991, interviews were conducted in 60,000 households, equivalent to 2% of the population of London (LRC, 1997). The sample size allows for robust estimates for travel variables on comparatively small ethnic minority populations. Table 2.10 below presents data on cycle mode choice by ethnicity for Londoners.

Table 2.10 Percentage of trips undertaken by bicycle by ethnicity for Londoners (inside M25 area) for a 24-hour weekday in 1991

Ethnicity	Population	Percentage by bicycle
White	5,969,000	2.0
Black Caribbean	306,000	1.1
Black African	152,000	0.7
Black Other	64,000	2.0
Indian	369,000	0.6
Pakistani	91,000	0.4
Bangladeshi	83,000	0.7
Chinese	50,000	1.2
Other	268,000	1.8
No response	131,000	
Total	7,483,000	1.8

It is interesting to note the very low percentages for some ethnic groupings, particularly Bangladeshis and Indians. These populations tend to be concentrated, for example, the Bangladeshi population is centred in Tower Hamlets, and social patterns may create conditions for short trip length journeys. Despite the suitability of the bicycle for shorter journeys, they are not manifest in the figures as bicycle journeys. The wide variation shown by this data leads to the conclusion that ethnicity could play a significant part in the mode share by bicycle nationally.

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[1] Note that the National Travel Survey will cover some trips on the National Cycle Network, but possibly not all of them where they are off the road in open country, or purely for leisure or exercise.

2.2.4 International use level comparisons

Table 2.11 compares levels of cycle ownership and use in European countries (European Commission, 1999).

Table 2.11 European cycle ownership and use

Country	Cycles per thousand inhabitants[1]	Regular cyclists (1-2 times per week)[2]	Occasional Cyclists (1-3 times per month)[2]	Kilometres per inhabitant per year[3]
Belgium	495	28.9%	7.0%	327
Denmark	980	50.1%	8.0%	958
Germany	900	33.2%	10.9%	300
Greece	200	7.5%	1.8%	91
Spain	231	4.4%	3.9%	24
France	367	8.1%	6.3%	87
Ireland	250	17.2%	4.0%	228
Italy	440	13.9%	6.8%	168
Luxembourg	430	4.1%	9.7%	40
Netherlands	1010	65.8%	7.2%	1019
Austria	381	-	-	154
Portugal	253	2.6%	2.8%	35
Finland	596	-	-	282
Sweden	463	-	-	300
UK	294	13.6%	0.8%	81

Notes:

1 Cycle ownership levels as at 1996.

2 Eurobarometer figures for 1991, for age over 15 years.

3 Kilometres cycled per inhabitant per year for 1995 for the entire population including children

Cycle ownership lies generally within the band 200 to 500 cycles per thousand head of population in most European countries. The noticeable exceptions at more than twice the average are Denmark, Germany and The Netherlands with around 1,000 per thousand head of population. The countries with the lowest levels of ownership are Spain, Portugal and Greece, all of which are in Southern Europe. Higher use in northern Europe is generally in countries that have a greater extent of infrastructure designed for bicycle use. It is subject to debate whether or not this more specifically cycling oriented infrastructure is the cause of the greater cycling, or whether or not it is the consequence of a topography, climate and culture more conducive to cycling. Low use in Southern European countries is again perhaps linked with the heat of the climate, and the perception of the bicycle as a toy, or a machine for sport.

The majority of countries have rates of regular use (once to twice per week) among the adult population of less than 15%. Again the exceptional countries are The Netherlands, Germany and Denmark with between a third and two thirds of the population cycling either once or twice per week. Interestingly Belgium also has a high rate of regular use.

Kilometres per inhabitant are in the range up to 300 kilometres per inhabitant with the exceptions being The Netherlands and Denmark. Interestingly Germany is at a level much nearer to the European norm, and could indicate either shorter average distances travelled or a rate of regular trip making greater than that in The Netherlands and Denmark. This latter seems implausible.

Further aggregate data on pan-European use is presented by Rietveld and Daniel (2004) in Table Table 2.12 below.

Table 2.12 Country mode shares by person kilometres and trips

	Cycling		Walking		Motorised Transport		Public Transport		Other
Country	**Person-kms %**	**Trips %**	**Person-kms %**	**Trips %**	**Person-kms %**	**Trips %**	**Person-kms %**	**Trips %**	**Trips %**
The Netherlands	6.66	30	2.96	18	76.11	45	14.27	5	2
Denmark	5.48	20	2.52	21	73.79	42	18.20	14	3
Germany	2.47	12	3.16	22	76.52	49	17.85	16	1
Belgium	2.42		2.86		78.64		16.09		
Sweden	1.95	10	2.76	39	76.09	36	19.20	11	4
Finland	1.82		2.79		79.05		16.34		
Ireland	1.62		3,23		77.83		17.32		
Austria	1.11	9	3.42	31	77.26	39	24.21	13	8
Italy	0.97	5	2.60	28	80.19	42	16.24	16	9
Greece	0.63		3.25		76.43		19.68		
UK	0.60	8	2.83	12	84.18	62	12.39	14	4
France	0.49	5	2.65	30	79.12	47	17.75	12	6
Portugal	0.26		3.09		82.54		14.11		
Spain	0.18		3.35		78.77		17.70		
Luxembourg	0.00		3.05		78.66		18.29		
EU15	1.42		2.89		79.07		16.61		
Switzerland		10		29		38		20	1
Canada		1		10		74		14	1
USA		1		9		84		3	3

Notes:

1 Data taken from Rietveld and Daniel (2004) which in turns is taken from EU Energy and Transport Figures (percentage person-kilometres) and www.ibike.org/library/statistics.htm (percentage trips)

2 Motorised transport for the person kilometres includes car and powered two-wheelers and public transport includes tram, metro, bus, coach and railway.

The data confirms the European North-South divide in cycle use demonstrated in Table 2.11 and, at least so far as trips are concerned, demonstrates the very high degree of motorisation in North America.

A study by Herz (1985) in Germany of 150,000 week-day trips of 44,000 people throughout the year 1976 revealed that schoolchildren and apprentices used the bicycle (28% of trips) more than economically active people (6.3% of trips). Unsurprisingly there was a greater proportion that used the bicycle in households without a car (19.7% for men and 11.5% for women) than with a car (3.8% for men and 7.4% for women). Housewives used the bicycle (11.5%) more than the elderly (6.4%). The population of the town with the largest proportion of trips undertaken by bicycle was found to be around 100,000 with significantly less use in towns of less than 5,000 and over 500,000. In "mountainous" areas cycling drops off to one-half to one-third of what it would be if the effect of topography were not present. In the winter of 1976 cycling was at a level of around 70% of the number of Summer cycling trips.

A later study by Bracher (1992) reports wide variation in cycle use across Germany. Nearly 30% mode share is achieved in Dessau, Erlangen, Münster, Rosenheim and Landshut. These towns range from populations of 50,000 to 269,000. In the large cities of Hamburg, Munich, Cologne and Frankfurt the mode share is 10% and is near the national average of 11%. Ten years later, Bohle (2002) quotes Münster, Bremen, Freiburg and Erlangen as having cycling shares in the range 25%-30%. Bracher suggests that factors that influence cycle use strongly are the type of settlement and the distribution of distances within the settlement caused by land use patterns. Bohle notes that topography and socio-economic characteristics, with more well educated people of higher social status using bicycles, are factors. He further notes that many Germans have generally positive attitudes towards cycling and that advantages to the individual (e.g. health benefits, time savings and general promotion of well-being) stimulate cycling as much as the provision of infrastructure.

Large cities have distinct working, living and shopping districts that would tend to create longer trip lengths than for smaller towns. The towns "function" (undefined by Bracher) and topography are also suggested as playing a part. On any given day the national average mode share by bicycle for 10-15 year olds is 33%. Overall, 30% of trips are for leisure, 34% are for shopping and personal business and 36% are for trips to work and education. Months between June to September inclusive are peak months for cycling. The majority of cycle trips are for distances of 1.1 to 2.0 kilometres.

Pucher (1997) has also compared cycle levels of use of a number of cities in Germany and has quoted the lengths of cycle track and cycle lane for three of them. Assuming the population density and highway networks are related in a directly proportional way to the size of the population, then the measure "metres of cycle network per person" may act as a proxy for the level of cycling provision and this may be related to proportion of trips made by bicycle. This relationship is shown to hold in Table 2.13 below, but the comprehensiveness of the network and the proportion of individual journeys which need to be made on other than the cycle network are not revealed, but are salient.

Table 2.13 Cycling in Germany

City	Data Year	Population (thousands)	Percentage of trips by bicycle	Length of Cycle Network km	Metres of cycle network per person
Münster	1994	270	32	395	1.46
Bremen	1991	554	22	750	1.35
Freiburg	1992	179	19		
Hannover	1990	524	16		
Munich	1995	1,257	15	644	0.51
Cologne	1992	961	11		
Nuremberg	1995	500	10		
Düsseldorf	1990	578	9		
Kassel	1994	192	7		
Stuttgart	1990	599	6		
Essen	1990	627	5		

It is not self-evident from Pucher's work whether or not infrastructure "causes" greater proportions to cycle. Pucher also found that the number of students as a proportion of the population (high in Münster and Freiburg) and the number of cycle parking bays available (4,000 and 9,000 in Freiburg and Münster respectively) were important issues. Students are relatively impecunious and are less likely to own motorised transport, they are also, as a recognisable community in their own right, more likely to behave in conformity with a self-reinforcing sub-culture than the general population. It would make an interesting study to explore why students in some locations cycle and some in other locations do not. The factors of topography, facilities, peer group and congestion could be considered.

In The Netherlands in 1990 the bicycle accounted for 7.6% of distance travelled annually and 28.5% of trips (CROW, 1993a). Bicycle use was 23% greater in 1990 (13.5 billion kilometres) than in 1980 (11.0 billion kilometres). McClintock (2002) explains this as being a reflection of public commitment to protect the environment and the willingness of individuals to change their travel behaviour. Welleman (2002) is more functional and notes that topography plays a part in creating a lot of cycling. He also notes, however, that there are many other flat urban areas in other parts of Europe that do not have the same level of cycling as The Netherlands. Welleman considers that the spatial structure of a town is important and notes that 70% of Dutch cycling trips are 7.5 kilometres or less. The state of availability of alternatives is also important and he notes that the Dutch have around 400 cars per thousand head of population and that the public transport system is not always an efficient alternative to the bicycle. A final, and intangible but none the less important aspect, is what he terms the "cultural historical values" of the population and he notes that cycling amongst first generation Turks, Moroccans and Surinams living in The Netherlands is at a lesser rate than for the indigenous population. He asserts that cycling is recognised as a mode of transport that is also "part of life". Complementary to the arguments about cultural and spatial planning issues is, however, the provision of additional bicycle paths which took the total length from 9,300km in 1978 to 16,100km in 1988, that is an increase of 73%.

Welleman notes that cycling in The Netherlands seems to have stabilised and the target of a further 30% increase to 2010 from 1986 will be difficult to achieve.

Rietveld (2000a) analysed Dutch cycle use in relation to multi-leg journeys that use more than one mode. He notes that in 1994 in The Netherlands the share of the bicycle for all trips was 28% but for access trips to the train as the main mode the percentage is only 23%. Considering the home end of the journey the percentage that uses the bicycle is 35% but that at the destination end of the journey the percentage is 10%, creating this lower average. This asymmetry in availability for use of the bicycle, he suggests, could be tackled by more secure parking provision at the destination end of a journey for a second bicycle, renting schemes or better facilities for the carriage of bicycles on trains. Continuing the theme Rietveld (2000b) notes that national statistics usually collect only main mode for a journey. Using 1997 data, when bicycle trips accounted for 28% of the total number of trips in The Netherlands, he shows that the total number of trips by bicycle per person per day rises from 1.05 to 1.09 when multi-modality is accounted for. Comparable figures for distances in kilometres per person per day are 3.11 and 3.20. He contends that, to compete against the car as a mode, the overall journey with train as main mode needs to be considered. This should include consideration of the access mode and encouragement of this leg of the journey by bicycle rather than on foot could significantly change the balance of choice towards the train. Hence, railway companies should not be interested solely in speed and frequency of the main mode, but on accessibility to public transport nodes by non-motorised modes.

Pucher (1997) summarised levels of cycle use for urban travel across Europe at 1990 levels. In The Netherlands, use as a percentage of all urban trips was 30% with Denmark not much lower at 20%. Western Germany at 12% was at a similar level to Switzerland and Sweden at 10% each. England and Wales is quoted at 8% with France at 5%. The figures are compared with Canada and the USA at 1% each. Reasons for the disparity in levels between countries could be as a result of different levels of car ownership, economic necessity, climate and topography. Pucher could not identify significant disparity in levels of these indicators between any of the countries mentioned and noted that topography within urban areas is likely to be relatively similar (apart from perhaps in Switzerland) because urban areas are likely to be constructed, for reasons of convenience, on relatively flat terrains. Such analysis at an aggregate country level does not, however, account for the differences within a country, for example the flat East of England relative to the hilly Pennine towns. A significant difference between Europe and the North American continent however is in size of urban settlement and urban trip lengths are about 50% longer in North America than in Europe. A second significant difference between urban areas is in terms of length of cycle track and cycle lane provided and the legal position of the cyclist relative to other traffic (in terms of priority and enforcement of violations).

Jensen (undated) has undertaken an analysis of the level of cycling in Odense in Denmark over the period 1995 to 1999 using data from the national travel survey of Denmark. Odense (population 153,000) is the "National Cycle City of Denmark" where developments in cycle facility design have been pioneered. A total of 2,603 respondents in the Municipality were interviewed over the period and Table 2.14 below summarises the main findings.

Table 2.14 Main findings from trip analysis of Odensers

Age	Mode share	Income	Mode share	Employment	Mode share	Commuting Distance	Mode share
10-19 years	46%	0-100DKK	38%	Student / pupil	48%	0-2km	49%
20-29 years	39%	100-200DKK	26%	Unemployed	20%	3-5km	40%
30-39 years	22%	200-300DKK	23%	Pensioner	13%	6-9km	25%
40-54 years	21%	300+DKK	18%	Self-employed	13%	10-19km	14%
55-84 years	17%			Manual worker	27%	20-49km	11%
				Lead employee	26%	50+km	11%
				Other employee	22%		

Correlations clearly exist between age and employment status and also employment status and income level. It is interesting to note the commuting distance effect on mode share. The author also notes other linkages between type of domicile and level of car ownership but again these are not so strong and more likely to have age, employment status or income as the fundamental variables of significance. A cross-correlation of district against a range of determining factors including those tabulated above and discussed above, demonstrated generally good agreement apart from for three districts. In one of these three it was noted that the lower than otherwise forecast level of cycle usage could be due to the greater preponderance of "foreigners" (sic) living in the district. This raises the issue of culture and its effect on bicycle as a choice of mode. The other two districts are noted as being slightly hillier than the average for the Odense area.

Australia mimics other western countries in its levels of car, public transport, walking and cycling use. A project in Perth in Western Australia has been introduced that seeks to market alternatives to the car individually to prospective mode-switchers (Ashton-Graham et al., 2002) based on the particular circumstances of an individual. This approach recognises that infrastructure is not the only determiner of travel choice and the project has been successful in increasing the quantity of cycling by 61% (up from 2% to 3% mode share). It was noted however that the increase in cycling was created by a greater number of cycle journeys by existing cyclists rather than by a shift from other modes to cycling by previous non-cyclists.

2.3 Accident data

2.3.1 A warning about official statistics

Most accident analysis depends on police reporting. Hospital based studies (e.g. Stutts et al., 1990) show that there may be significant under-reporting of cycle accidents and this will lead to inaccuracies in assessment of victim characterisation (e.g. age and sex) and accident type (e.g. proportion including another vehicle which are less under-reported than solo accidents).

Under-reporting of casualty only accidents is noted in the official statistics (DfT, 2002a). Of those that are reported, about a fifth do not appear in statistical returns and there is a tendency to underestimate casualty severity and, finally, reporting rates for vulnerable road user groups are lower than the average.

2.3.2 Great Britain accident statistics

Accident data in the UK is reported through the STATS19 police reporting procedure and summary data is reported annually (DfT, 2002b). Table 2.15 below compares casualties and casualty rates for all classes of user against those of the bicycle user.

Table 2.15 Casualties and casualty rates in the Great Britain

	All casualties				Cyclist casualties			
	1994-98 average	1999	2000	2001	1994-98 average	1999	2000	2001
Fatal	3,578	3,423	3,409	3,450	186	172	127	138
Serious	44,078	39,122	38,155	37,110	3,546	3,004	2,643	2,540
Slight	272,272	277,765	278,719	272,749	20,653	19,664	17,842	16,436
All	319,928	320,310	320,283	313,309	24,385	22,840	20,312	19,114
Traffic[1]	4,458	4,660	4,677	4,735	43	41	40 (41)	40 (42)
KSI rate[2]	11	9	9	9	88	77	68 (67)	67 (63)
Slight rate[2]	61	60	60	58	484	478	441 (430)	412 (389)
All rate[2]	72	69	68	66	572	555	509 (490)	479 (453)

Notes

1 *Traffic is quoted in 100 million vehicle kilometres.*
2 *Rate per 100 million vehicle kilometres.*
3 *Figures in brackets calculated by the author based on revised pedal cycle volumes, see Table 2.1*

The total number of "all casualties" and cycle casualties is falling. The rates for all casualties[1] and cycle casualties are also falling for each type of casualty. Improvement over the baseline average for cyclists killed or seriously injured is 28% compared with a reduction of 18% for all casualties. For slight casualties the reduction is 21% for cyclists compared with 5% for all casualties. The situation would seem to be progressively better for cyclists and is against a backdrop of increasing cycle use. This is a significant finding as it shows that there is not necessarily a positive causal relationship between cycle traffic volumes and accident casualty rates.

[1] It should be noted that the traffic volumes quoted are as published in the Road Accidents Great Britain and not corrected for the revised estimates, see Table 2.1.

Table 2.16 below indicates the casualty severity by age band for casualties to cyclists in Great Britain in 2001 (DfT, 2002b).

Table 2.16 Cyclist casualties by age in Great Britain, 2001

Age band	KSI male	KSI female	KSI total	KSI total (different age split)	KSI rate per 100,000 popn.	All severities	All severities rate per 100,000 popn.
0-4	7	1	8	8	0.2	81	2.3
5-7	55	11	66	66	3.0	620	28.0
8-11	171	41	212	212	7.0	1,834	60.0
12-15	338	50	388	388	13.0	2,916	98.0
16-19	199	30	229	229	8.0	1,727	61.0
20-24	155	43	198				
25-59	1,033	246	1,279				
20-29				*382*	*5.1*	*3,274*	*44.0*
30-39				*483*	*5.2*	*3,493*	*37.0*
40-49				*349*	*4.5*	*2,087*	*27.0*
50-59				*263*	*3.7*	*1,334*	*19.0*
60+	192	53	245				
60-69				*142*	*2.7*	*656*	*12.0*
70-79				*78*	*1.8*	*310*	*7.3*
80+				*25*	*1.1*	*93*	*4.0*
All	2,182	495	2,678	2,678	4.6	19,114	33.0

There are many more male casualties than female and there are many child cycle accidents, disproportionately so particularly for the 12-15 age group as indicated by the rate as determined by population.

The location of accidents to cyclists is presented in Table 2.17 below (DfT, 2002b).

Table 2.17 Accidents involving pedal cycles

	Pedal cycles involved in accidents in built-up areas	Pedal cycles involved in accidents in non-built-up areas	Pedal cycles involved in accidents on motorways
Roundabout	1,884	204	4
T, Y or staggered junction	7,562	272	1
Crossroads	1,944	58	0
Multiple junction	297	9	0
Slip road	78	43	0
Other junction	581	28	0
Using private drive or entrance	1,121	79	0
Not at or within 20 metres of junction	4,436	871	1
Total	17,903	1,564	6

The majority of accidents occur in built-up areas, as would be expected. The vast majority of accidents occur at junctions and, of those that occur at junctions, the majority are junctions with priority as opposed to control.

Wardlaw (2000 and 2002), a self-confessed autodidact in relation to cycling and safety, notes that the number of hours spent driving for an average motorist in the UK is 280 hours, but the average number of hours riding a bicycle is 100-120 hours. Based on the Department for

Transport Casualty Report (DfT, 2002a) that states that a doubling in exposure increases accident risk by 30%, Wardlaw suggests that the true rate of accidents for cyclists should be adjusted downwards by a factor of 0.54[1]. This notion of reduction in the actual incident rate based on time of exposure Wardlaw justifies by stating that "common events are safe and rare events are dangerous". Wardlaw feels then liberated to make cross-mode comparisons based on equivalent times of exposure and Table 2.18 below summarises his deductions.

Table 2.18 Relative accident rates between modes in the UK (Wardlaw, 2002)

	Fatalities per million hours utilisation – mode user	Fatalities per million hours utilisation – third party
Pedestrian	0.20	
Pedestrian at 280 hours exposure	0.11	
Cyclist	0.46	0.50
Cyclist at 280 hours exposure	0.25	0.27
Driver	0.13	0.45
German Driver	0.26	
Belgian Driver	0.35	

Using the above figures, Wardlaw demonstrates that cycling is not as unsafe as is presupposed relative to the car.

2.3.3 European accident statistics

Developing the argument further, Wardlaw compares data across Europe for the year 1990.

Table 2.19 European comparisons

	Cyclist fatalities per million hours used	Cyclist fatalities per million hours used adjusted to 280 hours use per year	Driver
UK	0.67	0.36	0.18
France	0.35		0.60
Denmark	0.21		0.26
Netherlands	0.29		0.21
Germany	0.56		0.28
UK 1950s	0.41		0.83

Wardlaw notes that the lowest absolute rates of death per million hours used are in Denmark and The Netherlands. Germany is not that dissimilar to the UK, despite what Wardlaw considers

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[1] Assuming the usual accident exposure model $a = kE^n$, where a is the accident rate, k is a constant and E is the exposure and then if $1.3a = k(2E)^n$, it may be shown that n = 0.38. If a cyclist cycling 100 hours per year has an accident rate $a_1 = 100c_1$, comparing this with a cyclist cycling 280 hours per year gives $\frac{280c_2}{100c_1} = \frac{k.280^{0.38}}{k.100^{0.38}}$, hence $c_2 = \frac{2.8^{0.38}}{2.8}c_1 = 0.53c_1$. Wardlaw quotes 0.54 as he uses a rounded 0.4 as the power of the numerator in the last equation.

to be greater provision of facilities in Germany. He also notes that cycling is safer in France and 1950s Britain than travel by car. The reason for the lower rates in Denmark and The Netherlands could be linked with the greater safety offered by the greater number of cyclists and this theme is taken up in Section 4.4.

Wardlaw (2000) notes that the risk of death per mile cycled fell by 60% from 1991 to 1994 and this is similar to the reduction in death for all road users over the same period. He asserts from this that cyclists are able to gain to the same extent from improvements in the road environment as other road users.

Pasanen (1997) quotes comparative accident data for Europe as shown in Table 2.20 below.

Table 2.20 Comparative accident rate data for Europe (Pasanen, 1997)

Country	Average cycling Kilometres per person per day (ascending order)	Cyclist fatalities per 100 million kilometres
Great Britain	0.1	6.0
Italy	0.2	11.0
Austria	0.4	6.8
Norway	0.4	3.0
Switzerland	0.5	3.7
Finland	0.7	5.0
Germany	0.8	3.6
Sweden	0.9	1.8
Denmark	1.7	2.3
The Netherlands	3.0	1.6

Countries with lower levels of cycling tend also to have higher rates of fatalities to cyclists. This is explored further in the literature review on safety studies and is linked with the greater expectation of cyclists being present, and hence influencing the behaviour of all traffic.

2.4 A chronology of UK policy development in relation to cycling

As has been seen from the section on the history of cycling, its prominence in transport policy terms began to wane significantly in the 1960s with the expansion in the roads programme. This was despite the definition of an "environmental" capacity for a street and network of streets in the seminal report Traffic in Towns (Buchanan, 1963)[1]. Lying behind this concept is the notion that there are limits to the growth and the impact of traffic if character, safety and health are to be maintained. The wilderness years for cycling continued through the 1970s and into the 1980s, precedence being given to the great so-called "car economy". McClintock (1999) notes that cycling was detected on the "radar of policy" in the Transport White Paper of 1977 which introduced a special budget for innovatory cycle schemes. Nothing much came of this until the

[1] It might also be noted, however, that Traffic in Towns does not mention cycling.

cycle towns projects of the mid 1980s in Nottingham, Stockton, Bedford (Kempston) and Cambridge.

Cycling currently enjoys support across a number of policy areas including transport planning, health promotion and planning for sustainable development. It is difficult to define a single policy development as being the renaissance for cycling policy generally. Despite this, a seminal international report which may be traced as the origin of much current sustainable development thinking, which in turn has influenced transport policy, is the World Commission on Environment and Development report (Brundtland, 1987) which defined sustainability as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs". The subsequent United Nations Earth Summit at Rio de Janeiro in 1992 resulted in the UK Government's sustainable development strategy (DfT, 1994) and a requirement on local authorities to develop agendas for sustainable development which include action plans in relation to transport.

As early as 1992 the British Medical Association (BMA, 1992) suggested that cycling as a means of regular moderate exercise could play a highly important role in reducing stress and tension, lessening coronary heart disease, decreasing obesity and reducing osteoporosis.

The impact of new trunk roads on cyclists has been given sparse treatment in the procedures in Volume 11 Section 3 Part 8 of the Design Manual for Roads and Bridges, the section that deals with the measurement of their impacts (DMRB, 2004) and the specific point is made that reducing the impact on "pedestrians and other travellers" (note that cyclists are not specifically mentioned) is just one of the factors to be considered in route choice and design. Volume 5, Section 2 Part 4 of the Design Manual for Roads and Bridges notes that policy with regard to cyclists and trunk roads is "to take their needs into account from the outset when planning new trunk road construction or improvements". This sentiment has the prospect of being greatly reinforced by forthcoming guidance to become part of the manual on "Vulnerable Road User Auditing". Alternative provision off the trunk road is stated as being preferred but provision within the highway boundary, perhaps in the edge of carriageway hard strip, and for crossings may be provided. The manual notes that consideration should be given to segregated cycle tracks where average annual daily flows exceed 100 cycles. The advice notes that there is no ideal solution to the problems encountered by cyclists at roundabouts and a peripheral cycle track, slowing entry speeds, signalisation and grade separation are all options with varying benefits and drawbacks.

The Department of Transport issued a "Statement on Cycling" in 1994 that discussed attitudes towards safety, security, convenience and stylishness of cycling. It endorsed a role for employers to encourage cycling and commended promotional campaigns such as National Bike Week.

Also in 1994, Planning Policy Guidance Note 13 (DoE, 1994) was issued by the Department of the Environment which had as one of its three aims the encouragement of means of travel which have less environmental impact than the motor car. The guidance suggested that "effective route networks" should be developed to encourage cycle use.

A Royal Commission on Transport and the Environment (RCEP, 1994) recommended that cycle use should be increased to 10% of all urban journeys by 2005, compared to the existing 2.5%. This was based on a view that the "unrelenting growth in transport has become possibly the greatest environmental threat facing the UK".

In 1995 the Government launched the "Cycle Challenge" with a £2million fund to which local authorities could bid to promote innovative pilot schemes which could then be replicated elsewhere.

The most significant milestone in cycle policy development in the UK was the National Cycling Strategy (DfT, 1996). In opening, Stephen Norris, the then Minister for Local Transport, remarked that "it is crystal clear that the bicycle has been underrated and underused in the UK for many years". Cycling was now seen to have a role within a sustainable transport policy framework and it was asserted that cycling offers "practical alternatives to the private motor car". The central target was to double the number of trips by cycle (on 1996 figures) by the end of 2002 and to quadruple the number of trips by cycle (on 1996 figures) by the end of 2012. Local authorities and other transport providers and trip generators were encouraged to set local targets which would contribute to the central target. Convenience, safety, provision within the highway, cycle parking, cycle security, awareness raising, resources, best use of existing infrastructure and progress and monitoring were all the subject of mechanisms to assist in delivering the overall target. As part of the awareness raising, the National Cycling Forum was established and has produced "issues" leaflets for retailers and public transport planners and providers amongst others.

The Department of Transport collaborated with the Institution of Highways and Transportation (IHT), the Cyclists' Touring Club and the Bicycle Association (of manufacturers) to produce in 1996 guidelines for the planning and design of cycle-friendly infrastructure (IHT, 1996). The guidelines are about highway matters as they relate to cyclists, not just about facilities. At the same time Sustrans, the civil engineering charity, brought out guidelines and practical details for the construction of the National Cycle Network which were subsequently revised in 1997 (Sustrans, 1997). These two sets of guidelines concentrated a wide breadth of experience and practice to assist planners and engineers in the design and construction of schemes for cycle traffic.

1997 saw the publishing of revised National Road Traffic Forecasts (NRTF) (DfT, 1997). The forecasts are based on transport policies as at 1997 and no specific reference is made to cycling, although an "unresolved difficulty" in the forecasts was the lack of modelling of the assumed link between increasing car ownership and declining local bus use. Future enhancements to NRTF modelling are under development (DfT, 2000b).

In the same year, 1997, the Road Traffic Reduction Act placed a duty on local highway authorities "to prepare, at such time or times as the Secretary of State may direct, a report which, inter alia, must specify targets for a reduction in the level of local road traffic in the area, or a reduction in the rate of growth in the levels of such traffic".

In the early 1990s the Government began to require local authorities to submit for transport funding through the annual Transport Planning and Policy submission using what was known as the "package approach", i.e. a group of measures which taken together would meet local transport policy objectives. In the 1995 guidance the Government (DfT, 1995) emphasised that it expected to see cycling given due prominence. It suggested there would need to be concerted action from all interested groups and that the Government would be looking for policies that make better provision for cyclists. In a review of Transport Policy and Programme submissions in 1994/1995 Davies and Young (1995) noted that Government guidance stressed demand management and fell short of endorsing specific modes. They noted that the allocation of resources specifically to cycling was very small and dwarfed by the resources consumed in maintaining the existing highway network. They suggest that all highway authorities should set specific capital and revenue budgets to cover cycling.

In one of its first actions in power, the incoming Labour Government committed itself to a new strategy to meet a target reduction of 12.5% in greenhouse gas emissions and a 20% reduction in CO_2 emissions at the Kyoto summit of world leaders in 1997 (which followed on from the Rio Summit in 1992).

A further significant action, the incoming Government established a review of the 1994 Sustainable Development Strategy. The Government also suggested that developers should be encouraged to focus investment within urban areas, especially existing centres, rather than perpetuating the move to out-of-town sites.

Also in 1998 the Government issued a white paper on transport (DfT, 1998a) that suggested that the way forward was through an integrated transport policy which would mean:

- integration within and between different types of transport;
- integration with the environment;
- integration with land use planning;
- integration with policies for education, health and wealth creation.

So far as cycling is concerned, the white paper endorsed the National Cycling Strategy target and expressed a wish to see better provision for cyclists during all parts of their journey (destination, interchange, junctions and road space allocation). Reviews of existing cycle provision and audits of potential cycle provision for new schemes are proposed as well as the application of speed restraint to support cycle strategies. A new body, the Commission for Integrated Transport, was established and was to lead on the issue of road traffic reduction target setting under the 1997 Road Traffic Reduction Act.

Despite the re-emphasis on cycling, guidance on the New Approach To Appraisal (NATA) (DfT, 1998b) did nothing to enhance the status of cycling again referring to them under the category "pedestrians and others". It re-iterated the need to produce a schedule showing important routes, changes in typical journey lengths (time and distance) and likely changes in travel patterns with an estimate of the number of people affected.

Five year Local Transport Plans (LTP) replaced annual Transport Policy and Programme submissions, with the first draft LTPs being submitted in July 1999. Guidance from Government (DfT, 1999a) expects local authorities to produce or update local cycling strategies as part of the LTP and states that provision for cycling should be of good quality but with shared use of footways as a last resort where there is no opportunity to improve conditions on the carriageway. The guidance for Full LTPs, issued the following year (DfT, 2000c), sets out a number of minimum requirements for cycling which include a road user hierarchy with evidence that cyclists have been given a high priority and a discrete strategy for cycling with clear targets.

Eadie (1999) has reviewed the cycling strategies of the ten unitary authorities in Greater Manchester. Even within such an area, which is regarded as homogenous so far as central Government is concerned as there is a common "Local Transport Plan", there are significant differences in the development of cycling strategies. One local authority did not have a cycling strategy at the time of the review; one has a document that outlines policies and plans and Eadie is unsure as to whether this may be regarded as a strategy; the strategies of two other local authorities pre-date the National Cycling Strategy and the remaining six to varying extents reflect national policy. This contrasts with the City of York where there is a cycle strategy, a strong history of cycle provision and a strong commitment to financing further works. Harrison (2001) reports a £600,000 programme for 2001/2002.

In a survey of council members and officers the Commission for Integrated Transport (CfIT, 2003) found that 79% of members either strongly agree or tend to agree that their authority has the political will to deliver increased cycling. This contrasts with only 33% of officers. This mismatch implies that either the officers or members are misinformed or are responding aspirationally rather than realistically. This is cause for some disquiet.

There is no evidence of significant use of modelling to develop strategies and plans for greater bicycle use as part of the local transport planning process. The author was involved in the development of a transport strategy for Carlisle as part of the precursor to the Local Transport Plan process that involved a spreadsheet based multi-modal model. Parameters were assumed based on experience and judgement and high mode specific constants of approximately 100 minutes were applied to the bicycle mode for journeys of around 10 to 20 minutes to validate the model against existing cycle usage. Reductions on the mode specific constant for the future scenario of better cycle provision were assumed in order to model the effects of enhanced provision for cycle traffic. It should be stressed, however, that the focus of the model was on diversion from car to public transport use. Eadie (1999) reports that Trafford MBC has used the proprietary model Quo Vadis to identify priority routes for best allocation of resources.

The Government's urban task force report (DfT, 1999b) concerned itself with the public realm and with the re-configuring of "space left over after planning" to achieve high quality well connected street patterns. The report suggested that LTPs should secure better integration between different transport types and recommended targets for increasing year on year the proportion of trips by foot, bicycle and public transport. It suggested that comprehensive cycle networks should be a priority.

The Home Office announced in August 1999 that the police will have new powers to enforce a number of offences using fixed penalty notices, including the offence of footway cycling outlawed under the 1832 Road Traffic Act. It is unlikely that the power will be used widely, but reserved for situations, for example, such as wanton cycling through pedestrianised areas. It is unlikely to deter the occasional use of the footway by cyclists to avoid dangerous road junctions.

Government Guidance On Methodology for Multi-Modal Studies (GOMMMS) (DfT, 2000d) builds on the New Approach To Appraisal but contains only passing reference to specific cycle provision mentioning that "dedicated infrastructure" can "achieve significant improvements in safety for cyclists and improve journey times". These statements have the flavour of the obvious about them.

The Government initiated a speeds review arising out of the 1998 white paper and concluded (DfT, 2000e) that, in relation to the impact on quality of life and suppression of alternative modes of transport, there is currently more information needed to guide policy decisions. It is conceivable that reductions in general speed could make cycling more attractive for reasons of both safety and journey speed.

The Ten Year Transport Plan for England (DfT, 2000a) revised the National Cycling Strategy target for cycling in England by re-basing to 2000 and setting a target of tripling cycling by 2010. The National Cycling Strategy target remains extant for Scotland and Wales. The revision to the target is recognition that the original NCS target for 2002 would not be (and was not) achieved.

In 2001 the Government issued a revised version of Planning Policy Guidance Note 13 (ODPM, 2001) which kept the original aims but suggests that local authorities should actively seek to establish partnerships for action with other public bodies, commercial organisations and the voluntary sector to achieve the objectives of motor traffic reduction. McClintock (2002) notes that PPG13 is particularly strong on the importance of interchanges with good cycling and walking access and stresses the importance to employers of providing good quality information on alternatives to the car.

The Transport Act 2000 empowers local authorities to charge for road space, or charge employers a levy on the number of work place car parking spaces that they provide for employees. Most local authorities have been tentative in embracing these powers and to date only London, through the efforts of a charismatic Mayor, has introduced a congestion charging zone[1]. The reduction in traffic within the charging zone has been of the order of 17% with some significant increases in cycling and the scheme is being generally judged a success. Others authorities may follow suit, but their willingness will be tempered by concerns about the attractiveness of their towns and cities for inward investment based on perceived higher transport costs.

So far as rural areas are concerned, the Countryside and Rights of Way Act 2000 redefines the legal status of some types of public right of way, some of which have rights for pedal cyclists. A "Road used as a public path" is redefined as a "restricted byway", which has rights of way on foot, horseback or leading a horse and for vehicles other than mechanically propelled vehicles as prescribed under the Road Traffic Act 1988 (these include pedal cycles). The Act is an attempt to rationalise and clarify the legal position of public rights of passage that have become unclear over the centuries. The main legislation specifying duties and powers of local authorities in regard to public rights of way is the Highways Act 1980. Specifically for cycling this is supplemented by the Cycle Tracks Act 1980, which empowers highway authorities to convert footpaths (that is rights of way on foot only) to rights of way for pedal cycles with or without rights of way on foot.

Many local authorities operate to design guidance that requires them to make specific provision for cyclists whenever highway or traffic engineering work is being undertaken. So for example, the introduction of an island in the centre of a road to act as a pedestrian refuge is likely to be accompanied by a short section of cycle lane on both approaches to ensure that there is adequate room for cycle traffic. Re-white lining after re-surfacing of a road may also result in a re-allocation of road space with specific provision for cycle traffic. Similarly minor alignment changes at junctions would normally also incorporate facilities for cycle traffic, such as advanced stop lines. Such provision is made mostly on the basis that some other traffic management or highway maintenance activity is taking place and is provided for no other

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[1] This, however, was accomplished using powers in the Greater London Act 1999

reason than to improve conditions for cycle traffic. Most local authority traffic engineers are generally concerned with the performance of the highway only in terms of capacity and safety from the point of view of motor traffic. Sums allocated specifically to cycling schemes as part of local authority settlements remain relatively low, with the most significant allocations being for maintenance and repair of structures and the highway pavement.

The Transport White Paper of Summer 2004 (DfT, 2004a) has an aim over the next two to three decades of increasing cycling by making it more convenient, attractive and realistic for short journeys, especially those to work and school. The aim is to be achieved by local action planning, strong marketing, sharing good practice and national demonstration projects. The "one size fits all" national target has been abandoned, but there is promise of working more closely with local authorities to put in place local plans and targets. The extent to which that close working has so far been carried out is a consultation in Autumn 2004 on proposed definitions for mandatory indicators for the forthcoming round of revisions to full Local Transport Plans (DfT,2004b), which suggests that an annualised index of cycle trips be created based on a set of counts representative over time and location within a district.

The results of the research presented in this thesis could help local authorities in understanding the extent and the limits to growth in cycle use.

2.5 International policy development

Cross-European policy studies

A useful introduction to the developments in Europe in the latter part of the 20th century may be found in Bracher (1989). Table 2.21 below summarises Bracher's findings from across Europe on policy, attitudes and promotion of cycling. The findings were derived from responses from 124 "cycle experts" (31% planners, 12% politicians, 42% cyclists and 15% "other") from across the countries surveyed.

Table 2.21 European country policies for, attitudes to and promotion of cycling

Country	Policy Framework	Attitudes	Promotion
Austria	• Federal Transport Plan of 1987 does not mention the bicycle except in regard to safety • Variation between cities on whether cycle is regarded as being for leisure or utility	• Attitudes positive, conditions negative	• Nothing significant
Belgium	• 1.6% of road-building budget earmarked for cycle paths • Bicycle taxes are collected (results in cycle number under-reporting) • Cycling organisation opinions are not taken into consideration	• Cyclists are "neglected and obstructed"	• No national programmes
Switzerland	• Responsibility with municipalities who tend not to co-ordinate between themselves	• Relatively good provision especially with public transport	• Widely promoted and supported
Federal Republic of Germany	• Politicians are active at all levels	• Attitudes generally positive but provision heavily criticised	• Programmes based around protecting the environment
Denmark	• From 1975 parliamentary interest has been deep	• Overwhelmingly positive	• Seemingly none (and not required)
Spain	• No role in Government policy • Initiatives recorded in only 25 towns	• Bicycle regarded as a toy and for sport • Late motorization means esteem of car remains high	• None
France	• No national policy or budget	• Fun for sport but otherwise cyclists suffer a bad image	• Some at municipality level
Italy	• Does not figure prominently in national policy • Individual towns take the lead	• In northern Italy bicycle seen more for utility purposes than for pleasure	• Extensive campaigns in selected towns and cities
Netherlands	• Integral component of national policy	• Used extensively for utility purposes and is seen very positively	• None other than for new schemes
Sweden	• No information	• Regarded as fun and widely used for utility	• None mentioned

It seems significant that it is in countries that have policies at national level in connection with cycling that generally have higher levels of cycling use.

While generally there were prevalent positive images of cycling across Europe there was a significant and very negative attitude to many aspects of transport that impinge on and affect cycle traffic and cycling. With the majority of respondents being from the cyclists' lobbying fraternity (and the author points out that the vast majority were men), then this overall finding is unsurprising.

A study of four European cities (Amsterdam, Barcelona, Copenhagen and Brussels) by the European Commission (1998a) suggested that for cities with low levels of cycling it would be important to undertake the following tasks:

- develop a road infrastructure with high cycling priority;
- promote cycling as being convenient, efficient and environmentally friendly;
- provide bicycles at places of work;
- introduce "call-a-car" services; and,

- improve home delivery services.

In cities with any level of cycling it would be important to undertake the following additional tasks:

- introduce new types of cycle rack and storage;
- introduce bicycle registration programmes; and
- make it possible to insure bicycles;

The list is derived from an analysis of factors that are understood to make cycling popular in Amsterdam (28% of trips made by bicycle) and Copenhagen (26% of trips made by bicycle). It is unclear from the analysis what the likelihood or motivating factors are for politicians to promote such policies and the related measures.

Prompted by Ritt Bjerregaard, the European Commissioner with responsibility for the environment, the European Commission published a booklet (European Commission, 1999) aimed at local authority decision makers to promote cycling. In the foreword he says he has taken the unusual step of approaching elected decision makers directly because in his view the worst enemy of the bicycle in urban areas is not cars but long held prejudices. It is also interesting to note that the policy document does not come out of the transport directorate, but the environment directorate. The booklet summarises good reasons to promote the bicycle including economic and environmental impacts and health impacts and introduces examples of provision from cities across Europe. The essence of the policy direction seems to emanate from concern for the quality of air and the effects on the global climate of carbon dioxide emissions from transport. In this regard the booklet supports European Union Framework Directive 96/62/EC OJ L 296 21.11.1996 which obliges towns with more than 250,000 inhabitants and other areas with recorded air pollution problems to inform the population of air quality standards and to adopt improvements plans.

The Netherlands

The bicycle had been the prime means of travel in The Netherlands from the 1920s until the beginning of the 1960s when car ownership began to rise dramatically (CROW, 1993a). It is significant that until the mid-1970s bicycle traffic had been a policy area of concern solely to town councils and provinces but from the mid 1970s it was central Government that began to invest in cycle paths and some demonstration projects were completed. As a consequence of the perceived negative impacts of increasing car traffic the Government formulated a new policy interestingly directed towards quality of life and economic development rather than transport per se. The Second Structural Scheme for Traffic and Transport (SSTT-II) was passed by the Dutch parliament in 1990 and the Bicycle Master Plan for The Netherlands is a subset of SSTT-II. The aim of the plan is to increase bicycle kilometres by 3.5 billion kilometres (30%) from 1986 to 2010. Variation in levels of cycling is not as disparate in urban areas in The Netherlands as in Germany. For example Arnhem, with 20% of traffic being by bicycle is quoted as a town with a low percentage of cycling, Groningen meanwhile approaches 50%.

Germany

Maddox (2001) highlights the contention there is between Pucher (1997), who asserts that the resurgence of the bicycle is entirely due to public policies that have greatly enhanced safety, speed and convenience of bicycling and Monheim and Monheim-Dandorfer (1990) who assert that between 1976 and 1982 bicycle trips in Germany increased by 30% and this increase is explained by the German people rediscovering the usefulness of the bicycle. Maddox quotes Brög and Erl (1985) data that show that 50% of the growth in trips between 1972 and 1995 occurred between 1972 and 1982, that is before policies to promote the bicycle were created.

The German Federal Ministry of Transport, Building and Housing launched a National Cycling Plan covering the period 2002 to 2012 (BMVBW, 2002) that promotes cycling as an essential mode that increases mobility. The Federal Government recognises that the main responsibility for the promotion of cycling lies with states (Länder) and local authorities, but has doubled funds for the construction and maintenance of cycle paths along federal highways. Other features of the plan include adjustments to the legal framework covering cycling, a road safety programme and a variety of research projects. Cycling, while being seen as primarily linked with enhancing mobility, is also seen as contributing to preventive health and climate change policies. Land-use planning will begin to espouse the concept of a "city of short distances" to enhance the ability to access goods and services using the bicycle. Operational issues, such as parking provision, will be addressed to create a coherent "cycling system", akin perhaps to a "railway system".

North Rhine-Westphalia, recognising the potential symbiotic relationship between cycle use and rail use, funded a project to establish quality cycle parking at 100 stations (Sully, 1998). This demonstrates that state level interest in cycling, as well as federal interest, is present in cycle promotion.

Denmark

In 1976 Denmark had the worst child accident rate in Europe that led to an Act of Parliament which required local authorities to build safe routes to schools. Denmark is now one of the safest countries for cycling in Europe (Sustrans, 2000).

Cycling has a long tradition in Denmark and particularly the capital, Copenhagen. Tracks alongside the main roads were constructed from the 1920s and expansion continued through the 1960s and 1970s. In the 1980s a number of state supported experiments with cycle routes were undertaken in Århus, Odense, Herning, Elsinor, Nakskov and Odder and studies raised concerns about safety on cycle tracks. These concerns were overcome with enhanced design and markings at junctions. In 1993 a network of 10 national cycle routes was established across

Denmark. In the 1990s there was a growing realisation that a network of separate paths was not necessarily the only answer; the routes were not always direct and they could be relatively deserted. New developments were constructed with good direct networks of cycle routes and roads in urban districts were re-constructed with separate road and path networks (Danish Road Directorate, 2000). In 1999 Odense was declared Denmark's National Cycle City and a testing ground for infrastructure developments.

It is interesting to note that Copenhagen traffic planners are promoting a new network of so-called "green routes" that offer quieter routes for long distance commuting that have few junctions, little traffic and are in surroundings that are as green and attractive as possible. The first route is being constructed on an abandoned railway line and the promoters unashamedly quote Sustrans in the UK as their inspiration (Jensen, N., 1999). The routes are of a high specification with two-way cycle lane widths of 4 metres with a separate 2 metre strip for pedestrians. The routes will be lit and have regular maintenance, such as snow clearing, just as for any other highway. The cost is estimated to be approximately £50 million for 115 kilometres of route. Such visionary investment in capital and maintenance for cycling is unknown in recent times in the UK.

Beyond Europe

Beyond Europe there is evidence that developing nations are reluctant to promote the bicycle as they perceive motor traffic growth as a sign of economic development. This is evidenced by public policy and public pressure in relation to the development of one-way streets and free car parking in León, Nicaragua. This is despite present high levels of bicycle use and the detrimental effect such policies have on the development of further use of the bicycle (Grengs, 2001). From Shanghai, de Boom et al. (2001) report resistance to western transportation planning pressure to maintain and enhance the present very high levels of bicycle use. This reluctance is based on the view that cycling is in some way "second rate", cyclists "get in the way" of motor traffic and, as a city re-establishing itself as a major industrial and trading centre, cycling has an inappropriate image.

Forester (1994), a Briton long resident in the United States of America, has campaigned extensively over many years for the recognition of bicycles as vehicles that are well capable, if ridden appropriately and within the rules of the road, of being a form of traffic that should be integral with and safe from risks posed by motor traffic. The reverse, that cycle traffic is in some way less than capable of forming a part of the general traffic stream, he terms the "cyclist inferiority superstition" and is based on the perception of risk of collision based on the different relative speeds of bicycle and motor traffic and the potential damaging effect of a motor vehicle on a cyclist. Equally, based on his campaigning experiences in connection with US highway law, the interpretation of research evidence and various American design guidance, he countervails that the motoring lobby considers cyclists an obstacle to the free passage of traffic.

Interestingly, and against conventional wisdom, he suggests that the lobby for the provision of facilities that segregate cyclists from traffic became effective only when the weaker pro-motoring lobby was joined by the stronger pro-environmental lobby. The environmental lobby he characterises as essentially anti-car and, in this stance, adopted the bicycle as a more benign alternative to champion. Forester distinguishes environmental proponents of cycling from the club cyclists (for example, the League of American Wheelmen, LAW, the equivalent of the UK Cyclists' Touring Club, CTC) and suggests that the speed and distances achieved by this latter cohort of cyclists are the ones that are relevant for consideration.

Further he argues cogently that many forms of facility that are provided for cyclists render the cyclist less safe than they would otherwise be within the general traffic stream. A straightforward example of one of these arguments is in relation to the use of cycle lanes on the approaches to junctions. The cycle lane will laterally separate the bicycle from the remainder of the traffic stream and place the cyclist further out on the arc of vision of the motorist, causing the cyclist to be more vulnerable than they would otherwise be.

Taking a diametrically opposed view to Forester (1994), Pucher et al. (1999) rather revere the continental European approach to provision for cycling and in a qualitative comparative study of seven North American cities deduce that bike lanes and paths separated from motor traffic will "unquestionably" make cycling more attractive to non-cyclists and also list other relevant factors that they suspect account for differences in cycle levels between the seven cities as being: public attitude and cultural differences, public image, city size and density, cost of car use and public transport, income, climate and danger.

2.6 Measures for the promotion of cycling

2.6.1 The issues that measures need to address

Jones (2001) summarises a range of complaints about poor quality provision that he found were recurrent themes at a series of seminars organised by the National Cycling Forum for practitioners and activists. These included:

- Conflict with pedestrians on shared-use footways, particularly those that take space away from existing footways.
- Lack of continuity of routes, for example with "give way" and "cyclist dismount" signs.
- On-street cycle lanes that are too narrow.
- Street furniture that creates obstacle.
- Poor surfaces on off-road routes.
- Road junction design that puts cyclists in danger, e.g. large roundabouts with high entry speeds.
- Off-road paths that take inconvenient routes.

- Off-road shared paths that create an expectation in the mind of motorists that they will not see a cyclist on the road.

Jones also notes that cycle schemes are often left out of impact assessments for developments, that designs are used that are flawed (e.g. traffic calming features that make life more difficult for the cyclist), and that there is evidence of poor quality and lack of attention to detail and lack of maintenance after the scheme is built.

The issues identified by Jones are almost certainly not exhaustive, for example, the list does not address bicycle parking or inter-modal issues. This section presents measures that are currently used to promote travel by bicycle and they fall broadly into issues in connection with either engineering or promotion.

2.6.2 Principles for engineering design

Much traffic engineering design for general traffic is based around empirical measurements taken from the performance of real junctions, for example the calculation of saturation flows across stop lines at traffic signals. Provision for cycle traffic has relied less on comprehensive empirical studies and more on small-scale demonstration projects that may have their applications extended by using practitioner experience and judgement. An example is the Harland and Gercans (1993) study described in more detail in the section on monitoring.

Davies et al. (1998) suggest that "cycling could not be provided for on a totally segregated network". The promotion of a totally segregated network presupposes that one is desirable based on the notion that the presence of other traffic reduces safety. Their implication is that this might be desirable, if it were not for practical and funding issues which may prevent such a circumstance emerging. In a similar vein to Forester (1994), Franklin (2002) promotes the notion of "vehicular cycling" where the cyclist is fully recognised and acts as any other vehicle on the public highway. He suggests that the undermining of "vehicular cycling" in the hope of encouraging more cycling through segregation is not a "fail-safe" strategy. His implication is that off-carriageway cycling, that is cycling on segregated facilities, will discourage the regard there is for the cycle as a vehicle.

There is however a range of ability, experience, power and speed possessed by cyclists and their needs are different. CROW (1993a and 1993b) has identified fundamental infrastructure requirements for all types of cycle network as follows:

Coherent/comprehensive:	a comprehensive network linked to where cyclists begin and complete their journey.
Direct:	a system of connections which is as direct as possible and avoids detours.

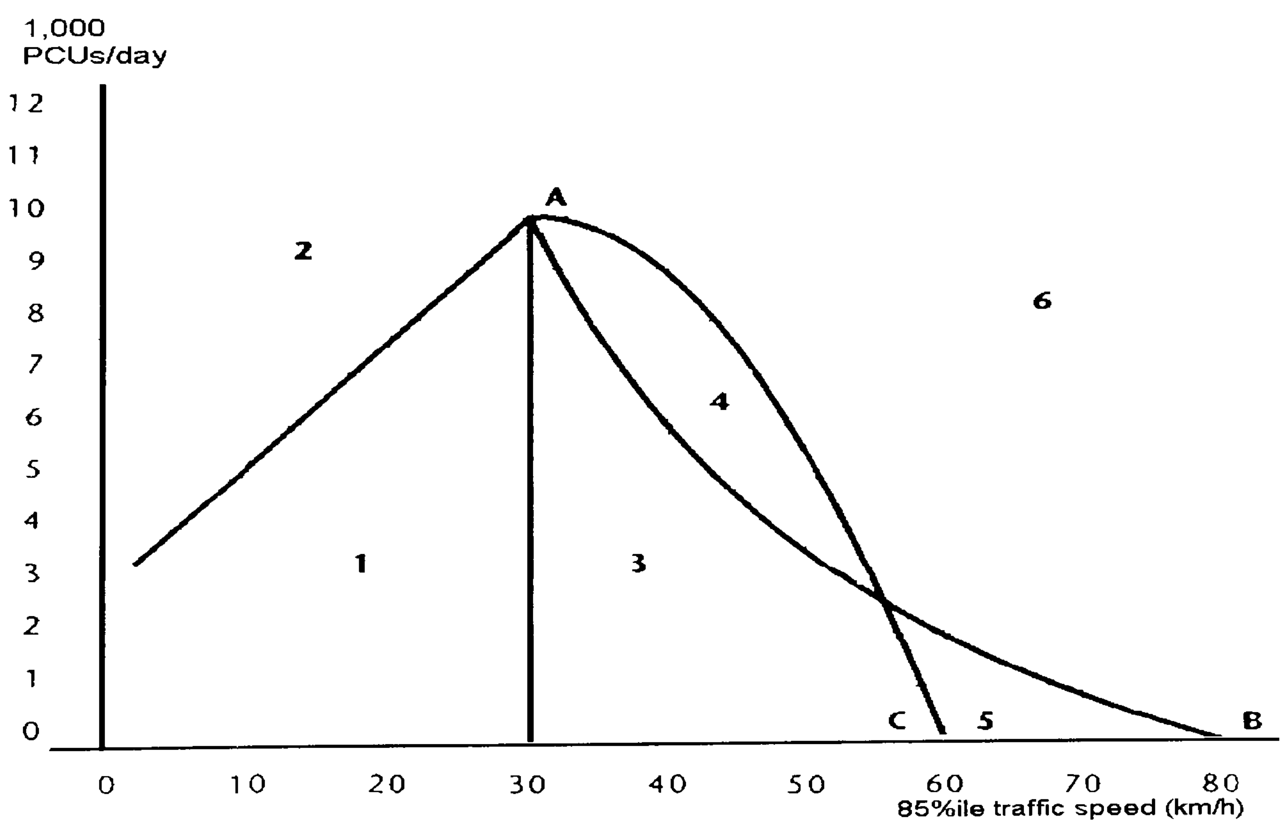
Attractive: design and integration with surroundings that makes it pleasant to cycle.

Safe: facilities that guarantee safety from other road users and involves personal security as well as road safety.

Comfortable: facilities that allow a rapid and comfortable flow of bicycle traffic.

Different cyclists are likely to value the different attributes given above in different ways, for example some may be content to trade a lack of directness for enhanced security. Jackson and Ruehr (1998) note that experienced cyclists, who "dominate the ranks" of those who are part of the "organized advocacy community", tend to favour on-road provision and this may unduly influence the provision that is made for cyclists. The extent to which schemes have addressed the design criteria is open to question, particularly in the light of the legion examples of cycle lanes abruptly ending or being of only short length. CROW (1993b), the Dutch design guidance, presents a design diagram to assist in the determination of the type of facility for cyclists as shown in Figure 2.1.

Figure 2.1 CROW (1993b) design chart for the provision of cycle facilities



It is suggested that within Area 1, with 85%ile speeds of less than 30km/hr, all modes can be mixed. Area 2 is theoretical only, as the volumes of traffic denoted are not achievable at low speeds within the constraints of normal width highways. At the highest speeds and flows, in Area 6, segregation is necessary for safety reasons. Danger does not rise linearly with speed, partly as a result of stopping distance being a function of the square of the speed and partly as a result of damage being a function of kinetic energy, again proportional to the square of the speed. The line A to B represents a line of equal risk at different traffic volumes and speed. Area

3 is deemed not to be sufficiently risk exposed to require segregation but may require delineation of cycle lanes depending on particular physical circumstances. In Area 5 segregation on tracks is deemed desirable but volumes are so low that it may be possible for mixed traffic conditions. In Area 4 some form of segregation is deemed to be required because of the combined volume and speed. It is understood from one of the authors of the Dutch design guidance that there has been no theoretical underpinning or research effort behind the design chart.

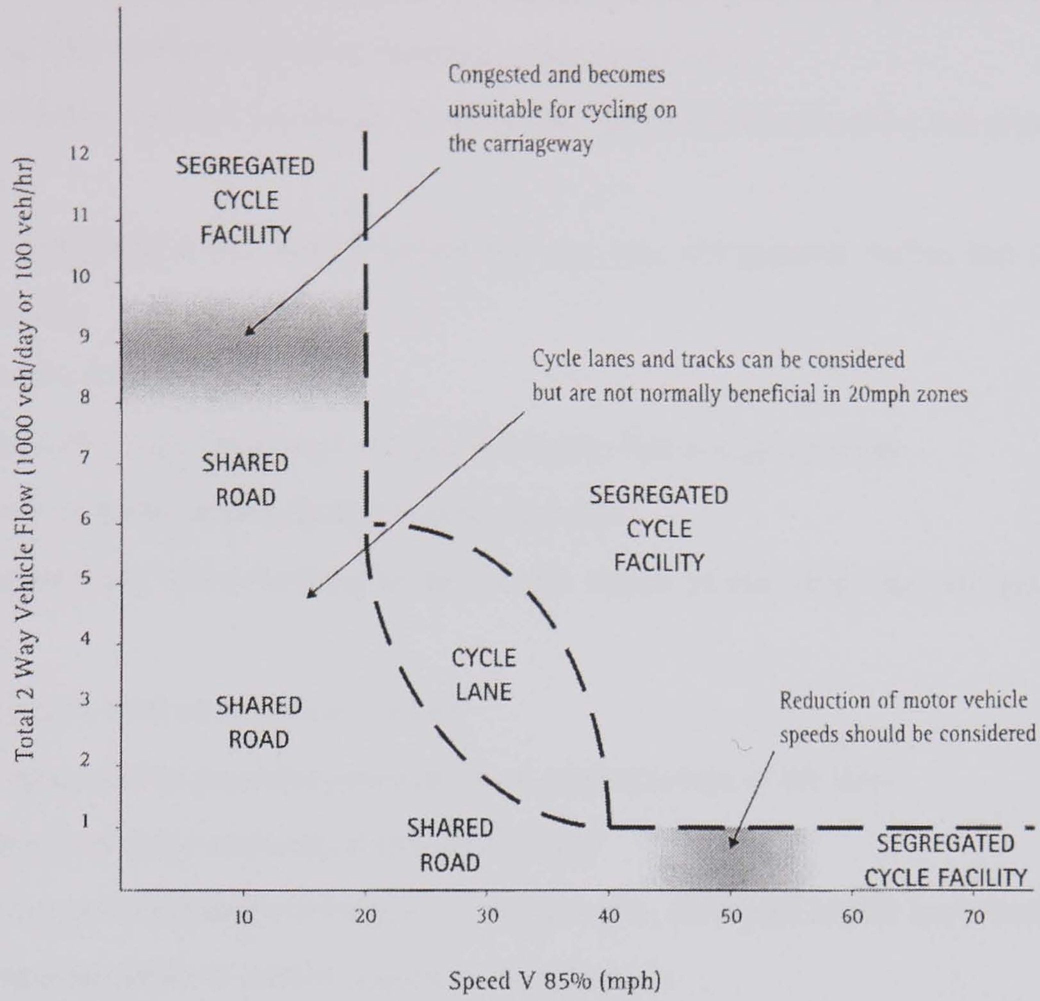
The Institution of Highways and Transportation Guidelines (IHT, 1996) fall short of producing a graph of volume versus speed but make the following assertions:

Less than 20 mph	• Cyclists can mix safely
20mph to 30mph	• Cyclists can mix safely unless there are "significant" numbers of HGVs or child cyclists
	• Additional lane width is desirable where traffic flows are "heavy"
30-40mph	• Segregation or additional lane width is preferable
40mph and greater	• Segregation will be necessary for the majority of cyclists

Local circumstances such as parking, lane widths and junctions are described as crucial to consider and in the first instance consideration should be given to reducing motor vehicle speeds.

Sustrans (1997) has amended the CROW design diagram for the provision of facilities for cyclists based on the judgement that the relatively high proportions of people using the National Cycle Network (NCN) who are inexperienced will mean that a greater degree of protection needs to be afforded to them. This is shown in Figure 2.2.

Figure 2.2 Sustrans (1997) design chart for the provision of cycle facilities



The Lancashire County Council (Lancashire County Council, 2004) cycle design guidelines deliberately avoid presenting a chart equivalent to either Figure 2.1 or 2.2, but, using the work of Landis et al. (1997) as theoretical underpinning (see Section 4.2), present graphs of level of service against flow and width.

The traffic engineer, particularly in the UK has been intent on maximising capacity and improving safety of the highway network normally from the point of view of general motor traffic. When considering design for cycle traffic, the engineer is encouraged to consider making changes such that a particular highway carries less traffic and/or traffic at slower speed so that the environment for cycle traffic is safer. This may be achieved by area wide traffic management measures and calming measures. It may however be inconsistent with other transport policy objectives. It is reluctance or inability to make these changes to the traffic environment that leads to a need to provide some form of cycle provision such as cycle lanes (Area 4 in Figure 2.1). Often decisions about changes to the highway network of this nature are resisted for political reasons, for example the strident voices of local traders, or the car owning voting population.

The tension between maximising capacity and the needs of cycle traffic has led to the recognition that education and training (McClintock, 1999) and career and professional development (Hatch, 1999) for bicycle professionals is important. A traffic engineer fully conversant and competent with design for cycle traffic is one more likely to produce quality designs and schemes than one who is not.

2.6.3 Examples of measures used in Europe

Pucher (1997) notes a number of innovative measures that have been promoted in Münster and partially copied in a number of other German cities as follows:

- Fahrradstrassen, special streets for bicycles that permit general traffic but give strict priority to cyclists
- Falsche Einbahnstrassen, streets which are one way for general traffic but allow two-way bicycle traffic
- Bus lanes for use by cyclists
- Street networks with dead ends for general traffic but not for cyclists
- Permission to make turns banned to general traffic
- Fahrradschleusen, lanes leading to reservoirs ahead of the stop line for general traffic at junctions
- Traffic signals with priority for cyclists
- Permission to ride in pedestrianised areas at certain times of the day [1]
- Comprehensive cycle training of school children
- Surprise law enforcement (of bicycle working order, theft and traffic law obedience)
- Cycle rental facilities at public transport interchanges
- Bicycle route network developments with signing and marking
- Bicycle festivals
- Award schemes for employers providing journey end facilities and promotion

Pucher suggests that it is the combination of these measures, together with others to restrict car use such as speed limit lowering, the elimination of free parking and fuel duty increases, that have led to the levels of cycling now evident in Germany. The extent to which the measures have increased cycling use or arrested declining use would need to be judged against the trends in cycle use at the level of individual urban areas within Germany.

2.6.4 Engineering measures for cyclists

Traffic reduction followed by traffic calming are the two approaches highest in the Institution of Highways and Transportation's list of guidelines (IHT, 1996) for cycle-friendly infrastructure. These are followed by junction treatment and management, re-distribution of carriageway space and, finally, provision of cycle lanes and cycle tracks. The logic of the listing is that all effort should be made to incorporate cycle traffic within the carriageway before the potentially more costly solutions of segregated facilities are considered. There has been a rapid increase in

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[1] Permission to use pedestrianised areas at certain times of the day is currently granted in the City of York on routes known as footstreets (Harrison, 2001).

specific provision on carriageway for cycle traffic with measures such as cycle lanes and advanced stop lines. This could indicate that traffic reduction measures and traffic calming measures have been considered and deemed not suitable. It could, however, belie an unthinking response amongst traffic engineers so that they are seen to be making at least some provision for cycle traffic. The more recent cycle audit and cycle review guidelines (IHT, 1998) could assist in decision making on the application of measures. The audit and review guidelines acknowledge that the breadth of characteristics required for cycle traffic means that it is difficult to draft design guidance.

Returning to the opening theme of Section 2.4.2, it is noticeable that much advice is based around the sharing of examples of good practice as evidenced by the list of traffic advisory leaflets available from DfT (DfT, 2004c). However, there is an increasing body of research from the Transport Research Laboratory and other European sources which considers provision for cycle traffic and this is discussed in more detail in Chapter 3.

While the IHT guidelines are regarded as the closest there are to objective standards currently available in the UK, it is suggested by Franklin (2001a) that the minimum standards in the guidelines have become the norm. As testament to this no winner of the National Cycling Awards Engineering Category was declared for 1999 or 2000 (Franklin, 2001b). Linked with such minimum standards, but also related to the growth in the perception that "off-carriageway" is the place to be, is the growth in the number of people who choose to cycle on footways. Franklin considers this trend an inevitable consequence of the provision of cycle tracks within footways in some locations.

Cycle lanes

Guidelines tend to specify lane widths for cycle lanes based around the physical characteristics of the cyclist and their kinematic envelope within a safe lane demarcated at the road boundary. Bracher (1992) points out that the higher the speed of the adjacent motor traffic, the more separation distance there should be between car and cycle and research on this issue is reviewed in more detail in Section 3.6 in Chapter 3. Higher speeds imply larger forces of impact and hence, to maintain a similar level of safety, the chance of impact needs to be reduced and this may be achieved by a greater distance separation between vehicles. Also higher speeds create more air turbulence and lateral forces on cyclists. The value of a cycle lane is therefore potentially not so much a function of the presence or otherwise of the cycle lane itself but a result of its effectiveness in minimising the adverse influences of the environment through which it passes.

De Boom et al. (2001) have recorded bicycle flows of up to 9,000 per hour per 3 metre lane in Shanghai, levels that are unlikely to be replicated in western cities for some time. An equivalent lane carrying motor vehicles with a typical occupancy of 1.3 would carry up to a maximum of perhaps 2,000 people per hour.

Combined cycle and bus lanes

Guthrie and Gardner (1999a) note that the drawing of authoritative conclusions on the effectiveness of the combination of cyclists and buses in bus lanes is not possible due to lack of data, especially accident data. However, amongst respondents to their survey, combined cycle and bus lanes are popular with cyclists but not with bus drivers.

Cyclists and roundabouts

So far as roundabouts in the UK are concerned, the primary motivation in their design is in terms of maximising capacity and reducing delay within a safe context. Designs developed in The Netherlands have been based around the principal of improving safety (van Arem and Kneepkens, 1992) by the necessary reduction in speed to negotiate a more prescribed and limiting geometry (approach angle nearer to a right angle, narrower entry, narrower circulating carriageway width).

Cycle traffic at UK roundabouts is often catered for by a separate route (perhaps shared with pedestrians), away from the roundabout, or alternatives to the roundabout may be considered (e.g. signal control). A cycle lane around the edge of the roundabout with "give ways" for the cyclists at each exit arm are self defeating as most cyclists will want to maintain momentum and not be forced to give way at each exit. "Jug handle" turns (turns in the shape of a "G") may be used to cross entry and exit arms to provide progression both clockwise and counter clockwise around a roundabout.

The continental design of roundabout, albeit with significant cycle lane markings, has been trialled on the Heworth Roundabout in the City of York (Harrison, 2001).

Cyclists and signal controlled junctions

Advanced stop lines were first introduced in Britain in Oxford in 1984, and followed their introduction in many Dutch towns, the first being Leiden in 1978 (Wheeler, 1992). Advanced stop lines are a facility for cyclists where the all-vehicle stop line is set back from its normal position and an additional stop line, up to which only cyclists are allowed to progress at a red aspect, is positioned at the normal position of the stop line. Advanced Stop Lines are being installed at many signalised intersections to allow cyclists to clear the junction ahead of other traffic, improve their visibility to motorists, assist cyclists in making right turn manoeuvres through junctions and help protect cyclists from left-turning traffic.

During the display of the red aspect cyclists can move from the approach cycle lane (always required by the regulations on the approach to an advanced stop line, but not always provided) to the right hand side in readiness for a right turn manoeuvre. The additional advantage is that there is more space provided by the approach cycle lane for cyclists to reach the front of any queuing traffic and they can wait for a green aspect in front of, and therefore in full view of, queuing traffic. In an initial study of demonstration sites at Oxford, Newark and Bristol, Wheeler (1992) showed that over 75% of cyclists made proper use of the facility. 90% of motorists kept out of the cycle lane and 82% of motorists kept out of the reservoir between the advanced stop line and the general traffic stop line during the red aspect. It should be noted that these first demonstration sites had an additional signal head at the motor vehicle stop line which was set back 5 metres from the cyclists' advanced stop line. Current designs use a set back of typically 4-5 metres, but do not have the additional signal head.

Ryley (1996) studied both nearside cycle lane approaches to advanced stop lines and cycle lanes positioned to the right of nearside lanes. 12 hours of video film at six sites from five cities (Portsmouth, Chelmsford, Manchester, Bristol, Cambridge) was studied and the conclusions reached that a central cycle lane is useful at sites with more than one approach lane, a large proportion of left-turning motor traffic and a large proportion of ahead cyclists. Few right turn cyclists were found to use the full length of a nearside cycle lane facility and as vehicle flows increase a nearside lane is used less by right turning cyclists. No safety problems for cyclists entering a central cycle lane were apparent. The extent of benefit of advanced stop lines depends on cycle time and division of green time amongst approaches. The greater the time of the red aspect for a particular approach as a proportion of the cycle time, the greater the probability of a cyclist arriving during red time and of then being able to use the reservoir ahead of the general traffic stop line for positioning for a right turn manoeuvre. Despite the provision of advanced stop lines being for safety reasons, neither the Wheeler (1992) nor the Ryley (1996) studies could conclude on changes in accident levels due to their low incidence both before and after the introduction of the facility.

Gårder et al. (1994) assessed cycle path provision through signalised intersections supposedly designed to improve safety but demonstrate that more important "local" conditions such as signal timings, can give very high risk at some intersections and so "blanket" provision of cycle lanes for cyclists is not always as effective as careful design of the whole intersection for all traffic.

Signalised crossings

Pelican Crossings have been introduced for pedestrian crossings of major roads to provide positive control of traffic to enhance the safety of the crossing for pedestrians. Toucan crossings, with a wider crossing width, provide a shared crossing facility for pedestrians and cyclists and were introduced in 1991. Puffin crossings were also introduced in 1991 and provide a "call cancel" facility, in other words, if after the button has been pressed, the pedestrian moves away from a detector mat, the call to the controller to provide a pedestrian phase is cancelled and unnecessary delay to general traffic is avoided. In addition puffin crossings use microwave detection of pedestrians on the crossing to adjust the pedestrian green aspect, again to minimise delay to general traffic. Detection facilities were added to Toucan crossings in trials in 1994 and investigated by Taylor and Halliday (1997) who found that users understood the function of the component parts of the crossing (push button, detector mats etc.). They found that few pedestrians and cyclists were concerned about sharing a facility.

Area wide calming

The urban safety project was undertaken in five towns and cities in the UK (Sheffield, Bristol, Bradford, Reading, and Burnley/Nelson) (Mackie et al., 1990). The areas were chosen to have average accident risk, have a range of road types, large enough to show interaction between main roads and residential roads and be large enough to have statistical confidence in the results. A variety of measures were used including the introduction of mini-roundabouts, banned turns, closures, central refuges and treatments at the entries to the areas. The measures used were interdependent and no significant conclusions can be drawn about the particular impact of individual measures. The objectives of the project were to demonstrate that accidents in urban areas could be reduced by 10% to 15% and to develop the principles used and experience gained to provide guidelines for general application. In terms of road user groups however, it was found that only cycling accident savings were significant at the 10% level of confidence but this is true only because of a large increase in child cycling accidents in control areas. The overall accident reduction in the five areas was estimated to be 13%.

The Department for Transport (DfT, 1987) summarises a wide range of measures to control traffic on a neighbourhood wide basis for the benefit of residents, pedestrians and cyclists. The measures proposed generally comprise physical intervention (humps, rumble strips, footway widenings, entry treatments, width restrictions with or without enforced priority, environmental closures, chicanes) in order that speeds may be reduced. Such "designed-in" speed reduction is fundamental to the success of a "20mph zone" (DfT, 1991).

