



The effects of drivers' speed on the frequency of road accidents

Prepared for Road Safety Division, Department of the Environment, Transport and the Regions

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Executive Summary

Introduction

TRL has undertaken a major programme of research for the Department of the Environment, Transport and the Regions (DETR) to investigate the impact of traffic speed on the frequency of road accidents. This work followed a comprehensive review of non-UK studies, published by TRL in 1994, which found a positive relationship between speed and injury accidents – the higher the speed, the more accidents - indicating that a 5% change in accidents was associated with a 1mile/h change in average speed.

The objectives of the later work were:

- to investigate the applicability of this finding to different types of UK roads;
- to understand the speed-accident relationship much more fully – in particular, to determine which key factors involving speed are associated with accident frequency and to quantify the effects; and
- to use the relationships thus established to indicate how accidents could best be reduced.

Methodology

Two separate but complementary approaches were adopted as follows:

i Road-based studies

Sections of road between major junctions were studied. The speeds of all vehicles on a sample of road sections were measured, together with traffic and pedestrian flows and details of the road layout. The number of injury accidents that had occurred on these road sections was obtained from national records. Relationships were then developed to predict the number of injury accidents likely to occur on:

- urban classified roads (speed limit 30 or 40miles/h);
- rural single-carriageway main roads (speed limit 50 or 60miles/h).

ii Driver-based studies

In the driver-based studies, individual driver data were collected. The speeds at which drivers chose to drive on the public road were observed and these speeds were related to information on the drivers' accident history and personal characteristics obtained from questionnaires sent to the drivers. Relationships were then developed to quantify the association between:

- a driver's choice of speed and their personal characteristics;

and between

- a driver's accident involvement, their personal characteristics, and their choice of speed.

In both cases the studies were extensive. Overall, more than 300 sections of road were included and more than 2 million observations of vehicle speed were made. In the

driver-based studies, more than 10,000 individual drivers completed questionnaires.

The task of understanding the impact of speed on road safety is a complex one. The distribution of speeds on a road at a particular point or in a particular set of circumstances reflects the speed choice decisions of many drivers. It can be characterised by statistical measures such as the average speed, the spread of the distribution (eg. the standard deviation, or the coefficient of variation – the ratio of the standard deviation to the average speed), the 85th percentile point of the distribution, and others. Moreover, in addition to the characteristics of the speed distribution there are many other features of a road section which may affect accidents - vehicle flows, pedestrian activity, road layout, and so on.

Statistical modelling techniques have been used to explore the relationships between these variables and to develop models in which the effect of speed on accident frequency can be quantified separately from the confounding effects of other variables. Details of the methods used to collect and analyse the data and the statistical structure of the models are given in the full report and its appendices. The following paragraphs summarise the main results.

Results

Taken together, the evidence is compelling that in a given set of road and traffic conditions the frequency of accidents increases with the speed of traffic, and the higher the speed the more rapidly does accident frequency rise with increases in speed. We begin with the results for urban roads.

Urban roads

The statistical modelling showed that no single measure of the speed distribution was wholly effective in accounting for the variation in the accident frequency between sites. For example, although the average speed of traffic was an effective predictor of accidents, the accident predictive model was significantly improved by including a term reflecting the spread of speeds. To characterise the speed distribution, this urban model therefore uses the *average speed* and the *coefficient of variation* – the latter used as a measure of the spread of speeds. The data show that the coefficient of variation typically falls as the average speed increases, and the *combined* effect of this correlated variation is that *the accident frequency rises approximately in proportion to increases in the average speed*.

The findings therefore suggest that traffic operations (eg. police enforcement), or road design changes aimed at reducing speed and therefore accidents, might be aimed at reducing either the average speed, or the spread of speeds, or some combination of the two. For example, the police could choose to target drivers at the top end of the speed distribution. Such a policy would have a significant effect on speeders (those drivers exceeding the speed limit) but relatively little effect on the average speed. In contrast,

road engineering measures might be devised which would influence all drivers and so reduce the average speed, but which might have little effect on the spread of speeds. To estimate the likely accident consequences of such changes, it is necessary to know what effect each of the two factors – the average speed and the spread of speeds – has on accidents *separately*. In this respect the model demonstrates that:

- The faster the traffic moves *on average*, the more accidents there are: the rise is rapid – the accident frequency rises approximately with the square of the average traffic speed.
- The larger the *spread* of speeds around the average speed, the more accidents there are – the accident frequency increases exponentially as the spread of speed increases.

An alternative way of analysing the data is to concentrate on the role of those drivers at the top end of the speed distribution. The effect they have on accidents is demonstrated by an alternative statistical model developed to represent the data in terms of the *proportion of drivers exceeding the speed limit* and the *average speed in excess of the speed limit of those drivers doing so*. The analysis shows that the accident frequency increases with both of these variables, though they are correlated – that is, within the data for urban roads, the mean ‘excess’ speed increases as the proportion of speeders increases. The *combined* effect is that *the accident frequency rises approximately in proportion to increases in the proportion of speeders*.

Rural roads

For rural roads the results follow a broadly similar pattern. The statistical model developed for these roads was based on data from road sections in England, Sweden, and the Netherlands. As in the case of the alternative urban model, this rural model shows that the accident frequency is directly related to the *proportion of drivers exceeding the limit* - the higher this proportion, the more accidents that occur. In this model the speed limit on the road also features as a category variable.

The analyses allowed both urban and rural road sections to be divided into separate sub-groups, reflecting their operational characteristics with respect to speed. These are examined in more detail in the main report.

Driver-based studies

The driver-based studies showed that drivers who choose speeds above the average on some roads tend also to do so on all roads. These drivers tend to be young, to drive high mileages, and to be more inclined than others to violate both formal and informal traffic rules. The accident liability of drivers is associated with speed such that higher speed drivers are associated with a significantly greater accident involvement than are slower drivers; moreover, the higher the speed the more rapid is the rate of increase in drivers’ accident liability.

Conclusions

The results of the road-based and driver-based studies are mutually re-enforcing and provide clear evidence that, in any given situation, higher speeds mean more accidents and the higher the speed the more rapidly does accident frequency rise with increases in speed.

- 1 Reducing the speed of the fastest drivers (ie. those travelling faster than the average for the road) would yield the greatest benefits in reducing death and injury. This demonstrates the value of those engineering and enforcement measures which target *the fastest drivers*.
- 2 The scope for reducing accidents by means of speed management depends on the operational characteristics of the road. The percentage reduction in accident frequency achievable per 1mile/h reduction in average speed is between 2-7%. The earlier 5% figure remains a robust *general* rule. The reduction achievable, however, varies according to the road type and the average traffic speed. Specifically, it is:

- about 6% for urban roads with low average speeds;
- about 4% for medium speed urban roads and lower speed rural main roads;
- about 3% for the higher speed urban roads and rural main roads.

In urban areas the potential for accident reduction (per 1mile/h reduction in average speed) is greatest on those roads with low average speeds (Figure A). These are typically *busy main roads in towns with high levels of pedestrian activity, wide variations in speeds, and high accident frequencies*.

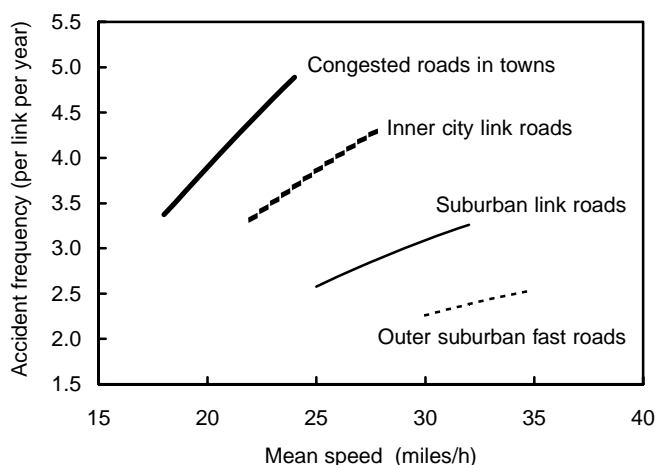


Figure A Accident frequency against mean speed for urban road groups

These results will be important in deciding which speed reduction policies would achieve the greatest safety benefits. Even if the higher severity of accidents on rural roads is taken into account, the implications for prioritisation of remedial measures will remain broadly unchanged.

3 Speed reductions on urban roads would reduce both pedestrian and vehicle accidents and would reduce accidents at minor junctions along road sections. It seems likely (on the basis of studies of the effect of speed cameras in West London) that accidents at major junctions would be reduced as well. Minor (residential) roads offer a similar percentage accident reduction potential to that for other urban roads, per one mile/h reduction in average speed, at equivalent levels of speed.

4 Together, the results relate to a large proportion of the national road network, a proportion which is associated with more than 90% of the total number of injury accidents occurring annually. For this part of the network, taking into account:

- the effect of different accident remedial measures on the characteristics of the speed distribution;
- national accident numbers;
- the accident reductions that can be expected to result from different reductions in speed;
- the reductions in speed that are likely to be achievable and acceptable in different circumstances; and
- the proportion of the network to which these reductions could be applied;

we conclude that:

- the overall national potential for reducing accidents by means of general engineering and enforcement strategies aimed at speed restraint (making reasonable assumptions about the proportion of roads suitable for cost-effective treatment) is:
 - greater for urban roads than rural roads;
 - greater for residential than major urban roads;
- on rural roads, speed management measures that target *specific* problems or specific roads are more likely to be justifiable in terms of accident reduction than *'blanket'* speed management measures. In particular, a reduction in the national speed limit on rural single-carriageway A and B class roads to 50miles/h, is likely to be effective in reducing accidents only on a modest proportion of roads. Targeting 'problem' roads would be a more effective strategy.

5 It is well established that speed is a contributory factor in a large number of accidents. The key question is by how much the national accident toll could be reduced by moderating speed. Of course, widespread behavioural changes and a consequently large decrease in average speeds would be required to eliminate *all* accidents in which speed is a contributory factor. But on the basis of the results in this Report we can estimate what might be a reasonable *minimum* accident reduction to aim for. This represents only a proportion of the accidents in which speed is a contributory factor, but provides a guide to the sensitivity of the accident numbers to a small change in average speed.

Thus, applying reasonable but modest assumptions about the speed reductions achievable on the various road types, it can be shown that an annual saving of

about 23,000 injury accidents could be expected, resulting from a reduction in average speeds (averaged across the whole network) of just 2miles/h. **This would mean that each year more than 200 deaths and about 3,500 serious casualties would be prevented.**

The value of restraining speeds in terms of saving unnecessary death and injury is clearly great.

1 Introduction

1.1 Background

'Road accidents are currently ranked as the eighth largest cause of death in the world, and it is predicted that by the year 2020 they will be the third largest cause Over 45,000 people are killed on the roads in the EC every year, along with 1.5 million reported casualties. This figure could be as high as 3.5 million when under-reporting is taken into account'

This powerful opening statement was taken from a report prepared by several of Europe's leading transport research institutions for the DUMAS project (Developing Urban Management And Safety) (European Commission, 1999). Another recent report (Allsop, 1998) highlights the dilemma implicit in modern road transport systems:

'The rapid door-to-door journey times made possible by motor vehicles and the road system are one of the great benefits conferred by modern transport. But the levels of speed that make possible these journey times also have effects in terms of operating costs, noise, exhaust emissions and the occurrence of traffic accidents and consequent death, injury and material damage.'

Journeys are made for a wide range of purposes and include trips between shops, schools, offices, theatres, factories, docks, airports, rail termini and many other origins and destinations; they are essential to the commercial, community and leisure activities of any modern developed society. Low journey times are highly desirable for the trip makers, but low journey times mean high speeds with the adverse consequences highlighted by Allsop. The key question then arises, how is the balance to be struck? - or put another way, *what traffic speeds are acceptable to society as a whole?* Governments and local highway authorities are faced with a range of questions raised by the general public, pressure groups and other organisations relating to speed. These questions include the level at which speed limits should be set, the use of traffic calming measures, the role of speed in accidents and the whole question of law enforcement and penalties – including the use of speed cameras. Moreover, speeding is a subjective and often emotive issue; people rarely see themselves as speeding 'unacceptably' - it is only other people's speeding that they object to (Silcock et al, 1999). The contradiction is endemic.

To explore possible answers to some of these questions, an objective assessment of the role of speed management in road safety policy is clearly needed. To achieve this, the Department of the Environment, Transport and the Regions (DETR) has recently undertaken a full-scale review (DETR, 2000). The present report is intended to complement this review by presenting and evaluating the

latest research findings from TRL regarding the impact of speed on road accidents. Some of the work was summarised briefly elsewhere by Lynam et al (1999).

TRL's research in this area has formed a major DETR-funded programme over the last decade which has been concerned with evaluating the relationship between speed and accidents at a fundamental level. In order to establish this kind of relationship it is necessary to account for the following simultaneously interacting factors:

- *Traffic speeds.*
- *Traffic flows.*
- *Different vehicle types in the traffic stream.*
- *Pedestrian activity and crossing facilities.*
- *Road layout and geometry.*
- *Driver experience, attitudes and training.*

1.2 Accidents and casualties

The formal definition of what is meant by a road accident in the context of the various types of study will be given in Section 2.1. However, the distinction between accidents and casualties is worth making at the outset.

DETR collects extensive statistics of both accidents and casualties (DETR, 1999a). An accident may involve a single vehicle (for example a car colliding with a tree) but it more often involves other vehicles or other road users.

A casualty, on the other hand, is an individual road user who has been injured in an accident. Therefore, in a personal injury accident there will be at least one, and possibly several casualties. In the national reporting of accidents ('STATS19' - see Section 2.1) each casualty is classified as *slightly injured, seriously injured, or fatally injured.*

This report is concerned with *accidents* - in particular the frequency with which they occur. Ways of predicting accident frequencies in given circumstances are developed – in particular, how these frequencies are influenced by how fast people choose to drive. The accident frequency is the number of accidents which occur on a given stretch of road per unit of time (usually per year).

The numbers and severities of the *casualties* resulting from the accidents are not predicted directly by the equations presented later in this report, since the average number of casualties generated in each accident will depend upon the specific circumstances. If estimates of the number of casualties are needed when applying the results given in this report, separate estimates of the numbers of casualties per accident will have to be fed in. We return to this point later, in Section 5.7.

