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Models of perceived cycling risk and route acceptability

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Abstract

Perceived cycling risk and route acceptability to potential users are obstacles to policy support for cycling and a better understanding of these issues will assist planners and decision makers. Two models of perceived risk, based on non-linear least squares, and a model of acceptability, based on the logit model, have been estimated for whole journeys based on responses from a sample of 144 commuters to video clips of routes and junctions.

The risk models quantify the effect of motor traffic volumes, demonstrate that roundabouts add more to perceived risk than traffic signal controlled junctions and show that right turn manoeuvres increase perceived risk. Facilities for bicycle traffic along motor trafficked routes and at junctions are shown to have little effect on perceived risk and this brings into question the value of such facilities in promoting bicycle use. These models would assist in specifying infrastructure improvements, the recommending of least risk advisory routes and assessing accessibility for bicycle traffic.

The acceptability model confirms the effect of reduced perceived risk in traffic free conditions and the effects of signal controlled junctions and right turns. The acceptability models, which may be used at an area wide level, would assist in assessing the potential demand for cycling and in target setting.

Keywords: Risk; Bicycle; Acceptability; Logit model; Bicycle facility

1. Introduction

Promoting cycling has environmental, social, energy and congestion benefits as it leads to reduced motorised traffic and also confers health benefits on the user. Unfortunately, it is recognised that cycling can be one of the least safe modes of travel for the user. While actual, or objective risk, is relatively high for cycling compared with other modes, the perceived risk, that is the risk that is assumed to exist by existing and would-be mode users, is the important criterion in terms of behavioural response and is the subject of this paper. As is well catalogued in the qualitative literature, the risk of an accident is a major deterrent to cycling. For example, Henson et al. (1997) noted the ‘unpleasantness of traffic’, ‘personal security’ and ‘poor motor vehicle driver behaviour’ as barriers to bicycle use whilst other deterrents identified are ‘aggressive driver behaviour’, ‘personal security fears’ and ‘disregard for the Highway Code’ (Davies et al., 1997), ‘stress and danger’ (Gardner, 1998) and ‘traffic and accidents’ (Davies and Hartley, 1999). However, inconsistencies in the relative importance of risk alongside other determining factors are easy to identify in the qualitative literature and such findings should be regarded as a means of informing and guiding research rather than an end in itself.

In the quantitative literature, Waldman (1977) identifies risk alongside hilliness as the main deterrents of bicycle use in his model of the proportion that cycle to work. At a disaggregate level, a number of studies based on individuals’ actual (Noland and Kunreuther, 1995; Wardman et al., 2001) or stated choices (Bovy and Bradley, 1985; Hopkinson and Wardman, 1996; Wardman et al., 1997, 2001) also confirm the importance of risk through the impact on whether or not to cycle and which route to take. These studies point to the provision of facilities, such as bicycle lanes and traffic free routes, and traffic conditions, such as motor traffic speed and volume, as impacting on perceived risk. They have, however, focussed on a narrow range of facilities and neglected junctions.

Studies of cyclists’ perceptions of safety either when riding or being shown a route on video (Landis et al., 1997; Harkey et al., 1998; Guthrie et al., 2001; Jones and Carlson, 2003) tackle the

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important issue of response to traffic flow, vehicle composition, lane width and surface condition. It might be argued that their limitations so far as route choice modelling is concerned, have been the exclusion of junctions and the use of ratings for discreet features and sections rather than whole journeys, hence limiting the ability to create a measure for perception of risk at route level.

There have been junction based studies and these have found that reductions in risk for bicycle traffic may be obtained by specific features such as raised crossings (Gårder et al., 1998), careful design of the whole junction (Gårder et al., 1994) or by virtue of larger flows of bicycle traffic (Ekman, 1996; Wang and Nihan, 2004). Landis et al. (2003) found that the perception of level of service for a straight on movement through a junction was related to running lane width, junction crossing width and volume of traffic. These junction studies have not comprehensively assessed the risk of an entire journey.