Many measures are designed to reduce general traffic speed but potentially have equally severe effects on limiting the speed for cyclists (and therefore attractiveness to some types of cyclist). To overcome this issue specifically for vertical deflections, the sinusoidal hump was introduced (DfT, 1998c). Rather than having a circular profile and hence an immediate change in vertical acceleration on traversing the hump, the sinusoidal hump has a gently rising profile before the curve reverses for the crest of the hump. The changes in vertical acceleration are sufficiently gradual for cyclists' comfort yet still require a car to slow down to traverse the hump in comfort.

Road narrowings (central islands, pinch points (kerb build-outs) and chicanes) are also used as devices to reduce vehicles' speeds but they can have the effect of "squeezing" cyclists closer to general traffic. In some cases a "bypass", perhaps following the original line of the kerb, may be provided for cyclists. Such short distance alternative provision, particularly if kerbed, can pose design problems for drainage design and maintenance and for ease of regular sweeping. Davies et al. (1997a) found that cycle bypasses and cycle lanes on sections of road containing road narrowings schemes were popular with cyclists and propensity to use the cycle bypasses seemed to be linked more with good straight, obstruction free convenient designs than with oppressive speeds or volumes of traffic on the main carriageway. Cyclists reported feeling increased stress and nervousness at narrowing sites and this is probably due to uncertainty about driver behaviour, reduced distance between cyclists and overtaking vehicles and because some drivers are forced to slow down and wait behind cyclists. Contrasted with this increased uneasiness is the reduction in accidents from 1.51 to 0.96 per year at sites in the study where narrowings were installed. This reduction is not statistically significant. Motor vehicle encroachment into cycle lanes at narrowings was high at sites with residual widths for motor traffic of less than 3.0 metres. At central island sites with general traffic running lane widths of 3.5 metres to 4.2 metres, less than 15% of drivers waited behind cyclists. The study recommended, very reasonably, that in the context of promoting cycling as a means of transport, road narrowings that increase the perception of danger amongst cyclists should be avoided. Leading on from this assertion it was suggested that narrowings should have either cycle bypasses or adequate width for both cycle and motor vehicle traffic.

Changes in vehicle technology, road layout or control specifically with the intention of enhancing safety may result in "behavioural adaptations" which are "those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change" (OECD, 1990). Grayson (1996) argues however that the observed effectiveness of traffic calming devices in creating speed reductions and the large effect of speed reduction on accidents means that any adverse behavioural effect is likely to be comparatively small.

2.6.5 Off-highway routes

Significant use of off-highway routes perhaps had its genesis in the United States of America, where, during the 1960s and 1970s significant abandonment of railroads led to environmental campaigners' vision for "rails to trails conservancy" (Bulpitt, 2000). From the mid-1970s groups in the UK emerged, keen on the preservation of railway routes for transport purposes. First amongst these became the UK's only civil engineering infrastructure works charity, Sustrans, which developed from a cycle campaign group in Bristol. The concept of "greenways" continued to develop and was taken up by Spain and Belgium, as well as latterly by countries that have a high level of cycle use such as Denmark.

Perhaps of equal significance to the high profile, and often longer distance "greenway" routes being created by Sustrans are the many existing paths through parks and other routes created by local authorities on non-highway land. There are examples of extensive cycle schemes in some specific local authority areas. For example, Milton Keynes, a new town since 1967, has an extensive system of "Redways", red coloured bitumen macadam surfacing forming a comprehensive system of interconnecting routes for pedestrians and cyclists. The Redways were reviewed in the 1980s leading to the designation of local and cross-city Redways, new signing, lighting landscaping and control through white lining (Ketteridge and Perkins, 1993).

Other national bodies such as the Environment Agency and the British Waterways Board and water utility companies will also, where they consider it safe to do so with respect to other recreational users such as anglers, allow cycling along sections of canal towpath and flood levee etc. As well as routes that have no legal status other than being permissive paths, cyclists are legally able to use bridleways, Roads Used as Public Paths (RUPPs, but to be re-designated as Restricted Byways when a relevant Statutory Instrument is made, see Section 2.2) and Byways Open to All Traffic (BOATs). These tend to be more manifest in rural rather than urban areas.

Off-highway schemes in urban areas over non-highway land are often designed and implemented as a matter of convenience and to meet other objectives, such as leisure and tourism promotion, rather than to provide direct and convenient routes for utility cycling. As schemes are often designed with leisure cycling in mind, such routes will often not help form integrated networks for cycle traffic.

Much of the attention directed to the 10,000 mile UK National Cycle Network has been at the work on off-highway routes and its promoter, Sustrans, has issued guidelines for provision of facilities for cyclists off-road (Sustrans, 1997). Sustrans' motivation is a desire to find solutions to problems caused by traffic growth and the deaths, injuries, noise and pollution caused. The organisation traces its routes to the formation of the "Cyclebag" transport environmentalists group formed in Bristol on the 7th July 1977. The first path to be constructed linked Bristol to Bath. The enterprise expanded using employment schemes of the early 1980s such as the Youth Opportunities Programme and the Community Programme.

Design principles addressed include widths for shared use with pedestrians, signing and highway crossing details. The three overriding principles are that routes should be attractive for novices (i.e. traffic free routes and avoids main roads), memorable for visitors (attractive "travelling landscapes" with sculptures), and useful for local cyclists (become spine routes linking many other local cycle paths) (Sustrans, 2000).

Sustrans works with local authorities and the genesis of the network has been based around the development of good working relations with willing local authorities. It became Sustrans intention to build one quality route in each major city to show the Government that the creation of safe attractive routes could generate new cycle journeys. Serendipity in the form of pre-existing transport corridors, such as disused railways and canals, has also been important in shaping the network.

Voluntary supporters grew from 200 in 1993 to 40,000 in 1999 and provided a good basis for a lottery millennium fund application in 1995. The original plan was to create 2,500 miles of network by 2000 with an additional 4,000 miles by 2005. Local authority enthusiasm has meant that the total length planned has been increased to 10,000 miles.

While the network is certainly comprehensive in its geographical extent, it could be argued that it misses the point in that it has not been designed from a starting point of a consideration of potential cycling demand. With exceptions specifically designed in the vicinity of schools and along corridors that do penetrate well into urban areas (for example the original Sustrans path into the heart of Bristol), the network can be thought of as serving the leisure and touring market.

There are many significant road corridors that carry volumes of traffic at speeds that would indicate a requirement for cycling, according to Figure 2.1 above, to be catered for by segregated routes. A segregated route may lie along a route corridor closely juxtaposed with the highway route that it parallels. It may, however, deviate from the highway route yet still connect neighbourhoods in either a more or a less direct way than the highway route. The distinction in terms of cycle route planning seems trivial. In terms of route choice and design however, it may be more desirable in certain circumstances to keep a cycle route closely associated with but segregated from a highway route (for example personal security, lighting during the hours of darkness). In other circumstances the attractiveness of alternatives remote from the highway (e.g. through interesting park landscapes) may be more appealing.

There is significant and growing concern that cycling along "traffic free" routes will create an impression that cycling is not a vehicular activity and that cyclist behaviour does not, along such routes, need to comply with some code of conduct. By contrast of course there is a well defined and fairly widely understood code for vehicle behaviour on the public highway network.

A very good example of a route away from the highway that creates advantage for the cyclist is the Millennium pedestrian and cycle bridge over the River Ouse in the City of York (Harrison, 2001) that connects a housing area in the South west of the City with the university and science park complex in the South East. The bridge removes the need for a significant detour to use one of the three congested city centre bridges and it is hoped that the Millennium Bridge will create an even greater demand for cycling than currently exists in the city.

2.6.6 Public transport interchange and journey end facilities

Some suggest that cyclists, in addition to parking, need journey end facilities such as lockers, changing rooms and showers. Cycle stands and "sheds" need to be made available very close to building entrances.

Sully (1998), in a study for cycle parking at Dublin rail stations, notes that the two high priorities for cycle parking at public transport interchanges are visibility (through closeness to the ultimate destination an good signing) and accessibility (requiring no detours to get to the cycle parking). These requirements are common to all types of cycle parking.

A minority of cyclists take their bicycle with them on the train. At present, quite reasonably, the modern tram systems in the UK do not allow carriage of bicycles, but many are under pressure to allow customers to do so, at least in the off-peak period. The cost and booking requirements for carriage of cycles on trains varies by train operating company. Guthrie and Gardner (1999b) report that a review of a Department of Transport funded "cycle challenge" project on Anglia Railways in Suffolk and Norfolk shows that around one third of respondents to a survey felt that taking their bicycle on the train would have some advantages. They also found that bicycle racks at stations will contribute towards reducing car dependency and increasing cycle use.

Cycle centres for safe storage, shower and changing facilities and accessory sale and repair in the UK offer a focal point for cyclists and promote a pro-cycling culture and create a sense of belonging (Guthrie, 1999).

2.6.7 Cycling promotion

Franklin (1997) has written an excellent text published by the Stationery Office with diagrams in the style of the Highway Code that aims to teach adult cyclists more efficient ways of riding to reduce its perceived strenuousness and to increase competence to increase user safety.

The UK Government has funded projects through the "cycle challenge" scheme to promote cycling. One of the largest such projects, and similar in nature to many others, has been the Nottingham cycle-friendly employers project (Cleary and McClintock, 2000). Out of 230 bids, 65 were funded beginning in 1996 and in the case of Nottingham the funding has encouraged provision of much enhanced cycle parking at the sites of the eight partners to the scheme (the city and county councils, the two universities and medical school and hospital, a further education college, Boots plc and Experian). Incentives to enhance cycling included: showering and changing facilities, secure cycle parking, mileage allowances, interest free loans for bicycle and equipment purchase, pool bicycle provision, information material, promotional events and support for bicycle users groups. Monitoring of the cycle network in Nottingham has shown an increase in use from 1990 to 1998 of 19.5%. This compares with a decrease of 3.5% at a "control point" off the cycle network.

Employers benefit from less pressure on their land holding for space hungry car parking and an appreciation from employees for being responsive. In some cases employers have also learnt about travel planning which may then assist them in achieving planning permission for subsequent expansion, as the operation of a travel plan may become part of a planning condition. The project showed that an enthusiastic facilitator in the employer organisation is needed, a forum for discussion and networking between different organisations is beneficial and the needs of novice and existing cyclists should be taken into account.

As well as creating some new cycle commuters, Cleary and McClintock contend that the project has also helped sustain pre-existing cycle use.

In an employer based study of travel linked with the promotion of travel plans in Hertfordshire, Dickinson et al. (2003) found that women were significantly less likely to cycle for the journey to work than men even if they lived near enough. This phenomenon was linked with the problems of dropping off and picking up children. They note that the increasing presence of women in the workforce on a more equal basis with men could result in a trend towards more traffic congestion.

2.7 Summary of the Chapter

The Table in Appendix B summarises contributions from the research discussed in Chapters 2, 3 and 4.

Pedal cycle traffic flow has apparently increased in the decade to 2001 and flow is seasonal. The NTS shows a levelling off in 1999/2001 in the declining trend in the average number of cycle trips per person. The journey to work accounts for less than half of all cycle traffic and the census in 2001 shows the bicycle is used by 2.89% of workers for the journey to work. 14 of the districts in England and Wales show an increase of 1% point in cycle mode share for the journey to work in the decade to 2001. Seven of these are London boroughs. A detailed comparative analysis of the differences in cycle use amongst the London boroughs could be instructive.

Cycle use in the UK is low and lower than use in The Netherlands, Denmark and Germany. Differential rates of cycle use are evident between different ethnic cohorts within the population in London and The Netherlands, and variation in cycle use may also be linked with socio-economic classification, geography of the urban area, infrastructure provision, climate and topography and legal status of the bicycle.

Official accident data for the UK is suspect because of under-reporting, however, the trend seems to be of reducing numbers of cycle accidents against a background of increasing cycle use. Cross-European comparisons show that cycling fatalities are fewer in countries with higher cycle use such as The Netherlands and Denmark, than in the UK.

Policy development in relation to transport over the last ten years in the UK can only be described as feverish, yet not much has changed in relation to the development of measures on the ground that are complementary to the needs of cycle traffic. Provision for cycle traffic is most often still made only on the back of other traffic management schemes or highway improvements. European countries that have strong policies at national level to promote cycling generally have higher levels of cycle use than other countries.

The central principal of the IHT guidelines of limiting speed and volume is inconsistent with what may be discerned as the historical custom and practice of maximising capacity for motor traffic flows while managing safety. The education and training of professionals working in the area of promotion and provision for cycling is recognised as needing developing to help in this regard.

Chapter 3 Review of cycle modelling literature

3.1 Structure of the chapter

The study of choice in transport, the purpose of which is to estimate the valuation of attributes in order to forecast demand and assist in estimating benefits, has at its disposal a number of approaches and analysis techniques. This chapter reviews research in the field of choice in connection with the bicycle, which may be divided into qualitative studies and quantitative studies. Quantitative studies are further divided into mode choice studies and route choice studies. Much cycling research has been qualitative in nature relying on questionnaire surveys of attitudes to cycling, the identification of reasons for not cycling and potential measures to improve cycling. An increasing volume of work is being undertaken to quantify the factors that are relevant to cycle trip generation, mode choice and route choice. As a prelude to a review of qualitative and quantitative studies, a discussion of monitoring studies, which are concerned with the analysis of volume and variation in volume of use, is presented. An increasing volume of research has been undertaken concerned with the physical attributes of routes for cyclists, what may be described as traffic engineering research, and this is discussed also.

Monitoring can take many forms including continuous flow measurement in a time series and the counting of flow at discrete periods in the form of a cross-sectional survey. Regular counts of trip making can be undertaken based on surveys at trip origins or destinations and bicycle kilometres travelled may be assessed from interview surveys. Monitoring studies are discussed in Section 3.2.

Qualitative research studies in transport consider attitudes revealed through a wide range of survey instruments. Examples include the use of focus groups, which are sessions in which responses are made by groups of around eight people (stratified to be representative in whichever way is appropriate) and guided by a facilitator on a set of issues. Questionnaire surveys with closed-end questions may also be used to deduce ranking scales or other forms of attitudinal response about different facets of transport. The aim of qualitative surveys is to reach a deeper understanding of the important issues as they affect transport users. Often, once these issues are identified, they are carried forward to further, quantitative research. Qualitative research with respect to cycling is discussed in Section 3.3 and the section is grouped into studies undertaken at national level, studies undertaken in individual urban areas, and studies that have been undertaken across different European countries to try to understand cross-cultural issues.

Quantitative analysis is concerned with the deduction of relationships between factors determined to be important in explaining observations of behaviour. Aggregate quantitative modelling is based on the assessment of factors that influence a whole population. The dependent variable is often a proportion of that population, for example, the proportion that cycles for the journey to work at ward level. Waldman (1977), in an early piece of quantitative work using a representative sample of census data from across the UK described in Section 3.4, undertook to quantify factors that influenced the propensity to cycle for the journey to work at aggregate level.

Disaggregate quantitative modelling considers choices made at the level of the individual. Data based on actual observations of behaviour (revealed preference) are valuable, so long as all the supposed influencing factors are measured and modelled. Revealed preference data is, however, limited in that it is unable to assist in assessing choices that do not currently exist, for example the provision of new infrastructure. The technique of stated preference has been used increasingly in transport modelling to present to respondents a series of hypothetical choices that are so constructed as to yield information on the relative values of different attributes for choices that do not exist at the time of the survey. Sample enumeration, a technique in which the probability of an individual choosing a mode is multiplied by the population making a choice, may be used to derive overall demand for a mode. Disaggregate mode choice research related to the bicycle is described in Section 3.4 and route choice research in Section 3.5.

The chapter rounds off with a discussion of the way that cycling is incorporated into transport models more generally (Section 3.6) and how costs and benefits of cycle infrastructure have been determined (Section 3.7). Section 3.8 concludes with an evaluation of the research that has been reviewed. A summary table of main findings from the references sources quoted in Chapter 3 is presented in Appendix B.

3.2 Cycle monitoring studies

3.2.1 Data collection techniques and issues

As has been shown in Chapter 2, levels of cycle use in the UK are low. Manual traffic counts undertaken as part of monitoring for general highway traffic may often include separate counts of cyclists but the flows are so low that the confidence limits are wide. Continuous monitoring of cycle volumes may be undertaken using automatic traffic counters (ATC), but these need to be well attuned to detecting the passage of a cycle and they work with greater effectiveness on segregated cycle paths. Experience with inductive loop ATCs, even when established at suitable sites, demonstrates that they can significantly underestimate actual cyclist numbers (Philippou, 1999). Other road vehicles can mask cyclists, cyclists may pass two abreast or may steer around the loop (e.g. via the footway). Emmerson et al. (1999) suggest use of employers and schools to undertake counts but this requires good co-operation and an interest by the employer or school. A further alternative suggested by Emmerson et al. is the counting of parked bicycles at selected locations.

The census provides a ten yearly record of journeys to work and is statistically robust, but its intermittency means that the currency of its data is poor towards the end of the ten year period. The National Travel Survey provides continuous data on personal travel including frequency of use of the bicycle. It is based on a random sample of private households. In 1998 20 "primary sampling units" (individual or groups of postcode sectors with an average of 2,900 delivery points) were selected per month with 21 addresses drawn from each primary sampling unit. While such data provide a picture of trends at a national level they cannot provide data on variations within particular locations where the monitoring of the impact of particular schemes may be required.

In addition to general local and national monitoring, cycle flow levels may be monitored against particular factors such as the weather and time of day, or particular measures that have been introduced with the specific aim of increasing bicycle use.

3.2.2 Scheme based monitoring studies

TRL conducted a large-scale cycle routes experiment (Harland and Gercans, 1993) considering the levels of cycle use and attitudes to cycling in Cambridge, Exeter, Kempston (Bedford), Beeston (Nottingham), Southampton and Stockton. The routes afforded better access to town centres from one sector of the outskirts of the town. It is notable how the programme for the study was delayed because of the difficulties of achieving the planning and implementation of the routes. Local politicians, statutory bodies and local cycling groups as well as residents often sought re-considerations of the designs or in some cases the abandonment of parts of the proposed routes. The negative impact of cycling on the safety of adjacent pedestrians was frequently a great concern. Cyclists were typically often perceived as being teenage boys who would assist in worsening the crime rate.

Use of the bicycle on the routes, taken from cross-sectional counts reduced to average weekday flows and repeated over the years 1984 to 1990, showed no consistency relative to the trend in cycle use nationally. Swings of plus and minus twenty percent in rate of use were reported and were assumed to be related to the random fluctuations in the relatively low flows measured. It was concluded that a one-week period within a year was insufficient for measuring changes in flow. Notwithstanding, it was deduced that there had been an attraction to the routes from adjacent roads and that the routes acted to sustain the level of cycling at a more constant level relative to the secular decline.

Overall the study concluded that there is no evidence to suggest that the 80% of cycle owners who do not use their bicycles regularly are deterred from cycling by the absence of safe routes. Most cyclists questioned in the study would have been walking or travelling by bus had they not been cycling.

Attitude surveys showed that construction of cycle routes in Exeter, Kempston, Beeston and Stockton led to reductions in the number of people who think cycling is dangerous but only in Exeter was there shown to be an increase in overall cycle numbers. From this work the authors conclude that there appears therefore to be little linkage between people's opinions about safety and their use of the bicycle.

"Before" and "after" casualty rates were compared with a control area for each town and this analysis showed that the risk of cyclist injury had been neither increased nor diminished. In the areas with cycle routes there has been a reduction in cyclist casualties on major roads balanced by an increase in casualty rates on minor roads. Again, this objective analysis does not fit with the perception of change in risk observed by residents.

The research concludes that provision of facilities alone, which would need to encompass cycle routes as well as area-wide safety management on minor routes, will not encourage cycle use.

The implementation of the Greater Nottingham Cycle Route Project (McClintock and Cleary 1996) found a decrease in the number of cyclists between 1985 and 1990 and this was assumed to be linked with adverse weather experienced during this period. The decrease in cycling on Saturday compared with generally stable cycling during the remainder of the week suggested that the network had encouraged utilitarian weekday cycling only. Partially conversely, female cyclists and those on shopping or education trips seemed more willing to use the facilities. While the total number of accidents remained stable over the period, the number of serious accidents as a proportion of the number of accidents declined. There were instances where, due to poor scheme design and implementation, cyclists preferred to use the adjacent road rather than the cycle path alongside the road. It was noted that there was only one route which improved journey time compared with the situation before implementation of the scheme. There appeared to be no correlation between cycle ownership and cycle flows within the study area and time period. A questionnaire survey of employees at the University, the county council and GPT, a large telecommunications company within the area where the cycle scheme was implemented, showed that around half considered that there had been improvements in perceptions of safety. It was found that while lifestyle factors such as moving house and health concerns could influence mode choice it was solely the provision or otherwise of facilities for cyclists which could affect perceptions of safety.

In an update, McClintock (2001) notes that there has been an increase of 18.7% in use of the cycle network from 1990 to 2000 and this compares with an increase of 11.4% on routes not part of the cycle route network.

Parkin (2001) used a panel of volunteer cycle surveyors in Bolton to record the number of other cyclists they saw on every day journeys. The data form a time series over a four year period. No statistically significant differences in volumes of flow were found between days of the week.

but flows on Sundays were generally higher indicating a preponderance for leisure journeys. Larger rates of flow were observed in the Summer with a sharp decline in cycling between September and December 2000 (Note that Autumn 2000 was particularly wet). It was also noted that the morning peak for cycle traffic appears to occur earlier than for motor traffic.

3.2.3 Monitoring against climatic condition

Emmerson et al. (1998) report monitoring of cycle flow against weather conditions at two locations, one in Bidston on the Wirral and the other in Chingford in Essex. Minimum and maximum temperature and rainfall in the 24 hours to 09:00am and the 24 hours from 09:00am were considered. It was found that month and day of the week explained more of the variation in cycle flows at the sites under consideration than did the weather condition. To support this, national cycle data from the National Travel Survey (Philippou, 1999) shows that cycle use in the peak Summer month of July is approaching 1.8 times greater in volume than that for the month of January (Note: February and December have lesser volumes than January). It is highly likely, of course, that the difference between levels of cycling in different months is as a result of differences in the weather between those months.

Emmerson et al. also found that maximum temperature was much more significant than either of the rainfall factors. A 1^0C rise in temperature was associated with a 3.3% increase in cycle flow at Chingford and a 2.9% increase in flow at Bidston. Rainfall was measured at 9:00am each day. It was thought that the propensity to cycle on a particular day may be related to the previous day's weather ("it rained yesterday, therefore it might today, therefore I will not cycle today") and therefore the effect on cycling of rainfall in the 24 hours preceding 9:00am as well as the 24 hours succeeding 9:00am was considered. Using linear regression with the factors multiplicative in their action rather than additive (i.e. a logarithm transformation was used), it was found that rainfall in the 24 hours succeeding 9:00am (i.e. rain on the same day as the count) was more significant than rainfall in the preceding 24 hours. Rain on the day reduced cycle flows by 11% at Chingford and 15% at Bidston. At both sites the effect of the quantity of rain was much weaker than the occurrence or otherwise of rain.

Based on data from Washington DC, Niemeier (1996) also concludes that temperature has a greater effect than rainfall on levels of cycling but this is in a different climatic regime than exists in the UK. Bergström and Magnusson (2003) undertook a questionnaire survey of employees in the Northern Swedish town of Luleå and the Southern Swedish town of Linköping. They note that rating scale responses to various questions based on 270 respondents from Luleå and 163 respondents from Linköping show that distance seems to be more significant for the mode choice during the winter period. Those cyclists who cycle all year and in Winter value exercise, cost and the environmental aspects of cycling while Summer-only cyclists evaluated precipitation, temperature and road condition higher than all year cyclists. Based on this last finding the authors suggest that an improved winter snow clearance regime could increase the number of Winter cyclists. They also note, with caution because of the low proportion of females in the sample, that women are harder to convince to cycle in the Winter because of the precipitation, temperature, road condition and darkness and that it may be easier to convince younger people to cycle in the Winter.

In an Australian study based amongst students in Melbourne, Nankervis (1999) attempted to differentiate between short-term weather condition and long term seasonal variation seemingly with the objective of de-mystifying assumptions about cycle commuter viability relative to weather conditions. The data set comprised two periods during 1980-81 and the year 1990-1991 and an attempt was made to study the combined effects of different weather conditions, including temperature, wind and rain. The study confirmed expectations that there is less cycling in the Winter when conditions are more adverse than in the Summer, but student cyclists are not easily dissuaded from cycling during adverse seasons or weather conditions. Rather tendentiously based on the available data, the author asserts that education campaigns to alter the perception of prospective cyclists could have the effect of reducing the decline in cycling during Winter months.

3.3 Qualitative cycle research

3.3.1 National studies

In a national review of attitudes to cycling Davies et al. (1997b) quote Brög (1982) who asserted that isolated measures including infrastructure changes are of limited impact, but that the cumulative impact of integrated groups of measures could be significant. Davies et al. were concerned that much of the work in relation to cycling had been "opinion polling" in nature and many studies had been directed to assessing negative aspects and overcoming them in order to unlock suppressed demand. The socio-psychological processes of behaviour change had however not been tackled.

The research by Davies et al. (1997b) used in-depth interviews, focus groups and stated preference exercises. General attitudes to cycling were found to be positive. Cycling was seen as healthy, a way to relieve stress and a good family activity. Cyclists view cycling as fast, convenient and useful for multi-purpose trips. However, cycling was generally seen as a minority activity and time pressure, stress, aggressive driver behaviour, decline of the two-parent family, personal security fears, out-of-town shopping, general Government policy for road building, car ownership increases and British drivers' disregard for the Highway Code were all seen as suppressing factors. There were discrepancies between the views of cyclists and non-cyclists. For example cyclists view cycling as "fast" while non-cyclists thought that it required time and preparation. The image of cyclists was varied and ranged from "sporting" to "eccentric".

By contrast cycling in The Netherlands, Denmark and Germany was seen as "normal". Five cyclist types were identified: practical cyclists (young fit males who commute), idealist cyclists (socially and ecologically aware), fair-weather cyclists (short un-demanding journeys mainly off-road), lifestyle cyclists (weekend cyclists who use the bicycle as an accessory linked with car use) and mainstay cyclists. The first four categories are classified as emerging cyclists, while the last category comprises those who have frequently cycled for some time and have no reasonable alternative. Propensity to cycle and the type of cycling undertaken may depend on lifecycle stage.

Davies et al. also found some regional differences, for example personal security and cycle theft were more significant in Liverpool and London. Even in York and Hereford where cycling to work had a 20% and 10% mode share respectively, cycling lacked a "major everyday image".

Frequent cyclists cycle because it provides them with freedom, independence and flexibility. Two main classes of deterrent to cycling, indirect and direct, were identified. Indirect deterrents were classified as competing modes, particularly the car, which once acquired represented associations of status, potency and convenience as well as simply being a mode of transport. Direct deterrents included cycling's lack of status, danger from traffic, personal safety fears, sexual harassment, cycle theft and vandalism, traffic fumes, weather, hills, personal image, cycle technology, purchase and maintenance difficulties. The surveys had difficulty in "untangling" the issue of fear of danger from motor traffic, that is, the balance between being injured, noise, fumes and the stress of busy traffic. This is perhaps a central issue in the use of the bicycle, but the research was unable to provide any indication as to the relative weights of the different factors.

Features of road design and operation that posed particular hazards and were cited most often were found to be parked cars, roundabouts and right turns. Other features included potholes, drainage grates and general debris. Road narrowings as part of traffic calming were considered difficult to negotiate and road humps were not considered to slow traffic sufficiently. Interestingly, cycling facilities seemed to cause as many problems for cyclists and non-cyclists as they solved, for example because of parked cars. Cycle routes were often considered not sufficiently direct or comprehensive. Danger was often cited as a main reason not to cycle, but safe cycle paths were not found to induce a change in anticipated behaviour.

The authors suggest that changes in "practical", "situational" and "emotional" states could be triggers to accept or reject cycling. A day-to-day decision may involve four important factors: task to be undertaken (journey length and load), physical circumstances (hills, weather traffic), time availability and antecedent state (mood and energy levels). For non-cyclists to begin cycling the authors suggest that "extended decision making" (after Ajzen et al. 1980) is required. This involves assessments of an "ego relationship" (how does cycling enhance my self-image?), "perceived risk of negative consequences" (e.g. danger in use), "social sanctions" (ostracism due to non-conformist stance) and "hedonic significance" (what is the amount of pleasure I will gain?). Each stage has the potential for very negative responses from a wide range of types of individual.

Interestingly they found that a bicycle was perceived as a personal item rather than a household item and this contrasts with a car that is more often used by a household. "Possessiveness" of a bicycle might be inversely related to household size and the number of bicycles in the household. A household with more bicycles will have the potential for a greater degree of sharing at least to the point where the size of bicycle (e.g. stand-over and saddle height) is not a material consideration. The more the sharing of bicycles amongst the household, the greater was found to be the possibility of more trips being made per bicycle.

The study concludes that a shift to levels of cycling found in Denmark and Germany would require a significant change in attitude that would require "individual and social behaviour change", "organisational change" and "situational and environmental measures". Failure in any one area, it is hypothesised, could lead to failure overall and specific practical measures include raising the status of cycling, cycle-friendly employer schemes, improved safety through speed restraint, high quality cycle facilities and improved cycle security arrangements.

Davies and Hartley (1999) surveyed people who had bought a cycle from Halfords, the high street retailer, and found that the most common motivation for purchasing a cycle was "to get fit". They noted however that purchasing a bicycle often coincided with a change in lifestyle (e.g. moving house, entering education). The main use amongst the sample was for leisure (70%) with commuting accounting for the majority of the remainder (20%). New cycle owners expected that the "best thing" about cycling would be "keeping fit/healthy" (83% of responses) with the next closest being "environment friendly" with 16% of responses. The "most difficult thing" about cycling was expected to be traffic (38%), weather (36%), hills (25%) and accidents (16%).

Out of the 76 people recruited at four stores (in Birmingham, Chelmsford, Harlow, York), 48 carried out a travel diary survey one month after the recruitment and 52 completed a face-to-face interview two months after recruitment. It was noted that women cycled less often than they had anticipated compared with men and the authors suggest that this may be because barriers to cycling for women are greater than they are for men. Only 25% of the sample said they were affected by busy roads, but those who were affected used strong language to describe their experiences ("life threatening", "horrible", "stressful", "harrowing", "absolutely petrifying").

Most used their bicycle once or twice a week. Everyone reported being pleased with cycling and wanted to increase the amount of time they cycled. It is not clear the extent to which this finding is due to the sample "self-justifying" their purchase. There is some evidence that cycling was more effort than had been anticipated. There is no evidence in the survey as to whether the expectation that the weather rather than hills would affect more people (see above) was reversed in practice.

Davies et al. (2000) surveyed employers' attitudes to cycling by undertaking in-depth structured open-format questioning by telephone of twelve private sector employers and face-to-face interviews with a range of seniority of staff from four local authorities. The employers all have employers travel plans in place. Transcripts of the telephone interviews were studied closely to distil common and significant themes. The motivation for changing travel behaviour was mentioned frequently and was concerned with company image, necessity because of Government policy and the inherent logic of making moves to promote alternatives to the car. Barriers to the greater take up of the bicycle were seen as including safety, facilities at the journey end and a lack of support because of generally held sceptical views and a perception of impracticality.

Taylor (1996) investigated the potential for using the bicycle as part of a journey by public transport. At five railway stations (Bedford, Cambridge, Guildford, Milton Keynes and Woking), 55.3% of the sample were found to cycle. At three bus park-and-ride sites (Bristol, Thornhill in Oxford and Askham Bar in York), 4.4% of the sample cycled. It was found that men were more likely to make up the "cycle and ride" population than women at railway stations. Cyclists are more likely to be younger than others using the transport interchanges and, unsurprisingly, the majority of cycle trips were journeys to work. Despite 50% of the non-cyclists in the sample travelling less than 5 kilometres to railway stations and 40% having access to a bicycle only 3% of station users and 1% of park and ride users said they would use a bicycle if their car was unavailable. Cyclists said that their bicycles were more attractive than their cars because they were more convenient, healthy and economical. They also said that they would like more sheltered and secure parking facilities.

Gardner (1998) studied the potential impact of growing leisure cycle use on utility cycling. 325 people who cycle mostly for pleasure, 115 people who cycle mostly as a means of transport and a control group of non-cyclists of 104 were interviewed using a short factual quantitative questionnaire. 15 face-to-face and 12 telephone in-depth qualitative questionnaires were also administered. The respondents were drawn from Bath, Bristol, Birmingham and from the High Peak Trail in Derbyshire. None of the sample displayed overtly "green" or anti-car sentiments but were distinguished only by their "ordinariness". It was found that those who had never cycled and those who had once cycled but given up would be more likely to start cycling for leisure purposes than for utility purposes. Leisure cycling was seen as relaxing and enjoyable and yet utility cycling was seen as the antithesis: stressful and dangerous. Cycling was a part of all respondents' childhood and the connotations of freedom and adventure that cycling brought as a child may be linked with the freedoms and adventure that are experienced in adulthood. Such adventure is in stark contrast to the daily grind of a commuter journey.

The Automobile Association (AA) undertook a study (Automobile Association, 1993) of 1,000 motorists (not necessarily their members) drawn from Birmingham, Norwich and Maidstone. They found that about one in five motorists in the sample undertake utility cycle journeys at some time or other with more coming from socio-economic groups AB (24% of the category are "cycling motorists") than DE (14% of the category are "cycling motorists"). Three types of journey that might be undertaken more often by bicycle are the journey to work, the journey to shops (excluding grocery shopping) and trips to leisure or social activities. In 1997 the AA followed up with a survey (Lawson and Morris, 1999) of 687 of their members (and hence does not represent a cross-section of the population) and in questions on policies to support or discourage motoring found (unsurprisingly!) that members who cycle for any purpose are generally slightly more supportive of transport policies designed to discourage car use than those members who are non-cyclists. Lawson and Morris make the point that two thirds of bicycle sales in the UK are mountain bikes, while in Denmark and The Netherlands only about one third are mountain bikes and that this is a clear indicator of different cultures surrounding cycling.

In June 2002 the AA followed up with a further survey 10 years on from the original 1992 survey (Lawson, 2002). 34% of motorists had cycled in the two years prior to the survey, slightly higher than the 31% in 1992. 13% cycle only for leisure (12% in 1992) and 21% cycle for utility purposes (19% in 1992). 59% of the sample do not cycle and half of these are unlikely to begin to cycle. Many more cyclists in 2002 than in 1992 say they would be encouraged to cycle if they wanted to get fit and healthier.

Bohle (2000), in a national study of 1,500 cyclists interviewed in Germany, found that cycle tracks are regarded as slightly more attractive than cycle lanes marked on the carriageway and that minor roads offer a greater attractiveness than major roads with a cut off at around 5,000 vehicles per day. The results were derived from face-to-face interviews and through discussion groups.

3.3.2 Individual urban area studies

Henson et al. (1997) used focus groups to identify deterrents to pedal cycle usage in Greater Manchester. Subsequent questionnaire surveys using these "deterrence factors" were scored by an undisclosed number of respondents on a seven point scale to identify their relative weight for the four journey purposes of travelling to and from work, shopping journeys, social entertainment journeys and personal business. Table 3.1 below shows the percentage of "total deterrence" against each deterrent factor. Each deterrent score by journey purpose was weighted to account for the proportion of trips for each purpose according to 1995 National Travel Survey proportions of journeys by purpose.

Table 3.1 Deterrent scores for cycling in Manchester (Henson et al., 1997)

Deterrent to Pedal Cycle Usage	Sum across respondents of deterrent score according to journey purpose				Total sum	% of total sum
	Work	Shopping	Social	Leisure		
Poor security of bicycle when parked	403	258	397	265	1323	17%
Unpleasantness of traffic and pollution	439	93	334	172	1038	14%
Poor weather	271	218	265	170	924	12%
Personal security	289	106	244	146	785	10%
Poor image			456	72	528	7%
General inconvenience	184		340		524	7%
Area too hilly	276		232		508	7%
Poor motor vehicle driver behaviour	290	34		104	428	6%
Poor load carrying ability		189		222	411	5%
Poor road surface	227	74		102	403	5%
Physical effort		109	206		315	4%
Too far to travel by pedal cycle	201		104		305	4%
Lack of confidence to cycle		41		96	137	2%
Total					7629	100%

Poor pedal cycle security when parked was most significant for shopping and personal business journeys (23% and 20% respectively). Unpleasantness of traffic and pollution was dominant for the work journey category (17%) and appeared to influence route choice as well as perceptions of well-being linked with health concerns. Manchester is notorious for its wet weather; evidence from the survey suggests that weather has a greater influence on shopping rather than work journeys (19% as opposed to 11%), but habit is probably the over-riding influence determining the relative proportions. Personal security is ranked relatively highly and the authors suggest that it is linked in people's minds with the witnessing of incidents that then help to determine route choice. They suggest that, at least amongst cyclists, attitudes towards cycling are becoming more favourable. However amongst non-cyclists in the focus groups there were generally held negative attitudes.

So far as hilliness is concerned, the authors note from the focus groups that the specific vertical alignment of the route as opposed to the general topography of an area is the most significant determining factor for making a cycle journey. Other general points which emerge are that non-cyclists rate deterrence factors generally one scale point more highly than cyclists and that females gave higher scores on average.

It is interesting that unpleasantness of traffic and pollution were linked in the specified factors. It is not possible to separate the possibly distinct and separate effects of "traffic" as opposed to "pollution". Certainly traffic and pollution are correlated as the one emits the other. From the point of view of the recipient of the effects of traffic, air pollution is only one among many potential impacts, others being risk, severance and noise. The extent to which a recipient can and does distinguish between the pollution and its source is potentially relevant only in so far as the source may have other effects of different magnitude of impact on the recipient. It is also interesting to note the disparity between some factors which could be deemed to be linked for example: "unpleasantness of traffic / pollution" (14%) against "poor motor vehicle driver behaviour" (6%); "general inconvenience of using a pedal cycle" (7%) against "poor load carrying ability" (5%) and "area too hilly" (7%) against "physical effort" (4%). This emphasises the need to specify variables as accurately and as specifically as possible.

Other similar work in the same area of the country has been undertaken by Tanner (1997) considering the characteristics of commuter cyclists and would-be commuter cyclists that are employees of the National Health Service (NHS) in Wigan. Inter alia, the sample of 306 respondents was asked what they thought would encourage cycling for the journey to work; 36% suggested showers and changing facilities, 35% provision of cycle paths (presumably implying off-highway provision), 32% traffic free routes, 29% cycle parking facilities, 28% lockable covered parking, 25% a cycle allowance and 22% lockers for clothes. A significant 43% noted that none of the above would be factors that encourage cycling.

In Nottingham, McClintock and Cleary (1996) note that four of the top five deterrents to cycling (danger/fear of involvement in an accident, 21.1% of response, congestion/volume of traffic, 10.6% of responses, aggressive/inconsiderate drivers, 7.5% of responses, air/noise pollution 5.5% of responses) may be attributed to the motor vehicle. The remaining one is weather (18.3% of responses). The facilities in Nottingham have improved safety based on both objective analysis (the accident data) and the perception of users and non-users of the cycle network. The authors note however that the facilities are relatively small in extent and sometimes have confounding effects (such as seeming to make it acceptable to cycle on the footway even where a segregated cycle lane is not marked). It is not clear from the analysis whether the perception of improvement reflects the actual improvement and the authors also note that more experienced cyclists (rather than would-be cyclists) are more fully aware of the relatively limited extent of safety improvements wrought by particular facilities. The work in Nottingham also confirms that the cyclists are not homogenous when it comes to trading convenience with safety. Males tend to value the former while females and young riders value the latter.

In a study of the barriers to cycling in Southampton, the Cyclists' Public Affairs Group (CPAG, 1997) found that the largest "selling point" for cycling when being promoted to the public is its potential to enhance "Health and Fitness" (36% of respondents). This was followed by cycling's environmentally friendly image (27% of respondents). The authors suggest that it has to be the weight associated with these two factors outweighing the negative impact of the deterrence factors that will then allow a culture of cycling to predominate.

More recent work in Belfast (RSNI, 2004) demonstrates that existing cyclists think that a wide range of infrastructure measures are better or much better than an "average road" including cycle lanes on the road (70% of respondents), cycle tracks adjacent to the road (76%), shared-use footways (57%) and cycle paths away from roads (78%). Traffic calmed roads (32%) and signposted back streets (19%) were not as popular. When respondents were asked to suggest improvements, 36% suggested more cycle and bus lanes, the next most popular category being off-carriageway facilities (12%).

3.3.3 *European studies: cross-cultural issues*

A comprehensive literature review of European qualitative research would demand more space than is available within a research document dealing quantitatively with the variation in cycle use within the UK. Nonetheless, as variation in levels of use is the overall theme, it is instructive at least to provide a flavour of European research which, akin to the direction in UK research work, is moving from qualitative to quantitative research. An important distinction between European work and UK work is the additional development of alternative theories of choice and this is introduced in this section with examples of its quantitative outworking being provided in Section 3.4.6.

Brög (1982) developed a "situational approach" to determine potential for change towards greater use of the bicycle. He determined that there are five dimensions to bicycle potential:

i. Option of using a bicycle (bicycle available and trip less than 15km).

ii. Constraints against using bicycle or requiring use of specific mode (transport of baggage, weather conditions, health, need car for work).

iii. Perception of route (no bicycle paths, too many hills, dangerous intersections).

iv. Perception of riding bicycle and time required (too slow, too tiring, clothes get dirty).

v. Subjective willingness (willing to use bicycle mode).

The list is hierarchical and a positive response to (i) is required before a decision is made about (ii), and so on. Based on a national survey within towns of population up to 100,000 there remained 30% who were subjectively willing to use the bicycle with proportions removed for each "dimension" being as shown in Table 3.2 below.

Table 3.2 Hierarchical dimensions of bicycle use (Brög, 1982)

Dimension	Percentage saying no	Percentage remaining
Option of using a bicycle	11	89
Constraints against using bicycle or requiring use of specific mode	37	52
Perception of route	6	46
Perception of riding bicycle and time required	8	38
Subjective willingness	8	30

It may be seen that the "constraint" dimension removes the largest percentage of possible users. Brög makes the point that an aggregate analysis of attitudes could easily over-estimate the proportion that take part in cycling if the "constraint" dimension is not properly considered. He concludes that bicycles can frequently not be used due to several simultaneous constraints. Even if the route were improved, the effect may be minimal because of other constraints such as transport of baggage. He suggests that there is a large group of people in favour of bicycles but who do not use them and amongst this group he suggests, controversially, that it may be more effective to restrict car use than implement measures to encourage cycling.

Jensen, M. (1999) suggests that much debate is based on the assumption that a high degree of mobility is an amenity and a necessity in modern life. It is suggested that the "rational" approach adopted to analyse transport issues fails to capture the emotional and sensual sides of owning one's means of transport. In depth interviews with 30 individuals in Denmark allowed for the definition of six person types: passionate car drivers, everyday car drivers, leisure time car drivers, cyclists/public transport users "of heart", cyclists/public transport users "by convenience" and cyclists/public transport users "of necessity".

Of the 788 respondents to a telephone survey, 1.4% were characterised as being cyclists/public transport users "of heart", 16.4% cyclists/public transport users "by convenience" and 6.5% cyclists/public transport users "of necessity". A difficulty with the research from a cycling point of view is that it has assessed both cyclists and public transport users as though they are the same group with the same characteristics. While this may be valid when assessing a travelling population as a whole, based on the lack of determinable difference between the populations, it does not allow for accurate definition of characteristics pertinent solely to potential or actual cyclists.

Evidence on the effect of habit can be found in the work of Gommers and Veeke (1986) who showed that there is a time lag between the introduction of new facilities and their adoption by the cycling public.

The University of Lund, funded by the European Union 4th Framework Programme, led a study into means of enhancing walking and cycling. The research was based around the concept of a marketing model (Hydén et al., 1998) in which as much is learnt about the people as necessary, the pre-conditions for use are made attractive, there is association between the behaviour and positive stimuli, and finally extrinsic stimuli are given in order to change the behaviour. Overall the conclusion of the researchers is that facilities for cyclists (and walkers) need to be of an appropriate standard so that users become convinced of the truth of marketing messages they receive. Apart from fly-by-night commercial operations, this is a recognised truth in any retail business.

Simons (1987) reports that the Dutch preference for cycling is based on the fitness it brings and the fact that it is "friendly" to the environment. He goes on to suggest, however, that there are other more practical motives as well. The bicycle is generally the fastest mode in urban areas for distances up to 8 kilometres, there is no difficulty finding a parking place and the bicycle is cheap to buy and to run. Apart from these rational motives he suggests there are also more "emotional" motives such as 86% of the Dutch thinking of the bicycle as a means to enjoy ones free time, 62% thinking that the bicycle gives a feeling of "togetherness and happiness" and 15% attaching feelings of freedom and independence to the bicycle.

Differences in propensity to use the bicycle between countries may be as a result of different levels of infrastructure provision but, perhaps more significantly, may also be as a result of cultural differences. Culture, however, is a difficult concept to define in the context of transport but may generally be thought of as an attitude in the minds of the "general public" resulting from influences on them from their peer groups (social and work), the media and their interpretation of the law. History and tradition may also play a part and this has already been noted in Section 1.3 on the history of cycling, for example the contrast between civic leadership attitudes in Italy and The Netherlands in the early part of the nineteenth century. The most appropriate definition of culture in relation specifically to choosing cycling as a mode is probably developed in the Theory of Planned Behaviour by Ajzen (1985) and may be thought of as the constraints placed upon a person by "social norm". Davies et al. (1997b and 2001) note other factors that may play their part such as personal esteem, independence, aspirations and philosophy. These are discussed in more detail in a quantitative context in Section 3.4.6, the section on Extended Decision Making Theory.

Presada (1999) from Brazil suggests that the bicycle is nothing more than a "discriminated (against), under-rated and ignored vehicle". He sees a transition from social stigma and lower class use of the bicycle to more widespread use and recognition and reputation through triathlons. Modern bicycles, being made of the latest materials to the latest designs, can be costly and therefore become attractive within a consumerist culture. He suggests that the breadth in the market allows for a range of social inclusion and that corporate sponsorship and the creation of sporting idols assists in the transition of the bicycle from an "alternative" culture to mainstream culture.

It may be seen that much European research on bicycle mode choice begins with and centres on the person and the attributes of the person before introducing other constraints such as journey attributes. This has attractions in the sense that it seems logical that choice, being a behavioural mechanism, ought to be very interested in the person, but has the disadvantage that it is likely to be less sensitive to transport variables than might otherwise be the case.

3.4 Cycle mode choice research

3.4.1 Waldman's national study based on census data

Waldman (1977) set out to test the assertion that considerably more people would make journeys by bicycle if they could do so safely. He suggested that it was necessary to find objective evidence that would support or refute the implications of qualitative surveys, and he quotes a Camden Friends of the Earth finding of 1975 that 46% of respondents to a survey cite danger as their main reason for not cycling and a report by an officer from Bedfordshire County Council to a conference in 1977 that 45% of respondents to a survey in Bedford cited danger as a major disadvantage of cycling. The study used readily available data as "rough and ready" measures of the factors that were deemed to influence the level of cycling.

The initial sample was selected as being every other borough taken from the tables of workplace and transport in the census of 1966. Initial analysis showed the range of cycling as being from 0% to 50% and the initial sample under-represented boroughs with more than 25% cycling. All boroughs with 25% or more cycling were added to the sample and it was then found that the County Boroughs and London Boroughs were under-represented and so an additional 30 randomly selected County Boroughs and London Boroughs were added to the sample. The final sample comprised 195 Urban Districts, Municipal Boroughs, County Boroughs and London Boroughs.

The dependent variable CYCLE was defined as the proportion of people who live and work in an area who reported riding a bicycle as their major mode of travel to work. The sample comprised only those who "live and work in an area" in order that an estimate based on town size could be made of trip-length, deemed a determining factor.

Factors thought to be most influential were hilliness, rainfall, trip-lengths, accident-risk, availability of alternatives and lifestyle factors. Wind was thought to be important but a measure was not available and it was therefore not modelled and, despite the availability of alternatives being mentioned as important, neither car ownership not public transport accessibility were modelled. Table 3.3 below defines the factors studied.

Table 3.3 Factors studied by Waldman, 1977

Factor	Definition	Min	Mean	Max
CYCLE	Proportion of people who live and work in an area who reported riding a bicycle as their major mode of travel to work	0	0.16	0.57
HILL	No. 25ft contour changes per road-mile	0	3.7	18.2
RAIN	No days rainfall in 1966 of more than 2.5mm	50	100	160
RESTD	Estimate of accident risk	9	52	203
R	Radius of the built up area (km)	0.309	2.093	8.118
TL	Trip length factor derived from R	0.204	0.929	1.110
INCOME	Average Household income	649	1218	2586
SEGA	Proportion of agricultural employees	0	0.017	0.152
SEGM	Proportion non-agricultural manual workers	0.295	0.629	0.865
SEGN	Proportion in non-manual occupations	0.133	0.345	0.682

The resulting model developed by Waldman is given in Equations 3.10 and 3.11 and comprises a town specific factor, w, acting on socio-economic variables. To arrive at this model, however, he adopted fairly extensive and contentious methodology to derive a measure for trip length (TL) and estimate of danger (RESTD). These are discussed in turn below before the development of the final model is discussed.

Trip Length

The radius of the built-up area for roughly circular towns was measured directly and for semi-circular towns or those with the centre near the edge were measured as though the missing half existed. The radius for oblong and elliptical towns was taken as the average of the major and minor axes with further non-specified approximations being made for irregularly shaped towns.

The first calculation Waldman performed was an attempt to derive a distance measure for trip lengths and this he based on the size of the town using the derived measure for the town's radius based on the assumption that all trips begin or end at the town centre. The trip length factor was derived by defining annuli (0-0.4km, 0.4-0.8km, 0.8-1.6km, 1.6-2.4km, 2.4-3.2km, 3.2-4.8km and over 4.8km) and assuming that CYCLE is defined as in Equation 3.1 below. No regard was paid to the actual spread or density of population within the inscribed circle implicit from the defined radius. Indeed, of course, population density could have been a significant independent variable in its own right.

$$CYCLE = Wa_1PD_1 + Wa_2PD_2 + ...Wa_nPD_{n1} \quad \text{Equation 3.1}$$

Where

CYCLE =	the proportion of people who live and work in an area who reported riding a bicycle as their major mode of travel to work
W =	a weighting factor for each town (see text below)
$a_{1,n}$ =	probabilities of cycling from within annulus *n*, based on even population density
$PD_{1,n}$=	proportion of people living within annulus *n* assuming homogenous population density.

The weighting factor *W* was determined by regressing CYCLE on HILL, RESTD and RAIN in a similar manner as in the final model form (see Equation 3.11) but without the trip length factor. Waldman does not quote the final form of the model to derive *W*. CYCLE was regressed on Equation 3.1 to derive the seven "*a*" coefficients. The coefficients were plotted against distance and the following functional form was derived:

$$y = 3.23x - 0.46 \text{ for } x \le 0.6\text{km and } y = \frac{0.62}{x} + 0.49 \text{ for } x > 0.6\text{km} \quad \text{Equation 3.2}$$

Where x is the measure of distance and y is the value of the coefficient a. It is not clear from the reference why Waldman did not regress CYCLE on all the relevant independent variables, but instead adopted this two stage approach to the modelling. The development of the measure for distance seems very contrived.

The functional form in Equation 3.2 indicates an increase in cycling with distance up to 0.6 km followed by a decrease with distance thereafter. At distances below 0.6km competing modes are predominantly walking and cycling but for many of the shortest journeys it will not be worthwhile cycling because of the time and effort involved in locking and unlocking the bicycle at the beginning and end of the journey. Thereafter it is reasonable to suppose that the decline in cycling with distance will be because of other competing modes which are more suited to greater distance. Assuming essentially circular areas and integrating over the whole range of distance from the centre, Waldman derived the forecast of proportion of the town which cycle to work in an area as:

$$CYCLE = \frac{2}{R^2}\int_0^R x.f(x).dx \qquad \text{Equation 3.3}$$

Where:

CYCLE =	the proportion of people who live and work in an area who reported riding a bicycle as their major mode of travel to work
R =	radius of the built up area
x =	distance from the centre
f(x) =	probability function of cycling

Substituting Equation 3.2 for *f(x)* in Equation 3.3 Waldman derived a function for trip length for a town based on radius R as:

$$TL = 2.15R - 0.46 \text{ for } x \leq 0.6\text{km} \quad TL = \frac{1.24}{R} - \frac{0.62}{R^2} + 0.49 \text{ for } x > 0.6\text{km} \qquad \text{Equation 3.4}$$

Where:

TL =	trip length factor
R =	radius of the built up area

(Note: A reworking of his calculations indicates a numerator of 0.92 instead of the 0.62 Waldman quotes for the second term of the second equation in Equation 3.4.)

Estimate of danger

In terms of estimating danger, ideally Waldman would have derived a measure based on knowledge of traffic conditions. Changes in the conditions would then lead to re-estimates of the effect of danger. Waldman used accident data and considered both pedestrian and cyclists accidents in deriving a measure of danger. He assumed that the rate at which cycle accidents occur on a journey to work is equal to that on other journeys. Initially danger was estimated based on Equation 3.5.

$$D = \frac{BIKEAX}{PEOPLE.PC} \qquad \text{Equation 3.5}$$

Where:

D =	Estimate of Danger
BIKEAX =	recorded number of accidents involving cyclists in the local authority area
PEOPLE =	estimate of the number of people who make journeys in the area (see Equation 3.6)
PC =	the proportion of cyclists amongst *PEOPLE* (see Equation 3.7)

$$PEOPLE = POPN + (INFLO.(\frac{POPN}{EMPRES})) \qquad \text{Equation 3.6}$$

and where:

POPN =	the resident population of the area
INFLO =	the number of people entering the area to work
EMPRES =	the number of residents who are in employment

$$PC = \frac{(INFLO.CYCLEIN) + (OUTFLO.CYCLEOUT) + (RESWORK.CYCLE)}{(INFLO + OUTFLO + RESWORK)}$$

Equation 3.7

OUTFLO =	the number of the people leaving the area to work
CYCLEIN =	the proportion of the *INFLO* who cycle
CYCLEOUT =	the proportion of the *OUTFLO* who cycle

RESWORK = the number of residents employed in the area

The logic of the form of Equation 3.6 is ambiguous and overall there are two drawbacks recognised by Waldman to the use of Equation 3.5. Firstly D depends on CYCLE in its computation and hence a measure for an independent variable will contain the dependent variable. Secondly, where the proportion that cycle is low, the confidence interval on the estimate of danger would be large. In only four cases were the 90% confidence intervals less than 10% of the estimate of D. Waldman derived a more reliable estimator for D from a step-wise regression of D on the pedestrian accident rate (PD), OUTFLO, the ratio of cars to population (CARPOP), INFLO, POPN, the ratio of INFLO plus OUTFLO to RESWORK (FLORATIO), the administrative type of the borough (ADMIN), PEOPLE and R. This re-estimate of danger reduced to:

$$RESTD = 0.127 \times 10^{-6}.OUTFLO + 4.56.DP + 0.0205.CARPOP - 0.00367$$ Equation 3.8

Where:
RESTD = re-estimate of the danger variable
DP = recorded number of accidents involving pedestrians divided by *PEOPLE*
CARPOP = the ratio of cars to population

Equation 3.8 was used for the 159 boroughs where DP was deemed acceptable and for the remaining 36 boroughs the following equation was used.

$$RESTD = 0.801 \times 10^{-7}.OUTFLO + 0.757 \times 10^{-3}.R + 0.831 \times 10^{-3}.ADMIN + 0.00108$$

Equation 3.9

Where:
ADMIN = type of borough (UD=1, MB = 2, CB = 3, LB = 4)

It is not intuitive that the pedestrian accident rate and the number of people leaving an area to work are adequate measures of an estimate of danger to pedal cyclists. Nor does it seem satisfactory that two equations are used; the second only in circumstances where a variable in the first equation cannot be relied upon.

Final model form

A number of overall model forms were considered: using total number of bicycle accidents for each borough as a proxy danger value; use of logarithms of variables, squares of variables and products of variables in regressions; using the odds ratio (CYCLE/(1-CYCLE)) as the dependent variable; trying to fit hyperbolic functions; greater differentiation of SEGs; separate calibrations for conurbations and dummy variables for characteristics of an area (e.g. free-standing, or conurbation). The final model comprised two separate regressions:

$$CYCLE = w(3.88.SEGA + 1.26.SEGM + 0.618.SEGN) + (5.37 \times 10^{-5}.INCOME) - 0.0796$$

Equation 3.10

Where:

$$w = e^{(-0.193.HILL - 0.00944.RESTD - 0.00623.RAIN - 0.104)}.TL^{0.786}$$ Equation 3.11

The model form defined by the two equations above was developed based on the a priori notion that the proportion of the population that cycle is a function of the proportions in the different socio-economic groups corrected by a town specific factor, *w*, which takes account of other assumed influencing factors. It is unclear whether or not this notion prevailed based on an alternative assessment where the town specific factors were allowed to act independently of socio-economic factors.

The order of procedure adopted by Waldman was first to regress the logarithm of CYCLE on HILL, RESTD, RAIN and the logarithm of TL, and he obtained an R^2 of 0.713. While it is counterintuitive that *w* increases with increasing TL this may be because some of the trip lengths considered were short and the proportion who cycle over short trip lengths is small. This results from the "fixed costs" of cycling, that is the time and effort in unlocking and locking the bicycle at the beginning and end of the journey. Second in the procedure he regressed CYCLE on the product of *w* and the socio-economic variables and the inclusion of INCOME (despite being intuitively of the wrong sign) was found to increase the R^2 by 2% and so was left in the model. The final R^2 was 0.745 and Equation 3.10 shows the resulting coefficients.

Socio-economic group and income variables were only significant when they were present together and only then explained 3% of the variation in CYCLE. The coefficients were consistent with what Waldman describes as a "widely held view" that manual workers are more likely to ride a bicycle than non-manual workers. Waldman remained cautious about the validity of the trip length factor due to the manner of its derivation from the town radius. The effect of rainfall was not negligible but it is unlikely that rainfall alone would be the factor determining whether a town has many or few cyclists.

Table 3.4 below indicates the parameter value, t-statistic and implied elasticities (percentage change in proportion cycling based on a percentage change in an independent variable about its mean value) calculated by the author from Waldman's models.

Table 3.4 Implied elasticities about the mean value from Waldman's (1977) model

Parameter	Coefficient	t-statistic	Elasticity
Constant (regression for W)	-0.104	0.475	
HILL	-0.193	9.698	-0.79
RAIN	-0.00944	6.170	-0.69
RESTD	-0.00623	2.721	-0.54
TL	0.786	0.416	0.87
Constant (regression on CYCLE)	-0.0796	3.446	
INCOME	1.255	3.017	0.49
SEGA	3.882	5.318	0.07
SEGM	0.537×10^{-4}	10.726	0.82
SEGN	0.618	2.809	0.22

The t-statistics are ratios of the coefficient values to their standard errors. An absolute t-statistic of 2 or more indicates a greater than 95% confidence that the coefficient is statistically different from zero. The constant in the regression on W is not statistically significantly different from zero and neither is the trip length coefficient. Despite this, Waldman chose to leave them in the final model.

All elasticities are below unity with increases in hilliness, rainfall and danger leading to reductions in cycling mode share for the journey to work (negative elasticities). As trip length becomes longer, then so too does the cycling mode share (a positive elasticity) and this is a reflection perhaps of inappropriate specification of the trip length factor or the fact that there are many short journeys below the distance at which cycling may be useful. There is significant variation in elasticities for socio-economic groups with manual workers being the most responsive (elastic) "market".

Through the modelling, Waldman discovered what he considers to be the joint effects of hilliness and danger. His model was used to predict CYCLE for extreme values of HILL and RESTD and he compared them with actual values of CYCLE as shown in Table 3.5 below.

Table 3.5 Waldman's (1977) joint effects of hilliness and danger

Type of borough or town	Predicted CYCLE	Example Town	Actual CYCLE
HILLY but SAFE	4%	Matlock	4%
		Worsley	4%
		Bodmin	6%
FLAT but DANGEROUS	6%	Hammersmith	5%
		Liverpool	3%
		Barking	9%
HILLY and DANGEROUS	0%	Sheffield	1%
		Plymouth	2%
		Burnley	2%
FLAT and SAFE	43%	Goole	52%
		Newark	42%
		Cambridge	36%

There are a number of methodological drawbacks to Waldman's work as have been identified in the discussion above. The main three drawbacks are the contrived nature of the development of a measure for trip length, the complex nature of the variable for danger and the a priori assumption about the form of the model, with socio-economic factors being "corrected" for town specific physical factors. The analysis to be undertaken in this research will address these drawbacks and the methodological approach is discussed further in Chapter 5. Waldman's work, however, having recognised some of its own deficiencies, provides a useful reference point for undertaking further work.

It is evident that there is a need to thoroughly update the work of Waldman because as recently as 1991 Rowell and Fergusson (1991) have been using Waldman's model as the basis for forecasting cycle mode shares for the journey to work. Assuming the variable for danger for the safest town in the sample applying to all towns, they showed that the proportion cycling for the journey to work could be as high as 26% rising to 47% if the town were flat. They do however acknowledge that these figures are appropriate within the social, economic and policy framework existing at the time with the implication that further updated work is needed.

3.4.2 Ashley and Banister's Manchester study based on census data

Ashley and Banister (1989a, b and c) studied cycling to work based on census data at ward level in the three metropolitan districts of Trafford (highest cycle use in Manchester), Manchester and Bolton (lower cycle use and relatively hilly). The dependent variable was the proportion of residents who cycle to work. It was recognised that there are differences between males and females in respect of cycle choice. However, it was thought that the numbers, if split, by sex would be too small for statistical analysis. Earlier work by Banister had shown a greater propensity by females to cycle in areas of high cycle use.

Distance was represented using the two census classifications of under 5km and 5-9kms. Intra-ward distances were calculated based on the ward size. The bus was seen as the most significant competitor to the bicycle and as a measure of this as an alternative the "mean 16-hour bus flows per kilometre of uni-directional major route links in a ward (excluding motorway)" was calculated. It was recognised that fog, snow, and rain could influence cycle use, but it was only rain which was investigated. Isohyet maps were constructed to determine rainfall levels by ward in 1980, the year before the census date of 1981.

The incidence of accidents to cyclists was rejected as a measure of danger because official accident data is known to be in error in this regard. It was judged that danger, and the perception of danger, could be related to the volume of motorised traffic, the composition of the traffic stream, the condition of the road pavement and the number of junctions encountered along a route as well as their method of control. Hilliness was defined as "the number of contour crossings of the defined major road network in a ward" and for comparison "the number of 5 metre contour crossings relative to the total length of major road network".

Social class and income were considered as were "personal characteristics" such as age, state of health (not able to be measured), personal attitude to physical fitness (number of sports shops and gyms in the ward was considered but rejected and therefore not measured) and social trends (again not possible to measure and therefore not measured). Measures to represent cyclists' facilities (both journey end and en route) were not included.

A variety of models were constructed but it was found that each model displayed heteroscedasticity. Various transformations were tried and the one that stabilised the distribution of the residuals was the square root of PCYJTW (proportion of residents who cycle to work). The final model chosen is shown in Equation 3.12 ($R^2 = 0.631$).

$$\sqrt{PCYJTW} = (0.2507 - 0.02648\ LGELNLEN - 0.03966\ HILLY + 0.1097\ ONCARHH)^2$$

Equation 3.12

Where:

PCYJTW = proportion of residents who cycle to work at ward level
LGELNLEN = natural log of sum of all uni-directional major road link lengths (or parts of links and excluding motorways) in a ward.
HILLY = number of 5 metre contours in a ward crossing the defined major road network divided by the sum of all uni-directional major road link lengths (or parts of links and excluding motorways).
ONCARHH = proportion of households in a ward with one car.

The authors note concern that the model is not as expected because there is no proven relationship between LGELNLEN and danger. It is possible that this parameter is representing other non-modelled effects. The lack of a distance variable and the strong correlation between rainfall and hilliness were also noted. It should also be noted that the coefficient for ONCARHH is of the wrong sign. It is hard to justify how the significant manual interventions and arbitrary exclusions in the development of the model could have led to a reliable model. A cause of the problems in the modelling could be the relatively small sample size resulting from analysis of wards in only three districts.

The derived model was tested in a predictive manner on the metropolitan districts of St Helens, Salford and Coventry. The model did not perform well and overall the authors reflect that the model could be viewed as one of "statistical association" and not one of "cause and effect".

3.4.3 Crespo Diu's study based on census data

Partly resulting from the research being undertaken as part of this thesis, Crespo Diu (2000) selected 635 wards from 28 districts in England and Scotland to study the proportion of the population cycling to work. The selected variables were used in two models. The first model comprised a transformation of the logit model (Equation 3.13) into a linear form (Equation 3.14) and the dependent variable, proportion cycling to work, was estimated.

$$P_i = \frac{1}{(1+e^{-Z_i})} \qquad \text{Equation 3.13}$$

$$\ln[\frac{P_i}{(1-P_i)}] = Z_i = \beta_{i0} + \beta_{i1}X_{i1} + \ldots.. + \beta_{in}X_{in} + \varepsilon_i \qquad \text{Equation 3.14}$$

Where:
P_i = Cyclists to work as a percentage of total number of workers for ward *i*.
B = coefficient to explanatory variable
X = explanatory variable value for ward *i*.
ε_i = independently distributed random variable with mean zero

The logit function upper limit is 100% as a proportion cycling. Crespo Diu rightly acknowledges that this is not realistic based on an average proportion cycling of around 2%-6% and an upper limit from European cities being around 40-50%.

Introducing S as the saturation level into the logit formulation instead of unity, as in Equation 3.15, and reformulating as in Equation 3.16, allows for the saturation to be estimated as an independent variable.

$$P_i = \frac{S}{(1+e^{-Z_i})} \qquad \text{Equation 3.15}$$

$$\ln[P_i] = \ln[S] - \ln[1 + e^{-(\beta_{i0}+\beta_{i1}X_{i1}+.....+\beta_{in}X_{in}+\varepsilon_i)}] \qquad \text{Equation 3.16}$$

The transformation in Equation 3.16 is unnecessary however as its form remains non-linear in the variables and hence requires a statistical analysis tool capable of handling non-linear regression models.

Crespo Diu's resulting models for both the linear regression without an upper bound estimate but including the weighting correction described above and the non-linear regression with an upper bound estimate are as shown in Table 3.6 below.

Table 3.6 Crespo Diu's resulting linear and non-linear models

	Linear model (Eqn. 3.14)		Non-linear model (Eqn. 3.16)	
	Coefficient	t-statistic	Coefficient	t-statistic
Constant	-2.7991	-4.9		
Ln(S)			3.8147	15.5
Males	0.0309	3.7		
Less2	0.0328	16.5	0.0326	12.1
F2to4	0.0234	10.7	0.0189	7.0
Rainfall	-0.0395	-10.3	-0.0425	-13.0
Flat	0.823	11.6	0.7400	7.9
Builtup	-0.209	-2.7	-0.2188	-2.4
Safety	-0.0173	-13.9	-0.0173	-11.2
Nocar	-0.0072	-2.1	-0.0094	-2.4

Notes:

MALES = *1 of males and 0 for females*

LESS2 = *proportion travelling less than 2 kilometres to work*

2TO4 = *proportion travelling 2 to 4 kilometres to work*

RAINFALL = *annual average days with "considerable" rainfall and snowfall*

SAFETY = *number of casualties to cyclists in the period 1981-1985 divided by the number of people that cycle to work*

FLAT = *1 for flat terrain and 0 for hilly terrain*

BUILTUP = *1 for urban areas and 0 for rural areas*

NOCAR = *proportion of households with non cars*

The results are sensible and show that sex and distance to work as well as the physical factors of rainfall and hilliness are important. The extent to which an area is built up and safety are also important. Crespo Diu's work has been a valuable contribution to the main research and has emphasised in particular the following issues:

- Good measures for a number of independent variables are not readily available, particularly climate data, hilliness data and road safety data. Further work needs to be undertaken to derive suitable variables.
- Socio-economic groups are not significant yet it does seem reasonable to suppose that there are some characteristics pertinent to the person that will assist in explaining cycle

use. This lack of significance of the socio-economic variables is seen as a drawn back in the modelling.

- It is unnecessary to transform the non-linear model with the saturation level, as it remains non-linear in the variables and hence needs a non-linear regression analysis technique.

Despite these few shortcomings the linear model succeeded in explaining 69.9% of the variation in the proportion of cycling to work. Although not directly comparable, the R-squared value for the non-linear model is 0.53. The approach taken by Crespo Diu has potential and needs to be developed further and this is discussed more in Chapter 5.

3.4.4 Rietveld and Daniel's aggregate model for The Netherlands

In very recently reported work Rietveld and Daniel (2004) studied the variation in cycle use across 103 Dutch municipalities with the objective of deducing the importance of policy sensitive variables in the facilitation of high levels of cycle use. The considered the following variables grouped into three areas:

- **Physical Factors**: presence of slopes (scaled to a measure between zero and unity) wind speed and rainfall
- **Population and individual features**: size of the city, insurance premiums as a proxy for danger of theft, density of human activity, share of people aged 15-19, presence or otherwise of a university, presence or otherwise of a School for Higher Vocational Training, number of cars per capita, level of disposable income per capita, share of non-native residents, share of catholic schools (based on the sometimes suggested premise that Catholics cycle for leisure and protestants tend to use the bicycle for commuting and other utility trips), the share of VVD (liberal party) voters.
- **Factors influenced by policy**: number of stops or turns off imposed on cyclists per unit distance, proportion of time spent walking and cycling slowly, obligation to give priority at crossroads, the number of times that it is not possible to cycle side by side, frequency of hindrances on a trip (e.g. posts in the ground), vibrations[1], the percentage of trips for which riding a bicycle is faster than riding a car, the ratio of the bicycle trip duration and the car trip duration, noise nuisance, satisfaction levels with municipality bicycle policies, the number of bicycle plans made by the municipality, effects on the budget, quality of the bicycle network and bicycle racks, parking prices and safety.

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[1] All of the preceding measures are derived from surveys undertaken by the Dutch Cycle Union, Fietsersbond. Fietsersbond has developed an instrumented bicycle to measure the last variable, vibrations.

Not all of the measures are fully explained or the metric used explicitly defined. The last measure for safety is tangentially revealed as being the number of serious accidents to cyclists per million bicycle kilometres over a four year period. This measure suffers from the same difficulties of correlation identified by Waldman (1977), but is not recognised by the authors.

A step-wise semi-log ordinary least squares regression was carried out with the dependent variable being the logarithm of the share of bicycle use for trips of up to 7.5 kilometres in length in the municipality. No explanation for the use of the particular form of the model, or the appropriateness of using the computer driven step-wise procedure for inclusion of variables is offered but the resulting model is summarised in Table 3.7 below.

Table 3.7 Semi-log regression for 103 Dutch Municipalities (Rietveld and Daniel, 2004)

Variable	Coefficient	t-statistic
Constant	-0.9101	-6.31
Population (thousands)	-0.000829	-3.90
Human activity indictor	-0.00669	-3.00
Proportion go 15-19 year olds	4.19	2.10
School for Higher vocational Training	0.0742	2.32
Proportion of VVD voters	-0.753	-3.27
Proportion of foreigners	-0.625	-1.91
Number of cars per capita	-0.260	-1.95
Relief (hills and slopes)	-0.745	-10.76
Stop frequency	-0.0499	-3.63
Parking costs	0.0522	4.13
Hindrance frequency	-0.0126	-2.22
Speed (compared with car)	0.03392	4.41
Safety level	0.0109	1.83
Degree of satisfaction	0.0509	3.50
Adjusted R-squared	0.726	

Without knowing the level of the metric it is difficult to accurately deduce the effect of individual significant parameters, but the relatively high t-statistic level of the hilliness variable, even for The Netherlands where the variation in this factor is relatively small, is noteworthy. The authors offer some level comparisons with bicycle use as follows:

- An increase in population of 100,000 equates with a reduction in bicycle use of 8%
- A 1% increase in the share of young people equates with a 4% increase
- A 1% increase in "foreigners" equates with a reduction of 0.62%
- The presence of a school for higher vocational training equates with a 7.4% increase
- A hilly city equates with a reduction of 74%

- One additional car per capita equates with a reduction of 26%
- If a bicycle journey is 10% faster than by car this equates with an increase of 3.4%
- 0.3 fewer stops per kilometre equates with an increase of 4.9%
- An increase of 14 Eurocents per hour parking charge equates with a 5.2% increase
- 0.25 fewer hindrances per kilometre equates with an increase of 1.3%
- A 1% increase in people dissatisfied with bicycle policy equates with a 0.05% reduction in cycling
- One less victim per million bicycle-kilometres over four years equates with an increase of 1.1%

Presuming that the measures determined by the Fietsersbond are accurate, they offer a level of detail and sophistication to the model as they reflect well the true impact of infrastructure on cyclists' level of effort and comfort. Some of the other variables (thinking perhaps of the populations voting record) are unusual in the context of mode choice but their selection reflects the European consideration of culture in a wider context as being of importance in transport.