1.3 Structure of the report

Section 2 of this report clarifies some basic issues and briefly outlines the study which was the starting point of the work. Section 3 goes on to summarise the programme of research that TRL has carried out to explore factors such as those listed above in Section 1.1. The outcome of the research, which is underpinned by international research, has been the identification and quantification of the link between speed and accidents. Section 4 of this report focuses on the implications of the results, and Section 5 discusses priorities for speed management strategies.

The report is supported by a Technical Appendix (Appendix A) which gives full details of the predictive models and their development, and provides tables for use by transport professionals and statisticians. A further Appendix (Appendix B) outlines areas in which further knowledge is needed.

2 Clarification of some basic issues

2.1 What do we mean by an accident?

The work described in this report is based on two types of accident:

- personal injury accidents (PIAs) recorded in national accident statistics (STATS19);
- accidents reported by drivers themselves by means of questionnaires (self-report).

Personal injury accidents:

- take place on the public highway;
- involve one or more vehicles;
- involve injury to at least one person (ie. involve a casualty).

To be included in official statistics the accident must have been reported to the police who will have completed a form (STATS19) which provides details of the accident. STATS19 includes information about the ‘attendant circumstances’ of the accident (the location, the time, the road type, the lighting condition etc.), about the vehicle and its driver (the vehicle type, manoeuvre being executed, driver age and sex etc.), and about the casualties involved. Accident information is collected nationally and maintained by DETR in a substantial electronic database.

Self-reported accidents:

are those a driver reports having been involved in when asked to do so by means of a questionnaire or interview. In most of the self-report accident surveys of this kind undertaken by TRL the definition of an accident has been as follows:

‘An accident is any incident which occurred on public roads (not on private property or in a car park) and which involved injury to the driver or to another person, and/or damage to property or to the vehicle being driven’.

Generally drivers have been asked to recall accidents they have experienced in a period not exceeding 3 years prior to the survey date. The majority of the accidents reported in this way do not involve injury – they are damage-only accidents. Research shows that around 8 accidents resulting in damage only (ie. where no reported injury occurs) can be expected to occur for every one PIA.

It is important to note that self-reported accidents are accident ‘involvements’. Thus, for example, an accident involving two cars recorded in STATS19 could in principle be reported in a questionnaire survey by both drivers – in which case it would result in 2 accident involvements. Accident involvements can of course also be obtained from the STATS19 database by accessing accidents by vehicle or

by driver. However, for the purpose of the (‘road-based’) analyses presented later, STATS19 accidents have been accessed by location and are not therefore reckoned as accident involvements. On average the ratio of involvements to accidents is about 1.3-1.4.

2.2 What do we mean by speed?

The aim of the studies presented in this report is to relate accidents to speed – but what exactly do we mean by speeds, and how should they be measured?

Individual road users make subjective statements about *going too fast or too slowly* and these assessments will be influenced by a number of factors including the road environment, the speedometer reading, the vehicle being driven and the traffic levels existing at the time. To illustrate the subjectivity of such judgements, a motorist in a hurry on a motorway in a modern car might consider 70miles/h to be relatively slow, but the same motorist negotiating a hazardous bend would probably find 70miles/h too fast; moreover the same person seeing a vehicle pass their front door or their children’s school may well find a speed of 40miles/h excessive. So absolute speed makes little sense without reference to factors related to the road environment, the vehicle, the traffic, or the driver. This leads to the concept of speed levels that are *appropriate or inappropriate for the conditions*, as opposed to the absolute speed - an issue which is discussed briefly in Appendix B (Section B6).

From the research point of view, definitions of speed are needed which enable clear measurement. Two types of speed data are typically collected:

- ‘Spot speeds’.
- Journey times.

The spot speed of a vehicle is the speed of an individual vehicle measured as that vehicle passes a particular point (or spot) on the road. The journey time is determined by the average speed of a vehicle between two points separated by some distance. The first is the measure most commonly used in research into accidents and is the method employed to collect most of the speed data described in this report.

Both kinds of speed measurement yield a *distribution* of speeds for vehicles using a particular section of road. Clearly at the point where speeds are being measured, the various vehicles passing the point will usually be travelling at different speeds. Moreover, even if on different occasions the speed measurements include the same driver driving the same car at the same place, the observed speed will differ from one occasion to another due to a whole range of factors. Speed distributions – whether in space or time (or a combination of the two) - contain a wealth of information which can be captured by means of a number of *statistical parameters* describing the characteristics of the distribution.

The most familiar parameter of a distribution is the average (or mean), but this is not the only statistic of value in research and application. In road design, the practice over the last two decades has been for engineers to use what is known as the 85th percentile speed of traffic. The

85th percentile is the speed at or below which 85 per cent of drivers drive, and is thus a measure of the higher speed end of the distribution on a particular road. The amount by which the 85th percentile exceeds the mean speed will depend on the spread of the speed distribution. The most common measure used to characterise the spread or variability of speeds found on any road is the *standard deviation* of the speed distribution. The *coefficient of variation* is then the ratio of the standard deviation to the mean – a dimensionless number describing the shape of the distribution.

Figure 1 depicts a speed distribution typical of those that may be obtained by a roadside survey. The figure illustrates some of the parameters mentioned in the previous paragraph, and those which will be used in the later analyses; they will be the subject of more detailed discussion later in the report.

2.3 The starting point for the present work

TRL's Project Report PR58: Speed, Speed Limits and Accidents (Finch et al, 1994) provided a comprehensive account of the key research findings from the early 1960s onwards. The overall message of the report can be summarised as follows:

- A review of longitudinal studies (also known as before-and-after studies) provided convincing evidence that a decrease in speed reduces accidents, and a corresponding increase in speed increases accidents.
- Those studies which gave rise to conflicting evidence as to whether accidents are influenced by traffic speeds were subject to methodological limitations or flaws.

By gathering all of the published data together and performing an overall analysis, the authors came to the following conclusions:

- 1 A change in the speed limit results in a change in the average traffic speed which is roughly one-quarter of the value of the change in the limit.
- 2 Small changes in speed limits are proportionately more effective at changing average traffic speeds than are substantial changes.
- 3 A 1mile/h change in the average traffic speed is associated with a 5 per cent change in injury accidents.

This latter conclusion was based upon empirical observations derived from a wide range of studies carried out in a number of countries over a significant period of time, and is illustrated in Figure 2 which is taken from Finch et al (1994). Many of the studies were conducted to establish the impact on accidents of changing the posted speed limit on certain types of road. Thus the road types varied from study to study, as did the volume of traffic using the roads, though most were high quality, high speed inter-urban roads. The imposed changes in speed limit also varied in their level and effect; some were imposed because of the oil-crisis in the early 1970s – a fact which may have affected other aspects of driver behaviour. In addition, the analysis inevitably relied on a number of assumptions. For example, it was assumed that factors such as traffic flow, enforcement levels, safety legislation and driver behaviour remained constant during the study periods involved – ie. these variables were not explicitly accounted for in the analysis carried out by Finch et al or in some of the original studies.

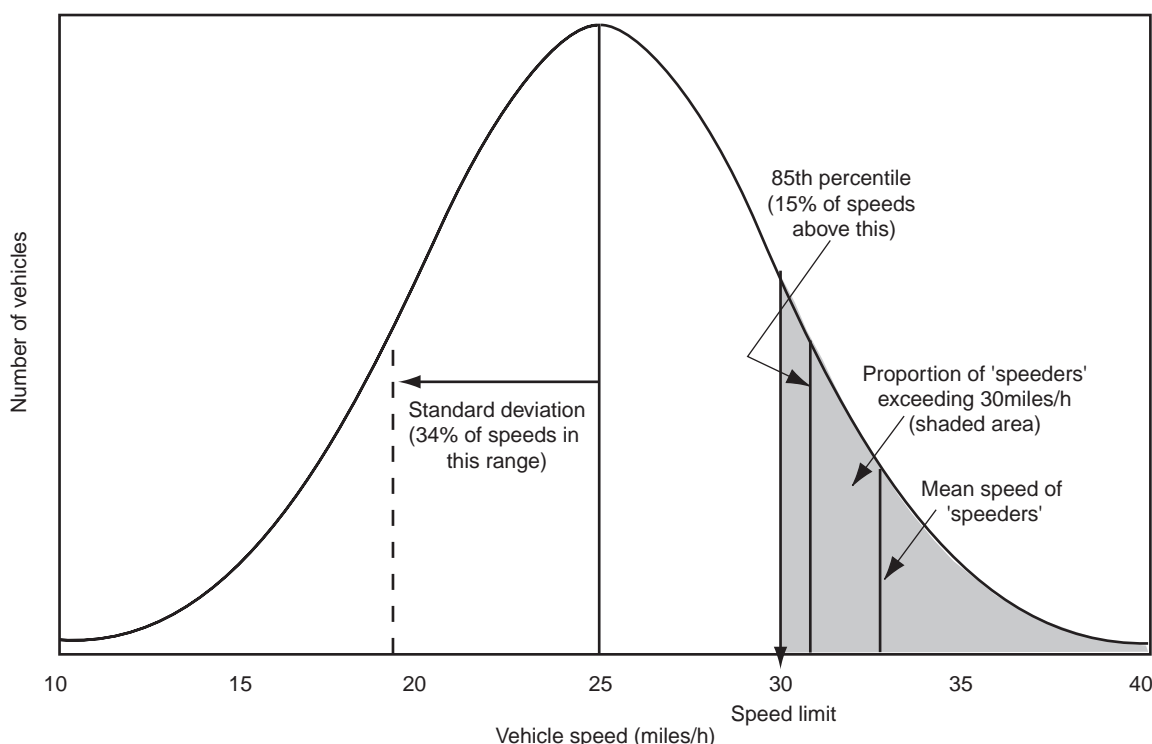


Figure 1 A typical speed distribution showing commonly used parameters

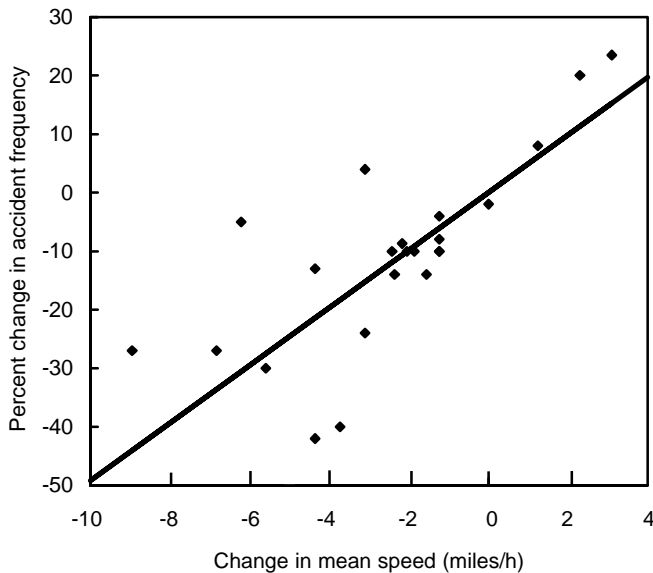


Figure 2 A relationship between speed and accidents (from Finch et al, 1994)

This analysis of a wide range of studies suggested that a 5% accident reduction might be expected for each 1 mile/h reduction in average speed. Allowing for sampling variability in the data, we can be 95% confident that the true value lies between 3.2% and 6.7%. If the data relating to the oil-crisis period are excluded, the best estimate figure becomes 3.6%, and we can be 95% confident that the true value lies between 1.9% and 5.3%.

This relationship inevitably relates only to the range of road types and traffic conditions covered by the data included in the analysis. In particular, the effect on accidents of each 1 mile/h reduction in average speed cannot reasonably be extended outside the range of speed reductions observed in the various studies. Although the analysis attempted to detect any evidence for a non-linear (curved) relationship, the variability of the data available was such that this possibility could neither be detected nor rejected.

Thus the analysis gave strong evidence of an association between mean traffic speed and accidents on certain types of high quality inter-urban roads. But would the same relation hold true for congested urban roads? Or for low flow rural single-carriageways? Or for UK traffic conditions? The programme of work described in Section 3 was developed to address these questions.

2.4 Section summary

TRL research has involved two key types of accidents - personal injury accidents (PIAs) included in the STATS19 database and self-reported accidents.

There are many different parameters that can be used to characterise different aspects of speeds and speed distributions. Until now the mean speed and the 85th percentile have been favoured. However, the use of a single speed parameter (such as the mean) for understanding the complex relationship between speed and accidents will not necessarily prove adequate, and other descriptors — particularly those relating to the spread of speeds — may be needed.

Evidence of a positive link between speed and accidents came from an analysis by TRL of results obtained from a range of studies found in the international research literature. This analysis suggested that a 1 mile/h change in the mean speed of all traffic was associated with a 5 per cent change in injury accidents. (Assuming that the average speed on the roads in the international studies was between 30 and 50 miles/h, this implies that a 1 per cent change in speed produced a change in accidents of between 1.5 and 2.5%.)

The refinement of this rather ‘broad-brush’ association was the starting point for the TRL research programme into speed and accidents which will be presented in the remainder of this report.

3 The TRL research

3.1 A two-pronged approach

The speed research carried out at TRL over the last decade can be divided into two main categories:

- Road-based studies.
- Driver-based studies.

The main distinguishing feature of these categories is the ‘unit’ of study. In road-based studies the unit of study is the road and the traffic conditions that prevail on the road. This type of study usually involves assembling the appropriate accident data from STATS19 and relating these data to extensive speed, traffic and geometric data collected by means of roadside surveys on a variety of different road sections or junctions. Data will include variables such as the characteristics of the speed distribution observed on the road, traffic flow variables including the proportion of heavy goods vehicles, relevant geometric variables including road width, and variables reflecting pedestrian activity. These data are then analysed in order to relate accident occurrence to speed, taking account of the various other road and traffic factors that may prove to be significant.

In the second type of study the unit of study is the driver. In this case, the speeds of individual drivers are measured – either driving freely on the public road or in test drives with an observer in the car. The self-reported accident histories of the drivers are obtained by questionnaire or interview, together with demographic data (age, sex, occupational group etc.), exposure data (annual mileage etc.), trip-specific variables (vehicle driven, passenger, trip purpose) and a range of psychological variables quantifying attitudes, motivations and cognitive ability. These data are then analysed to relate the accident liabilities of the individual drivers to the speeds chosen by them taking account of any explanatory variables which appear significant.