Using bicycle accident data, Stone and Broughton (2003) found: a consistent increase in fatality rate with increasing motor traffic speed; a progressive change towards impacts into the rear of cyclists with increasing speed limit; a very substantially greater risk for crossing conflicts than for merging or diverging conflicts. Jacobsen (2003) uses time series and cross-sectional data from Europe and North America to show that accident casualty rates for bicycle traffic do not rise in proportion to increasing volumes of bicycle use. The accuracy of the assessment of risk using accident statistics is, however, limited because: there is significant under-reporting of bicycle accidents (e.g. Stutts et al., 1990); the statistics do not reflect perceptions of risk (for example, cyclists may avoid or take extra care in seemingly hazardous situations); there are limitations to disaggregation by route type and location.

The first two models of the perception of risk presented here are based on a 10-point risk rating scale. The first model uses the types of route and junction shown to respondents on video in the survey as the building blocks of the journey and the second model uses generic features of a journey, including variables for the proportion of the journey with bicycle facilities, the average volume of motor traffic and parked vehicles along the journey, and the number and type of junctions and the type of turn being made. These models, both of which are disaggregate because they are based on individual responses, would be of use in route choice modelling, in assessing perceived risk reduction of competing cycling investments, specifying the most appropriate improvements to be made at route level, in recommending least risk advisory routes and assessing accessibility for bicycle traffic based on perceived risk of routes. The emphasis in application is primarily on evaluation of routes for the existing cycling market.

The third model is based on a risk threshold and provides a measure of the acceptability of cycling. This model may be usefully deployed with area-wide as opposed to journey specific variables to provide a single overall estimate of the potential demand for cycling in a district. This would be of use in mode choice modelling, in setting feasible targets to underpin transport planning processes and to enhance the representation of risk within econometric demand models of variations in bicycle use across districts (Parkin, 2004). The emphasis is primarily on the potential for increasing bicycle use which is typically addressed at district level.

2. Method

2.1. The survey instrument and procedure

The representation of routes and junctions was based on video clips that were taken in a novel way from a moving bicycle and show the forward view with a wide angle lens from a digital video camera strapped to the upper chest of the cyclist. The 10 route and junction clips selected for use are summarised in Table 1 and are chosen to represent journeys that a cyclist could typically encounter travelling to work. All route and junction clips are within urban areas with a posted speed limit of 30 mph. They allow the estimation of the contributory effects of different journey conditions, including traffic volumes and the numbers of side roads, pedestrians and parked cars, and different types of infrastructure, including bicycle lanes, bus lanes, traffic free routes, and advanced stop lines at traffic signal controlled junctions. Thirty-second duration clips were shown to respondents in their workplace using a laptop computer. The methodology of showing video from a moving bicycle is novel and has the advantages that the respondents sense that they are moving with the traffic, think about their position in the road relative to road features and other traffic, and respond accordingly. Respondents will also look ahead and consider the developing road situation as though they were the cyclist.

Considerable efforts went into piloting to develop a methodology that would provide a clear and realistic representation of the variation in perception of risk for the various components of a bicycle journey. In the first pilot, nine journeys comprising of four clips each were presented to respondents based on orthogonal fractional factorial procedures (Kocur et al., 1982), which is standard in stated preference experiments and is based on a structured combination of choice sets to maximise the accuracy of the estimation of their relative weightings. However, respondents became confused during journey presentations about which of the clips they had seen were part of the journey they were being asked to rate and which were part of preceding journeys. A simpler pilot survey was conducted based on respondents rating individual route and junction clips and this demonstrated that the video clip methodology could yield sensible variations in ratings across the different types of situations represented. The presentation of individual clips does not allow, however, for the aggregation of the ratings of individual clips into an overall journey risk rating.