3.4.5 Non UK disaggregate mode choice studies

Noland (1995) aimed to study behavioural response to perceptions of risk in connection with mode choice and undertook a mail based survey of residents in the Philadelphia metropolitan area achieving a sample of 506. Two measures of perception of risk were created on a seven point scale based on responses to a question about how likely respondents thought an accident was in the next five years by each of the modes of bicycle, car, walking and "transit" and the second how seriously injured they would be if they were in an accident.

Three models were constructed based on the logit function and different combinations of the variables from the two questions and it was deduced that there is behavioural response to mode choice due to risk perceptions. If a mode is made safer it may be presumed that more people will use it for commuting. The direct elasticity for bicycle mode choice from one of the models was estimated as −1.19 indicating that for a given percentage reduction in bicycling risk there will be an increase in bicycle use greater than the percentage reduction in risk. This is a very high elasticity and is not very believable. Noland notes that this high elasticity could lead to adverse consequences if a perceived risk reduction does not correspond with the actual risk reduction. It was also found that the perception of risk lowers with increasing age and is lower for males.

Using the same data set and a multinomial logit model, Noland and Kunreuther (1995) consider policies for increasing bicycle transportation for commuting trips. Elasticities of the probability of cycling relative to convenience (3.208), comfort (0.983), parking availability (0.838), cycling competency (1.942) and "lack of shoulders" on the road (0.496) showed that improvements in convenience would have the largest effect. The elasticities are high relative to elasticities normally found in transport modelling and may be as a result of the level of cycling being so low. If convenience is associated with journey length, that is changes in land-use policy to reduce length, then it is implicit that the most effective policies will be long run. Provision of bicycle lanes adjacent to the carriageway (in the shoulder) can be introduced in the short-run but will have only limited effect. Cross-elasticities of probability of cycling relative to car cost (0.299), car convenience (-0.562), car comfort (-0.286) and number of cars owned (-0.203) show that it is in reducing the convenience of the car that the greatest elasticity is evident. The authors note that characteristics of road design can have an impact on convenience and risk and suggest that perceptions of these factors need to be more closely addressed in future work.

Again in the USA, Cervero and Radisch (1996) set out to compare travel in Rockridge, an older compact mixed use neighbourhood, with Lafayette, a spacious community with car-oriented retail facilities. Rockridge, with average trip lengths of 6.8 miles is compact while Lafayette, with average trip lengths of 11.2 miles, is "not particularly inviting to any kind of movement other than the private automobile". For trips of one mile or less, the share of automobile trips in Rockridge was 15 percentage points lower than for Lafayette. A disaggregate binomial logit model was constructed for the choice between "car" and "non-car" for home based non-work trips (620 observations). The non-car modes were transit, walking, cycling and "other". A dummy variable for "neighbourhood type" and variables for number of persons per household, vehicles per household, and annual salary of respondent were used and were all significant. The model Rho-squared (0.292) was reasonable. A separate logit model for home-based commuter trips was constructed with the same modes as for the non-work trips model (840 observations). The neighbourhood dummy variable was not significant, but the other predictor variables of commute destination, number of vehicles per household, sex and age were significant. The authors conclude that the home end built environment exerts a stronger influence on trips for shopping, personal business and other non-work purposes than on commuting, albeit the commuting that was considered was long distance to the Central Business District of San Francisco and Berkley. The research suggests that a town with a fine grained highway network would create a higher level of cycling than a town with a coarse grained highway network.

Ortúzar et al. (2000) undertook a comprehensive stated preference household based study in Santiago to estimate the demand for a cycleway network. Rising car ownership (110 per 1000 inhabitants in 1997) in Santiago is creating increasingly serious pollution and congestion and the Government has undertaken isolated measures to implement cycle facilities. These measures have failed because cycle lanes are not respected by motorists, there are few bicycle parking facilities and there is a general culture biased against greater cycle use. The study's objective was to consider the potential for increased cycle mode share based around a plan of cycleways segregated from motor traffic for the whole city with approximately 3.2km of cycleway per square kilometre of the city. These proposals are considered to form a wholly new mode. In many instances the network is designed to integrate with the Metro and provide for interchange with parking facilities at the Metro stations.

Focus groups led to a household based interview to consider stated preference (SP) choice games for bicycle or a bicycle-Metro combination as an alternative to the current mode used based on 851 observations. In addition to the SP model, a fourth stage consisted in estimating models where the postulated options were "would consider using bike" and "would not consider using bike" and used socio-economic information and data about current trip characteristics. The SP and the fourth stage model were applied to the Santiago strategic model trip matrices.

The authors assert that the general tendency shown by the "would consider using bike" models is for those who are most willing to cycle to be those who are young, on low income, without a car in the household and with a low educational level. The author's focus on these socio-economic variables is peculiar in the sense that other equally important determinants of choice are present and include accessibility to Metro, peripherality, purpose and trip length. No attributes specific to the proposed cycleways were modelled.

The authors note the importance of the walk and wait variables in the SP models and the transfer penalty (that acts for the mixed modes of park-and-ride, feeder bus and bike-Metro). The dummy variable for weather also has a significant parameter.

The two models were used to forecast mode shares in Santiago assuming a comprehensive system of cycleways was introduced. The results indicated that sectors of the city could capture 10% of travel demand to the bicycle and on average demand would rise from 1.6% currently to 5.8% with the cycleway network.

3.4.6 UK disaggregate mode choice studies

In assessing whether improved facilities can meet the targets of the UK national cycling strategy, Wardman et al. (1997) suggest that models that deal with aggregate behaviour are unsuitable because they are unable to analyse cycle facilities to the required level of detail. They carried out a stated preference based study amongst 114 car users and 107 bus users (1026 and 963 SP responses respectively) who were deemed "in scope", i.e. had the potential to switch to the bicycle as a mode of transport for the journey to work. The six attributes presented at three different levels to the respondents were in vehicle time (car or bus), cost, cycle time, cycle facilities en route, weather and facilities at destination.

Two binary logit mode choice models were built, car versus bicycle and bus versus bicycle. The novelty in this work was the assumption that the value of the en route facility is not a constant (value in pence) but varies with the journey time.

The value of time in fine weather with no on-route facilities was estimated at 9.58p/min, 6.22 times greater than the combined value of car/bus in vehicle time of 1.54p/min. This high value of time represents the disutility of cycling in what may be regarded as typical peak urban conditions. Table 3.8 below shows valuations of time in different conditions.

Table 3.8 Wardman et al. (1997) valuation of cycling time in different conditions

Mode	Facilities	Weather	Money Value
Cycling	None	Fine	9.58 p/min
Cycling	Un-segregated	Fine	7.53 p/min
Cycling	Segregated	Fine	2.87 p/min
Cycling	None	Wind	13.36 p/min
Cycling	Un-segregated	Wind	11.32 p/min
Cycling	Segregated	Wind	6.66 p/min
Cycling	None	Rain and Wind	21.28 p/min
Cycling	Un-segregated	Rain and Wind	19.24 p/min
Cycling	Segregated	Rain and Wind	14.58 p/min
Car/bus			1.54 p/min

Notes

1 Money values as at May 1996

It may be noted that, even in segregated facilities, the estimated value of cycle time is broadly double that of using the car/bus. Segregation brings additional protection from risk and unpleasantness and this is estimated to be the greater part of the value of cycling time. Adverse weather conditions have a dramatic effect on the value of cycling time.

Forecast cycle shares were produced for 13 scenarios. Un-segregated cycle lanes were shown to have only a marginal impact on mode share and cycle facilities such as segregation on its own would be unlikely to meet the National Cycling Strategy policy aspiration of a quadrupling of cycle use by 2012. In order to produce a 12.6% mode share for existing bus users, the forecasting model showed that it would be necessary to provide a segregated path for the whole journey, which for car users would create a 10.9% mode share.

The authors conclude that it would be interesting to isolate the contributions of risk as opposed to benefits of a more pleasant environment in which to cycle. The analysis also does not value cycle priority measures, cycle friendly junctions, traffic calming schemes and shared use footways, road surface or traffic levels. Interactions between weather and facilities have been studied but interactions between facilities and gradient, distance, traffic levels and socio-economic characteristics on the value of time in cycle facilities have not been studied. Attitudes are recognised as being important and their impact on cycle levels is suggested to be worthy of further analysis.

Wardman et al. (2000) used both revealed preference and stated preference data to explain observed variations in cycle trip rate across individuals for urban commuting journeys, forecast the effect of a range of improvements and evaluate scheme proposals. The data comprised four types: (i) National Travel (NTS) Survey Revealed Preference (RP) mode choice data, (ii) surveyed RP mode choice data specifically for the purpose of modelling cyclists' mode choice, (iii) Stated Preference (SP) mode choice data and (iv) SP route choice data.

The final choice data set comprised 23,926 from NTS, 969 from the RP data set, 2115 SP responses from those who said there were cycle facilities and 3106 SP responses from those who said there were no cycle facilities in their area. This distinction is relevant in that presence, and hence familiarity, with facilities may engender a different view, perhaps either more positive or more negative, than for respondents who state that there are no facilities in their area. Respondents were all drawn from the East of England cities of Leicester, Norwich, York and Hull.

In the mode choice model three coefficients for ratings of danger, tiredness and cycling ability were shown to be statistically significant. Hilliness may not have been significant because none of the cities surveyed were particularly hilly. The model did not produce statistically significant or theoretically consistent effects from age, sex or socio-economic group. Income effect was also very minor and was left out of the final model.

The study provided a range of new insights into choice in relation to cycling, including that time spent cycling is valued 2.9 times more highly than in-vehicle time. The intriguing, although impractical, prospect of people being paid to cycle was modelled and it was found that a payment of 50 pence per day would increase the cycling proportion by 18% (4.5% mode share to 5.3% mode share), rising to 36% (6.1% mode share) for a £1 payment.

The authors recognise that the model did not assess the impact of topography as much as they would have liked. The study did not examine very specific cycling improvements such as advanced stop lines or toucan crossings or innovative roundabout designs. The authors suggest that the health effects of cycling could be worth investigating. Discussion of the route choice aspects of the study are contained in Section 3.5.

The first stage of the study by Wardman et al. (2000) aimed at identifying the proportion of the general population that would consider using a cycle to travel to work in urban areas in eight geographical regions and is reported in Siu et al. 2000. Door-to-door responses were drawn from Leicester, Norwich, Hull and York and telephone responses were drawn from Bradford, Sheffield, Blackburn, Leicester, and Nottingham. Data from the separate surveys were combined to produce percentages of people who would consider cycling by topographic characteristic. It was found that 32% would consider cycling in flat areas, 16% in undulating areas and 5% in hilly areas.

It was shown that males were more likely to cycle than females. Car drivers and passengers and bus users were less likely to transfer to cycle than walkers and the city location has a significant effect. This is due to hilliness and in moderately hilly areas the probability of considering cycling is 1.5 times less than flat areas and 2.3 times less likely in hilly areas. Neither age nor occupation has a significant effect on propensity to cycle.

3.4.7 Mode choice based on extended decision making theory

Bamberg and Schmidt (1994) undertook a study of the "intention to use a car" and the "intention to use a bicycle" for journeys to university events (lectures and other social events) of 188 students in Geissen in West Germany. The authors' intention was to test the applicability of the Theory of Planned Behaviour (Ajzen, 1985). Ajzen suggests that "intention" and subsequent behaviour are determined by three parameters. Firstly, "Attitude towards a behaviour", which can be measured as the sum of the products of "beliefs about an outcome" and the "evaluation" of that outcome as shown in Equation 3.17 below.

$$A_B \propto \sum_n b_i e_i \quad \text{Equation 3.17}$$

Where A_B is attitude towards the behaviour, b is the belief that performing the behaviour B will lead to outcome i and e is the evaluation of the outcome i. Secondly, the "Subjective" or "Social Norm", which can be measured as the sum of the products of "beliefs of significant other person(s)" about the activity and the individual's "motivation to comply" with the significant others' beliefs as shown in Equation 3.18 below.

$$SN \propto \sum_n b_j m_j \qquad \text{Equation 3.18}$$

Where SN is the subjective norm, b is the normative belief concerning referent j and m is the individual's motivation to comply with person j. The final parameter is "Perceived Behavioural Control", which can be measured as the sum of individual measures of control, such as time, money, car availability etc. as shown in Equation 3.19 below.

$$PBC \propto \sum_n c_i p_i \qquad \text{Equation 3.19}$$

Where PBC is the perceived behavioural control, c is the control belief about action i and p is the power of control action i.

Bamberg and Schmidt constructed a questionnaire, the answers to which were rated on a 7 point scale of –3 to +3 that related to the three parameters of the Theory of Planned Behaviour as indicated in Table 3.9 below. The scales "Intention" and "Social Norm" varied from –3 to +3, and it may be seen that the measure for social norm did not therefore comply with the sum of the products formula if Equation 3.18. The scale for attitude was taken as the "outcome" (+3 to –3) plus the product of the belief about the outcome (-3 to +3) and the evaluation of the outcome (-3 to +3), that is a scale of –12 to +12 (i.e. 3+(3x3)). The scale for the perceived behavioural control was taken as the product of the individual control (-3 to +3) multiplied by the evaluation of that control, that is a scale of –9 to +9.

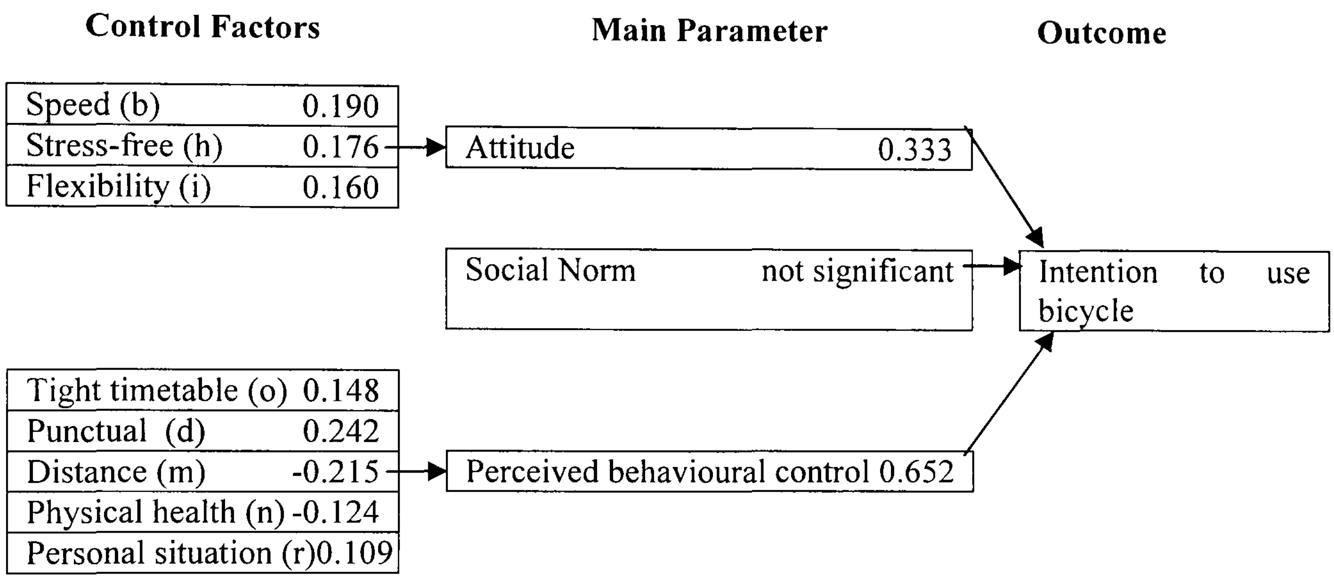
On the day of the questioning 63.4% of the sample used the car, 20.2% used the bicycle, 13.7% the bus and 2.7% walked. Structural Equation Modelling was used to deduce the significance of the variables "attitude", "social norm" and "perceived behavioural control" in relation to stated intention, and also the factors that were thought to affect "attitude" and "perceived behavioural control". The authors are comfortable in assuming that a seven point scale is sufficient for use in linear regression models.

Table 3.9 Theory of Planned Behaviour questions (Bamberg and Schmidt, 1994)

Parameter	Related questions	Worded descriptions of the ends of the –3 to +3 scale
Attitude	• For me to go by bicycle to classes this semester would be:	Good – bad
	• For me to go by bicycle to classes this semester would be:	Advantageous - disadvantageous
…….And beliefs about the outcome	I would get to classes by car / bicycle this semester: Inexpensively (a), Quickly (b), Comfortably (c), Punctually (d), without accident risk (e), safe from crime (f), stress-free (h), flexibly (i), in an ecologically justifiable way (j)	Likely – unlikely (for each)
……And evaluation of beliefs about the outcome	Getting to classes is: Inexpensively, quickly, comfortably, punctually, without accident risk, safe from crime, stress-free, flexibly, in an ecologically justifiable way	Important – unimportant (for each)
Subjective norm	• Most of the people who matter to me think that I should/should not go to classes by car / bicycle	Yes – no
Perceived Behavioural control	• It is easy/difficult for me to go by car/bicycle to classes this semester	Likely – unlikely
	• It is easy/difficult for me to go by car/bicycle to classes this semester	Likely - unlikely
… measured as individual controls	• During the semester there will be a car at my disposal (k)	Likely – unlikely
	• During the semester I will have enough money to run a car (l)	Likely – unlikely
	• During the semester I will be obliged to travel by car due to the great distance between home and classes (m)	Likely – unlikely
	• Given my physical health I will not be able to cycle to classes (n)	Likely - unlikely
	• During the semester, because of tight timetable and distances between university buildings I will have to go by car (o)	Likely – unlikely
	• During the semester, because of tight timetable and distances between university buildings I will have to go by car (p)	Likely – unlikely
	• During the semester I will have so little money that I will have to go by bicycle (q)	Likely – unlikely
	• During the semester because of my personal family situation, I will be obliged to go to classes by car (r)	Likely – unlikely
	• Today I came to class by car / bicycle	Yes - No
Intention (the outcome)	• I intend to go to classes this semester by car / bicycle	Likely - unlikely

Structural equation modelling is a multivariate data analysis technique that allows for multiple relationships of dependent and independent variables; this compares with multiple regression where there is only one dependent variable but many independent variables. In structural equation modelling a dependent variable in one equation may be an independent variable in another equation. The structure of the relationships usually accords with a preconceived theory. In the case of the mode choice investigated in this study it is the Theory of Planned Behaviour and Table 3.10 below summarises the parameters that were found to be significant and that accord with the Theory of Planned Behaviour for intention to use bicycle.

Table 3.10 Significant parameters for bicycle choice model (Bamberg and Schmidt, 1994)



No significant relationship with the main parameter "social norm" was detected in the data through the method used. There are other significant relationships that were discovered but that do not comply with the Theory of Planned Behaviour as follows:

- Flexibility correlated with Intention directly (-0.103)
- Tight timetable correlated with attitude (0.242)
- Social norm correlated with attitude (0.394)
- Social norm correlated with perceived behavioural control (0.381)

It is significant that the strongest influence on intention to use car is distance (weight of 0.501). Car availability is the most significant "perceived behavioural control" (weight of 0.725).

Despite not having a significant influence directly on the intention to cycle, "social norm" does influence "attitude" and "perceived behavioural control" (third and fourth bullet points above). Hence, social norm is influential, but not directly on intention as suggested by the Theory of Planned Behaviour as proposed by Ajzen. The effect as detected may be understood in the sense that controls and attitudes are both to some extent subjective and ones personal attitudes and ones perceptions of constraints are determined within a social construct where social expectations may place boundaries on behaviour.

Forward (1998) undertook a study of attitudes to cycling in Barcelona, Amsterdam and Copenhagen as part of the European funded ADONIS project. The aim of the study was to analyse cross-cultural differences in attitudes and behaviour to modal choice. The study used the Theory of Planned Behaviour (Ajzen, 1985) as described above. Scores on a seven-point scale from a questionnaire returned by 354 respondents were taken to the questions shown in Table

3.11. In addition questions were asked on frequency of mode used in the last two months in order to understand the issue of habit in connection with mode choice.

Table 3.11 Questions for assessment using Theory of Planned Behaviour (Forward, 1998)

Belief	Question
Perceived Behavioural Control	*I would be more or less likely to bike a distance of 2.5km in the next three to four weeks if:* I am in a real hurry; The traffic is heavy; The weather is dry; It is night time; I have a lot to carry
Subjective Norm	*These people would strongly approve/strongly disapprove of my engaging in this activity* Friends; Partners; Family
Attitude	*If I carried out the suggested journey then it will* Increase my comfort; Make me feel relaxed; Increase my sense of freedom; Increase my travel time; Cost me a lot of money; Increase my chances of being involved in a traffic accident; Increase my chances of being threatened by other people; Make me worried in case the vehicle is stolen; Help me to become healthy and fit.
Habit	*In the past two months I have walked / cycled/ driven a distance of approximately 2.5km* Not at all; Less than once a month; About once a month; About two or three times a month; About one or two times a week; Three or more times a week

Notes:

1 Responses were on a 7 point scale, 1=strongly disagree and 7=strongly agree.

2 Habit is on a six point scale.

Using the seven-point intention scale as the dependent variable and attitude, subjective norm and perceived behavioural control as the independent variables, a stepwise regression analysis was performed which demonstrated that 57% of the variance in intention to cycle was explained by variables remaining in the model at the end of the process. Subsequent addition of habit increased the explained variance to 78%. The significance of habit in the manner asked in this survey seems to explain nothing more than the fact that if one cycles, then one says one cycles and one actually does cycle. Factors of importance in relation to cycling are presented in the report as correlations between individual beliefs and the overall intention to use a particular mode as shown in Table 3.12 below.

Table 3.12 Correlations (Pearson r) between specific beliefs and intention (Forward, 1998)

Belief	Question	Correlation with intention to cycle Pearson r
Perceived Behavioural Control	*I would be more or less likely to bike a distance of 2.5km in the next three to four weeks if:*	
	I am in a real hurry	0.70
	The traffic is heavy	0.63
	The weather is dry	0.70
	It is night time	0.73
	I have a lot to carry	0.57
Subjective Norm	*These people would strongly approve/strongly disapprove of my engaging in this activity*	
	Friends	0.40
	Partners	0.51
	Family	0.49
Attitude	*If I carried out the suggested journey then it will*	
	Increase my comfort	0.44
	Make me feel relaxed	0.45
	Increase my sense of freedom	0.37
	Increase my travel time	-0.31
	Cost me a lot of money	-0.14
	Increase my chances of being involved in a traffic accident	-0.13*
	Increase my chances of being threatened by other people	-0.38
	Make me worried in case the vehicle is stolen	-0.26

Note

*1 Correlations shown are significant at the 1% level except for those marked * which are significant at the 5% level.*

The correlations presented above do not indicated the effect of the parameter. For example, while the weather being dry is highly correlated with the intention to cycle, the weight of this parameter on the intention may be quite small. It may be noted that the control beliefs are the most strongly associated with intention. Respondents thought that cycling would make them feel relaxed, that cycling would be a comfortable mode, and that their sense of freedom would be increased. However the responses showed that respondents did not think that cycling would increase their journey time, cost a lot of money, increase the chance of an accident, increase the chance of being threatened by others or create worry about the bicycle being stolen. Some of these appear counterintuitive. It would have been good to be presented with correlations by city, however the authors lapse into the presentation of a whole series of mean values for the scores when they consider comparisons between the cities. All that may be deduced is that the mean for perceived behavioural control of cycling, the mean for the subjective norm and the mean for attitude is less in Barcelona than in either Amsterdam or Copenhagen. Unsurprisingly the means for intention and habit in connection with cycling are also lower in Barcelona than in the other two cities.

In a follow on study to Davies et al. (1997b) described in the section on qualitative studies above, Davies et al. (2001) undertook a quantitative study of the attitudes of individuals to cycling. The research was based within an established social market research paradigm known as "diffusion theory" or the "innovation model" (Rogers and Shoemaker, 1971 and Rogers, 1983). Categories are defined as follows:

- Innovators: venturesome, maverick, experimental minority.
- Early adopters: like to be in established forefront of ideas, trendsetters.
- Early majority: will follow a trend but need peer leaders (early adopters).
- Late majority: will come on board when it is clear that most people are going along.
- Laggards: resist change, suspicious and may never change at all.

Piloting took place in three phases, the first phase comprising 159 face-to-face and telephone interviews in Reading. Phase 2 comprised interviews with 200 in Woodley, near Reading, Darlington and Nottingham. Phase 3 comprised interviews with 100 people each in Woodley, Hull and Middlesbrough. An omnibus survey (a large social market research questionnaire survey) comprised 3000 interviews with a few questions targeted at cycling. In phase 3 "cyclists" were defined as having cycled in the last 12 months, while "non-cyclists" were defined as not having cycled in the last 12 months. The omnibus survey differentiated "cyclists" as having cycled at least once during the Summer months and "non-cyclist" as someone who had not cycled at all during the Summer months.

From the Phase 3 pilot it was found that 93% of cyclists had a bicycle in working order, whereas only 24% of non-cyclists had a bicycle in working order. 10% of cyclists said that they would have problems controlling a bicycle especially in traffic, whereas 36% of non-cyclists said that they would have problems controlling a bicycle. Amongst the non-cyclists, 13% of males said that they would have problems controlling a bicycle, but this figure was 51% for females.

Phases 2 and 3 of the survey found that during childhood, 80% of "cyclists" but only 58% of "non-cyclists" used a bicycle for fun and for transport. Fitness, laziness and "too many obstacles" were seen as barriers to cycling. A cluster analysis to group a "contemplation of change stage" with other characteristics from the survey was undertaken and nine reasonable groups were identified, as shown in Table 3.13 below.

Table 3.13 Cluster analysis of contemplation of change stage (Davies et al., 2001)

Contemplation of change stage	Percentage owning working bicycle	Characteristics	Estimated percentage of national population
Almost always cycle	100%	All responses positive	7%
Cycle quite often	100%	All responses positive	8%
Rarely cycle or use cycle sometimes	80%	All responses positive except: "cycling is fast" and "hate standing out in crowd" where responses even	15%
	67%	Not self-conscious, Think cycling is a hassle and not fast	5%
Would not consider using a bicycle or realised that could but would not	17%	Think cycling is not fast or convenient, Tend to disagree that cycling gives freedom, Tend to agree that there are too many obstacles, BUT not self-conscious	27%
	50%	Positive to cycling but Non-committal about: standing out in crowd, obstacles to cycling, necessity to cycle	18%
	0%	Agree that it is convenient and confers freedom, Too much hassle, Friends would laugh at them, No need to cycle	12%
	75%	Do not think cycling is fast, Would feel self-conscious, Too many obstacles, Do not agree that there is not a necessity for them to cycle	6%
	0%	Tend to think there is no necessity to cycle, Do not agree that cycling confers freedom, Agree that cycling is convenient, Disagree that it, would be a hassle, their friends would laugh at them, too many obstacles	3%

These clustered responses have been used to develop thoughts about the type of promotion needed to encourage more cycling. Such a complexity of response does not lend itself well to an easily targeted campaign of marketing.

3.5 Cycle route choice research

Bovy and Bradley (1985) used stated preference (SP) surveys to examine facilities (separate path or no facilities), surface roughness and volume of traffic. It is an interesting study as it is an early application of SP and the first applied to cycle mode choice. They observed that, for a trip length of 9 minutes, an improvement from "no facilities" to a "separate path" would compensate for a travel time loss of 3 minutes. A similar time loss would compensate for a move from a rough to a moderately rough path. The sample was disaggregated into groups based on value of time and it was found that those who were more sensitive to time valued a bicycle path at only 1.5 minutes of travel time as compared with the "comfort-sensitive group" that valued the path at 6 minutes of travel time. The rho-squared statistic was larger for this disaggregated analysis indicating perhaps that there are sub-groupings amongst the cycling population. The authors note however that the effect may be partly as a result of the specific nature of the stated preference exercise.

Hopkinson et al. (1989) reviewed literature on route choice criteria and quote Bovy and Den Adel (1985) who interviewed cyclists to determine their route choice criteria. Bovy and Den Adel found that the road surface and distance and time are the most important factors. Other factors such as the existence of cycle paths, the level of traffic, the availability of other modes of transport, the existence of obstacles, the number of traffic signal controlled junctions, attractiveness, weather and social factors were less important but still had an effect. The effect of "obstacles" was also noted in work by Clerx and Peels (1985) who found that 44% of secondary school children cited the number of waiting points as a relevant factor.

Westerdijk (1990) describes a survey undertaken as part of the European Union DRIVE series of research projects, the aim of which was to consider route choice of cyclists and pedestrians. 50 respondents in Great Britain were interviewed across a range of ages, 121 respondents in Sweden and 113 respondents in The Netherlands. Only respondents from Sweden and The Netherlands were asked about cycling.

A map of the city of residence of the respondents was laid out in front of the respondents and they were asked to give the origin and destination of a frequently made trip. The route taken by the respondent was then drawn on the map. Other routes that were possible were then drawn on as described by the respondent up to a maximum of four routes. The respondent was then asked to identify his or her global preference for his or her best route, this was set at 100 on a "scale", and worst route, and this was set at zero on the "scale". Respondents were then shown a list of attributes, and asked to rate the routes according to the attribute. By comparing the global position of a route on the scale with the position for the attribute alone, relative "contributing" weights for the attributes were determined. The resulting weights are as shown in Table 3.14 below.

Table 3.14 Westerdijk's (1990) relative weights of route characteristics

Characteristic	Dutch Sample	Swedish Sample
Distance	0.21	0.19
Number of junctions with signal control	0.10	0.09
Number of junctions without signal control	0.10	0.10
General pleasantness of route	0.17	0.17
Attractions along the route	0.15	0.11
Quality of road surface	0.14	0.09
Traffic safety	0.14	0.19
Gradient	0.00	0.07
Total	1.00	1.00

The weights for the two countries are similar. No gradient question was asked of the Dutch sample. The characteristics do not seem well specified in that it is unlikely, for example, to be the presence or absence of a junction that is of interest to a cyclist so much as the manoeuvre which the cyclist has to make through a junction. A right turn (in the UK) will carry more penalty than a left turn for example. Distance is clearly the most significant characteristic. The author concludes that general pleasantness along the route and traffic safety are also important.

Trade-offs between attributes showed that a cyclist is prepared to cycle an extra 200 metres to have a route that is one scale point more pleasant and to cycle 250 metres to have a route that is one scale point safer. It is unfortunate that the scale points are not more related to measurable factors of pleasantness or safety.

Based on research in The Netherlands, CROW (1993b) notes that 50% of cyclists use a route that differs less than 5% in time from the fastest route and over 70% of cyclists use a route that is no more than 10 per cent longer than the route with the minimum journey time.

Hopkinson and Wardman (1996) studied the valuation of improved facilities using a stated preference exercise in a route choice context with 155 observations in the City of Bradford. Three variables; time, cost and cycling facilities were considered. The novelty in the work was the introduction of cost in the form of a toll, in order to derive monetary valuations for different route choice characteristics. Cycling facilities and time were treated as a joint variable because the valuation of the facilities would be dependent on the time spent in them. Five factors were identified as affecting cycle journey quality:

- 13ft (3.96 metres) as opposed to an 11ft (3.35 metres) nearside lane.
- segregated path.
- bus lanes for buses and cyclists.
- cycleway.
- journey time.

Table 3.15 below indicates the valuations placed on the different physical circumstances presented to respondents.

Table 3.15 Cycle facility stated preference evaluations (Hopkinson and Wardman, 1996)

Pairwise comparison	Evaluation
Wider nearside lane and 15 minutes *versus* standard lane and 15 minutes	18.32 pence
Wider nearside lane and 25 minutes *versus* standard lane and 15 minutes	10.38 pence
From above value of a 10 minute difference	7.94 p or 0.79p/min
Segregated path and 15 minutes *versus* standard lane and 15 minutes	30.11 pence
No bus lane and 20 minutes *versus* no bus lane and 15 minutes	(no value)
Bus lane and 15 minutes *versus* no bus lane and 15 minutes	6.76 pence

It may be seen from the above table that a segregated path is relatively highly valued and may be linked with perceptions of reduction on risk from motor traffic. Risk reduction appears to be more highly valued than reductions in journey time. A bus lane on a 15 minute journey is valued at 6.76 pence. Time savings within a route appear to have low or non-significant values and this is explained as being due to the fact that a time saving may imply a greater level of effort being expended, or the time variations in the SP were unrealistic and were ignored.

A revealed preference model based on times reported by cyclists indicated that route choice is sensitive to relative time differences but it was noted that the time variations accrue from differences in distance rather than delay.

The research concludes that perceived risk related factors have a strong bearing on route choice and that reductions in risk are highly valued by cyclists. The authors call for empirical evidence to confirm whether or not their finding is true that risk reduction is a more important stimulus to cycling than journey time savings. It is suggested that the analysis be extended to see how valuations vary by age, sex, perceived risk and journey purpose. It is also noted that time savings may be classified as "within route" arising from variations in delay and effort and "between route" which result from different distances. It is suggested that further research would be needed to verify the low values of time for within route time variations. Secondly, further work is needed on the relationship between journey time, time of exposure to risk and value of a cycle facility.

Ryeng (1999) surveyed 790 cyclists in Trondheim and asked them to select, by drawing, their chosen route towards, through and away from a signalised crossroad junction. Each respondent was presented with 16 different physical layouts for cyclists. Cross-tabulations indicate that the choice of route depends not only on the physical factors but "who the cyclists are". Young and male cyclists choose normal traffic lanes more frequently than older and female cyclists. Female cyclists and cyclists who wear a helmet choose a cycle lane more frequently when they are available. The analysis demonstrates the difficulty in designing cycling facilities attractive for all cyclists and points to the different risk taking attributes amongst cyclists.

Contrary to much of the above evidence, Sharples (1999a) asserts that cyclists' route choice may be measured principally by time and distance but bases this only on a qualitative questionnaire and cycle flow data from Manchester, Edmonton and London.

The stated preference route choice of Wardman et al. (2000) (see Section 3.4.5 for discussion of overall study) comprised choices between the current route and either "the flattest possible gradient between your home and work" for people who rated hilliness at greater than 50 out of 100 or "free from both air pollution and noise caused by traffic" for the remainder. This latter category was also presented with four categories of cycleway surface, road quality tarmac, footway quality tarmac, cinder and bridleway. It was found that, as expected, time spent on bitumen bound cycleways has a lesser disutility than time spent in typical road conditions. Somewhat unusually, in the view of the authors, segregated cinder tracks and bridleways were valued less highly than present road conditions.

The survey indicated that the average time for a cycle commute journey was 15 minutes and the average proportions of time spent in different conditions was 6% for cycleway, 4% for segregated cycleway within the highway, 19% for cycle lane, 53% on major road with no cycle facilities and 18% on minor road with no facilities. The mode share for this proportion was 4.5%. Many different combinations of route type were modelled to forecast mode shares and the greatest proportion at 7.3% (a 62% increase compared with the base) was forecast for a situation where the entire route was segregated cycleway.

Abraham et al. (2002) undertook a stated preference route choice survey in the City of Calgary. The work builds on experience in an earlier survey in Edmonton where having "secure parking" was found to be as important as saving 26.5 minutes of travel time in "mixed traffic" and a "dedicated linear facility" (bicycle lane or bicycle path) is preferable even if three to four times slower than a direct route on roads in "mixed traffic".

In the Calgary survey 2,470 cyclists were observed, of which 1434 stopped and 975 provided contact information leading to a final sample size of 934 for subsequent follow up. For each journey an assumed air temperature between 0^0C and 25^0C was randomly selected and three journey options were offered. Randomly selected journeys were sent to the respondents, the majority by email (845). 547 responses were received each with three sets of journeys with each of the three journey options ranked in order of preference by the respondent. The survey is unusual in that the journeys offered to the cyclists for choice may, as a result of being randomly generated, have borne no resemblance to their actual journeys. For example an elderly woman, who cycles never more than 5 minutes from her home may have been asked to choose between journeys of an hour's duration. Second, in a ranking exercise, it would have been more logical to offer more than three alternatives. Third, the number of attributes and number of levels of attributes is high for a survey of this type.

Unusually the paper does not provide a tabulation of the parameter values and t-statistics, as is conventional, but a bar chart plot. The authors take as the base, with a utility of –1.0, cycling for 10 minutes on an arterial road. Relative to this the value of cycling on a cycle track through a park is –0.23. The utilities for other of the routes surveyed lie between these two extremes. Using the relative utility of approximately –0.35 for a parking charge of $1 per trip, the authors deduce values of time of $17 per hour for cycling on an arterial road and $4 per hour for cycling on a cycle track in a park.

In a Swedish study of the change in demand for routes based on the introduction of cycle facilities, Nilsson (2003) reports that in nine out of thirteen streets where cycle lanes had been introduced, flows of bicycle traffic rose by an average of 12%. However, the bicycle lanes did not have a moderating effect on the speed of motor traffic with speeds rising by 2.9kph on average.

3.6 The incorporation of cycling in transport models

Traditional four stage transport models assume that the trip generation phase precedes distribution, mode choice and finally assignment. Some models undertake mode choice and assignment modelling as one process, while others combine mode choice with trip generation. There is good reason to suppose that cyclists will not embark on a journey unless a choice of acceptable route is available. In this instance therefore the mode choice in modelling ought to be determined at the same time as assignment. It may not therefore be possible to differentiate neatly between mode choice and assignment so far as cycling is concerned.

Sharples (1993) notes that there are a number of features pertinent to modelling cycle traffic in traffic streams for junction operational assessment and assignment that may be different than for motor traffic. These include spread of speed, platoon dispersion (due to range of speed in a group of traffic), interaction with other vehicles, illegal manoeuvres, value of time and gap acceptance. There is little suggested or researched in order to derive parameters for these factors within the context of modelling cycling within SATURN, a proprietary traffic assignment model. It is arguable however that each of these factors could affect the way a potential cyclist considers a journey and decides upon their mode. ("I will never be able to turn right at XYZ on my bicycle, therefore I will go in the car").

In an review of cycle traffic modelling, Sharples (1999b) reports that in the UK cycling has been modelled in Manchester (using SATURN, as noted above), in Ipswich (using Quo Vadis), in Edmonton, Canada (using EMME2) and in Leicester (using TRIPS/START).

Barber (1997) reports on the regional transport model for the Portland Metropolitan Area in which the bicycle is to be included in the main mode choice process. Cuthbertson and Kippen (1996) report on a disaggregate hierarchical mode choice model constructed for High Wycombe. At the higher nest level choice is multinomial choice between public transport, car, walk and cycle with a lower nest for choice between rail and bus. The Hopkinson and Wardman (op.cit., 1996) monetary values for different cycle facilities are used to determine cycle use in the study corridor and increases of between 2% and 44% (widening the nearside lane to fully segregated provision) were obtained.

Skinner (2000) reports that cycling as a mode is modelled in the Greater Manchester Strategic Transport Model. Existing levels of cycling are derived from census data with relationships being derived for rate of cycle trip making based on car ownership levels. Forecasting to the future is achieved in two stages. Stage one forecasts changes in household car ownership levels with the consequent implied changes in cycle trip making. In the second stage a hierarchical logit model with cycling as a separate main mode is used. The validation of the model derived mode constants for cycle against other modes. Future changes in costs for other modes resulted in changes in demand for cycling. A subsequent stage in the modelling relied on changed parameters for cycling coming from a Delphi panel comprising, inter alia, the author of this thesis. Factors such as hilliness and weather were deemed policy insensitive, but it was assumed that other factors such as security of cycle parking facilities could be positively influenced by appropriate measures. Overall it was "professionally judged" that the deterrent factors could be reduced in the order of 25% and the mode constant was reduced accordingly to derive cycle mode shares. It is understood that this technique has also been used to model travel to Heathrow airport.

Working of behalf of the Baltimore Metropolitan Council in the United States of America, Landis et al. (2000) developed a Geographical Information System (GIS) based model of what they termed "latent demand" for cycling. The model was based in the traditional simulation of trip distribution being based on Newton's model of gravity. The number of trips between a generator and an attractor is a function of the product of the total productions and attractions for each zone in question (proxy for gravity of two bodies) and divided by a function of the impedance to travel between the zones (equivalent to Newton's square of the distance). The impedance function assumed virtually 100% trip making by bicycle for distances under 1 mile which then declined to 0% at 2 miles for school trips, 3 miles for social or recreational trips and 4 miles for work trips. No regard was given to traffic having an impeding effect, as it was "latent" trips that were being considered. These trips may become "revealed", the authors assert, were the effects of traffic not to be present. The latent demand was determined for each of four trip types, namely: earning a living, personal / family business, social / recreational and school / church / civic trips in accordance with the USA National Personal Transportation Survey classifications. The model was used to estimate the "latent demand" for bicycle trips on a segment of roadway and this was deduced by determining the product of a) the number of generators and attractors, b) their average trip generation and c) the effect of that distance on whether the trip would be a bicycle trip (i.e. the impedance effect expressed as a probability of travelling by bicycle). The total latent bicycle demand was deduced by summing over all trip purpose types.

The development of a "latent" demand in this fashion may be an interesting theoretical exercise and a very appropriate use of GIS software. The model parameters, particularly the impedance function, used by Landis et al., however, do not seem to have been validated from any survey. Significantly the "latent" demand ignores the socio-psychological effects of traffic on bicycle choice and also does not account for any of a multiplicity of other reasons that may affect the total "latent" demand for cycling, particularly human choice mechanisms.

The UK National Transport Model (DfT, 2003d) comprises a "Demand, mode choice and distance travelled" model that assesses demand for travel which is then constrained by a "road capacity and costs model". The demand model is informed by transport policies in the Ten Year (2000 to 2010) Transport Plan and a range of forecasts (low and high) is created based on different levels of the following variables:

- Different levels of the effect of rising income to on people's propensity to travel further and responds to changes in money costs;
- Gross Domestic Product 2% higher and 2% lower than the H.M. Treasury forecast;
- Different levels of effect of so-called "soft" policy measures;
- Different levels of change of rail travel costs relative to income growth.

The National Rail Model also provides a corrective influence on the demand forecast from the main "Demand, mode choice and distance travelled" model. The level of cycling predicted by the model is created by the quantity of demand for travel that is "choked off" from being motor traffic as a consequence of congestion and the range of change in the number of cycling trips is forecast to be from 30% to 37% higher in 2010 than in 2000. This compares with the Ten Year Plan target of tripling cycle kilometrage. To meet the plan target, cycling trips would need to be on average 2 to 2.5 times as long as they are currently. The implication of the modelling is that the target will not be met. Without the Ten Year Plan the level of cycling is forecast to be either static or to decline by 2%.

3.7 Cost and benefit evaluation

Sharples (1995a) notes that the cost per kilometre of implementing cycle schemes is less than the cost of implementing highway schemes and that therefore only small changes in benefits can affect the economic case for a scheme. She suggests a framework to evaluate proposed cycle facilities with relevant factors for cyclists as shown in Table 3.16 below.

Table 3.16 Factors to evaluate cycle schemes (Sharples, 1995a)

Interest	Units
Usefulness	Number of users
Anticipated new trips	Number of cycle trips
Time savings	Minutes (£)
Distance savings	Metres
Delays/no. obstacles	Change in number of junctions
Vehicle operating costs	Pounds
Facility capacity	Traffic flow
Intimidation	Descriptive
Effort	Gradients
Personal security	Descriptive
Cycle security	Descriptive or rank
Fitness, health	Function of number of new users, trips and delays
Convenience	Descriptive
Mobility	Descriptive
Transport energy, medical cost savings	Pounds (function of number of users)
Gender specific	Descriptive

Usefulness is not adequately defined by the author. Time savings of a couple of minutes can be a significant proportion of the overall bicycle journey. The paradox is noted between non-cyclists dislike of mixing with fast moving traffic and cyclists not wanting to deviate from the most direct route to a destination. This could be an intense dilemma at the heart of route choice for many cyclists. The application of the framework to the facilities added to the Wilmslow Road in Manchester (Sharples, 1995b) merely provides a series of headings for general discussion about changes in infrastructure which affect cyclists.

So far as economic analysis of cycle schemes is concerned, there is only evidence of attempts to evaluate leisure routes. Based on estimates of numbers of cyclists and growth in the tourist economy along the route of the coast to coast path in the North of England, Sustrans (undated) has used the following estimates of cyclists' monetary spend to assist in justifying the West Wales sections of the Celtic Cycleway:

- Cycle tourist per mile cycled: 45p-88pence
- Cyclist day trippers per mile cycled: 17-38 pence.

Spend is assumed to be in connection with visitor attractions, daily consumables and, for tourists, overnight accommodation costs. A high net present value of benefits over a thirty year period was obtained for the West Wales Cycleway based on total capital costs of £5.68 million, recurring maintenance costs of £50,000 every five years, a return rate of 6% and "modest" cyclists numbers of 10,000 per annum on busy routes and 5,000 per annum on more rural sections of route.

Elvik (2000) identifies a number of potential changes as a consequence of schemes for cyclists that may contribute to monetary benefit but which are not normally included in Norwegian cost and benefit estimation as follows:

- changes in the amount of walking and cycling;
- changes in travel times for cyclists;
- changes in road user feelings of insecurity;
- changes in road user state of health.

The first change would require mode share modelling, which may be partly based on an evaluation of a value of time that may be used to assess benefits caused by travel time changes. The extent to which feelings of insecurity may be evaluated, Elvik notes, would require wide ranging research on the factors to be assessed, the types of user it may be relevant to and the relationship with actual accidents. The last item, changes in road user state of health, would generate benefits in reduced number of days of illness.

An undergraduate project at the University of Leeds has studied the economic benefits of a foot and cycle bridge across the River Ouse in south York that connects a large housing area with the university. The benefits that are being considered include:

- Costs: cost of bridge, cost of construction including disruption, land take, approaches etc.
- Benefits: accidents and travel time savings to walkers and cyclists both new and existing, estimate of future use, non-user benefits if traffic congestion reduction, vehicle operating cost savings, public health benefits due to more exercise, reductions in danger (rather than just accidents), changes in property values, social benefits due to reduction in severance caused by motor traffic.

3.8 Evaluation of the cycle modelling literature

The Table in Appendix B summarises contributions from the research discussed in Chapters 2, 3 and 4. This section evaluates the contributions of the research which then allows for a confirmation of the research opportunity and aim and objectives of the research to be expressed in Chapter 5.

From monitoring studies of towns in the UK some argue (Harland and Gercans, 1993) that the low numbers of cyclists before and after the introduction of facilities shows that facilities alone are an insufficient policy measure to encourage significantly greater cycle use. McClintock and Cleary (1996) found in Nottingham that the provision of a network of cycle routes had encouraged utilitarian weekday cycling with other important influences on use being sex, journey purpose and lifestyle factors (e.g. moving house and health concerns). The provision of facilities also affected perceptions of safety.

Emmerson et al. (1998) found that the month and the day of the week are important factors determining level of use and potentially these temporal variations are more important than climatic variations. The degree of variation amongst cyclists due to climate and day of week is greater than for car drivers. This finding is perhaps self-evident, but the work confirms that a measure for rainfall and temperature are important.

Much research of a qualitative nature has been undertaken into cycle use (Davies et al., 1997b; Davies and Hartley, 1999; Gardner, 1998; Automobile Association, 1993; Henson et al., 1997; Brög, 1982; Jensen, M. 1999; Simons, 1987; Presada, 1999). Inconsistencies between studies are easy to identify, however, and show the limited value for creating reasonable models of behaviour. For example, despite an otherwise wide recognition of hilliness being an important determining factor, hilliness does not feature strongly in the work of Henson et al. (1997) and the deterrent factors deduced by Henson et al. (1997) are different and differently ordered than those of McClintock and Cleary (1996). Rationalisation of findings from even within the same study is difficult, for example Davies et al. (1997b) found that while general attitudes to cycling are positive, cycling is seen as a minority activity with many negative factors (e.g. stress, personal security etc.). In terms of time, cycling is seen on the one hand as fast and convenient yet on the other hand time pressure is listed as a negative attribute. Of interest is the recognition that there are direct deterrents (e.g. danger) and indirect deterrents (e.g. status of the car as a mode). It is not clear from this classification whether the effect in terms of magnitude in a quantitative model should be any the lesser or greater for an effect being either direct or indirect. Hence such classification is perhaps of little value. It is instructive to realise that the benefits of cycling (e.g. it being a good family activity) are less tangible to measure than some of the negative factors (e.g. danger, although this certainly is not straightforward). It can be surmised, however, that many of the negative attributes of cycling (time pressure, danger, status) will directly influence propensity to use the bicycle for a commute journey.

There is strong evidence that purchasers of bicycles do so for leisure reasons and not for commuting and that the perception of cycling for these two different activities is antithetical. (Davies and Hartley, 1999; Gardner, 1998).

Davies et al. (1997b) do however provide an interestingly wide perspective of choice mechanisms that goes well beyond the normal utility framework based around *homo economicus* making rational choices espoused in traditional transport modelling. This is supported by Jensen, M. (1999) who suggests that it is important to capture the emotional and sensual sides of owning one's own means of transport. Image is deemed to be important, as are varying classes of existing and emerging cyclist types. Decision making extended over time and related to the ego, perceived negative consequences, social consequences and overall degree of hedonic value offered by the mode are all considered to be important. If these are important, then they would represent a need for a significant extension of the list of factors considered in transport mode choice modelling.

Brög (1982) supports a notion of choice based around a hierarchy of decision making with potential cyclists remaining non-cyclists if in the first instance their journey type does not allow it (distance), then constraints such as baggage and weather prevent it, followed by perceptions of route (e.g. danger) and then perceptions of riding (e.g. effort) mitigating against it. Perhaps this hierarchy of choice could be modelled quantitatively. Brög offers no evidence that the hierarchy is appropriately structured, it is merely a hypothesis.

Simons (1987) suggests that a degree of the propensity of the Dutch to cycle is linked with desires for fitness and concern for the environment. This suggests that it is not entirely therefore a matter of facility provision that has created the levels of cycle use in The Netherlands. Circumspection is required in interpreting this finding however, based on the inconsistencies identified in qualitative assessments for assessing more direct features of cycling such as rating for danger.

Overall, qualitative research suggests that facilities alone (at least facilities to the extent that they have been provided in schemes in the UK) are unlikely to yield significant increases in cycle use if they are not accompanied by journey end facilities and other more wide ranging campaigns encompassing attitude changes towards issues such as speed and general social position of cycling. Theories developed by qualitative researchers suggest decision making based on a hierarchy, or at least an inter-play, between many person type, transport and physical variables.

Waldman (1977) undertook the first UK national study of cycling based on the journey to work. His contribution is that hilliness and danger are important factors. He identified, but failed to address fully, an important issue in respect of defining a measure for danger at district level: it is difficult to derive a measure that does not incorporate the dependent variable, the proportion cycling. His estimate of danger and therefore his results need to be viewed in this light. He constructed a complex relationship to estimate trip length based on the size and shape of the settlement (all of which were urban in nature), and based on the importance of distance, the limitations of this concoction need to be borne in mind. Waldman also found that socio-economic factors in respect of cycling are not as important as might have been considered a priori. The research is based on census data in part dating from 1966 and there is appropriateness in superseding the work with latest census data and current modelling techniques.

Ashley and Banister (1989a, b and c) undertook a small scale study using census data for selected wards in Manchester and their final model contained a measure for hilliness confirming Waldman. They took a more sophisticated view in relation to estimating risk than Waldman and their assumption that it is related to volume and composition of traffic, road condition, number of intersections and their method of control seems more plausible than Waldman's contrived formulae. The derived model does not however reflect any of these attributes. The methodology of elimination of non-statistically significant variables and the stage in the methodology of the introduction of transformations for the dependent variable lead to the conclusion that their final model is not robust, and this is confirmed by its lack of predictive power.

Crespo Diu (2000), undertaking analysis as a precursor to the work of this thesis, used 1991 census data from a large sample size (635 wards). He represented distance to work based on Special Workplace Statistics from the census and in so doing created a much more reliable and less complex measure for distance than did Waldman. His estimate of danger again was calculated using the proportion of cyclists for journey to work and has the same drawbacks as Waldman. Hilliness was measured by a variable taking the value either 0 or 1. This is too coarse to be reasonable.

The model structure is well thought through and incorporates a variable for saturation level of cycling as a proportion of journeys to work, which was found to be approximately 45% and is similar to levels of cycling found in some of the most heavily bicycle-trafficked towns in Europe. Again similar to Waldman, Crespo Diu found the explanatory power of socio-economic group variables to be low. One anomaly in the model was the unexpected negative sign for the variable for car ownership and this Crespo Diu found difficult to explain. The modelling techniques used in the analysis show promise and are worthy for use in analysis of 2001 census data, together with more refined estimates of independent variables.

Increasingly a body of knowledge is being developed on mode choice at a disaggregate level (e.g. Noland, 1995; Noland and Kunreuther, 1995; Cervero and Radisch, 1996; Wardman et al., 1997, Wardman et al., 2000, Ortúzar et al., 2000).

Noland (1995) undertook a study that gave close consideration to safety and mode choice and found that three different methods of accounting for the combination of the perception of the risk of an accident and the perception of the severity of a bicycle accident were all significant in the mode choice model. The elasticities of demand relative to the factors affecting cycling appear high relative to usual transport demand elasticities. Cervero and Radisch (1996) found that the type of neighbourhood (car orientated or not) had an influence on mode choice. Ortúzar (2000) found that socio-economic group, age and educational level influenced propensity to cycle and that segregated cycleways could produce rises in use of the bicycle to as much as 10% mode share for certain sectors of Santiago.

The significant value of segregated facilities has also been shown by Wardman et al. (1997) but there is recognition that the disaggregation of the benefit of that segregation has not been achieved (i.e. reduction in danger versus increase in "pleasantness" of route). Wardman et al. (1997) have also shown the significant detrimental effect of climatic conditions.

Using the largest data set for cycling studies in the UK to date, using pooled National Travel Survey data and surveyed revealed preference and stated preference data, Wardman et al. (2000) demonstrated that the value of time for cycling at 6.5 pence per minute is 2.9 times higher than in-vehicle time. Outdoor parking was valued at 2.5 minutes, indoor parking at 4.3 minutes and showers plus indoor parking at 6.0 minutes. A change of 10% in the general proportion of the population cycling was found to be the equivalent of a reduction of 1 minute of cycle time. A change in the proportion of work colleagues cycling did not have a statistically significant effect. Only the coefficients for ratings for danger, tiredness and cycling ability were statistically significant. The SP data was drawn exclusively from the East of England (drier and flatter) cities and, perhaps as a direct consequence, hilliness was not significant in the model.

Disaggregate analyses of route choice show that road surface, distance, volume and speed of traffic are all important factors in selecting a route (Bovy and Bradley (1985), Bovy and Den Adel (1985), Hopkinson and Wardman (1996)). Time savings quoted in the context of stated preference work were found not to be significant but could result from the perception that they are viewed by cyclists as equivalent to making more effort. Wardman et al. (2000) found that the valuation of time in segregated facilities is a third of that where no segregation exists.

There is support (Brög, 1982; Davies et al., 1997b; Forward, 1998 and Gardner, 1999) for the notion that there are a wide range of ethnographic factors, such as lifecycle stage, which are relevant to cycle mode choice. It is not clear the extent to which the consequences of observable characteristics in cycle choice are intrinsic in the make-up of aggregate groupings of the population and the extent to which they are influenced by other characteristics more directly able to be influenced, such as traffic condition. If the "cultural" phenomena are primary determiners of choice then they need to be accounted for in cycle mode choice analysis. If not then they may merely be the back-drop against which "harder" measures (such as danger etc.) are used in analysis. The work of Ajzen (1985) assists in the view that these softer issues ought to be seen as primary determiners. The evidence from Europe suggests that cycle use is linked not just with adequate facilities but also with wider cultural factors.

Chapter 4 Review of traffic engineering bicycle research

4.1 Preamble on risk and structure of the chapter

Promotion of the use of the bicycle for everyday transportation covers a wide field of professions and interests, including town planning, transport engineering and the health professions. Promotion is accompanied by the innate human desire to "do something" and this has often translated into the provision of facilities for cyclists designed to render cycling more attractive. Such facilities have often been directed at increasing the perceptions of safety for the cyclist, but issues of directness and comfort are equally important. This chapter presents research on these aspects.

Cyclists are vulnerable on the road network because, according to Brownfield (1996), they are less conspicuous than other vehicles and drivers may be generally less aware of the presence and potential presence of cyclists. In addition there may be significant differential in speed between a cyclist and other road users and there may be a general failure to yield priority in the appropriate manner in favour of cyclists. A more thoughtful analysis by Stark (1996) suggests that interactions between cyclists and other vehicles varies in nature by time of day (e.g. as a result of lighting conditions) and land-use activities fronting the route. Certainly it is true that the vulnerability of cyclists is not lost on existing and potential users of the mode. The perceptions that exist about this vulnerability are however myriad and complex and an understanding of the cultural constructs surrounding risk lead people to react in different ways to different situations.

Adams (1985, 1995 and 1999) has undertaken a stream of work that began with an international review of the effectiveness of seat belt legislation and ended with a tripartite definition of risk, as follows:

- Perceptible risk; that is risk controlled by an individual, for example climbing a tree and riding a bicycle.
- Risks perceptible with the help of science, for example cholera and other infectious diseases.
- Virtual risks about which scientists cannot agree, for example the potential connection between Bovine Spongiform Encephalopothy and variant Creutzfeldt-Jakob disease or climate change.

An individual will decide on action based on their inherent propensity to take risk but also influenced by rewards and experience of (accident) losses. Governments take action based on known scientific facts in relation to risks, however Adams points out that science can never provide an objective measure of risk as the management of a risk will modify the risk and he suggests an analogy with Heisenberg's uncertainty principle. At a national policy level, where the risk is not agreed upon and so is in the realms of the virtual, he identifies four person types:

- The individualist who wishes to be relatively free from the control of others.
- The egalitarian who wants more control to guard against a catastrophe.
- The hierarchist who regards the management of risk as being for those in authority.
- The fatalist who does not have a view and will take whatever comes.

Adams notes that everyone takes risks and hence by definition, accidents will result. He suggests that it is important to distinguish self-risk (e.g. driving without a seat belt) from behaviour that puts others at risk (e.g. driving with inappropriate speed for the condition). He also identifies the subtle distinction that there exists in a "free-market" between what people may be prepared to accept to forgo and what people may be prepared to pay to partake. He uses the analogy of the price a person would be willing to pay to stop someone polluting the air not necessarily being the same as the price someone would accept to stop polluting. It is an interesting cultural construct in itself that the way he expresses this dichotomy is based on the assumption of a right to pollute. Reversing the polarity and apply the analogy to road transport, what is the price a cyclist might accept from a motorist to compensate the cyclist for the motorists presence on the road? The paradigm of economics as a construct through which to resolve this issue would begin to require concepts such as pigouvian tax.

Adams rightly notes that attempts to impose sanction for the imposition of self-risk are likely to be of little value and at worst can have contrary effects, for example the individual prepared to take high risks will compensate for having to wear a seat belt by driving more rapidly and will consequently place others in greater danger. We learn from Adams' body of work that there are no certainties when it comes to choices where risk is a factor.

In so far as cycling is concerned, traffic engineering research has centred on the physical factors that might influence the perceived "level of service" (to use American terminology) or, as the Transport Research Laboratory neologism would have it, "cyclability", and these issues are discussed in Section 4.2. Safety research is the other dominating stream of research and European and UK aggregate studies are presented in Section 4.3 with studies based at individual locations being discussed in Section 4.4. North American research is presented in Section 4.5 with a review of the inter-connectedness of safety and the law being presented in Section 4.6. Section 4.7 presents an evaluation of traffic engineering bicycle research. A summary table of main findings from the references sources quoted in Chapter 4 is presented in Appendix B.

4.2 "Level of service" and "cyclability"

Landis et al. (1997) set out to develop a bicycle "level of service" model based around factors known to affect cycling including:

- Motor vehicle flow and composition,
- Motor vehicle speed,
- Junctions (type and frequency),
- Width of the lane / path, car parking,
- Convenience (gradient, directness, continuity and signing),
- Riding surface,
- Attractiveness and personal security.

150 cyclists rode a 17 mile test course in Tampa, Florida with thirty segments of road displaying different characteristics (traffic volume, speed, composition, road type, lane width, pavement surface condition, land development forms). Respondents rated attributes on a six point scale and a bicycle "level of service" model was developed based on responses as shown in Equation 4.1 below[1].

$$B = 0.589\ln(\frac{V}{L}) + 0.826\ln[S(1+H)] + 0.019\ln(C.N) + 6.406(P)^{-2} - 0.005(W)^{2} - 1.579$$

Equation 4.1

Where:
B = perceived hazard of the shared-roadway environment
V = volume of traffic in same direction as cyclist in 15 minute period
L = total number of through lanes
S = posted speed limit (surrogate for average running speed)
H = percentage of heavy vehicles
C = trip generation intensity of the land use adjoining the road segment (stratified to a commercial trip generation of 15, multiplied by the percentage of the segment with adjoining commercial development)
N = effective frequency per mile of non-controlled vehicular access (e.g. driveways, on-street parking spaces)
P = 5 point Federal Highway pavement surface condition rating (1 = very poor, 5 = very good)
W = average effective width of lane

It is unclear and unexplained why the model is formed with natural logarithms of some parameters and power functions of others. It would appear that transformations are a convenience to reduce the independent variables to scales sufficient to result in a dependent variable on the scale 1 to 6. This is insufficient justification, however, for the particular choice

[1] It should be noted that "level of service" in six bands A to F forms a standard American classification for roads. This level of service is described as being related to speed, travel time, freedom to manoeuvre, traffic interruptions and comfort and convenience. So far as motor traffic is concerned, measures of effectiveness include motor vehicle density (passenger cars per mile per hour), delay (seconds per vehicle) and average speed. These are deemed inappropriate for cycle traffic and so a novel measure is required, hence the research of Landis et al. (1997).

of transformation. It is unclear also why the speed of traffic is directly related and adjusted by the composition of traffic (percentage heavy goods vehicles). The single term for speed and composition does not allow for the separate effects of speed and composition to be deduced by the regression modelling. It is normal UK practice to relate composition to volumes of traffic rather than speeds, for example in the calculation of passenger car units (PCUs) which reduce vehicles of greater impact (e.g. heavy goods vehicles) to a car unit equivalent. There would have been some logic in attempting to relate width of lane and volume to produce a measure of "density of traffic". The separate measures are however modelled distinctly and with different mathematical transformations.

Table 4.1 below shows baseline values for the relevant attributes and the percentage contribution to the overall level of service of the road.

Table 4.1 Level of service model typical values (Landis et al. 1997)

Attribute	Value	Contribution to level of service, B
V	12,000 vpd	
L	2 lanes	2.844
S	40 mph	
H	1%	3.055
C	40	
N	42 per mile	0.141
P	4 (good)	0.400
W	12 feet	-0.700
constant		-1.579
B		**4.141**

A reduction in pavement quality to 2 raises the value of B, level of service to 5.342 (29% increase). Lane width within the range ± 2 feet (a typical variation) changes the perception by ± 5-6%.

Volume and speed of general traffic clearly have the greatest impact on level of service. However, even large variations in these values have less impact than changes in pavement quality. A halving of volume reduces B to 3.733 (10% decrease) and a halving of speed reduces B to 3.569 (14% decrease). The authors note that less experienced riders' perception of level of service was rated less highly than that of experienced riders.

Harkey et al. (1998) undertook a study on behalf of the American Federal Highway Administration to develop a so-called "Bicycle Compatibility Index". Compatibility was considered to be equivalent to stress experienced by a cyclist, stress being defined as mental effort required to handle conflict with motor traffic. Work of Sorton and Walsh (1994) had shown that cyclists could recognise such mental effort as being related to levels of traffic volume, motor vehicle speed and lane width. In a pilot, using twenty-four respondents that viewed 13 video clips and were shown the actual sites where the clips were taken, it was found that there was a reasonably good match in respondents' ratings, hence proving the method of using video. For the main survey 202 respondents from Olympia, Washington, Austin, Texas and Chapel Hill (North Carolina) were shown 67 clips each lasting 40 seconds of conditions that ranged as follows:

- Lane widths adjacent to the kerb: 3.0m to 4.7m
- Motor vehicle speeds from 40km/h to 89 km/h
- Traffic volumes from 2,000 vehs. / day to 60,000 vehs. / day
- Bicycle lane or "paved shoulder width (equivalent to a space reserved for cyclists) from 0.92 m to 2.44m

Other variables included the number of intersecting driveways, type of frontage development, type of street, number of traffic lanes and the presence or absence of gullies, footways and central reserves. The respondents were asked to rate on a six point "comfort" rating scale based on volume of traffic, speed of traffic, space available to ride a bicycle and an overall rating. Linear regression analysis was performed that determined the main effects, interactions and finally, eliminated insignificant variables. The final model form is given in Equation 4.2 below.

$$BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD$$
$$+ 0.506PKG - 0.264AREA + AF$$

Equation 4.2

Where:

BCI = Bicycle Compatibility Index
BL = Dichotomous variable for presence of a bicycle lane or paved shoulder greater than 0.9 metres
BLW = bicycle lane width (metres)
CLW = lane width of lane adjacent to the kerb (m)
CLV = volume of motor traffic in nearside lane (vehs. / hr)
OLV = volume of traffic on other lanes in same direction (vehs. / hr)
SPD = 85%ile speed of traffic (km/h)
PKG = dichotomous variable for presence of parking lane with greater than 30% occupancy
AREA = Dichotomous variable for roadside development being residential
AF = $f_t + f_p + f_{rt}$, where:

Hourly nearside lane HGV volume	f_t	Parking time limit	f_p	Hourly right turn volume	f_{rt}
>120	0.5	<15	0.6	>270	0.1
60-119	0.4	16-30	0.5	<270	0.0
30-59	0.3	31-60	0.4		
20-29	0.2	61-120	0.3		
10-19	0.1	121-240	0.2		
<10	0.0	241-480	0.1		
		>480	0.0		

A Comfort Score of 6 equates to poor conditions and a Comfort Score of 1 to good conditions. It is odd that the presence of a cycle lane as narrow as 0.9 metres should reduce the score (i.e. improve the rating), when a lane of width as narrow as 0.9 metres is barely wide enough to contain a static, let alone a moving, cyclist. Further it is odd that there are no interactions deduced between the width of the lane and the speed. It is widely surmised that for higher motor traffic speeds a wider cycle lane would offset some of the discomfort of adjacent fast moving traffic. Further, it is peculiar that heavy goods vehicle volumes, parking times and right turn

(NB right hand rule of the road) are deemed to interact. It is even stranger to cause them so to do in the model in such a prescriptive and additive form.

Despite the peculiarities noted above Harkey et al. were content to note that the range over which the model predicted was a healthy 1.24 to 5.49. Based on a two lane road in a commercially developed area with 3.4 metre lanes, an 85%ile speed of 56 km/h and traffic volumes of 250 vehicles per hour it was noted that a decrease in lane width of 0.3 metres would result in a change in the rating from 3.68 to 3.53. This improvement is similar to that of a decrease in volume of 100 vehicles per hour (to 3.48) and a decrease in speed of 8 km/h (to 3.52). It was noted that the addition of a 1.2 metre cycle lane reduced the rating dramatically to 2.22. The authors note that a re-analysis with a grouping by experience of cycling of the respondents ("casual recreational", "experienced recreational" and "experienced commuter") showed that casual recreational cyclists had the highest mean score across all sites (3.1) compared with experienced recreational (2.7) and experienced commuter (2.6) cyclists. While the research provides a useful contribution as to the value of using video images for perception surveys of this type, the analysis has not teased out the potential interactions between speed and volume and lane width. Further, the conclusion to the paper cites an example of the use of the model to re-design a section of road. The conclusion, using the model, is that the road would be better for cyclists with a 1.2 metres cycle lane. According to usual Dutch (CROW, 1993b) and UK (IHT, 1996) design guidance this is an inadequate width for a cycle lane.

Allen et al. (1998) have developed a basis for determining "level of service" for cyclists on routes away from the highway and for cycle lanes on the highway from simple measures of volume. Making assumptions about mean speed of cyclists, pedestrian (on shared use paths) and motor traffic it is possible to deduce the number of times that motor vehicles, cyclists and pedestrians meet each other in "on-coming" manoeuvres and in passing manoeuvres. The level of service assigned is, however, arbitrary and does not relate to perceptions of cyclists of the level of service being offered on a particular route by virtue of the volumes of traffic on that route. The authors do however make the interesting point that an unacceptable number of passing events is always reached before capacity is reached. This may be true, but again, it is based on an arbitrary notion of what is unacceptable.

Guthrie et al. (2001) attempted to create an index of "cyclability" based on cyclists' assessments of road and traffic conditions. The research used an ordinary 5-speed bicycle to which was added a sideways pointing video camera and a computer that recorded the lateral distances at which vehicles passed, the volume of overtaking traffic, an effort rating from sensors on the chain ring and the length of each link traversed by the cyclist. 51 cyclists rode a 9.2 kilometre route comprising 11 links, most of which were in the range 700 metres to 1100 metres. Nine links were surfaced roads, one was un-surfaced and one was a shared use footway. All were in rural Berkshire or Crowthorne in Berkshire and near to the Transport Research Laboratory

(TRL). The 51 subjects were all TRL employees, 37% were "frequent utility" cyclists, 17% "frequent leisure" cyclists, 15% were "infrequent" cyclists and the remaining 32% did not, at the time of the survey, cycle. 71% of the sample was male. 15% of the sample was neutral in attitude to cycling, with the remainder either "liking cycling" or "very much liking cycling".

A brief description of the eleven links is described in Table 4.2 below.

Table 4.2 "Cyclability" study link descriptions (Guthrie et al. 2001)

Link Name	Description
Nine Mile Ride	Straight, flat, high volumes, speed limit 60 mph
South Road	Downhill on average, low flows, attractive scenery, high speeds
West Road	Rural aspect, low flows and speeds
Old Wokingham Rd (S)	Longest (1800m) link, straight, low density housing, high flows
Ellis Road	Housing estate road, low flows, many side turnings
Edgecumbe Park Drive	Short twisting housing estate road, drives, low speeds & volumes, poor surface
Duke's Ride	Uphill gradient, "A" class road, 45mph speeds on average,
Heath Hill Road	Unsurfaced, very low speed very few recorded passing vehicles
High Street	Calmed to 20mph adjacent to shops, many side turnings, lowest lateral passing distances (1.1 metres)
Bracknell Road	Only 300 metres long, narrow, a few side entrances, some concealed and bus stops
Old Wokingham Rd (N)	High speeds and volumes with wide lanes

The links are generally non-urban in nature and no specific consideration was given to junctions separate from links. There was considerable variation in length of the links. Respondents were asked to rate each link for the following attributes on a scale of 1 (bad for cycling) to 10 (very good for cycling):

- Road width, traffic flow, speed of traffic, HGVs buses etc., gradient, bumpiness (texture and potholes), lateral conflict (minor junctions, accesses and parking) and aesthetics
- Overall feeling of safety, overall feeling of effort, overall feeling of pleasure, cyclability rating (combining all measures together)

Analysis included what is not stated as, but is presumed to be, simple linear regression including all variables and also a stepwise regression, also presumed to be linear, to find an optimum subset of variables that explain a significant amount of the variance of the dependent variable.

The standard regression (R-squared=0.24) included parameters for average passing width, minimum passing width, volume of overtaking, link length, lane width, power (effort), average vehicle speed, speed limit, sex, cyclist type, number of drives (side entrances) per kilometre and number of parked cars per kilometre. Sex and cyclist type variables did not improve model performance. This is most likely to be because of the small female sample size (15) and the preponderance of positive attitudes amongst the sample to cycling. It should be noted that, as all the respondents work for a transport research organisation, they will have at least a passing acquaintance with the issues in connection with cycling and it is difficult to say how this may have affected the results. Coefficients for gradient and number of side turns per kilometre are reported as being "unattainable". It is supposed by the researchers that this is in connection with correlation between effort and gradient and length of link and number of side turns per kilometre. The stepwise regression (R-squared = 0.30) produced results shown in Table 4.3 below.

Table 4.3 "Cyclability" stepwise regression parameters (Guthrie et al. 2001)

Parameter	Coefficient	Standard error	Significance
Gradient	-0.63	0.12	P<0.01
Lane widths	1.03	0.44	P=0.02
Side turning / km	-0.28	0.03	P<0.01
Speed limit	-0.09	0.01	P<0.01
Constant	82.9	0.94	P<0.01

Taking from the survey the simple averages of link gradient (0.09%), lane width (2.805 metres), side turnings per kilometre (4.75) and a speed limit of 30mph, the above model predicts an unlikely cyclability index of 82, well beyond the scale of 1 to 10 asked of respondents. As an alternative to the objective measures being the independent variables that explain cyclability, a further stepwise model was created that related the respondents subjective ratings to their overall stated cyclability rating. The "subjective" stepwise regression (R-squared=0.55) results are re-produced in Table 4.4 below.