The remainder of Section 3 describes in outline the studies undertaken by TRL using this two-pronged approach, and the later sections consider the results and their consequences.

3.2 Statistical methods employed

Multivariate regression modelling is the main statistical method used in these studies. Regression models determine whether a statistically significant relationship exists between a single *dependent* variable (in this case the frequency of accidents) and any number of *independent* or *explanatory* variables. It is effective even if these variables are to some extent inter-related. The regression model quantifies the strength of the association between the dependent variable and the significant independent variables in terms of *regression coefficients*. The resulting statistical model (or relationship) can then in the appropriate circumstances be used to *predict* the effect on accidents (the dependent variable) of changes in the value of the explanatory variables. In the present context, the regression relationships developed will allow us to predict the change in the frequency of accidents which would be expected to result from a change in speed and in the other variables included in the model.

The particular regression modelling technique that has been used for accident modelling in the road- and driver-based analyses is *Generalised Linear Modelling*. This technique has been widely employed in other TRL accident studies and is well documented (for example, McCullagh and Nelder, 1989). It is described more fully in Appendix A (Section A1).

3.3 Road-based studies

3.3.1 Introduction

Over the last decade or so TRL has completed a considerable number of research projects in which the personal injury accidents (PIAs) occurring at various types of major junctions and on the road sections between them have been related to traffic and geometric parameters (Maycock and Hall, 1984; Hall, 1986; Pickering et al, 1986; Layfield et al, 1996; Summersgill and Layfield, 1996; Summersgill et al, 1996; Taylor et al, 1996; Kennedy et al, 1998). This on-going research aims to quantify the role of junction and road design in accident occurrence. Relationships have been developed between the frequency of accidents (of various types) as the dependent variable, with traffic and pedestrian flows and the characteristics and geometry of the road or junction as the explanatory (or independent) variables. These accident-flow-geometry relationships allow road engineers to predict the safety consequences of changes in the design and thereby to optimise the design of roads and junctions from a safety point of view. The influence of road geometry on accidents clearly acts through 'intermediate' mechanisms: for example, a change of geometry – reducing the vehicle path curvature on a roundabout or re-timing a traffic light so as to reduce over-running of the red phase - may reduce the speed of vehicles, which in turn reduces the probability of an accident. Speed is believed to be a powerful 'intermediate' influence in this sense.

Building on these studies, and following the insights provided by TRL's Project Report PR58 (Finch et al, 1994), the TRL programme was extended to investigate the

importance of *speed* in determining accidents on urban and rural roads in Great Britain. To make these research projects more tractable, and because accidents at major junctions had already been addressed in the other work cited above, only road sections *between* major junctions were included (ie. the junctions themselves were not included). Sections 3.3.2 and 3.3.3 respectively summarise the studies undertaken on urban and rural roads.

3.3.2 Urban roads

The data

A link section – or 'link' – is defined as a stretch of road between two major junctions (ie. junctions at which the driver loses priority). The link may include 'minor junctions' (T-junctions and crossroads), but it possesses reasonably consistent characteristics and in principle it offers drivers uninterrupted travel, since they have priority over other traffic emerging onto the road from side-roads. A speed limit change, from say 40miles/h to 30miles/h, which will affect traffic speeds, is also used to define the end point of a link section: thus, no link section *contains* a speed limit change within it, but it may be *bounded* by one at either or both ends.

The study by Summersgill and Layfield (1996) mentioned in Section 3.3.1 employed a national sample of A, B and C class urban roads. In all there were 300 link sections of which 222 were on two-way roads in 30miles/h zones, 50 were on one-way roads in 30miles/h zones and 28 were on two-way roads in 40miles/h zones. All roads in the sample were single-carriageways situated in urban areas with a population greater than 20,000. The characteristics of these roads and the traffic flows on them had been stable over a 5 year period; they were all without a bus lane, and were lit. The survey of these link sections was extensive, covering a large range of geometric features and variables of potential interest. Some 500 measurements were made for each section, covering the following broad areas:

- Traffic flow.
- Pedestrian activity.
- Composition of traffic by vehicle type.
- Road geometry and layout.
- Parking features and activity.
- Visibility.
- Road markings and signs.
- Pedestrian crossing facilities.
- Roadside development and land use.

Details of all reported personal injury accidents occurring on the link sections were obtained from the relevant local highway authorities for a 5 year period (from April 1983 to March 1988) inclusive. These accidents were PIAs included in the STATS19 database, but local authority accident records were used in this case so that detailed text descriptions of the nature and location of each accident were available (STATS19 does not include such descriptions).

The resulting database was initially used to investigate the relationship between accidents, road features and traffic and pedestrian flows. To examine explicitly the role of speed, the database was enhanced with detailed information on traffic speeds for a sub-set of 100 of the two-way link sections. This sub-set was selected at random, following consultation with the relevant local authorities to ensure that these sections had not undergone any modification since the original survey and that traffic flows had remained largely unchanged. Link lengths in this sub-set ranged from 0.4km to 1.8km; 34 links were on A class roads, 22 were on B class roads and 44 were on C class roads.

Speed and flow data were obtained at three different locations along each link section using automatic roadside measurement equipment. Measurements on each link section were taken on a single weekday for the period 07:00 – 19:00, thus capturing information on both morning and evening peaks as well as the quieter inter-peak period. Periods of bad weather or temporary events like roadworks were avoided and re-surveys at the same or alternative sites were undertaken when necessary. This survey method gave high quality speed data and ensured consistency between the speed and flow measurements taken. For each link, the speed data from the 3 locations for both directions were combined to give a single set of speed observations representative of the link as a whole. For the analyses to be described in this section, only the speed data for the off-peak period (09:30 – 16:30) were used.

Preliminary analysis revealed that 50 per cent of link accidents had occurred within 20m of a minor junction *within the link*, and that 82 per cent of these minor junctions were priority T-junctions. Vehicle speed at these junctions was therefore likely to be a particularly important component of the overall speed-accident relations. Accordingly, the link speed data were supplemented by an additional 24 hour speed/flow survey at each of the three junction entry and exit points at 20 T-junction sites which occurred within 10 of the 100 links.

Investigation of average speed and speed variability

An initial inspection of the 100 urban links revealed that yearly accident frequencies were much higher in London (3.14 accidents per link per year) than elsewhere in the country (1.57 accident per link per year). Of course, the higher traffic flows in London would contribute to explaining this effect, as would higher junction densities and pedestrian activity; these factors would be evaluated in the multivariate analysis. In keeping with national trends, 70 per cent of accidents occurred at major junctions at the end of each link section, and 30 per cent took place within the links themselves. The objective of the present investigation was to study the effect of speed on the latter.

The conditions encountered on any stretch of road are unlikely to be fully captured by the engineering categories of motorways, dual-carriageways, and single-carriageways, nor by the administrative classification into A, B, and C roads. A classification based more closely on the actual conditions prevailing on the road sections is needed to develop an understanding of accident occurrence, and from it, what remedial safety strategies

might be applied. Therefore, a statistical *cluster* analysis was used to group the links according to their overall speed characteristics. To do this, the various measures of the speed distribution (eg. average speed, variability of speed, proportion of slow moving traffic) were used as grouping variables. Four distinct groups (or clusters) were identified – groups which were distinguished not only by their speed characteristics (the basis of the clustering), but also in terms of their roadside development and road function. In ascending order of overall speed levels, and descending order of accident frequencies, the four groups represented:

- 1 *Highly congested roads in towns.*
- 2 *Typical inner city link roads.*
- 3 *Suburban link roads.*
- 4 *Outer suburban fast roads.*

Baruya and Finch (1994) give a full description of the analysis leading to this classification. Based as it is on the parameters of the speed distributions observed on these road sections, this classification strongly suggests that the speed characteristics capture the key elements of road use, environment and function.

Relationships were then explored between total accidents and the available explanatory variables for the 100 sites, using the Generalised Linear Modelling technique. The yearly accident frequency per link was found to be strongly related to:

- *The average traffic speed (the greater the speed, the more accidents).*
- *A measure of the spread of traffic speeds (the broader the spread, the more accidents).*
- *Traffic flow (the more traffic, the more accidents).*
- *The amount of road-crossing by pedestrians (the more activity, the more accidents).*
- *The number of minor junctions (the more minor junctions, the more accidents).*
- *Whether the link is on an A, B or C class road (more accidents if it is on a B class road).*
- *The proportion of heavy goods vehicles in the traffic stream (the higher the proportion, the more accidents).*
- *Whether or not the link is in London (more accidents if it is in London).*

Note that, even *after* taking account of variables such as traffic and pedestrian flow and the number of minor junctions, a ‘London effect’ was still apparent: ie. if all other factors were the same, there were more accidents on links in London than elsewhere. This effect has been noted for major junctions in previous work (for example: Summersgill et al, 1996; Taylor et al, 1996).

The effect of the speed (and other) variables on accidents is examined more closely in Section 4, and the underlying statistical model (known as *Urban Link Model UI*) is given in Appendix A (Section A3.1). A version of this model was first reported by Baruya and Finch (1994).

Investigation of extreme (high) speeds

Analysis of the speed data at the 20 T-junctions included in the study confirmed the expectation that the traffic speed distributions on the main road entries and exits were *bimodal*: they had two ‘humps’ – one hump representing the low speeds caused by turning traffic, and the other representing the speeds of vehicles driving through the junction unhindered by other traffic. An example of such a bimodal distribution is shown in Figure 3.

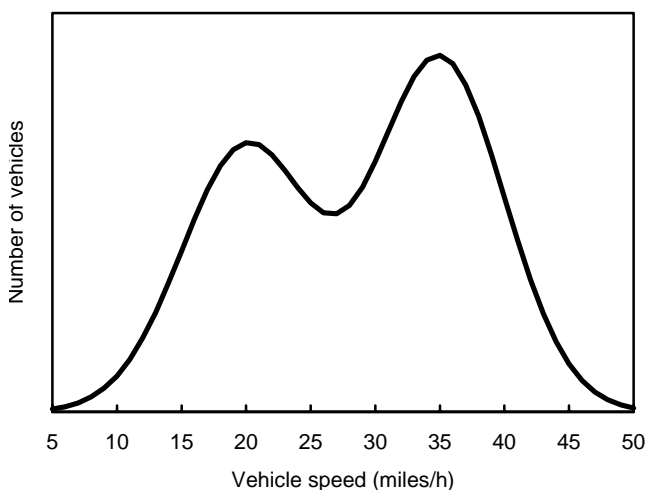


Figure 3 Example of a speed distribution caused by a minor junction

Bimodal distributions need to be treated with care in statistical analyses. For example, although it is easy to calculate the average speed, it has little meaning on its own. Ideally the components of the traffic stream corresponding to each hump would be treated separately, with turning traffic being treated separately from through traffic. This however, is far from straightforward for two reasons. Firstly, although the data could be collected for the two components - turning and non-turning traffic - vehicles in these groups interact: on slowing, turners impede some, but not all, non-turning traffic. Secondly, in order to apply the results of such a study to practical road design, a designer would need detailed data about the two components of the traffic stream – which in practice is unlikely to be available. To circumvent these difficulties, analyses were undertaken which avoided using variables relating to the whole distribution (like average speed or coefficient of variation of speed) but instead used variables concerned with *extreme* speeds – for example the proportion of vehicles exceeding the speed limit (or some other relevant threshold).

Exploratory modelling work using the small set of junction data mentioned earlier in this Section provided a strong indication that extreme speeds might well be particularly important in determining accidents. To follow this up, further accident-speed modelling was undertaken using the larger data set (the 100 link sections) with an expanded set of speed variables, including several concerned with extreme speeds. These analyses showed that accident frequencies on the 100 link sections were

strongly related to measures of extreme speeds, as well as to measures of average speed. Details are given in Appendix A (Section A3.2). A second urban link model, known as *Urban Link Model U2*, was developed using excess-speed variables alone. This model showed that the frequency of injury accidents (PIAs) per year per link was related to:

- *The proportion of drivers who exceed the speed limit (the more speeders, the more accidents).*
- *The average speed by which these drivers exceed the speed limit (the higher the ‘excess speed’, the more accidents).*
- *The traffic flow (the more traffic, the more accidents).*
- *The amount of road-crossing by pedestrians (the more activity, the more accidents).*
- *The number of minor junctions (the more junctions, the more accidents).*
- *Whether the link is on an A, B or C class road (more accidents if it is on a B class road).*
- *The proportion of heavy goods vehicles, buses and coaches in the traffic stream (the higher the proportion, the more accidents).*
- *Whether or not the link is in London (more accidents if it is in London).*

Again a London effect was apparent, even after allowing for other variables. Details of this model can be found in Appendix A (Section A3.2).

The effect of the speed (and other) variables on accidents is explored more closely in Section 4. The overall predictive capability of models U1 and U2 is similar, but U2 provides more insight into the role of speeding drivers.

3.3.3 Rural roads

A great deal of road safety research has focused on urban areas, where about three-quarters of injury accidents and more than two-thirds of the resulting casualties occur. However, around 1990 a trend was identified on the rural road network in Great Britain for the proportion of the more severe accidents to increase over the years. Whilst the national percentage of both casualties and traffic outside built-up areas has remained fairly constant over the last decade, the percentage of fatalities has gradually increased (Barker et al, 1998). TRL therefore undertook a Europe-wide study of the effect of speed on accidents on rural roads. This sizeable work package was part of the MASTER project (**MAN**aging Speeds of Traffic on European **R**oads).

The data

Detailed data on traffic speeds, flows, road geometry and accidents for samples of rural single-carriageway link sections (as defined in Section 3.3.2 for urban roads) were supplied to TRL by the Institute of Road Safety Research (SVOV) of the Netherlands, the Swedish Road and Transport Research Institute (VTI) and the Instituto Superior Tecnico (TRANS-POR) of Portugal. Equivalent data for the UK were supplied by 11 local authorities

mainly from central and southern England; these data were from roads selected by the authorities concerned. The data were necessarily limited to key variables which were readily available in all participating countries, supplemented by information taken from maps.

The accident data were personal injury accidents that had occurred on each link section during the 5 year period between 1992 and 1996. Speed and flow data related to continuous observations over several days, but only weekday off-peak data (09:00 to 16:00) were used in the final analyses.