A methodology that was found to work well involved respondents summarising their home to work journey by bicycle in terms of journey times in different route conditions and the numbers of junctions of different types passed through. They did this by annotating a straight line which was assumed to represent their journey and an example is shown in Fig. 1. The journey starts with 5 min of travel on a residential road followed by 7 min on a traffic calmed road. This leads to a signal controlled junction at which there are no facilities and a right

Table 1
Summary of video clips used in the survey

Clip code	Description	Type	Turn	Bicycle facilities	Pedestrians	Parked vehicles on left	Roads joining	Two way flow vehicle/h
J_1	Traffic signals straight on with bicycle facilities	TS	SO	Y	15	0	2	480
J_2	Traffic signals straight on without bicycle facilities	TS	SO	N	0	0	2	592
J_3	Traffic signals right turn with bicycle facilities	TS	RT	Y	4	0	1	910
J_4	Traffic signals right turn without bicycle facilities	TS	RT	N	1	0	2	360
J_5	Roundabout straight on with bicycle facilities	Rbt	SO	Y	0	0	2	90
J_6	Roundabout straight on without bicycle facilities	Rbt	SO	N	4	3	2	90
J_7	Roundabout right turn with bicycle facilities	Rbt	RT	Y	2	0	4	225
J_8	Roundabout right turn without bicycle facilities	Rbt	RT	N	0	4	2	56
J_9	Mini-roundabout straight on	Rbt	SO	N	0	0	3	480
J_{10}	Right turn off main road	Pri	RT	N	4	0	5	752
R_1	Residential street with parking	R		N	8	42	7	0
R_2	Residential street without parking	R		N	4	0	1	0
R_3	Traffic calmed road	R		Y	4	2	10	45
R_4	Bicycle route on footway	R		Y	5	0	1	480
R_5	Route through a park	R		Y	2	0	0	0
R_6	City centre bicycle only route	R		Y	62	3	2	0
R_7	Busy road with bicycle lane	R		Y	21	0	2	780
R_8	Busy road without bicycle lane	R		N	2	0	10	1500
R_9	Busy road without bicycle lane and with parking	R		N	9	8	5	2640
R_{10}	Busy road with bus and bicycle lane	R		Y	20	18	11	2040

TS, traffic signals; Rbt, roundabout; Pri, priority junction; R, route; SO, straight on; RT, right turn.

turn is made onto a busy road. The journey on the busy road lasts for 15 min and a straight on manoeuvre at a roundabout with facilities is made part way along this road. The journey ends with 3 min travel on a traffic free route. The parts of the journey the respondents described were matched by the interviewer to the 10 route and 10 junction video clips selected from Table 1.

The first rating respondents were requested to make was based on the risk from traffic for the whole of this base journey on a 10-point scale, with 1 being the lowest level of perceived risk and 10 the highest. In comparison with the designs in the pilot surveys, the journey being presented to the respondent was relevant and realistic, was made up of standardised journey components, and the task required of respondents was relatively straightforward. These can be expected to have had a favourable impact on the quality of responses obtained.

Respondents were presented with a number of adjustments to the base journey which were made by adding and subtracting junctions and substituting lengths of route and they were asked to provide a risk rating, again for the whole journey, with these additions, subtractions and substitutions. Variations in ratings of risk in response to variations in the characteristics of the journey reveal the risk that respondents attach to each journey component. For example, the respondent depicted in Table 2 began with 3 min on route type R_1 (residential road with on-street parking) and a total of 15 min on route type R_7 (busy road with bicycle lane) as well as the junctions J_1 three times (straight on at traffic signals with bicycle facilities), J_3 once (a right turn at traffic signals with bicycle facilities) and J_{10} once (right turn off a main road). For this journey the respondent provided a risk rating of 6. The first two adjustments (lines 2a and 2b) comprised adding junctions J_9 (straight on at a mini-roundabout) and then, instead, J_8 (a right turn at a roundabout without bicycle facilities). The original risk rating of “6” was unaffected by the addition of J_9 but increased to “9” by its replacement with the more risky J_8. The next three adjustments (lines 3a, 3b and 3c) to the common base comprised the removal in turn of all occurrences of J_1, J_3 and J_{10} and consequently the respondent’s reported risk ratings were reduced to “4”, “5” and “5”, respectively. The route substitutions came next. Firstly, on line 4a, R_1 is substituted by R_9 (a busy road without a bicycle lane and with on-street parking) and this, as expected, increases the perceived risk rating from the original “6” to “7”. Finally, on line 4b, R_7 is substituted by R_2 (residential road) and the reported risk rating is lower, as expected, at “5”. Lines 4c and 4d in the table would allow for two further route substitutions, but these are not required