Table 4.4 Subjective "Cyclability" stepwise regression parameters (Guthrie et al. 2001)

Parameter	Coefficient	Standard error	Significance
Overall pleasure	0.59	0.05	P<0.01
Overall safety	0.38	0.05	P<0.01
Bumpiness rating	0.16	0.03	P<0.01
constant	-0.78	0.32	P<0.01

The model is akin to asking for an overall rating of a cordon bleu meal and then asking for individual ratings for the components of the meal, one would anticipate high correlations and it is disappointing to find so little in the subjective ratings that go to explain the overall cyclability rating.

Tables of bivariate correlations between the subjective and objective variables are presented by the researchers for all links and also separately for high speed and high flow and low speed and low flow links. The "all links" correlations are replicated in Table 4.5 below.

Table 4.5 Bivariate correlations between subjective and objective attributes (Guthrie et al., 2001)

	Power	Average passing width	Min. passing width	Lane width	Average vehicle speed	Speed limit	Volume of overtaking vehicles
Aesthetic rating	-0.2913	0.2065	0.2975	**-0.4079**	-0.079	**-0.309**	-0.2808
Bumpiness rating	-0.1095	0.0689	0.0000	0.1691	**0.4904**	0.1592	0.1617
Gradient rating	**-0.3679**	0.1921	**0.3192**	**-0.3336**	-0.2138	**-0.3916**	-0.2434
Lateral conflict rating	-0.0649	0.1599	0.1086	-0.1795	0.2152	0.0189	0.0514
Speed rating	-0.2864	0.274	**0.4765**	**-0.5238**	**-0.5069**	**-0.5499**	**-0.5138**
Overall safety rating	-0.2822	**0.3061**	**0.4276**	**-0.4641**	**-0.3840**	**-0.4953**	**-0.4599**
Overall effort rating	**-0.4005**	0.2979	**0.4037**	-0.2926	-0.1396	**-0.3801**	**-0.3298**
Overall pleasure rating	**-0.3800**	0.2629	**0.3796**	**-0.4216**	-0.162	**-0.4282**	**-0.4214**

Note: Emboldened figures indicate correlations greater than 0.3, all of which are significant (p<0.001)

The overall safety rating is correlated with every objective measure apart from power. It is unclear why the overall effort rating is correlated with speed, volume and passing width and this may reflect general noise in the data. Similarly it is unclear why overall pleasure is not correlated with average passing width or average vehicle speed when it is correlated with minimum passing width and speed limit. There are generally many fewer larger and significant correlations displayed for the disaggregated data (high speed/high volume and low speed/low volume) not reproduced here.

The research may be criticised for being too male biased and having a cohort of respondents related to the transport field and displaying generally positive attitudes to cycling. The links were generally non-built-up in nature and of widely differing lengths. Most links were fairly flat and so it would be difficult to justify extrapolation to steeper gradients more usual in hillier areas. Junctions were not considered as a distinct part of the study.

Notwithstanding these criticisms it is possible to concur with the researchers that:

- Cyclability can be to some extent predicted from traffic and carriageway conditions
- The "cocktail effect" of traffic flow and lane width is complex and likely to involve non-linear relationships and the data from the study is insufficient to disentangle these effects.
- The methodology adopted means that it is potentially difficult to expose less experienced cyclists to conditions that are more onerous for the cyclist.

It is more difficult to concur with the researchers on the following issues:

- They assert that the percentage explanation of "cyclability" by traffic and flow conditions is lower than in the Landis et al. (1997) study because of the inclusion of "aesthetics" and "effort" as explanatory variables. There is no reason to suppose that variables not necessarily perfectly correlated with traffic and width would necessarily reduce the power of explanation of traffic and flow variables.

- The assertion that gender and frequency of cycling do not seem to have explanatory power is more a function of the lack of variation in these parameters in the sample than their potential true power to influence.
- The length of shared pedestrian/cyclist footway was rated second worst of all the links in the study. The authors note that this is in contrast to the often quoted desire for segregation for cyclists. It is inappropriate to drawn a conclusion from a section of footway that (from the photographic evidence presented in the reference) is so clearly inadequate in width and has other obstacles with which cyclists have to contend. Segregation may be undesirable, but links designed to appropriate standards would have to be tested to before any conclusions could be drawn.

The researchers recommend further research with a larger sample size and to include a greater variety of conditions. They also note that the level of background cycling (c.f. Ekman (1996) discussed in the next section) could be an important variable. Sight lines and visibility were also reported by respondents as being important. It is also suggested that a narrower definition of "cyclability" may also be easier to measure concentrating on safety and comfort alone.

Carré (2001) equipped a bicycle with a video camera for filming both the road scene and the movements of the cyclist. He found that cyclists are more interested in efficiency when choosing a route than riding through pleasant surroundings. Above all he concludes that a cyclist is motivated to keep moving at a constant speed and avoid stops.

4.3 European and UK safety research using aggregate data

Tight et al. (1989) studied vulnerable road user (VRU) accident attributes and characteristics of travel with a view to determining how road traffic informatics (RTI) could be implemented to reduce vulnerability. The study concludes that RTI may have a place where VRU flows are high and there are many accidents, or the risk of accidents is high, or where VRU flows are low and suppressed by high vehicular flow. This conclusion does not appear to have moved on the cause of RTI use for VRUs dramatically far.

Slightly more interesting is the related work by Tight and Carsten (1989) who compared trip making and accident rates in Great Britain, The Netherlands and Sweden. The number of cycle trips per person per day in Great Britain in 1985-86 was 0.07. This compares with 0.32 for Sweden (1984-85) and 0.95 for The Netherlands (1986). In terms of distance per trip the Dutch travel slightly further on average, 3.3 kilometres compared with 2.6 kilometres for Great Britain and 2.5 kilometres for Sweden.

Based on a rate of casualties per head of population, Sweden is the safest (29/100,000) followed by Great Britain (48/100,000) followed by The Netherlands (81/100,000). Based on a casualty rate per million vehicle kilometres, Great Britain is worst (7.3) followed by Sweden (1.0) and The Netherlands (0.7). In all three countries cyclists are over-represented in the casualty figures. Based on local studies in three towns in each country (Bradford in Great Britain, Växjö in Sweden and Groningen in The Netherlands), Tight and Carsten showed that there were differences in the characteristics of accidents. 75.6% of Bradford's cyclist casualties occur away from junctions, whereas in Växjö the percentage is 30.8% and Groningen 42.9%. 37% of cyclist casualties in Bradford are under the age of 15 compared with 14% in Växjö and 13% in Groningen. The 20-29 age group is over-represented in Växjö but substantially under-represented in Groningen where it accounts for 29.1% of casualties. The authors suggest that children in Bradford may play in more heavily trafficked streets than the other cities. This could be further supported by the analysis of casualties by time of day and week. It was found that Bradford had more of a problem at weekends than either Växjö or Groningen.

The European Commission (1998b) ADONIS project sought to analyse cyclist (and pedestrian) accident factors and at the outset expected to find that drivers do not perceive vulnerable road users as potential hazards and merely look for other motor vehicles. In depth analysis was undertaken of accidents in the cities of Barcelona, Amsterdam and Copenhagen and evidence was found that "danger signals" went disregarded with no reaction to avoid an accident. For example, they found that some car drivers did not observe their duty to give way, but although cyclists perceived such cars, they did not perceive the risk they posed. There are few cyclists in Barcelona but differences in changed behaviour were identified between cyclists in Amsterdam and Copenhagen who had been involved in accidents. In Amsterdam cyclists wait longer before crossing, they signal more often and choose safer routes. In Copenhagen cyclists cross more often at signalised crossings and are more aware of the importance of achieving eye contact with car drivers. Higher than appropriate vehicle speed, misjudgements, courtesy on the part of a car driver (in for example letting a cyclist or pedestrian perform a conflicting movement) leading to conflict with other drivers, lack of appreciation of the negative impacts of weather on safety and, lack of perception of car drivers and parked vehicles were all significant contributory factors to accidents. For those who had been involved in accidents, cycle paths or lanes were popular suggestions for overcoming the safety issues of cycling.

A further European Union project entitled WALCYNG, considered, inter alia, the "safety problems" of pedestrians and cyclists (Pasanen, 1997). The researchers, comprising a varied selection of academics and practitioners from Austria, Italy, Finland, Norway, Spain, Germany, The Netherlands and Sweden, consider that pedestrians may "forget" to watch for traffic in critical situations. They also assert that "car drivers should be able to notice cyclists without any specific and demanding efforts". The report is well stocked with opinion and short on cross-cultural analysis. The final conclusion of the report, which is open to misinterpretation and is contentious, is that cyclists should be "incited with guiding (guidance?) and with pleasant conditions to use main cycle routes".

Stone and Broughton (2003) tabulate incidence and fatality rates from over 30,000 STATS19 reports for cycling accidents during 1990-1999. They note the problem of "missing denominators", that is exposure to risk based on mileage and number of journeys made, necessary to compare different accident rates. They deduce accident incidence rates, I, the number of accidents expressed as a percentage of the total number of accidents, and associated fatality rates, K, the number of killed or seriously injured expressed as a percentage of the number of accidents. Table 4.6 re-presents their data for sex, age, speed limit and point of impact.

Table 4.6 Accident incidence and fatality rates

	Accident incidence rates, I	Associated fatality rates, K
Sex of cyclist		
Male	80.8	5.0
Female	19.2	4.3
Age of cyclist		
0-9	9.7	3.0
10-19	32.7	3.6
20-29	18.6	3.4
30-39	13.3	4.5
40-49	9.1	5.3
50-59	7.1	8.2
60-69	4.5	10.8
70-79	2.8	14.6
80-89	0.9	19.1
90+	0.1	-
Speed limit (mph)		
30	76.0	3.0
40	8.2	6.4
50	0.9	13.0
60	11.9	11.2
70	2.8	19.6
First point on impact on bicycle		
Front	52.1	2.9
Back	13.7	10.0
Right	19.1	7.0
Left	11.2	4.4

Stone and Broughton note that the difference between males and females is not great but is in a predictable direction. The significant increase in K for the over fifty age groups is significant and replicated for each year. The authors suggest that either over fifties are careless, or suffer more in an accident because of age. Discounting the data for 50 mph (only 277 accidents), there is a consistent increase in fatality rate with increasing speed. They note with interest the much greater fatality rate for cyclists hit from the rear than from the front. Table 4.7 re-presents data for accident rate by type of junction.

Table 4.7 Accident incidence and fatality rates by junction type

	30 mph		40 mph		50 mph		60 mph		70 mph	
	I	K	I	K	I	K	I	K	I	K
No junction [1]	19	3.3	2.6	8.9	0.4	18	6.1	12	1.4	22
Roundabout	5.2	2.6	1.2	3	0.1	-	0.9	5	0.3	-
Mini-roundabout	0.8	-	0.1	-	0.0	-	0.0	-	0.0	-
T or staggered jnc.	34	3.0	2.7	5.4	0.2	14	2.6	13	0.2	19
Y-junction	0.9	-	0.1	-	0.0	-	0.2	-	0.0	-
Slip road	0.3	-	0.1	-	0.1	-	0.1	-	0.7	23
Cross-roads	9.3	4.1	0.6	6	0.1	-	0.7	11	0.1	-
Multiple junction	1.2	5	0.1	0	0.0	-	0.0	-	0.0	-
Drive or entrance	4.3	2	0.5	8	0.0	-	1.1	8.0	0.0	-
Other junction	1.6	2	0.2	-	0.0	-	0.2	-	0.0	-
Totals	76.6		8.2		0.9		11.9		2.7	

Notes

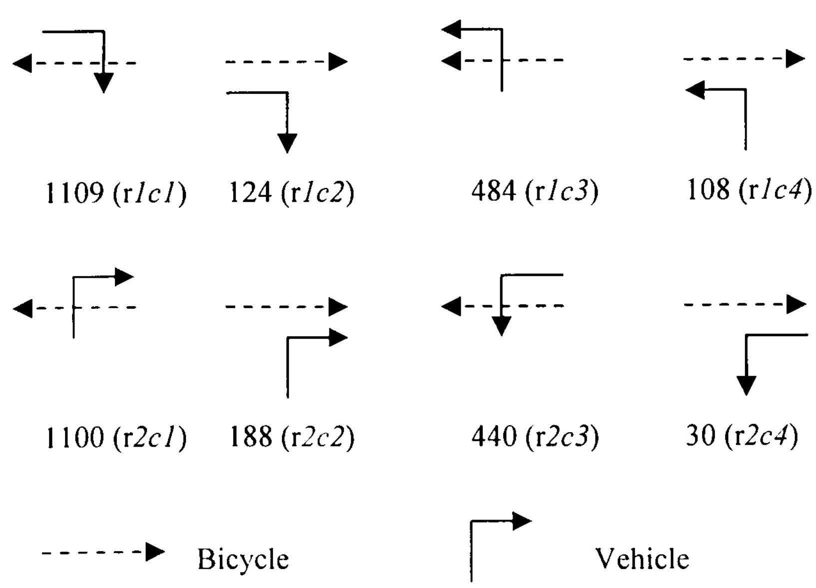
1 "I" represents accident Incidence rates and "K" represents associated fatality rates

2 No junction or not within 20 metres of a junction

It should be noted that 60mph is the national speed limit for a single carriageway road, if no other speed limit is set. 70.5% of all accidents occur at junctions and the junction type at which most accidents occur is the T or staggered priority junction. Stone and Broughton note a progressive change towards impacts into the rear of cyclists with increasing speed limit for accidents that do not occur at junctions (from 12% at 30mph to 56% at 70 mph).

An in-depth analysis of accidents at T and staggered junctions is undertaken based on compass points defined in the STATS19 accident data. This data is robust for this analysis only for 48% of the cases and Figure 4.1 shows the frequencies of occurrence of accidents for the possible different manoeuvres at a T junction with the bicycle moving along the main road. Analysis is not possible for movements of the bicycle and the vehicle leaving or joining the main road due to difficulties in interpreting correctly their movements from the accident data. Stone and Broughton present data only for the cyclist using the main road only.

Figure 4.1 T junction turning movements



Note

1 The numbers indicate the frequency of accidents for the movement depicted.

The differences between the frequencies give an indication of the relative risks of the difference manoeuvres. Reversing the paths of both bicycle and vehicle moves the situation from r1c1 to r1c4, and assuming that nationally either is equally likely to occur, the manoeuvre in r1c1 is about 10 times as risky as the movement depicted in r1c4. Knowing there are priority junctions where the right turns into the side road is banned would indicate that the risk ratio of 10 is a lower bound estimate. Similarly r2c1 is more than 37 times more risky than r2c4. These differences in risk are unsurprising due to the lack of conflict inherent in the r1c4 and the r2c4 movements.

Extending the argument further Stone and Broughton note that it is likely that cyclists and vehicles will flow in the same direction as part of the diurnal variations in flow caused by peak period into and out of town centres. On this basis they suggest that the r1c2 situation will occur more frequently than the r1c1 situation and hence the risk ratio between these two (of 8.9) is an underestimate. This is a less robust assumption, particularly in areas where there are high proportions of off-carriageway cycle provision.

The meta-analysis based on path reversal and correlated peak flows helps to add robustness to the unsurprising finding that where there is a "crossing" conflict, with vehicle and cycle heading in different directions on the main road, the risk is very substantially greater than where the "crossing" conflict is with the vehicle and the cyclist in the same direction of travel. In turn this is substantially greater than where the paths of the vehicle and the cyclist do not cross.

Noland and Quddus (2003) analysed factors that affected cyclist fatalities and injuries over a twenty year period (1979 to 1998) in the UK. Accident data based on the 11 standard statistical regions of the UK (excluding Northern Ireland) and the two levels of severity (killed or seriously injured (KSI) and slightly injured) were used. Data included road infrastructure (total road length by category: motorway, trunk roads, other roads), vehicle ownership, population, household income, expenditure on alcohol, population by age cohort. Proxies for medical care improvements included length of inpatient stay in hospital, infant mortality rate, persons awaiting treatment per capita, NHS staff per capita and General Practitioners per capita.

The dependent variable (KSI or slight injuries) is a non-negative, non-normally distributed count variable and precludes use of simple multiple regression techniques that assume a normally distributed error term. A negative binomial model was used to overcome the problem of the other common distribution, the Poisson distribution, equating the mean to the variance. Year dummy variables were included to account for year effects.

The models developed were inconclusive in respect of medical technology proxies. Were one to assume that a greater percentage of motorway in a region would imply less motor traffic on other roads (a very arguable proposition), then one might expect fewer KSI and slight injuries with a greater proportion of motorway. The models did not demonstrate anything conclusive in respect of motorways. So far as trunk roads are concerned, the authors pre-suppose that a greater proportion of trunk roads would lead to more KSI and slight injuries. Again this is arguable as trunk roads purport to be designed to higher standards with better maintenance regimes than other roads. This effect is positively correlated in all but the model for KSI that does not include medical proxies. The models show a strong negative effect for KSI, but not for slight injuries, which indicates that regions with more minor roads will experience fewer casualties. Noland and Quddus also used a variable for trunk road mileage per land area, which they see as a measure of development density and found that there are lower slight injuries where development is greater, representing an urbanization effect. However the opposite effect is evident for the KSI data.

So far as vehicles are concerned, older vehicles are associated with more KSI and slight injuries. Reduced KSI is associated with increased income in the model including medical proxies. Per capita expenditure on alcohol is associated with increased KSI, but the effect does not hold for slight injuries and is one of the more robust associations in the data. More KSIs are associated with higher proportions of the 0-14 age group, with a declining trend with age band increase. Whether this is due to fewer potential child victims or a larger low risk driving group is unclear.

4.4 European and UK safety studies based on location

Accident frequency at junctions has been measured traditionally by the cross-product formula as shown in Equation 4.3 below.

$$A = kQ_a^{\alpha} Q_b^{\beta} \qquad \text{Equation 4.3}$$

Where:
A = accident frequency
Q_a, Q_b = flow functions, for example total inflow to junction, right turning flow
K, α, β = parameters to be estimated

The number and description of flows may vary by type of junction and accident frequency being estimated. A series of reports by the Transport Research Laboratory (Taylor et al., 1996, Summersgill and Layfield, 1996, Summersgill et al. 1996, Layfield et al. 1996), has revised and updated formulae for accident frequency estimation for vehicle and pedestrian flows at 3 arm traffic signal controlled junctions, non-junction accidents, 3-arm priority junctions and crossroads and staggered junctions. Interestingly cycling accident frequency analysis was not incorporated as part of the analysis. A more recent report Kennedy et al. (1998) considered accidents at mini-roundabouts and found that the rate of pedal cycle involvement in accidents was higher at mini-roundabouts than at priority junctions, with signalised junctions having the lowest involvement rates for two-wheelers.

So far as the relative merits of different provision in terms of safety is concerned, Hall et al. (1989) began a study of cyclist remedial measures recognising that there is little published evidence on the effectiveness of cycle facilities. Using data from three counties, the change in pedal cycle casualties at sites treated as part of the normal accident remedial activity was studied. In only one of the three counties were pedal cycle accident numbers sufficiently high to provide reliable evidence of changes from the before period to the after period. The differences were not however significant (a 1.6% drop on an expected number of 247). Using data from five counties Hall et al. assessed specific cycle schemes but noted problems as outlined below:

- Formal before and after studies are generally not available because cycle safety schemes are identified and promoted through using local knowledge of engineers and cycle pressure groups rather than formal scheme identification procedures. Accident numbers are also small.
- The area of influence of a scheme is difficult to identify. For example, provision at a roundabout may attract cyclists who had been previously using other routes to avoid the roundabout. The converse, the provision of an attractive alternative route to avoid a junction, may also display the same area wide effect.

Table 4.8 below summarises changes in accident numbers by scheme type from the study.

Table 4.8 Accident rates by type of cycle scheme (Hall et al., 1989)

Type of Scheme		Cycle Accidents Number	Cycle Accidents No / km.yr	All Accidents Number	All Accidents No / km.yr
With flow cycle lanes	Before (35.0km.yrs)	56	1.6	130	3.7
(4 schemes)	After (22.9km.yrs)	46	2.0	133	5.8
	Expected (22.9km.yrs)	54	2.4	77	3.4
Shared use footways	Before (25.0km.yrs)	41	1.6	123	4.9
(2 schemes)	After (30.7km.yrs)	43	1.4	144	4.7
	Expected (30.7km.yrs)	65	2.1	139	4.5
Contra-flow cycle lanes	Before	62			
(1 scheme)	After	91			
	Expected	76			

Notes

1 *Before and after periods were not of the same length and so comparison is made after having corrected for the number of years as well as the length of route, i.e. kilometre years (km.yrs).*

2 *The expected number of accidents is determined with reference to the change in the number of accidents in the region as a whole.*

With flow cycle lanes reduced the number of accidents to cyclists compared with what would have been expected had there been no lane introduced. This is set against a background of a significant rise in all accidents at the four locations where the lanes were introduced. The accident rate in the region as a whole increased by 50% (1.6 to 2.4 accidents per km.yr) but this increase was moderated to 2.0 accidents per km.yr by the provision of with flow cycle lanes. Shared use facilities show a good reduction in accidents for cyclists but little difference in total accidents. For the contra-flow cycle lane the previous detour to avoid a one-way street was avoided but the results show that there has been an increase in the number of accidents at the site.

Overall the results do not allow any conclusions to be drawn about the relative merits of different types of provision for cyclists: each remedial measure was installed to overcome a particular perceived problem. The extent to which the particular problems were addressed would seem to be variable. No conclusions about the accident reducing potential of different schemes can be drawn because the analysis did not deal with changes in levels of cycle use or fully assess the differences in accident rates to cyclists away from and at the sites in question.

Sissons Joshi et al. (1993) used travel diaries of car drivers, pedestrians, cyclists, motor cyclists and bus drivers to investigate perceptions of risk on the road. They found that pedestrians and cyclists experienced an incident every 8.8 kilometres and this compared with an incident every 69.6 kilometres for motorcyclists, car drivers and bus drivers. Buses and lorries were involved in more incidents than their flow, as a proportion of total flow, would have suggested. 34% of incidents reported by cyclists were at junctions and this contrasts with the 68% of accidents overall being reported as occurring at junctions.

While lack of use of the bicycle in the UK may be seen to be significantly influenced by road safety, even in countries with high levels of bicycle use, such as Denmark, there is evidence of disproportionate risk for cyclists (Nielsen and Bernhoft, 1995). The main problems have been observed as lack of observation of duty to give way (on the part of both cyclists and other vehicle drivers), collisions on (either head-on or rear shunts) on links between junctions and solo accidents, such as loss of control.

At junctions Brundell-Freij and Ekman (1991) found that the number of conflicts per cyclist at intersections increased with general traffic vehicle flow for high (above average) bicycle flows, but decreased with vehicle flow for low (below average) rates of bicycle flow. Risk per bicycle movement was higher for low rates of bicycle flow. This finding may be understood in the sense that at higher rates of bicycle flow the bicycle is sharing influence over the way traffic flows into and through a junction whereas for lower flows the bicycle is more subservient to motor traffic.

This led to Ekman (1996) hypothesising that there exists a Safety Performance Function that describes the relationship between accidents and flow. He studied 95 junctions in Malmö and collected 7 years of accident data, conflict data from two days of observation, car and bicycle flow for each direction of entry to each junction (left, right and straight on) and pedestrian flows crossing the approaches.

Conflicts as opposed to accidents were used to deduce the Safety Performance Function for each approach because the number of conflicts was greater (by a factor of about 4) than the number of accidents in the accident records and because the conflict data was collected contemporaneously with the flow data. The Swedish Traffic Conflict technique defines a conflict as a "situation where two road users are involved, which would have led to an accident if both road users had continued with the same speed and in the same direction". The conflicts were measured by trained observers. Ekman aggregated data into fifteen bicycle flow groups (flows ranging from nearly zero to nearly 300) and showed that as bicycle flow rises so does the average number of conflicts with other traffic per approach. Ekman dismissed a linear regression model (R^2 =0.65) and a regression model with an exponential function (R^2 = 0.07) in favour of using a three point floating average. This created a non-parametric model with no pre-assumption about the form of the relationship between the variables. It is unclear why the linear model was dismissed so readily.

In order to derive a Risk Performance Function, that is an estimate of the risk for an individual cyclist, Ekman divided the number of conflicts over the period of observation by the average flow over the period of observation to obtain the number of conflicts per vehicle in the general traffic stream. He showed that the number of conflicts per cyclist is higher for lower bicycle flows. The difference varies by about a factor of two either side of a bicycle flow of 50 bicycles per hour.

Ekman also plotted bicycle conflicts per approach against exposure of the cyclist to motor traffic and showed that there is no increase in conflict with increasing exposure. In Ekman's words "there are cars enough at 100 cars per hour". A similar plot for bicycle conflicts per cyclist shows that if anything there is a reducing conflict with increasing exposure. This is counter-intuitive and may result from interactions and expectations that have not been exposed as part of the analysis.

Overall, Ekman concludes that the level of bicycle flow is more important than level of car exposure and that the perception of both cyclists and car drivers is different for higher cycle flows. Ekman notes that at less than 50 bicycles per hour the chances of a car driver seeing a cyclist is rare and behaviour to rare events (he uses the analogy of wild animals crossing the road!) may be different than to frequent events. A significant drawback to Ekman's work is the absence of any recognition that speed is a significant factor in risk and accident occurrence. In terms of route planning and design, Ekman suggests that cyclists should be concentrated onto specific routes and not encouraged to spread over minor routes.

Jacobsen (2003) used data from 68 Californian Cities, 47 Danish towns, 14 European countries and time series data from the UK and The Netherlands in separate power function models and confirmed that a doubling in cycle use would produce around only an increase of 32% in injuries. He found a consistency in response across the different data sets and time periods and concluded that more cycling produces a reduction in the risk associated with cycling. He concurs with Ekman and concludes that the behaviour of motor vehicle drivers is modified by the presence of varying numbers of cyclists.

Nyberg et al. (1996) report from Northern Sweden that "poor maintenance" (snow/ice, wet leaves and gravel) contributed to 51% of injuries to cyclists requiring hospital treatment. The majority (70%) of treatments from this cause occurred in the months October to March. Kerbs were responsible for 20% of required medical treatments and "bad road surface" (cracks, holes, uneven paving and "steep lateral slant") contributed to 18% of required medical treatments. The remainder were linked to crashes into other objects.

Gårder et al. (1998) undertook a study of the effect of providing raised crossings for bicycles across the mouths of side roads. The study was undertaken in Gothenburg where 44 crossings were raised by between 40mm and 120mm along six streets. Surveys showed that the bicycle flows increased along these streets by between 75% and 100% and this compares with a secular rise in cycle traffic in the city of 20%. Analysis of the bicycle flow relative to the number of reported accidents shows that the relative risk (defined as the expected number of accidents per passing cyclist) decreases with increasing bicycle flow. A 50% increase in flow would reduce the risk by 24%. It was also found that the speed of turning motor vehicles (the motor traffic that would conflict with straight ahead cyclist traffic) fell by 40% to 10 to 15 km/h. It was also found that bicycle speeds rose by 13%.

Interviews of randomly selected cyclists showed that their perceptions of the risk had fallen (risk after divided by risk before = 0.80). The researchers also asked a panel of experts about their view on the change in risk level based on a 40 percent reduction in conflicting motor vehicle speed, a raised crossing of 40mm height and a 13 percent increase in speed amongst cyclists. The experts considered the increase in cyclists speed to be important and indicated that they thought there would be a 10% reduction in the number of "bicycle with motor vehicle" accidents. The experts considered that there would be a greater reduction in injury risk than accident risk, but this is not quantified in the paper. The experts thought that a path raised 10mm and painted a bright colour would create a 30% improvement in safety. The authors conclude that bicycle paths may be made reasonably safe if all bicycle crossings of side roads are raised and painted a bright colour and that both motor vehicle and cycle speeds should be kept low.

Lancashire County Council (2003) reports accidents to cyclists in its cycle design manual. Of accidents that are of known cause or are attributable in some way, the majority (54%) are attributable to motor vehicles. When child (under 16 years) cyclist accidents are removed this jumps to 72% attributable to motor vehicles. Causes of child cyclist accidents are predominantly cycling onto or off the carriageway, and emerging from a minor road into the path of a vehicle and this suggests that there is a need to train child cyclists to obey the rules and discipline required on a highway. So far as adult accidents are concerned the majority (67%) of those accidents attributable to vehicles occur at junctions. There are few accidents associated with moving traffic along a highway.

The Lancashire manual suggests that danger on the highway can be evidenced by a lack of cyclists but the corollary is that measures must not be introduced which could falsely create the impression of greater safety where no such greater safety exists. This may encourage use, but in dangerous situations.

The Swedish National Road and Transport Research Institute (SNRTRI, 2000) studied roundabout design with a view to understanding its impact on accident rates. They found that lower motor traffic speed and volume, fewer number of lanes on entry and a central island diameter not less than 10 metres are beneficial in reducing the number of bicycle accidents.

4.5 North American safety research

Forester (1994) presents data on frequency of accident types to League of American Wheelman (LAW) cyclists, based on a study by Kaplan (1976) and these are reproduced in Table 4.9 below. Also presented are results from a study by Cross (1980) of non-motor vehicle associated accidents in Santa Barbara. As Cross did not measure motor vehicle accidents, Forester has adjusted the Cross results using the US national average proportion of 16% of car-bike collisions. The Kaplan study does not sub-divide the large "fall" accident category, but Cross's study provides greater detail. It may not be assumed, despite the overall proportions for the grouped Cross data being similar to the Kaplan data, that the Cross sub-division of types (for non-club cyclists) is representative of a pattern for the Kaplan data (club cyclists). Both studies demonstrate that collisions with moving cars as less than approximately a fifth of the total accidents to cyclists and that there are many falls for other reasons. This does not equate with the general perception that the greatest risk to cyclists is posed by motor vehicles. No indication is given of the severity of the accident by type.

Table 4.9 Accident types and frequencies for American cyclists (Kaplan, 1976)

Type	Kaplan study of LAW cyclists: percentage of accidents	Cross study of non-motor vehicle accidents in Santa Barbara adjusted by Forester: percentage of accidents
Defective road surface		19.0
Object caught in moving parts		11.6
Inadequate bike handling skill		10.6
Not looking ahead		7.3
Stunting		3.0
Carrying object in hand		1.2
Fall	44	
Total of Cross study types		52.7
Collision with moving motor vehicle	18	16.0
Collision with moving bicycle	17	17.8
Collision with moving dog	8	1.3
Collision with parked car	4	-
Bicycle failure	3	6.0
Collision with pedestrian	1	-
Obstructed view of fixed object		1.1
Evading motor vehicle		0.8
Degraded visibility		0.3
Other	5	
Total of Cross study types		2.2
Total	100%	96%[1]

Notes

1 *Forester's Table adds to 96% with no explanation.*

2 *Sample sizes for the two studies are quoted as being "similar".*

Forester's argument is that cyclists who are experienced are better and safer cyclists. The Cross data shows that Santa Barbara cyclists that cycle 3,500 miles per year have 143 accidents per million bicycle-miles. For those that cycle only 500 miles per year the accident rate is 1,000 accidents per million bicycle-miles.

Forester also presents and re-works a study of car-bike collisions undertaken by Cross and Fisher (1977). Whereas Cross and Fisher aggregate separate studies of rural and urban collisions, Forester recognises the importance of the different nature of each environment. Also Forester ranks types not only by manoeuvre (for example, "motorist turns right") but also with the appropriateness of the actions of the cyclist. These he classifies as: correct road position, sidewalk (footway) cycling, cycling on wrong side of road, cyclist swerve. The study investigated 919 collisions from four representative areas of the United States of America (Los Angeles, Denver-Boulder, Orlando-Tampa and Detroit-Flint).

By addition of a separate sample of fatal accidents, it was shown that an "exceedingly high" proportion of fatal accidents involved a car overtaking a bicycle. It should be recognised that the overall proportion of the "car overtaking bicycle" collisions is relatively small at 9.5% as shown in Table 4.10 below.

Table 4.10 Major classes of car-bicycle collision (Cross and Fisher, 1977)

	Urban percentage	Rural percentage	All percentage
Turning and crossing	89.0	60.0	85.0
Car overtaking	7.0	30.0	9.5
Other parallel-path collisions	4.0	10.0	4.7
	100.0	100.0	100.0

Forester notes that 52.3% of the accidents occurred when, by his interpretation of the description of the collision, the cyclist was performing an illegal manoeuvre or behaving incompetently.

Kaplan's work, referred to in Forester, has been updated by a 1996 survey of League of American Bicyclists (LAB, the League of American Wheelmen, having changed its name) undertaken by Moritz (1998). The sample was stratified by State and yielded 1956 validated (internally consistent) responses representing the 23,500 membership. Tables 4.11 and 4.12 below indicate the principal responses relating to accidents in different conditions.

Table 4.11 Collision or fall for all crashes (Moritz, 1998)

	1996 survey	Kaplan 1974 survey
No other object – simple fall	59%	41%
Moving motor vehicle	11%	18%
Stationary motor vehicle	1%	4%
Bicycle	9%	17%
Pedestrian	2%	1%
Animal	3%	8%
Fixed object	14%	N/A
Other	1%	11%
Non-reported	N/A	N/A
Total	**100%**	**100%**

Table 4.12 Crashes by facility type (Moritz, 1998)

Facility type	**Crash rate per million kilometres**	**Relative Danger Index**
Major without bicycle facilities	41	0.66
Minor without bicycle facilities	59	0.94
Signed bicycle route only	32	0.51
On-street bicycle lanes	26	0.41
Multi-use trail	88	1.39
Off-road / unpaved	282	4.49
Other (most often "footway")	1026	16.34

Notes:

1 *Relative Danger Index is defined as the proportion of crashes reported for a particular facility type divided by the proportion of kilometres ridden on that facility type. A figure greater than 1.0 indicates a facility on which crashes occur at a higher rate than would be expected based simply on distance.*

It should be borne in mind that the results are representative of only a subset of the population that are experienced cyclists. Notwithstanding, assuming that newcomers to cycling become experienced, it may be surmised that the results are representative of levels of hazard to experienced cyclists. Firstly, considering crash[1] rates per million kilometres it may be deduced that the introduction of signed bicycle routes and bicycle lanes would reduce the incidence of crashes. It is noteworthy that trails, off-road routes and cycling on the footway are very significant in creating conditions for accidents. Secondly, considering the Relative Danger Index, a similar pattern emerges.

In a study in the USA, Rodgers (1997) showed that, as well as being related to age, the crash risk of adult cyclists is related to distance travelled, riding surface ("bike path", "roadways" or "off-road trail"), bicycle type (general purpose bicycle, racing bicycle or all-terrain bicycle) and geographical region (East, Midwest, South, Mountain or Pacific state). Risk on "off-road trails" was found to be three times that on "roadways" and reflects presumably a significant proportion in the sample whose off-road riding was undertaken as an adventure sport. Accident risk on "roadways" was found to be 50-60% higher than on "bike paths". Cyclists in Pacific Coast States experience risk 1.3 to 1.8 times greater than for other States but no explanation for this variation by region is offered, again it could be linked with thrill seeking.

Aultman-Hall and Hall (1998) surveyed cyclists who had parked their bicycles in various public and private cycle parks in Ottawa and Toronto by leaving a reply paid questionnaire attached to the bicycle handlebar. From a distribution of just over 6,000 survey forms 2,964 were returned. Respondents were asked to identify their regular commute journey and recall the number of collisions that they had experienced in the previous three years. There could be bias created potentially as a result of a greater number of people responding if they had experienced an incident in the previous three years. Clearly, it is not possible to compare the incident rates of respondents against non-respondents and a surrogate of comparing the period of time it took for respondents to return the questionnaire against the number of incidents was considered, the assumption being that those who had been involved in incidents were more likely to return them sooner. No bias was detected based on this assumption, although the hypothesis being tested is rather hopeful. There were more incidents recorded in recent history, raising the spectre of re-call bias. Respondents were asked to identify the route that they used on a map provided with the questionnaire. Overall the researchers were hoping to identify differences in incident rates against facility type, but overall the survey instrument was unable to support these comparisons.

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[1] "Accident" is a word that the authors associate with chance and they prefer the word "crash" with its enhanced connotations of wilfulness. The word "crash" is used in the text where original authors have used it.

In a similar vein Noland (2003), having analysed various road infrastructure improvements using the proxies of average number of "interstate", arterial and collector lanes, the percentage of lane miles for these three categories and the percentage of each category with lane widths of 9ft, 10ft, 11ft and 12ft, shows that changes in highway infrastructure between 1984 and 1997 have not reduced traffic fatalities and injuries. Factors that do appear to reduce total fatalities are fewer young aged 15-24, more older people aged over 75 and better medical technology represented by the proxy of white infant mortality rates. The analysis does not account for changes in volume or speed of motor vehicles over the period, instead relying on the level of and type of infrastructure provision as being a proxy for these changes.

Overall it may be deduced that different, indeed apparently better, or at least more fit for purpose roads and or cycle tracks will not necessarily create conditions in which fewer accidents occur.

4.6 Safety and the law

The Parliamentary Advisory Council for Transport Safety noted in its report on the law and its enforcement (PACTS, 1999) that the law must be reasonable and appropriate and it must be communicated to and understood by all road users. There are 3,600 deaths and 324,000 other recorded casualties each year on the roads of the UK and action is taken on around 10 million road traffic offences.

Breaking road traffic law is a criminal activity although the authors note that it is not widely regarded as such. Drivers who have committed road traffic offences or who have been stopped by the police are more likely to be involved in crashes.

Mechanisms which are used in order to enhance obedience of the law include:

- instrumental compliance (penalties);
- social compliance (threat of sanctions);
- normative compliance (individual assessment of the whether the law is just and moral).

It is suggested by PACTS that the DfT and the Driving Standards Agency (DSA) should develop driving test questions requiring answers which demonstrate a deeper understanding of the casualty reduction issues behind a law and which test more rigorously a knowledge of risks, penalties and enforcement. PACTS is also of the view that misunderstanding of the law and its interpretation needs to be examined and, where necessary, additional practical information provided to reduce casualties.

It is noted that for speeding offences there is currently a weak deterrence effect from detection and punishment.

A study by Räsänen et al. (1999) before and after a change in Finnish law removing the necessity for car drivers to yield to the right to bicycles approaching on a cycle track to cross a road on a bicycle crossing, showed a generally low level of change in behaviour in terms of speed of approach. This lack of change in behaviour reflected the status quo before the change in the law, that is the custom and practice was for the narrow, low volume cycle path to be, in the psychology of the driver, regarded as inferior, and no right of way was generally offered by the driver. The change in law merely confirmed the prevailing practice. Contrariwise, at intersections of two general traffic streams the priority to the right rule remains in force and at these locations an approaching cyclist from the right would have priority. There is therefore an inconsistency in the required behaviour of the driver dependent upon the nature of the approaching road from the right. Overall, the research suggests that clear priority rules need to be uniformly and rigidly enforced to be effective and have an impact on behaviour.

CTC (2003), in its submission to the Commons Transport Select Committee inquiry into traffic law and its enforcement, makes a number of significant an interesting points in relation to the law and cycle traffic. In particular it notes the usual use of the law in areas such as employment contracts, and public health and consumer protection, to correct imbalances that are not in favour of the vulnerable. CTC suggests that traffic law should begin to do the same. CTC also notes the prevalence of the power of the car lobby to influence attitudes even to the extent that the independence of newspapers may be questioned as they are so well financially supported by the advertising revenue of car manufacturers.

4.7 Evaluation of traffic engineering bicycle research

The Table in Appendix B summarises contributions from the research discussed in Chapters 2, 3 and 4.

Research on "level of service", or "cyclability" (Landis et al. (1997), Harkey et al. (1998) and Guthrie et al. (2001)) shows that traffic flow, vehicle composition and lane width are all important factors. The surface condition of the route is also important, but none of the research to date appears successfully to have properly disentangled the contribution of their effects.

Safety studies reveal that there are many complex interactions between cycle traffic and motor traffic. There are many features of behaviour such as misjudgements, courtesy, appreciation of the weather and attitude to the law, as well as the often-quoted issue of inappropriate speed that are influential. The disproportionate impact of buses and lorries in the work of Sissons Joshi et al. (1993) supports the notion that the composition of the traffic stream is also important. Overall Ekman (1996) concludes that the level of bicycle flow is more important than level of car exposure in assessing risk and that the perception of both cyclists and car drivers is different for higher cycle flows. Evidence, particularly from North America (Forester (1994) and Noland (2003)) suggests that purpose built cycle facilities free from motor traffic are not a panacea.

Chapter 5 The research opportunity and proposed methodology

5.1 Structure of chapter

This chapter begins with a statement of the research aims and objectives and there follows in Section 5.3 a justification of them which incorporates a description of the research opportunity left available by the stream of previous work undertaken in the field. Section 5.4 describes the explanatory variables used in the modelling and Section 5.5 outlines the model structure. Section 5.6 considers alternative ways of achieving the study objectives in order to help justify the actual work undertaken. Section 5.7 summarises the chapter and re-introduces the subsequent chapters that contain the analysis and presentation of results.

5.2 Aim and objectives

The aim of this research is:

> to construct a model of the proportion of journeys to work for English and Welsh electoral wards that are by bicycle using relevant person, transport and other physical factors as explanatory variables.

Interactions between the variable types are investigated and the model used to forecast bicycle mode shares that would obtain for different levels of the variables that are policy sensitive. An important part of the research is devoted to the development of an area wide aggregate measure for perception of risk of cycling.

The objectives of the research are stated as follows:

- The determination of factors that influence whether or not the bicycle is chosen as a mode for the journey to work.
- The derivation of an appropriate measure for the identified factors, particularly the perception of risk.
- The analysis of the relative importance of the measured factors within an appropriately formulated choice model.
- The estimation of different potential levels of cycle proportion for the journey to work based on different levels of the determining factors, particularly perception of risk.

The research is concerned with determining the factors that determine the level of cycle use at ward level and a hypothesis may be stated as follows:

> *The variation in cycle trip making for the journey to work between wards in the UK may be explained by factors which can be defined and measured at*

aggregate level and include socio-economic and demographic factors, physical factors such as land-use factors, hilliness and weather and transport related factors, especially perception of risk. The relative importance of the different factors as they influence the proportion of journey to work trips that are made by bicycle can be modelled and the effect of changes in perception of risk on cycling mode share may be estimated.

5.3 The research opportunity and justification for the research

The National Cycling Strategy (DfT, 1996) set a target of doubling cycle trip making from a 1986 base by the year 2002 and doubling again by the year 2012. For England, the strategy was moderated by the Ten Year Transport Plan, which set a target of trebling cycle use between 2000 and 2010 (DfT, 2000a). The Transport White Paper of Summer 2004 (DfT, 2004a) has an aim over the next two to three decades of increasing cycling by making it more convenient, attractive and realistic for short journeys, especially those to work and school. The "one size fits all" NCS and Ten Year Transport Plan targets have been abandoned, and local authorities must set their own targets. Every local authority will begin from a different base of current cycle use and infrastructure condition. Analysis relating cycle use to local factors that influence choice would assist in providing an understanding of the potential for increasing the quantity of cycle trip making and hence assist in the setting of targets.

The seminal contribution to aggregate analysis of cycling data in the UK was that of Waldman (1977). He demonstrated that hilliness and danger are important factors influencing the choice of cycling for the journey to work. His estimates of danger were complex and derived from, inter alia, accident rates to cyclists. The dependent variable in his analysis, proportion of journeys to work made by bicycle, was hence correlated with the measurement of the independent variable representing danger. The difficulty was not lost on Waldman and he recommended that measures should be developed for accident risk that can be related to traffic conditions and road features such as junctions. Perceptions of risk in different conditions as they influence behaviour in relation to choice for the journey to work will be investigated in this research.

A further complexity in Waldman's work was the derivation of a measure for trip length. A measure for journey to work distance as part of this research will be derived directly from census data.

Mathew (1995) quotes estimates of cycling proportion using Waldman's model assuming that the accident rate is halved and this reference demonstrates that recent analysis is relying on research undertaken some time ago. Other than the recent but limited work of Rietveld and Daniel (2004), no known model equivalent to Waldman's has been created for a European or other country, and this re-emphasises the opportunity available in this research. There is no other widely drawn UK study of mode choice at the aggregate level to compare with Waldman's work. The work of Ashley and Bannister (1989a, b and c) was confined to districts in Manchester and the work of Crespo Diu (2000) was based on a sample of wards with very approximate estimates for some of the explanatory variables.

The research is relevant to undertake because the last comprehensive UK wide analysis of this type was undertaken in 1977. It is also timely as it uses recently available data from the census of 2001 and will come available as local authorities grapple with the need to set local targets for cycle use as a consequence of the Transport White Paper of Summer 2004 (DfT, 2004a).

There have been significant improvements in the use of techniques for modelling mode share since the completion of Waldman's work and it is now possible to handle much larger data sets than Waldman was able to consider. The technique of non-linear regression analysis using the logit formulation with an upper boundary has been proved in the work of Crespo Diu for assessing variability in cycle use at an aggregate level.

A different method of approach for the analysis would be to consider the use of disaggregate modelling techniques to evaluate, for example, the value of off-carriageway cycleway as compared with cycling on the carriageway[1]. The availability of aggregate data from the 2001 census provides the analyst, however, with a useful and comprehensive source of data for aggregate modelling. It will allow practitioners to understand, so far as the determining factors are able to explain them, the reasons why their local area has the level of cycling exhibited by the 2001 census. To varying degrees of certainty depending on the extent to which correlation can be separated from cause, it will be able to make recommendations to practitioners on changes that could result in increases in bicycle use and potentially allow for a better targeting of resources for promotion of the bicycle for journeys to work.

Various techniques for determining ratings for perceptions of risk have been adopted by various researchers (Landis et al. (1997), Harkey et al. (1998) and Guthrie et al. (2001)). The common thread has been a rating scale completed by the respondent with variation in factors deemed relevant to perception of risk. The research presented in this thesis uses video to widen the range of situations that may be presented to the respondent and also to achieve a larger sample size than would be possible by requesting respondents to actually cycle around a course. The survey instrument is targeted towards a measure for risk based on parameters that may then be measured in some way at an aggregate level for an area and includes junctions as well as routes both with and without cycle facilities and away from trafficked highways.

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[1] This is discussed further in Section 5.6

5.4 The relevant explanatory variables

Chapter 6 provides a full description of the source and metric for all the variables used in the model. The dependent variable will be the proportion of journeys to work at ward level made by bicycle from the 2001 census. Independent variables comprise socio-economic and other variables derivable from the 2001 census and include[1]:

- socio-economic classification (Jensen, undated, Waldman, 1977, Crespo Diu, 2000, Ortúzar, 2000);
- age (Jensen, undated, Ryeng, 1999, Ortúzar, 2000, Rietveld and Daniel, 2004 and many others);
- car availability (Crespo Diu, 2000, Ortúzar, 2000, Ryeng, 1999 and many others);
- sex (McClintock and Cleary, 1996, Waldman, 1977, Ryeng, 1999 and many others.);
- ethnicity (LRC, 1997, Tietveld and Daniel, 2004);
- distance to workplace (Jensen, undated, Waldman, 1977, Crespo Diu, 2000, Ortúzar, 2000, Bovy and Den Adel, 1985, Westerdijk, 1990).
- Level of qualifications (Ortúzar, 2000)

Data for income (found to be significant by Jensen, undated and Ortúzar, 2000 amongst others) has not been possible to collect but might have been an important variable in the model. Non-transport related physical factors comprise:

- hilliness (Waldman, 1977, Ashley and Banister, 1989a, b and c, Rietveld and Daniel, 2004);
- rainfall (Emmerson et al., 1998, Wardman, 1997);
- sunshine;
- temperature (Emmerson et al., 1998); and
- wind (Wardman et al., 1997).

Transport related factors comprise:

- network density and population density (Cervero and Radisch, 1996, Rietveld and Daniel, 2004);

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[1] A reference after a variable indicates that monitoring or quantitative research reported in Chapters 2, 3 and 4 supports the view that the variable is important.

- traffic intensity (Bovy and Den Adel, 1985, Landis et al., 1997, Harkey et al., 1998, Guthrie et al., 2001);
- condition of the road surface (Bovy and Den Adel, 1985, Landis et al., 1997, Harkey et al., 1998, Guthrie et al., 2001);
- Type of facility for cyclists (Bovy and Bradley, 1985, Bovy and Den Adel, 1985, McLintcock and Cleary, 1996, Noland, 1995, Wardman et al., 1997, Wardman et al., 2000, Ortúzar et al. 2000, Abraham et al. 2000, Rietveld and Daniel, 2004); and
- perception of risk from motor traffic (Waldman, 1977, Noland, 1995, Hopkinson and Wardman, 1996, Landis et al., 1997, Harkey et al., 1998, Guthrie et al., 2001, Rietveld and Daniel, 2004).

The measure for the perception of risk resulted from the collection of primary data and its analysis as described in Chapters 7 and 8. This research builds on the work of Landis et al. (1997), Harkey et al. (1998) and Guthrie et al. (2001) and uses video based techniques to deduce perceptions of risk in different environments. The separate effects of traffic noise and pollution were not specifically addressed and have not been expressly modelled. A measure for public transport accessibility (found to be significant by Bovy and Den Adel, 1985 and Ortúzar, 2000 amongst others) at aggregate level has not been possible to define and this is discussed further in Chapter 6.

5.5 Methodology

The main model

The most common, and a very practical, formulation for a binary choice at a disaggregate (individual person) level may be written in the form of the logit model:

$$P_i = \frac{1}{(1 + e^{-Z_i})} \qquad \text{Equation 5.1}$$

This formulation is also applicable to modelling aggregate mode shares. In this case, P_i may be taken as the proportion of individuals in ward i who will make a positive choice to undertake an activity (cycling for the journey to work in this case), the levels of the independent variables are represented by Z_i defined in Equation 5.2.

$$Z_i = \beta_{i0} + \beta_{i1}X_{i1} + ... + \beta_{in}X_{in} + \varepsilon_i \qquad \text{Equation 5.2}$$

β are coefficients to the explanatory variables, X for ward i measured as levels of the independent variables and ε_i is an independently distributed random variable with mean zero.

It would be possible to model cycling mode choice in a multinomial logit model with as many modes as there are choices, for example, bicycle versus car versus bus versus walk. A construction of this type would require a lot of data for each of these modes. The binary choice model still contains within it a representation of the factors that affect propensity to cycle and consequently can provide a measure of the proportion that cycle.

The logit function upper limit is 100%. Crespo Diu (2000) recognised that it is not realistic to expect an upper limit for the choice to cycle to be 100%. Introducing S as the saturation level for the choice into the logit formulation instead of 1 (i.e. 100% mode share), as in Equation 5.3, allows for the upper limit of the saturation to be estimated as an independent variable[1]:

$$P_i = \frac{S}{(1 + e^{-Z_i})} \qquad \text{Equation 5.3}$$

Equation 5.3, with Z_i as defined in Equation 5.2, will be used for modelling the variation in cycle use between wards in England and Wales.

All relevant variables will be included in the model. If variables turn out not to be significant they will be removed, considered further as to whether their measure is realistically not significant and if so discarded from the model and the model will be re-calibrated. There is likely to be a good deal of iteration and consideration at the stage of elimination of variables.

The Risk Rating Model

An important variable, recommended to be considered in more detail by Waldman (1977) is risk. It is inaccurate to adopt accident data for cyclists as a measure of exposure to risk for the following reasons:

- The number of cycle accidents occurring will be a function of the number of cycle kilometres ridden. The number of cycle kilometres ridden is related to the amount of cycle trip making and hence the dependent variable is related to an independent variable.
- The number of accidents that go unreported, particularly accidents to cyclists is relatively large and so the accuracy of the measure itself is open to question.
- The number of accidents is not a good proxy necessarily for the perception of risk that people may have.

These reasons lead to the realisation that a measure for perceived risk is required. The pursuit of this measure forms a large part of the research reported in this thesis and is based on presenting real-life cycling situations to potential cyclists and asking them to provide a rating of how they

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[1] Note that Crespo Diu adopted the following transformation of Equation 5.3 for modelling: $\ln[P_i] = \ln[S] - \ln[1 + e^{-(\beta_{i0} + \beta_{i1} X_{i1} + \ldots + \beta_{im} X_{im} + \varepsilon_i)}]$

perceive the risk to themselves. This is undertaken using video as a presentation tool and a sample has been drawn from those in employment who are able to ride a bicycle, whether or not they currently use the bicycle for the journey to work.

The rating of risk by individuals for a journey allows for an analysis of the contributory risk to that journey by different situations that arise in the journey, including different types of route and junction form. The risk ratings may then be extrapolated to an indicator of risk for a whole district based on the make up of the cycling infrastructure in that district. This risk indicator becomes a potentially important measure in the overall model of cycling mode choice.

5.6 Examination of alternative approaches

Wardman et al. (1997) warn that aggregate models would be unable to analyse cycle facilities to the required level of detail to allow for an assessment of their impact on cycle trip rates. This issue is epitomised by the difficulty Waldman had in defining a suitable measure for an estimate of danger from traffic. Wardman et al. (1997) and Wardman et al. (2000) have been successful in quantifying at a detailed level the value of a number of different facilities for cyclists. The recommendations from this research suggest further work to isolate the contributions of different facilities, for example risk reduction as opposed to benefits of a more pleasant environment in which to cycle. The research also did not value cycle priority measures, cycle friendly junctions, traffic calming schemes and shared use footways, road surface or traffic levels, with the implicit suggestion that this would be worthwhile.

Disaggregate analysis does not however provide for the aggregation of the effects to create variables that may be compared with aggregate proportions from the census data. The alternative to disaggregate analysis to assess the value of different cycling facilities is the creation of a measure for perception of risk based on some overall appreciation of risk for an area. This has the advantage of the unit of measurement being an area and not a specific facility and therefore relates to aggregate level analysis. The difficulty lies in the determination of such a measure that properly reflects the individual components of risk and benefit of particular facilities, the extent of those facilities and the combination of those facilities.

The manner of consideration of attitudes has led researchers (Brög, 1982; Davies et al., 1997b; Forward, 1998 and Gardner, 1999) to consider choice mechanisms such as extended decision making theory. It would be possible to pursue research that values such mechanisms in the construction of models of choice. Such research would not however place as much emphasis on the evaluation of the contributions of safety and effort, both of which to some extent are variable through policy instruments. Recognising the importance of extended decision making theory however, it is appropriate to consider which "cultural" phenomena are primary determiners of choice and, so far as is possible, to account for these in a quantitative choice model.

Mathew (2000) puts forward the Cyclists' Touring Club point of view that frequently the forgotten cyclists are the ones that go unrecorded in surveys based only on the journey to work. This is an argument to suggest that cycling analysis should not be based solely on census journey to work data. While this comment is valid, it has to be recognised that the most extensive and geographically specific data on cycle use available is the proportion which cycle for the journey to work derived from the census. A robust analysis using the cycle to work dependent variable will allow conclusions to be drawn regarding the influence of important determining factors. At least some view could then be taken as to the impact of these factors on cycle journeys for purposes other than the journey to work.

5.7 Summary

A main model to estimate the proportion that use the bicycle for the journey to work is constructed based on the logit formulation with a saturation level parameter to be estimated. The independent variables are defined from the literature review and measures for them are described in detail in Chapter 6. A measure for perception of risk is created from primary data collected using video based techniques and the methodology and descriptive analysis of the results are presented in Chapter 7. Chapters 8 and 9 provide a more detailed analysis of the results in order to derive an appropriate measure for risk at a district wide level. Chapter 10 and subsequent chapters described the main model and its use.

Chapter 6 Data sources and measurement

6.1 Introduction

This chapter describes the data sources and methods of measurement of factors that are analysed to explain the variation in journey to work made by bicycle. The dependent variable is the 2001 census journey to work proportion that use the bicycle and this is discussed in Section 6.2.2. The independent variables are, for convenience of description, separated into data derived from the 2001 census (Section 6.2), physical factors (Section 6.3) and transport factors (Section 6.4). The measurement of risk has been a major part of the research programme and is separately described in Chapters 7 and 8.

6.2 Census Data

6.2.1 Level of aggregation and coverage

The 2001 census (ONS, 2003c) provides data on the number of journeys to work made by bicycle and a summary of the main findings from the census data at national, regional and district level is contained in Chapter 2. Data for the main model has been extracted and analysed at ward level for England (7987 wards in 354 local authorities) and Wales (881 wards in 22 local authorities).

Consideration has been given to the level of aggregation appropriate in the data for the main analysis. To use district level data implies an aggregation from ward level and Table 6.1 below indicates the range in percentage of journeys to work undertaken by bicycle in wards over the range of districts from Cambridge (ranked highest for percentage of journeys to work by bicycle) to the first district above 1% of journeys to work by bicycle (Rotherham).

Table 6.1 Range of percentage bicycle use by ward for selected English districts

Rank order	Reason for selection	District Name	District percentage cycle for the journey to work	Range in ward level percentage cycle for the journey to work
1	Highest ranked	Cambridge	28.34%	21.93%-35.38%
29	1st district above 6% in the rank order	Suffolk Coastal	6.04%	1.68%-12.19%
94	1st district above 4% in the rank order	Havant	4.09%	2.30%-6.68%
233	1st district above 2% in the rank order	Lewisham	2.00%	1.11%-2.91%
339	1st district above 1% in the rank order	Rotherham	1.02%	0.65%-1.60%

Data in the table demonstrates that the variation in cycle use between wards can be fairly high. This variation, as may be expected, is higher where the overall district percentage that cycle for the journey to work is greater.

While recognising that the majority of districts have cycle to work proportions that are fairly low (260 less than 4%), the variation even for districts with low proportions can be quite high (for example Lewisham). This finding would indicate that it is better to undertake the analysis at the more appropriate level of the ward. It should be born in mind however that some of the non-census based explanatory variables will be available, or derivable in a reasonably economic manner, only at a level higher than ward level, usually district level.

So far as Scotland is concerned the locality is the prime building block of the census. Table 6.2 below summarises the mean and range of the number of journeys to work for England, Wales and Scotland at ward and locality level.

Table 6.2 Mean and range on number of journeys to work

Country	Mean number of journeys to work	Range
England and Wales (ward level)	2,664	0 – 17,560
Scotland (locality level)	3,623	149 - 265,387[2]

Notes

1 Journeys to work are the number of people in employment of age 16-74 (and including full time education in Scotland) not based mainly at home

2 The locality with the most journeys to work is central Glasgow

The mean for the locality in Scotland is larger than for the ward level in England and there are 33 Localities with more than 10,000 journeys to work or education in Scotland. The next lower level of aggregation in Scotland is the level of the ward of which there are 1,222, indicating a mean number of journeys to work of 1731 (2,116,117/1222). Census data for Scotland is available separately through the General Register Office for Scotland and distinct download routines and data preparation routines are necessary for the Scottish data. This additional analysis burden, coupled with the lack of fit between the ward and locality sizes for the journey to work and the additional difficulty in obtaining data for other determining factors, has led to the decision to analyse data only for England and Wales. The purpose of the analysis is to determine and measure the factors that influence the propensity to cycle to work and, based on variation across 8,868 Wards, the England and Wales data set is sufficiently large to undertake this task.

There are 18 wards, listed in Table 6.3 below, for which no population data is provided in the 2001 census and these have been eliminated from further analysis, bringing the total number of wards for analysis down from 8868 to 8850. These wards do not have population data provided because the population size is so small that it would be possible to deduce facts about individuals from the data.

Table 6.3 wards for which no population data is provided in the 2001 census

Ward Code	Ward	District
00AAFB	Aldgate	City of London
00AAFC	Bassishaw	City of London
00AAFD	Billingsgate	City of London
00AAFF	Bread Street	City of London
00AAFG	Bridge & Bridge Without	City of London
00AAFH	Broad Street	City of London
00AAFJ	Candlewick	City of London
00AAFK	Castle Baynard	City of London
00AAFL	Cheap	City of London
00AAFM	Coleman Street	City of London
00AAFN	Cordwainer	City of London
00AAFP	Cornhill	City of London
00AAFR	Dowgate	City of London
00AAFU	Langbourn	City of London
00AAFW	Lime Street	City of London
00AAGA	Vintry	City of London
15UHFA	Bryher	Isles of Scilly
30UHHH	University	Lancaster

In order not to disclose personal data because of low numbers, there are fifty wards (listed in Appendix C) that do not have data available at ward level for cross-tabulations and distance for the journey to work. Analysis has therefore been undertaken on the remaining 8,800 wards in England and Wales.

6.2.2 Journey to work data

The proportion using the bicycle for the journey to work is calculated based on the number of persons making a journey to work, persons who work from home are deducted from the denominator in the calculation. A full analysis of the variation in journey to work data by bicycle is presented in Chapter 2. At ward level the range for proportion using the bicycle for the journey to work is 0% to 35.38%.

6.2.3 Socio-economic classification

The 2001 census is the first to have socio-economic groupings specified in line with the national socio-economic classification system (ONS, 2000). Table 6.4 below summarises the classification and the mean, minimum and maximum percentages of employees aged 16-74 in each classification for all wards in England and Wales. It also shows the percentage of the population aged 16-74 represented by full time students.

Table 6.4 National Socio-economic Classification at ward level

No.	Description	Percentage of employees aged 16-74 at ward level		
		Mean	Minimum	Maximum
1	Higher managerial and professional occupations			
1.1	Large employers and higher managerial occupations	5.0	0.0	25.5
1.2	Higher professional occupations	7.3	0.0	45.9
2	Lower managerial and professional occupations	26.6	9.4	43.4
3	Intermediate occupations	12.4	3.7	53.8
4	Small employers and own account workers	11.8	1.7	43.8
5	Lower supervisory and technical occupations	10.2	1.1	25.9
6	Semi-routine occupations	15.2	1.6	35.2
7	Routine occupations	11.5	1.0	31.9
	Students (as percentage of population)	6.2	0.0	91.0

6.2.4 Income data

Income data is available commercially at either postcode or enumeration district level and is presented either as banded data or average and gross income for the area specified. The measure is derived from data collected as part of the National Shopping Survey, warranty card (store card) information and from registrations made for on-line goods and services. Data is updated once per year but collected as a constant stream. Unfortunately data did not become available for analysis as part of this research. Even were it to have become available there is a strong likelihood that it would have been correlated with the socio-economic classification data. Also it is quite likely that the socio-economic classification data is a better indicator of propensity to cycle, based on the socio-psychological issues revealed in the literature search, than income would have been.

Set against this there is the issue of expense of a journey and income data could have been valuable in measuring the propensity to take select modes other than the cheapest.

6.2.5 Car availability

The number of cars or vans available in a household is a question asked in the census. The measure used is the percentage of employees in a ward in a household with different levels of car ownership and the mean minimum and maximum levels are summarised in Table 6.5 below.

Table 6.5 Car ownership at ward level

Description	Mean %	Minimum %	Maximum %
Percentage of employees in households with no car or van	8.0 (22.3)	0.0 (1.4)	63.8 (63.8)
Percentage of employees in households with 1 car or van	37.7 (44.9)	10.9 (21.8)	71.6 (55.6)
Percentage of employees in households with 2 cars or vans	39.9 (25.1)	3.8 (3.8)	67.1 (48.6)
Percentage of employees in households with 3 cars or vans	10.6 (5.9)	0.3 (5.9)	26.9 (18.9)
Percentage of employees in households with 4 or more cars or vans	3.9 (1.8)	0.0 (0.0)	17.5 (9.6)

Note: Figures in brackets are for London wards

In addition to the separate classes of car ownership be household level a measure of the number of cars per employee has been calculated and this has an average value of 1.647 with a minimum of 0.426 and a maximum of 2.393.

6.2.6 Sex

The proportion of ward employees aged 16-74 that are male is used as the indicator of sex. At ward level, the minimum percentage male is 47.3% and the maximum 77.8% with a mean of 54.8%.

6.2.7 Age and qualifications

Table 6.6 below summarises the mean minimum and maximum percentages for each age band for employees derived from the 2001 census.

Table 6.6 Percentages of employees by age band at ward level

Description	Mean %	Minimum %	Maximum %
Employees aged 16-24	10.7	4.1	50.6
Employees aged 25-34	23.0	8.9	53.9
Employees aged 35-49	38.6	17.5	52.0
Employees aged 50-59	21.4	3.2	39.4
Employees aged 60-64	4.4	0.4	10.4
Employees aged 65-74	1.9	0.0	7.7

In addition to age, the percentage of employees that have higher level qualifications (tertiary education) has been determined for each ward. The mean proportion with higher qualifications is 23.8% with the minimum level being 4.4% and the maximum level 81.6%.

6.2.8 Ethnicity

A variable that may influence propensity to cycle if culture is anything to do with the decision making process would be the ethnicity of the population. Options available for respondents included "White" (with British and Irish sub-divisions), "Mixed" (including White and Black Caribbean, White and Black African, White and Asian and any other mixed background), "Asian" (including Indian, Pakistani, Bangladeshi and any other Asian background). "Black" (including African and Caribbean and any other black background) and "Chinese" or other ethnic group. A statistic based on the percentage of the population that is non-white (including mixed races) has been derived from the census data and the proportion varies across wards in the UK from 0% to 88%, with a mean of 5.2%.

6.2.9 Distance to work place

A summary of the overall data for England and Wales is shown in Table 6.7 below together with the distance band boundary descriptions. Distance travelled is calculated based on a straight line between the postcode of residence and the postcode of workplace as stated on the census return.

Table 6.7 Overall England and Wales proportions by Journey to Work distance band

Distance Band	Number 16-74 year old workers in band	Percentage
Less than 2km	4,731,186	23.3%
2km to less than 5km	4,725,068	23.3%
5km to less than 10km	4,305,035	21.2%
10km to less than 20km	3,601,201	17.7%
20km to less than 30km	1,268,657	6.2%
30km to less than 40km	556,004	2.7%
40km to less than 60km	508,061	2.5%
60km and over	623,556	3.1%
Total	20,318,768	100.0%

Notes: Totals and proportions exclude the 3,210,283 that work mainly from home

Table 6.8 below shows that average and maximum values for the proportions in each band at ward level. The minimum proportion in every case was zero with the exception of the "less than 2km" band for which the proportion was 0.009.

Table 6.8 Average and maximum proportions of journeys for each distance to work band at ward level

Band	Average proportion	Maximum proportion
Less than 2km	0.31	0.90
2km to less than 5km	0.21	0.59
5km to less than 10km	0.19	0.48
10km to less than 20km	0.16	0.56
20km to less than 30km	0.06	0.30
30km to less than 40km	0.02	0.21
40km to less than 60km	0.02	0.16
60km and over	0.03	0.61

Journeys by bicycle are generally thought reasonable for distances of less than about 5 kilometres. A further combined measure of distance to work has been determined, the average distance to work. This has been calculated for each ward assuming that the class mark for the band is its mid-point and taking 70km as the class mark for the 60km and over class. The average distance is 9.930 kilometres, with the minimum being 1.45 kilometres and the maximum 51.812 kilometres.

6.3 Physical factors

This section describes the measures adopted for hilliness and weather.

6.3.1 A preamble on effort

It is not the actual effort, or exertion, which is of so much interest as the perception by the cyclist of the exertion required. This may vary depending on perception of hilliness of a route and also by the physical effect which exertion may have on the cyclist. Most studies in connection with effort concentrate on experienced sports cyclists rather than everyday commuter cyclists or novice cyclists. Loftin et al. (1990) studied pedal rate (cadence) variation for constant power output and found that, at high cadences, ventilation (respiration) has the most effect on ratings of perceived exertion but at lower pedal rates heart rate has a more profound effect. Jameson and Ring (2000) worked eighteen trained cyclists at rates of 100W, 150W and 200W and pedal cadences of 50rpm, 70 rpm and 90 rpm. Pedal cadence only influenced local exertion sensations of muscle pain and knee pain, which were higher at lower cadences. In findings different to Loftin et al. (1990), neither overall perceived exertion nor central sensations (breathlessness and heart beat intensity) were significantly affected by cadence. Increased work rate increased exertion perception for all ratings but ratings of overall perceived exertion were based on a combination of muscle pain and breathlessness.

The participants are likely all to have been prepared for the experiment and been wearing clothes designed for sports activity. They were fanned while riding the exercise bicycle used in the experiment. There was a five minute “warm up” period and a five minute “warm down” period either side of the 4 minute test period. While the overall time of the experiment of 14 minutes is unlikely to be significantly different from the time for an urban commuting journey, it is unlikely that an urban commuter would consciously “warm up” and “warm down” during a journey. It is also unlikely that all urban commuters will wear clothes designed for sport, for example to wick away sweat. Experienced cyclists tend to ride at higher cadences than novices and everyday commuters. Overall the perception of exertion of an urban commuter is therefore likely to be a function of degree of heating of the body, as well as muscle pain and breathlessness. Inexperienced cyclists may also cycle at inappropriate cadences and therefore in addition experience knee pain.

Graham (1998) undertook a study of stops and energy consumption for a sample of twelve everyday cyclists. The cyclists circumnavigated a 2.5km route involving seven roundabouts. Traffic was light and the cyclists repeatedly cycled the course, on some circuits pausing momentarily at the give way line to the roundabout, on other occasions progressing without pausing. Graham hypothesised three styles of energy consumption amongst cyclists as follows:

- Hypothesis 1: the cyclist maintains a constant acceleration until normal cruising speed is reached. This would require additional energy relative to the case with no pauses and, as the average power output is therefore higher, would create additional stress and heat to the point of discomfort.
- Hypothesis 2: the cyclists’ average power output during the journey is the same as if the cyclist maintained normal cruising speed throughout, this results in a cruising speed less than would be the case without pauses.
- Hypothesis 3: power output is constant so that normal cruising speed is reached asymptotically.

The trial with cyclists demonstrated that the actual average additional times on the circuit with pauses was closest to the extra time expected by Hypothesis 2. Graham recognises the inadequacies of Hypothesis 2 by considering a journey where pauses are unevenly distributed. For example, were all pauses to occur in the first half of the journey, it is unreasonable to suppose that greater than the average power output is maintained for the first half of the journey with the anticipation that “recovery” will take place in the full second half of the journey. Graham’s analysis assumes even accelerations of $3m/s^2$ and decelerations of $1.5m/s^2$, and the same masses and air resistance losses for each cyclist in the trial. No attempt is made to explain the (admittedly small) variation in additional journey time in the sample. Explanations in terms of cyclists’ age, sex and type of cyclist (sporting, commuting, etc.) may also have been instructive.

Overall Graham concludes that cyclists' power output in response to a pause may accord with Hypothesis 2. If there is a long period without a pause the cyclist may attain a higher cruising speed, as in Hypothesis 3. A model of how a cyclist "redistributes power output over time" is recommended as a way forward.

It may be noted that the extra time on a journey caused by pauses is greater than that which would be required if the cyclist braked from normal cycling speed and then recovered speed with normal acceleration. This additional time is shown to be equivalent to an additional distance of some 55 metres for a typical cyclist's acceleration, cruising speed and braking, but is independent of actual power output. This distance figure is recommended as a guide for planning cycle routes.

In a far less thoughtful study than Graham's, Mercat (1999) realised the importance of the number of times a cyclist is required to slow down, stop, wait and set off again as well as the effects of gradient and quality of surface. For a racing cycle with tyres at 6 bar pressure, Mercat deduced that the air and rolling resistance is equal at 17 kph. With mediocre road quality and bicycle quality, he deduced that the energy to overcome friction can rise by 80%. He concludes that, based on an energy analysis, road surface, correct tyre pressure and the weight and quality of the bicycle are very important factors. So while some, for example, Bosch (1999) primarily concern themselves with measures of comfort resulting from different road surface conditions (he deduced that 0.12 "jolts per metre" is the threshold above which a cycle route is deemed to be uncomfortable), Mercat makes the leap to the connection with energy use.

Mercat notes that based on an average energy use of 100 watts required to cycle at 25 km/hr, the energy required to get back up to speed is equivalent to riding 139 metres at constant speed and this is longer than Graham's estimate of 55m indicating a lower power output for Graham's cyclists. Similarly the energy expended going up a gradient of 5% at 10 kph is twice as great as on the flat at 20 kph.

Without any scientific evidence but nonetheless appearing to be reasonable, Sharples (1999c) provides a series of assumptions about cycle speeds to be used in modelling route choice for cyclists. Sections of road where cycling is not allowed were assumed to have a speed of 5 kph, equivalent to walking, paths shared with pedestrians 10kph, cycle paths 15 kph and routes along general highway, 20 kph. If a link crossed two contours on a 1:25 000 map, then the speed was reduced by an arbitrary 5 kph.

Using data from 71 employees who work at the same office, Sully (2000) has reviewed trip lengths of cyclists and found that the mean journey distance is 3.0 kilometres. He points out that this is less than the 5 miles (8 kilometres) generally reckoned to be a distance over which cycling could take place and is a recognition of the limitations placed on cycling because of the effort required.

Focussed more on the bicycle than the rider, Chien and Tseng (2004) designed an automatic gear-shifting logic for bicycles that accounted for individual cyclist's comfort and found that bicycle speed, pedal rates per minute (rpm) and gradient of the ground had an effect on their control process.

From the work that has been undertaken in the field of effort it may be seen that the gradient (hilliness), road surface condition and the number of stops required on the network are important indicators of effort. A measure for hilliness is discussed below and measures for the road surface condition and number of stops required are discussed with Transport Factors in Section 6.4. Measures for weather are also discussed in this section.