The English data related to a total of 78 links consisting of 47 from A class roads, 16 from B class roads and 15 from C class roads. The data from mainland Europe related to 140 road sections, consisting of 28 from the Netherlands, 73 from Sweden and 39 from Portugal. Detailed information about the data and the analyses undertaken can be found in Baruya (1998). The study was also reported by Baruya et al (1999).

During the 5 year study period there were 565 personal injury accidents on the 78 English links:

- 353 (62.5%) took place away from junctions.
- 99 (17.5%) took place at priority T-junctions.
- 76 (13.5%) took place at accesses to private premises.
- 37 (6.5%) took place at cross-roads and other junctions.

The average accident frequency was 1.45 accidents per link per year. Accident rates (accidents per 100 million vehicle-kilometres driven) averaged 41.5 and ranged from 0 to 322. The yearly accident frequency per kilometre of road was the highest on A class roads (1.04 accidents per km of road per year) whereas the accident rate per 100 million vehicle-kilometres driven was the highest on C class roads (75.5). These figures are somewhat higher than the national averages. Further investigation of the data revealed that C class roads had very different characteristics from the A or B class roads - the latter two being similar in many respects. With insufficient data in the sample to permit a thorough analysis of C class rural roads in their own right, further analysis was restricted to the 63 highly similar A and B class roads.

International analysis

Of the 203 link sections, 171 (including 38 links from England) had sufficiently detailed data to be included in all analyses. The Dutch, Swedish and Portuguese speed limits are classified in 10 km/h bands (70, 80, 90, 100 and 110km/h). To match these, the English rural limits of 50 and 60miles/h were designated as 80 and 100km/h respectively, even though this introduced a minor conversion error. The accident data for the European roads covered different time periods - the Dutch accidents covered a period of 4 years, the Portuguese 3 years and the Swedish and the English accidents 5 years. However, the conversion of these accident numbers to yearly frequencies and rates avoided introducing undue bias between countries in this respect. A comparison of accident rates, expressed as accidents per 100 million vehicle-kilometres, revealed that the Swedish rural road sections possessed the

lowest average accident rate per link (15.3), followed by the Netherlands (21.5), England (33.3) and Portugal (53.3). The comparatively low rates for the Swedish and Netherlands links, and the comparatively high rates for the Portuguese links, reflect relative national accident rates (International Road Federation, 1999).

It was found that the accident frequencies for some roads were remarkably similar with respect to flow, speed and traffic characteristics, *irrespective of their country of origin*. The 'cluster' analysis technique applied to the urban data was therefore applied, using six variables (traffic flow, road width, mean speed, standard deviation of speed, proportion exceeding the speed limit and a measure of slow moving traffic) as the clustering variables. Four distinct categories (groups) of rural road were identified that cut substantially across national boundaries. The first two groups were of lower quality roads, with average to high flows, narrow to medium width, and low to average mean traffic speed. The third group consisted of roads with low flows, narrow to medium width and high proportions of speeding motorists. The fourth group reflected road and traffic conditions at the other end of the scale, featuring low-flow, wide road sections built to a high quality and having high traffic speeds. Most of the Swedish links were in the third and fourth groups while most of the Portuguese links were in the first group; the low accident rate for the Swedish roads noted earlier reflects this high build quality, while the high accident rate for Portuguese roads reflects the lower build quality.

Encouraged by the cross-national characteristics of the roads under study, speed-accident modelling was attempted on the entire database of 171 rural road sections, using the Generalised Linear Modelling technique. However, it became clear that accident rates for Portuguese roads were too dissimilar for these to be incorporated into a single speed-accident model. Hence, a relationship was established for the Dutch, Swedish and English data alone. The resulting model (called the EURO model) showed that the yearly injury accident frequency per link section was related to:

- *Characteristics of the speed distribution (in particular the mean speed and the proportion of speeders).*
- *The posted speed limit.*
- *The traffic flow (the more traffic, the more accidents).*
- *The number of minor junctions (the more junctions, the more accidents).*
- *The length of road under study (the longer the road, the more accidents).*
- *The road width (the narrower the road, the more accidents).*

The model fitted the data well and was an excellent predictor of accident frequencies on rural roads in the three Northern European countries included. Details of the EURO model are given in Appendix A (Section A4). The characteristics of the speed distribution and the speed limit in the EURO model mutually interact, and the interpretation of how they affect accidents has to be done with care. This issue is considered in detail in later sections and in Appendix A.

3.4 Driver-based studies

Driver-based studies have been described in detail in other TRL reports (which are referenced in the following text). Consequently, only a brief summary is given here.

The speed at which drivers choose to drive in various road and traffic conditions is an important characteristic of their behaviour, and one that ultimately must influence both the frequency and severity of the road accidents in which they are involved. So far, this report has been concerned with research which has attempted to establish the fundamental links between accident frequencies, traffic speeds and certain road features on sections of road. If however, we wish to consider whether speeds can be modified by influencing the speeding behaviour of individual drivers, there is a need for a better understanding of the range and relative importance of those factors which influence the driver's speed choice. Driver-based studies of speed are a fairly recent innovation in accident research. Their aim is to complement the relationships discovered in the road-based studies, and to provide a basis for developing measures designed to influence drivers' behaviour and so reduce accidents. TRL has managed a major programme of behavioural research over the last decade (see Grayson, 1997) which has included several studies specifically concerned with accident involvement and speed choice.

Although not specifically addressing the question of speed choice, TRL Report TRL315 (Maycock et al, 1991) provides a foundation for studies of this kind by exploring the relationship between the self-reported accident involvement (or *accident liability*) of individual drivers and the characteristics of those drivers. In this context, accident liability is defined as the number of accidents an individual driver is *expected* to be involved in per unit time (usually per year). It is a statistically determined expectation based on the observed accident frequencies of a large number of drivers; the values of accident liability normally encountered range from 0.05 to 0.5 accident involvements per year. Maycock et al (1991) showed that accident liability is mainly dependent on the driver's age, driving experience (the number of years since passing the driving test) and exposure (in its simplest form, annual mileage). Accident liability falls non-linearly with increasing age and experience, and increases with annual mileage travelled, but not in proportion to mileage.

The data used were obtained through a full-scale national postal questionnaire survey of self-reported accidents which consisted therefore mainly of accidents that involved damage only rather than personal injury (see Section 2.1). The methodology used and the results obtained in this study served as a platform for two subsequent studies of the relationship between individual accident liability and speed choice. These studies are reported in Maycock et al (1998) and Quimby et al (1999a, 1999b); they are summarised below.

3.4.1 Study methodology

The general objectives of both studies were:

- To identify those characteristics of a driver that are most influential in determining their choice of speed on different types of road.

- To explore the links between these characteristics, the speeds chosen and the accident liabilities of the drivers involved.

Both studies used a combination of on-road observation and postal questionnaire surveys. The first stage consisted of making unobtrusive speed measurements of a large sample of car drivers in free-flow conditions on a sample of roads. Vehicles were regarded as 'free-flowing' if the gap ('time headway') between them was at least 3 seconds. At the time the vehicles were observed, the registration numbers were recorded. By means of the vehicle registration numbers, drivers were contacted through the Driver and Vehicle Licensing Agency and were sent a questionnaire.

The questionnaires asked drivers to report all the accidents (as defined in Section 2.1) in which they had been involved in the last 3 years and to give some details about each accident. The questionnaire also asked for the drivers' age, their driving experience (measured as the number of years since they passed the driving test) and information about the drivers' exposure in traffic (in particular an estimate of their annual mileage). Some information was also collected about the trip being undertaken at the time the vehicle was observed (trip purpose, passengers, car ownership and engine size), and some data reflecting the drivers' opinions about their own speeding behaviour compared to other drivers. The questionnaire also included a range of questions which allowed some aspects of the drivers' psychological characteristics to be assessed.

Clearly questionnaire surveys can result in bias due to the self-selecting nature of respondents. However, the large samples obtained in these studies represent a significant, if not wholly representative section, of the driving public: in Maycock et al's study, 6435 questionnaire responses were obtained from drivers observed on 43 sections of single- and dual-carriageway trunk roads and motorways across Great Britain. In Quimby et al's study, 5080 responses were obtained from drivers observed on 24 non-motorway (mainly rural) sections of road in the vicinity of TRL. Even if there is some non-response bias in the absolute levels of the accident liabilities found in these surveys, the relationships within the data should provide useful insights into which factors are important as determinants of an individual driver's speed choice and his or her accident liability.

Of course, the implicit assumption made in attempting to relate a measurement of a driver's speed made on a single occasion to that driver's accident history over a period of years is that the driver's speed choice is consistent from place to place and from occasion to occasion. On the evidence from a large-scale field study carried out in the USA (Wasielewski, 1984) and more recent work in TRL's behavioural studies programme (West et al, 1992), this assumption seemed to be a reasonable one. The assumption was however, subsequently tested during a series of test drives undertaken as part of the study reported by Quimby et al (1999b). These test drives took place in the subject's own vehicle and speeds were measured by filming roadside markers from the car as the driver drove round a route

consisting of 10 different road sections. The measured speeds showed that drivers' speeding behaviour (relative to the average speed of traffic on the road) was indeed broadly consistent on different parts of the route, consistent on repeated test drives, and broadly consistent with the original spot speeds observed.

3.4.2 Analysis and results

Factors that influence speed choice

The results of both studies showed that the *absolute* observed speeds of drivers were strongly related to the characteristics of the road they were driving on and varied greatly between sites. Because of the dominance of site-to-site variations in these absolute speeds, the drivers' *relative* speeds were used as the main variable of interest. The relative speed in this context is defined as the ratio of the observed speed of a driver to the average speed of all drivers observed at a particular site. Using the relative speed thus largely removes the large absolute differences in speed between road sections, but retains the key feature of interest in examining driver speed choice – namely the relative position of a particular driver in the speed distribution: does the driver typically drive faster or slower than average or is he/she an average-speed driver?

In both studies, statistical modelling using the data from the questionnaires revealed that faster drivers (relative to the mean) tended to be young, to drive high annual mileages in large cars, and tended to be travelling alone when observed. Analysis using the psychological scales gave mixed results, the strongest effect arising from a scale designed to measure *violation intent* (a scale which measures self-reported frequency of committing traffic violations – Reason et al, 1991) – the fastest drivers tended to score highly as violators of traffic regulations.

The relation between accident involvement and speed choice

In the present context, the most relevant results from the studies arose from the analysis of the self-reported accident data. Averaged across the two studies, drivers reported 0.26 accidents per year, of which about 12 per cent involved injury of some kind. The Generalised Linear Modelling technique used in the road-based studies was also used here to relate these accidents to the questionnaire variables. It was found that, as in the earlier study (Maycock et al, 1991), the number of self-reported accidents was related to age, driving experience and annual mileage. The addition of psychological variables indicated that accident involvement was also related to: *hazard involvement* (the frequency with which drivers report that they have found themselves in hazardous situations as a result of a perceptual failure), and to *driving style* (a variable summarising drivers' own rating of themselves on 6 scales - for example between 'patient' at one end and 'impatient' at the other).

In both speed choice studies, the questionnaire data were first used to relate the relative speed of drivers to age, annual mileage and a number of category variables including vehicle ownership (company or privately owned), journey purpose, engine capacity, whether the

driver was carrying a passenger or not and the driver's occupational group. These speed models (one for each study) were then used to predict the relative speed for each driver in the two samples, and these predicted speeds used as explanatory variables in simple accident models. For the trunk road data, the models imply that a 1 per cent change (increase or decrease) in an individual driver's choice of speed is associated with a 13% change in the individual's accident liability: the corresponding change for the non-motorway roads study was 8%. It is important to stress at this stage however that these models merely represent *associations* between the variables. These associations represented by the models may arise from a causal link between speed and accidents or from causal links between accidents and a number of key variables (age or mileage for example) and between speed and the same variables.

The accident-speed association for drivers is illustrated in Figure 4 which shows the *relative* accident involvement of a driver compared to that of a driver travelling at the average speed (ie. one with a relative speed of 1.0). It shows clearly that drivers who habitually travel faster than average are involved in more accidents in a year's driving. A more detailed description of the way in which the curves shown in Figure 4 have been derived may be obtained from the original reports (Maycock et al, 1998; Quimby et al, 1999a, 1999b).

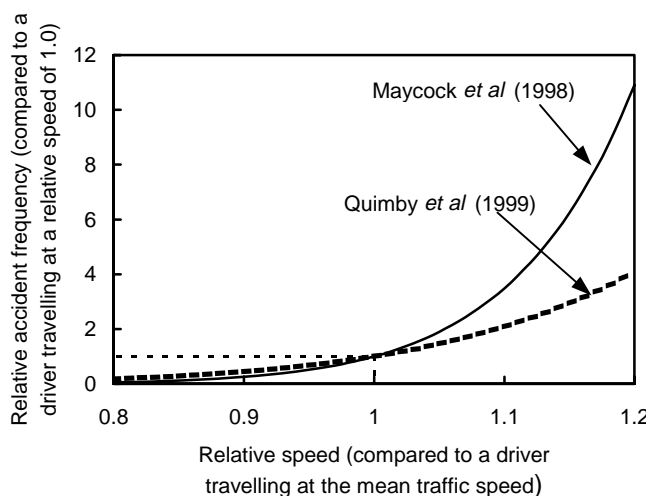


Figure 4 Individual drivers' risk curves

3.5 Comparison between road-based and driver-based studies

In general terms, the driver-based results mirror those from the road-based studies which suggest that the speeders (those whose relative speed is well above 1.0) contribute considerably to the number of accidents expected to occur on a particular section of road. However, taking the results illustrated in Figure 4 at face value, the size of the change in accident frequency resulting from a change in speed appears to be much higher in the driver-based studies than that suggested by the international analysis of road sections (Sections 2.3 and 2.4).

At a fundamental level, the road-based and the driver-

based studies are addressing the same problem – that of understanding the relationship between the occurrence of injury accidents on road sections and the speeds at which drivers travel on those road sections. The studies differ, however, in their methodology and content. Allowing for these differences it should be recognised that the studies are mutually re-enforcing in their outcome in demonstrating that increased speed is associated with increased accident frequency, and show the broad functional dependency in each case. Further and more detailed comparison of the results would go beyond the scope of the present report and would need to consider the following.