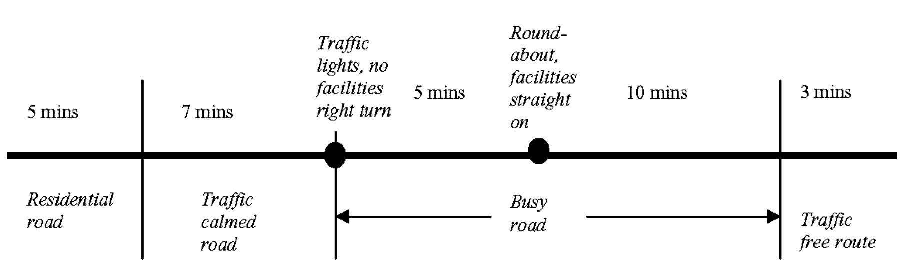

Fig. 1. Typical respondents’ journey description.

Table 2
Example of base journey and variations (respondent no. 88)

	Time on route (min)										Added junction	Respondent's risk rating
	3	3		4		4		4				
1, original journey	R_1	R_7	J_1	R_7	J_1	R_7	J_3	R_7	J_1	J_{10}		6
2a, add junction											J_9	6
2b, add junction											J_8	9
3a, remove junction			J_1		J_1				J_1			4
3b, remove junction							J_3					5
3c, remove junction										J_{10}		5
4a, substitute route	R_9											7
4b, substitute route		R_2		R_2		R_2		R_2				5
4c, substitute route												
4d, substitute route												

because there are only two route types present in the original journey.

The interviewer kept a running list of the number of times a route or junction clip appeared in a journey and a matrix of the substitutions that were made. This allowed substitutions to be selected in order to evenly spread the comparisons between clips within the constraints of realism. To avoid overburdening the respondent, not more than nine adjustments were made to the base journey. The sample of 144 commuters yielded 873 rated journeys. Respondents were also asked to indicate the risk scale point above which they would perceive it was too dangerous to cycle and this point on the scale will be used in the model of acceptability.

2.2. Survey sample

The sample of 144 commuters was drawn from employees of Bolton Metropolitan Borough Council, the University of Bolton and Bolton Royal Hospital between January and July 2002. Only respondents who were physically able to ride a bicycle took part in the survey and they were classified as "never cycle" (35.4%), "cycle on occasional holiday times and weekends" (38.9%) and "cycle between one and three times per month or at greater frequency" (25.7%). Those who never cycle have been included in the sample because they form part of the population that might cycle under different conditions and their responses to the video display material are relevant and valid so far as mode choice modelling is concerned. Respondents were aware that the survey was connected with commuting, but were not made aware at recruitment stage that the survey was specifically concerned with cycling.

Bolton is relatively hilly with 1.35% of commuters cycling to work in the 2001 census. There is an over-representation of bicycle commuters (8.3%) in the sample, but this facilitates analysis of potential differences between regular and less regular cyclists. About 23.6% of the sample were aged 34 and under, 36.1% were aged 35–44 and 40.3% were aged 45 and over. Eleven percent of the sample did not hold a driving licence and 52.1% were female.

While the sample is relatively small it represents well the population commuting into a medium sized, northern town that is relatively hilly. Responses may be different in other urban areas because of different physical geography, only further study in other urban areas would reveal any such variation.

3. Results

Models have been developed to explain variations in risk ratings and acceptability measures across individuals. With respect to risk ratings, separate models are reported based on the independent variables representative of each of the route and junction types (Section 3.1), and on generic variables, such as the proportion of route with facilities for bicycle traffic and traffic volume per hour passing the cyclist (Section 3.2). The acceptability model, presented in Section 3.3, is based solely on the generic variables because it is estimated for use at the district wide level where these variables are more applicable.