6.3.2 A measure for hilliness

Ideally it would be good to investigate the specific vertical alignment of roads and cycle routes within a district as opposed to the general topography.

After investigation of the mapping available through EDINA (EDINA, 2003) and the necessary time and effort involved in downloading topography, road and district boundary data to a suitable GIS environment for subsequent analysis, it became apparent that an already derived measure for hilliness would be required for the purposes of this research.

Comprehensive data on the countryside has become available on-line sponsored by the Department for Environment, Food and Rural Affairs (Defra, 2003) and topography is available for each 1km square of the UK. Available datasets include mean altitude, altitude 10th percentile, altitude 90th percentile and slope (both in percentage gradient and degrees). So far as cycling is concerned the point at issue is the slope. The downloadable software and complementary datasets are able to be interrogated using user-specified areas to determine the number of kilometre squares of a particular mean slope (to the nearest 1%). The mean slope for a kilometre square is determined by passing a 3 x 3 operator (grid) over the 20 x 20 matrix within each kilometre square column by column and row by row. The 3 x 3 operator determines the slope at the centre point of the matrix by calculating the change in slope in both orthogonal directions for the surrounding matrix points and then combining the orthogonal components to provide and average measure of slope.

It is possible for the user to select an area based on local authority district boundary and Table 6.9 below shows sample data for a selection of hilly and less hilly districts.

Table 6.9 Sample topography data from CIS

	Percentage 1km squares with 2% slope or greater	Percentage 1km squares with 3% slope and greater	Percentage 1km squares with 4% slope and greater	Percentage 1km squares with 5% slope and greater
Bolton	99%	93%	76%	59%
Kirklees	100%	100%	100%	98%
York	20%	5%	1%	0%
Leicester	88%	69%	29%	7%
Camden	89%	61%	50%	33%

For the purposes of the analysis of cycle use it is necessary to derive an appropriate indicator of hilliness for a district. Based on the nature of the data available a useful indicator would be the percentage of 1km squares in the district that have slopes greater than a certain percentage. It may be seen from Table 6.9 that, using a cut-off of 2% or greater, there is little difference in the indicator between extremely hilly areas (e.g. Kirklees) and less hilly areas (e.g. Bolton). Similarly at the opposite end of the scale there is little difference between York and Leicester for slopes of 5% and greater, whereas there is a more significant difference between the two at 4% or greater. It is not immediately clear whether an indicator based on 3% and greater slopes or 4% and greater slopes is appropriate and data for both of these levels of hilliness have been extracted from the CIS for use in the analysis as shown in Table 6.10 below.

Table 6.10 Mean and range on hilliness variable

	HILL3%	HILL4%
Mean	67.53%	53.99%
Minimum	0.00%	0.00%
Maximum	100.00%	100.00%

It should be noted that for some coastal districts slope data is not available in the inter-tidal region, notwithstanding the percentages have been calculated based on the denominator containing the full number of 1km squares. It should also be noted that the distribution of the slopes within the district may be concentrated, or evenly spread. Where the district is rural and has unevenly spread hilliness then it is possible that the hilliness indicator will have less correlation with cycling levels than may otherwise be the case, particularly if, for example, settlements are located in relatively flat valleys. Where there is urbanisation in a district, it is likely that the urbanisation will be in flatter parts of the district and hence the hilliness measure will again have less correlation with the level of cycling than would otherwise be the case. To a small extent counteracting this argument is the fact that suburbs to an urban area will usually become more hilly in a hilly area and the "cognitive mapping", or people's perception of an area and its appropriateness for cycling, may be influenced by the general lie of the land rather than the lie of the land specifically for a journey to work, for example.

The local authority area descriptions in the Countryside Information System (CIS) generally comply with those for the 2001 census. Exceptions are noted below:

- Topographical data for Swindon was assumed to be the same as for West Wiltshire.

- Topographical data for West Berkshire was assumed to be the same as for Newbury.
- Topographical data for Medway was assumed to be the same as for an aggregation of Gillingham and Rochester by Medway.
- Topographical data for South Hams (Devon) erroneously coded as "South Hampshire" in CIS.

Topographical data for the Isles of Scilly was unavailable in CIS and it was assumed to be the average of the two adjacent Cornish districts of Penwith and Kerrier.

6.3.3 Measures for weather

A measure for rainfall, sunshine and temperature

A central issue for the rainfall metric is its level of aggregation. There are many weather stations across the country. Different stations measure different climatic conditions depending on their location, ease of access, frequency of observation and ownership. Weather stations bear no particular relation to administrative boundaries and so some districts may contain a number of weather stations, while others may contain none.

In the first instance raw data from rainfall weather stations (Meteorological Office Land Surface Station Data) was reviewed that is made available to the academic community through the British Atmospheric Data Centre (BADC, 2004). This data is available only between 1900 and July 2000. There are also many data gaps even up until July 2000 and this is partly due to failed data extraction jobs but also because data is actually missing from the master Meteorological Office database from which BADC extracts the data. It became clear that, even if data were available up to and including April 2001, it would take a significant amount of effort to rationalise the extensive data available into appropriate districts. Data can be extracted directly from the Meteorological Office archive for dates after July 2000 on request, but the time and effort needed to specify appropriate weather stations for each district would have been long and large.

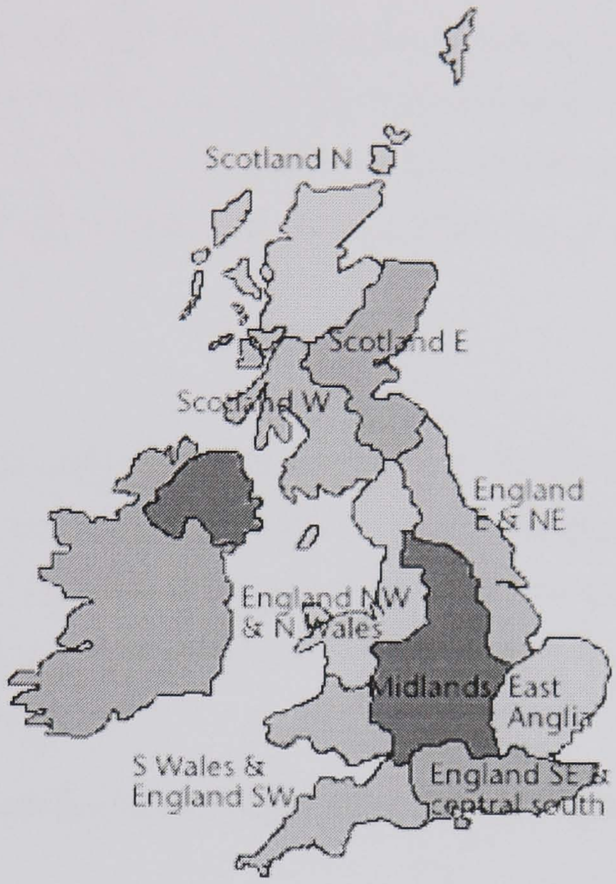
There would have remained the issue of the development of an appropriate methodology for aggregation. It would be feasible to deduce rainfall data for a sample of districts from the source data. However, for the whole of England and Wales, it presents itself as a task beyond the scope of the research in hand.

Nimrod is a fully automated system for weather analysis and BADC holds the analyses at a time resolution of 15 minutes for, inter alia, rainfall rate and rain accumulation. Unfortunately the BADC holds Nimrod data only from late 2002 and again it was not possible to use this data source for rainfall data for this research.

As an alternative approach, a consideration was given to the availability of aggregated weather data sources. The Meteorological office presents historic weather data (Meteorological Office,

2004) aggregated to monthly intervals for six regions of the UK as identified in Figure 6.1 below.

Figure 6.1 Meteorological regions of the UK



While these regions are relatively large, the fact that they are aggregated as six and not a larger number indicates that the Meteorological Office considers the aggregation at this level to be reasonable. Rainfall, in so far as it is an indicator of the propensity to cycle, does not vary that much across the regions noted above and these regions are a reasonable level of aggregation for use as an indicator of propensity to cycle. Table 6.11 below presents rainfall, sunshine and mean temperature data for the month of April 2001 and the period May 2000 to April 2001 for these regions.

Table 6.11 Rainfall, Sunshine and temperatures for England and Wales 2000-2001

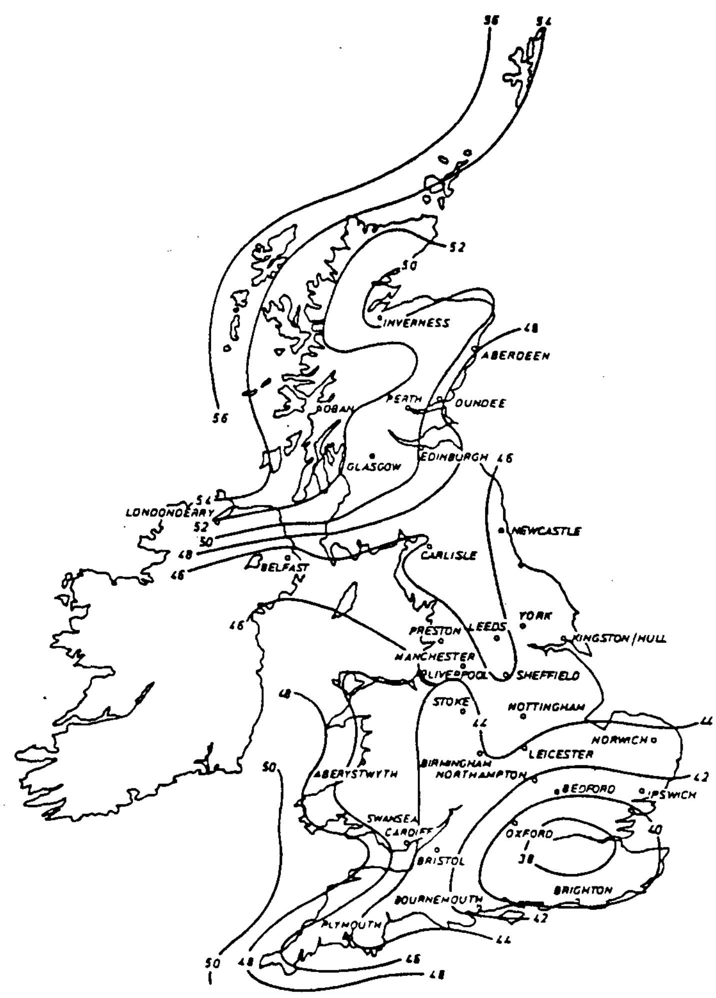
	April 2001			May 2000 to April 2001		
Region	Sunshine (hours)	Rainfall (mm)	Mean Temperature (^{0}C)	Sunshine (hours)	Rainfall (mm)	Mean Temperature (^{0}C)
England E & NE	124.7	87.7	6.5	1392.5	988.0	8.59
Eng NW & N Wales	127.7	127.1	6.5	1404.1	1583.6	8.63
Midlands	127.6	94.0	7.3	1377.1	1035.7	9.31
East Anglia	141.1	73.4	8.0	1440.6	889.5	10.11
S Wales & Eng SW	149.7	119.5	7.6	1406.9	1642.9	9.73
England SE	138.3	78.5	8.2	1463.0	1228.1	10.30

It was hoped that an analysis could be undertaken of the variation of rainfall, sunshine and temperature within the regions to confirm that this variation is so small that use of the data at this level of aggregation is reasonable. Owing to the lag in availability of climatic data on BADC (and the extensive and complex task of undertaking this analysis in any event), this analysis has not been possible. Each ward has had associated with it the total rainfall (in millimetres), total sunshine hours and mean temperature relevant to the region in which it lies for the year up to and including April 2001. The previous year has been considered as it is more representative than the single month of April 2001. It should be noted that there were many low pressure systems that crossed the UK during the Autumn of 2000 making it the wettest Autumn since records began in 1766 (Meteorological Office, 2004). By contrast January 2001 was the sunniest since 1961.

A measure for wind

Wind data is again available from Meteorological Office Land Surface Station Data through the British Atmospheric Data Centre (BADC, 2004), but suffers the same missing data issues as for rainfall data. An alternative approach has been adopted that uses the basic wind speed contours used in structural engineering design taken from British Standard 6399 (British Standards, 1997), as shown in Figure 6.2.

Figure 6.2 Basic Wind Speeds from BS 6399



Note: Wind speeds given in contours at 2 m/s intervals.

A basic wind speed in metres per second has been adopted for each county area using the map in Figure 6.2 and interpolating to the nearest one metre per second.

6.4 Transport factors

This section describes the measures for the extent and nature of the highway network, traffic intensity and surface condition. A brief discussion is begun on the development of a measure for risk across a district which is completed in the analysis and the discussion of the analysis of risk presented in Chapters 7, 8 and 9. The same section also discusses the effects of cycle facilities.

6.4.1 Network density, traffic intensity and population density

The quantity of cycling may vary depending on the extent and nature of the highway network and the network of motor traffic-free routes available to cycle traffic. If the network density is high this would imply:

- a larger number of junctions, and therefore junction conflicts, than in areas with fewer roads; and
- potentially generally lower speeds for motor traffic, yielding a benefit for cycle traffic.

Higher densities will tend to obtain in urban areas and lower densities in rural areas. Total built-up road length and total non-built-up road length is available from the Department for Transport web site (DfT, 2004d) for the 137 Unitary Districts and 34 county authorities of the UK (i.e. the administrative areas that remain two-tier). There are two ways of using the road length data that is presented at these two different levels of aggregation. The first is to associate county level data (i.e. road length divided by area for the county) to each of the separate districts within a county. The second is to divide the road length into the separate district areas based on the proportions of the county area that the district areas constitute. It is this second methodology that has been adopted, as it may be useful for other purposes to have the proportion of the county that a district comprises. Areas for districts were obtained from the Office of National Statistics website (ONS, 2004).

For counties where the principal urban areas have been separated out as unitary authorities and are otherwise homogenous rural areas, the approach of dividing based on area is probably acceptable. For counties where there are still fairly significant urban areas that form districts within the county, the method is less appropriate, but the best that is possible.

It was noted that, despite Plymouth being a unitary authority, no data was given and so the area of Plymouth as a proportion of Devon as a whole (80/6562) was used to factor the Devon County data to give a value for Plymouth.

The number of stops (and therefore starts) required on a bicycle journey will vary depending on the density of the road network. An approximation to the relative frequency of junctions between districts may be made by dividing the total road length (including built-up and non-built up) by the overall area (hectares) of the district. This measure could also act as a proxy for the risk inherent in a highway network. Network density would also indicate the degree of urbanisation of a district.

It is arguable that the level of cycle use in a district is a function of the degree of congestion evident on the highway network. When it is not easy to move about by car, then movement might be undertaken by bicycle instead. A further measure derivable from the data is a measure for traffic intensity based on the number of journey to work trips in a ward divided by the length of road available in the district. Similar to this measure, but less related to the road network is the population density which is a proxy for degree of urbanisation.

Table 6.12 below shows the mean and range of district areas and road lengths, network density, traffic intensity and population density.

Table 6.12 District area and road length data

	District Areas (hectares)	Built-up road length (kms)	Non-built-up road length (kms)	Total road length (kms)	Network Density (Total road length divided by area)	Traffic intensity (No. workers in ward / road length in district)	Population Density (people aged 16-74 / hectare
Mean	522	1919	2489	4408	3.55	2.58	825
Minimum	3	8[1]	0[2]	36	0.31	0.06	16
Maximum	5196	4437	10185	12930	19.73	33.31	10406

Notes:

1 Isles of Scilly

2 Urban areas such as the City of London and others.

6.4.2 A measure for risk and the effect of cycle facilities

A measure of risk across a district may be based either on objectively measured factors that may logically be seen as having an impact on risk, or based, more behaviourally, in the perception that people have of risk in different situations. At an aggregate level the measures of network density and traffic intensity discussed above are reasonable proxies for such a measure of risk. They do not, however, allow for the more detailed perception of risk that cyclists experience because of particular features on individual journeys. Research is required that allows for journeys in different conditions to be constructed and an overall measure of risk (termed Risk Ratings in this research) for these journeys to be developed. Beyond that then, a typical journey, or some sort of aggregation to district level is required in order to develop a measure for risk (termed Risk Index in this research) appropriate to a geographical area such as a district.

Chapters 7, 8 and 9 present research based on the collection of primary data, to develop Risk Ratings and Risk Indices. These measures for risk are closely associated with the types of condition that are experienced by a cyclist and include on and off carriageway routes, routes with and without cycle facilities and different types of junction with and without cycle facilities. Further discussion on the applicability of network density, traffic intensity and Risk Indices is contained in Section 9.4 and is concerned with deriving appropriate measures for the lengths and type of facilities available to cyclists in different areas.

6.4.3 A measure for surface roughness

Road condition has been found to be a factor which influences bicycle level of service (Landis et al., 1997 and Guthrie et al. 2001). In the UK the National Road Maintenance Condition Survey is compiled by the DfT (DfT, 2000f). The Index is calculated from a "defects index" based on individual defects weighted by their relative cost of repair relative to a base year. The National Average Index for non-trunk roads is 108.9 and the variation in local authority average index (from Annex 7 of DfT, 2000f) is between 40 and 300. The 90% confidence interval for the average local authority indices is typically around 50. The data is not available for each UK authority and so a different measure is required.

The Audit Commission collects data on a wide range of performance indicators for public services within the UK. So far as highway condition is concerned the relevant measures that are collected are the following two "Best Value Performance Indicators":

- BVPI 96 (6.3a in Wales): Condition of Principal Roads: Percentage of the network with negative residual life derived from deflectograph surveys covering at least 50% of the eligible network. Deflectograph data covering at least 20% of the eligible network must have been produced in the last year for which data has been included in the National Road Maintenance Condition Survey or later, while the remainder of the deflectograph data must come from surveys carried out in the 4 previous years. If an authority nominates part of its network for 'deemed coverage' one fifth of the deemed coverage can be counted towards satisfying the coverage criteria. Alternatively (as for non-principal roads), a visual survey of all principal road length in the year using United Kingdom Pavement Management System (UKPMS) Coarse Visual Inspection (CVI) except for part of the network nominated for 'deemed coverage'. Local authorities will be requested to indicate percentage of network with a UKPMS defects score of 70 or higher.
- BVPI 97 (6.3b in Wales): Condition of non-principal roads: CVI survey of the non-principal road network, to be carried out under UKPMS Rules and Parameters. Although CVI surveys are intended to be carried out over the entire network, authorities need not survey part of their network (that they know to be in good condition) that they nominate for 'deemed coverage'. The part of the network with 'deemed coverage' is included in total network length for the purposes of calculating the indicator.

The above definitions (Welsh Assembly, 2001) for the performance indicators are for Wales. The procedure for England is in essence the same (DfT 2003e), although there are continuing year on year improvements in the techniques for assessing highway pavements. From the definitions and the variable manner of collection of the data (either visual inspection or deflectograph survey) it is apparent that the BVPI presented for one authority may not be comparable with that of another authority. Notwithstanding, BVPIs 96 and 97 are the only available measure of road condition for districts across the UK and it is proposed to use these data to assess their propensity to influence the use of the cycle for the journey to work.

Data for the English highway authorities has been based on audited out-turn data for 2000/2001 (ODPM, 2003). Data for Wales has been taken from the Audit Commission web site (Audit Commission, 2003).

There was a considerable amount of missing data, particularly for BVPI97. The list below identifies the way in which the missing data was handled:

- The value for BVPI97 was assumed to be the same as for BVPI96 for the following authorities: City of London, Camden, Greenwich, Barking & Dagenham, Bexley, Bromley, Enfield, Havering, Newham, Sutton, Rochdale, Salford, Tameside, Trafford, Liverpool, Doncaster, North Tyneside, South Tyneside, Sunderland, Birmingham, Sandwell, Buckinghamshire, Derbyshire, Hampshire, Norfolk, Northamptonshire, North Yorkshire, Shropshire, Warwickshire, Bracknell, Reading, Halton, Stockton, Derby, Darlington, Portsmouth, Southampton, East Riding of Yorkshire, Kingston-upon-Hull, Swindon, Denbighshire, Isle of Anglesey, Cardiff
- The value of BVPI96 was assumed to be the same as for BVPI97 for Hillingdon
- The values for BVPI96 and 97 were assumed to be the same as for neighbouring / county authorities for the following: West Berkshire (as for Reading), Windsor & Maidenhead (as for Reading), Torbay (as for Devon), York (as for East Riding of Yorkshire), Stoke-on-Trent (as for Staffordshire), Vale of Glamorgan (as for Bridgend).

Doubts or auditors qualifications were expressed as to the accuracy of the following:

- BVPI96: Swindon, Reading, West Sussex, Surrey
- BVPI97: Leicester, West Sussex, Surrey, Walsall, Middlesbrough, Caerphilly.

It is also noted that the floods of Autumn 2000 could have affected road condition and highway authorities' ability to measure carriageway condition and repair carriageway. Overall therefore the road condition data needs to be treated with caution.

The maximum percentage for BVPI96 is 51% (mean of 11.6%) and for BVPI97 is 56% (mean of 9.4%), the minima are 0% in for both performance indicators.

6.4.4 Motor traffic effects

Physical effects of motor traffic

Traffic passing a cyclist exerts a lateral force because of the air turbulence created. Wilkinson et al. (1992) note the tolerance limit defined by the US Federal Highway Administration is 3.5lbs, equivalent to traffic travelling at 50 mph four feet from the cyclist. Behaviour much lower than the tolerance limit, or above the tolerance limit is unexplained. At speeds of 40mph and less the tolerance limit for the sideways force is not breached at lateral distances of even down to 1 foot. Clearly other factors in relation to desire to be proximal to traffic would come into play as the over-riding behavioural determiners and these have been investigated by, for example, Landis et al. (1997), Harkey et al. (1998) and Guthrie et al. (2001). These effects have been investigated further in the perception of risk survey described in Chapters 7, 8 and 9.

Traffic noise

Noise is a nuisance and prevents communication between pairs of riders on busy roads. No specific measure of the impact of noise separate from the other effects of traffic has been undertaken as part of this research. The perceptions of risk survey described in Chapter 7 may have subsumed into it part of the effects of noise.

Traffic pollution

Kingham et al. (1998) undertook a study to compare exposure to benzene and particulates of a car driver, a train passenger, a bus passenger, a road cyclist and cyclists on a path away from the road on a route from Marsden to Huddersfield in the Pennines. The exposure amongst road cyclists to benzene was 4.05 times less than for a car driver and the exposure to particulates was 1.26 less than for the car driver. On the path cyclists were exposed to 1.73 times less benzene and 2.41 times fewer particulates. This evidence is perhaps contrary to popular perception. No measure for pollution has been derived for this research but, once again, traffic intensity may act as an appropriate proxy.

6.4.5 A measure for public transport accessibility

The National Travel Survey provides travel variables for bus service frequency, walk time to bus stop, walk time to railway station, and bus journey time to railway station. A deficiency in NTS is that details for rejected modes are not included. In their analysis of cycle mode choice, Wardman et al. (2000) "engineered" times and costs for all modes (including rejected modes) in their mode choice model on the basis of the distance travelled by the chosen mode by a respondent. The costs and times for the rejected mode were determined from cost per mile data and speed data from other respondents who had chosen the rejected mode. For the purposes of the mode choice study undertaken by Wardman et al., this was appropriate. For the aggregate and geographically specific study currently being undertaken, NTS does not unfortunately offer appropriate data.

Again, Best Value performance data has been reviewed and the following two performance indicators come close to providing an appropriate measurement for the accessibility of the public transport alternative:

- BVPI101: Number of bus kilometres
- BVPI102: Number of bus journeys

There are also other indicators about satisfaction with public transport information and user satisfaction. Inspection of BVPIs 101 and 102 for 2000/01 (ODPM, 2003) reveals that data is far from comprehensive for districts across the country. Data is not available for London or many metropolitan unitary authorities and is available only at county level for a number of shires areas. The BVPI indicator is also therefore an inadequate measure for the public transport alternative.

Transport Statistics Great Britain, available on the Department of Transport web site provides data on bus kilometrage at regional level (DfT, 2004e). Communication with the bus statistics division at the department for transport indicates that data is held at county and unitary authority level, but is regarded as commercially restricted at that level and is therefore unavailable for public dissemination. Fares indices are not reliable below the regional level, as published.

In conclusion, no public transport accessibility data is available on a geographically specific basis at a level of dis-aggregation useful enough for this analysis.

6.5 Summary

Table 6.13 below summarises the data and level of aggregation of the data used in the analysis. It is should be noted that some data sources are available at ward level. Other data is available at only a higher level of aggregation.

Table 6.13 Data used to determine the propensity to cycle for the journey to work.

Code	Unit	Description	Level of aggregation	Source
%JTWB	%	Percentage journeys to work by bicycle	8800 wards	Census 2001
All 1674	No	All people aged 16 to 74	8800 wards	Census 2001
All 1674 workers	No	All people aged 16-75 in employment	8800 wards	Census 2001
%male	%	Percentage of males of all people aged 16-74	8800 wards	Census 2001
Age	%	Percentage in bands 29 and under, 30-44, 45-59 and 60 and over	8800 wards	Census 2001
%NOCAR	%	Percentage households with no car	8800 wards	Census 2001
%1CAR	%	Percentage households with 1 car	8800 wards	Census 2001
%2CAR	%	Percentage households with 2 cars	8800 wards	Census 2001
%3CAR	%	Percentage households with 3 cars	8800 wards	Census 2001
%4+CAR	%	Percentage households with 4 or more cars	8800 wards	Census 2001
Socio-economic classification	%	Percentage of all people aged 16-74 in Socio-Economic classifications 11, 12, 20, 30, 40, 50, 60, 70, 81, 82, student and "not classifiable"	8800 wards	Census 2001
NWHITE	%	Percentage of all people aged 16-74 that are non-white.	8800 wards	Census 2001
Distance to work bands	%	Percentage of journeys to work in distance band under 2km, 2-5km, 5-10km, 10-20km, 20-30km, 30-40km, 40-60km, 60km plus	8800 wards	Census 2001
BVPI96	%	Percentage of principal road length with negative residual life or UKPMS defects score of 70 or higher.	137 Unitary Districts and 34 counties	Audit Commission / ODPM
BVPI97	%	Percentage of non-principal road length with UKPMS defects score of 70 or higher.	137 Unitary Districts and 34 counties	Audit Commission / ODPM
Area	Sq km	Area of district	376 districts	Office of National Statistics
TBURL	Km	Total built-up road length	137 Unitary Districts and 239 districts within counties.	Department for Transport
TNBRL	Km	Total non-built-up road length	137 Unitary Districts and 239 districts within counties	Department for Transport
TRL	Km	Total road length	376 Districts (see above)	Sum of TBURL and TNBRL
Risk and cycle facilities		See results from Chapter 9		Primary data
HILL3%+	%	Percentage of 1km squares with mean slope 3% or greater	376 Districts	Countryside Information System
HILL4%+	%	Percentage of 1km squares with mean slope 4% or greater	376 Districts	Countryside Information System
Sunshine	hours	Total annual hours of sunshine for the year May 2000 to April 2001	Six meteorological regions	Meteorological Office
Rainfall	mm	Total annual millimetres of rainfall for the year May 2000 to April 2001	Six meteorological regions	Meteorological Office
Wind speed	m/s	Basic wind speed for structural design	County level	BS 6399
MeanTemp	^0C	Mean temperature for the year May 2000 to April 2001	Six meteorological regions	Meteorological Office

Chapter 7 Risk Rating methodology and descriptive statistics

7.1 Overview of Chapter

This chapter discusses the method, execution of the survey and the descriptive analysis of data from a survey to determine the perception of the risk of cycling. The results of the analysis of perception of risk are used to inform on the creation of an area wide measure for risk to be used in the model of national variation in cycle use and this is detailed in Chapter 8.

Initial structured interviews (Stage 1) were undertaken to confirm the types of features that cyclists perceive as risky. The sample size was very small but the survey was designed to confirm the issues of relevance to cyclists and potential cyclists.

The main part of the survey (Stage 2) comprised face-to-face interviews with a sample of 144 drawn principally from Bolton Metropolitan Borough Council employees. Digital video images were displayed on a computer and responses on ratings of "risk from traffic" and "threats to personal security" were requested. The result from this data collection exercise were used to create a model of relative perceived risk to cyclists in different conditions along routes and at junctions, as described in Chapter 8.

7.2 Initial structured interviews

The first stage of the survey took the form of a structured interview with four males and two females. The proforma for the interview is in Appendix D. Two respondents described themselves as "occasional" cyclists, two as "leisure" cyclists, one as a "sports" cyclist and one as a "commuter" cyclist. The interviews took place on an ad hoc basis over the period February to November 2001.

Each respondent, bar the commuter cyclist, indicated an aspiration to cycle more frequently and the reasons included improvements in health, activeness and exercise. The weather was cited as a reason not to cycle more frequently. Table 7.1 below indicates what respondents find risky about cycling.

Table 7.1 Areas of risk identified in the structured interviews

Area	Risks
General	Weather (causing slippery surfaces and lack of visibility), traffic speed, volume and composition, pedestrians stepping out, road surface condition, lack of segregation, badly planned cycle facilities
Major roads	Articulated lorries, being passed continuously, poor surface quality and gully pots and manholes
Right turns	Lack of awareness by other drivers,
Roundabouts	Large roundabouts, poor lane discipline by drivers, other traffic not expecting cyclists
Signal controlled junctions	Lack of awareness by other drivers
Give way junctions	"Blind" sight lines, lack of appreciation by drivers of cyclists' speed
Other	Locations with many pedestrians

None of the responses is particularly surprising. There were some, perhaps unsurprising, comments about poorly designed cycle facilities. Generally, the issues centre on the physical impact of motor traffic, in particular how its effects may be made worse by inattention to cyclists on the part of drivers. Both weather and road surface condition feature quite strongly as other major risk factors. Disappointingly, nothing emerged voluntarily to differentiate between different junction types.

More specific questions were asked about particular cycle features and the responses are summarised in Table 7.2 below.

Table 7.2 Views on cycle facilities

Area	View
Advanced Stop Lines	Don't know what to do with them, ignored by drivers, not very useful for cyclists, good in that they give a notional protected space
Cycle lanes	End where you need them most, good idea to guide drivers as to how much space they should take, good to provide a degree of segregation, cycle lanes end up being in the drainage channels, filled with parked cars, they need improving, good they give notional protected space
Roundabout facilities	Good they take you off the roundabout, but never use them, don't think much of getting off and pushing

Advantages and disadvantages were equally forthcoming for each type of cycle facility. The responses indicate a large degree of inadequacy in the implementation of features as experienced by the respondents.

This brief qualitative review indicates the main risks as being from road surface, weather, badly designed facilities and other traffic. The depth of questioning was insufficient to differentiate levels of risk between different junctions types and route types. It is confirmed that traffic, road surface condition, road layout and weather are contributory factors to perception of risk.

7.3 The survey

What is risk?

"Risk" is frequently disaggregated into two components, one component concerned with the chance of an event happening and the other component concerned with the potential severity of effect if the event occurs. Ratings for these two separate aspects could be collected separately and subsequently aggregated in some manner, perhaps analogous to that in Noland (1995), to create an overall Risk Rating (RR). Asking respondents to provide an overall single Risk Rating would subsume within that rating the perceptions that the respondents possess about the separate effects of perception of danger and casualty severity. As the research is not, per se, concerned with dis-aggregation of perceptions of these two, but with an overall Risk Rating, it is not necessary to investigate them separately.

In contrast to the above, it is reported (see for example, Henson et al. 1997) that there are separate effects of risk borne of danger from traffic and risk to a cyclist from other sources, such as other actual or perceived potential criminal activity on the street. Respondents will be asked therefore to assess "Risk from Traffic" and separately assess "Threats from sources other than traffic". A Personal Security Rating (PSR) may be created to describe this second effect and evaluations of this are also sought in the survey.

Using respondents cycling a route versus virtual techniques

Quantitative studies of factors that influence the "level of service" of riding a bicycle have been undertaken in the USA by Landis et al. (1997) and Guthrie et al. (2001) undertook surveys of "cyclability" in the UK. Both studies measured responses from cyclists circumnavigating a pre-determined circuit. The nature of these studies ensured that the cyclist fully experienced the environment and every movement of the bicycle. In both surveys, ratings were requested from respondents that were analysed in relation to quantitative measures of the road environment such as speed and volume of traffic and road width.

Exposing cyclists to real life road conditions is time consuming and limits the sample size for a given budget. A circuit short enough to be of reasonable length may not exhibit a wide range of conditions and many separate circuits may need to be used. Exposing inexperienced cyclists to relatively risky environments is adjudged infeasible and, potentially, unethical. If riskier environments were avoided, the full value of a "negative weighting" from inexperienced cyclists may not be recorded.

High quality digital video images taken by a cyclist were used in the research reported here. They were obtained by strapping a Sony PC-1E digital video camera with a wide-angle lens to the chest of the surveyor-cyclist, as shown in Figure 7.1.

Figure 7.1 The surveyor-cyclist and the Sony PC1-E

Video recording from a moving car is not uncommon and is used by the police and transport professionals for data collection. A similar use of digital video image has been a trial undertaken on behalf of the Driving Standards Agency (DSA, 2001) to test the effectiveness of using video, collected from a moving car, as presentation material in the driving test to check candidates' ability at hazard perception. So far as is known, use of video taken from a bicycle for presentation material to respondents has not been used in the UK, although Harkey et al. (1998) have used a similar technique in the USA and Guthrie et al. (2001) used a camera mounted on a bicycle to measure distance from traffic. A significant advantage of video is that there is no variation in the conditions that respondents see, that is, the traffic seen passing does not vary as it would in a real-life road test.

Consideration was given to videoing conditions on a route or at a junction from a static position. A static position would be easy to establish if a good view of the route or junction were available. The difficulty would have been to view a reasonably long length of a route and inevitably there would be some distance between the camera (and hence the viewer of the video tape) and the conditions on the road. This distance would reduce the impact of the conditions on the respondent and of their perception of what it feels like to be in the conditions portrayed.

The alternative was to video conditions from a position on the road. This immediately implies movement with traffic and presents a number of advantages as follows:

- The respondent senses he or she is moving with the traffic.
- The respondent will feel and think about his or her position on the road from the point of view of the cyclist rather than from the point of view of an observer or perhaps a motorist.

- The respondent will feel himself or herself to be closer to traffic and other hazards and will think and respond accordingly.
- The respondent will look ahead and consider the developing road situation as though he or she was the person on the bicycle.

The advantages of re-creating some of the feeling of actually cycling on the part of the respondent by taking video images from a moving bicycle is overall more realistic than taking the stance of an observer.

Approximately 2 hours of video, recorded in a range of different circumstances in Leeds, York and Bolton, was edited to 57 video clips (see Appendix E). The locations were selected based on knowledge of routes and junctions to maximise the range of circumstances recorded. A subset of 20 video clips, as shown in Table 7.3 below, was selected to represent a comprehensive range of junction types and routes both with and without specific facilities for cyclists[1].

Table 7.3 Summary of video clips used in the survey

Town Note 1	Clip code	Clip No.	Route Description	Type Note 2	Turn Note 3	Cycle Facilities	Other Pedal Cyclists	Pedestrians	Parked Vehicles on left	Roads joining	Two way flow veh/hr
B	J1	19	Deane Rd / College Way	TS	SO	Y	0	15	0	2	480
B	J2	6	Park St/Spa Rd/Mayor St	TS	SO	N	0	0	0	2	592
B	J3	20	Deane Rd / Trinity St	TS	RT	Y	0	4	0	1	910
B	J4	8	College Way/St Helens Road	TS	RT	N	0	1	0	2	360
Y	J5	51	Monkgate / Heworth Roundabout	Rbt	SO	Y	0	0	0	2	90
B	J6	36	Chorley Old Road / Ring Road 1	Rbt	SO	N	0	4	3	2	90
Y	J7	50	Monkgate / Heworth Roundabout	Rbt	RT	Y	0	2	0	4	225
B	J8	37	Chorley Old Road / Ring Road 2	Rbt	RT	N	0	0	4	2	56
B	J9	32	Brownlow Fold Way	Rbt	SO	N	0	0	0	3	480
B	J10	31	Blackburn Rd / Brownlow Fold Way	P	RT	N	1	4	0	5	752
B	R1	39	Harrow Road Victorian grid pattern	R		N	0	8	42	7	0
B	R2	38	Oakwood Drive	R		N	0	4	0	1	0
B	R3	35	Avenue St	R		Y	0	4	2	10	45
Y	R4	54	Huntington Road	R		Y	0	5	0	1	480
L	R5	56	Hyde Park	R		Y	0	2	0	0	0
Y	R6	47	Minster Yard – Deangate	R		Y	0	62	3	2	0
Y	R7	49	Bootham inbound	R		Y	0	21	0	2	780
B	R8	28	Blackburn Rd outbound	R		N	0	2	0	10	1500
B	R9	10	St Helens Rd outbound 2	R		N	2	9	8	5	2640
B	R10	18	Deane Rd inbound 2	R		Y	0	20	18	11	2040

Notes
1 *In the town column, B=Bolton, Y=York and L=Leeds.*
2 *TS = Traffic Signals, Rbt = Roundabout, P = Priority junction, R = Route.*
3 *SO = straight on, RT = Right turn.*

[1] Clips are available from the author on request.

The clips represent a range of junction types both with and without specific facilities for cyclists and a range of routes with varying levels of traffic.

The survey instrument

Video clips were transferred from the digital video camera to a laptop computer and stored as files readable by Windows Media Player™. An Access™ database was constructed both as a location to store survey responses and, through a linked suite of forms, to guide the surveyor through the process of displaying the video clips to the respondent.

The principal questions asked of the respondents were as follows:

- How do you rate risk to you from traffic?
- How do you rate threats to you from sources other than traffic?

The rating scale used in the final version of the survey ranged from "1" – "10". "1" was described as being either "not at risk" or "not threatened" depending on the question being posed. "10" was described as being either "at great risk" or "very threatened", depending on the question being posed.

7.3.1 The pilot surveys

The pre-pilot – structured groups of four clips

Initially, for what became known as the pre-pilot, it was thought appropriate to group video clips into batches of four comprising 30 seconds of video each. Two selected Route Clips would represent 50% each of the route of a commuting journey of 15 minutes and two selected Junction Clips would represent two turns that need to be made on that journey. The overall route was then to be rated by the respondent. A structured combination of Route Clips and Junction Clips would be created and presented to respondents. The structure of the combinations of clips would be analogous to the structure of an orthogonal stated preference design so that all combinations of clips would feature in the survey. The significant advantage of such a structured combination of clips would be that the analysis would be able to deduce relative weightings for different circumstances within a route from the survey responses.

Use of this survey structure with a handful of respondents, drawn from volunteers at Bolton Institute from an email request, quickly showed that after the first set of four clips (two Route and two Junction) had been seen, it became difficult for respondents to hold sets of four clips in their mind long enough to make a judgement about the overall route. (For example, after the fourth clip of a second set of four clips had been seen, it was difficult to remember what the first clip in the second set had been and to not confuse it with a clip that had been seen in the previous set.)

This methodology was therefore abandoned.

The pilot - ratings of individual clips

As an alternative to respondents rating an overall route based on four clips, a structure was devised in which each respondent separately rated the 30-second clips of routes and junctions. So as to ensure that respondents viewed the clips in different orders so that there was not a bias in the responses created by the order of viewing, a careful structure to the ordering was adopted. A "base order" of the clips, with reference to Table 7.3 above, was created as follows: R2, J1, R7, J3, R5, J6, R6, J8, R1, J2, R4, J4, R3, J9, R8, J10, R10, J5, R9, J7. The clips alternate between routes and junctions, the selection of the particular clips is otherwise random. Respondent number 1 was shown the clips in "base order". Respondent number 2 was then shown the second clip in the base order (J1) first, but the order for the remaining clips was reversed. Respondent number 3 was shown the third clip in the base order (R7) first and the remainder in "forward order" and so on and so forth as indicated below:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	1	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3
3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	1	2
4	3	2	1	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5

Etc.

The principle underlying this method is to ensure that the same clips do not repeatedly appear near the beginning. Ratings may vary depending on length of route because of the time spent on that route and respondents were presented with the routes as though they comprised either a 15, 20 and 25 minutes journey. The first respondent was told the journey was of 15 minutes duration, the second, 20 minutes and the third 25 minutes, the fourth 15 minutes and so on and so forth. These times were associated with the clips in order that, for example, a deduction could be made that 20 minutes in a condition is worse than 15 minutes in a condition.

Of the 25 respondents in the pilot sample, 9 were female, five were from Bolton, 5 from Leeds and 15 from York. The Bolton respondents were drawn from volunteers from the earlier email request. The York and Leeds respondents were drawn from on-street sampling using a screening questionnaire where the trigger question was "would you consider riding a bike for your journey to work?". Hindsight suggests that the question potentially eliminated a range of respondents who may have been biased against cycling for the journey to work but who may otherwise have been able to provide useful data to the survey. 11 were in the age range 45-54 and all were in the age range 18-64. All respondents were employees bar three students and one self-employed person. 12 respondents` usual mode of travel to work was either as car driver or car passenger. Table 7.4 below indicates the type of person, in relation to their cycling habits, interviewed in the pilot sample.

Table 7.4 Pilot survey – cross tabulation of cyclist type against frequency

Cycle frequency	Type of cyclist					Total
	Cannot cycle	Do Not cycle	Leisure cyclist	Commuter / Utility	Mixture	
Never	1	8				9
Occasional / holiday times		2	3			5
1-3 times per month			1			1
1-2 times per week			3			3
2+ times per week			2	4	1	7
	1	10	9	4	1	25

There is an even balance between those who do not cycle and those who do. For those who do cycle, their pattern of cycling is likely either to be only "occasional holiday times" or "more than twice per week".

The first concern to be tested as part of the pilot survey analysis is the extent to which respondents understand the questions being asked of them. This may be judged partly on the basis of comments volunteered during the survey and partly on whether they are responding by using the full range of the rating scale available to them. No specific questions were asked as part of the pilot to judge the effectiveness of the survey and this is a shortcoming, albeit one that has not created subsequent problems. It should be noted that for the pilot survey the rating scale used ranged from 0-9, not the 1-10 scale adopted for the full survey. The minimum value recorded on the scale for both the "risk" and "threat" questions in the pilot was one. The Risk Rating of 10 was recorded 6 times as the maximum for any given clip. Nine appears 7 times, eight appears 5 times, seven appears 6 times, six appears 8 times and five appears 4 times. There is therefore a relatively even spread across the upper half of the rating scale of maximum ratings scores. Respondents are able to differentiate between the clips being shown to them. The ratings scales and the questions are understandable and are eliciting a range of responses that are consistent with each other. It was decided to change the scale for the full survey to a scale of 1-10 so that there would not be calculation problems with the lowest point on the scale being zero.

Table 7.5 below gives the average risk score for the clips as noted. It is perhaps surprising that R1, the residential road with on-street parking, is being given a high Risk Rating. This may be due to individual features displayed in the clip, which include a lady standing in the road by the side of the driver's door of a car and the noise of children playing and a barking dog. Each clip possesses its own set of complex characteristics because of the "real life" circumstances in which it was taken. These real life circumstances, and individual's responses to them, are discussed in the analysis section, but are encapsulated, insofar as they can be numerically, in the tabulation of Table 7.3. Apart from R10, the busy road with bus and cycle lane, there is little difference in Risk Ratings between the "busy road" clips (R7, R8 and R9). The clip that purports to contain parked cars (R9) only demonstrates the parking at the very end of the clip and so is very similar to the clip without parked cars (R8).

Right turns at junctions are perceived as riskier than straight on movements and generally cycle facilities bring the risk score a little lower. It is interesting to note the very small effect on risk scores of facilities at junctions. There seems to be little difference between scores for right turn movements between different junction types. The mini-roundabout was not perceived as being as risky as the normal sized roundabout.

Table 7.5 Mean and standard error of Risk Ratings and Personal Security Ratings from the pilot survey (Scale 0-9)

	ROAD / ROUTE LENGTHS	RR	PSR
	Quieter Roads		
R1	Residential street with parking	4.52 *0.55*	4.00 *0.51*
R2	Residential street without parking	1.52 *0.30*	1.28 *0.35*
R3	Traffic calmed road	3.24 *0.44*	2.00 *0.33*
	Traffic free routes		
R4	Cycle route on footway	2.20 *0.44*	1.96 *0.37*
R5	Route through park	0.28 *0.14*	1.48 *0.38*
R6	City centre cycle only route	3.28 *0.49*	1.72 *0.38*
	Busy Roads		
R7	Busy road with cycle lane	4.04 *0.57*	2.00 *0.41*
R8	Busy road without cycle lane	4.16 *0.53*	2.00 *0.39*
R9	Busy road without cycle lane & with parking	3.84 *0.52*	2.48 *0.44*
R10	Busy road with bus and cycle lane	1.20 *0.33*	2.84 *0.45*

	JUNCTIONS	RR	PSR
	Traffic Signals		
J1	Straight on with cycle lanes	4.00 *0.48*	1.12 *0.25*
J2	Straight on without cycle lanes	4.64 *0.54*	1.64 *0.36*
J3	Right turn with cycle lanes	5.52 *0.59*	2.00 *0.42*
J4	Right turn without cycle lanes	5.44 *0.57*	1.48 *0.27*
	Roundabouts		
J5	Straight on with cycle lanes	4.36 *0.55*	1.16 *0.27*
J6	Straight on without cycle lanes	4.64 *0.55*	1.40 *0.31*
J7	Right turn with cycle lanes	4.32 *0.55*	1.52 *0.33*
J8	Right turn without cycle lanes	5.12 *0.57*	1.28 *0.25*
J9	Straight on at mini-roundabout	3.44 *0.46*	1.68 *0.31*
	Other		
J10	Right turn off main road	5.36 *0.65*	1.68 *0.33*

Notes

1 The table shows the mean Risk Rating followed by standard deviation in italics

A priori, it was thought that some respondents may have been very averse to cycling across some of the junctions. All respondents were therefore asked whether or not they would have considered dismounting and pushing across each junction that they viewed. At three of the junctions, J1 (traffic signals straight on with cycle lanes), J2 (traffic signals straight on without cycle lanes) and J9 (straight on at a mini-roundabout), there were no respondents who indicated that they would have pushed. On reflection, this seems reasonable as none of these junctions was particularly threatening in any way. At five of the remaining seven junctions there is a difference between the means of the risk scores for those who would have considered pushing and those who would not have considered pushing at the 5% level of significance (student's t-test). There was no significant difference found for junctions J3 (traffic signals right turn with cycle lanes) and J8 (roundabout right turn without cycle lanes). It seems odd that two of the most dangerous manoeuvres, shown in clips J3 and J8, did not demonstrate significant differences in the risk scores between those that would have pushed and those that would not have pushed.

Risk from traffic and threats from other sources

Respondents may be unable to differentiate adequately between identifying risk from traffic and threats from other sources. A pair-wise (i.e. by each respondent) comparison has been undertaken on the ten non-junction clips and at the 5% level of significance there is a difference between the Risk Rating and Personal Security Rating apart from clips R2 (residential street without parking), R1 (residential street with parking) and R4 (cycle route on footway). The lack of difference for these clips could be by chance (exacerbated by small sample size) and, overall, respondents appear to understand and respond to the questions about "risk" and "threat" differently.

The pilot survey has shown that respondents are able to distinguish readily between video images and this indicates that meaning, as to the level of risk, is being conveyed by the videos. In addition the pilot demonstrates that it is necessary to identify those who may push across a junction and that "risk" and "threat" are being perceived differently.

Discussion of the pilot methodologies

Both the "pre-pilot" and the "pilot" have comprised methodologies that have allowed each of the twenty clips to be presented to each survey respondent. For maximum survey efficiency it would be ideal for this maximum exposure to be maintained. Each clip is approximately 30 seconds long and results in 10 minutes of viewing time. Adding to this 10 minutes for thinking and recording the ratings and 5 minutes for personal classification questions confirms an overall survey time of 25 minutes, which is reasonable.

There is a substantial difference "in kind" between the clips, that is, some clips depict movements through junctions while others depict sections of route. It is not self-evident that a Risk Rating stated for a thirty second clip of a movement through a junction, recognising the nature of junctions as "punctuation marks" in the "sentence length" of the road, will be co-scalar with a Risk Rating stated for a thirty second clip taken from a route, which could be from a few metres to many kilometres in length. Also there is the issue of the extent to which a Risk Rating for a route will vary depending on the length of time on the route.

Two approaches present themselves. The first approach is to construct routes (as in the "pre-pilot") and to allow statistical analysis to estimate the relationships between clips. The second approach is to show individual clips (as in the "pilot") and, by some means, deduce the relative weightings for junctions versus routes indirectly.

While the first method may create more nearly a "complete" route experience, it has been shown that the ability of respondents to recall accurately which clips form part of which route is limited. The individual clip approach is straightforward for a respondent but is unrealistic in the sense that individual clips will be shown outside a journey context. Relationships between clips, in order to build risk indices for areas, would need to be deduced from post-hoc analysis based on postulated relationships.

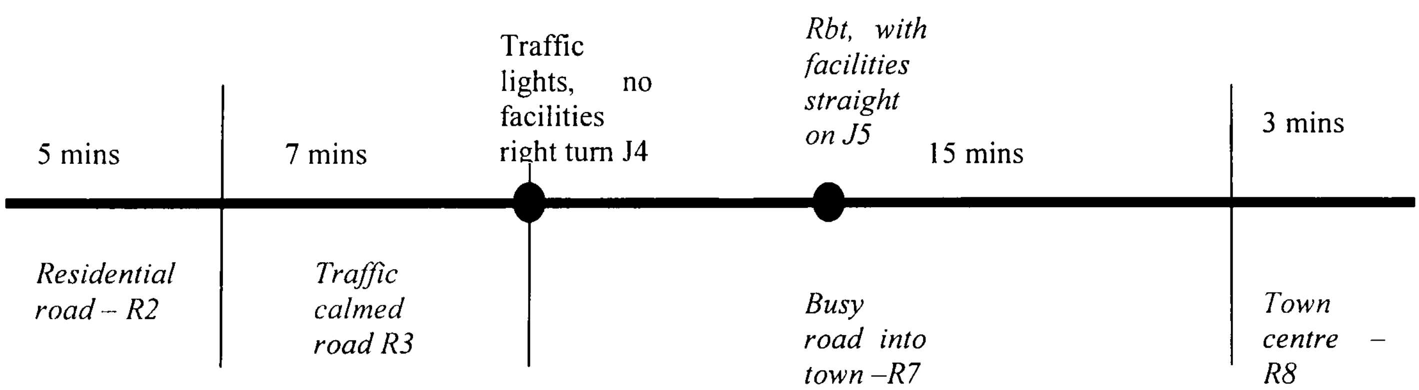
A new methodology

An alternative method of survey was conceived that would ask respondents to describe their journey to work as they would make it by bicycle and then for an equivalent representation of that route to be created from an appropriate combination of video clips selected from the bank of twenty. Variations could then be created from this "base" journey using other clips from the bank of twenty. The methodology has the advantage of being realistic in terms of journey length and type of route that may be experienced by a respondent and is similar to SP exercises that are customised to the respondent's circumstances. It is a methodology based on the construction of routes and possesses the advantages of that methodology. However, by replacement of junctions and routes one at a time, responses to individual clips may also be deduced. Such individual route or junction replacement also has the advantage that it should be manageable by respondents.

7.3.2 The final pilot and full survey

Methodology

Respondents were visited generally at their place of work or, if they preferred, in their home. They were asked, with the aid of a line on a piece of paper, to summarise their journey to work as they would make it by bicycle. This may have been to the nearest railway station if the journey would be too long to make solely on a bicycle. The respondents were asked to divide the line into time periods relating to the different routes types that they would encounter and mark main junctions with a large dot and describe them. An example was provided as shown below:



A reference table was provided comprising descriptions of the twenty clips similar to the descriptions in Table 7.5 above.

The surveyor then showed the respondent the video clips representing each component of the journey in turn. Crucially, the respondent was asked to think from then on about what he or she saw in the clips and to forget the actual journey that he or she had described. Respondents were asked:

- to rate risk from traffic for the whole journey;
- to rate threats from sources other than traffic for the whole journey;
- to describe issues they were thinking about when they rated threats from other sources;
- whether they would have considered dismounting and pushing at each junction encountered; and,
- to rate risk from traffic if each route length on the journey was twice as long.

Respondents were asked to describe what they were thinking about when they rated threats from sources other than traffic, as it is not clear beforehand what the issues would be. They may, for some respondents, relate predominantly to "personal security" issues; for others they may relate to the state of the infrastructure. Based on the experience of the pilot it is worthwhile maintaining the distinction that may be present in Risk Ratings between those who might and might not dismount to cross a junction and hence this question remained in the survey.

The final question about doubling the time on the route is an attempt to deduce the impact of a variation in the length of exposure on the risk rating.

The surveyor proceeded with:

- the addition of a junction to the original route described;
- the removal of one of the junction types from the original route described;
- the substitution of route types for each route type appearing in the original route.

As the survey progressed preliminary analysis showed that the data being obtained about junctions was less comprehensive than for routes. Consequently the methodology was extended to allow for the addition of two junctions (one at a time) and for the removal (in turn) of each of the junction types appearing in the original journey. Table 7.6 below is an example of a respondent's route together with the additions, removals and substitutions that were made and the Risk Rating (RR) and Personal Security Rating (PSR) responses made. Note that a Risk Rating for a journey that was twice as long was asked only of the original journey, and not for any of the subsequent journeys with additions, removals or substitutions or for the PSR.

Table 7.6 Example of completed base journey and variations (Respondent No. 88)

Total time =18	3	3		4		4		4			+/-	RR	PSR
1 Original	R1	R7	J1	R7	J1	R7	J3	R7	J1	J10		6 / 8	7
2a Add J											J9	6	
2b Add J											J8	9	
3a Remove J			J1		J1				J1			4	
3b Remove J							J3					5	
3c Remove J										J10		5	
4 Subs Ra	R9											7	
5 Subs Rb		R2		R2		R2		R2				5	
6 Subs Rc													
7 Subs Rd													

The first two lines in Table 7.6 shows that the route comprised 3 minutes in R1, followed by 3 minutes in R7 followed by junction type J1 followed by a further 4 minutes in R7 etc.. The Risk Rating is given in the column RR as “6”, the following “8” is the Risk Rating assuming that the length of time for the whole journey is doubled. The Personal Security Rating is given in the column PSR as “7”. The row commencing “2a Add J” shows that junction type J9 was then added to the route and the Risk Rating was then given as “6” for the whole journey including this addition. Junction removals follow junction additions. The final changes to be made were to routes and these took the form of substitutions so that the overall journey time was preserved. The first substitution made (in row “4 Subs Ra”) was R9 for R1 and the Risk Score, all other routes and junctions being as per the original route, is given by the respondent as “5”.

Each time an addition, removal or substitution was made, the surveyor asked for a revised Risk Rating from the respondent.

In a pilot form of this finally adopted survey methodology, respondents were also asked to estimate how much longer or shorter a journey would have to be to get back to the base journey Risk Rating. This would be a very direct method of relating time to Risk Ratings. However, none of the five respondents in the pilot could understand what was being asked of them and this question was discontinued for the remainder of the survey.

Personal questions relating to sex, income and frequency of use of the cycle were also asked, as summarised in Appendix F.

The surveys

Various options for creating a sample were considered including on-street recruitment for surveying in an adjacent building. The pilot surveys had shown the difficulty of such "cold recruitment", especially for inexperienced surveyors. An alternative method was sought and, being based on journey to work, large easily accessible employers were considered. After some negotiation, Bolton MBC agreed to place a request to take part in a journey to work travel survey in the pay packets of its 12,000 employees in November 2001. No mention of cycling was made as this would have likely created a biased response. 176 (1.5%) responded positively. A further 12 respondents were drawn from Bolton Institute volunteers remaining from the panel that volunteered at earlier stages in the piloting and 18 respondents drawn from an email request to staff at the Royal Bolton Hospital. A telephone multi-question screening survey was undertaken with the question "can you ride a bicycle?" used to determine inclusion or otherwise in the full survey.

Table 7.7 Summary of responses to the survey

Number	Description
6	Unable to be contacted to screen.[1]
33	Screened but cannot/would not cycle and not pursued to full survey
23	Screened but unable to be contacted for full survey administration
144	Screened and full survey administered
206	Total Sample size
200	Size of sample that was screened

Notes
1 Those not contacted were either always unavailable or have moved on by the time of the survey

Of the 200 in the sample that have been screened, 69.5% drive themselves to work, 10.5% use the bus, 5.5% use the bicycle and 7% walk. Motorcycling, being a passenger in a car and using the train were the remaining modes used. There is an over-representation of cyclists in the sample relative to the 2001 census (1.34%). This may be explained by a higher population than the average that work for Bolton MBC and cycle to work. Alternatively, those who cycle may be more attentive to transport issues and be more likely to volunteer for transport surveys. The sample is not overly biased by a large proportion of cyclists and a good proportion of cyclists allows for a better comparison between cyclists and non-cyclists responses. It is good to achieve the highest proportion of cyclists possible so that more reasonable comparisons may be made between cycling and non-cycling respondents.

16.5% of the 200 cannot cycle or said they could not or would not cycle to work. 15% of the sample said that they needed their car for work purposes.

23.5% said that they would prefer a means of travel to work other than the one that they actually use. Limits on being able to use another means of travel included, for example, inadequate public transport (in terms of distance to public transport nodes or availability of a service at the times required or the overall length of the journey), distance to work (limiting ability to walk or cycle), need to carry books or equipment and need to drop off or pick someone up or some other trip chaining activity. A similar percentage of 22.3% of current car users said they would prefer a means other than the one they currently use. This finding demonstrates that there is not a universal aspiration amongst the sample to become or remain car users for the journey to work.

The screening surveys took place in January and February of 2002, with additional screening in June and July. The main survey took place between April and July of 2002. The closing comment of the surveyor in the screening survey indicated that a follow up interview would be arranged. Follow up interviews generally took half an hour and were conducted at the place of work of the respondent. In some instances volunteers preferred the survey to take place at their home. The survey methodology and descriptive results from an interim sample size of 104 for the main survey was reported in a European Transport Conference Paper (Parkin et al., 2002).

7.4 The results

7.4.1 Sample characteristics

A sample of 144 for the main survey has been achieved with 52.1% of respondents being female. Table 7.8 below summarises other data about the respondents based on questions summarised in Appendix F.

Table 7.8 Sample age, income and car ownership profiles

Age		Income		Car ownership	
Band	%	Band (£1,000s)	%	Band	%
15 & under	0.0	Under 8	2.9	0	7.6
16-17	0.0	8-16	25.8	1	41.0
18-24	2.8	16-24	30.1	2	41.0
25-34	20.8	24-32	31.4	3+	10.4
35-44	36.1	32+	9.8		
45-54	29.2				
55-64	11.1				
65+	0.0				
Total	100.0		100.0		100.0

Notes

1 Income based on sample of 143 as one refused to state.

2 2001 census data for age in brackets.

The sample demonstrates a reasonable spread amongst age and income band[1]. The relatively low number indicating that their household does not have a car is a reflection of the fact that all respondents are in employment. 16 of the sample (10 female) do not hold a driving licence. 45.8% of the sample said that they usually drop off or pick someone up or that they stop off for another activity on their way to or from work. 35.4% said that their employer requires them to have their car available at their place of work. This high figure is not untypical for local authorities where casual and essential car user allowances are common and staff work in client based services such as, for example, social services and food standards.

[1] The age bands for the survey had been selected to be consistent with the 2001 census, however, it became apparent at the time of the analysis that for some inexplicable reason the bands are not consistent. For reference purposes it may be noted that 35.7% of the UK population is aged 29 and under, 22.0% is aged 30-44, 20.1% is aged 45-59 and 22.2% is aged 60 and over.

Respondents were asked to state which mode of travel they had used for the journey to and the journey from work on each day of a seven day week starting on the "week last Monday". The majority (81%) of respondents used the same mode to and from work for every day that they worked and the mode shares are indicated in Table 7.9 below. It should be noted that some respondents were interviewed during the week after a Bank Holiday had occurred and other respondents had either taken time off work or work only part-time. They are separately identified in the table.

Table 7.9 Mode shares for those that consistently use a single mode.

	Of those travelling five days		Of those travelling 4 days because of a Bank Holiday Monday		Of those travelling 4 or fewer days			
Mode	No.	%	No.	%	No.	%	Total	%
Train	3	4.8%	1	4.5%	2	6.5%	6	5.2%
Bus, minibus, coach	5	7.9%	1	4.5%	3	9.7%	9	7.8%
Motorcycle, scooter or moped	2	3.2%			1	3.2%	3	2.6%
Driver of car or van	43	68.3%	18	81.8%	24	77.4%	85	73.2%
Passenger in a car or a van	1	1.6%					1	0.8%
Bicycle	6	9.5%	2	9.1%	1	3.2%	9	7.8%
On foot	3	4.8%					3	2.6%
Total	63	100.0%	22	100.0%	31	100.0%	116	100.0%

It is striking therefore that, ignoring the effect of a Bank Holiday, 31 out of the 116 did not work every day of a five day week. Six respondents worked either on a Saturday or a Sunday or both. It is also interesting to note that 28 (19% of the sample) did not use the same mode on each day that they worked. Nine of the 28 used a different mode to get to work than the one they used to get home from work, the majority of these (five) generally alternated between being a passenger in a car and using the bus. Of the remaining 19 that varied their mode between days (rather than within a day), 17 alternated use of the car (as driver) with some other mode.

Table 7.10 below shows how respondents categorised themselves in relation to cycling and frequency of cycling.

Table 7.10 Respondent categorisation by cyclist "type" and frequency

Cyclist Type		Cycling frequency	
Description	%	Bands	%
Can cycle but do not	61.8	Never cycle	35.4
Leisure cyclist	16.7	Occasional holiday times / weekends	38.9
Commuter / utility cyclist	8.3	1 – 3 times per month	5.6
Cycle tourist	2.1	1 – 2 times per week	6.9
Sports cyclist	0.0	2+ times per week	13.2
Mixture of types	11.1		
Total	100.0		100.0

The largest proportion of people categorise themselves as being able to cycle but that they do not cycle (61.8%). There are none who cannot cycle, as these were eliminated at the screening stage. Of those who categorise themselves as being of a certain cycling type (i.e. excluding "can cycle but do not"), the majority (44%) indicate that they are leisure cyclists. The majority that undertake commuting or utility journeys also undertake other types of cycling and therefore indicate that they are a "mixture" of types. It is interesting that there is a significant proportion that has indicated that they "can cycle but do not" who then suggest that they cycle on an occasional basis. In other words they will admit to occasionally "pedalling" but do not categorise themselves as leisure "cyclists". It would appear that, where a respondent indicates that they do cycle, cycling is undertaken either very frequently (greater than once per week) or (in the majority of cases) only occasionally.

A question on ethnic origin indicated that only 3.5% of the sample was non-white. It was originally hoped that the sample would be more representative of the population of Bolton leading to the possibility of deductions about variation in use and perceptions based on ethnic grouping.

The state of health of respondents may influence their perceptions of risk and the following standard census question was used "over the last twelve months would you say your health as on the whole been a) good, b) fairly good, c) not good?". 80.6% stated that their health had on the whole been "good".

It was thought that whether or not a person has had a road accident, for the sake of argument in the last three years, could influence their perceptions of risk. 39 respondents (27%) had had a road accident and 32 of these were in a motor vehicle at the time of the accident. Only 7 were therefore potentially exposed as a vulnerable road user at the time of the accident.

7.4.2 Descriptive analysis of Risk Ratings

Respondents were asked to compose their journey from estimates of time in different circumstances for their journey-to-work time by bicycle. The mean overall journey-to-work time was 23 minutes and 5 seconds with a standard deviation of 15 minutes and 40 seconds. These statistics are based on the sample of 144 respondents. Based on the 873 individual journeys in the sample (that is an average of 6.06 journeys for each of the 144 respondents), the mean is 23 minutes and 35 seconds and the standard deviation is 15 minutes and 26 seconds. The frequency plot is shown in Figure 7.2 and graphically illustrates the positive skewness (1.618) and positive kurtosis (3.293) of the distribution of time.

Figure 7.2 Frequency plot of journey times based on 873 sample

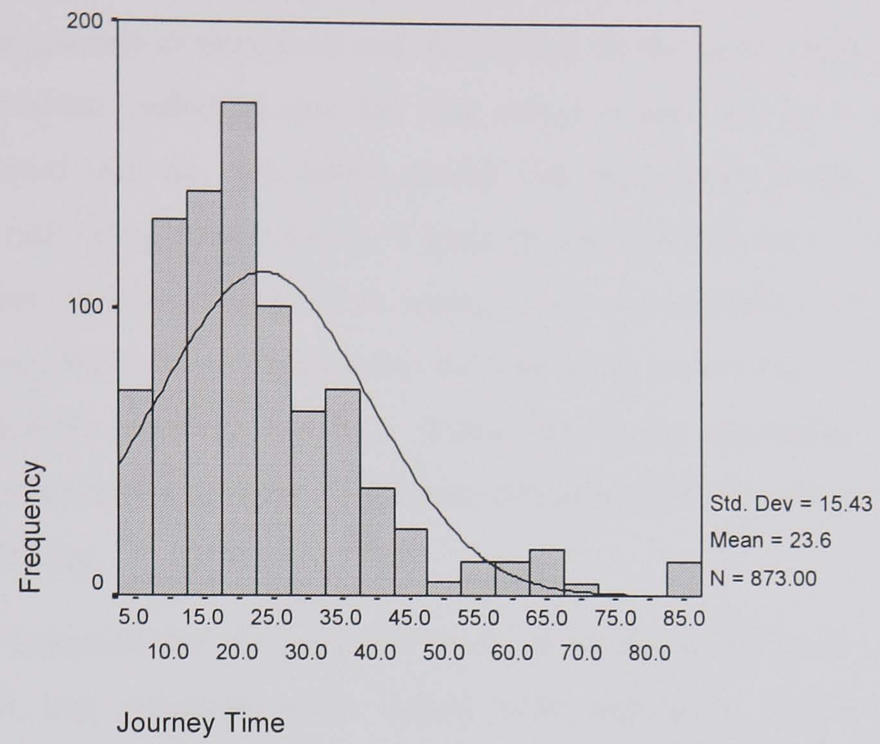
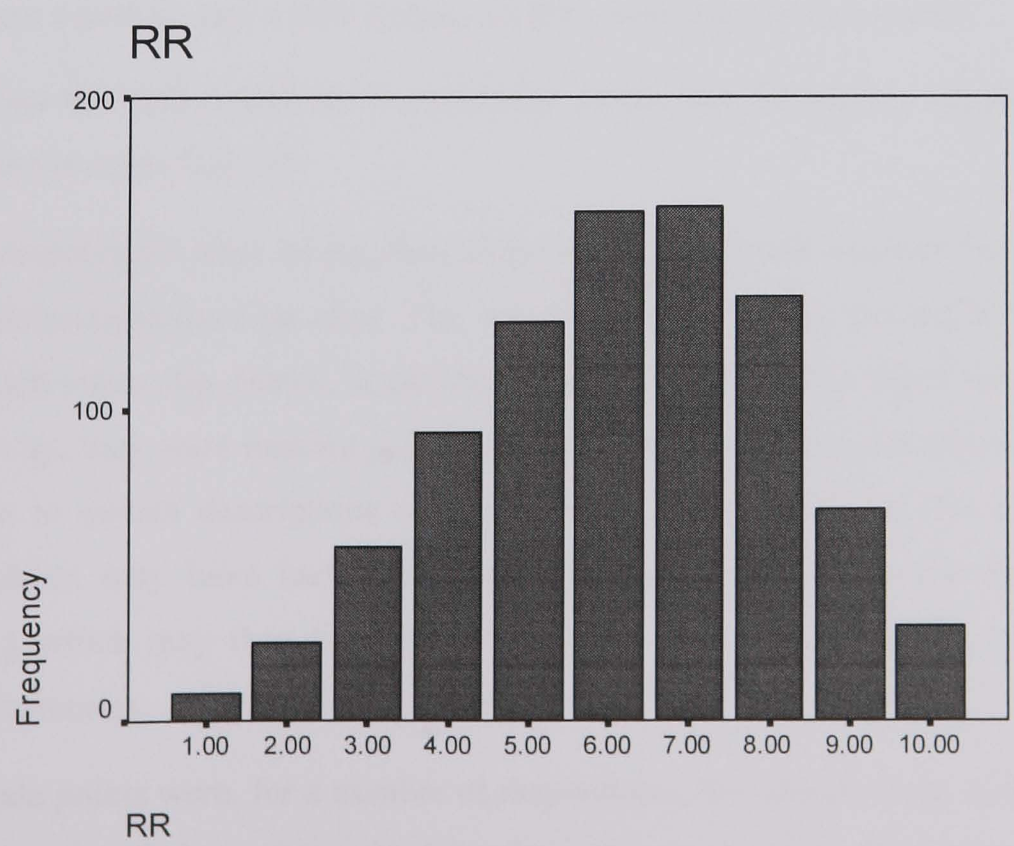


Figure 7.3 shows a frequency plot for Risk Rating for the 873 observations. The mean value of 6.15 is near the mid-point of 5.5 on the scale and the standard deviation is 1.98. Hence approximately 15% of the ratings are less than 3.5 and 15% of the ratings are greater than 7.5, indicating a good spread of usage of the scale. The distribution is negatively skewed (-0.249, standard error 0.083), hence demonstrating a longer tail to the lower end of the rating scale and also demonstrates negative kurtosis (-0.423, standard error 0.165) demonstrating a lesser degree of clustering around the mean than would be anticipated for a normal distribution.

Figure 7.3 Frequency plot of Risk Rating from 873 sample



Note: 1 is perceived lowest risk, 10 perceived highest risk

For the base journey, respondents were asked to provide a risk rating if "each route length on the journey was twice as long". 81 (56.3%) indicated that there would be no difference between a risk score for the journey as portrayed and the journey in the same conditions if it took twice as long. 32 respondents indicated that the risk rating would rise by 1 scale point and 24 respondents indicated that the risk rating would rise by 2 scale points and 3 respondents indicated that the risk rating would rise by 3 scale points. Reasons for a rise in risk most often cited included a person becoming tired or losing some concentration. Others were unable to elucidate the reasons for their perception that the risk score would rise. This could be taken to imply that a numerical response had been drawn out of the respondent that is of doubtful veracity and this could imply that the evaluations of the Risk Rating for double time will be of little value in modelling.

Four respondents indicated that they thought their risk score would be up to three scale points less. Reasons for the reduction were linked with increasing familiarity, and therefore confidence, in being able to deal with risk in the conditions being experienced or the subtle reduction in risk being caused by the particular balance of links and junctions that obtained in the base journey.

From these results it would appear that generally the effect of different times in a condition do not affect the Risk Rating significantly. However, for many who had rated their base journey quite highly, it was perhaps difficult to see how the Risk Rating for the double time journey, with an upper limit was 10, could be much higher than for the base journey.

Subsequent to a Risk Rating having been stated for the base journey, additions and removals of junctions and route length substitutions were made one at a time and, for each different journey, respondents were asked to state a Risk Rating for the whole journey once more.

A range of issues that will contribute to variability in the data set became apparent during the execution of the survey as follows:

- Many respondents were taking clues about how they should consider the clips from the worded descriptions of the clips. This was evidenced by them looking at the worded list after each video clip. Hence, in addition to making judgements based on what they saw in the clip, they were making judgements on how it had been described. Prejudices in relation to certain descriptions may be present in the responses (for example, some respondents may have had bad experiences in relation to poorly designed traffic calming which may then have influenced how they considered clip R3 that depicts traffic calming).
- The scale points were, for a number of respondents, too coarse. Some selected numbers such as, say 6.5, but were guided by the surveyor to revise their choice to a whole number point on the scale. Consider a respondent with a journey time of 20 minutes

with a particular route type obtaining for the first 2 minutes of that journey. If that route type was then changed, say to one with an "intrinsic" rating one scale point higher, then for the overall journey the respondent would be potentially trying to add 2/20ths of that difference to the base risk rating.