Firstly, the individual driver risk curves are functions of *relative* speed (ie. the ratio of the driver's speed to the average speed) and not of absolute speed – and this itself is almost certainly a simplification of a more complex relationship. The fact that accidents are related only to relative speed means that if on a particular road the whole of the speed distribution is shifted bodily (upwards or downwards), keeping the distribution of relative speeds unchanged, the predicted accident frequency on that road when aggregated over drivers would remain unchanged also. In this theoretical situation there would have been a substantial (arbitrary) change in absolute speed of traffic on the road with no predicted change in accidents. On the other hand, if instead of shifting the distribution bodily, the shape of the distribution is changed such that a small increase or decrease in the proportion of higher speed drivers occurs, then because of the non-linearity of the curves of Figure 4, the average speeds will change a little, but accidents will change considerably more. What this means is that the actual change in accidents which will result from a given change in speed depends critically on the changes to the shape of the distribution as well as on changes in the mean speed. More detailed information about the changes in speeds and the distribution of speed which take place on a road section (or which represent the differences between one road section and another) would be needed to be able to use the driver risk curves to predict what the relationship between accident frequency and speed in the road-based studies might be.

Secondly, drivers' self-reported accidents are not allocated to any specific section of road but to all the roads the driver uses in his or her driving year. Moreover, accident frequencies are not proportional to annual mileage. This means that high-mileage drivers have a lower number of accidents per mile compared to those who drive fewer miles annually. The road-based studies use the accidents that occur on a fixed length of road, and there is a distribution on each road section of high-mileage and low-mileage drivers. These distributions would need to be known to make comparisons between the two types of study, particularly as the population of higher speed drivers will contain a rather higher proportion of higher-mileage drivers.

3.6 Section summary

TRL's research into speed and accidents contains two major streams, one comprising road-based studies and the other driver-based studies. Multivariate statistical

modelling has been employed in both types of study to explore the relationship between accidents, the observed variations in speed (or relative speed) and a range of other relevant factors, so that the underlying associations between accidents and speed can be estimated free from the effects of confounding variables.

An extensive database relating to a sample of **urban road sections** has been assembled. Analysis of this database has yielded evidence of a complex relationship between accidents, speed and other traffic and geometric variables. The analysis has also led to an objective classification of urban roads into four coherent sub-groups which reflect the operational and environmental characteristics of the road sections included in the survey. Statistical modelling has shown that variables representing excessive speed are strongly and positively associated with accidents.

A study involving a sample of **rural road sections** in three northern European countries has led to the development of an equivalent relationship between accidents, speeds and other factors. It was found that the roads in this sample could also be divided into four groups with respect to a number of key indicator variables.

Two **driver-based studies** have been briefly described which have been specifically concerned with accident involvement and speed choice. These have shown that the accident involvement of individual drivers and the relative speeds at which drivers choose to drive are both dependent upon a number of factors, the most important being age, and exposure (annual mileage driven). When the predicted speed ratio for individual drivers is used as an explanatory variable in a simple accident model, it is found that a 1 per cent change in an individual's choice of relative speed is associated with between an 8 and 13 per cent change in that individual's likelihood of being involved in an accident, the changes being in the same sense (ie. an increase in speed being associated with an increase in accident likelihood). This accident-speed relation may result from a causal link. The findings of the driver-based and the road-based studies are mutually re-enforcing, but the link between the driver risk curves (Figure 4) and the findings from the road-based studies is complex. More work is needed to understand this link fully.

From the outline given here of the road-based studies employed, we now go on to consider first the results, and then their consequences.

4 Practical implications of the research results

4.1 Introduction

Section 3 has necessarily given only a brief summary of TRL speed-accident research. However, the key message should by now be clear - the evidence from both road- and driver-based studies points to a strong link between the likelihood of an accident occurring and the speed at which drivers travel. But this is not a simple relationship. The road-based research on urban and rural roads reveals that three distinct, but highly inter-related, characteristics of speed need to be considered. These are:

- the mathematical average (or mean) as a ‘central’ measure of speed behaviour;
- the ‘coefficient of variation’ - a measure of the range or ‘spread’ of speed behaviour – defined as the ratio of the standard deviation to the average speed;
- measures of (high) extreme speeds – the proportion of drivers exceeding a set threshold and the average speed (in excess of the threshold) of those doing so.

Practical decisions on the application of speed management techniques to reduce accidents need to be informed by a number of factors including:

- whether the current speed characteristics on particular roads justify some intervention;
- which changes, on which roads, are likely to provide the greatest safety benefits.

The accident predictive models developed from the road-based studies allow these questions to be addressed, taking account of the inter-relationships between the variables. Not only are the speed variables defined above correlated with each other, but other variables present in the speed-accident relationship are also correlated with speed variables. For example, as illustrated in Figure 5, road characteristics and traffic and pedestrian flows all have a direct effect on the distribution of vehicle speeds (of which average speed is one measure), but at the same time, these same variables affect accident frequency directly. Investigating the effect of changing individual factors can give some insight into their influence, but the final outcome in practice will result from a combination of the effects of *concurrent* changes in two or more variables.

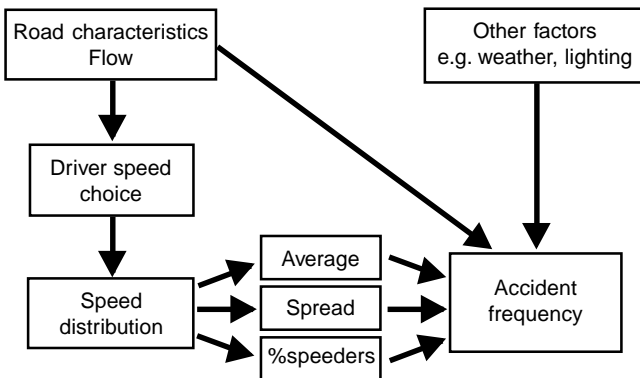


Figure 5 The inter-relationship between variables

In the remainder of Section 4 we set out in as simple terms as possible, the predicted effect on accidents of changes in the key explanatory variables. The effects of the speed variables are discussed for each of the urban models (U1 and U2) and then for the rural EURO model. The effects of other factors are discussed with reference to the urban model U2 and then the EURO model.

These effects are illustrated in a number of ways, as now explained. Sections 4.1.1, 4.1.2 and 4.1.3 first explain the principles, and what can be extracted from the models.

Sections 4.2 and onwards then describe the results themselves, in these terms.

4.1.1 The effects on accidents of vehicle speeds – urban models: the principles

i The observed effect of the speed variables changing together

Each of the accident predictive models is based on a pair of speed variables. For example, the Urban Model U1 is based on the mean speed and the coefficient of variation of speed. In the sample of 100 links used to derive this model, these variables change together in a certain way – ie. as the mean speed changes so does the coefficient of variation of speed, and this relationship can be described by a descriptive statistical equation linking the two. For each model, the observed association between the relevant pair of speed variables determines the detailed form of the resulting accident predictive relationship. Here we are looking at what happens to the accident frequency when the pair of speed variables change together from site to site in the database from which the models were developed (ie. to reflect the *co-variation* in these variables observed in the data). It is thus *descriptive* of the effects occurring within that dataset.

ii The effect of each speed variable changing on its own (the ‘univariate’ effect)

In practice, in order to examine the effects of different speed management policies that might be embarked upon, we may wish to predict what the change in accident frequency would be if we were able to control the inter-relationship between the speed variables – ie. to impose a *different* association between the variables from that observed to occur at present in a particular situation. At the extreme we would wish to understand what the effect on accident frequency of each of the speed variables would be *if* we could vary them entirely independently – for example, if we could influence the coefficient of variation of speed without changing the mean speed. Here we are looking at what would happen to the predicted accident frequency if this could be achieved.

iii Predicted effect of speed variables changing together

The univariate effect as described in (ii) is based on the simple assumption that *any desired* change in one measure of the speed distribution can be effected without influencing other measures of that distribution. In practice of course this is rarely possible; the range of techniques which can be used to influence the average speed and the shape of the distribution is limited and the resulting concurrent changes achievable in the measures of speed are determined by those techniques. When a speed modification measure is implemented the concurrent changes in the speed variables will not in general be the same as in (i), so we need to be able to predict the joint effect on the accident frequency of the speed variables co-varying to reflect what might be *achievable in practice* - for example through enforcement or by existing or new safety engineering measures.

4.1.2 The effects on accidents of vehicle speeds – rural EURO model: the principles

Like the urban models, the accident-predictive rural EURO model is based on a pair of speed variables which includes mean speed. However, it has not proved possible to establish for rural roads a relationship equivalent to that for urban roads, in which the effect of mean traffic speed on accident frequencies can be examined *in its own right*. This is almost certainly because of limitations in the available data. The reasons why the EURO model cannot be used for this purpose are complex and are presented in some detail in Appendix A (Sections A1.5; A4). As a result, the illustration of the effects of the speed variables is restricted in this case to the univariate effect of the proportion of speeders, and to the observed effect of the mean speed and the proportion of speeders changing together.

4.1.3 The effects on accidents of other factors: the principles

As explained above, changes in some of the non-speed variables in the models can be expected to result, to a greater or lesser extent, in changes in the measures of speed. For example, a change in the number of minor junctions along a link might affect vehicle speeds; this would result in an indirect effect on accidents (through speed) as well as a direct effect. For simplicity however, we shall present only the univariate effects of these variables (this is analogous to (ii) in 4.1.1 above). The exception is for the ‘speed limit’ and ‘road width’ variables which feature in the rural EURO model. In this case it has been possible to estimate the direct effect of these variables on the mean speed and the proportion of speeders. The effect on accident frequency is therefore presented as the combined effect of changes in the speed limit (or road width) and the consequent changes in the mean speed and the proportion of speeders (this is analogous to (i) in 4.1.1 above).

4.2 Practical implications of the urban road models

Ranges of the data. It should be remembered that the models developed from the road-based studies estimate accident frequencies *on links on A, B and C class roads*. They include the effect of speed on accidents at minor junctions where the main road link has priority, but they do not address accident frequency at major junctions. They are based on speeds during off-peak periods, since these most closely relate to drivers’ ‘free speeds’.

The range of variable values from which the models were derived are as follows:

	Within London	Outside London
Number of minor junctions per link	1 to 14	2 to 20
AADT vehicle flow	800 to 32,000	1500 to 27,000
Mean speed (miles/h)	19 to 33	19 to 35
Percentage of speeders	4 to 73	2 to 82
Mean excess speed (miles/h)	3 to 6	3 to 7

(Most of the roads had a 30miles/h speed limit.)

The fit of models U1 and U2 is very good, explaining about 90% of the variation in the accident data.

4.2.1 The effects on accidents of mean speed and speed variability (Urban Model U1)

In urban model U1 two variables together describe the influence of speed on predicted accident frequency. These are:

- the mean speed, V (miles/h);
- the coefficient of variation of speed, Cv.

The mean speed of traffic on a road is the consequence of many factors, such as road geometry and traffic flow, as well as driver preference. So it reflects the ‘average’ road and traffic conditions as well as the average driver’s speed choice in response to these conditions. Both safety engineering and enforcement techniques can be used to alter drivers’ speeds collectively, thus changing the value of the mean traffic speed.

The speed variability describes the deviation of speeds from the average. Variability in speeds may arise through speed-choice behaviour ie. some drivers simply wishing to drive faster than others, or it may arise through varying traffic conditions (eg. different levels of flow), or a combination of the two. The analysis revealed that the coefficient of variation of speed was statistically an effective predictor of accident frequency in addition to mean speed.

For total injury accidents on urban link sections the following relationship between yearly accident frequency per link (AF) and these speed variables was obtained:

$$\text{AF is proportional to } V^\alpha e^{\beta C_v} \\ \text{ie. } \text{AF} = k_1 V^\alpha e^{\beta C_v} \quad (1)$$

where: α takes the value 2.25 and we can be 95% confident that this value lies between 1.09 and 3.41;
 β takes the value 5.89 and we can be 95% confident that this value lies between 1.85 and 9.93;

k_1 is a constant.

This expression was very highly statistically significant and details of the model are given in Appendix A (Section A3.1).

Univariate effect of each speed variable

The effects of changing each of the speed variables separately (ie. assuming that all else remains constant while each varies) are as follows:

- The accident frequency on urban classified roads rises approximately with the square of the mean traffic speed – providing the coefficient of variation of speed remains constant.
- The accident frequency on urban classified roads rises exponentially as the coefficient of variation of speed rises – providing the mean speed remains constant. Thus the accident frequency is very sensitive to any increase in the variation of speeds about a given mean speed.

These univariate effects are now illustrated. Figure 6 shows the predicted accident frequency at different levels of mean speed, separately for London and elsewhere (at

the mean observed values for other variables in the model, including the coefficient of variation of speed). The curves are plotted over the range of mean speeds observed in the database from which the models were developed. The difference between accident frequencies in London and outside London (all else, including the mean speed, remaining constant) separates the two curves substantially and reflects higher London accident frequencies in general.

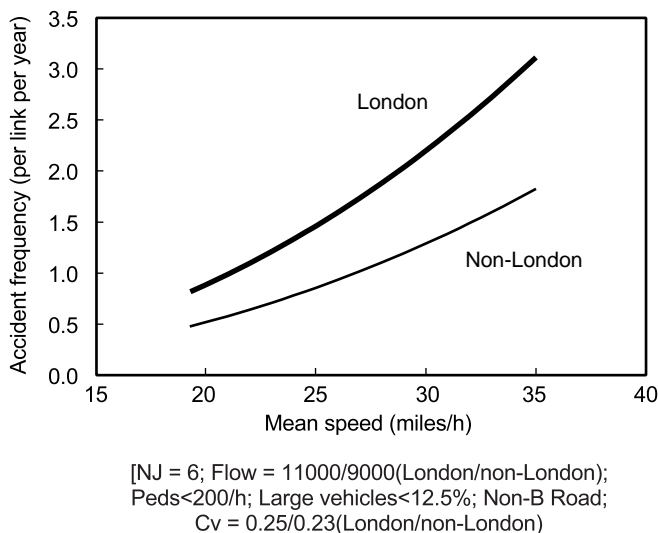


Figure 6 Accident frequency against mean speed

Figure 7 shows the predicted accident frequency at different levels of the coefficient of variation of speed, separately for London and elsewhere (at the mean observed values for other variables in the model, including mean speed). The curves are plotted over the range of Cv values observed in the database from which the models were developed.