3.1. Risk rating model based on route and junction types

Respondents can be expected to employ rating scales in different ways. Some may consider the rating scale intervals as having the same effect on risk whether the interval occurred at the bottom, in the middle or at the top of the rating scale. For others, an interval may have an effect that varies over the scale so that, for example, an increase of one point from scale point 9 to scale point 10 is associated with a greater increase in perceived risk than an increase from scale point 5 to scale point 6. Non-linear least squares regression was used to estimate relationships between the risk rating for the whole route and the independent variables that were linear, sigmoid and other non-linear functional forms. Where possible, they were constrained to be asymptotic to the scale end points of 1 and 10. After extensive testing (Parkin, 2004), the model that explained the most variation in the risk rating (RR) was the logistic model which took the form:

$$RR = 1 + \frac{9}{1 + a\,e^{-Z_{ij}}} \qquad (1)$$

Table 3
Risk model based on route and junction types

Variable	Coefficient estimate	*t*-Statistic	Coefficient estimate	*t*-Statistic
Constant	1.062	9.0	1.066	9.2
dR_1, residential street with on-street parking	0.102	1.6	0.252	3.4
dR_2, residential street without on-street parking	0.024	0.3	0.187	2.4
dR_3, traffic calmed road	−0.185	−2.4	−0.152	−1.8
dR_4, bicycle route on footway	−0.518	−6.0	−0.443	−5.1
dR_5, route through park	−0.484	−5.5	−0.423	−4.6
dR_6, city centre bicycle only route	−0.735	−5.6	−0.714	−5.5
dR_7, busy road with bicycle lane	0.114	1.7	0.118	1.8
dR_8, busy road without bicycle lane	0.274	4.1	0.307	4.7
dR_9, busy road without bicycle lane and with parking	0.325	4.7	0.307	4.5
dR_{10}, busy road with bicycle and bus lane	−0.104	−1.3	−0.096	−1.2
J_1, traffic signals straight on with bicycle lane	−0.005	−0.1	−0.136	−3.4
J_2, traffic signals straight on without bicycle lane	0.070	2.4	−0.063	−1.8
J_3, traffic signals right turn with bicycle lane	0.152	1.6	0.184	1.9
J_4, traffic signals right turn without bicycle lane	0.126	2.8	0.033	0.7
J_5, roundabout straight on with bicycle lane	0.093	0.9	0.184	1.7
J_6, roundabout straight on without bicycle lane	−0.036	−0.7	−0.183	−3.1
J_7, roundabout right turn with bicycle lane	0.764	3.9	0.551	2.9
J_8, roundabout right turn without bicycle lane	0.169	2.3	0.090	1.2
J_9, mini-roundabout straight on	−0.115	−1.2	−0.164	−1.7
J_{10}, right turn off main road	0.085	1.4	0.048	0.7
$(dR_1 + dR_2) \times$ occcyc			−0.384	−4.3
$(dR_1 + dR_2) \times$ regcyc			−0.231	−3.1
$(dR_3 + dR_4 + dR_5 + dR_6) \times$ occcyc			−0.258	−2.7
$(J_1 + J_2 + J_3 + J_4) \times$ occcyc			0.128	3.8
$(J_5 + J_6 + J_7 + J_8) \times$ male			0.231	3.2
$(J_1 + J_2 + \cdots + J_9 + J_{10}) \times$ young			0.135	4.9
$(J_1 + J_2 + \cdots + J_9 + J_{10}) \times$ old			0.088	4.00
Adjusted $\bar{R}^2$	0.207		0.275	

Z_{ij} represents the overall risk of a journey made up of routes i and junctions j which are represented either as dichotomous variables to denote the presence of a route (dR) or junction type (dJ) on a journey or as continuous variables denoting the length of time on a route type (R) or the number of times a particular junction type (J) was passed through on a journey. This is represented for the 10 route and junction types as:

$$Z_{ij} = \sum_{i=1}^{10} \alpha_i \, dR_i + \sum_{i=1}^{10} \beta_i R_i + \sum_{j=1}^{10} \gamma_j \, dJ_j + \sum_{j=1}^{10} \delta_j J_j \qquad (2)$$

A construction of this form estimates the contributory effects of both the presence of a particular condition and the intensity of that condition in terms of the duration of time or the frequency of occurrence. The model can be enhanced by the inclusion of person type dichotomous variables either as additive terms, to allow for different starting points of person type groups on the scale, or as interaction terms, to allow the route and junction coefficients to vary by person type group. The person type variables examined were the regularity of cycling (*regcyc* if cycle between one and three times per month or more and *occcyc* if cycle on occasional and holiday times and weekends), sex (*male*) and age (*young* if aged 34 and under, *old* if aged 45 and over).