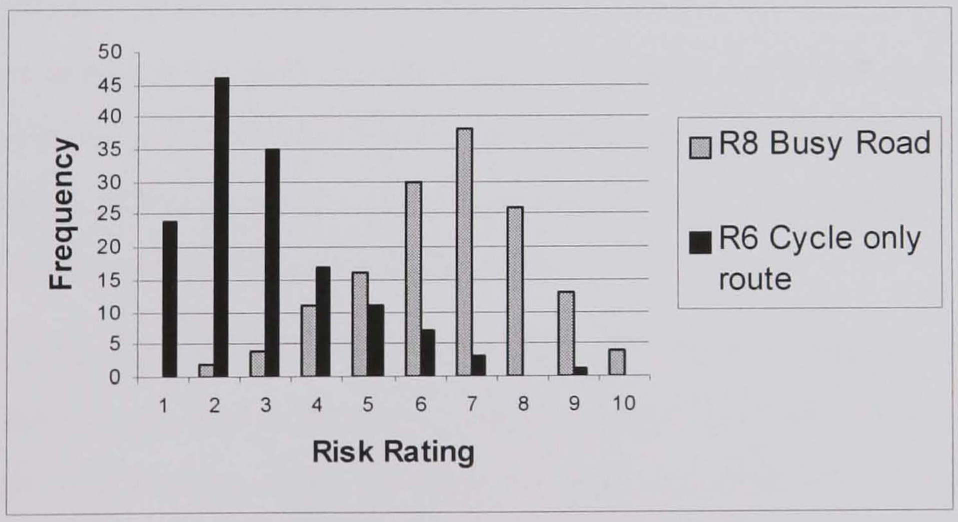
- Linked with the comment above, many respondents seemed to change their risk ratings to an unreasonably large degree after a removal, addition or substitution had been made. Potentially they were attempting to demonstrate some change had taken place, but they were perhaps not recognising fully that they were still being asked to rate the whole journey and not an individual clip involved in an addition, removal or substitution.
- Based on comments respondents were making, it was necessary, sometimes continuously, to remind them that they were rating the clips they were viewing and not the actual journey that they would make were they to cycle from home to work.
- Some respondents surmised that some of the roads could contain more traffic than was actually evident in the clips and suggested that, were they to cycle down that type of road at the time of day that they would be cycling to work, the volumes would be higher. This point is linked to the point above and again would create variation between respondents.
- One respondent asked whether they were rating based on what they actually saw happen in the clip or based on what could happen. This indicates that some respondents may use their general road experience to conjecture and this will lead to variability based on general experience.
- It was sensed that some respondents were simply being obtuse. Other respondents noticeably became tired or found the exercise rather difficult.
- It was sensed that there could be "affirmation bias" being displayed by some respondents. This was displayed as both "positive" and "negative" bias. For example, respondents' comments sometimes indicated that they thought they were being asked to assume that, for example, the provision of some cycling facility was less risky than the lack of provision of that facility. Hence they were assuming that the survey was trying to demonstrate that cycling facilities were safer and may have responded to reinforce this perception. Others thought the survey was an attempt to "rubbish" cycle facilities and responded accordingly.
- The descriptions of issues of many respondents in relation to the Personal Security Rating indicated many features that are related to the carriageway environment (e.g. pedestrians in the road and parked cars). The respondents valuation of Risk Rating may depend on how many of the Personal Security Rating issues they assume are part of the (traffic) Risk Rating. An example here is R6 (city centre cycle only route) where there

is no motor traffic but the Risk Rating given by respondents is often not "1", i.e. the lowest point on the scale. This is presumably because of the presence of pedestrians.

While the above is a comprehensive list of possible sources of error and may, at first reading, be taken as fairly condemnatory of the resulting data, it should be recognised that errors of the type described above are common in various degrees in all surveys of this type. There is no reason to suspect that the errors are of such significance or bias as to create an unusable data set. Each of the errors above will lead to a lower predictive power in any model that is created from the data than would be the case if the error were not present. Some errors may be random and cancel out, for example, the affirmation bias.

The results of the survey comprise a rating, which, for the full survey, is on the scale 1 to 10. The manner of interpretation of the scale of 1 – 10 by the respondents is important to understand and questions were asked in relation to this at the end of the rating exercise. Firstly respondents were asked to provide an individual Risk Rating for R8 (busy road without cycle lane) and R6 (city centre cycle only route) based on being in the condition for ten minutes. Figure 7.4 indicates the frequency of selection of individual points on the rating scale for these two routes. The mean Risk Rating for R8 is 6.60 (standard deviation 1.67) and the mean Risk Rating for R6 is 2.9 (standard deviation 1.56). If the analysis of routes fails for any reason, at least the results will provide a set of ratings for two route length types.

Figure 7.4 Risk Rating Frequency Plot for Busy road without cycle lane (R8) and city centre cycle only route (R6)



Note: 1 is perceived lowest risk, 10 perceived highest risk

Strictly speaking the Risk Rating scale provides ordinal variable data. That is, for example, an 8 on the scale can be assumed to be of higher order than a 7, but the size of the interval cannot be deduced. A scale with a large number of points is frequently assumed to have properties similar to interval variable data, that is variables where the differences between the points on the scale are of known magnitude. Bryman and Cramer (1999) quote Labovitz (1970) who argues that the assumption that a rating scale provides interval variable data has the significant advantage of releasing for use the powerful tool of regression analysis, not open if the data is assumed ordinal. The analyst is left with the problem of estimating the magnitude of the intervals on the rating scale. Initially one may assume that the magnitude of interval on the scale between 1 and 2 is the same as the interval between 2 and 3 and so on. This may appear reasonable, but it is not certain that respondents will be regarding the scale as linear in this way. To further understand how respondents were interpreting the rating scale the following questions were asked at the end of the risk rating part of the interview:

A) How have you been thinking about the scale of 1-10? Is the difference between the 1 and the 2 the same as the difference between the 9 and the 10?

B) Is there a numbered point on the scale above which you were thinking it would be too dangerous for you to cycle?

C) Has the presence of a particular feature in one of the routes strongly influenced your risk rating? For example has the presence of a bad junction kept your risk rating high?

Question (A) was asked to deduce whether respondents were considering the rating scale to be linear. 61.1% stated that they considered the difference between 1 and 2 on the rating scale to be the same as the difference between 9 and 10 on the rating scale and on this basis it is assumed that these respondents are regarding the scale as linear. Of the remaining respondents the majority considered the quantity of additional risk between 9 and 10 on the scale to be much larger than the quantity of additional risk between 1 and 2 on the scale, hence they were considering the value of the Risk Rating to be increasing in a non-linear manner. A few respondents thought that there were non-linear increases in interval size at both ends of the scale. A small number of respondents found it difficult to answer the question and suggested that an individual point on the scale in their minds suggested a particular set of circumstances and that there was no relationship between the points on the scale. The behaviour of these respondents suggests that they were treating the scale points as categorical variables and they were classified as being part of the remaining 38.9%.

There were a significant number of respondents that took a lot of thinking time before being able to confirm that they were considering the scale as linear. This could be taken to suggest that they were unsure, and perhaps ended up suggesting that the scale was linear merely because they could not conceive or explain how it could be something other than linear.

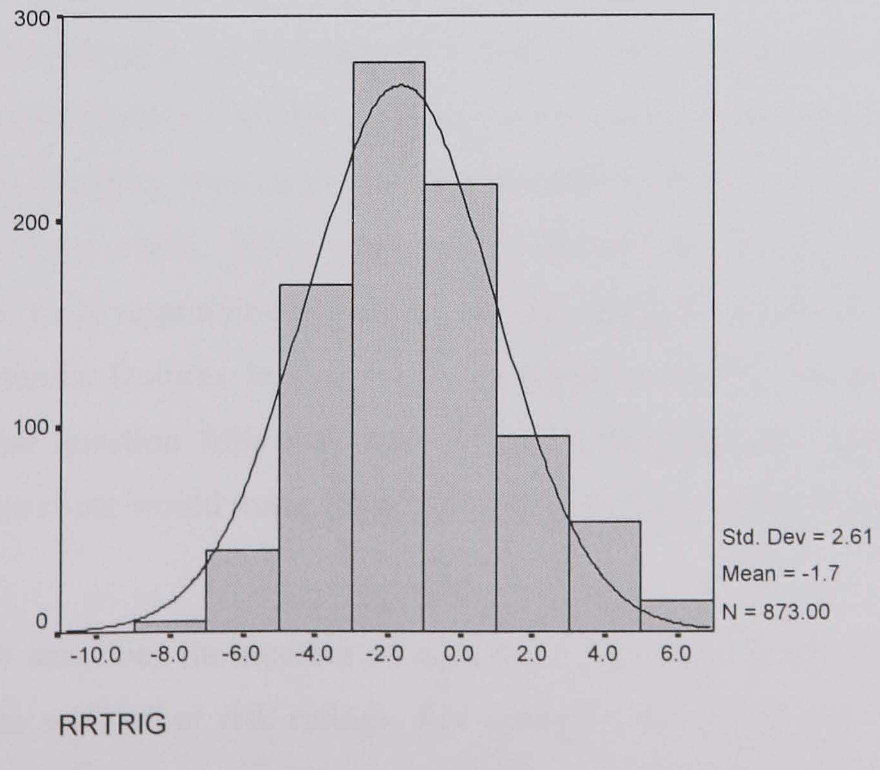
The distribution of the numbered point on the scale above which the respondents considered it would be too dangerous for them to cycle (question B) is considered as a "risk threshold level" and is presented in Figure 7.5 below. The mean value is 7.85 and the standard deviation is 1.81.

Figure 7.5 Distribution of Risk Rating risk threshold level

Note: 1 is perceived lowest risk, 10 perceived highest risk

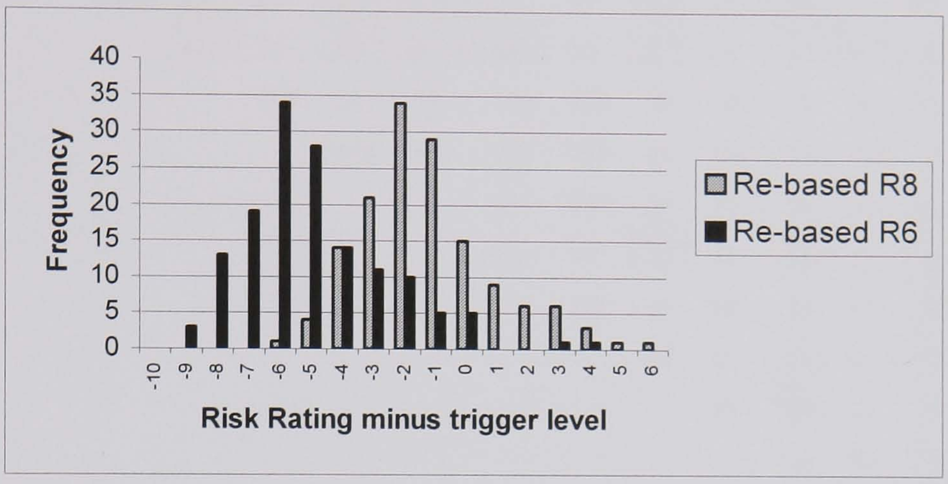
Figure 7.6 shows the Risk Rating corrected for the individual respondents risk threshold level (question B); that is, the frequency plot of Risk Rating minus risk threshold level. The mean value is –1.67 indicating that respondents generally rated conditions at a level below their threshold above which they had stated that they would not cycle. The standard deviation is 2.61 and the distribution is slightly positively skewed (0.373, standard error 0.083), but demonstrates no kurtosis (0.000, standard error 0.165). This variable conforms more closely to a standard normal distribution than the Risk Rating alone, plotted in Figure 7.3. It should be noted that 71.4% of the Risk Ratings for individual journeys have been rated by respondents at a Risk Rating lower than the respondents' individual risk threshold level and this implies that for the majority of journeys risk is not perceived to be at a level above which it would be too risky for a respondent to cycle.

Figure 7.6 Frequency plot of Risk Rating minus risk threshold level from 873 sample



Risk Ratings may be re-based to account for an individual's risk threshold level and this has been done as shown in Figure 7.7 for R8 and R6, where the variable is "Risk Rating minus risk threshold Level".

Figure 7.7 Re-based Risk Rating Frequency Plot for Busy road without cycle lane (R8) and city centre cycle only route (R6)



The mean Re-based Risk Rating for R8 (busy road without cycle lane) is –1.25 with a standard deviation of 2.19. This indicates that R8 is an average 1.25 scale units less than the risk threshold level. R6 (city centre cycle only route) is an average 4.97 scale units less than the risk threshold level. The spread of the Re-based Risk Rating data for R8 is greater than the Risk Rating data for R8. The greater spread is replicated for R6 as well (standard deviation 2.32).

It was considered that a number of respondents may not smoothly vary their ratings as the mix of conditions was varied, but that they may remain fixed, for example, at a high risk rating because of the presence of a particularly difficult junction or route length. There would hence potentially be a step-wise movement in Risk Ratings as different conditions are added in and removed from a journey sequence. The presence of this type of response was to be detected by the third question (C), above. 84.7% of respondents suggested that their risk rating was kept high because of the presence, for example, of a "bad" junction. It appears, however, based on a contemporaneous consideration by the surveyor of the responses given on the rating scale that the majority of respondents were freely moving up and down the scale as additions, removals and substitutions were made. There were only a handful of respondents that the surveyor detected that were truly responding in with significant changes in Risk Rating for the presence or absence of particular features, but too few to be treated separately. Respondents probably did not understand the question fully and were merely stating that the presence of higher risk attributes along the route would make for a higher Risk Rating. Clearly this is a statement of the obvious.

Table 7.11 below describes the number of occasions ("journeys") that a particular risk rating appears in a route with other risk ratings. For example, the fourth cell from the left on the second line indicates that route type R2 appears with route type R5 37 times.

Table 7.11 Frequency of direct comparison between variables in a rated route

	R2	R3	R4	R5	R6	R7	R8	R9	R10	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	Total
R1	64	61	71	59	18	159	329	142	72	161	232	49	167	51	80	20	71	31	110	489
R2		40	26	37	10	74	148	42	27	58	95	25	63	6	45	12	22	15	55	219
R3			10	12	7	37	93	38	26	32	82	10	44	7	36	4	24	13	18	144
R4				21	2	28	70	29	13	32	57	7	39	9	25	2	11	6	20	112
R5					5	25	64	14	12	34	39	11	34	11	17	3	9	8	31	113
R6						12	25	10	3	15	23	5	16	3	9	0	3	5	8	45
R7							209	66	28	162	159	49	102	33	56	9	43	25	59	323
R8								148	86	207	315	63	195	51	141	22	75	56	120	613
R9									33	67	137	25	79	25	52	8	31	24	56	238
R10										63	74	13	22	11	29	2	15	4	17	127
J1											132	25	94	25	52	10	36	14	37	289
J2												44	151	17	86	15	35	25	65	432
J3													25	11	24	2	4	12	32	90
J4														22	59	11	30	25	44	283
J5															9	2	6	5	14	68
J6																7	38	20	19	184
J7																	5	3	8	31
J8																		14	18	108
J9																			14	72
J10																				174
																			Total number of "journeys"	873

Notes

1 *To help quickly interpret this table, grey shading indicates presence in the same "journey" on fewer than 20 occasions.*

2 *The "Total" column represents total number of appearances of the relevant route or junction type in all journeys and is not the sum of the individual cells preceding.*

3 *The overall total of 873 is the total number of "journeys" and not the overall sum of the individual route or junction type appearances.*

R6 and J7 have the fewest number of appearances in observations. This is because they occurred with least frequency in the base route as defined by respondents and were not introduced in subsequent variations on the base route as much as they ought to have been.

The nature of the survey methodology dictates that there will be no pre-prescribed uniformity in the matrix above. This is because respondents were asked for their actual home to work journey, which creates a bias towards frequent occurrences of certain types of route, such as R8 (busy road without cycle lanes). It may be seen that there are a number of instances where there are fewer than 20 occasions when a specific pair of route and junction types appear together in a journey for which a Risk Rating observation is taken. There are, particularly for the popular route type R8, occasions when there are well in excess of 100 occasions when a specific pair of route and junction types appear together in a journey for which a Risk Rating observation is taken.

Figure 7.8 shows a plot of the frequency of occurrence of individual route ratings from the totals column in Table 7.11 above. It is shown that the majority of occurrences of a route type are for times of up to ten minutes. It is only with higher frequencies of occurrence that significant numbers of appearances of a route type for greater than 10 minutes is apparent.

Figure 7.8 Frequency of appearance of route types in 873 sample showing makeup of time in condition

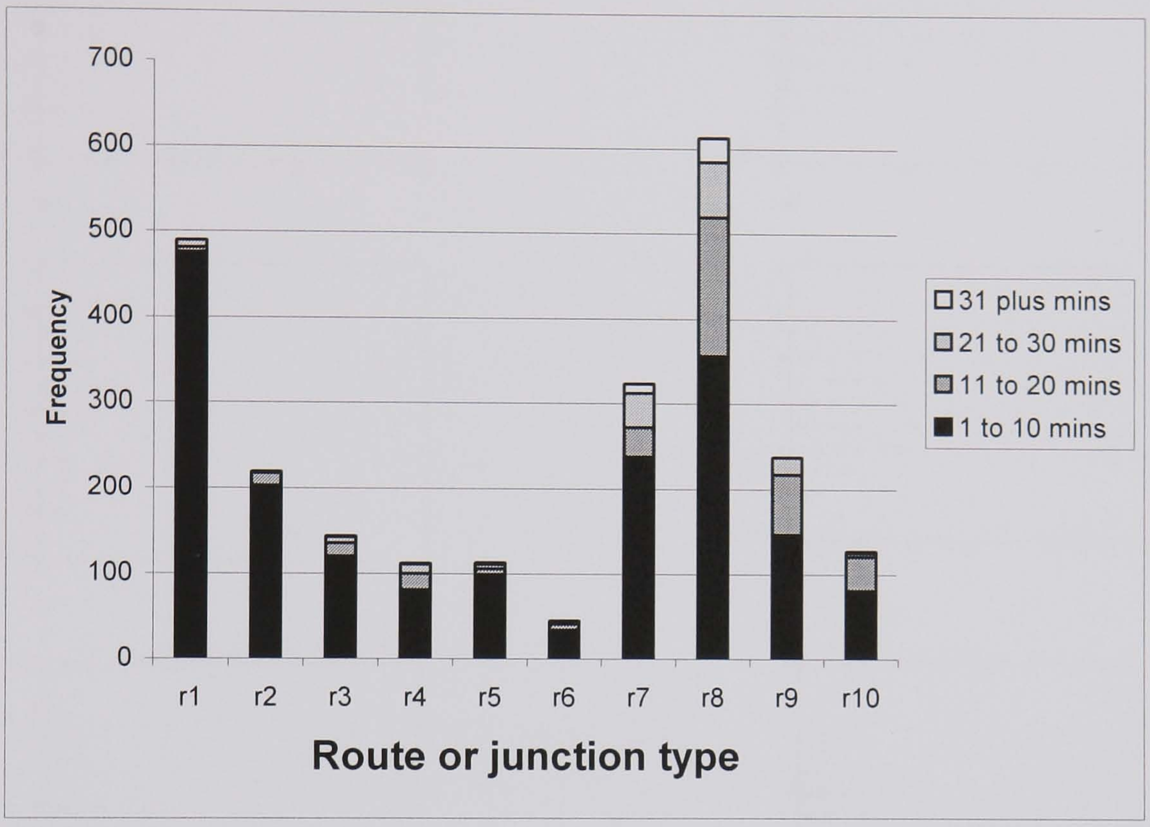


Figure 7.9 shows scatterplots of Risk Rating against the time in a condition for individual route types for a given observation. The scatter plots generally show fewer occurrences of Risk Ratings at the lower end of the Risk Rating scale and hence mimic the distribution of the Risk Rating in Figure 7.3. They also demonstrate the positive skewness of the distribution of time in Figure 7.2 by virtue of the fewer observations at higher periods of time. It is difficult to judge from the plots whether anything may be concluded about the effect of journey duration on rating and this will have to wait to the more detailed analysis presented in Chapter 8.

Figure 7.9 Scatter plots of time in individual route type (minutes) against overall journey Risk Rating

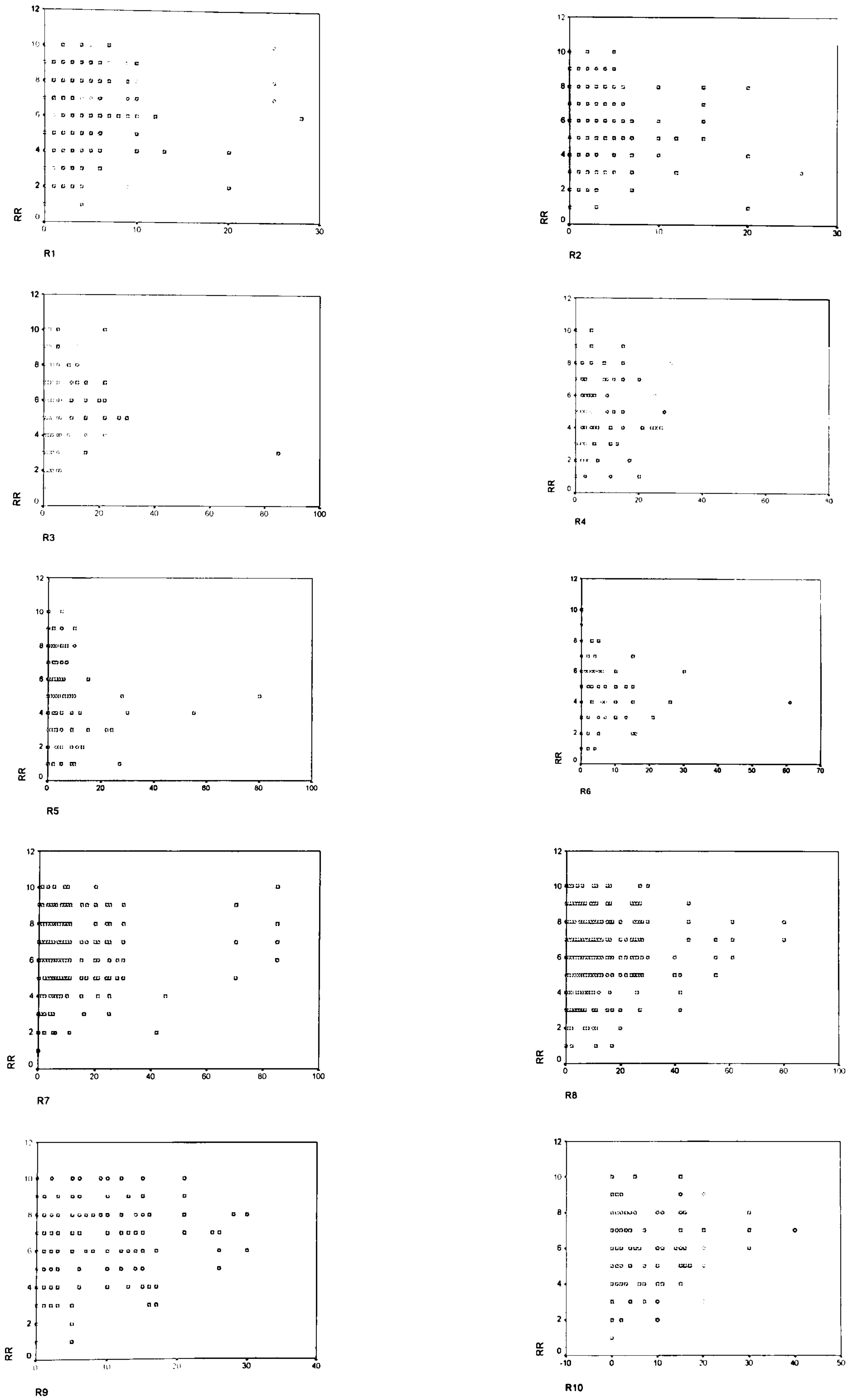


Table 7.12 below summarises the means and standard deviations of the times in the ten different route conditions by respondents.

Table 7.12 Means and standard deviations of times in different conditions

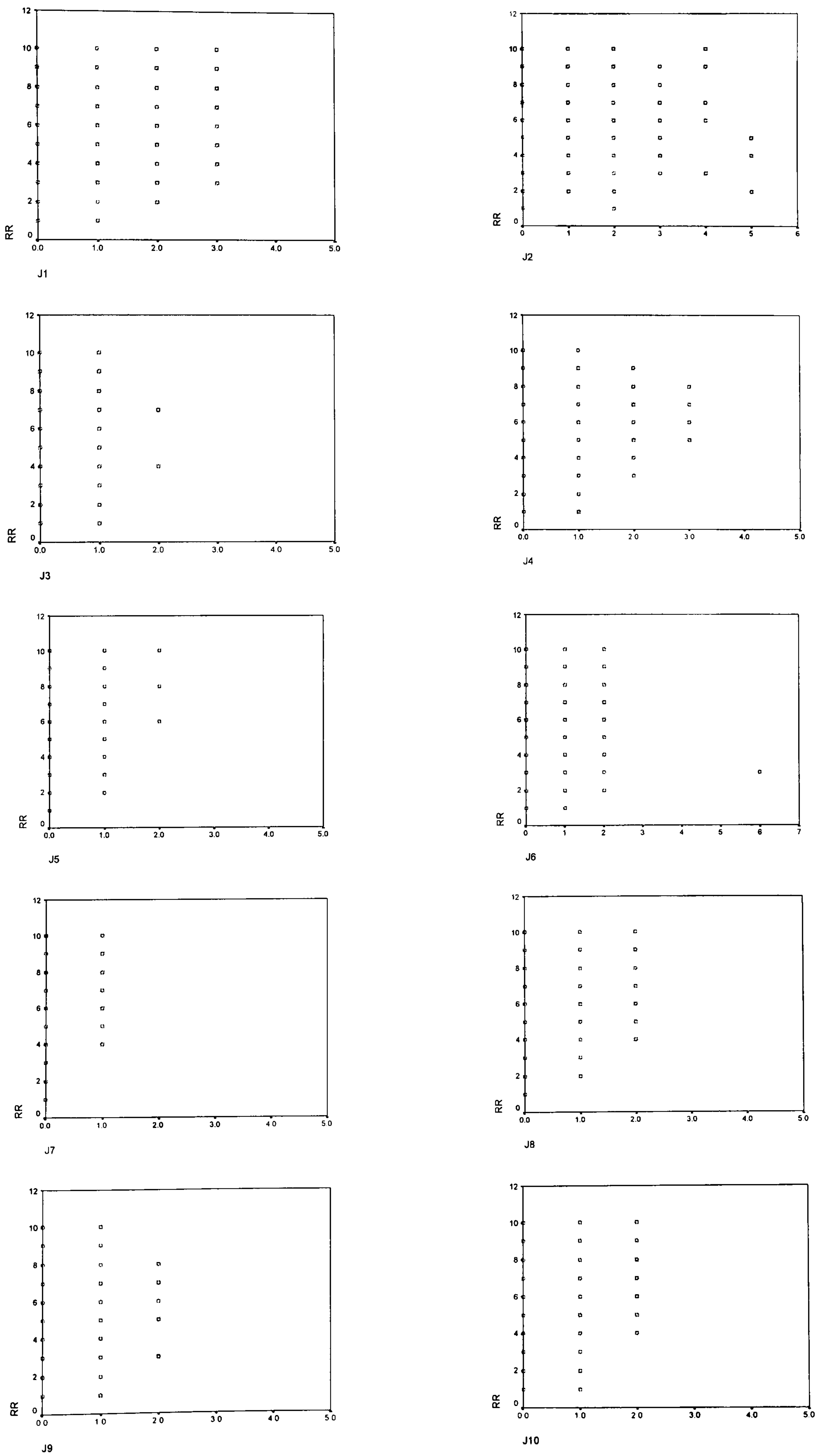
Route type		Mean time (decimal minutes)	Standard deviation (decimal minutes)	Maximum (minutes)	90^{th} %ile (minutes)
R1	residential street with parking	2.12	3.48	28	5
R2	residential street without parking	1.15	2.88	26	4
R3	traffic calmed road	1.01	4.22	85	2
R4	cycle route on footway	1.11	4.47	70	2
R5	route through park	0.93	4.32	80	2
R6	city centre cycle only route	0.45	3.02	61	0
R7	busy road with cycle lane	4.18	10.25	85	10
R8	busy road without cycle lane	8.62	11.61	80	24
R9	busy road without cycle lane and with parking	2.60	5.68	30	12
R10	busy road with bus lane and cycle lane	1.41	4.50	40	4

Notes
1 the 10%ile figure for every route is zero minutes.

The distributions of time are significantly skew and the maximum values vary in size quite considerably, from 26 minutes to 85 minutes. Times on busy routes (R7 and R8 and R9 are well represented in terms of time on the route.

Figure 7.10 shows scatterplots of Risk Rating against the number of times passing through individual junction types for a given observation. With the exception of Junction Type 7, all junctions appear in a number of observations more than once. Junction Type 6 is represented by a respondent six times, but otherwise generally appears only up to twice in any observation.

Figure 7.10 Scatter plots of number of junctions by type against Risk Rating



Chapter 8 Risk Rating regression analyses

8.1 Overview

This chapter contains a description of the regression analyses undertaken on the Risk Rating data. The collection methodology and descriptive statistics for the data used in the analysis are described in the preceding Chapter 7.

Preliminary analysis was undertaken using a variety of models including a linear model and various transformations as follows: logistic, logarithmic, exponential, square and square root. Some of these transformations are not intrinsically linear and can not be reduced by transformation to be linear. The statistical software package available to the author is SPSS (Norusis, 1990) and the analysis has been carried out using non-linear regression analysis routines.

A structured approach to the analysis has been adopted and carried out in five phases. Phase 1 of the structured analysis investigates the various "response shapes". This analysis is based on a dichotomous variable (1 or 0) for the presence or otherwise of particular route and junction types in a respondents' journey. Subsequently, in Phase 2, an investigation of the effect of time in different conditions is investigated. The presence of multiple occurrences of particular junction types on a route is also investigated.

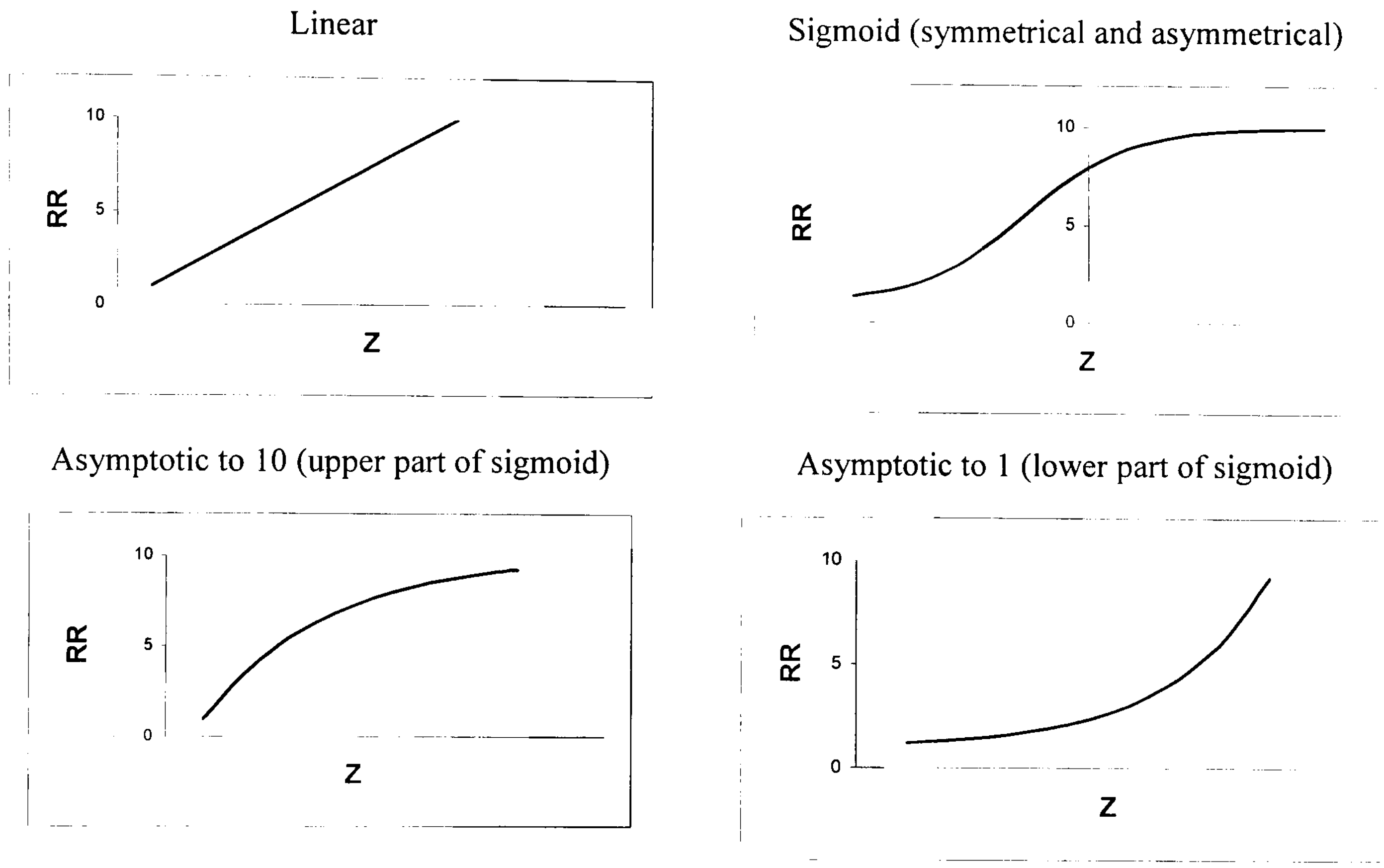
Phase 3 involves the rationalisation of the model to eliminate route and junction types that have parameters that do not perform well. In addition, respondents who have spurious characteristics are investigated and eliminated and the logistic model is alighted on to take forward for further analysis. Phase 4 involves the segmentation of the model by additive person type variables including cyclist type, sex and age. Phase 5 presents the results of the final model which includes person type variables in multiplicative form.

The work presented in this chapter represents a comprehensive analysis of the Risk Rating data and stands alone as an outcome of the Risk Rating survey using the primary data collected as part of the research. The use of the primary data for the main model investigating variation of cycle use across England and Wales is described in Chapter 9 and a different modelling paradigm is used for this behavioural modelling.

8.2 Phase 1– response shapes

Respondents were asked to use a rating scale from 1 to 10 to indicate perception of risk. The relationship between the numbered points on the rating scale and the quantum of risk being perceived may or may not be linear. The curve shapes that are feasible for the responses from the sample, and confirmed by preliminary analysis of the data and background reading (Hair et al. 1998), are summarised in Figure 8.1 below.

Figure 8.1 Rating scale response shapes



Notes:

1 *"Z" is a measure of perceived risk derived from a function representative of the routes and junctions comprising the journey shown to respondents. RR is the respondents Risk Rating for that level of perceived risk.*

Most respondents (61%) stated that the difference between 1 and 2 on the rating scale to be the same as the difference between 9 and 10 on the rating scale and implying a linear change in the Risk Rating relative to the perceived risk. The majority of the remaining 39% of respondents considered the additional risk between 9 and 10 on the scale to be greater than the additional risk between 1 and 2 on the scale. This indicates a shape asymptotic to 10. A handful of respondents thought that there were non-linear increases in Risk Rating interval size at both ends of the Risk Rating scale, indicating a sigmoid shape. The shape asymptotic to 1 is shown in Figure 8.1 for completeness and indicates the potential for responses asymptotic only to 1. Other shapes are feasible, for example the inverse of the sigmoid, with the asymptote being a value of Z, but these are not supported logically by the respondents judgements on the use of the scale.

The scale was limited to responses from 1 to 10 and hence the shape of a response curve would usefully be asymptotic to 1 and 10 to create lower and upper bounds for the model. This feature has the disadvantage, however, of creating non-linearity in the scale where none may be present.

A number of models have been tested based on the curve shapes of Figure 8.1 and their functional forms are summarised in Table 8.1[1].

Table 8.1 Rating scale response shape functional forms

Model Name	Functional Form Modelled	General Form
Linear	$RR = \alpha + Z_{ij}$	
Asymptotic to 10	$RR = 10 - \alpha e^{-Z_{ij}}$	
Logistic	$RR = 1 + \frac{9}{(1 + \alpha e^{-Z_{ij}})}$	$RR = \frac{1}{(1 + \alpha e^{-Z_{ij}})}$
Gompertz	$RR = 1 + 9\exp(\alpha \exp(-Z_{ij}))$	$RR = \alpha_1 \exp(\alpha_2 \exp(-Z_{ij}))$
Asymptotic to 1	$RR = 1 + \alpha e^{Z_{ij}}$	

RR represents the Risk Rating and α is a constant. The function for Z_{ij} is defined as:

$$Z_{ij} = \sum_{i}^{R,J} \sum_{j=1}^{10} B_{ij} D_{ij} \qquad \text{Equation 8.1}$$

Where:
i=R or J for route or junction, j = 1 to 10 for Routes 1-10 and Junctions 1-10.
B_{ij} = coefficient to explanatory dichotomous variable D_{ij}.
D_{ij} = dichotomous variable for presence of clip type i (R for route and J for junction) numbered j (1 to 10 for both route and junction types).

As has been noted the majority (61%) of respondents stated that they consider the rating scale as being linear, that is to say a unit increase in the measure of perceived risk, Z_{ij}, would be accompanied by a fixed quantity of change in the Risk Rating at all points on the rating scale. This implies that the shape of the response curve does not have asymptotes to each extreme of the scale. Respondents of this type would comply with the linear model shown in Table 8.1.

The majority of the remaining respondents (39%), who consider the additional risk between 9 and 10 to be greater than the additional risk between 1 and 2, may be responding in line with the "Asymptotic to 10" model. The small number of respondents who suggested asymptotes at both ends of the scale may be represented by the sigmoid shape. Two sigmoid formulations have been tested, a logistic and a Gompertz function. The logistic function is symmetrical about its point of inflection but the point of inflection need not occur at the mid-point (5.5) of the scale. The basic form of the logistic model is shown in the right hand column of Table 8.1 and varies between the limits of zero and unity. Rescaling is necessary for the rating scale of 1 to 10 and this is achieved with the transformation shown in the middle column of Table 8.1.

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[1] A variety of power functions (Z_{ij}^{n}) were also estimated for models asymptotic to 10 and asymptotic to 1. None performed as well as the exponential functions and none were pursued.

The Gompertz function usefully allows for non-symmetry because of the different values that the factors of the exponential term may take (α_1 and α_2 in the general form of the model in the right hand column in Table 8.1). Again, the Gompertz function has been transformed to rescale to the 1 to 10 of the Rating Scale. As a final potential option, although not specifically one suggested by the respondents, is a model that is asymptotic to 1.

It may be seen from Table 8.1 that the upper and lower boundary conditions for asymptotic models have been specified as the end points of the rating scale (the constants 1, 9 and 10 appropriately used). Models were also estimated where the upper and lower asymptotic boundaries have been estimated in the process of non-linear regression analysis (that is, the constants 1, 9 and 10 were instead specified as variables to be estimated), but, using the R-squared as a measure, all of these models displayed lower powers of explanation than models where the boundaries were specified.

Non-linear regression analysis is a method of estimating models which are non-linear in the parameters. Often it is possible to reduce a non-linear model by transformations to make the relationship linear and then to proceed with ordinary least squares regression. Particularly with the transformations necessary to create the appropriate boundary conditions, it has not been possible to make transformations to create linear models and so non-linear regression analysis has been employed throughout. Model estimation is accomplished using iterative estimation algorithms, in particular in SPSS, the algorithm that has been used is the Levenberg-Marquardt algorithm. For each iteration, parameter estimates and residual sum of squares estimates are determined. Iterations ceased when the difference between successive residual sum of squares were less than 0.0001.

The choice of initial values for the parameters influences the rate of convergence (Norusis, 1990) and the resulting model may, if a local optimum is found, not be the best-fit model. In order to overcome this problem, the initial coefficient values (B_{ij}) were selected to create, for each individual route or junction clip, a Risk Rating that lies in the range 1 to 10 and hence initial values will be relatively close to the final values that will be estimated.

Summary statistics for a non-linear regression are summarised as:

Regression sum of squares: the sum of the squared predicted values across all observations (the number of degrees of freedom is equal to the number of parameters being estimated).

Residual Sum of Squares Total: the sum of squared differences between the model predicted value and the dependent variable across all observations (the number of degrees of freedom is the number of observations minus the number of parameters being estimated).

Uncorrected Sum of Squares Total: the sum of squared values of the dependent variable across all observations (the number of degrees of freedom is the number of observations).

Corrected Sum of Squares Total: the sum of squared differences between the overall mean and actual values of the dependent variables across all observations (the number of degrees of freedom is the number of observations minus one).

R-squared, the coefficient of determination for a non-linear model, is defined as $=1-\frac{ResidualSS}{CorrectedSS}$. R-squared is interpreted as the proportion of the total variation of the dependent variable about its mean that is explained by the fitted model. Unlike R-squared for linear regression, its value may be negative if the model fits worse than the mean and care needs to be taken in its interpretation (Kvalseth, 1985).

Table 8.2. below summarises results from the Phase 1 models. The variables dR1 to dR10 are the dichotomous variables for the presence of Routes R1 to R10 and the variables dJ1 to dJ10 are the dichotomous variables for the presence of Junctions J1 to J10.

Respondents scale the same risks differently and so there will be a large amount of residual variation, as is demonstrated by the generally low R-squared values. Low R-squared values are however not uncommon in analysis of this type (e.g. Jaensirisak, 2003).

Table 8.2 Phase 1 results

Variable	Linear model		Logistic model		Gompertz model		Asymptotic to 10 model		Asymptotic to 1 model	
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Constant	5.502	**23.606**	1.010	**9.172**	-0.702	**-12.369**	4.533	**17.643**	4.579	**21.610**
dR1	0.220	1.632	0.101	1.590	0.076	1.575	0.052	1.501	0.042	1.623
dR2	0.044	0.295	0.010	0.145	0.012	0.233	0.017	0.459	0.006	0.208
dR3	-0.480	**-2.863**	-0.228	**-2.922**	-0.166	**-2.868**	-0.108	**-2.698**	-0.101	**-2.967**
dR4	-1.099	**-6.004**	-0.507	**-5.984**	-0.370	**-6.166**	-0.250	**-6.409**	-0.231	**-5.501**
dR5	-1.052	**-5.613**	-0.490	**-5.650**	-0.340	**-5.602**	-0.220	**-5.544**	-0.253	**-5.604**
dR6	-1.560	**-5.641**	-0.736	**-5.608**	-0.510	**-5.845**	-0.307	**-5.778**	-0.378	**-4.995**
dR7	0.344	**2.435**	0.157	**2.337**	0.116	**2.279**	0.078	**2.111**	0.065	**2.456**
dR8	0.549	**3.971**	0.263	**4.067**	0.206	**4.314**	0.147	**4.446**	0.094	**3.377**
dR9	0.654	**4.620**	0.318	**4.655**	0.250	**4.704**	0.189	**4.721**	0.116	**4.518**
dR10	-0.234	-1.304	-0.103	-1.237	-0.065	-1.039	-0.036	-0.801	-0.058	-1.623
dJ1	-0.166	-1.199	-0.087	-1.324	-0.067	-1.362	-0.042	-1.199	-0.025	-0.931
dJ2	0.236	1.854	0.098	1.637	0.056	1.227	0.020	0.614	0.063	**2.605**
dJ3	0.337	1.657	0.154	1.579	0.105	1.393	0.070	1.242	0.076	**2.088**
dJ4	0.281	**2.155**	0.142	**2.289**	0.112	**2.374**	0.081	**2.380**	0.048	1.941
dJ5	0.115	0.495	0.049	0.444	0.034	0.396	0.020	0.329	0.029	0.692
dJ6	0.087	0.571	0.056	0.777	0.063	1.136	0.060	1.500	-0.005	-0.162
dJ7	1.351	**4.137**	0.784	**3.987**	0.641	**3.812**	0.511	**3.574**	0.203	**4.047**
dJ8	0.348	1.848	0.169	1.872	0.121	1.738	0.081	1.553	0.075	**2.170**
dJ9	-0.361	-1.620	-0.148	-1.395	-0.113	-1.412	-0.077	-1.403	-0.069	-1.576
dJ10	0.105	0.668	0.042	0.561	0.038	0.675	0.032	0.771	0.012	0.402
R^2	0.217		0.219		0.218		0.214		0.219	
$\bar{R}^2$	0.198		0.200		0.199		0.195		0.200	

Notes

1 Emboldened t-statistics are significant.

2 The constant term is the a term as defined in Table 8.1.

The adjusted R-squared is determined as $\bar{R}^2 = [R^2 - k/(n-1)][(n-1)/n-k-1)]$ and eliminates the problem of R-squared varying depending on the number of regressors. "*k*" represents the number of variables and "*n*" the number of observations. As the dependent variable is the same in each model, the R-squared values are comparable across the models. In the case of non-linear regression it is not possible to obtain exact confidence limits and asymptotic (large sample) approximations only are possible. A ratio of the parameter coefficient to the standard error of the coefficient has been determined, however, as though it were a t-statistic (labelled as such in the table above) and considered to be significant if its modulus is greater than 1.96.

The functional forms in Table 8.1 are constructed in such a way that a variable that contributes a "bad effect" (for example the presence of a busy road, R8) is positive and will serve to increase the Risk Rating. Other "bad effects" include the presence of other main roads (R7 and R9), but with the exception of R10 (which is the main road with a bus lane), and residential roads (R1 and R2). Routes with traffic calming (R3), on the footway (R4), through a park (R5) and on a cycle only route through a city centre (R6) all have the effect of reducing the risk rating. All junction types add to the Risk Rating with the exception of J1 (straight on at traffic signals with cycle facilities) and J9 (straight on at a mini-roundabout). With the possible exception of the additional risk rating caused by residential roads, none of the results are so out of line as to be considered for removal from the model at this stage.

Even though the Asymptotic to 1 model is not a model described by respondents as a possibility, it has three additional parameters that are significant compared with other models. The similarity in pattern of parameter estimates that are significant leaves the choice of model shape open at this stage in the analysis. The differences between the R-squared values for the different models are small and demonstrate that none of the modelled response shapes is very different from any other modelled response shape.

8.3 Phase 2 - inclusion of time and number of junctions

Phase 1 analysis considers only the presence of route and junction types as a determinant of Risk Rating. This second phase of analysis considers whether the time in a route condition and whether the number of times an observed journey encounters a junction is significant. The alternative formulation for Z_{ij} comprising both the dichotomous variable for the presence of a journey variable and the variable for the time or the number is shown below:

$$Z_{ij} = \sum_{i}^{R,J}\sum_{j=1}^{10} B_{ij}D_{ij} + \sum_{i}^{R,J}\sum_{j=1}^{10} E_{ij}T_{ij} \qquad \text{Equation 8.2}$$

Where:
i=R or J for route or junction, j = 1 to 10 for Routes 1-10 and Junctions 1-10.
B_{ij} = coefficient to explanatory dichotomous variable D_{ij}.
D_{ij} = dichotomous variable for presence of clip type i (R for route and J for junction) numbered j (1 to 10 for both route and junction types).

E_{ij} = coefficient to explanatory variable T_{ij}, time in condition or number of junctions passed through.
T_{ij} = time (mins) for routes and number of junctions passed through for junctions.
ε_{ij} = independently distributed random variable for clip ij.

It would have been possible to place the T_{ij} term as a multiplier to the D_{ij} term. This would have had the undesirable effect of constraining the coefficient term to act on both the dichotomous variable term and the time term. Keeping them separate allows for the power of the effect of time to be separately considered from "presence or otherwise" of a route or junction.

Estimates of coefficients to the variables for Phase 2 are shown in Table 8.3. As before the variables dR1 to dR10 are the dichotomous variables for Routes R1 to R10 and the parameters dJ1 to dJ10 are the dichotomous variables for Junctions J1 to J10. The variables R1 to R10 are the variables for the time on the route for routes R1 to R10 and the variables J1 to J10 are the number of occurrences of junction type J1 to J10 on a journey. Note that whenever J7 appeared as a junction in a journey it only ever appeared once, hence dJ7 is identical to J7 and only J7 is modelled.

Using the adjusted R-squared as a measure, it may be noted that each model increases its power of explanation by a similar amount in comparison with the models from Phase 1, which only use dichotomous variables for the presence of junctions[1].

There are coefficients that are significant in the Phase 1 model that are not significant in the Phase 2 model (for variables dR3, dR7, dR9, dJ4 and dJ7). Conversely there are coefficients that are significant in the Phase 2 model that are not significant in the Phase 1 model (for variables dR2, dJ5, dJ6 and dJ10). Table 8.4 presents results for models that have variables only for the time on a route and the number of junctions passed through, that is no dichotomous variables for the presence of the route or junction are present in the model.

[1] The F test indicates that the change is significant at the 1% level.

Table 8.3 Phase 2 results: dichotomous, time on route and number of junction variables

Variable	Linear model		Logistic model		Gompertz model		Asymptotic to 10 model		Asymptotic to 1 model	
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Constant	5.373	**21.948**	1.053	**8.698**	-0.720	**-11.780**	4.589	**16.910**	4.414	**20.209**
dR1	0.022	0.135	-0.011	-0.142	-0.020	-0.333	-0.028	-0.648	0.018	0.580
dR2	0.532	**2.613**	0.222	**2.274**	0.162	**2.228**	0.118	**2.347**	0.113	**2.809**
dR3	-0.276	-1.378	-0.140	-1.495	-0.098	-1.440	-0.062	-1.326	-0.058	-1.381
dR4	-1.308	**-5.420**	-0.614	**-5.468**	-0.437	**-5.603**	-0.292	**-5.800**	-0.284	**-4.985**
dR5	-0.770	**-3.471**	-0.353	**-3.325**	-0.253	**-3.505**	-0.163	**-3.540**	-0.160	-2.754
dR6	-1.380	**-3.931**	-0.632	**-3.671**	-0.455	**-4.054**	-0.288	**-4.288**	-0.299	**-3.025**
dR7	0.219	1.344	0.091	1.161	0.060	1.015	0.030	0.707	0.046	1.522
dR8	0.403	**2.522**	0.193	**2.543**	0.145	**2.574**	0.094	**2.390**	0.072	**2.256**
dR9	0.421	1.822	0.183	1.657	0.140	1.652	0.105	1.684	0.080	1.856
dR10	-0.389	-1.447	-0.166	-1.326	-0.108	-1.161	-0.065	-0.995	-0.105	-1.904
dJ1	-0.230	-0.827	-0.108	-0.819	-0.078	-0.782	-0.032	-0.450	-0.044	-0.833
dJ2	0.083	0.389	0.017	0.167	-0.013	-0.170	-0.041	-0.734	0.040	1.006
dJ3	1.821	1.408	0.825	1.378	0.619	1.445	0.446	1.556	0.345	1.274
dJ4	-0.039	-0.135	-0.025	-0.176	-0.024	-0.220	-0.022	-0.276	0.004	0.084
dJ5	-2.102	**-2.448**	-1.093	**-2.238**	-0.826	**-2.125**	-0.588	-1.939	-0.375	**-2.647**
dJ6	0.966	**2.796**	0.449	**2.658**	0.365	**3.054**	0.295	**3.777**	0.176	**2.291**
dJ8	-0.282	-0.500	-0.153	-0.534	-0.127	-0.560	-0.093	-0.538	-0.031	-0.319
dJ9	0.041	0.044	0.005	0.012	0.032	0.099	0.059	0.273	-0.021	-0.116
dJ10	-1.190	**-2.492**	-0.621	**-2.539**	-0.474	**-2.493**	-0.355	**-2.491**	-0.213	**-2.492**
R1	0.057	**2.666**	0.030	**2.656**	0.025	**2.786**	0.021	**2.972**	0.009	**2.432**
R2	-0.109	**-3.702**	-0.050	**-3.499**	-0.036	**-3.651**	-0.024	**-4.132**	-0.023	**-3.366**
R3	-0.009	-0.516	-0.003	-0.440	-0.003	-0.497	-0.002	-0.665	-0.002	-0.548
R4	0.012	0.689	0.006	0.780	0.004	0.684	0.002	0.535	0.003	0.764
R5	-0.025	-1.462	-0.014	-1.479	-0.008	-1.404	-0.004	-1.443	-0.011	-1.727
R6	-0.031	-1.195	-0.018	-1.263	-0.012	-1.353	-0.007	-1.414	-0.010	-1.145
R7	0.015	**2.028**	0.007	1.948	0.006	1.954	0.004	1.980	0.003	**2.017**
R8	0.008	1.176	0.003	1.060	0.003	1.151	0.002	1.292	0.001	1.096
R9	0.021	1.195	0.011	1.345	0.009	1.365	0.007	1.350	0.003	1.072
R10	0.016	0.781	0.007	0.732	0.005	0.651	0.003	0.545	0.004	1.037
J1	0.119	0.824	0.054	0.788	0.036	0.701	0.016	0.434	0.028	1.031
J2	0.108	1.053	0.058	1.153	0.048	1.244	0.041	1.464	0.019	0.998
J3	-1.365	-1.092	-0.620	-1.076	-0.475	-1.156	-0.344	-1.265	-0.246	-0.931
J4	0.331	1.629	0.168	1.678	0.137	1.746	0.109	1.808	0.050	1.382
J5	2.050	**2.685**	1.065	**2.368**	0.802	**2.221**	0.568	**1.997**	0.375	**3.082**
J6	-0.715	**-2.890**	-0.322	**-2.676**	-0.242	**-2.960**	-0.180	**-3.648**	-0.150	**-2.521**
J7	1.320	**4.124**	0.764	**3.962**	0.635	**3.862**	0.507	**3.649**	0.194	**3.948**
J8	0.588	1.304	0.296	1.258	0.229	1.209	0.160	1.093	0.099	1.308
J9	-0.169	-0.201	-0.068	-0.171	-0.080	-0.277	-0.088	-0.462	0.005	0.033
J10	1.159	**2.936**	0.599	**2.878**	0.467	**2.838**	0.352	**2.798**	0.197	**2.916**
R^2	0.275		0.276		0.275		0.271		0.278	
$\bar{R}^2$	0.240		0.241		0.240		0.236		0.243	
Phase 1 $\bar{R}^2$	0.198		0.200		0.199		0.195		0.200	

Notes

1 *Emboldened t-statistics are significant.*

2 *The constant term is the α term as defined in Table 8.1.*

Table 8.4 Phase 2 results time on route and number of junctions only

Variable	Linear model		Logistic model		Gompertz model		Asymptotic to 10 model		Asymptotic to 1 model	
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Constant	5.380	**34.020**	1.039	**13.562**	-0.730	**-18.223**	4.888	**26.253**	4.646	**31.854**
R1	0.070	**3.816**	0.034	**3.695**	0.027	**3.674**	0.022	**3.874**	0.011	**3.465**
R2	-0.054	**-2.470**	-0.025	**-2.513**	-0.019	**-2.655**	-0.014	**-3.035**	-0.010	**-2.137**
R3	-0.017	-1.136	-0.009	-1.239	-0.006	-1.270	-0.003	-1.116	-0.005	-1.338
R4	-0.046	**-3.275**	-0.026	**-3.539**	-0.016	**-3.315**	-0.007	**-2.812**	-0.015	**-3.690**
R5	-0.067	**-4.550**	-0.061	**-5.173**	-0.041	**-5.529**	-0.010	**-4.017**	-0.036	**-5.199**
R6	-0.090	**-4.344**	-0.070	**-4.446**	-0.043	**-4.637**	-0.015	**-4.588**	-0.041	**-4.154**
R7	0.018	**2.658**	0.008	**2.418**	0.006	**2.427**	0.005	**2.665**	0.003	**2.422**
R8	0.018	**3.054**	0.009	**2.992**	0.008	**3.201**	0.007	**3.561**	0.002	**2.386**
R9	0.046	**3.978**	0.022	**3.697**	0.018	**3.745**	0.014	**3.793**	0.007	**3.771**
R10	0.001	0.100	-0.001	-0.085	0.000	0.075	0.002	0.556	-0.001	-0.432
J1	0.037	0.506	0.026	0.765	0.016	0.641	-0.001	-0.058	0.014	1.008
J2	0.188	**2.958**	0.089	**2.955**	0.065	**2.826**	0.046	**2.743**	0.037	**3.138**
J3	0.441	**2.210**	0.193	**2.028**	0.140	1.895	0.114	**2.031**	0.091	**2.584**
J4	0.286	**2.993**	0.145	**3.175**	0.116	**3.262**	0.083	**3.142**	0.048	**2.783**
J5	0.151	0.673	0.039	0.351	0.032	0.375	0.036	0.566	0.031	0.767
J6	-0.062	-0.538	-0.019	-0.345	-0.002	-0.037	0.008	0.269	-0.025	-1.126
J7	1.458	**4.372**	0.818	**4.085**	0.682	**3.947**	0.564	**3.805**	0.212	**4.185**
J8	0.389	**2.529**	0.140	1.853	0.101	1.712	0.116	**2.560**	0.066	**2.417**
J9	-0.164	-0.780	-0.070	-0.699	-0.052	-0.701	-0.046	-0.915	-0.025	-0.619
J10	0.332	**2.523**	0.155	**2.472**	0.122	**2.536**	0.088	**2.465**	0.057	**2.362**
R^2	0.177		0.193		0.189		0.175		0.195	
$\bar{R}^2$	0.157		0.173		0.169		0.155		0.175	
Phase 1 $\bar{R}^2$	0.198		0.200		0.199		0.195		0.200	

Notes

1 *Emboldened t-statistics are significant.*

2 *The constant term is the α term as defined in Table 8.1.*

There are generally nine dichotomous variables that are significant from the Phase 1 analysis (Table 8.2) and between thirteen and fifteen that are significant from the Phase 2 analysis (Table 8.3). There are between twelve and fourteen time and number variables significant in the analysis that contains no dichotomous variables (Table 8.4).

If both the dichotomous variable and the time or number variable are both significant then it would be worth keeping them both in the model. If both are non-significant in the joint model (Table 8.3) but are separately significant (Tables 8.2 and 8.4) then it is appropriate to choose the variable which gives the best model fit. If only one variable (either the dichotomous variable or the time or number variable) is significant, it is appropriate to keep that variable in the model. Consideration is given in Phase 3 to the derivation of a more refined model adopting these principles.

It is worth noting at this point however that generally the R-squared for the models with time on route and number of junctions are generally lower than for the models with dummy variables (Table 8.4 compared with Table 8.2). It is also worth noting that the R-squared is similar across the different model formulations and is a result of the shape of a non-linear models not being that different from a linear model across the range of Risk Rating. There is greater variation between the R-squared values depending on the variables included.

8.4 Phase 3– elimination of variables and respondents

There are nine journeys described by respondents that are longer than two standard deviations above the mean (that is 54.46 minutes). Of these, five have their journey times divided in some manner between more than one route type, and none of the route types for these journeys have times that are greater than two standard deviations above the mean. Of the remaining four, one is a male commuter / utility cyclist (respondent number 123) on route type R8 for 61 minutes who cycles more than twice per week. The other three are females that "can cycle but do not" and who "cycle occasional holiday times / weekends" (respondents numbers 55, 75 and 190). Two of these respondents state that they would be in condition R7 for 70 minutes and 85 minutes respectively, the third stating that she would be in R8 for 80 minutes.

As the accuracy of the breakdown of the route for these three respondents is so limited, and the effect of the longer times on the analysis will be so marked, these three female respondents have been eliminated from further analysis.

Variables may best be selected where their coefficients are significant, as suggested in Phase 2 (both dichotomous and "time or number" variables if both are significant together, or just one or other variable that gives the best fit if it is significant alone). This process of refinement results in the elimination of both the dichotomous and the time variable for R10 and the dichotomous and number variables for J1 and J9. For only four variables, R2, J5, J6 and J10, are the coefficients significant for the variables in both the dichotomous and the time or number form. Table 8.5 presents results of the analysis for the sample of 857 without non-significant variables.

Table 8.5 Phase 3 results: non-significant variables omitted

Variable	Linear model		Logistic model		Gompertz model		Asymptotic to 10 model		Asymptotic to 1 model	
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Constant	5.472	28.867	1.024	11.254	-0.715	-15.278	4.624	22.048	4.598	26.257
dR2	0.514	2.678	0.227	2.475	0.171	2.525	0.128	2.765	0.103	2.669
dR3	-0.400	-2.440	-0.192	-2.504	-0.134	-2.361	-0.082	-2.106	-0.089	-2.682
dR4	-1.258	-6.819	-0.585	-6.773	-0.422	-7.018	-0.286	-7.421	-0.266	-6.143
dR5	-1.028	-5.647	-0.482	-5.687	-0.331	-5.601	-0.210	-5.505	-0.250	-5.659
dR6	-1.658	-6.157	-0.785	-6.104	-0.550	-6.448	-0.340	-6.626	-0.388	-5.273
dR8	0.456	3.258	0.215	3.272	0.169	3.509	0.122	3.682	0.078	2.759
dR9	0.570	3.931	0.278	3.974	0.217	4.030	0.163	4.058	0.100	3.768
dJ5	-2.632	-3.113	-1.303	-2.814	-0.997	-2.674	-0.725	-2.436	-0.454	-3.223
dJ6	0.965	2.880	0.446	2.751	0.362	3.133	0.287	3.767	0.169	2.308
dJ10	-1.132	-2.462	-0.614	-2.569	-0.478	-2.570	-0.359	-2.567	-0.186	-2.285
R1	0.054	3.034	0.026	2.867	0.021	2.894	0.016	2.877	0.009	2.957
R2	-0.104	-3.596	-0.047	-3.444	-0.035	-3.631	-0.024	-4.157	-0.022	-3.224
R7	0.019	2.083	0.009	1.932	0.006	1.854	0.004	1.756	0.004	2.166
J2	0.139	2.329	0.063	2.203	0.042	1.943	0.024	1.508	0.030	2.738
J3	0.419	2.181	0.190	2.031	0.133	1.863	0.088	1.667	0.093	2.723
J4	0.335	3.673	0.164	3.704	0.131	3.852	0.099	3.936	0.057	3.410
J5	2.454	3.366	1.212	2.909	0.923	2.712	0.671	2.416	0.432	3.769
J6	-0.718	-2.978	-0.318	-2.743	-0.238	-2.985	-0.175	-3.536	-0.150	-2.643
J7	1.363	4.212	0.787	4.032	0.645	3.905	0.515	3.665	0.207	4.172
J8	0.381	2.586	0.173	2.396	0.123	2.206	0.083	1.981	0.082	3.174
J10	1.097	2.920	0.587	2.883	0.463	2.875	0.348	2.814	0.174	2.767
R^2	0.259		0.260		0.259		0.256		0.258	
$\overline{R}^2$	0.239		0.241		0.240		0.236		0.239	
Table 8.3 $\overline{R}^2$	0.240		0.241		0.240		0.236		0.243	

Notes

1 The constant term is the a term as defined in Table 8.1.

Routes that ostensibly have some form of control to benefit cycle traffic are significant for the dichotomous variable for their presence and include R3 (traffic calmed road), R4 cycle lane on footway, R5 (route through a park) and R6 (traffic free route in city centre). The dichotomous variable for the presence of R2 (quiet residential road) is adding to the risk rating but this is counteracted by the variable for the length of time on the route[1]. The presence of a busy road (R8) increases the risk as does a busy road with parking (R9), but interestingly neither of these variables are significant for time in the condition. This result does not support the supposition that the longer the time in perceived "risky" conditions, the greater the risk rating. What it suggests is that there is a single "lump sum" penalty for having to encounter those conditions. Albeit with low coefficient values, it is interesting to note the effect of increasing risk that R1 (residential route with parking) and R7 (busy road with cycle lane) has on the Risk Rating.

[1] This effect is caused by the correlation of 0.69 between the two variables and one or other will be eliminated subsequently.

So far as junctions are concerned, there is correlation between J5 and dJ5, J6 and dJ6, and J10 and dJ10 and this explains the coefficients present in the Phase 3 models and will be addressed (along with the variables R2 and dR2) in the next phase of analysis.

The variables for number of junctions of type J2 (straight on at traffic signal controlled junction with no cycle facilities), J3 (right turn at traffic signal controlled junction with cycle facilities), J4 (right turn at traffic signal controlled junction with no cycle facilities), J7 (right turn at roundabout with cycle facilities), J8 (right turn at roundabout with no cycle facilities) all serve to increase the Risk Rating.

There is merit in each model formulation based on theoretical considerations about how respondents may perceive the rating scale. The models have remained consistently similar through the phases of analysis and it is not readily apparent that there is an obviously more discerning model amongst the five proposed. The variability in the responses is of such a magnitude that there is indifference in the explanatory power between the models. Two methods of model selection present themselves, one is based on the choice of parameter estimates that are significant and the other based on the magnitude of the adjusted R-squared. There is little to choose between the models based on parameter estimate significance, each model unsurprisingly demonstrating significance for the same parameter estimates. The adjusted R-squared value for the logistic model is marginally greater than for the other models and has been selected for further analysis.

It is apparent that, generally, the dichotomous variable is a better predictor for routes while for junctions it is the number passed through (rather than the dichotomous variable for junction type) that is a better predictor. The starting point for subsequent analysis has consequently been taken as the use of the dichotomous variable for routes and the number variable for junctions.

8.5 Phase 4 – logistic model with additive person variables

Phase 4 comprises the segmentation of the selected logistic model by type of cyclist, age, sex and driving status.

There could be a universal view across all respondents about the orientation and magnitude of the effect of a route or junction type on the overall Risk Rating. Whether or not a route or junction type, with such a universal view amongst respondents, creates a parameter coefficient that is significant will, in this circumstance, be determined by whether there are sufficient in the sample to make the response to this route or junction type significant.

Alternatively, there could be divergent views on the effect of a route or junction type on the overall Risk Rating amongst respondents. This variation could be due to simple "taste variation" or be linked with person type. Considering circumstances where specific bicycle facilities are present, responses could be along the following lines:

- Facilities have made a pre-existing situation safer, this route or junction type is less risky than others, without facilities, that may be encountered (potentially an inexperienced cyclist and / or one that is showing positive bias towards cycle facilities)
- The presence of facilities is indicative of a risky situation and the presence of facilities makes no difference to the risk that is experienced (someone who cannot determine the effect of facilities, or cognitively assents to their effect as being neutral)
- The presence of facilities is indicative of a risky situation, and their presence has constrained ability to manoeuvre on the road and hence it has become more risky (an experienced road user observing poor facilities)
- The risk on the road is not that great and the presence of facilities has constrained ability to manoeuvre on the road and they have made a safe situation risky (again an experienced road user observing poor facilities)

The suppositions above would imply the possibility of the generation of a set of responses that are dichotomous across person types and hence, in an overall sample, create a parameter that may be insignificantly different from zero. With hindsight, it would be possible to criticise the survey on the basis that none of the video clips were as typical as they might have been of the type of junction being portrayed. In defence, one can say that no combination of road layout and traffic is uniquely superior to any other in describing a "typical" situation.

Person type variables that could influence responses drawn from the questionnaire about the respondents include age, sex, whether or not a driving licence is held and whether or not an accident has been experienced in the last three years and, finally, ethnicity.

Dealing with cyclist type first and referring back to the descriptive analysis (Table 7.10), it may be seen that there are principally three types of cyclist by frequency of cycling, namely: those that never cycle (35.4%), those that cycle occasional holiday times and weekends (38.9%) and those that cycle at a frequency greater than once per month (25.7%). If there are differences in perception then they may be manifest by the different frequencies, hence levels of experience, of cycling of these three groups (the "nevers", the "occasionals" and the "regulars"). Two dichotomous variables have been created. The first, OCCCYC, takes the value unity if the respondent reportedly was an occasional cyclist. The second REGCYC, takes the value unity if the respondent reportedly cycled more than once per month.

A variable, SEX, which takes the value of unity if the respondent is male, was created. Table 7.8 indicates that 23.6% of the sample were in age bands up to age 34, 36.1% were in the age band 35 to 44 and 40.3% of the sample were in age bands age 45 and over. Two dichotomous variables have been created to consider age. The first, YOUNG, takes the value unity if the respondent is age 34 or younger. The second, OLD, takes the value unity if the respondent is age 45 or older.

Only sixteen respondents do not hold a driving licence, but nonetheless a variable, DRIVLIC, has been added that takes the value unity if the respondent holds a driving licence. 27% of the respondents had had a road traffic accident of some sort in the last three years and the variable, ACCIDENT, which takes the value unity if a respondent had had an accident in the last three years, was created.

A final potential classification of the respondents is concerned with their ethnicity. Unfortunately only 3.5% of the sample is of non-white origin and an analysis of ethnicity has not been pursued.

In the first instance, the person type variables described above have been added to Z_{ij} in the following manner[1]:

$$Z_{ij} = \sum_{i}^{R}\sum_{j=1}^{10} B_{ij}D_{ij} + \sum_{i}^{J}\sum_{j=1}^{10} E_{ij}T_{ij} + X_1 occcyc + X_2 regcyc + X_3 sex + X_4 young + X_5 old + X_6 drivlic + X_7 accident$$

Equation 8.3

A model of this form adds a constant to the evaluation of Z_{ij} for the presence of the additional attributes being considered[2]. Table 8.6 below presents results of the logistic model runs that began with all of the variables and proceeded through eliminations to create a final additive model.

The coefficient for OCCCYC is significant and demonstrates that if a person is an occasional cyclist then his or her risk rating score will be lower than for a person who never cycles. This could indicate that occasional cyclists have a greater understanding of cycling conditions and as a consequence a lesser perception of risk for a given condition. While of the same sign, the coefficient for REGCYC is numerically smaller, and is also not significant. On the one hand the direction of the REGCYC adjustment to a Risk Rating supports the view that people who cycle at least occasionally have a moderated view of risk compared with those who never cycle. On the other hand, it could be viewed as a little disturbing that occasional cyclists are regarding similar situations as less risky than regular cyclists.

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[1] The model includes the dichotomous variables for routes and the variable for the number of junctions on a journey.

[2] Subsequent models will apply the person type variables as factors to the journey variables.

Table 8.6 Phase 4 logistic model results

Variable	All variables		After variable elimination	
	Estimate	t-stat	Estimate	t-stat
constant	0.963	6.58	0.999	9.68
dR1 – residential street with on-street parking	0.038	0.58		
dR2 – residential street without on-street parking	-0.006	-0.08		
dR3 – traffic calmed road	-0.194	-2.46	-0.212	-2.77
dR4 – cycle route on footway	-0.529	-6.13	-0.537	-6.28
dR5 – route through park	-0.478	-5.37	-0.510	-5.88
dR6 – city centre cycle only route	-0.765	-5.82	-0.771	-5.93
dR7 – busy road with cycle lane	0.111	1.67	0.094	1.49
dR8 – busy road without cycle lane	0.285	4.27	0.276	4.22
dR9 – busy road without cycle lane and with parking	0.275	3.91	0.281	4.10
dR10 – busy road with cycle and bus lane	-0.101	-1.20	-0.120	-1.48
J1 – traffic signals straight on with cycle lane	-0.005	-0.13		
J2 – traffic signals straight on without cycle lane	0.071	2.41	0.074	2.56
J3 – traffic signals right turn with cycle lane	0.203	2.09	0.176	1.87
J4 – traffic signals right turn without cycle lane	0.130	2.84	0.135	2.99
J5 – roundabout straight on with cycle lane	0.143	1.34	0.163	1.56
J6 – roundabout straight on without cycle lane	-0.010	-0.18		
J7 – roundabout right turn with cycle lane	0.785	4.02	0.760	3.95
J8 – roundabout right turn without cycle lane	0.139	1.83	0.123	1.69
J9 – mini-roundabout straight on	-0.145	-1.48	-0.152	-1.59
J10 – right turn off main road	0.114	1.76	0.127	2.04
occcyc	-0.202	-2.80	-0.167	-2.64
regcyc	-0.102	-1.29		
male	-0.149	-2.29	-0.182	-3.02
young	0.278	3.40	0.313	3.98
old	0.190	2.68	0.216	3.21
drivlic	-0.012	-0.13		
accident	-0.065	-0.94		
R^2	0.255		0.252	
$\overline{R}^2$	0.230		0.233	

Notes

1 The constant term is the α term as defined in Table 8.1.

The coefficient for MALE is significant and demonstrates that men regard similar situations as being less risky than women.

It is interesting to note the same sign addition to Risk Rating for those who are young and those who are old. It would seem that those in the age band 35 to 44 regard a situation on average as having a smaller Risk Rating than their older and younger counterparts.

Neither possession of a driving licence nor accident history is significant in affecting respondents' perception of risk.

A further model has been run that has eliminated REGCYC, DRIVLIC and ACCIDENT and also eliminated both of the variables for routes on residential roads and the junctions J1 and J6. A full discussion of the route and junctions types and the possible reasons for their level, sign and significance is presented along with the results for Phase 5.