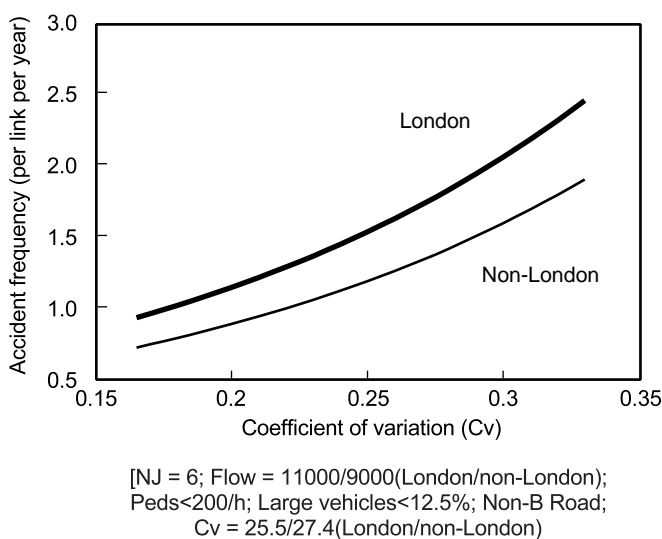
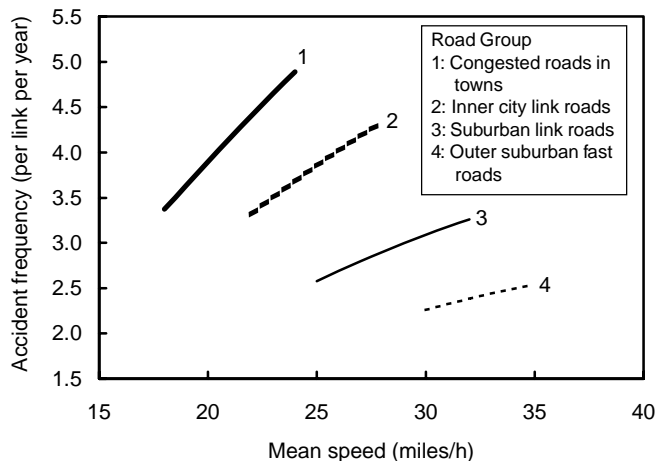


Figure 7 Accident frequency against the coefficient of variation of speed

Observed effect of both speed variables (V and Cv) changing together

In this Section we consider the *observed combined effect* of the two speed variables changing together as they do on the links in the database from which the models were developed.

The exponents (α and β) in equation (1) cover the entire range of urban roads in the database, but the constant of proportionality, k_1 , depends on site factors which vary between the four sub-groups of roads identified in the study (Section 3.3.2). Figure 8 shows the family of accident frequency versus mean speed curves generated using the average values of these factors for each sub-group. For each road group separately, the figure represents the observed combined effect of the mean speed and the coefficient of variation of speed on accident frequency with all other factors held constant at the average value for the group. (The equivalent curve for all data combined is shown in Figure A1 in Appendix A).



[For each Road Group, the average values for key variables are shown in Table 3 - see Section 5.3.1]

Figure 8 Accident frequency against mean speed for urban road groups

The figure illustrates two points. Firstly, the combined effect on accidents of changes in the mean speed and the associated changes in the coefficient of variation of speed is almost linear. Secondly, the differences in the slopes of the curves for the different road groups show that for roads of lower quality (which have the lower mean speeds), a change in the mean speed has a bigger effect on accident frequencies than it does on roads of higher quality (which have higher mean speeds). Roads in group 1 are characterised as heavily congested, older town centre types of road while those in group 4 are more modern, well-engineered suburban types of road.

We can also present the combined effect of the speed variables in a form which enables a comparison to be made with the '5% reduction in accident frequency per 1 mile/h reduction in mean speed' result obtained from Finch et al (1994). The expected percentage reduction in accident frequency per 1 mile/h reduction in the mean traffic speed is shown in Figure 9 for varying levels of mean speed. The method of derivation is given in Appendix A (Section A5.1).

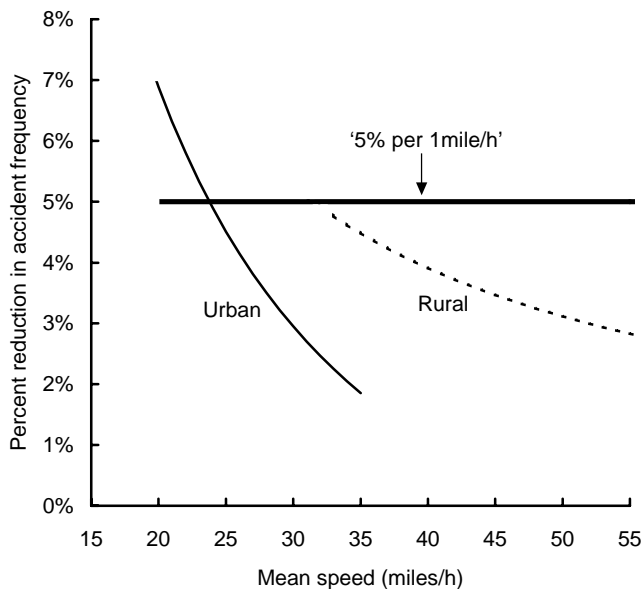


Figure 9 Predicted accident savings per 1mile/h reduction in mean speed

For comparison purposes, an equivalent relationship for rural roads (see Section 4.3.1) is shown in Figure 9 as a dotted line. The constant percentage relationship derived from Finch et al, 1994 (see Section 2.3) is also shown, as a horizontal line set at the value of 5 per cent.

The curve for urban roads shows that:

- on average, for 'slower' urban roads with a mean speed of 20miles/h there is a potential saving in accident frequency of 7 per cent if this mean speed can be reduced by 1mile/h;
- on average, on 'faster' urban roads with a mean speed of 34miles/h the equivalent saving is likely to be 2 per cent.

The potential for achieving accident reductions on urban roads through speed management depends therefore on the characteristics of the road. The curves in Figure 9 and the potential accident savings derived from them are the *best estimates* available of the effects. It should be recognised however, that as with any predictions based on regression models derived from observed data, these estimates are subject to some statistical uncertainty. See Appendix A (Section A1.6).

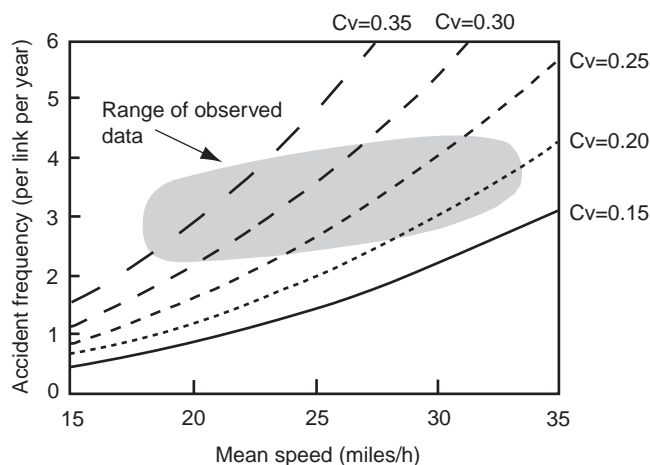
Thus the effects of differences in the road environment underlying the original 'broad-based' result of '5% per 1mile/h' have now been separated out explicitly. This quantitative approach will enable engineers and policy makers to target accident reduction measures more effectively. It is important to remember that the results relate to all injury accidents (ie. they do not differentiate between accidents involving different severities of injury). It is not possible to develop separate results for serious and fatal accidents because of data limitations. The issue is discussed further in Section 5.7.

Predicted effect of both speed variables (V and Cv) changing together

The importance of variation in speeds in determining accident frequency has been debated for some time,

following a report by Solomon (1964) which suggested that the accident involvement rates for drivers rises with their deviation from the mean traffic speed. Garber and Gadirau (1988) found that speed variability was an important predictor of accidents for a cross-sectional sample of US rural highways. The recent TRL work not only confirms the importance of variation in speed, but also suggests that in estimating the impact of speed on accidents, speed variation cannot be regarded as a substitute for mean traffic speeds – both factors are important.

This inter-relatedness may in some cases be important. For example, certain engineering measures might reduce mean traffic speeds but at the same time increase the speed variability to an extent where the accident frequency may stay the same – or even rise. Conversely, engineering measures may increase the mean traffic speed, but decrease the speed variability sufficiently for accident occurrence to fall. Figure 10 illustrates the *predicted combined effect of the mean speed and coefficient of variation of speed*. It provides an indication of the changes in accident frequency that would be expected to result from changing the speed distribution in a known way, while all other factors remain constant. The shaded area represents the domain covered by the data in the database from which the models were developed. Outside this domain the predicted effects can be considered to be less robust.



[Flow = 10000; Non-London; Ped2 = 1; NJ = 6; Non-B Road; Large vehicles < 12.5%. AF = 0.000435. $V^{**2.252} \cdot \text{Exp}(5.893 \cdot Cv)$]

Figure 10 Accident frequency against mean speed for different values of Cv

4.2.2 The effects on accidents of extreme speeds (Urban Model U2)

A speed distribution has two extremes which, like the mean and spread are affected by other factors (including, for example, the engineering methods deployed to control speeds and the degree of enforcement). The characteristics of these extremes of speed are reflected to some extent in the measures of mean speed and variability in speed, but they may also be directly relevant to road safety. Extremely low speeds may arise, amongst other factors, from traffic congestion, roadworks, inadequate road or

junction design, and a preponderance of vulnerable road users. On the other hand, extremely high speeds may stem from aggressive driving, low flows, wide and straight road design, good visibility, and so on.

Although the TRL research has investigated both extremes of the speed distribution and their relation to accidents and other factors, the focus in this report is on the extremely high – or excessive speeds – which emerge from both the road- and driver-based studies as being particularly important in relation to safety. In Urban Model U2, two measures that relate excessive speed to the speed limit were used in place of the mean speed and the coefficient of variation of speed. These are:

- the proportion of drivers exceeding the speed limit (ie. the degree of non-compliance with the speed limit) – denoted here by P (%);
- the mean speed by which these drivers exceed that limit (*the mean excess speed*) – denoted by V_{ex} (miles/h).

These represent an alternative focus to that given by the mean speed and the coefficient of variation of speed, and enable the effects of excessive speeds to be examined specifically. The presence of mean excess speed (V_{ex}) in the U2 model implies a more complex effect than that suggested by the proportion (P) of speeders alone. V_{ex} is a measure of the shape of the *upper tail* of the speed distribution. For a given value of P , its magnitude depends on how elongated the tail is. Generally, the longer the tail the higher the value of V_{ex} .

For injury accidents on urban link sections the following relationship between yearly accident frequency per link (AF) and these speed variables was obtained:

$$\begin{aligned} \text{AF is proportional to } P^\gamma e^{\lambda V_{ex}} \\ \text{ie. } \text{AF} = k_2 P^\gamma e^{\lambda V_{ex}} \end{aligned} \quad (2)$$

where: γ takes the value of 0.14 and we can be 95% confident that this value falls between 0.01 and 0.27;

λ takes the value 0.17 and we are 95% confident that this value lies between 0.03 and 0.32;

k_2 is a constant.

This expression was very highly statistically significant and details of the model are given in Appendix A (Section A3.2).

Univariate effect of each speed variable

Considering the effect of each of the speed variables separately (ie. assuming that all else remains constant while each varies), the implications are as follows:

- *The accident frequency on urban classified roads rises with increasing proportions of drivers exceeding the limit.*

The practical consequences of influencing the proportion of speeders may be illustrated as follows. If the proportion of speeders were to increase by a tenth, for example from 20% to 22%, the accident frequency would be expected to increase by 1.4%, if all else is held constant. If on the other hand the non-compliance level could be halved from 20% to 10% - for example by increased or more effective enforcement of the speed limit - then the accident frequency would be reduced by about 10%.

- *The accident frequency on urban classified roads rises with mean excess speed.*

Specifically, a 19% increase in accidents would be expected to result for an increase in the mean excess speed of 1mile/h – if all else is held constant. The 19% per 1mile/h speed change (a figure which excludes any effect of the likely concurrent change in P) may be compared with values shown in Figure 9, which depicts the range of accident savings if the *overall* mean speed is altered by 1mile/h. At most these are in the region of 5 – 7 per cent per 1mile/h change in mean speed for urban roads, which is less than half of the saving predicted by changes in *excess* speed. Whilst it may be easier in practice to reduce the mean speed by 1mile/h than to reduce the excess speed by 1mile/h, this finding nevertheless has important policy implications: *targeting excessive speed* - for example, through the use of engineering measures which reduce the speed of the fastest drivers – *may well bring greater benefits than attempts to influence the speeds of all drivers.*

These univariate effects are now illustrated. Even though the *average* non-compliance level in the database (the value of P) was slightly lower (by 5%) for link sections in London than elsewhere, the range of non-compliance level on individual roads did not differ greatly between the two areas. In London the non-compliance level (P) ranged from 4% to 73%; outside London the range was from 2% to 82%. Figure 11 shows predicted accident frequencies at different levels of P for London and elsewhere (at the mean observed values for other variables in the model, including the mean excess speed). Again, the difference between accident frequencies in London and outside London (all else, including the proportion of speeders, remaining constant) separates the two curves substantially and reflects higher London accident frequencies in general.

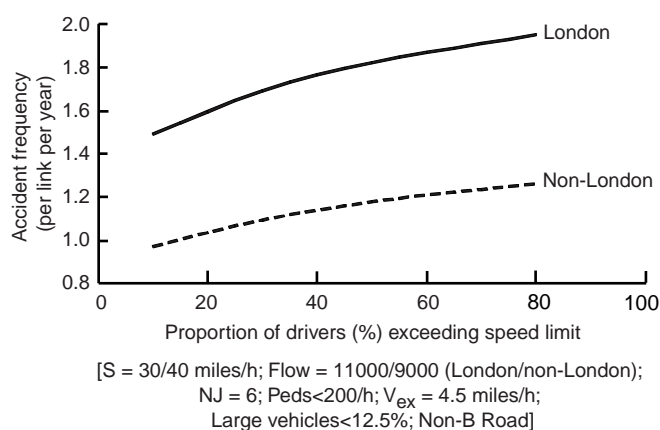


Figure 11 Accident frequency against the proportion of drivers exceeding the speed limit (P)

Figure 12 shows the predicted accident frequency plotted against various values of the mean excess speed for links inside and outside London (at mean observed values of all of the other variables in the model, including the proportion of speeders, which is held constant for each curve).