The dichotomous representation (α_i) provided the best fit for almost all routes whilst in contrast the number of junctions of a particular type (δ_j) provided the better fit in almost all cases (Parkin, 2004). It was never possible to achieve significance of both variables (α_i with β_i or γ_j with δ_j). The reported models standardise on the use of α_i and δ_j and are presented in Table 3. Two models are presented: one that comprises solely of journey variables and a second that includes person type variables. Given that a higher rating equates to more risk, a positive coefficient estimate denotes a journey feature that contributes to a higher perceived risk. As the primary interest has been the evaluation of different types of route and junction, the non-significant journey coefficient estimates have been retained.

The adjusted R^2 values are relatively low but this is to be expected given the variation in the way that respondents might be using the rating scale. A much better fit can be obtained by specifying dichotomous variables for each individual to allow for different uses of the scale but this does not materially alter the coefficient estimates. Most main effects in the model are of the right sign and either significant at the usual 5% level or not far removed. Additive person specific coefficients were far from significant and were not retained. The model does, however, contain interaction effects which were significant. Given the large number of coefficients, it could hardly be expected that significant interaction effects would be estimated for more than a few of them. The process has therefore been to constrain the interaction effects to be the same across similar route and junction types.

Cycling along residential roads contributes to additional risk and a residential road with on-street parking (dR_1) has a marginally greater detrimental effect than a residential road without parking (dR_2). Interaction terms show that people who do not cycle at all perceive the most risk from residential roads, followed by regular cyclists and then occasional cyclists.

A traffic calmed road in a residential area (dR_3), and traffic free routes (dR_4–dR_6) reduce the perceived risk for a journey and this is to be expected. In a similar manner as for residential roads, occasional cyclists perceive even lower risk along traffic free routes than people who never cycle.

Busy roads (dR_7–dR_9) increase perceived risk and, although bicycle lanes (dR_7) do have a favourable impact, they do not neutralise the perceived negative effect of motor traffic. Parked vehicles on a busy road (dR_9) appear to have no additional effect. The presence of a bus lane (dR_{10}), however, does reduce the risk rating and this may stem from the greater separation from the motor traffic compared with a bicycle lane (dR_7).

Turning now to junctions, proceeding straight on through signal controlled junctions with bicycle facilities (J_1) is associated with a lower level of risk, and risk would be slightly higher for the same manoeuvre without bicycle facilities (J_2). A right turn at a signal controlled junction adds to risk and the presence of facilities does not offset this (J_3 and J_4). The interaction term shows that occasional cyclists perceive more risk at signal controlled junctions than either regular cyclists or those who never cycle.

Although passing through roundabouts is expected to have an adverse effect on risk, the effect is larger where facilities are in place (J_5 and J_7 with facilities as opposed to J_6 and J_8 without facilities). This at first appears counter-intuitive, but might be explained by the presence of facilities suggesting to respondents that the roundabout was more risky than it might otherwise have been perceived to be. Note, however, that the imprecision of some of these coefficient estimates may have contributed to the unexpected results. The interaction terms indicate that the risk of roundabouts is more acutely perceived by males.

The straight on manoeuvre across a quiet mini-roundabout (J_9) reduces the perceived risk and may reflect the traffic calming properties of such installations. Right turns off main roads (J_{10}) contribute to greater risk although the effect is smaller than expected. Neither J_9 nor J_{10} have significant coefficients, however. The young and the old perceive junctions as adding more risk than for those in the middle years of life (aged 35–44).

3.2. *Risk rating model based on generic journey features*

We now turn to models of risk for a whole journey based on variables describing the generic features of a journey in terms of: the type of junction; the type of turn being made; whether bicycle facilities are present; 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. These features are not modelled explicitly in the previous model based on video clips of routes and junction as building blocks of a journey. However, variables for these effects could explain some of the perceived risk and might, therefore, explain some of the variation observed in the previous model. The model with this type of variable would be easier to apply in practice than a model based on the specific video clips of the previous model.