8.6 Phase 5 - logistic model with multiplicative person variables

Phase 5 considers a model with person type variables considered multiplicatively. The form of multiplicative model as shown in Equation 8.4 below was adopted. This form does not include the person variables REGCYC, DRIVLIC and ACCIDENT, eliminated in the additive form. It does, however, still include the person type variables as additive variables because, a priori, it is not clear whether or not, when non-significant variables are removed, an additive effect because of person type might remain.

$$Z_{ij} = \sum_{i}^{R}\sum_{j=1}^{10} B_{ij}D_{ij} + \sum_{i}^{J}\sum_{j=1}^{10} E_{ij}T_{ij} + \sum_{i}^{R}\sum_{j=1}^{10} B_{ij}^{'}D_{ij}occcyc + \sum_{i}^{J}\sum_{j=1}^{10} E_{ij}^{'}T_{ij}occcyc + \sum_{i}^{R}\sum_{j=1}^{10} B_{ij}^{''}D_{ij}sex + \sum_{i}^{J}\sum_{j=1}^{10} E_{ij}^{''}T_{ij}sex$$
$$+ \sum_{i}^{R}\sum_{j=1}^{10} B_{ij}^{'''}D_{ij}young + \sum_{i}^{J}\sum_{j=1}^{10} E_{ij}^{'''}T_{ij}young + \sum_{i}^{R}\sum_{j=1}^{10} B_{ij}^{''''}D_{ij}old + \sum_{i}^{J}\sum_{j=1}^{10} E_{ij}^{''''}T_{ij}old + X_1 occcyc + X_3 sex + X_4 young + X_5 old$$

Equation 8.4

A model of this type would have included 104 variables plus a constant and this is too many coefficients for the data to estimate. A series of preparatory models was run of the form in Equation 8.5 below. Equation 8.5 is written showing the OCCCYC person variables as being multiplicative, three other models of similar form were run with each of the person variables MALE, YOUNG and OLD being multiplicative. These considered each person variable as a multiplicative set of variables in turn, and comprised 44 coefficients to be estimated.

$$Z_{ij} = \sum_{i}^{R}\sum_{j=1}^{10} B_{ij}D_{ij} + \sum_{i}^{J}\sum_{j=1}^{10} E_{ij}T_{ij} + \sum_{i}^{R}\sum_{j=1}^{10} B_{ij}^{'}D_{ij}occcyc + \sum_{i}^{J}\sum_{j=1}^{10} E_{ij}^{'}T_{ij}occcyc + X_1 occcyc + X_3 male + X_4 young + X_5 old$$

Equation 8.5

Table 8.7 below summarises the multiplicative variables for each of the four preparatory models that were significant

Table 8.7 Multiplicative variables with significant coefficients in Eqn 8.5 models

Person type variable considered	Coefficient significant when multiplied with:
Multiplicative variable OCCCYC	dR1, dR5, J1, J10
Multiplicative variable MALE	dR2, dR3, dR5, dR8, dR10, J3, J6, J8
Multiplicative variable YOUNG	dR5, dR10, J1, J4, J6, J9
Multiplicative variable OLD	dR2, dR5, dR10, J6

The person variable MALE is significant when multiplied with the widest range of journey type variables. dR5 (dichotomous variable for the presence of a route through a park) is significant for all person variable types, hinting at a strong sensitivity to person type for this sort of route.

A model of the form in Equation 8.4 has been run including all ten dichotomous variables for route and number variables for junctions and the multiplicative variables that are significant (shown in Table 8.7). This model together with a model that was further refined to eliminate some variables that were not significant are shown in Table 8.8

Table 8.8 Multiplicative logistic models

Variable	All variables Model A		After variable elimination Model B	
	Estimate	t-stat	Estimate	t-stat
constant	0.692	6.98	0.970	7.97
dR1 – residential street with on-street parking	0.096	1.25	0.205	2.93
dR2 – residential street without on-street parking	-0.247	-2.53	-0.012	-0.17
dR3 – traffic calmed road	-0.580	-5.84	-0.297	-3.88
dR4 – cycle route on footway	-0.531	-6.45	-0.551	-6.63
dR5 – route through park	-0.520	-2.86	-0.324	-3.26
dR6 – city centre cycle only route	-0.847	-6.99	-0.799	-6.39
dR7 – busy road with cycle lane	0.158	2.48	0.143	2.21
dR8 – busy road without cycle lane	0.246	2.85	0.337	5.18
dR9 – busy road without cycle lane and with parking	0.317	4.80	0.327	4.85
dR10 – busy road with cycle and bus lane	-0.174	-1.27	-0.030	-0.29
J1 – traffic signals straight on with cycle lane	-0.217	-4.87	-0.199	-4.52
J2 – traffic signals straight on without cycle lane	0.058	2.06	0.067	2.34
J3 – traffic signals right turn with cycle lane	0.044	0.39	0.146	1.58
J4 – traffic signals right turn without cycle lane	0.074	1.62	0.100	2.15
J5 – roundabout straight on with cycle lane	0.279	2.75	0.219	2.11
J6 – roundabout straight on without cycle lane	-0.272	-3.59	-0.271	-3.51
J7 – roundabout right turn with cycle lane	0.658	3.82	0.758	4.19
J8 – roundabout right turn without cycle lane	0.125	1.51	0.087	1.03
J9 – mini-roundabout straight on	-0.279	-2.85	-0.220	-2.20
J10 – right turn off main road	0.234	2.83	0.129	2.12
dR1 x occcyc	-0.322	-2.78	-0.450	-5.07
dR5 x occcyc	-0.454	-2.57	-0.580	-3.32
J1 x occcyc	0.294	4.36	0.281	4.35
J10 x occcyc	-0.249	-2.04		
dR2 x male	0.065	0.50		
dR3 x male	0.574	4.01		
dR5 x male	0.595	3.56		
dR8 x male	0.214	1.76		
dR10 x male	0.426	2.69		
J3 x male	0.576	2.85		
J6 x male	0.326	2.83	0.265	2.25
J8 x male	0.400	2.31	0.356	2.00
dR5 x young	0.599	2.66		
dR10 x young	0.091	0.42		
J1 x young	0.277	3.30	0.327	3.90
J4 x young	0.386	2.83	0.321	2.31
J6 x young	0.179	1.28	0.360	2.51
J9 x young	0.514	1.90	0.485	1.71
dR2 x old	0.440	3.33		
dR5 x old	-0.599	-3.18		
dR10 x old	-0.345	-1.97	-0.317	-1.98
J6 x old	0.234	1.76	0.315	2.36
Occcyc	-0.077	-0.76		
Male	-0.801	-6.19	-0.317	-4.69
Young	-0.244	-2.18	-0.146	-1.32
Old	0.215	2.39	0.216	2.85
R^2	0.416		0.350	
$\overline{R}^2$	0.382		0.322	

Notes

1. *The constant term is the α term as defined in Table 8.1.*

The logistic model with multiplicative form for the inclusion of person variables is superior to the additive model and is able to explain something over a third of the variation in the data. The eliminations of parameters in the refined model have been limited to those variables that are either multiplicative or person type, and the basic ten route and junction variables have been left in the model. Initially the variables dR2 x male, dR10 x young and occcyc were removed and subsequently all of the multiplicative variables that were correlated with a correlation of greater than 0.50 were removed from the model.

Each of the journey variables is discussed in turn below based on the Model B described in Table 8.8. above.

- R1 (Residential street with parking): This clip displays significant on street parking with a driver standing in the road locking a parked car door, a dog barking and narrow roads. The coefficient for dR1 (0.205) indicates that it increases the Risk Rating, but that if a person is an occasional cyclist then the Risk Rating is reduced (-0.450). This implies that occasional cyclists perceive less risk inherent in on-street parking than do people who never cycle and regular cyclists.

- R2 (Residential street with no on-street parking): The coefficient for this clip is not significant. The effect of such a route on Risk Rating has not been deduced from this survey.

- R3 (Traffic calmed road), R4 (Cycle route on footway), R5 (route through park) and R6 (city centre cycle only route): The latter three variables (R4, R5 and R6) represent routes that are traffic free. The presence of these types of route reduces the Risk Rating for a journey. In addition, R5 is also represented by the variable dR5 x occcyc. For an occasional cyclist R5 has a greater reducing effect on Risk Rating (-0.580). Again, in a similar way as for R1, this implies that occasional cyclists perceive greater benefit in a route through a park (presumably its attractiveness is in its being away from traffic) than do those who never cycle or regular cyclists.

- R7 (Busy road with cycle lane): The lane shown in the clip is not as wide as design standards suggest (a minimum of 1.5 metres) and some may see the presence of the lane as providing some sort of facility and relief from the adjacent traffic stream. Others may perceive similar risk as in the situation with no cycle lane. Notwithstanding, overall the presence of a busy road with a cycle lane serves to increase the Risk Rating (0.143).

- R8 (Busy road without cycle lane): The presence of this type of route increases the Risk Rating for a journey (0.327).

- R9 (Busy road without cycle lane but with on-road parking): There is little difference in the magnitude of the coefficient between R8 and R9 and this indicates that there is little additional risk perceived by people when they are passing vehicles parked on the carriageway on a busy road.

- R10 (busy road with bus lane): There could be a difference of opinion as to the exposure to risk within a bus lane between different respondents resulting in a parameter which is not significant. The multiplicative variable dR10 x old is just significant at the 5% level and indicates that an older person would perceive a reduction in Risk Rating (-0.317) for this type of route.

- J1 (Traffic signals straight on with cycle facilities): The presence of a traffic signal controlled junction reduced the Risk Rating (-0.199), but interestingly if the cyclist is occasional or young then this effect is reversed (0.281 and 0.327). This implies that people who never cycle and regular cyclists see more benefit in facilities at junctions than occasional cyclists.

- J2 (Traffic signals straight on without cycle lanes): The cyclist has to manoeuvre from the nearside lane across a left turn only lane to proceed straight on. Dichotomy could develop in the sample between those who perceive the manoeuvre across the left turn lane and further, perceive it to be risky and those that do not perceive it as such. The overall effect (0.067) is low.

- J3 (Traffic signals right turn with cycle lanes): The surveyor cyclist waited in the nearside cycle lane until the traffic signals turned to red before proceeding into the box behind the advanced stop line, hence incurring delay but being relatively safe by so doing. It could be that there is dichotomy amongst respondents between those who perceived the actions of the surveyor cyclist as indicating a high level of intrinsic risk and those that saw the manoeuvre as being relatively safe. Overall the presence of such junctions adds to the Risk Rating (0.146).

- J4 (Traffic signals Right turn without cycle lanes): The right turn requires the cyclist to wait in the centre of the junction during a green aspect of the traffic signals until the clearance period at the end of the stage. The junction is busy and other cars are moving in close proximity to the cyclist. It is unclear as to why this movement is not universally disliked and there seems to be no good reason why this clip should not have generated a response that adds more to the Risk Rating. Indeed the addition to the Risk Rating (0.100) is less than for the right turn with facilities (J3 above). For young people, however, the perceived risk is greater for this type of junctions (0.321).

- J5 (roundabout straight on with cycle lanes): The presence of roundabouts, even with cycle facilities, increases the perceived Risk Rating (0.219).

- J6 (roundabout straight on without cycle lanes): The coefficient for this variable is of wrong sign (-0.271) as it implies the greater the number of this type of junction on a route, the less the perceived Risk Rating for the journey. Male (0.265), young (0.360) and old (0.315) respondents however would go some way to correcting this negative sign.

- J7 (roundabout right turn with cycle lanes): A right turn with cycle facilities is rated worse than a straight on at a roundabout with cycle facilities (0.758 compared with 0.219) and is to be expected.

- J8 (Roundabout right turn without cycle lanes): Again, similarly as for the clip J6, the coefficient (albeit of correct sign) is very low (0.087) and lower than would be expected relative to the equivalent roundabout without cycle lanes. Again, similarly as for J6, but only for male respondents (0.356), there is a correction to this low value. The differences between the "with and without" cycle facilities at the roundabout are likely to be caused by effects other than the effect that has been controlled for (i.e. the facilities). In this sense the choice of roundabout clips has not been appropriate for this comparison.

- J9 (Straight on at mini-roundabout): The manoeuvre is over a fairly quiet mini-roundabout but the presence of such a junction would reduce the Risk Rating (-0.220). It is possible that some viewed the presence of the mini-roundabout as being beneficial because of its traffic calming effect.

- J10 (Right turn off a main road). The coefficient for J10 adds to the Risk Rating (0.129) and reflects the negative effect of having to cross a stream of traffic and take up a position in the main road ready to turn across another stream of traffic into a side road.

Overall it may be seen that most variables are of correct sign and contributing appropriately to the Risk Rating for a journey. Quiet and traffic free routes have the effect of reducing Risk Rating while busy roads have the effect of increasing Risk Rating, with little or no compensation being derived from facilities along the route. The presence of junctions tends to increase the Risk Rating, again with cycle facilities contributing little to the moderation of the effect of the junction. The comparison of roundabouts with and without cycle facilities appears not to have been appropriately deduced from this survey, however.

8.7 Conclusion

The analysis of respondents' stated Risk Ratings for journeys with different attributes presented in this chapter has provided a more detailed analysis of the data than is possible with simple descriptive statistics. Overall it is concluded that there is significant variation between respondents, but it is possible to produce a non-linear regression model that relates perceived risk on a route with the composition of the journey. There is little difference between any of the model formulations tested (Table 8.1), but the logistic model provides a marginally better fit to the data. The presence of different types of route and the number of different types of junction are determiners of perceived risk. Respondents generally rate risk associated with situations where there is no motor traffic less highly than other situations. Perception of roundabouts is that they generally add to the Risk Rating, and they add more to the Risk Rating than traffic signal controlled junctions. The regularity of cycling, sex and age are also factors that influence the perception of risk either additively or, for some route and junction types, multiplicatively.

The choice of whole number points on the Risk Rating scale was limiting as some of the smaller changes to journeys would only require small changes relative to Risk Ratings that had already been chosen. This will have led to a significant amount of variation on the data that may have been eliminated if a finer rating scale had been specified.

The manner of use of risk rating scales by respondents is complex and variable and a good deal of questioning in the survey and subsequent analysis needs to be undertaken to interpret results appropriately. This has been undertaken and use made of, for example respondents' thoughts about the "shape" of the response scale.

The survey was based around a respondent's base journey which led to "lumpiness" in the matrix of the number of times routes and junctions were presented to respondents. This was controlled for as far as possible during the surveys, but this variation will have led to a loss of power of the data to estimate the relationships between the different parameters. While a larger sample size may have assisted in raising the predictive power of the models, it is not clear that the inherent variation between different types of respondent could have been controlled for in a better way.

The analysis presented in this chapter has provided a thorough review of the data from the respondent survey and has demonstrated relationships about the perceptions of risk for routes and junctions for different person types. This is the first piece of research that has developed a relationship for the relative contribution to perception of risk for routes and junctions. It has also highlighted the effect of person type on perception of risk. The overall aim of the research is to create a model capable of predicting, at an aggregate level, the propensity for people on their journey to work to use the bicycle. While the model forms used in Phases 1 to 3 and the resulting logistic model in Phases 4 and 5 have provided useful insight into the data that has been collected, the level of detail, particularly in relation to person type and junction detail, is too great for use in subsequent aggregate analysis. Also, rather than a model that explains the data, a model is required that can forecast behavioural response. This is discussed in Chapter 9.

Chapter 9 Towards an area wide measure for risk

9.1 The three phases to the risk index modelling

The analysis in Chapter 8 fully elucidated the relationships between the journey variables and the person variables obtained from the respondent survey and resulted in a model where the dependent variable was the Risk Rating observed from the respondents. The analysis presented in this chapter builds on the experience of the five phases of the non-linear regression modelling undertaken in Chapter 8 and uses the logit model, with dichotomous "choice" as the dependent variable, to attempt to deduce a model form that allows the prediction of the "probability of acceptability" of use of the bicycle based on perception of risk. This "probability of acceptability", being more akin to behavioural choice, is a better modelling paradigm to estimate behavioural response to particular circumstances and may be taken forward as an indicator of the propensity to cycle based on the perception of risk.

Phase 6 considers the Risk Rating relative to the individual respondent's risk threshold level (response to Question (B) in the survey). The aim is to estimate a probability that it is perceived to be too risky to cycle as a function of the characteristics of the route. A dichotomous indicator (1 or 0, with unity being the equivalent of being "chosen" in a mode choice model) of whether cycling would have been acceptable to the respondent based on the relative values of the Risk Rating and the risk threshold level was determined for each observation and a logit model constructed. Person type variables are included in an additive and multiplicative manner.

In Phase 6 of the modelling (Section 9.2), the independent variables comprised dummies for the presence or absence of particular journey variables as depicted in the video clips and representing link and junction types, times on different links and number of times a junction was experienced on a journey. The analysis has been therefore very much related to the original survey instrument and the independent variables are the same as those used in the first five phase of analysis reported in Chapter 8. In Phase 7 of the modelling (Section 9.3) this strong link is broken by representing the journey instead by more generalised variables, such as for example, the proportion of time on a traffic free route experienced on a journey. This linkage is broken in order to generalise the model, making it less beholden to the specific survey methodology and more related to the factors relevant in cycle mode choice.

The final Phase 8 of the modelling (Section 9.4), relates the survey results to available aggregate data at district level, that is mapping data describing cycling facilities, and develops a model that contains variables that can be deduced from the mapping data and from the census data to create a measure for risk to be used in the main model of variation in cycle use.

ALOGIT was used to analyse the models (Hague Consulting Group, 1992). ALOGIT is based on the logit model and is a standard tool for disaggregate mode choice modelling in transport planning.

9.2 Phase 6 – choice based on risk threshold level

A choice (or acceptability) model based on cycling being acceptable if the Risk Rating was below the risk threshold level (Question B in the survey) can be constructed. The trigger question was "Is there a numbered point on the scale above which you were thinking it would be too dangerous for you to cycle?" The number of positive choices for cycling was 615 out of the 857.

Dichotomous choice may be modelled by the logit formulation, which is shown in Equation 9.1 below to indicate the analogous concept of "acceptability".

$$\Pr(acceptability) = \frac{1}{(1+e^{(Z_{ij}^{notacceptable} - Z_{ij}^{acceptable})})} \qquad \text{Equation 9.1}$$

The probability of acceptability of cycling is a function of the difference between the utility of cycling not being acceptable, $Z_{ij}^{notacceptable}$ (which is taken as zero) and the utility of cycling being acceptable, $Z_{ij}^{acceptable}$. The function for the utility of cycling being acceptable for the additive model is specified in the same way as is described in Equation 8.3, for the multiplicative form it is specified in the same way as is described in Equation 8.4. A higher acceptability is created by a larger utility, that is, larger positive coefficients for variables that have a "good effect" for cycling. A smaller acceptability is created by a smaller utility, that is, larger negative coefficients for variables that have a "bad effect" for cycling.

The following order of procedure has been adopted:

Model 6a: A model containing all of the independent variables (times on routes, R_i, dummies for presence of route, dR_i, or junction, dJ_i, and number of junctions passed through, J_i) but excluding the dummy for the presence of J7[1] and including the dichotomous variables for sex (MALE), occasional cyclist (OCCCYC) and regular cyclist (REGCYC) and age (YOUNG and OLD) in additive form. The lack of significance of the variables for holding a driving licence and accident history in the non-linear regression analysis have led to the decision not to consider these variables in the logit analysis.

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[1] Note that when J7 appeared in a journey it appeared only ever once, never on two or more occasions. Hence, J7 is numerically identical to dJ7, the dichotomous variable for the presence of J7 for all 857 sample observations.

Model 6b and 6c: Models containing just the time and number journey variables (6b) and the dichotomous variables (6c) as well as the person type variables in additive form.

Model 6d: A model containing the significant variables from the above three models, producing the best additive logit model.

Models 6e to 6i: A series of five models taking the five person type variables in turn to be represented in the model in multiplicative form in a manner analogous to the procedure undertaken in Phase 5 of the non-linear regression modelling using the logistic function.

Models 6j to 6m: A series of four models that began with a model (6j) that took the significant variables from the analyses of Models 6e to 6i and then progressively removed non-significant variables, producing the best multiplicative logit model.

The results for the resulting additive logit model (Model 6d) and the resulting multiplicative logit model (Model 6m) are presented in Table 9.1 below.

Table 9.1 Phase 6 logit model results

Variable	Model with additive person type variables		Model with multiplicative person type variables	
	Estimate	t-stat	Estimate	t-stat
Constant	2.208	7.7	2.172	11.9
R1 Residential road with on-street parking	-0.045	-1.8		
R7 Busy road with cycle lane	-0.030	-2.4	-0.039	-2.9
R8 Busy road with no cycle lane	-0.032	-4.0	-0.056	-5.5
dR3 route with traffic calming	0.284	1.1		
dR6 traffic free route in city centre	0.769	1.7		
J2 straight on at traffic signals with no facilities	0.230	1.5		
J3 right turn at traffic signals with facilities	-0.696	-2.5	-0.656	-2.0
J4 right turn at traffic signals with no facilities	-0.515	-4.1		
J7 right turn at roundabout with facilities	-1.747	-4.0	-1.240	-2.3
dJ1 straight on at traffic signals with facilities	0.453	2.3		
dJ2 straight on at traffic signals with no facilities	-1.192	-3.9	-1.054	-4.3
dJ2 x male			0.799	2.9
dJ2 x old			-0.536	-2.1
R1 x young			-0.334	-4.9
R7 x regcyc			0.122	2.4
R8 x male			0.032	1.9
R8 x regcyc			0.117	4.0
J3 x regcyc			1.581	1.9
J3 x young			-2.564	-2.2
J4 x regcyc			-1.080	-2.7
J4 x old			-0.656	-4.0
J7 x regcyc			-2.023	-2.3
male	0.658	3.5		
occcyc	-0.047	-0.2		
regcyc	1.223	4.5		
young	-1.229	-5.1		
old	-0.901	-4.2		
Final log-likelihood	-414.89		-397.64	
Rho-squared w..r..t. constants	0.187		0.220	
Adjusted rho-squared	0.155		0.189	

Notes

1 *Initial log-likelihood with constants only was -510.08.*

2 *Rho-squared is determined as* $\rho^2 = 1 - LL(M)/LL(0)$, *where LL(M) is the log-likelihood of the (final) model and LL(0) is the initial log-likelihood..*

3 *The adjusted rho-squared is determined as* $\bar{\rho}^2 = 1 - \dfrac{\left(LL(M)\big/\sum_{q=1}^{Q}(J_q - 1)\right) - K}{LL(0)\big/\sum_{q=1}^{Q}(J_q - 1)}$, *where* J_q *is the number of alternatives faced by individual q and K is the total number of variables in the model.*

It is interesting to note the generally different journey variables that appear in the logit models as compared with the logistic models of Chapter 8. The explanation can only be in relation to the different dependent variable, in other words, the effect of using the threshold level is quite marked. None of the additive person type variables were significant in the multiplicative model, again dissimilar to the logistic model.

The results demonstrate differences between those that cycle regularly and those that do not cycle regularly and this confirms the finding from the logistic model. It is interesting to note however, that the coefficient that was significant for regularity of cycling in the logistic model was OCCCYC, rather than REGCYC. Perhaps this indicates a better appreciation of an appropriate threshold amongst regular cyclists.

Each journey variable that appears in the multiplicative model is discussed below.

- R1, residential road with on-street parking, appears only multiplicatively with YOUNG and its presence has the effect of decreasing the likelihood of cycling.
- R7, busy road with cycle lane, appears on its own and multiplicatively with REGCYC. The sign to the coefficient for time in R7 on its own indicates a negative effect on the likelihood of cycling (-0.039). This may be taken to suggest that, even though there is a cycle lane, the level of the traffic on the road has a perceived negative effect. For regular cyclists, the effect is made positive by the larger positive coefficient (+0.122) on the multiplicative variable. Regular cyclists seemingly perceive a benefit from a cycle lane.
- R8, the busy main road without cycle lanes, features in the model on its own and multiplicatively with MALE and REGCYC. The sign to the coefficient for time in R8 on its own indicates a negative effect on likelihood of cycling (-0.056) and to a value greater than for a road with a cycle lane (R7 above). This negative effect is reversed for males (+0.799) and regular cyclists (+0.117), both effects seeming reasonable.
- J3, right turn at traffic signals with cycle facilities, appears as the number of such junctions that are traversed as well as multiplicatively with REGCYC and YOUNG. The negative effect of such a junction (-0.656) is very heavily penalised further by young cyclists (-2.564), but this effect may not be solely in connection with the perceived risk of the junction but a dislike of the manner of execution of the right turn by the surveyor cyclist who waited in the approach cycle lane for a cycle of the signals before moving into the cycle box to make the right turn. Regular cyclists view the junction positively overall (+1.581).
- J4, right turn at traffic signals with no cycle facilities, appears only multiplicatively with REGCYC and OLD and in both cases is perceived as adding to the risk of a journey, interestingly more so in the case of regular cyclists. This may be because the close mixing of the cyclist with traffic in the right turn manoeuvre has been more accurately perceived by experienced cyclists than those who are not so experienced.
- J7, right turn at a roundabout with cycle facilities, appears on its own and multiplicatively with REGCYC. The negative effect of the junction on its own (-1.240)

is magnified for regular cyclists (-2.023). Again regular cyclists may be seeing risk in the junction that less experienced cyclists do not see.

- dJ2, presence of straight on at traffic signals without cycle facilities, appears on its own and multiplicatively with MALE and OLD. Interestingly it is the only journey variable that appears in dichotomous form. Its negative effect (-1.054) is reduced (by +0.799) for males and increased (by -0.536) for people who are old.

The logit analysis shows a complex set of largely plausible interactions between different route and junction types and person types.

The analysis has been undertaken with the video clips shown to the respondents as the vehicle for the creation of variables in the model. An alternative approach is to determine variables from the clips themselves, such as traffic flows, to create a model that is not directly linked to the video clips. This is done to generalise the model and is described in Phase 7 below[1].

9.3 Phase 7 - decomposition of the dichotomous variables

Table 7.3 provides a physical description of the type of junction, the type of turn being made, whether cycle facilities are present, the number of other cyclists, the number of pedestrians, the number of parked vehicles on the left, the number of roads joining the route and the two way flows on the routes. Phase 7 comprises the analysis of the Risk Rating data substituting the physical variables derived from Table 7.3 for the dichotomous, time and number journey variables used in Phases 1 to 6.

The variables that have been calculated from the clips for each journey made by a respondent are as follows:

- SIG – Number of signal controlled junctions travelled through on the journey
- RBT – Number of roundabouts travelled through on the journey
- PRI – Number of priority junctions travelled through (where priority is yielded) on the journey
- SO – number of straight on manoeuvres made through junctions on the journey
- RT – number of right turn manoeuvres made through junctions on the journey
- PRrFac – proportion of time on the journey on routes with cycle facilities. The proportion has been used as this will be a parameter that may be determined from

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[1] Some analysis analogous to that undertaken in Phase 7 has also been undertaken using the non-linear regression analysis techniques of Chapter 8, but is not presented here.

aggregate data for a district in the subsequent main analysis. Routes that include facilities are R3 (traffic calming), R4 (on footway), R5(through park), R6 (city centre cycle only street), R7 (cycle lane) and R10 (bus lane)[1].

- PRjFac – proportion of junctions on the journey with cycle facilities
- AvePed – Number of pedestrians per minute seen on the journey (calculated as the average based on the sum of pedestrians that would have been seen on each route type (actual journey time in minutes on each route type multiplied by number seen per minute) plus the numbers seen at each junction divided by the total journey time)
- AvePark – Number of parked vehicles per minute seen on the journey on the left hand side of the road (calculated based on the time weighted average from the route clips of the number of vehicles parked on the left side of the road).
- AveSide - Number of side roads per minute seen on the journey (calculated as the average based on the sum of the side roads on each route type (actual journey time in minutes on each route type multiplied by number of side roads per minute) plus the number of side roads at each junction divided by the total journey time)
- AveFlow – Motor vehicle flow rate (calculated as the time weighted average from the route clips of the two-way flow rates in vehicles per hour).

In addition to SIG, RBT and PRI, SO and RT, parameters dSIG, dRBT, dPRI, dSO and dRT have been created which are dichotomous variables which take the value unity if there are signals, roundabouts, priority junctions, straight on and right turn manoeuvres respectively as part of the journey.

Metrics for pedestrians, parked vehicles, side roads and flows have been determined for each of the 857 journeys in the sample based on time weighted averages. Even though averages across the journey have been calculated, there is still significant variation between the journeys in the sample as follows:

- Range of AvePed : 4 – 117 (overall mean 18.1)
- Range of AvePark : 0 – 84 (overall mean 14.1)
- Range of AveSide : 0.32 – 22.1 (overall mean 13.5)
- Range of AveFlow : 0 – 2640 (overall mean 1103.5)

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[1] Analysis in Phase 8 goes some way to disaggregating the variable PRrFac into component parts equivalent to that available on cycle mapping, to be discussed subsequently.

It was anticipated and shown that there is correlation between the junction variables SIG, RBT and PRI as a group with the variables SO and RT as a pair and so the analysis has two parallel strands, one which considers principally the junctions by their description and the other that considers the junction principally by the movement being undertaken through it. The following order of procedure has been adopted and is analogous to that adopted in Phase 6:

Model 7a1 and 7a2: A model containing the independent variables PRRFAC, PRJFAC, AVEPED, AVEPARK, AVESIDE, AVEFLOW and including the dichotomous variables for sex (MALE), occasional cyclist (OCCCYC) and regular cyclist (REGCYC) and age (YOUNG and OLD) in additive form. Model 7a1 contains the variables SIG, RBT and PRI and Model 7a2 contains the variables SO and RT.

Models 7b1 and 7b2: A model containing the independent variables for PRRFAC, PRJFAC, AVEPED, AVEPARK, AVESIDE, AVEFLOW and including the dichotomous variables for sex (MALE), occasional cyclist (OCCCYC) and regular cyclist (REGCYC) and age (YOUNG and OLD) in additive form. Model 7a1 contains the variables dSIG, dRBT and dPRI and Model 7a2 contains the variables dSO and dRT.

Model 7c: A model attempting to combine models 7a1, 7a2, 7b1 and 7b2 to produce the best model with the person type variables as additive variables.

Models 7d1 - 7d4 to 7h1 - 7h4: A series of twenty models based on four groupings of {SIG, RBT and PRI}, {dSIG, dRBT and dPRI}, {SO and RT} and {dSO and dRT}. Other journey variables PRRFAC, PRJFAC, AVEPED, AVEPARK, AVESIDE, AVEFLOW also appeared in each model. Each journey variable that appeared in the model appeared also in multiplicative form with the five person type variables (MALE, OCCCYC, REGCYC, YOUNG, OLD) in five separate models (four groups by five person types giving twenty models).

Models 7i, 7j and 7k: Model 7i was developed to reflect the best model arising from the twenty models above that represented junctions by type (that is, SIG, RBT and PRI) and Model 7j was developed to reflect the best model arising from the twenty models above that represented junctions by turn type (that is, SO and RT). The final overall best model combined these two models to create the final multiplicative model, Model 7k.

Table 9.2 below summarises the journey and person type variables that were significant in the twenty models 7d1 to 7h4.

Table 9.2 Variables that are significant in multiplicative models

	SIG	RBT	PRI	SO	RT	PRRFAC	PRJFAC	AVEPED	AVEPARK	AVESIDE	AVEFLOW
	Variable present as "number of"										
On own	*			*	*	*		*	*		
Male		*			*						*
Occcyc					*		*		*		*
Regcyc					*	*			*	*	
Young	*			*	*				*		
Old										*	*
	Variable present as "dichotomy for presence of"										
On own	*	*		*	*						
Male		*			*						
Occcyc	*	*			*						
Regcyc	*				*						
Young	*			*							
Old											

Notes

1 *An asterisk indicates that the variable is significant. The row "own" indicates that it is significant on its own. The row "male", for example that it is significant when present multiplicatively with "male".*

Table 9.3 below shows the results of the best resulting models from the Phase 7 analysis. As before, coefficients with a negative sign reduce the utility and hence the probability of acceptability of cycling. It is also noticeable that the type of person variables (sex, regularity of cycling and both age dichotomous variables in the additive model) are a significant determiner of whether or not the Risk Rating is above the risk threshold for cycling. A run of the model with only person type variables in additive form, that is no journey variables at all, produced an adjusted rho-squared value of 0.080.

The best multiplicative model shows that males have a fixed reduced perception of risk of cycling relative to females (0.620 added to the overall constant of 1.287) but that old people (age 45 and over) have a fixed increased perception of risk of cycling relative to younger people (-1.074 deducted from the overall constant of 1.287).

Table 9.3 Phase 7 logit model results

Variable	Model with additive person type variables		Best multiplicative model	
	Estimate	t-stat	Estimate	t-stat
male	0.566	3.2	0.620	3.5
regcyc	1.115	4.7		
young	-1.140	-5.1		
old	-0.959	-4.7	-1.074	-5.4
sig	-0.258	-2.9	-0.185	-3.0
dsig*young			-0.732	-2.6
so	0.094	1.0		
drt	-0.534	-2.7		
rt*young			-0.518	-3.0
prrfac	0.824	2.9	0.737	2.7
prrfac*regcyc			2.251	2.9
Avepark*young			-0.015	-1.6
Aveside*regcyc			-0.040	2.0
Aveflow	-0.00001	-0.1		
CONSTANT	1.565	4.7	1.287	6.4
Final log-likelihood	-446.431		-440.55	
Rho-squared w.r.t. constants	0.125		0.136	
Adjusted rho-squared	0.107		0.119	

The rho-squared for the above models based on the generalised parameters compared with those for the Phase 6 analysis presented in Table 9.1 are smaller. This lesser magnitude might be explained by the more directly related nature of the variables in Phase 6 to the survey instrument.

The coefficients for signal controlled junctions from the best multiplicative model indicate that their presence reduces the probability of being below the risk threshold level. The results indicate also that young people dislike signals more than people of other ages. Another way of considering this is relative to the constant for OLD (-1.074) and to note that passing through any number of sets of signals will reduce the difference of the perception risk between the YOUNG and the OLD by 0.732.

No significant variables have been estimated in respect of roundabouts and this is surprising based on the literature which suggests that cyclists are exposed to greatest potential hazard at roundabouts.

Right turns count more negatively if the respondent is young. The -0.518 value of the coefficient for RT x YOUNG indicates a reduction in the difference of perception between those who are young and those who are old. It could be surmised that it is only those who are neither young nor old (the age 35 to 44 group) that are not affected by right turns.

The proportion of a route that is in facilities is consistently significant in all the models and has the effect of increasing the probability of acceptability of cycling. Regular cyclists value facilities more than other types of cyclist.

None of the variables AVEPARK, AVESIDE, AVEPED and AVEFLOW were significant in the additive model but there are interesting effects when these variables are introduced multiplicatively in the model with person type variables. The only remaining multiplicative variables after variables with high correlations have been removed are AVEPARK x YOUNG and AVESIDE x REGCYC. The multiplicative model suggests that parking on the road creates a perception of better conditions for cycling unless the person is young. The coefficient for the multiplicative variable AVESIDE x REGCYC is positive leading to the immediate thought that side roads make conditions better for regular cyclists. The better way of interpreting this coefficient may be to consider it as "less worse" for regular cyclists than for other person types.

9.4 Phase 8 - development of a measure for risk across an area

Phase 8 of the modelling seeks to develop a pragmatic model that may be used at an area wide level to determine the level of risk for cycling inherent in a district.

A measure for risk across a district needs to be based on an aggregation of the conditions relevant to the perception of cycling risk that are likely to be encountered by a cyclist in a district. The discussion below, and using the results of the Risk Rating analysis contained in Chapter 8 and above in this chapter, indicate that the results from the Risk Rating survey may be more readily used in the form of a choice model demonstrating the probability of acceptability of cycling, based on conditions prescribed. The advantage of using the "acceptability of cycling" measure from the logit model is that it is more explicitly behavioural in nature and so will fit more closely with the main model, which is behavioural in nature. On this basis, in the context of an area, this probability may more readily be thought of as an "indicator" of potential cycling based on assessment of perceived risk.

The following three sections describe alternative approaches towards achieving a measure for the effects of risk on the acceptability of cycling.

9.4.1 An approach based on network statistics

Network density, a simple mean measure at district level of the number of roads per square kilometre of land area, provides an indication of the complexity of the network. The more complex a network, the greater is the number of junctions and conflicts, and hence the greater is the risk inherent in the system to users of the system. Traffic intensity, again a simple mean measure of the level of use of the infrastructure, provides a further measure of the level of use of the network. The better used a network, the greater the conflicts and hence the greater the risk inherent in the system for users of the system.

While these two measures do not reflect either the proportion of facilities or explicitly the number of junctions that need to be passed through, they represent a reasonable proxy for risk within a district. A measure for Network Density has been discussed in Chapter 6 and is used in the analysis in Chapter 10.

9.4.2 Sampling approach based on network statistics

The formulation of the measure for Risk Rating has been based on the times on routes of different type and the type and number of junctions that are traversed on a journey. In order to determine a more refined indicator of acceptability of cycling for a district than is possible by use of simple network statistics, it would be necessary to determine the composition of a journey to work in that district.

It is possible to take a sample of districts for detailed analysis across a range of network densities to determine the number of traffic signal, roundabout and priority junctions per kilometre of route. Based on the average distance for the journey to work from census data, it would be possible to determine the number of junctions of various types that would be encountered on journeys for districts of different network densities. This proxy journey composition could then be used to determine a Risk Rating for the journey which would become the Risk Index for the district.

While the methodology appears logical to an extent, it is clear that this route is tenuous and relies in essence on the aggregate parameters for "Network Density" and "Traffic Intensity". There are also issues about the practicality of pursuing this option within the resources available. This option is not pursued further.

9.4.3 Sampling approach based on infrastructure mapping data

Cycle guides are available for a number of towns in the UK. Some of these maps are produced by Cycle City Guides (CCG, 2003) and others are produced by local authorities. There is a substantial range in the quality and extent of such mapping for guides produced other than to the consistent standards adopted by professional mapping companies. The mapping usually defines cycle routes in the following terms:

- Length of traffic free path ("Green routes");
- Length of traffic free route adjacent to the carriageway ("Brown routes" and shown as "Brown" as opposed to "Green" for London only);
- Length of cycle lane and bus lane (Marked with a thin red line for cycle lanes and a dashed red line for bus lanes but available only for a limited number of Districts);
- Length of signposted cycle route ("Blue routes").

The most extensive routes identified on most of the cycle city guides are so-called advisory routes that generally make use of less busy streets. These streets, depending on the area, may be narrow and have a lot of parking (as often they are residential in nature). Without further detail from a site visit it is not possible to deduce the appropriate category of route (R1 with parking or some other type such as R3 with traffic calming). The advisory routes are determined by a combination of local cyclist input, the creation of reasonably direct routes between major destinations and the "moderating hand" of the Cycle City Guide map makers. The level of judgement and therefore variation amongst these advisory routes is therefore likely to be high.

Inspection of the mapping suggests that sections of traffic free path (Green) are around parks, along linear features such as canals or are very short in length. The relevant variables from the modelling for traffic free paths include R5, route through park and R6, city centre cycle only route.

Some of the Cycle City Guides (the more recent and the London Guides) show routes adjacent to the carriageway that are traffic free. The nature of these could vary from being inappropriately narrow segregation markings on a footway to proper fully designed traffic free routes. The relevant variable from the modelling is R4, cycle route on footway.

For a limited number of districts, lengths of cycle lane and bus lane are available. The relevant variables from the modelling are R7 (cycle lane) and R10 (bus lane).

The perception of risk along a sign-posted route is independent of whether or not it is signposted and so this variable may not be linked back with the perception of risk models. It may, however, be useful to consider the length of route that is signed as a variable in the main model analysis, as the length of signed route may influence the propensity to cycle.

Table 9.4 provides data on the coverage and lengths by various types of cycle route on the more recent mapping produced by Cycle City Guides. The colours refer to the colour coding for the type of route described above. Total road lengths are also presented along with the proportion of the road length represented by the facilities for cyclists. "jtwb" represents the proportion of the district that cycle for the journey to work.

Table 9.4 Cycle City Guide Coverage

District	Blue	Red cycle lane	Red bus lane	Red total	Green	Brown	Green and brown	jtwb	Road Length	blue%	Red cycle lane%	Red bus lane%	Red total %	green%	brown%	Green and brown %
Barking & Dagenham	21.50	23.67	2.67	26.33	8.40	2.40	10.80	1.65%	323.9	6.6%	7.3%	0.8%	8.1%	2.6%	0.7%	3.3%
Barnet	29.80	11.83	2.36	14.20	24.70	11.20	35.90	1.04%	729.3	4.1%	1.6%	0.3%	1.9%	3.4%	1.5%	4.9%
Bexley	41.90	12.18	1.46	13.63	23.10	5.80	28.90	1.08%	534.9	7.8%	2.3%	0.3%	2.5%	4.3%	1.1%	5.4%
Brent	29.00	4.50	5.08	9.58	17.50	2.00	19.50	1.79%	475.0	6.1%	0.9%	1.1%	2.0%	3.7%	0.4%	4.1%
Bromley	55.00	15.41	2.32	17.72	14.20	9.60	23.80	1.03%	898.5	6.1%	1.7%	0.3%	2.0%	1.6%	1.1%	2.6%
Camden	20.00	7.36	13.14	20.49	4.30	0.80	5.10	4.10%	284.0	7.0%	2.6%	4.6%	7.2%	1.5%	0.3%	1.8%
City of London	9.60	6.41	2.24	8.65	0.00	0.00	0.00	1.92%	59.2	16.2%	10.8%	3.8%	14.6%	0.0%	0.0%	0.0%
Croydon	70.00	32.98	3.08	36.06	11.00	2.00	13.00	1.13%	785.8	8.9%	4.2%	0.4%	4.6%	1.4%	0.3%	1.7%
Ealing	39.40	20.89	10.32	31.21	26.60	12.80	39.40	2.40%	580.8	6.8%	3.6%	1.8%	5.4%	4.6%	2.2%	6.8%
Enfield	3.80	2.40	4.80	7.20	13.40	22.90	36.30	1.29%	574.3	0.7%	0.4%	0.8%	1.3%	2.3%	4.0%	6.3%
Greenwich	43.60	9.92	5.23	15.15	26.60	5.20	31.80	1.57%	487.9	8.9%	2.0%	1.1%	3.1%	5.5%	1.1%	6.5%
Hackney	15.80	1.63	9.65	11.28	8.60	1.00	9.60	6.83%	274.0	5.8%	0.6%	3.5%	4.1%	3.1%	0.4%	3.5%
H.smith & Fulham	37.20	11.97	6.21	18.17	3.20	3.20	6.40	5.21%	222.6	16.7%	5.4%	2.8%	8.2%	1.4%	1.4%	2.9%
Haringey	14.80	1.48	10.73	12.21	12.50	4.50	17.00	2.73%	357.0	4.1%	0.4%	3.0%	3.4%	3.5%	1.3%	4.8%
Harrow	14.90	10.19	1.60	11.79	5.80	6.40	12.20	0.96%	472.5	3.2%	2.2%	0.3%	2.5%	1.2%	1.4%	2.6%
Havering	21.60	11.59	0.68	12.27	8.80	2.40	11.20	0.94%	632.6	3.4%	1.8%	0.1%	1.9%	1.4%	0.4%	1.8%
Hillingdon	17.20	2.62	1.47	4.09	36.60	17.70	54.30	1.88%	721.8	2.4%	0.4%	0.2%	0.6%	5.1%	2.5%	7.5%
Hounslow	39.00	26.49	4.72	31.20	12.50	21.00	33.50	3.35%	484.2	8.1%	5.5%	1.0%	6.4%	2.6%	4.3%	6.9%
Islington	21.30	7.67	14.26	21.93	1.60	0.60	2.20	5.15%	243.9	8.7%	3.1%	5.8%	9.0%	0.7%	0.2%	0.9%
Ken. & Chelsea	14.60	5.38	0.88	6.26	2.00	0.00	2.00	3.26%	209.9	7.0%	2.6%	0.4%	3.0%	1.0%	0.0%	1.0%
Kingston on Thames	17.80	21.44	2.15	23.59	8.40	3.20	11.60	3.42%	336.1	5.3%	6.4%	0.6%	7.0%	2.5%	1.0%	3.5%
Lambeth	35.90	3.66	22.22	25.87	5.60	1.20	6.80	4.47%	391.3	9.2%	0.9%	5.7%	6.6%	1.4%	0.3%	1.7%
Lewisham	43.20	2.51	12.69	15.19	11.30	0.60	11.90	2.00%	448.9	9.6%	0.6%	2.8%	3.4%	2.5%	0.1%	2.7%
Merton	23.00	3.93	3.52	7.45	14.20	4.40	18.60	2.55%	370.8	6.2%	1.1%	0.9%	2.0%	3.8%	1.2%	5.0%
Newham	41.60	9.41	6.21	15.62	13.60	10.00	23.60	1.50%	418.1	9.9%	2.3%	1.5%	3.7%	3.3%	2.4%	5.6%
Redbridge	23.50	0.72	0.12	0.84	11.30	4.20	15.50	0.99%	522.7	4.5%	0.1%	0.0%	0.2%	2.2%	0.8%	3.0%
Richmond on Thames	40.90	12.64	4.98	17.63	35.00	11.40	46.40	4.39%	410.8	10.0%	3.1%	1.2%	4.3%	8.5%	2.8%	11.3%
Southwark	38.80	6.11	17.79	23.90	10.10	2.80	12.90	3.98%	394.2	9.8%	1.5%	4.5%	6.1%	2.6%	0.7%	3.3%
Sutton	36.60	2.02	1.06	3.08	8.00	4.00	12.00	2.33%	420.5	8.7%	0.5%	0.3%	0.7%	1.9%	1.0%	2.9%
Tower Hamlets	28.30	15.73	12.56	28.29	19.30	2.40	21.70	3.24%	284.4	10.0%	5.5%	4.4%	9.9%	6.8%	0.8%	7.6%
Waltham Forest	46.80	24.77	5.98	30.75	9.60	7.40	17.00	1.88%	418.5	11.2%	5.9%	1.4%	7.3%	2.3%	1.8%	4.1%
Wandsworth	54.00	0.70	13.43	14.12	12.60	4.00	16.60	4.22%	423.6	12.7%	0.2%	3.2%	3.3%	3.0%	0.9%	3.9%
Westminster	42.00	7.39	16.45	23.84	7.00	2.60	9.60	3.14%	345.6	12.2%	2.1%	4.8%	6.9%	2.0%	0.8%	2.8%
Basildon	15.00	0.00	0.00	0.00	43.00	0.00	43.00	2.15%	7785.7	0.2%	0.0%	0.0%	0.0%	0.6%	0.0%	0.6%
Blyth Valley	1.20	0.00	0.00	0.00	52.00	0.00	52.00	2.36%	5050.0	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	1.0%
Bradford	0.60	13.00	4.00	17.00	55.20	0.00	55.20	0.84%	1900.7	0.0%	0.7%	0.2%	0.9%	2.9%	0.0%	2.9%
Bristol	26.40	8.00	15.00	23.00	83.20	0.00	83.20	4.94%	1113.2	2.4%	0.7%	1.3%	2.1%	7.5%	0.0%	7.5%
Cardiff	20.60	9.00	4.40	13.40	37.40	0.00	37.40	2.89%	1028.7	2.0%	0.9%	0.4%	1.3%	3.6%	0.0%	3.6%
Chelmsford	17.00	5.133	1.52	0.00	29.00	0.00	29.00	3.86%	7785.7	0.2%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%
Doncaster	8.20	3.00	2.00	5.00	65.00	0.00	65.00	3.13%	1598.4	0.5%	0.2%	0.1%	0.3%	4.1%	0.0%	4.1%
Gateshead	13.40	8.70	4.10	12.80	41.20	0.00	41.20	1.11%	882.4	1.5%	1.0%	0.5%	1.5%	4.7%	0.0%	4.7%
Leeds	13.40	18.00	5.20	23.20	43.70	0.00	43.70	1.40%	2923.8	0.5%	0.6%	0.2%	0.8%	1.5%	0.0%	1.5%
Leicester	29.60	2.20	8.00	10.20	81.60	0.00	81.60	4.32%	792.0	3.7%	0.3%	1.0%	1.3%	10.3%	0.0%	10.3%
Manchester	11.60	31.00	3.00	34.00	44.80	0.00	44.80	3.46%	1371.8	0.8%	2.3%	0.2%	2.5%	3.3%	0.0%	3.3%
Newcastle	7.00	6.93	5.97	12.90	42.40	0.00	42.40	1.89%	909.7	0.8%	0.8%	0.7%	1.4%	4.7%	0.0%	4.7%
Newcastle-u-Lyme	4.90	10.50	0.00	10.50	37.00	0.00	37.00	1.55%	6024.5	0.1%	0.2%	0.0%	0.2%	0.6%	0.0%	0.6%
North Tyneside	3.00	1.00	0.00	1.00	67.00	0.00	67.00	2.18%	754.8	0.4%	0.1%	0.0%	0.1%	8.9%	0.0%	8.9%
Rotherham	2.60	10.60	0.80	11.40	30.80	0.00	30.80	1.02%	1132.2	0.2%	0.9%	0.1%	1.0%	2.7%	0.0%	2.7%
Sheffield	18.00	4.60	13.00	17.60	80.00	0.00	80.00	1.16%	1952.5	0.9%	0.2%	0.7%	0.9%	4.1%	0.0%	4.1%
South Tyneside	17.00	18.30	1.70	20.00	34.50	0.00	34.50	2.07%	563.6	3.0%	3.2%	0.3%	3.5%	6.1%	0.0%	6.1%
Stoke-on-Trent	4.90	10.50	0.00	10.50	37.00	0.00	37.00	1.67%	845.1	0.6%	1.2%	0.0%	1.2%	4.4%	0.0%	4.4%
Wansbeck	22.00	0.00	0.00	0.00	18.00	0.00	18.00	2.31%	5050.0	0.4%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%
York	32.20	57.30	1.90	59.20	78.20	0.00	78.20	13.06%	823.9	3.9%	7.0%	0.2%	7.2%	9.5%	0.0%	9.5%

Note:

1 *All lengths in kilometres, cycle and bus lane lengths measured in one direction.*

2 *The maps for Sheffield and York are not produced by Cycle City Guides but are produced to a similar standard and have therefore been included in the analysis. York off-road, bus lane and cycle lane lengths have been provided by the City of York Council.*

3 *Gateshead, North and South Tyneside bus and cycle lane length data from Gateshead MBC.*

4 *Newcastle cycle and bus lane length data from Newcastle City Council.*

5 *The Map of Bristol is titled "Bristol and Bath", but only the city centre of Bath is covered and so has not been included. Bristol cycle lane and bus lane length data from Bristol City Council.*

6 *The map entitled Stoke-on-Trent includes Newcastle-under-Lyme and the two districts are so inter-related that the total route distances for the two have been taken and divided in two.*

7 *Leicester bus lane and cycle lane length data distinguished by the author and his mother.*

8 *Cycle lane and bus lane length data for Basildon, Blyth Valley, Chelmsford and Wansbeck is not available.*

With the exception of cycle lane lengths for London Boroughs and otherwise as noted, the lengths in the table above have been taken from the mapping using a map measuring wheel. Cycle lane lengths for London have been derived from a GIS based database system operated by the London Cycle Network Plus team based at the London Borough of Camden. Bus Lane length data has been provided by Transport for London. The maps are generally at a scale of 50mm per kilometre. The Sheffield and York maps are at a scale of 40mm per kilometre, with the centre of York being at a scale of 100mm per kilometre.

The districts represented in the above table comprise 1111 wards[1] of the total of 8850 wards in England and Wales. The average of the ward level journey to work percentages for all wards is 2.90% (2.82% excluding Oxford and Cambridge). The average for the Cycle City Guide wards is 2.69%. The Cycle City Guides do not therefore over-represent wards with higher levels of cycle use. The population of the districts represented by the mapping aged 16-74 is 9.033 million and is 24% of the UK population aged 16-74 (37.607million).

Table 9.5 below presents correlations between the lengths and percentages of total road length of different types of route and the percentage of people that cycle for the journey to work from the 2001 census. Correlations including and excluding the City of York are presented because of York having such a high proportion of people that cycle for the journey to work compared with other districts.

Table 9.5 correlations between cycling and route lengths

	Including York		Excluding York	
Route type	**Pearson correlation coefficient**	**significance**	**Pearson correlation coefficient**	**significance**
%BLUE length signposted route	0.190	0.172	**0.323**	**0.019**
%RED cycle lane	0.250	0.071	0.056	0.695
%RED bus lane	**0.335**	**0.014**	**0.587**	**0.000**
%RED total	**0.359**	**0.008**	**0.349**	**0.011**
%GREEN length traffic free path	**0.345**	**0.011**	0.129	0.363
%BROWN adjacent to road route	-0.093	0.507	-0.027	0.847
%GREEN plus BROWN	**0.278**	**0.043**	0.103	0.467
% Total route with facilities	**0.357**	**0.009**	**0.369**	**0.007**

Notes:

1 Emboldened figures indicated correlations significant at the 5% level.

[1] Note that there are six wards, annotated with an asterisk in Appendix C, which comprise part of the fifty wards for which population data is not available because the population size is so small that personal data would be revealed by its release and hence the total number of wards in these districts is actually 1117.

Cycle lanes, bus lanes and hence also the total of bus and cycle lanes correlate with the proportion that cycle when including the City of York at a significance level of less than 5%. Only the presence of bus lanes is significant when York is excluded. Considering the lengths of different types of cycle facility as a proportion of the road length in a district, it can be seen that the bus lanes once again are significant. When York is included in the data, the length of "green" routes (traffic free paths) is significant and when York is excluded, the length of signed cycle route is significant.

In so far as bus lanes[1] are concerned it is apparent that there could be an element of simultaneity rather then correlation taking place. In central London for example, where there are districts with some fairly high proportions that cycle for the journey to work, it would be expected that there would be greater lengths of bus lane for other reasons.

When the total length of all routes with facilities (signing, off-highway and lanes) is considered, the correlation is significant at the 1% level.

A drawing together of the threads

The data that have been collected and available for considering risk to cycling at an aggregate district level are by nature connected with the routes and not with junctions. It would be possible either to eliminate variables for which measures at a district wide level are not available, or to include such variables and make assumptions about their level. The latter course of action has been taken.

Consideration was given in Phase 6, reported above, to the acceptability of cycling based on the Risk Rating relative to the respondents' reported risk threshold level. The probability of acceptability of cycling was found to be related to the time in R7 and R8 with interactions with "regular cyclists" being found for both and interactions with sex being found for R8. The length of time in R1 was also found to be significant for "young" respondents. Various junctions were also found to be important in determining the probability of acceptability of cycling. The Phase 6 logit model variables for route are "times on routes" and such a model will require a definition, for a typical journey to work route, of the periods of time in different conditions at an aggregate level. This is effectively the same process as determining the proportion of a route in different types of condition and this was undertaken in the Phase 7 logit analysis.

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[1] It should be noted that some bus lanes exclude use by cycle traffic, but for the purposes of this analysis it is assumed that, whatever the legal position, cycle traffic would take advantage of a bus lane if it were present.

The Phase 7 model has used the proportion of a route that has facilities and this may more readily be determined directly from mapping data and subsequent modelling in Phase 8 considers in more detail the proportion of routes that have facilities for cyclists.

Table 9.6 below summarises the resulting models from further analysis considering different proportions built up from different route types as noted. A base model without person types has been run for comparison purposes and is shown in the first column of the table. For the models including person type variables, a series of models was run that contained interaction terms for person type with the proportion of routes of different types and the eliminations of variables took placed based on their significance and correlations with related variables.

The only variables from the mapping data that are significant are the proportion of the route that is Green (traffic free and away from the carriageway) and the proportion of route that is brown (traffic free adjacent to the carriageway). The proportion of route that is on carriageway with either a cycle lane or a bus lane is not significant. This is unfortunate bearing in mind the positive correlation found to exist between bus lanes and proportion cycling in Table 9.5 above.

Table 9.6 Logit model results with different proportions for cyclists' facilities

Variable	Model with route split and no person type variables		Model with route split and person type variables		Phase 7 Multiplicative Model	
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
MALE			0.632	3.5	0.620	3.5
OLD			-0.971	-4.9	-1.074	-5.4
SIG	-0.169	-3.1	-0.188	-3.1	-0.185	-3.0
PRGREEN	1.919	2.9	2.297	3.4		
PRBROWN	1.960	2.7	2.383	3.1		
PRRFAC					0.737	2.7
PRRFAC x REGCYC					2.251	2.9
DSIG x YOUNG			-0.728	-2.6	-0.732	-2.6
AVEPARK x YOUNG			-0.019	-1.8	-0.015	-1.6
AVESIDE x REGCYC			0.077	4.5	-0.040	2.0
RT x YOUNG			-0.564	-3.1	-0.518	-3.0
CONSTANT	1.105	8.0	1.306	6.6	1.287	6.4
Final log-likelihood	-494.48		-438.27		-440.55	
Rho-squared w.r.t. constants	0.031		0.141		0.136	
Adjusted rho-squared	0.025		0.121		0.119	

Notes

1 The multiplicative Model from Phase 7 is provided for comparative purposes and represents a model in which the total proportion of route with facilities is modelled as opposed to the proportions of route of different type (green, brown etc.)

It can be seen that the person type variables are significant determiners of the probability of acceptability of cycling. Being male increases the probability of acceptability, but being old reduces the probability of acceptability. It should be noted that being young in combination with having to pass through a traffic signal controlled junction, travel past on-street parking and undertake right turn manoeuvres reduces the probability of acceptability of cycling. The model is detecting some age related differences in the perception of specific features of a cycle journey. Relative to less regular cyclists, regular cyclists are less averse to crossing side roads, but the effect is relatively small.

The Phase 7 model that includes the total proportion of route that has facilities (that is green and brown for off-road routes and red for cycle and bus lanes) is similar to the model where the type of route is split down by route type. Regular cyclists value the facilities more highly than others and the quantum of the perceived benefit of facilities is diluted by the presence in the total of on-road cycle and bus lanes.

Use of the mapping and the results in the modelling

The mapping data above may be used in two ways within the main modelling. Firstly, the actual lengths of each type of provision may be used directly in the modelling of the sample of 1111 wards. In other words, the lengths of on-road facility and off-road facility may be used as indicator variables. Secondly, the data may be used to determine a measure of the acceptability of cycling based on perceptions of risk. Two models may be used, the model resulting from the Phase 7 analysis and the model where the route types are split, both of which are summarised in Table 9.6 above. Equation 9.2 specifies the model where the route is split by type below:

$$\Pr = \frac{1}{(1 + e^{-(1.306+0.632.sex-0.971.old-0.188.sig+2.297prgreen+2.383.prbrown-0.728.dsig.young-0.019.avepark.young+0.077.aveside.regcyc-0.564.rt.young})}$$

Equation 9.2

Translating the model for use at an aggregate level it would be possible to substitute the dichotomous variables for sex and age by the proportion of the ward that is male and in the appropriate age bracket from census data. It will be possible to determine a proportion of green and brown route by dividing the length of green and brown route by the total length of road in the District.

There is no data at district level for the variables SIG, DSIG, AVEPARK, AVESIDE, RT and REGCYC and it is proposed to use mean values from the primary survey as representative of these variables. Out of the sample of the 141 respondents remaining after the Phase 3 eliminations in Chapter 8, 112 noted the presence of signals on their journey to work with the total number of signals for the sample being 278. Combining the 112/141 with the coefficient -0.728 creates a variable -0.578.YOUNG and combining the 278/141 with the variable -0.188 creates a reduction on the constant of 0.371. The mean value for AVEPARK is 2080.71/141, for AVESIDE is 2066.407/141, for RT is 123/141 and for REGCYC is 0.257 (see Table 7.10). Putting these values into Equation 9.2 and grouping the variables gives the following Equation 9.3.

$$\Pr = \frac{1}{(1 + e^{-(1.225+0.632.sex-0.971.old-1.351.young+2.297prgreen+2.383.prbrown})} \qquad \text{Equation 9.3}$$

Similarly for the resulting model from Phase 7 the resulting model becomes:

$$\Pr = \frac{1}{(1 + e^{-(0.772 + 0.620.sex - 1.074.old - 1.255.young + 1.315prrfac})} \quad \text{Equation 9.4}$$

9.5 Conclusions

The change from the analysis of a Risk Rating (Chapter 8) to the probability of acceptability of cycling in different conditions of apparent risk has removed an element of the variation in the data and at the same time reduced the data set to a measure which has potential application at a district wide level.

The resulting measure for acceptability comprises person type data including age and sex and a measures for the proportion of a route that is traffic free (route types R4, R5 and R6 from the survey representing a cycle track on footway, a route through a park and a route on a traffic free town centre road). It might be surmised that the analysis has shown that the only important journey variable in respect of the perception of risk is the proportion of a journey that takes place along traffic free routes. Such a conclusion would be inappropriate because it is clear from earlier analyses, both the non-linear regression analyses in Chapter 8 and the dichotomous choice based analyses in this chapter, that there are many other journey attributes which, particularly when applied multiplicatively with indicators for person type, show a good degree of explanatory power in the variation in the observed Risk Ratings from the survey.

Nonetheless, based on the data that has been available as part of this research to describe the conditions as they might affect risk in a district, it has been shown that the proportion of route that is traffic free is the most significant (Equation 9.3). The provision of facilities on-carriageway, for example cycle lanes and bus lanes, has been found to explain the variation in level of acceptability of cycling from the survey data only when forming part of an overall measure of the proportion of a journey that has cycle facilities (Equation 9.4).

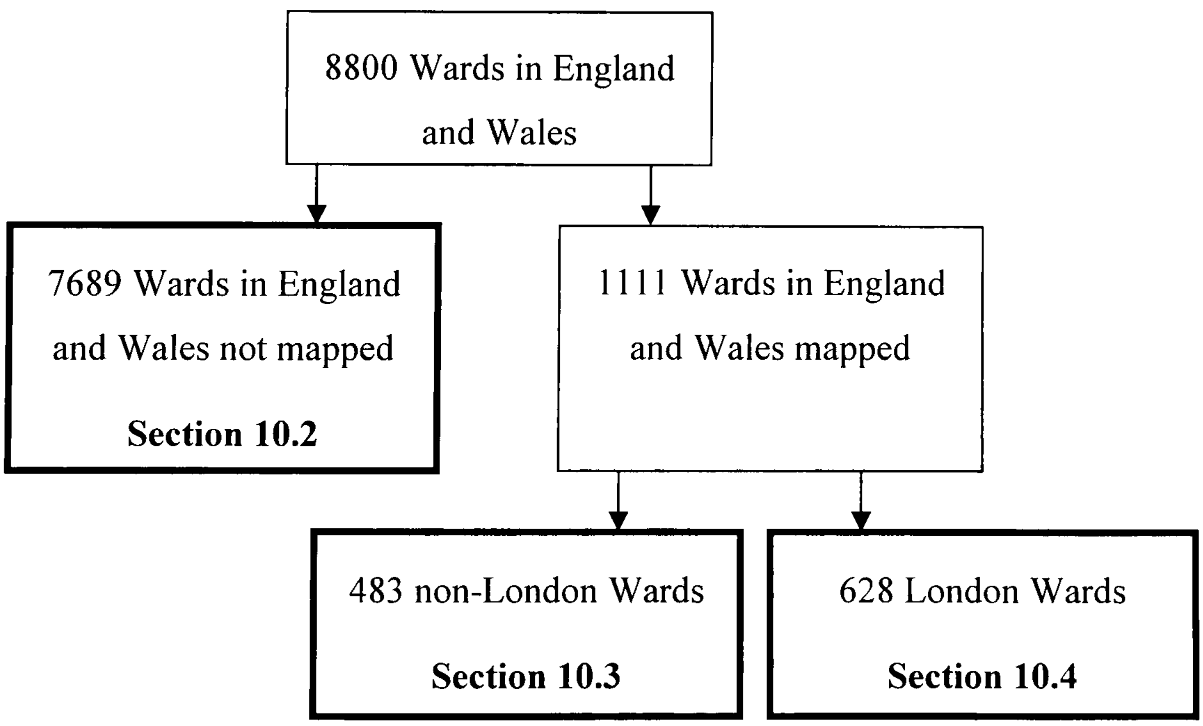
The use of a measure for risk for the 1111 wards for the 52 districts where mapping data is available will be possible and this may be carried out based on both the lengths of infrastructure of different types available to cyclists, that is the mapping data being used as an explanatory variable, and also based on an indicator of acceptability of cycling using the resulting Equations 9.3 and 9.4 above. This analysis is presented in Chapter 10.

Chapter 10 Models of variation in cycle use for the journey to work

10.1 Introduction

This chapter is divided into three sections. Section 10.2 deals with the analysis of the variation in the use of the bicycle for the journey to work in England and Wales but excludes the measure for acceptability of cycling determined from the analysis in Chapter 9. The measure for risk for these models relies on the alternative measure of network density and is based on the 7689 wards in England and Wales for which mapping data is not available (see Table 9.4 for a list of districts where mapping data is available). Section 10.3 describes models for the 483 non-London wards in the England and Wales for which mapping data is available and that therefore include the measure for acceptability of cycling and infrastructure measures discussed in Chapter 9. Section 10.4 describes a similar analysis as in Section 10.3, but for the 628 wards in London. Figure 10.1 below summarises the separate models.

Figure 10.1 Summary of variation in cycle use modelling



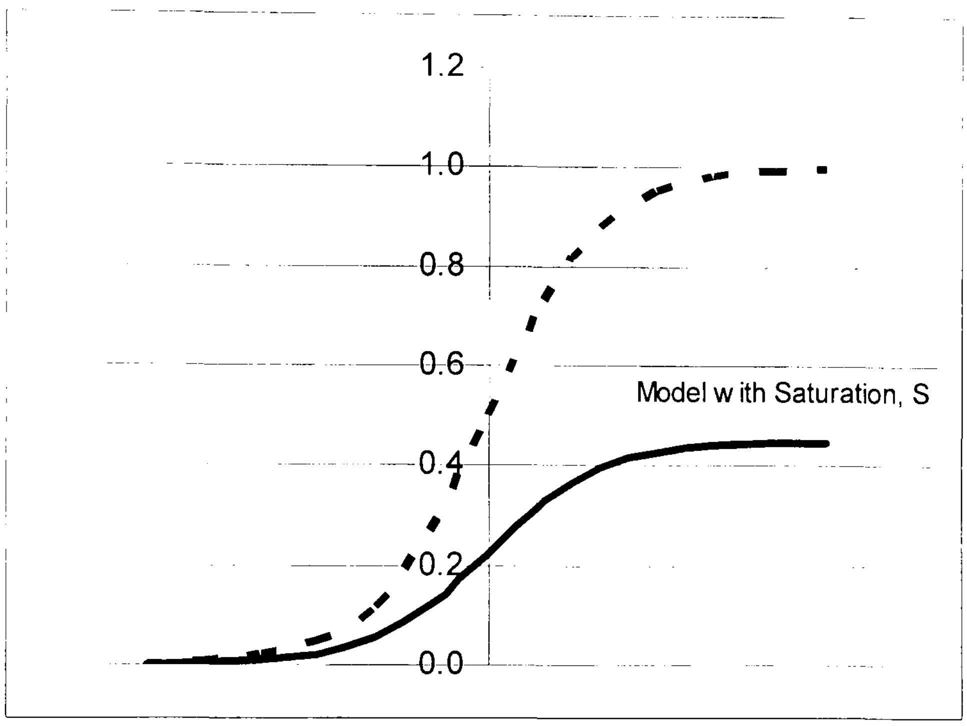
Preliminary analysis began without differentiating London but was unable to produce meaningful results and the reasons for this become clear by comparing the results for the London model with the other models. Section 10.5 compares modelled results with observed proportions for the journey to work and draws conclusions from the modelling.

The model form adopted is the non-linear regression model introduced and discussed in Chapter 5 and repeated in Equation 10.1 below.

$$P_i = \frac{S}{(1+e^{-Z_i})} \text{ Equation 10.1}$$

The model is a logit model, but with a saturation level of S rather than unity as shown in Figure 10.2.

Figure 10.2 Main model logit model with Saturation, S.



The saturation level, S, for cycling would be anticipated to lie at or above about 0.40, that is, at about the maximum observed level from the census data. The level of the saturation is a function of the most favourable set of current circumstances and conceivably these may be improved upon, leading to a possible future higher value for S. However, the use of a saturation level constrains the upper boundary to a more realistic level than the use of unity and evidence from Europe indicates that a level of around 50% bicycle use may be a realistic saturation level. For the non-mapped wards the maximum proportion that uses the bicycle for the journey to work is 35%, for the non-London mapped wards it is 20% and for the London mapped wards it is 10%. The utility, Z_i, is the sum of a set of attributes as identified in Table 10.1 below. All census data variables, with the exception of ethnicity, are related to employees and have been derived from Census 2001 Standard Tables. Ethnicity is derived from Key Statistics data and is presented as a proportion of the population in a ward.

Table 10.1 Independent variables tested against the dependent variable percentage journeys to work by bicycle

Coefficient	Description
A1	Percentage of males of all employees aged 16-74
A2	Percentage of employees aged 16-24
A3	Percentage of employees aged 25-34
A4	Percentage of employees aged 35-49
A5	Percentage of employees aged 50-59
A6	Percentage of employees aged 60-64
A7	Percentage of employees aged 65-74
A8	Percentage of employees with higher level qualifications
B1	Percentage of employees in households with no car
B2	Percentage of employees in households with 1 car
B3	Percentage of employees in households with 2 cars
B4	Percentage of employees in households with 3 cars
B5	Percentage of employees in households with 4 or more cars
B6	Average number of cars per employee
C1	Percentage of employees in Socio-Economic classification 11
C2	Percentage of employees in Socio-Economic classification 12
C3	Percentage of employees in Socio-Economic classification 20
C4	Percentage of employees in Socio-Economic classification 30
C5	Percentage of employees in Socio-Economic classification 40
C6	Percentage of employees in Socio-Economic classification 50
C7	Percentage of employees in Socio-Economic classification 60
C8	Percentage of employees in Socio-Economic classification 70
C9	Percentage of employees in Socio-Economic classification "student"
D1	Percentage of all people aged 16-74 that are non-white.
E1	Percentage of journeys to work in distance band under 2km
E2	Percentage of journeys to work in distance band 2-5km
E3	Percentage of journeys to work in distance band under 5-10km
E4	Percentage of journeys to work in distance band under 10-20km
E5	Percentage of journeys to work in distance band under 20-30km
E6	Percentage of journeys to work in distance band under 30-40km
E7	Percentage of journeys to work in distance band under 40-60km
E8	Percentage of journeys to work in distance band under 60km plus
E9	Average distance to work
F1	Percentage of principal road length with negative residual life or UKPMS score 70+
F2	Percentage of non-principal road length with UKPMS score 70+
F3	Network Density (total road kilometres divided by area)
F4	Traffic Intensity (total number of age16-74 workers divided by total road length)
F5	Population density (total population aged 16-74 divided by area)
H1	Percentage of 1km squares with mean slope 3% or greater
H2	Percentage of 1km squares with mean slope 4% or greater
I1	Total annual hours of sunshine for the year May 2000 to April 2001
I2	Total annual millimetres of rainfall for the year May 2000 to April 2001
I3	Basic wind speed for structural design
I4	Mean temperature for the year May 2000 to April 2001

10.2 Analysis of the 7689 non-mapped wards

Many of the 44 variables are measuring the same propensity but in a different metric (e.g. Hill3 and Hill4). Where there are variables of proportions in different bandings (for example car ownership classed by number of cars) one of the variables needs to be omitted and becomes the variable against which the others are compared (analogous to the omitted category with categorical variables). For these reasons not all of the variables will appear in the final model and the following order of procedure has been adopted to develop the final model:

- Create a model containing all individual variables apart from Hill4 and one excluded variable from each of the groups of banded variables.
- Eliminate variables displaying high correlation and that are not significant or otherwise of limited value in adding explanatory power to the model.
- For each of the groups of banded variables, eliminate the non-significant variables and replace the omitted variables as required to improve the power of explanation of the model.
- Test powers of the overall average variables for cars per employee and average distance.
- Test whether the 3% or the 4% variable for hilliness is the better indicator.

The resulting model is shown in Table 10.2 and presents the coefficient value, the t-statistic and the elasticity for the parameter. The results are presented for the 7689 non-mapped wards.

Table 10.2 The model using the 7689 non-mapped wards

Variable	Coefficient	t-stat.	Elasticity
S, saturation constant	0.4940	18.70	
employees aged 35-49	-1.1236	-5.39	-0.414
employees aged 50-59	-0.7990	-2.92	-0.168
employees aged 60-64	6.1271	7.74	0.268
Employees aged 16-34 and 65-74	Base		
employees with higher level qualifications	2.6102	15.84	0.561
employees in households with no car	-1.5201	-7.96	-0.092
employees in households with 1 car	3.5215	24.89	1.225
Employees in households with 2, 3 and 4+ cars	Base		
SEC11: Higher Man. & Prof. in large employers	-1.2940	-2.75	-0.061
SEC20: Lower Man. & Prof.	-5.1760	-16.14	-1.289
SEC30: Intermediate occupations	-1.7105	-4.98	-0.197
SEC40: Small employers and own account workers	-3.8345	-14.63	-0.448
SEC70: routine occupations	-2.6195	-7.37	-0.289
SEC12, 50, 60 higher prof., lwr. super. & technical, semi-routine.	Base		
Percentage non-white	-1.3058	-8.37	-0.040
Distance less than 2km	-0.4662	-6.03	-0.140
Distance 5-10km	-1.9311	-14.70	-0.347
Distance 10-20km	-1.1913	-8.78	-0.187
Distance 2-5km and 20km and over	Base		
Principal roads with defects	-0.3747	-3.94	-0.042
Non-Principal roads with defects	-0.9084	-8.99	-0.080
Network Density	-0.0715	-16.46	-0.192
Population Density	0.0001	10.40	0.063
Hilliness	-1.4120	-48.16	-0.935
Rainfall	-0.0005	-14.66	-0.556
Temperature	0.0616	5.80	0.554
R^2	0.591		
$\overline{R}^2$	0.590		

Notes: The adjusted R^2, $\overline{R}^2$ is defined as in the note to Table 8.2. Elasticity is determined about the mean value for the variable. For example, a 10% increase in the value of the variable for hilliness at the mean value for hilliness will create a 9.35% reduction in the proportion cycling for the journey to work (note this latter is not a percentage point reduction). It should be noted that a 10% increase in the employees in age band 35-49 is likely to be associated with some reduction in percentages in other bands and so the elasticities need to be read accordingly.