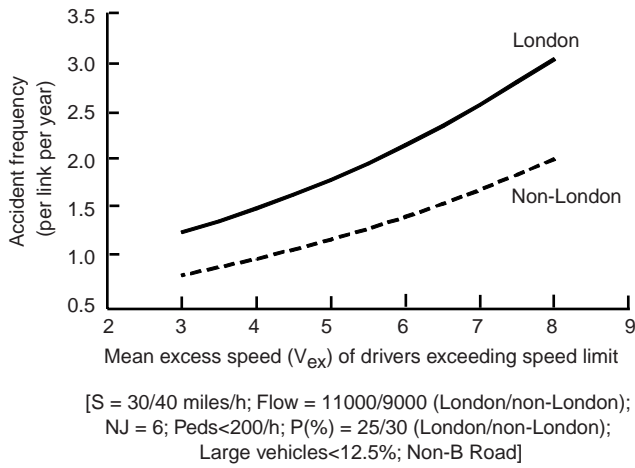


Figure 12 Accident frequency against mean excess speed (V_{ex}) (miles/h)

Observed effect of both speed variables (P and V_{ex}) changing together

We now look at the *observed combined effect* of the two speed variables changing together as they do between the links in the database from which the models were developed.

The exponents (γ and λ) in equation (2) are appropriate to the entire range of urban roads in the database, but the constant of proportionality, k_2 , depends on other site factors, which vary between the four sub-groups of roads identified in the study (Section 3.3.2). Figure 13 shows the family of accident frequency-proportion of speeders curves representing the observed combined effect of the proportion of speeders and the mean excess speed on accident frequency for the four sub-groups with all other factors held constant at the average value for each group. (The equivalent curve for all data combined is shown in Figure A2 in Appendix A).

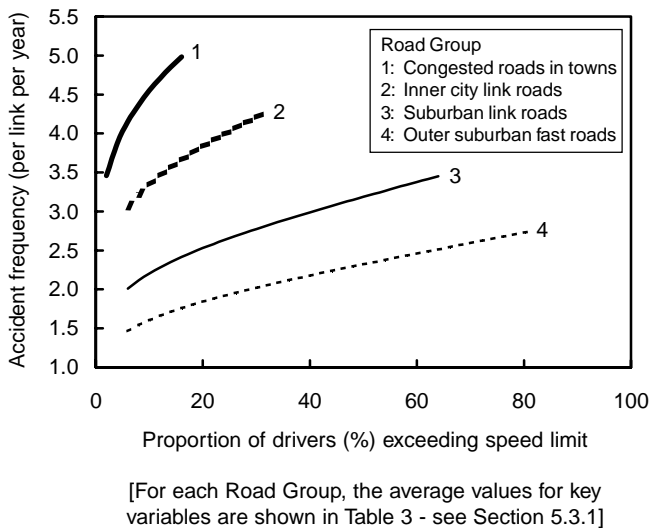


Figure 13 Accident frequency against proportion of speeders for urban road groups

The figure shows that a unit change in the proportion of speeders gives a greater reduction in accident frequency on the lower quality roads in group 1 than on the higher quality roads in group 4.

Predicted effect of both speed variables (P and V_{ex}) changing together

V_{ex} can theoretically vary independently of P (the proportion of speeders) in the way implied in Figures 11 and 12 because the same number of speeders can be distributed in a large number of different ways. Enforcement measures which aim to curtail the upper tail of the speed distribution *may* reduce the mean excess speed without a noticeable effect on P . This would occur if drivers reduced their speed but still remained above the speed limit. But if P is also reduced then there will be extra reduction in the accident frequency. Figure 14 illustrates the *predicted combined effect of changes in the proportion of speeders and the mean excess speed*. It provides an indication of the changes in accident frequency that would be expected to result from changing the speed distribution in a known way, while all other factors remain unchanged. The shaded area represents the domain covered in the database from which the models were developed. Outside this domain the predicted effects can be considered to be less robust.

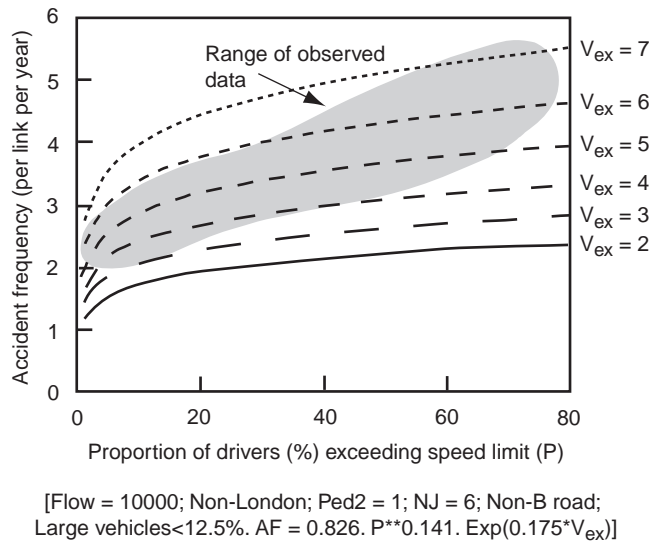


Figure 14 Accident frequency against proportion of speeders for different values of V_{ex} (miles/h)

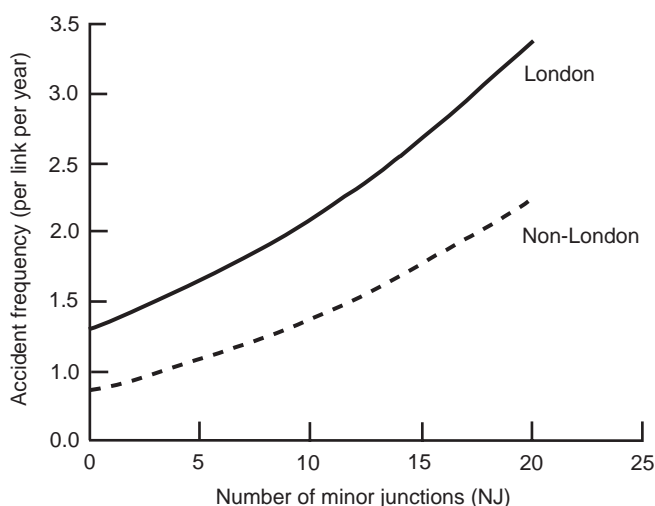
4.2.3 The effects on accidents of other factors (Urban Model U2)

The effects of changes in the (non-speed) variables in the two urban models (U1 and U2) are very similar; they are only presented here for Model U2.

The number of minor junctions

Any reduction in the number of junctions along a link will help to reduce the total number of accidents on the link. From model U2 it can be estimated that accident frequency

will be reduced at the rate of 5% for each junction removed, if it is assumed that other variables in the model (such as non-compliance with the speed limit) remain unchanged. Figure 15 shows the predicted accident frequency plotted against the number of junctions for links inside and outside London (at mean observed values of other variables in the model).



[S = 30/40 miles/h; Flow = 11000/9000 (London/non-London); Peds<200/h; Vex = 4.5 miles/h; P (%) = 25/30 (London/non-London); Large vehicles<12.5%; Non-B road]

Figure 15 Accident frequency against number of minor junctions (NJ)

This result is consistent with established traffic engineering practice (IHT, 1990). The *SafeNET* User Manual (TRL, 1999) considers the principle more extensively. It shows that for a given traffic flow and movement pattern, reducing the number of minor junctions will result in fewer accidents.

Traffic and pedestrian flow

Traffic flow has a very strong influence on accident frequency. In this study, it is found that accident frequency is related approximately to the square root of traffic flow. Across the range of traffic flows observed in the study (from the lowest to the highest flow – see Appendix A (Section A2.2)), accident frequency changes by a factor of six.

Pedestrian activity (in terms of crossing flows) has a particularly important influence on accident frequency. Four *levels* of pedestrian activity have been defined for use in the urban models (see Appendix A (Section A2.1)). Each is associated in model U2 with a different size of effect on the accident frequency:

- The ‘standard’ estimate of accident frequency is for a link having low pedestrian activity (fewer than 200 per hour crossing the link - including those crossing its side roads at minor junctions).
- Where pedestrian activity is low to medium (flows between 200 and 600 per hour), the accident frequency is 1.9 times the standard.

- Where pedestrian activity is medium to high (between 600 and 1800 per hour), the accident frequency is 2.5 times the standard.
- For the high activity category (flows above 1800 per hour - eg in busy shopping areas), the accident frequency is 4.6 times the standard.

Thus the model allows accidents to be predicted even if only relatively coarse information is available about pedestrian crossing activity. However, if the numbers of movements are known with greater accuracy, then the expected increase in accident frequency can be found by interpolating between the values given above.

The percentage of large vehicles (HGVs and buses/coaches) in the traffic flow

Two *levels* of this variable have been defined (the first represents traffic in which the percentage of large vehicles is up to 12.5% of the total traffic flow and the second represents a value greater than this). Model U2 predicts that for links with more than 12.5% of large vehicles in the traffic flow the accident frequency will be increased by a factor of 1.5.

4.3 Practical implications of the rural road model

Ranges of the data. In considering the rural road model, it should be remembered that the road-based studies estimate accidents on links on *A and B class roads*. The model includes the effect of speed on accidents at minor junctions where the main road link has priority, but they do not include the accident frequency at major junctions. The model is also based on speeds during off-peak periods, as these more closely relate to drivers’ ‘free speeds’.

The range of variable values for the English data from which the EURO model was derived were as follows.

	<i>A roads</i>	<i>B roads</i>
Number of minor junctions per link	0 to 5	0 to 6
Road width (m)	5.4 to 10	5.7 to 10.2
Link length (km)	1.0 to 3.4	1.0 to 2.6
AADT vehicle flow	3,600 to 27,000	2,500 to 11,000
Percentage of speeders	0 to 18	0 to 17
Mean speed (miles/h)	33 to 54	37 to 53

All of the English roads had 60miles/h (approx 96km/h) speed limits, but the data from which the EURO model was derived included links from Sweden and the Netherlands with speed limits of 80km/h, 90km/h, 100km/h and 110 km/h. The EURO model explains 75% of the variation in the data.

4.3.1 The effects on accidents of vehicle speed in the rural EURO model

As already explained, the effect on accident frequency of the mean speed of traffic in the EURO model was difficult to establish directly. However, the effect of the proportion of drivers exceeding the speed limit (ie. the degree of non-compliance with the speed limit – P%) was a statistically significant variable in the model.

For injury accidents on rural link sections the following relationship between yearly accident frequency per link (AF) and the proportion of speeders was obtained:

$$\text{AF is proportional to } P^\gamma$$

$$\text{ie. } AF = k_3 P^\gamma \quad (3)$$

where: γ takes the value of 0.11 and we can be 95% confident that this value falls between 0.01 and 0.23; k_3 is a constant.

This expression was statistically significant at the 5% level and details of the model are given in Appendix A (Section A4).

Univariate effect of the proportion of speeders

Considering the *univariate* effect of P, the implication of equation (3) is that *accident frequency rises with increasing proportions of drivers exceeding the limit*. The practical consequences of influencing the proportion of speeders may be illustrated as follows. If the proportion of speeders were to increase by one tenth, for example from 20% to 22%, the accident frequency would be expected to increase by 1.1%, if all else is held constant. If on the other hand the non-compliance level could be halved from 20% to 10% then the accident frequency would be reduced by about 8%.

Figure 16 shows the predicted accident frequency for a 2km length of road at different levels of non-compliance (P), separately for A and B class roads (at representative observed values of the other variables in the model). The results for A and B class roads are plotted separately in this figure and in those that follow because the traffic flows typical on these two road classes differ somewhat (resulting in the higher accident frequency on the A class roads).

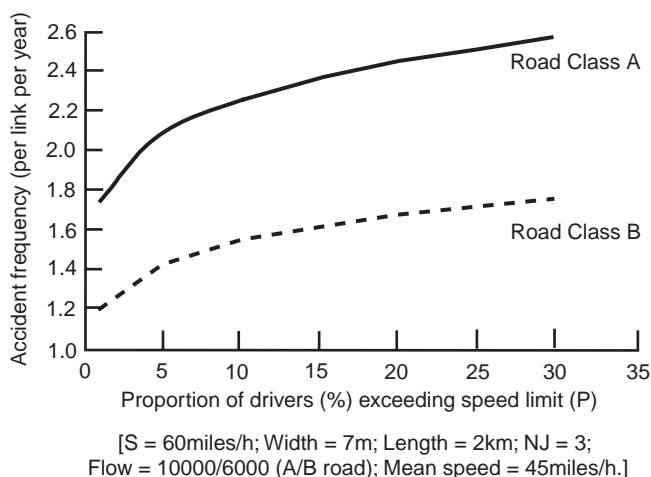


Figure 16 Accident frequency against the proportion of drivers exceeding the speed limit (P)

A reduction in non-compliance (P) can be achieved by increased or more effective enforcement of the speed limit. Generally, a reduction in P will cause a reduction in the mean speed. However, the size of the reduction depends on the changes which take place in the speed distribution

as a result of the enforcement. Studies in Australia (Rogerson et al, 1994) and the USA (Coleman et al, 1996) suggest that measured enforcement on rural roads can virtually eliminate the highest speeds without any appreciable change in the mean speed of all traffic. If an enforcement strategy is implemented which bears primarily on drivers who exceed the speed limit the most, then the assumption that the overall mean speed of all traffic remains substantially unchanged (as implied in Figure 16) may be a reasonable one.

Observed effect of both speed variables (V and P) changing together

Despite the fact that the effect on accident frequency of changes in the mean speed has not been directly established, the models from both the urban and rural studies allow comparative assessments to be made of the changes in the accident frequencies associated with changes in the mean speed, for both types of road, under certain assumptions (see Figure 9). (The derivation of the curve for accidents on rural road links is given in Appendix A (Section A5.2)). Figure 9 shows that the estimated savings in the number of accidents is less on rural than on the slowest urban roads. On rural A and B class roads there is typically little pedestrian activity and less roadside development than on urban roads although mean speeds are much higher. The figure shows that:

- For the 'slower' rural roads, with a mean traffic speed of 40 miles/h, there is a potential saving in accident frequency of about 4% per 1 mile/h reduction in this mean speed.
- For the fastest rural roads, with a mean traffic speed of 55 miles/h, the equivalent saving is likely to be less than 3%.