Table 4
Risk model based on generic journey features

Variable	Coefficient estimate	*t*-Statistic
Constant	1.057	10.3
PrOffRoad	−1.669	−7.7
PrAdjRoad	−1.150	−5.6
AveFlow	0.0001	2.3
AvePark	0.004	2.4
RT	0.137	4.2
SIG	0.050	2.3
DRbt	0.174	2.9
Adjusted $\bar{R}^2$	0.193	

Junctions may be represented in the model by the number of different types passed through on a journey. These are signal controlled junctions (SIG), roundabouts (Rbt) and priority junctions (Pri). The presence of a junction in a journey may also be modelled by a dichotomous variable (dSIG, dRbt and dPri). Additionally, junctions may be represented in the model by the presence of and number of turns of a particular type that are required (dSO and SO for straight on and dRT and RT for right turns). A variable for the proportion of time on a route that has bicycle facilities was constructed (PrRFac) based on route types R_3 (traffic calming), R_4 (on footway), R_5 (through park), R_6 (city centre bicycle only street), R_7 (bicycle lane) and R_{10} (bus lane). Variables for the proportion of route that it is off-road, based on route types R_5 and R_6, and the proportion of route that is off-road and adjacent to the carriageway, based on route type R_4, were also specified, along with variables denoting the proportion of junctions on the journey with bicycle facilities (PrJFac). The average number of pedestrians (AvePed), parked cars (AvePark), side roads (AveSide) and motor traffic volumes (AveFlow) have also been tested.

Table 4 presents the resulting model which uses the proportions of route off-road (PrOffRoad) and adjacent to the road (PrAdjRoad). As with the previous model, a negative coefficient denotes a reducing effect on the risk. PrOffRoad and PrAdjRoad were found to have substantially stronger effects separately than when acting within a combined variable for the proportion of route with facilities for bicycle traffic, which also contained the proportion of route with bicycle and bus lane. The proportion of route with bicycle and bus lane was separately found to be far from significant.

The flow of motor traffic on the road (AveFlow) and the number of parked vehicles at the side of the road (AvePark) both have the effect of increasing the perceived risk of cycling and this is to be expected. The number of right turns (RT) on a journey has a significant effect on the perceived risk, much more so than the risk from passing through signalised junctions. The presence of a roundabout on a journey (dRbt) has a significant and marked impact on perceived risk.

The proportion of junctions with facilities did not have a significant effect and this complements the finding in the previous model that facilities at junctions were not valued for reducing risk. Neither the number of side roads passed nor the number of pedestrians present has been found significant and

Table 5
Model of the acceptability of cycling

Variable	Coefficient estimate	*t*-Statistic	Coefficient estimate	*t*-Statistic
Constant (acceptable)	1.339	8.8	1.817	8.3
PrOffRoad	1.886	2.9	2.033	3.1
PrAdjRoad	1.938	2.7	2.110	2.7
RT	−0.343	−4.2	−0.330	−3.9
SIG	−0.115	−2.0	−0.154	−2.6
Male			0.746	4.4
Young			−1.384	−6.2
Old			−0.914	−4.6
Adjusted $\bar{R}^2$ wrt constants	0.038		0.094	

these measures must therefore be of secondary or no importance to the perception of risk of cycling. Straight-on manoeuvres and priority junctions were also found not to be significant.

A number of models were estimated that included person type variables and interactions between person type variables and journey variables. While these did show some significant effects, they were often at the expense of the main effects becoming non-significant. Additionally, models with person type variables would not be as straightforward to apply to route planning in practice.

3.3. Model of the acceptability of cycling

We turn now to a disaggregate logit model that explains whether a cycling route would be regarded as acceptable or not in each of the journey situations presented. Cycling is acceptable where a journey is rated at less than the risk scale point which the respondent denoted as being too dangerous to cycle. The logit model which explains the probability that cycling is acceptable (Pr(A)) is defined as:

$$\mathrm{Pr(A)} = \frac{1}{1 + \mathrm{e}^{Z_{ij}^{\mathrm{U}} - Z_{ij}^{\mathrm{A}}}} \tag{3}$$

The utility of cycling being unacceptable (U), Z_{ij}^{U}, is arbitrarily set to zero and the utility of cycling being acceptable (A), Z_{ij}^{A}, is a linear function of the variables. Given that this model is most sensibly applied at the district level, the variables are specified in generic terms as described in Section 3.2. A positive coefficient estimate increases the probability of acceptability.