The non-linear regression model based on the logit model with an upper bound to be estimated produces reasonable powers of explanation (adjusted R-squared 0.590) of the variation in propensity to cycle for the journey to work based on age, level of qualifications, car ownership, socio-economic classification, ethnicity, distance to work, state of the road surface, network density and population density, hilliness, rainfall and mean temperature. The estimate for the saturation constant, *S*, indicates an upper limit on proportion that would cycle for the journey to work of approximately 49%. This compares well with the ward with the highest proportion of cycle to work journeys in Cambridge of 35.38%.

It is instructive for a moment to consider the variables that do not appear in the model. The variable for the proportion of employees that are male was correlated with the constant (0.7) and this is to be expected because the percentage that is male does not vary a great deal. It is not therefore possible to explain variation in cycle use based on the proportion of male employees in a ward. The variables for wind and sunshine were also correlated with the constant and were similarly eliminated. Again this is because their variation is not that great. Traffic intensity was intended to be a measure of the degree of trafficking on the highway network but was not significant. Howver, the similar measure of population density was significant and remains in the model.

Wards with high proportions of people in the age brackets 35 to 49 and 50-59 are linked with lower proportions that cycle to work, but a larger proportion in the age bracket 60-64 increases the proportion that cycle for the journey to work. The omitted classifications are for the two age brackets younger than 35 and for those aged over 65, this latter being a small proportion of employees in any case. The positive sign for the age bracket 60-64 is unexpected, but the negative signs for the age brackets covering the ages 35 to 59 could reflect a "missing generation" of cyclists.

A ward with a higher proportion of people with higher level qualifications will have more people that cycle for the journey to work. An easy but inappropriate conclusion may be that intelligent people cycle. A more appropriate explanation may be that longer periods in education in formative years may create a habit that continues in later life[1].

If the proportion of employees in households with no cars is greater, then the less is the proportion that cycle. This is counter-intuitive, but the elasticity of this effect is low. The rate of use of the bicycle for the journey to work increases with an increasing proportion of employees from households with one car. This finding would seem to indicate that, at a level of one car, a household is active, but using the bicycle as the second mode of transport. The omitted classifications are proportions of employees from households with two cars, three cars and four or more cars and it would be expected that these higher car ownership levels work against the use of the bicycle. An overall measure, the number of cars per employee in a ward, was not significant but had a coefficient (-0.155) of correct sign, confirming that an increase in the number of cars per employee would result in a reduction in the use of the bicycle for the journey to work. The finding of the positive coefficient for the proportion of employees in households

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[1] Note that the dependent variable in the analysis is the percentage that cycle for the journey to work, which excludes educational journeys, and so the proportion of students in a ward is of only secondary relevance. The proportion of students in a ward was introduced in some models as a possible explanatory variable (C9 in Table 10.1) but was found not to be significant and of intuitively wrong sign, that is it implied that a higher proportion of students in a ward would be linked with a reduction in the proportion that cycle for the journey to work.

with one car supports a notion that responses to bicycle use are now in the context of a "post-motorised" society with many households having access to multiple numbers of cars (see Table 6.5).

Every socio-economic classification in the model has a negative coefficient and hence a rise in proportion of each of these classifications reduces the proportion cycling for the journey to work. These estimated effects are relative to the omitted classifications (SEC1.2 higher professional occupations, SEC50 lower supervisory and technical occupations and SEC60 semi-routine occupations). It is not possible rigidly to conclude that "higher" or "lower" classifications have distinct positive or negative links with the proportion cycling for the journey to work.

A higher proportion of non-white residents reduces the proportion of employees cycling for the journey to work, but the elasticity is relatively low. This finding indicates the potential for cultural heritage to play a part in the choice for or against cycling for the journey to work.

Journey to work distance is represented in the model by the bands under 2km, 5-10km and 10-20km. The omitted band, 2-5km does not have a negative effect and hence for wards with high proportions of distance to work in this band, higher proportions of cycle use may be anticipated. For the "under 2km" band the negative coefficient is likely as a result of bicycle use not being worthwhile, walking may be a better alternative. For the higher distance bands the negative effect relative to the omitted category of 2-5kilometres is a reasonable finding. It may be noted in passing that, at average journey speeds in the range 5mph to 15 mph, the time range for journeys between 2km and 5 km is between 5 minutes to 38 minutes and represent reasonably short commuting journey times.

A measure based on the average distance of the journey to work at ward level, the square of this value and the exponential of this value, were also tried but models with these representations of the distance were less powerful in explaining the variation in cycle use than the greater detail offered by the distance bands. The coefficient for average distance (0.032) was also of wrong sign.

It is interesting to note the effect of the measure for the pavement condition of the principal and non-principal highway. The higher the defects score is, the less the proportion that cycle for the journey to work. The indication from this model confirms a view that poorly maintained surfaces are both less pleasant to cycle along and also take a greater amount of energy to traverse than well maintained roads.

Network Density, traffic intensity and population density are three measures that are inter-related. Network density remains included as a measure that reflects the level of complexity of the road network. A variety of potential effects could be deduced from this measure. Firstly, it could reflect the ease of making journeys with denser networks providing more journey opportunities. Conversely, the higher the Network Density, the higher the number of intersections and hence levels of hazard. The sign of the coefficient in the model indicates that increasing network density is linked with lower proportions of people that cycle for the journey to work and so is perhaps more positively linked with this latter perception of greater hazard for greater network density. Traffic intensity did not remain significant in the model but is perhaps represented to some extent by population density. An increase in population density has the effect of increasing the likelihood of cycling for the journey to work with the implication that a higher population density is in an urban area. The coefficient is small but this is due to the average size of the variable and so the elasticity is in line with, but opposite sign to, the elasticity for network density.

Hilliness is a significant indicator of proportion that cycle for the journey to work. This may be surmised a priori simply from a knowledge of where the areas in England and Wales are that have a higher proportion cycling for the journey to work (see Chapter 2). It is also interesting to note the relatively high impact of rainfall (even despite its nature, that is, more as a regional indicator, than a specific ward level value for rainfall). Mean temperature has remained in the model as another physical variable and indicates that higher mean temperatures lead to a greater proportion cycling for the journey to work.

Insofar as the physical variables are concerned, the model has estimated coefficients that reasonably confirm what might be expected. The mix of socio-economic variables that remain significant has not painted as clear a picture as might have been desired, but the results do to some extent challenge thinking, for example in relation to the variation in bicycle use with respect to car ownership and about the current state of socio-economic variables in relation to mode choice.

10.3 Analysis of 483 mapped non-London wards

Two measures for the probability of acceptability of cycling have been used to estimate a model for the proportion that cycle for the journey to work. These two measures are described by Equations 9.3 and 9.4 in Chapter 9. For a measure of the physical routes over which a cyclist has to make a journey to work, the probability of acceptability described in Equation 9.3 uses the proportions of route in a district that are traffic free and remote from a carriageway (green routes) and adjacent to the carriageway (brown routes). The probability of acceptability in Equation 9.4 uses the overall proportion of routes that have cycle facilities (traffic free routes and on-highway facilities such as cycle and bus lanes). In addition the probabilities of acceptability are explained by the variables sex, old and young. These three variables are dichotomous variables for the person being male, being 45 or older and being 34 or younger. The measures for sex, old and young adopted in Equations 9.3 and 9.4 for the estimation of the probability of acceptability of cycling are, at ward level, the proportion of employees that are male, the proportion of employees that are 50 or older and the proportion of employees that are 34 and younger. The mean, minimum and maximum values for these measures for probability of acceptability for the wards with mapping data are shown in Table 10.3 below.

Table 10.3 Value range and mean for the Probability of Acceptability measure

	Probability of Acceptability based on Eqn 9.3 (proportion of routes green and brown)	Probability of Acceptability based on Eqn 9.4 (proportion of routes with cycle facilities)
Mean	0.71	0.61
Minimum	0.64	0.55
Maximum	0.76	0.66

The measures for the probability of acceptability of cycling represent the nexus between the stream of work described in Chapters 7 through to 9 on the perception of risk and represent the first attempt there has been at deriving an area wide measure for perception of risk of cycling that is independent of accident data.

As well as the measures for the probability of acceptability of cycling, the more direct metric of the proportion of the network available to cyclists that is of different types (signed/blue, cycle lane and bus lane/red, traffic free remote from carriageway/green and traffic free adjacent to carriageway/blue) has been analysed as well as the proportion of the total length of route with cycle facilities (blue plus red plus green plus brown). The proportions have been determined relative to the total road length in a district. Figure 10.3 below summarises the four models tested.

Figure 10.3 The four models tested with mapping data

A Probability of acceptability from Green and Brown Routes only (Eqn. 9.3)	**C** Direct use of proportions of routes of different types (green, blue etc.)
B Probability of acceptability from overall proportion of routes with facilities (Eqn. 9.4)	**D** Direct use of overall proportion of routes with facilities

The model that contains the probability of acceptability measure and explains the most variation is the model that contains the probability of acceptability derived from Equation 9.4 (B in Figure 10.3). The model that explains most of the variation using the measure of the proportion of route of the different types is the model that contains the proportions of the routes individually (that is, not summed) (C in Figure 10.3). These two models, are shown in Table 10.4 below.

Table 10.4 The model using the 483 mapped non-London wards

	Model with Probability of acceptability			Model with proportion of routes of different type		
Variable	**Estimate**	**Est/SE**	**Elasticity**	**Estimate**	**Est/SE**	**Elasticity**
S, saturation constant	0.5332	1.81		0.2183	10.21	
employees aged 35-49	-6.1037	-5.70	-2.248			
employees aged 50-59	-3.3261	-2.63	-0.599	-3.4829	-2.88	-0.611
employees aged 60-64	19.9108	5.13	0.686	19.1490	4.88	0.643
employees in households with no car	-3.8272	-7.35	-0.524	-1.6277	-3.39	-0.217
employees in households with 1 car	2.1651	3.02	0.947	1.8952	3.10	0.808
SEC11	-18.6457	-5.17	-0.692	-22.3618	-6.74	-0.809
SEC20	-3.2008	-2.54	-0.761			
SEC30	-11.4008	-8.14	-1.536	-9.6329	-7.09	-1.265
SEC40	-7.1103	-3.66	-0.544	-10.5838	-5.08	-0.790
SEC70	-8.2848	-5.78	-1.126	-7.7450	-8.01	-1.026
Distance less than 2km	-2.3551	-6.89	-0.636	-2.4362	-6.61	-0.641
Distance 5-10km	-4.0070	-7.34	-0.852	-4.7153	-7.84	-0.977
Distance 10-20km	-3.7634	-5.39	-0.551	-3.7530	-5.23	-0.535
Non-Principal roads with defects				-3.2047	-8.21	-0.305
Network Density				-0.1408	-4.92	-0.779
Population Density	0.0001	2.77	0.159	0.0003	2.88	0.344
Hilliness	-1.8073	-11.18	-1.139	-1.5677	-10.80	-0.963
Rainfall	-0.0007	-5.27	-0.777	0.0009	3.70	0.899
Temperature	0.2540	3.66	2.227	0.4367	7.54	3.732
Probability of acceptability	8.4269	3.96	4.931			
Proportion of signed route				43.5077	10.64	0.460
R^2	0.769			0.822		
$\overline{R}^2$	0.759			0.814		

Of all the proportions of route of different type, the only variable with a significant parameter was the proportion of signed route (blue route on the mapping). The variables for "higher level qualifications", percentage non-white and "principal roads with defects" are not significant in any of the 483 ward models. In addition, in the model containing the measure for the probability of acceptability, the "non-principal road defects" variable and the network density variable are not significant. Meanwhile, in the model containing the proportion of route that is signed, the variables for percentage of employees aged 35-49 and socio-economic classification 20 (lower managerial and professional occupations) are not significant. These eliminations are as a result of the greater predictive power offered by the newly introduced variables. The variable for probability of acceptability has a high elasticity and this is encouraging. What is discouraging is the variation in the saturation level between the models and the lack of significance of the saturation level for the model including the probability of acceptability.

Both models summarised in Table 10.4 are based on the 483 wards where there is mapping data available for cycle facilities. The alternative variable, which has been suggested for locations where cycle facilities data is unavailable, is network density. It might be possible to bring the powers of explanation of the non-mapped wards together with the powers of explanation of the additional data provided by the mapping data by adopting a variable for network density only where mapping data does not exist. This has been attempted but a reasonable model has not been possible to create: the coefficients for the mapping data variables "proportion of route that is blue" and probability of acceptability" were both of wrong sign.

10.4 Analysis of 628 mapped London wards

Preliminary modelling was undertaken including London with the other wards but it became clear that the relationships between the dependent variable and the independent variables were different in London than elsewhere. This is likely as a result of its dense but extensive urban nature and its better public transport. An attempt was made to account for these differences with a single dichotomous variable to represent the "London effect", but this was not successful. Consequently modelling has been undertaken for London separately and Table 10.5 summarises the results.

Table 10.5 The London models

	Model without mapping data			Model including routes		
Variable	**Estimate**	**Est/SE**	**Elasticity**	**Estimate**	**Est/SE**	**Elasticity**
S, saturation constant	0.2177	4.95		0.1775	5.76	
employees aged 35-49	3.9164	6.62	1.272	3.2924	5.42	1.042
employees aged 50-59	-3.7547	-3.85	-0.524	-2.7527	-2.77	-0.374
employees aged 65-74	-14.5554	-3.84	-0.208	-17.7330	-4.63	-0.246
employees with higher level qualifications	4.7486	11.24	1.674	4.8496	10.99	1.666
employees in households with 1 car	-0.8295	-2.08	-0.334	-0.7714	-1.97	-0.303
SEC11	-9.4029	-7.38	-0.554	-7.8602	-5.99	-0.451
SEC12	-6.4630	-6.64	-0.673	-7.6645	-7.48	-0.777
SEC40	-3.3011	-2.32	-0.270			
Percentage non-white	-1.9772	-12.10	-0.499	-1.9266	-11.44	-0.474
Distance less than 2km	-0.8010	-2.97	-0.173	-0.8543	-3.16	-0.180
Distance 2-5km	-2.6597	-7.01	-0.591	-2.5850	-6.75	-0.560
Distance 20-30km	-9.7695	-7.72	-0.409	-9.8735	-7.80	-0.402
Non-Principal roads with defects	1.0863	6.13	0.104	0.8494	4.66	0.079
Network Density	-0.1254	-9.44	-1.187	-0.1242	-9.32	-1.145
Population Density	0.0002	9.21	0.817	0.0002	8.12	0.711
Hilliness	-1.0593	-13.15	-0.391	-1.1328	-13.52	-0.407
Proportion of route that has bus lane				7.9036	6.03	0.127
R^2	0.764			0.778		
$\bar{R}^2$	0.758			0.771		

The variable "probability of acceptability" was not significant in either of its two forms according to Equations 9.3 and 9.4 and, so far as proportions of route of different types for cyclists is concerned, the only variable that was found to be significant is the variable for the proportion of route that has bus lane. A model using the overall proportion of routes with facilities had a marginally lower power of explanation than the model with just the proportion of bus lane.

There are a number of differences between the London model and the other models and these are summarised below:

- Age: The number of employees aged 35-49 has a positive link with the proportion that cycle for the journey to work. This might indicate that there is less size to the "missing generation" of cyclists found for the model for the rest of England and Wales.
- Car availability: The higher the proportion of households with one car, the less the proportion that cycle for the journey to work. This finding is different than for the rest of England and Wales and indicates a different relationship between car availability and cycling. It should be noted that car ownership patterns are different in London than the rest of the UK with the mean proportion of employees in households with one car being 44.9% as compared with the England and Wales mean of 37.7%. There is also a higher proportion of employees in households with no cars in London (22.3% mean) compared with England and Wales (8.0%). (See Table 6.5)
- Socio-economic classification: A smaller range of socio-economic classifications (SEC11, higher managerial occupations in large employers, SEC12, higher professional occupations and SEC40, small employers and own account workers) is linked with smaller proportions cycling for the journey to work. Compared with the rest of England and Wales a wider range of the social strata cycle for the journey to work in London.
- Distance: Distance ranges of less than 2km, 2-5km and 20-30km have a negative link with cycling for the journey to work. The shortest "distance omitted" category is 5km-10km. At average journey speeds of between 10mph and 15 mph this distance range equates with journey times of between 13 and 38 minutes and are not unreasonable. The difference with the rest of England and Wales indicates the reality of London being a very large metropolitan area.
- Hilliness: The elasticity to hilliness is less than for the rest of England and Wales and is to be expected based on the generally flatter nature of London.
- Weather factors: The variables for weather do not appear in the London model and are as a result of the climatic conditions being based on regional variation and hence a constant for all of the London boroughs.

10.5 Comparisons of actual with modelled proportions and conclusions

It was originally envisaged that a model for the whole of England and Wales would be created to explain the variation in cycle use for the journey to work and considerable efforts have been made on the route to creating such a unified model. However, careful study of the resulting models, and differences between the models, indicated that this was not going to be possible, mainly because of the effect of London. Consequently, three models have emerged. One for non-London wards where mapping data is not available, one for non-London wards where mapping data is available and, finally one for London wards. The lack of unification, does, however, lend additional credence to the results as they point to some differences between London and the remainder of England and Wales that are reasonable.

Insofar as the mapping is concerned, it has been shown that a model, at least not for London, has been created that uses the measure for probability of acceptability derived from the primary data and analysis of the perceptions of risk of commuters, both cycling and non-cycling commuters. The policy sensitive variable is the total proportion of a journey that has cycling facilities and this influences the probability of acceptability and the proportion that may use the bicycle for the journey to work. A slight doubt is cast on this conclusion when the result of the model for England and Wales is considered that includes proportions of different types of route: only the proportion of route that is signed was significant. This finding, however, is equally policy sensitive and indicates that a local authority should not neglect signing routes that are appropriate for cyclists to use for the journey to work. Not only does signing point to the infrastructure (either of a specifically cycling nature, or perhaps part of the general highway infrastructure of an area) and hence form part of the infrastructure, it also alerts cyclists to its presence and in some subtle way may advertise, promote and change attitudes towards the use of the bicycle for the journey to work. On the one hand it is encouraging that the two models for mapped wards for England and Wales have pointed to two different aspects of infrastructure provision (proportion of a journey with cycle facilities and, separately, signing). It is disappointing that the model that includes "proportions of route of different types" does not indicate more positively the effects hinted at in the model that contains the "probability of acceptability" of cycling.

Insofar as London is concerned, neither the measure for probability of acceptability nor the proportion of routes that are signed were shown to be significant, but the proportion of routes with bus lanes were shown to be significant. This effect, more so than with probability of acceptability and proportion of route that is signed, could be caused by simultaneity.

It has been shown that socio-economic factors and distance effects are important in both the England and Wales and London models, but in subtly different ways. In London a wider age range of people, of wider socio-economic background and living further from their place of work may be expected to cycle than in the rest of England and Wales.

The interesting effect of a "post-motorised" society is postulated where it is employees in households with one car that are more likely to cycle than their numerous counterparts in households with more than one car. This effect is not found in London where there are generally higher proportions of employees in households with fewer cars than in the rest of England and Wales.

Table 10.6 below provides actual and modelled cycle proportions for the journey to work based on the models summarised in Tables 10.2, 10.4 and 10.5. The first eight districts listed in the table are the first districts in rank order with cycle proportions for the journey to work above

0%, 1%, 2% etc. and represent a spread across the different levels of use of the bicycle for the journey to work. The last two districts are included because they were places in which some of the video for the primary data collection was taken.

Table 10.6 Actual and forecast cycle proportions for twelve districts

District	Actual district cycle proportion	Modelled proportion
Bradford T10.4	0.84%	1.08%/0.89%
Rotherham T10.4	1.02%	1.19%/1.27%
Lewisham T10.5	2.00%	2.28%/2.41%
Doncaster T10.4	3.14%	3.80%/3.71%
Camden T10.5	4.12%	3.95%/4.40%
Islington T10.5	5.16%	4.71%/5.72%
Hackney T10.5	6.82%	6.21%/6.77%
York T10.4	13.02%	12.60%/13.01%
Bolton T10.2	1.35%	1.13%
Leeds T10.4	1.39%	1.22%/1.25%

Notes:

1. *The designation after the district name indicates which table the modelled proportion is taken from.*
2. *The two modelled estimates for Table 10.4 are the estimates with the probability of acceptability and proportion of signed route respectively.*
3. *The two modelled estimates for Table 10.5 are the estimates without mapping and with mapping respectively.*

At a district level it may be seen that the model is good at differentiating the different levels of cycle use for the journey to work.

The findings confirm that:

- Hilliness and climate, two policy insensitive variables, have an important effect on the levels of use of the bicycle for the journey to work.
- There appears to be a missing generation of cyclists in the age range 35 to 59, but this is less marked in London where people up to the age of 49 are more likely to cycle than in the rest of England and Wales
- If car ownership is at a level of one car per household, as opposed to higher levels, there is a greater link with higher use of the bicycle for the journey to work and this perhaps indicates a "post-motorised" society.
- Employees in the socio-economic classifications lower supervisory and technical occupations, semi-routine occupations and higher professional occupations are more likely to use the cycle for the journey to work than other classes, however the differences are not marked and in London a wider spread of classes are likely to cycle, with only higher managerial and professional occupations and small employers and own account workers being less likely to cycle.

- For England and Wales distances for the journey to work of between 2km and 5km do not suppress the proportion that cycle for the journey to work, as do other distance bands. However, for London the distance band that is associated with greater cycle use for the journey to work the longer distance band 5km to 10km.
- Highway defects affect the proportion that cycle for the journey to work.
- Higher proportions of route that are either traffic free or have cycle facilities are associated with lower perceptions of risk and higher proportions that cycle for the journey to work. Similarly, signed routes may be linked with higher proportions that cycle for the journey to work.

It should be remembered, from Chapter 6, that measures for income and public transport accessibility were not able to be determined for this study and these two measures might well have demonstrated correlation with the proportion that cycle for the journey to work.

The above relationships between the proportion that use the bicycle for the journey to work and the independent variables may reflect cause and effect, that is if a change could be made in an independent variable, then a change would occur in the dependent variable. They may not however, be causally related but only correlated. Recognising the dangers of suggesting a causal link where one does not exist, it is nonetheless suggested that policy makers might be interested in carefully considering the proportion of the network in their area that is available to cycle traffic that is either traffic free or has facilities and the proportion of the network that is signed to show the most appropriate direct routes for cycle traffic. These themes are explored more fully in Chapter 11.

Chapter 11 Use of the Model

11.1 Introduction

This chapter presents a comparison of the work undertaken in this research with the original work of Waldman (1977). In section 11.3 it goes on to use the model to forecast the effect on the number of trips that use the bicycle for the journey to work assuming some changes in infrastructure that have been shown to be relevant to the proportion that cycle for the journey to work. Conclusions are drawn in Section 11.4.

11.2 A Comparison with Waldman (1977)

With an eye very much on the historical dimension to the study, Table 11.1 below replicates the table of comparisons produced by Waldman (1977) for his range of towns for comparing his model results with the actual proportions that use the bicycle for the journey to work.

Table 11.1 Model versus actual proportions using Waldman's example towns

Type of borough or town	Predicted CYCLE	Example Town	Actual CYCLE	Difference
HILLY but SAFE	2% (4%)	Matlock (2)	1% (4%)	1 (0)
	2% (4%)	Worsley (1)	1% (4%)	1 (0)
	2% (4%)	Bodmin (2)	1% (6%)	1 (-2)
FLAT but DANGEROUS	5%/6% (6%)	Hammersmith (16)	5% (5%)	0/1 (1)
	2% (6%)	Liverpool (33)	2% (3%)	0 (3)
	2%/2% (6%)	Barking (17)	2% (9%)	0 (-3)
HILLY and DANGEROUS	1%/1% (0%)	Sheffield (29)	1% (1%)	0 (-1)
	3% (0%)	Plymouth (20)	3% (2%)	0 (-2)
	2% (0%)	Burnley (15)	1% (2%)	1 (-2)
FLAT and SAFE	8% (43%)	Goole (2)	16% (52)%	-8 (-9)
	3% (43%)	Newark (26)	6% (42%)	-3 (1)
	23% (43%)	Cambridge (14)	28% (36%)	-5 (7)

Notes:

1. *Percentages in brackets are from Waldman's study.*
2. *Numbers in brackets after the place name are the number of wards used to determine the percentages.*
3. *Where two predicted proportions are given they are the first and second model estimates. In the case of England and Wales these are respectively the probability of acceptability or proportion of route that is signed, in the case of London they are the non-mapping model and the mapping model using the proportion of route that is bus lane.*

First of all, the actual proportions for the journey to work may be compared across the quarter century or so between the two analyses. Marked declines have occurred in some districts, while other have declined less far. Notably, the proportion in Hammersmith has not changed significantly. Waldman's model has greater extremes (0% to 43%) in comparison with the present model but the general relationship with hilliness unsurprisingly remains. The comparison of the models shows that they have similar differences between the actual percentages and the modelled percentages and, using the simple measure of the squares of the differences relative to the actual percentage within the chi-squared test, both are shown to demonstrate no significant difference between the actual proportions and predicted proportions.

11.3 Using the models to forecast

It is first important to note that the models derived in Chapter 10 may demonstrate relationships of association rather than cause and effect. Reasoned argument is required to allow a conclusion that a relationship is one of cause and effect. The majority of the variables measured in the models are not able to be influenced by practitioners promoting the use of the bicycle and hence are of little interest so far as policy setting and the implementation of measures is concerned. The list below identifies variables which do however have an effect on the proportion of the working population that cycles for the journey to work and are able to be influenced:

- Percentage of the principal road length with negative residual life or UKPMS defects score of 70 or higher
- Percentage of the non-principal road length with UKPMS defects score of 70 or higher
- Length of signed cycle route
- Length cycle lane
- Length bus lane
- Length of traffic free cycle route

The most significant variable that is not able to be influenced by policy is hilliness. Climatic conditions are also relevant but are again not able to be influenced, although it may be instructive to consider changes in the base weather conditions due to climate change forecasts for the UK to consider the impacts that such changes may have on bicycle use.

Table 11.2 below shows results from the 483 ward model assuming two levels of infrastructure improvement:

- Improvement A: assuming a 50% longer length of route that has facilities for cycle traffic, including cycle lanes, bus lanes and traffic free routes in the district.
- Improvement B: assuming a seven fold[1] increase in the length of route that has facilities for cycle traffic, including cycle lanes, bus lanes and traffic free routes in the district.

The modelling has been undertaken for the four districts of Bradford, Rotherham, Doncaster and York.

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[1] A number of different proportional increases were modelled and a seven fold increase alighted upon because it gives rise to a reasonable increase in predicted cycle use.

Table 11.2 Forecasts based on 50% and sevenfold increase in cycle facilities length

	Census	Modelled		50% increase			Sevenfold increase		
District	JTWB	JTWB	Trips	JTWB	trips	Increase in number of trips	JTWB	trips	Increase in number of trips
Bradford (72.2km)	0.84%	1.08%	2334	1.15%	2451	1.05	1.92%	4096	1.75
Rotherham (42.2km)	1.02%	1.19%	1479	1.24%	1551	1.05	2.06%	2562	1.73
Doncaster (70.0km)	3.13%	3.80%	5323	3.80%	5611	1.05	6.85%	9592	1.80
York (137.4km)	13.06%	12.60%	11993	14.62%	13925	1.16	32.06%	30529	2.50

Notes: Kilometrage in brackets after the district name indicates the present length of routes with cycle facilities.

The table above indicates that for an increase of 50% in the length of facilities and traffic free routes for cycle traffic there is a modest increase in the proportion of trips for the journey to work that would use the bicycle. For a very substantial increase, for example a seven fold increase, the number of trips increases more appreciably, but even at this level the increase in the length of route with cycle facilities does not produce increases in the proportion that cycle for the journey to work in line with the erstwhile National Cycling Strategy target of increasing use by between two and three fold. The increase in the length of route with cycle facilities in York is approaching the level of saturation, that is nearly 100% of the routes within the district having facilities. Even at this level the model does not suggest proportions higher than about a third using the bicycle for the journey to work.

The results could be taken to indicate the provision of infrastructure alone, based on the present levels of perceptions of risk amongst commuters, would not be sufficient to induce a significantly greater proportion to cycle and other mechanisms for behaviour change need to be considered. These could include the training of adult cyclists so that their skill levels and hence perceptions are adjusted to the extent that their choices are more in tune with the actual levels of risk rather than some perceived higher level of risk that actually does not exist.

Good design for cycle traffic demands networks that are coherent, direct, attractive, safe and comfortable. The analysis above is structured such that additional proportions of route that are traffic free or have facilities for cycle traffic are reducing the perception of risk for the potential user, and it is this reduced perception of risk that is then positively influencing greater use of the bicycle for the journey to work. A more comprehensive consideration of the issues in connection with infrastructure would indicate that the simple addition of length to a "bicycle network" may not be as productive as carefully ensuring that those additional lengths are completed in such a manner as to make the network more coherent, direct and attractive as well.

So far as comfort is concerned, the condition of the carriageway surface will have an influence. Table 11.3 below shows results from the 483 ward model using the measure of the proportion of the road network that has signed cycle routes, which also includes the variable BVPI97, the Best Value Performance Indicator for the proportion of the non-principal highway network that has reached the end of its residual life. Again, against the base modelled level, a sevenfold increase in signed route length is modelled and, separately, a reduction in highway pavement defects to zero is modelled.

Table 11.3 Forecasts based on sevenfold increase in signed route and zero pavement defects

	Census	Modelled		Sevenfold increase in signed route			Repair of highways with negative residual life		
District	JTWB	JTWB	Trips	JTWB	trips	Increase in number of trips	JTWB	trips	Increase in number of trips
Bradford (0.6km/ 5.11%)	0.84%	0.91%	1927	0.98%	2085	1.08	1.06%	2253	1.17
Rotherham (2.6km/ 0.5%)	1.02%	1.27%	1574	2.20%	2730	1.73	1.29%	1598	1.02
Doncaster (8.20km/ 3.3%)	3.13%	3.71%	5193	9.83%	13134	2.53	4.04%	5656	1.09
York (32.2km/10.6%)	13.06%	13.01%	12392	21.83%	20784	1.68	14.54%	13844	1.12

Notes: Kilometrage in brackets after the district name indicates the present length of signed cycle route. The percentage indicates the percentage of the non-principal road network that has negative residual life. Note that the percentage for Doncaster has been taken as the same percentage as for the principal road network in Doncaster.

There is some considerable variation in the impact of a sevenfold increase in signed route for cycle traffic and this is partly as a result of the very different starting levels for the different districts, but the increase in the number of trips may be in the order of an increase of approaching double. A reduction in non-principal roads with negative residual life to zero would result in increases in the number of trips cycling of around ten per cent. Again the increase will depend on the starting position of the local authority in respect of the defects score.

Cycle signing may be useful to promote appropriate routes and short cuts to cycle traffic where such routes may not be otherwise self-evident. There will however, be a limit on the extent to which a local authority will be able to take advantage of the additional power of cycle route visibility by such signing and it will be dependent on the nature of the infrastructure in the district.

It is perhaps an unrealistic assumption to make that there could ever be none of the highway network that has reached the end of its residual life. Indeed the measure may not be an accurate measure of the state of the road surface, which is a more important issue to cycle traffic than the nearness of the pavement to the end of its structural life, although clearly the two are related. What the model shows, however, is that an elimination of lengths of route with a score of seventy or more on the UKPMS indicates a potential improvement in the proportion that might cycle for the journey to work of the order of 10%.

11.4 Conclusion

It is far from established that the relationships developed in the modelling are relationships of cause and effect. However, assuming that an appropriate change in the level of an infrastructure variable could be made and would have an effect on the number of trips cycling for the journey to work it may be surmised that:

- A sevenfold increase in the proportion of routes in a district that have cycle facilities or are traffic free, hence reducing the perception of risk as determined from the primary data survey based on the model developed in Chapter 9, would have the effect of perhaps increasing the number that cycle for the journey to work by a factor of the order of two.
- A sevenfold increase in the length of route that is signed for cycle traffic similarly, and more directly because it is not related to perceptions of risk, would have the effect of increasing the number that cycle for the journey to work by a factor of the order of two.
- A reduction to zero in the percentage of non-principal roads with negative residual life would have the effect of increasing the number that cycle for the journey to work by a factor of the order of 1.1.

These forecasts have been produced from the model including infrastructure variables for England and Wales but excluding London. The infrastructure variable that appeared to be relevant for London was the proportion of route that has the facility of a bus lane and separate forecasts would be required for London.

The model form adopted is uni-modal and contains no information about the modes from which the bicycle might draw. On the basis of an equal abstraction from different modes and a knowledge of the proportions of journeys to work by the different modes, it would be possible to produce forecasts of the reductions in commuting by the other modes that could occur as a result of the actions described above.

Wardman et al. (1997) showed that cycle lanes on the highway have only a marginal impact on cycle mode share, but that a traffic free route for the whole journey would produce bicycle mode shares of between about 11 and 13%. The analysis presented above is at one and the same time more detailed and more general than the work of Wardman et al. On the one hand the research in this thesis has deduced the effects on the perception of risk of infrastructure, but this has shown to be significant only at the level of proportion of a route with facilities (whether on-road or off-road). On the other hand, the analysis has been aggregated to the district wide level. Recognising these differences, it is difficult to make a direct comparison between the results presented here and those presented by Wardman.

Chapter 12 Contribution of the research and recommendations

12.1 Introduction

This chapter describes the principal contributions that have been made in the methodology and analysis of data on perception of risk and in the development of a model on the variation in cycle use at ward level for England and Wales. Section 12.2 provides a summary of the main aspects of the research and the contemporary context in which the results will be disseminated. Section 12.3 emphasises the novel aspects of the survey methodology and analysis. Section 12.4 acknowledges some of the limitations of the work and this leads into recommendations identified in Section 12.5. Section 12.6 provides an overall conclusion to the research.

12.2 Importance to the development of modelling and planning for the bicycle

It is usual to consider mode choice issues at a disaggregate level. This research has however considered the proportion that uses the bicycle for the journey to work from census data for 2001 against factors that determine the use of the bicycle. The advantage of this approach is that comparisons can be made between districts using available aggregate data on mode choice and other variables. Also, aggregate data is cheaper to acquire, more readily available and is able to consider factors that are geographically related.

No recent aggregate analysis has been undertaken of the journey to work by bicycle that considered the effects of physical factors, such as hilliness, of the area through which the journey to work is made. This research provides that analysis.

The thesis has made good use of various sources of data that have become available electronically in recent years. While census data has been available in machine readable form for some time, this work makes use of publicly available census data from the office of national censuses web pages as well as the more detailed cross-tabulations available through CASWEB. It also makes use of weather data available from the meteorological office that is available on their web site and data on hilliness made available through the countryside information service web site funded by the Department of Environment Food and Rural Affairs.

Other publicly available data sources, such as best value performance indicators and various indicators available from the Department of Transport web site have also been used. In this sense, the thesis is very much a product of the present information age and has used data that would have been difficult, if not impossible, to collate even a few years ago.

Some significant work has been undertaken looking at Risk Ratings and useful insights were gleaned into the manner of use of ratings scales by respondents and techniques for maximising the quantity of useful comparative analysis from the data. A methodology was developed to sum the components of a journey in order to determine an overall Risk Rating for a journey, taking account of the different nature of routes and junctions. This methodology was further extended to develop a model of "probability of acceptability" of cycling at an area wide level. These aspects are discussed more fully in the next section.

Finally, the analysis has contributed to an understanding of the reasons for the variation that exists between different districts in respect of the proportion that cycle for the journey to work. Most of the relevant variables are linked with socio-economic conditions and other physical factors such as hilliness and rainfall, but some of the variables are able to be addressed through policy interventions and the model may be further refined and developed as a predictive tool to assist in target setting for local authorities.

12.3 Significance of the survey methodology and analysis and results

A significant part of the research has been concerned with the assessment of perception of risk based on the presentation of video taken from a moving bicycle to 144 respondents. The use of video in this fashion is novel because it used the video to assist in developing assessments of perception of risk. It provided a mechanism for placing respondents in a position in the road environment that they might otherwise not experience. The technique worked in the sense that it was feasible to deduce relative risk scores for cycling in different circumstances. It also proved possible to extend the analysis to deduce an area wide risk score based on the perception of cycling, another achievement that has not been accomplished hitherto.

The presence of different types of route and the number of different types of junction are determiners of perceived risk. Respondents generally rate risk associated with situations where there is no motor traffic less highly than other situations. Perception of roundabouts is that they generally add to the Risk Rating, and they add more to the Risk Rating than traffic signal controlled junctions. The regularity of cycling, sex and age are also factors that influence the perception of risk either additively or, for some route and junction types, multiplicatively.

The research is the first to deduce the contribution to the perception of risk of people cycling both along routes and through junctions. Attempts have been made by many to consider the relative weightings placed by cyclists on different route conditions but this is the first piece of work that has reduced the contributions of routes and junctions to the perception of risk to a single metric. The data was sufficiently robust for the analysis to estimate the multiplicative effects of route and junction types relative to person types.

The aggregation of the Risk Ratings into a district wide index is the second significant achievement of the analysis. This was accomplished by considering the "risk threshold level" that was asked of respondents during the primary data collection survey, that is the Risk Rating above which respondents thought it would be too dangerous to cycle. This risk threshold level allowed for the construction of a binary "probability of acceptability" model based on whether or not a rating was above or below the risk threshold level and was formulated within a logit model.

The third significant contribution of the analysis is in the development of the probability of acceptability model from a route specific to an area wide measure, hence allowing for its inclusion in an aggregate model of the variation in cycle use at ward level for all wards in England and Wales.

12.4 Limitations

The research has been limited to some extent by its being unfunded and this placed limitations on the number of respondents that could be handled in the primary data survey. A larger sample size than the 144 achieved, and drawn from more than a single sampling source would have allowed potentially for a wider range of route and junction types to have coefficients estimated for them. The ten point rating scale was relatively coarse compared to some of the subtle differences between journeys that respondents were being asked to consider. Further work could usefully expand the sample size and draw from a wider catchment of potential respondents.

The survey attempted to collect data on not only a "Risk Rating" based on the perception of risk from motor traffic, but also a "Personal Security Rating" which was meant to determine the effect on the perception of risk of cycling in situations, perhaps traffic free, where there could be still a perception of risk, but from a different source. The data on Personal Security Rating was determined only for the single base journey for each respondent and was consequently not as extensive as the Risk Rating data and not as robust for analysis. Little headway was made in the quantitative assessment of differences between risk from traffic and risk from other sources.

While a comprehensive assessment of interactions was undertaken in the estimation of the Risk Rating and Probability of Acceptability models, interactions between variables has not been considered in the main models of variation in the use of the bicycle for the journey to work at ward level. Interactions between socio-economic variables and some of the transport and physical factor variables might have shed additional light on the reasons for the observed variation. Similarly, assessment of the interactions between cycle facilities and hilliness could assist in refining estimates of coefficients and hence forecasts of the impact additional facilities.

It would have been instructive to use income and a proxy for public transport accessibility in the main model as either one or both of these are likely to have an influence on the propensity to use the bicycle for the journey to work.

12.5 Further appropriate work

Were a similar video based exercise to be undertaken then the following should be given due attention:

- The sample size relative to the number of different video clips should be given careful attention and in particular care should be taken to present sufficient junctions to respondents.
- The range of clips was probably adequate and representative of a wide range of conditions but future work might be better directed at carefully distinguishing between a subset or subsets of routes and junctions. For example, the perceptions of roundabouts in the survey were not fully elucidated and it may be worthwhile focussing on roundabouts as a subset of junctions.
- Approximately half of commuting hours are in darkness or semi-darkness but all of the video clips were in daylight. It could be useful to expand the survey to cover the hours of darkness.
- A video view taken behind the cyclist as well as in front would allow the respondent to gain a fuller, and more accurate picture of the road, that would after all be available to a supple necked cyclist.
- Pairs of videos of the same or similar routes and junctions with no other cycle traffic and with substantial amounts of other cycle traffic would allow for an estimation of the effect of the presence of other cycle traffic on the perception of risk.

The modelling of London separate from the rest of England and Wales has pointed to some differences in the take up of cycling by socio-economic classification, age and car ownership. It would be instructive to undertake the perception of risk survey in London with London commuters and the results from such an analysis may reflect differences in such perceptions between Londoners and others. A further significant change that has occurred since the 2001 census is the congestion charging scheme in central London and the effect of this would need to be included in any modelling with data from subsequent censuses.

The measure for hilliness used in the modelling was related to the general topography of an area and it would be instructive to undertake more detailed research on the relationship between effort and hilliness to understand the different approaches people make to cycling up a hill with varying gradients.

Choice is not solely a function of the options available and an application of extended decision making theory to cycling in the UK to replicate German and other European work could be informative. The extent of the literature search undertaken as part of this research of European literature on the cycling mode choice has been naturally limited and a thorough European wide literature research of the approaches to modelling cycling and the developments in policy in Europe would be informative.

Two further European extensions of the work could be considered using the same methodology. Firstly, for a North European Country, perhaps Germany, a model could be constructed along similar lines to test whether similar factors play a part in the variation in cycle use. Secondly, a pan-European study using a model with districts from more than one country could be established. Both of these models could face significant issues in terms of the collection of appropriate data for the modelling.

A final, further, area of analysis could be in estimating a model with similar determining factors but for cycle journeys for leisure or non-journey to work utility purposes.

The work undertaken in this thesis has led to an estimation of changes in the proportion of employees that cycle for the journey to work based on changes in the length of infrastructure with cycle facilities. An evaluation of the costs and the benefits of the provision of more facilities would be an important piece of analysis that would help inform policy.

12.6 Conclusions

The hypothesis that it is possible to explain the variation in cycle use for the journey to work at ward level has been proven. It is possible to relate the proportion that cycle for the journey to work to factors that influence that proportion and the factors are related to socio-economic variables, physical factors and transport related variables. Changes in the level of infrastructure provided for cycling could positively affect the proportion that cycle. Some principle findings from the modelling are identified below:

- Age: Wards with a higher proportion of people in the age brackets 35 to 59 are linked with lower proportions that cycle for the journey to work, leading to the proposition that there is a "missing generation" of cyclists. The number of employees aged 35-49 in London has a positive link with the proportion that cycle for the journey to work and might indicate a reduced size of "missing generation" for London.
- Qualifications: Wards with higher proportions that have higher level qualifications are linked with higher proportions that cycle for the journey to work.
- Car availability: At a level of one car per household as compared with two or more, there is a higher propensity to cycle for the journey to work. At an earlier stage of motorisation it might have been expected that this finding would have been true at the level of no cars per household as compared with one or more cars and reflects the "post-motorised" society that now exists. For London, the higher the proportion of households with one car, the less the proportion that cycles for the journey to work and this reflects the lower levels of car ownership in London.
- Socio-economic classification: Socio economic classifications SEC11 (higher managerial occupations in large employers), SEC 20 (lower managerial and

professional occupations), SEC30 (intermediate occupations). SEC40 (small employers and own account workers) and SEC70 (routine occupations) are linked with smaller proportions that cycle for the journey to work. For London a smaller range comprising only SEC11, SEC12 (higher professional occupations) and SEC40 of socio-economic classifications has this suppressing effect. The omitted categories are SEC50 (lower supervisory and technical occupations) and SEC60 (semi-routine occupations).

- A higher proportion of the ward population that is non-white is linked with lower proportions that cycle for the journey to work.
- Distance: For England and Wales the distance ranges of "less than 2km", 5-10km and 10-20km have a negative link with cycling for the journey to work. In London the ranges are "less than 2km", 2-5km and 20-30km. The shortest "distance omitted" category for London is 5km-10km as compared with 2-5km for England and Wales and is symptomatic of London being a very large metropolitan area.
- Highway defects: the higher the percentage of highway that has reached the end of its residual life the less the proportion that cycles for the journey to work.
- Network and population: A denser highway network is linked with lower levels of use of the bicycle and a higher population density is linked with higher levels of use of the bicycle for journeys to work.
- Hilliness: Greater hilliness is linked with a lower proportion that cycles for the journey to work.
- Weather factors: A higher average rainfall is linked with lower proportions that cycle for the journey to work and a higher mean temperature is linked with higher proportions that cycle for the journey to work.

In the model with the subset of wards that are mapped, the length of cycle lane, bus lane and traffic free route has been found to be important in so far as it impacts on the probability of acceptability of cycling determined from the risk rating model. The models show that an elimination in highway pavement defects is associated with an increase in cycling of 10% for a sample of four districts and a sevenfold increase in route length with cycle facilities is associated with a two fold increase in cycling for the journey to work.

There is a contention that a concentration on the part of researchers and other bicycle professionals on the perceptions of risk is counterproductive and the real emphasis should be on the provision of coherent and attractive routes that are comfortable and direct. Safety does feature in good design but there is a growing perception that a concentration on the control and elimination of barriers is not the same as the provision of conditions and a general "culture" in favour of cycling.

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BIDS International bibliography of the social sciences

Appendix A – List of Abbreviations

AA	Automobile Association
ATC	Automatic Traffic Counter
BOAT	Byways Open to All Traffic
BVPI	Best Value Performance Indicator
CIS	Countryside information system
CROW	Centre for research and contract standardisation in civil engineering. The Netherlands
CTC	Cyclists' Touring Club
CVI	Coarse Visual Inspection
Defra	(UK) Department for environment food and rural affairs. Prior to 2002 it existed as the DETR (see below) and prior to 1997 as the Department of the Environment
DfT	(UK) Department for Transport. (Prior to 2002 it existed as the DETR, Department of Environment Transport and the Regions, prior to 1997 it existed as the DoT, Department of Transport. References are noted as DfT throughout)
DSA	Driving Standards Agency
EDMT	Extended decision making theory
GIS	Geographical Information System
GOMMS	Guidance on methodology for multi-model studies
HGV	Heavy Goods Vehicle
IHT	Institution of Highways and Transportation
KSI	Killed or seriously injured
LAB	League of American Bicyclists (formerly League of American Wheelmen, LAW)
LTP	Local Transport Plan
MBC	Metropolitan Borough Council
NATA	New Approach to Appraisal
NCN	National Cycle Network
NCS	National Cycling Strategy
NHS	National Health Service
NRTF	National Road Travel Forecasts
NTS	National Travel Survey
ODPM	Office of the Deputy Prime Minister
OS	Ordnance Survey
PACTS	Parliamentary Advisory Council on Transport Safety
PCU	Passenger Car Unit, equivalent value of a vehicle expressed in car units, e.g. a heavy goods vehicle may be the equivalent of 2 PCUs.
PPG	Planning Policy Guidance
RUPP	Road Used as Public Path
RP	Revealed Preference
RPM	Revolutions per minute
RTI	Road Traffic Informatics
SEC	Socio-economic Classification
SEG	Socio-economic Group, classification by type of employment of head of household to describe a household
SP	Stated Preference
SPSS®	Statistical Package for the Social Sciences (a software product of SPSS Inc.)
STATS19	Statistics 19, standardised form for police reporting of road traffic accidents
TRL	Transport Research Laboratory (formerly the Transport and Road Research Laboratory, TRRL).
TSGB	Transport Statistics Great Britain
UKPMS	United Kingdom Pavement Management System
VOT	Value of time
VRU	Vulnerable Road User

Appendix B – Summary of research contributions

Ref.	Type of Survey	Choice	Specifics	Contribution	Section
LRC (1997)	Monitoring	Mode	London	Very low proportions of cycle mode share for some ethnic groupings, particularly Bangladeshis and Indians in London.	2.1.3
European Commission, 1999	Monitoring	-	Bicycle kilometres/per inhabitant	EU norm up to 300km/pers/year. Denmark & Netherlands 1,000km/pers/year.	2.1.4
Pucher (1997)	Monitoring	Mode	Mode share by German town	Great variation between towns in Germany 5%-32% mode share.	2.1.4
Jensen (undated)	Monitoring	Mode	Mode share by Danish town	Correlations clearly exist between age and employment status and also employment status and income level in cycling trips in Odense. High effect of commuting distance on mode share.	2.1.4
Bracher (1989)	-	-		National Government interest linked to high cycle use.	2.3
Harland and Gercans (1993)	Monitoring	Mode	Six towns in UK	Facilities alone (cycle routes and area-wide safety management) will not encourage cycle use.	3.2.2
McClintock and Cleary (1996)	Monitoring	Mode	Nottingham Network	Network had encouraged utilitarian weekday cycling only. Female cyclists / shopping / education trips more willing to use facilities. Lifestyle factors (moving house / health concerns) could influence mode choice. Provision of facilities affects perceptions of safety	3.2.2
Emmerson et al. (1998)	Monitoring	Mode	Two towns	Temperature more significant than rainfall, but both affect numbers cycling.	3.2.3
Davies et al. (1997b)	Qualitative	Mode	National	General attitudes to cycling positive. Cycling seen as healthy, a way to relieve stress, a good family activity. Cyclists view cycling as fast, convenient and useful for multi-purpose trips. Cycling seen as a minority activity. Negative factors: time pressure, stress, aggressive driver behaviour, decline of the two-parent family, personal security fears, out-of-town shopping, general Government policy for road building, car ownership increases and British drivers' disregard for the Highway Code. Personal security and cycle theft more significant in Liverpool and London. Indirect deterrents: competing modes, particularly car and its status, potency and convenience. Direct deterrents: lack of status, danger from traffic, personal safety fears, sexual harassment, cycle theft and vandalism, traffic fumes, weather, hills, personal image, cycle technology, purchase and maintenance difficulties. Traffic issues: parked cars, roundabouts and right turns; potholes, drainage grates and general debris, road narrowings, road humps were not considered to slow traffic sufficiently. Cyclists decision making stages: *task to be undertaken* (journey length and load), *physical circumstan*ces (hills, weather traffic), *time availability* and *antecedent state* (mood and energy levels). Non-cyclists to begin cycling: *ego relationship* (how does cycling enhance my self-image?), *perceived risk of negative consequences* (e.g. danger in use), *social sanctions* (ostracism due to non-conformist stance) and *hedonic significance* (what is the amount of pleasure I will gain?).	3.3.1

Ref.	Type of Survey	Choice	Specifics	Contribution	Section
Davies and Hartley (1999)	Qualitative	-	Four towns	Most common motivation for purchasing a cycle was "to get fit". Everyone reported being pleased with cycling. Some evidence that cycling was more effort than had been anticipated.	3.3.1
Gardner (1998)	Qualitative	-	Leisure	Leisure cycling was seen as relaxing and enjoyable and yet utility cycling was seen as the antithesis; stressful and dangerous. Many of the utility cyclists believe that leisure cycling increased their confidence to cycle in traffic at least slightly, however there is no strong link. Cycling was a part of all respondents' childhood with connotations of freedom and adventure which is in stark contrast to the daily grind of a commuter journey.	3.3.1
Davies et al. (2000)	Qualitative	Mode	Employers	Motivation and company image are important issues for employers considering travel plans. Promotion of travel plans does not "come naturally" to local authorities.	3.3.1
Henson et. al (1997)	Qualitative	Mode	Manchester	Top four deterrents: poor security of pedal cycle when parked, unpleasantness of traffic pollution, poor weather, personal security.	3.3.2
McClintock and Cleary (1996)	Qualitative	Mode	Nottingham	Top five deterrents: danger/fear of involvement in an accident, 21.1% of response, congestion/volume of traffic, 10.6% of responses, aggressive/inconsiderate drivers, 7.5% of responses, air/noise pollution 5.5% of responses, weather (18.3% of responses).	3.3.2
Brög (1982)	Qualitative	Mode		Situational approach hierarchical: Option of using a bicycle (bicycle available and trip less than 15km). Constraints against using bicycle or requiring use of specific mode (transport of baggage, weather conditions, health, need car for work). Perception of route (no bicycle paths, too many hills, dangerous intersections). Perception of riding bicycle and time required (too slow, too tiring, clothes get dirty). Subjective willingness (willing to use bicycle mode).	3.3.3
Jensen, M. (1999)	Qualitative	Mode		"Rational" approach adopted to analyse transport issues fails to capture the emotional and sensual sides of owning one's means of transport. Six person types defined: passionate car drivers, everyday car drivers, leisure time car drivers, cyclists/public transport users of heart, cyclists/public transport users of convenience and cyclists/public transport users of necessity.	3.3.3
Simons (1987)	Qualitative	Mode		Dutch preference for cycling is based on fitness and the fact that it is "friendly" to the environment. Practical motives include the bicycle being generally the fastest mode in urban areas for distances up to 8 kilometres, there is no difficulty finding a parking place and the bicycle is cheap to buy and to run.	3.3.3
Presada (1999)	Qualitative	Mode		Breadth in the bicycle sales market allows for a range of social inclusion.	3.3.3
Waldman (1977)	Aggregate	Mode	UK Census	1st UK national study based on journey to work Hilliness and danger are important factors. Estimate of danger (independent variable) calculated using proportion of cyclists for journey to work, therefore dubious. Socio-economic factors not so important.	3.4.1
Ashley and Banister (1989a, b	Aggregate	Mode	UK Census	Based on journey to work. Model contained measure for hilliness confirming Waldman, otherwise model dubious	3.4.2

Ref.	Type of Survey	Choice	Specifics	Contribution	Section
and c)					
Crespo Diu (2000)	Aggregate	Mode	UK Census	Large sample size (635 wards). Distance to work represented. Estimate of danger (independent variable) calculated using proportion of cyclists for journey to work, therefore dubious. Hilliness measure either 1 or 0, too coarse to be reasonable. Well thought through model structure incorporating a variable for saturation level found to be approx 45%. Found socio-economic group explanatory power low (cf Waldman). Unexpected negative sign for variable for no car owning households difficult to explain	3.4.3
Rietveld and Daniel (2004)	Aggregate	Mode	The Netherlands	In a semi-log regression analysis of 103 Dutch municipalities the following were found t be important: population size, human activity indicator, proportion of young people, presence of a higher vocational training school, proportion of liberal party voters, proportion of foreigners, number of cars per capita, hilliness, stop frequency, parking costs, hindrance frequency, speed compared to a car, degree of satisfaction and safety level	3.4.4
Noland (1995)	Disaggregate	Mode	Philadelphia	Safety studied in two dimensions: scores of perceived risk of accident and perceived severity of accident studied in detail in SP based model: Simple Risk Perception used risk x severity, Enhanced severity risk perception taken as 10 to the power of severity, enhanced probability risk perception score, risk re-scaled 0% to 100% x severity. All measures significant and SRP elasticity greater than 1.	3.4.5
Noland and Kunreuther (1995)	Disaggregate	Mode	Philadelphia	Elasticities of the probability of cycling relative to convenience (3.208), comfort (0.983), parking availability (0.838), cycling competency (1.942) and "lack of shoulders" on the road (0.496), (high compared with usual transport elasticities. Dubious.	3.4.5
Cervero and Radisch (1996)	Disaggregate	Mode	Lafayette and Rockridge	Neighbourhood type (fineness of street pattern) as well as household size have influence.	3.4.5
Ortúzar et al. (2000)	Disaggregate	Mode	Santiago	Average demand if cycleways provided would rise from 1.6% to 5.8% with some sectors reaching 10%. Young, on low income without a car in the household and with low (non-university / technical college) educational level more likely to cycle. Other equally important determiners of choice are present and include accessibility to Metro, peripherality, purpose and trip length.	3.4.5
Wardman et al. (1997)	Disaggregate	Mode	Leeds	Novelty: value of the en route facility is not constant but varies with time in facility. VOT in fine weather with no on-route facilities: 9.58p/min was 6.22 times greater than the combined value of car/bus in vehicle time of 1.54p/min. No facilities with wind and rain raise the VOT to 21.28 p/min. Segregated facilities drop the VOT in fine weather to 2.87 p/min. Isolation of risk as opposed to pleasant environment of a segregated cycleway would be interesting.	3.4.6
Wardman et al. (2000)	Disaggregate	Mode	NTS + 4 cities	Combination of NTS and RP + SP yielded largest data set yet used in cycling studies. Cycling VOT 6.5 pence per minute, 2.9 times more highly than in-vehicle time.	3.4.6

Ref.	Type of Survey	Choice	Specifics	Contribution	Section
				Outdoor parking was valued at 2.5 minutes, indoor parking at 4.3 minutes and showers plus indoor parking at 6.0 minutes. A change of 10% in the general proportion of the population cycling was found to be the equivalent of a reduction of 1 minute of cycle time. A change in the proportion of work colleagues cycling did not have a statistically significant effect. Only the coefficients for ratings for danger, tiredness and cycling ability were statistically significant. All SP data from East of England (drier and flatter) cities, hilliness was not significant in the model.	
Siu et al. 2000	Disaggregate	Mode	NTS + 4 cities	56% - 82% of population who met criteria (make more than two journeys to work per week and travel less than 7 miles) would consider cycling.	3.4.6
Bamberg and Schmidt (1994)	Disaggregate	EDMT	Geissen / students	"Attitude" (influenced by a range of factors) and "perceived behavioural controls" such as distance and cost, influence choice of the bicycle. The "social norm" influences "attitude" and "perceived behavioural control", undermining the Theory of Planned Behaviour, that suggests that each of the three "social norm", "attitude" and "perceived behavioural control" separately influence mode choice.	3.4.7
Forward (1998)	Disaggregate	EDMT	Barcelona, Copenhagen and Amsterdam	Beliefs that "control" behaviour are the most strongly associated with intention to cycle. Respondents also believe that cycling would make them feel relaxed, would be a comfortable mode, and that their sense of freedom would be increased. Also respondents did not think that cycling would increase their journey time, cost a lot of money, increase the chance of an accident, increase the chance of being threatened by others or create worry about the bicycle being stolen. Some of these appear counter intuitive.	3.4.7
Davies et al. (2001)	Disaggregate	EDMT		8% of a national sample report "almost always" using the bicycle and 7% "cycle quite often". 15% think cycling is fast but they do not like to stand out in the crowd. 5% think cycling is a hassle and not fast but are not concerned about standing out in a crowd. The remaining 65% would not consider cycling. Promotion to overcome barriers for the 15% and 5% groups are most worthwhile.	3.4.7
Bovy and Bradley (1985)	Disaggregate	Route		Examined separate path versus no facilities, surface roughness and volume of traffic. A separate path relative to no facilities is worth 3 minutes on a 9 minute journey. 3 minutes is also equivalent to a smooth path relative to a rough path.	3.5
Bovy and Den Adel (1985)	Disaggregate	Route		Road surface and distance/time the most important. Cycle paths, traffic levels, the availability of other modes of transport, the existence of obstacles, the number of traffic lights, attractiveness, weather and social factors were less important but still had an effect.	3.5
Westerdijk (1990)	Disaggregate	Route	Dutch and Swedish sample	Distance clearly the most significant characteristic.	3.5
CROW (1993b)	?	Route		50% of cyclists use a route that differs less than 5% in time from the fastest route. 70% of cyclists use a route which is no more than 10 per cent longer than the route with the	3.5

Ref.	Type of Survey	Choice	Specifics	Contribution	Section
				minimum journey time.	
Hopkinson and Wardman (1996)	Disaggregate	Route	Bradford	Route choice is sensitive to relative time differences but it was noted that the time variations accrue from differences in distance rather than delay. Risk related factors have a strong bearing on route choice and that reductions in risk are highly valued by cyclists. Time savings may be classified as "within route" arising from variations in delay and effort and "between route" which result from different distances. Further work is needed on the relationship between journey time, time of exposure to risk and value of a cycle facility.	3.5
Ryeng (1999)	Disaggregate	Route	Trondheim	Choice of route depends not only on the physical factors but on age and sex. (Young and male cyclists choose normal traffic lanes more frequently than older and female cyclists).	3.5
Wardman et al. (2000)	Disaggregate	Route	NTS + 4 cities	Time spent on tarmac cycleways has a lesser disutility than time spent in typical road conditions. Segregated cinder track or bridleway was valued less highly than present road conditions.	3.5
Abraham et al. (2002)	Disaggregate	Route	Washington DC	Values of time of $17 per hour for cycling on an arterial road and $4 per hour for cycling on a cycle track in a park were deduced. Those who stated that they prefer on-street provision do not have a lesser utility in cycling on-street than the average, but these cyclists do have a greater than average dis-utitlity in cycling off-street.	3.5
Landis et al. (1997)	Level of service and cyclability	-	Tampa	Volume and speed of general traffic clearly have the greatest impact on the perception of hazard.	4.2
Harkey et al. (1998)	Level of service and cyclability	-		Volume and speed of traffic and lane width affect a perceived "Bicycle Compatibility Index".	4.2
Guthrie et al. (2001)	Level of service and cyclability	-	Crowthorne	"Cyclability" principally determined by safety bumpiness and attractiveness. "Cyclability" may be partly predicted by vehicle speeds, lane widths, frequency of side turnings and gradient. There is a non-linear "cocktail" effect of the above variables. "Critical mass" (i.e. number of other cyclists) should be investigated as an independent measure. Sight lines and visibility may be relevant and important to cyclability. A narrower definition of "cyclability" limited to perhaps safety and comfort (excluding attractiveness of route) may be more helpful.	4.2
Allen et al. (1998)	Level of service and cyclability	-		Arbitrary assignment of level of service based on probability of being passed and meeting oncoming traffic.	4.2
Taylor (1998)	junctions	-	-	Mean gap time at junctions insignificantly different for cyclists and motor vehicles.	4.3
Hall et al. (1989)	Safety	-	Three Counties	Results do not allow any conclusions to be drawn about the relative merits of different types of provision for cyclists.	4.3
Ekman (1996)	Safety	-	95 junctions	The level of bicycle flow is more important than level of car exposure and that the perception of both bicyclists and car drivers is different for higher cycle flows.	4.4
Forester (1994)	Safety		USA regular cyclists	Most accidents involve turning and crossing movements, not movements along a carriageway.	4.5
Moritz (1998)	Safety		USA regular cyclists	Accidents on trails and off-road routes are far more prevalent per kilometre travelled than accidents on the highway. There are fewer accidents per kilometre to cyclists along routes that are signed bicycle routes or have painted	4.5

Ref.	Type of Survey	Choice	Specifics	Contribution	Section
				cycle lanes than on other routes.	

Notes

1 *Disaggregate and aggregate analyses are both quantitative*

2 *Extended Decision Making Theory*

Appendix C – Table of fifty wards for which there is no cross-tabulated census data

WardCode	Ward	WardCode	Ward
00AAFE	Bishopsgate*	20UHGJ	Ingleton
00AAFS	Farringdon Within*	20UHGM	Romaldkirk
00AAFY	Queenhithe*	20UHGP	Startforth
00AAFZ	Tower*	20UHGQ	Streatlam and Whorlton
00AAGB	Walbrook*	22UQGL	Birchanger
00NANM	Rhosneigr	29UBHT	Park Farm South
00NCQE	Abersoch	35UBGB	Embleton
00NCQQ	Clynnog	35UBGC	Harbottle and Elsdon
00NCQT	Cwm-y-Glo	35UBGD	Hedgeley
00NCRE	Garth	35UCFS	Bamburgh
00NCRX	Llanuwchllyn	35UCFT	Beadnell
00NCSZ	Tudweiliog	35UCFZ	Flodden
00NNQH	Banwy	35UCGA	Ford
00NNQP	Bwlch	35UCGH	Shielfield
00NNRT	Llanfihangel	35UFGN	Broomhaugh and Riding
00NQPK	Llanbadarn Fawr - Sulien	35UFGW	Hexham Gilesgate
00PPNT	Castle	35UFHM	Upper North Tyne
00PPPC	Green Lane	35UFHN	Wanney
15UHFB	St. Agnes	38UCGD	Holywell
15UHFC	St. Martin`s	39UFGM	Chirbury
15UHFE	Tresco	39UFGT	Clun Forest
16UFHH	Ravenstonedale	40UFFZ	Brompton Ralph and Haddon
20UHFZ	Barningham and Ovington	40UFGD	Dunster
20UHGB	Cotherstone with Lartington	40UFGE	Exmoor
20UHGH	Hamsterley and South Bedburn	41UEGJ	Keele*

The six wards marked with an asterisk feature in the 1117 wards of the subset of data for which mapping is available.

Appendix D – Risk Rating qualitative interview questions

Selection questions

1. Are you able to ride a bicycle? Yes/no. If no do not proceed further.

Background questions:

2. Age (banded)
3. Sex
4. Do you possess a driving licence?
5. When did you last ride a bike? (within the last week, month, year, three years, three years+)
6. How often do you ride a bike? (5+ times per week, 1-2 per week, 1-2 per month, less than 1-2 per month)
7. Which of the following do you relate to?

    I am a commuter cyclist, leisure cyclist, all weather cyclist, sports cyclist, touring cyclist, occasional cyclist, a non-cyclist.

Further Questions:

1. What features of cycling do you/ would you find risky
2. What features of cycling do you / would you find take a lot of effort?
3. In what ways might you find the following risky?
    - major roads
    - right turns
    - roundabouts
    - signal controlled junctions
    - give way junctions
    - other
4. What do you think about boxes at the stop lines for cyclists at traffic lights?
5. What do you think about lanes for cyclists along roads?
6. What do you think about lanes for cyclists around roundabouts?
7. What are the important factors that would influence whether you decided to use a bicycle for a particular journey?
8. Had you decided to cycle for a particular journey, what are the important factors that would influence which route you would take?

Appendix E – Schedule of video clip images

	No	Time mm:ss	Route Description	Type	Turn	Facilities	Other cyclists with flow	Other cyclists against flow	No pedes-trians	Parked Vehs. on left	Roads on left	Roads on right	Two way flow veh hr
B	1	1:00	Chorley New Road inbound	r		n	0	0	3	4	2	3	1860
B	2	1:00	Queen's Park 1	r		y	0	0	1	0	0	0	0
B	3	1:00	Queen's Park 2	r		y	0	0	0	0	0	0	0
B	4	1:00	Queen's Park 3	r		y	0	0	6	0	0	0	0
B	5	0:45	Queen's Park 4	r		y	0	0	0	0	0	0	0
B	6	0:37	Park St/Spa Rd/Mayor St	ts	so	n	0	0	0	0	1	1	592
B	7	1:00	Mayor St/Deane Rd/College Way	ts	so	n	0	0	0	0	1	1	120
B	8	1:00	College Way/St Helens Road	ts	rt	n	0	0	1	0	1	1	360
B	9	1:00	St Helens Rd outbound 1	r		n	0	0	2	2	2	2	1620
B	10	1:00	St Helens Rd outbound 2	r		n	2	0	9	8	3	2	2640
B	11	1:00	St Helens Rd inbound	r		y	1	0	14	2	4	5	2040
B	12	1:30	St Helens Rd/College Way wait	ts	lt	n	0	0	7	12	4	0	1530
B	13	0:30	St Helens Rd/College Way no wait	ts	lt	n	0	0	0	0	0	0	210
B	14	1:00	Deane Rd outbound 1	r		n	0	0	12	2	6	3	2100
B	15	1:00	Deane Rd outbound 2	r		n	0	0	2	0	2	3	2460
B	16	1:00	Deane Rd outbound 3	r		n	0	0	1	6	3	2	1500
B	17	1:00	Deane Rd inbound 1	r		n	1	0	1	3	7	4	2400
B	18	1:00	Deane Rd inbound 2	r		y	0	0	20	18	5	6	2040
B	19	0:30	Deane Rd / College Way	ts	so	y	0	0	15	0	1	1	480
B	20	1:10	Deane Rd / Trinity St	ts	rt	y	0	0	4	0	0	1	910
B	21	1:10	Trinity St / St Helens Rd	ts	lt	y	0	0	6	0	0	1	140
B	22	1:00	Trinity St / Blackhorse St	ts	so	y	0	0	2	0	1	1	1680
B	23	1:10	Trinity St / Newport St	ts	so	y	0	0	19	6	1	1	2730
B	24	1:00	Bradshawgate N'bound queues	r		n	1	0	5	0	1	1	480
B	25	1:00	Bradshawgate N'bound freeflowing	r		n	0	0	116	1	7	5	1980
B	26	0:40	Higher Bridge St/Topp Way	ts	so	y	0	0	1	0	1	1	720
B	27	1:00	Blackburn Rd / Halliwell St N'bnd	ts	so	y	0	0	10	0	5	2	840
B	28	1:00	Blackburn Rd outbound	r		n	0	0	2	0	6	4	1500
B	29	1:00	Blackburn Rd inbound	r		n	0	0	5	1	5	6	2640
B	30	1:30	Blackburn Rd / Halliwell St S'bnd	ts	so	y	0	0	1	0	2	1	3960
B	31	0:47	Blackburn Rd / Brownlow Fold Way	pr	rt	n	1	0	4	0	2	3	752
B	32	1:00	Brownlow Fold Way	rb	so	n	0	0	0	0	2	1	480
B	33	0:24	Gaskell St / Brownlow Fold Way	rb	rt	n	0	0	0	0	2	1	72
B	34	1:00	Gaskell St	r		n	0	0	0	0	4	4	180
B	35	0:45	Avenue St	r		y	0	0	4	2	5	5	45
B	36	0:30	Chorley Old Road / Ring Road 1	rb	so	n	0	0	4	3	1	1	90
B	37	0:28	Chorley Old Road / Ring Road 2	rb	rt	n	0	0	0	4	1	1	56
B	38	1:00	Oakwood Drive	r		n	0	0	4	0	0	1	0
B	39	1:00	Harrow Road Victorian grid pattern	r		n	0	0	8	42	3	4	0
Y	40	0:30	Skeldergate Bridge to Tower Street	ts	lt	y		1	15			1	180
Y	41	1:00	George's Field by R Ouse	r		y	1		8				60
Y	42	0:30	Fishergate - Tower St	r		n	1		11				1110
Y	43	0:20	Fishergate cycle signals	ts	so	y	2	2	16		1	1	80
Y	44	0:30	Fishergate cycle signals	ts	so	y		2	8		1	1	60
Y	45	1:12	Bishopgate lights	ts	rt	y	2		15		1	1	1080
Y	46	0:30	Leeman Road contra flow	r		y			4				0
Y	47	1:00	Minster Yard - Deangate	r		y			62	3	1	1	0
Y	48	1:00	St Leonards Place - Bootham	r		y	5		53		1	1	2460
Y	49	1:00	Bootham inbound	r		y			21		1	1	780
Y	50	0:45	Monkgate / Heworth Roundabout	rb	rt	y			2		2	2	225
Y	51	0:30	Monkgate / Heworth Roundabout	rb	so	y					1	1	90
Y	52	0:30	Tang Hall	r		y							0
Y	53	0:30	Tang Hall	r		y	1	1	2				60
Y	54	1:00	Hartington Road	r		y			5		1		480
Y	55	1:20	Hartington Road	r		y		22	150		1		1760
L	56	1:00	Hyde Park	r		y			2				0
L	57	1:30	Wellington Rd contra flow	r		y			47		1	1	1800

Notes

1. *Preceding letter denotes location: B= Bolton on Saturday 3/3/01, Y=York on Friday 23/3/01 and L=Leeds on Monday 26/3/01.*
2. *Designations of type: r= section of route, ts=traffic signals, rb=roundabout, pr=priority junction.*
3. *Designation of turn: so=straight on, rt=right turn, lt=left turn.*
4. *Designation of cycling facilities: y= yes.*

Appendix F – Risk Rating Personal Questions

1. Are you male or female? [male / female]
2. Which age band are you in? [15 and under / 16-17 / 18-24 / 25-34 / 35-44 / 45-54 / 55-64, 65 and over]
3. How many cars or vans are owned or available for use by one or more members of your household? [None / one / two / three / four plus]
4. Do you hold a driving licence? [yes / no]
5. What is your ethnic group? [White / mixed / Asian or Asian British / Black or Black British / Chinese or other]
6. Over the last twelve months would you say your health as on the whole been [Good / fairly good / not good]?
7. Last week were you [looking for paid employment / retired / student / looking after home or family / permanently sick or disabled / working as an employee / self-employed with employees / self-employed or freelance]?
8. What is your income? [under £8,000 per year / £8,000 to £16,000 per year / £16,000 to £24,000 per year / £24,000 - £32,000 per year / over £32,000 per year]
9. For the last complete week to Sunday can you please state your main means of travel to work. [work from home / tram or underground / train / bus or minibus / motorcycle or scooter / car as driver / car as passenger / taxi / bicycle / on foot / other ; separate responses for each day Monday to Sunday both for the journey to work and the journey from work]
10. Do you usually do one of the following? [drop off or pick someone up on your way to work / stop off for another activity on your way to or from work / none of the above or not applicable]
11. Does your employer require you to have your car available at your place of work? [yes / no]
12. Which description fits you best? [I can cycle but do not / I am a leisure cyclist / I am a commuter or utility cyclist / I am a cycle tourist / I am a sports cyclist / I am a mixture of these]
13. How often do you cycle? [never / occasional holiday times or weekends / one to three times per month / one to two times per week / more than twice per week]
14. Have you been involved in a road accident in the last three years? [yes / no]
15. In the last accident within the last three years, were you in a motor vehicle? [yes / no or not applicable]