The results are presented in Table 5. It can again be seen that the proportions of routes that are off-road (PrOffRoad) or adjacent to the road (PrAdjRoad) have a strong effect in making cycling more acceptable. Signal controlled junctions (SIG), and right turns (RT) (*Note*: the survey was undertaken in a country where the left hand rule of the road obtains) reduce the probability of acceptability but, unlike the risk model based on generic features of a journey, the effect of the presence of roundabouts, traffic flows and parking on a route has not been detected in this model. It is disappointing particularly that flow does not appear in the model of acceptability and this may be connected with the loss of explanatory power contained within a dichotomous "yes/no" choice variable as compared with a measure based on a 10-point scale. None of the other generic features found not to be significant in the previous risk model have been found to be significant in the acceptability model and this confirms their lack of importance with respect to risk and cycling.

Being a model of choice and hence behavioural in nature, the model may be usefully expanded to consider the effects of person type. The model demonstrates that young people and old people consider cycling less acceptable than those in the age band 35–44 years and males consider cycling more acceptable than females, which is to be expected. The inclusion of person type variables in the model means that, when used at an area wide level, proportions of the population by age and sex may be included to improve the accuracy of the resulting estimate of the acceptability of cycling for a district.

3.4. Application of the acceptability model at district wide level

The acceptability model may be adapted for use at an area wide level by adopting area wide averages for the relevant variables instead of variables specific to a journey. This technique has the distinct advantage that the measure of acceptability may be used in models of mode choice at an aggregate level. The technique has been used to estimate the acceptability of cycling based on perceived risk for UK districts in the development of a model of the variation in bicycle use across the UK for the journey to work (Parkin, 2004).

The problem with using district wide averages for the variables is that there is little variation between districts and hence little variation in the resulting acceptability. An alternative methodology would be to sample typical journeys within a district and to determine risk ratings for each journey. Such a method would retain the nature of the original model, that is, being related to an individual choice for an individual journey. A distribution of acceptability would be created and the mean and the spread of the distribution could be used as measures of the acceptability of cycling within the district.

4. Conclusions

This study successfully extends previous work on the perception of the risk of cycling by considering a whole journey, including junctions, and by covering a wide range of independent variables based on 20 different route and junction types using a novel means of presentation based on video taken from a moving bicycle which clearly conveys the situations that cyclists might possibly experience. Thorough piloting took place to develop the finally adopted methodology which coupled the reality of cycling within traffic with the reality of a journey well known to a respondent, the journey from home to work, and this will have enhanced the reliability of the responses to the survey.

It is striking that the presence of facilities at roundabouts and junctions generally has not had a significant effect on perceived risk or acceptability of cycling. This might be explained by respondents considering the presence of facilities as pointing to the presence of a hazardous situation, but that the facilities have not overcome the perceived hazard. The implication is that the provision of facilities at a junction may have a counter-intuitive effect and suggest to potential cyclists that the junction is more risky than it might otherwise have been perceived to be. This has implications for the encouragement of bicycle use through on road facilities provision.

Bicycle facilities along trafficked routes contribute only a little to the moderation of perceived risk, but the major component of the reducing effect is for facilities that are off-road or adjacent to the road. This finding confirms stated preference work that values segregated facilities highly and on-carriageway facilities less highly (Hopkinson and Wardman, 1996; Wardman et al., 1997) and challenges the assumption that the provision of bicycle lanes will encourage bicycle use. Other variables that influence the perceived risk of cycling are the two-way motor traffic flow on the journey and the number of vehicles parked on the road.

The models of the acceptability of cycling generally show existing high levels of acceptability based on perceived risk and indicate that there is perhaps little infrastructure provision that could significantly alter the level of acceptability. While the focus of this paper has been the perception of risk as an influencing variable on the level of use of the bicycle, it should be recognised that there are other attributes relevant to provision of infrastructure for bicycle traffic, such as the development of a coherent network of well signed routes that are comfortable, attractive and direct. These attributes need to be given due consideration in planning for the bicycle.

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