Again it is important to remember that the curve relates to *all* injury accidents and the corresponding curve for fatal and serious accidents may differ from this (see also Section 5.7).

It should also again be recognised that, as with any predictions based on regression models derived from observed data, these estimates are subject to some statistical uncertainty. See Appendix A (Section A1.6).

4.3.2 The effect on accidents of changes in the speed limit

The effect of changes in the speed limit need to be considered in the context in which the EURO model has been developed. The speed limit is included in the model as a category variable which to an extent reflects differences in road design. It contributes to 'between-site' changes in accident frequency – that is, it acts in the model to show how the accident frequency varies between roads having a different speed limit and, by implication, with those design characteristics which attach to the speed limit. For example, roads with a higher limit are likely to have a range of design features which improve their overall quality.

Clearly when the model is used to investigate the effect on the accident frequency of *changing* the speed limit on a particular road (that is, to look at the 'within-site' effect of

changing the limit) then there is an implicit assumption that those other characteristics of the road that influence accident frequency, but that are not explicitly included in the model, are changed to be consistent with the new speed limit. In practice, this is unlikely to be completely the case. It will therefore usually be necessary to take a broader design context into account when considering the effect of changes in the speed limit.

The EURO model has been used thus to *estimate* the effect of a change in the speed limit on a given road. For this purpose, models were developed from the rural database for predicting the mean speed and the proportion of speeders from other variables, including the speed limit. From these models, the amount by which non-compliance (P) and mean speed (V) can be expected to change as a direct result of changing the speed limit have been estimated. The models predict that if the speed limit is reduced by 10 miles/h, the proportion of drivers exceeding it will rise by a factor of 2.4 (assuming no change in enforcement). At the same time, the mean speed is expected to fall by 8%. Taking these dependencies into account, the EURO model indicates that *the net effect of a change in speed limit (S) from 60 miles/h to 50 miles/h would be a reduction in the accident frequency of about 8%*.

Figure 17 shows the average accident frequency on roads with different speed limits in force and therefore the predicted changes in accident frequency which would accompany changes in the limit. The effect is shown separately for A and B class roads, taking account of the resulting changes in P and V (at representative observed values of other variables in the model).

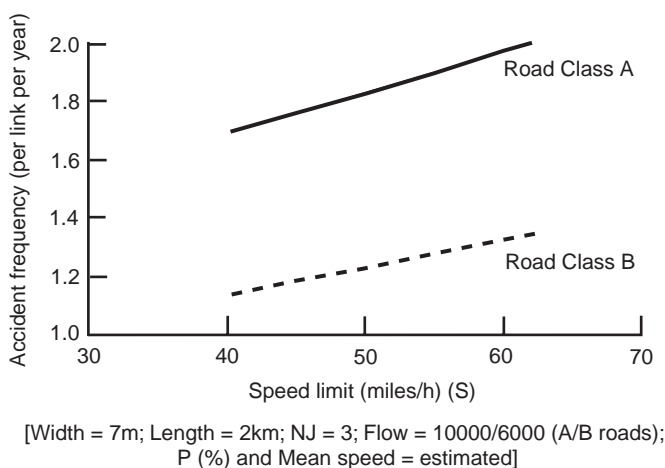


Figure 17 Accident frequency against speed limit (S)

4.3.3 The effects on accidents of other factors

The number of minor junctions

A change in the number of minor junctions, thereby altering accessibility, has a direct effect on the accident frequency. The model suggests that the accident frequency will be reduced by 4% for each junction removed. Hughes and Amis (1996) indicate that on rural single-carriageway roads, reducing queueing in the main road caused by turning traffic at minor priority junctions, will reduce

accidents. This finding is consistent with the type of effect found here.

Figure 18 shows the predicted accident frequency plotted against the number of junctions for links on A and B class roads (at representative observed values of the other variables in the model).

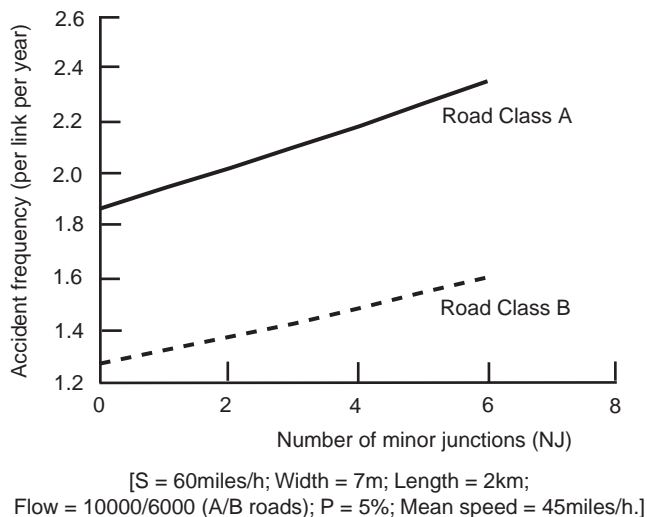


Figure 18 Accident frequency against number of minor junctions (NJ)

Traffic flow

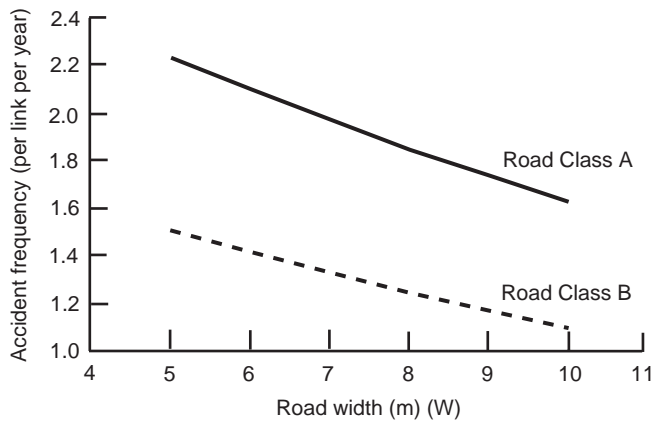
As expected, traffic flow has a strong influence on accident frequency. For rural roads, it is found that accident frequency is related approximately to the traffic flow to the power of three-quarters (a stronger relationship than that found in the urban models). Across the range of traffic flows observed on the English roads studied (from the lowest to the highest flow) the accident frequency changes by a factor of six.

Road width

The predictive models developed for mean speed and the proportion of speeders (as mentioned in Section 4.3.2) indicate the intuitively plausible result that as the road width varies across the sample of road links, then non-compliance (P) and mean speed (V) both change. Wider roads are associated with a lower accident frequency; accidents fall at a rate of 6% per metre of added width.

Figure 19 shows the predicted accident frequencies for links of different width, separately for A and B class roads, taking account of the resulting changes in P and V (at representative observed values of other variables in the model). The nature and magnitude of the effect on accident frequency shown in Figure 19 is similar to that obtained for modern UK single-carriageway roads in a study by Walmsley and Summersgill (1998). A larger effect (though in the same direction) was found by Hughes and Amis (1996) for rural single-carriageway A class roads in Cambridgeshire.

The underlying mechanism is not apparent from the data alone. It may be, all other things being equal, that it is because vehicles have more space to avoid collisions. But



[S = 60miles/h; Length = 2km; NJ = 3; Flow = 10000/6000 (A/B roads); P = 5%; Mean speed = 45miles/h.]

Figure 19 Accident frequency against road width (W)

it may also have to do with design elements not explicit in the models (for example wider roads may have a range of more recently adopted detailed design features which improve their overall quality). For these reasons, it is suggested that increases in width should not be viewed as an automatic remedial measure. A broader design context is needed.

Link length

Whilst the link length is an explanatory variable in the model (lengths between 1 and 25km were included in the European data) it is not itself a *design* variable. Road authorities cannot choose to change the link length at will, without influencing other things. But changing the priority of a minor junction within a link, so as to elevate it to the status of a major junction where traffic on the link then has to yield priority to entering traffic, will in effect change the link length, and thus the accident frequency. Such changes reflect a real change in traffic operation. In such a situation, in order to predict the changes in accident frequency, the two elements need to be considered separately: firstly the predicted change in the accident frequency for the link itself resulting from a change to two links of shorter length, and secondly the predicted accident frequency for the new 'major' junction which is created. This latter prediction would have to be made in its own right, using established methods (eg. Maycock and Hall, 1984; Pickering et al, 1986).

4.4 Scope of the results

The road-based models reported in the foregoing Sections have been developed for classified urban roads (mostly with 30miles/h speed limits) and for rural A and B class single-carriageway roads. These results, together with the known effects of the treatment of residential roads as 20miles/h zones (Webster and Mackie, 1996), cover a large proportion of the national road network - that proportion in fact being associated with the vast majority of accidents on links.

Together, therefore, the present results advance our knowledge of the relationship between drivers' choice of speed and the frequency of accidents very considerably. There are several areas which they do not tackle explicitly, and where further investigation would be valuable. The main gaps in our knowledge are described briefly in Appendix B.

4.5 Section summary

The results relating to traffic speed can be summarised qualitatively as follows:

There is a strong, positive relationship between the likelihood of an accident occurring and the speed at which drivers travel. This is not a simple relationship and more than one measure of the speed distribution is needed to fully describe it.

On urban A, B and C class roads, increases in average traffic speed, in speed variability as measured by the coefficient of variation, in the proportion of speeders and in the mean speed by which the speeders exceed the speed limit are all associated with increased accident frequency.

On rural A and B class roads, increases in the proportion of speeders are associated with increased accident frequency.

These results are relevant to a large proportion of the national road network, and to a significant proportion of the accidents occurring on that network. In Section 5 we go on to consider the effect on the accident frequency of the policy options open to those decision-makers responsible for improving road safety.

5 Identifying priorities for speed management

5.1 Introduction

The *choice* of road sections for speed reduction measures will be heavily influenced by three factors:

- the current incidence of accidents;
- the reduction in the accident frequency that could be achieved from changes in speed;
- the size of change in speed that is likely to be acceptable and achievable.

Clearly if accidents are not currently a problem on a section of road there will be little incentive on those grounds to introduce speed reduction measures. If on the other hand, accidents are a matter for concern and excessive speed is perceived to be a part of the problem, then some remedial action focusing on speed may be worth considering. Sections 5.2–5.4 look at the reductions in accident frequency achievable from changes in speed, summarising what has gone before, and Section 5.5 looks at ways in which speeds might be changed. Section 5.6 goes on to consider the overall impact on accidents of different speed management strategies by considering the number which can potentially be addressed and the speed reductions assumed to be achievable.

5.2 Summary of the effects of changing road, traffic and speed characteristics

Tables 1a and 1b summarise the results from the road-based models presented in Section 4. They show the factors by which the accident frequency would be reduced if various road, traffic and speed characteristics were changed. Table 1a shows the effects of changing road and traffic characteristics, although it is recognised that it will often not be possible to influence these. Table 1b shows the effect of changing speed characteristics.

Table 1b shows the greater potential for reducing accidents by reducing the mean speeds on the slower urban roads, as compared to the faster urban roads and rural roads. This was illustrated in Figure 9 in Section 4.2.1. It is important to realise that the factors shown are the *best estimates* available of the effects; they are subject to the usual statistical uncertainty inherent in their derivation from regression models fitted to observed data (See Appendix A (Section A1.6)).

5.3 The accident consequences of changing speeds on urban roads

5.3.1 The consequences on all types of accident by road type

As described in Section 3.3.2, different sub-groups of the sample of urban roads studied were identified which had different speed characteristics. The effect on accidents of a reduction in mean speed is different on these different types of road, as illustrated in Figure 8 in Section 4.2.1. Table 2 summarises these results and Table 3 shows the *average* characteristics of the roads in each of the groups 1-4 in the study sample. Together these serve to indicate how the accident frequency on a road with known characteristics

Table 2 The effect on accident frequency of a reduction in mean speed for different types of urban road

Group	Description	Percentage accident change per 1mile/h change in mean speed
1	Highly congested town roads	6.2
2	Typical inner city link roads	4.5
3	Sub-urban link roads	3.3
4	Semi-rural (fast) link roads	2.2

Table 3 Average characteristics of links in groups 1-4 of Table 2

Group	1	2	3	4
Mean speed (miles/h)	20.9	24.8	28.7	33.0
Proportion of speeders %	6	18	40	47
Total vehicle flow AADT	11038	9154	9927	9658
Link length (km)	0.55	0.68	0.75	0.99
Pedestrian flow across links (12hrs)	7840	4935	2898	2094
Pedestrian crossing flow at minor junctions (12hrs)	12777	6392	3274	1638
No of minor junctions per km	11.8	9.5	8.0	7.0
No of pedestrian crossings per km	1.8	0.8	0.5	0.3
No of Zebra crossings per km	0.7	0.4	0.3	0
Accidents per year	5.4	5.0	3.2	2.7
Pedestrian accidents as % all accidents	43	32	34	23
Vehicle-only accidents as % all accidents	57	68	67	77
Accidents at minor junctions per year %	72	74	58	69
Accidents on rest of link per year %	28	26	42	31

Table 1a Summary of the effects of changing road and traffic characteristics

Effect of...	Change	Urban roads – accident frequency multiplied by	Rural roads – accident frequency multiplied by
Changing the AADT traffic flow	25,000 to 5,000	0.47	0.30
Changing the pedestrian flow across a link	Highest to lowest	0.22	
Changing the number of minor junctions	From 10 to 5	0.76	0.83
Changing the road width	8m (compared to 6m)		0.88
Changing the percentage of large vehicles	From more than 12.5% to less than 12.5%	0.67	

Table 1b Summary of the effects of changing speed characteristics

Effect of...	Change	Urban roads – accident frequency multiplied by	Rural roads – accident frequency multiplied by
Reducing the speed limit	From 60 to 50miles/h		0.92*
Reducing the mean speed	From 25 to 20miles/h	0.76*	
	From 30 to 25miles/h	0.83*	
	From 55 to 50miles/h		0.86*
Reducing the proportion of speeders	From 80% to 20%	0.68*	
	From 30% to 10%		0.88
Reducing the mean excess speed	From 5 to 4miles/h	0.60*	

* indicates combined effect of associated changes in relevant speed variables

might typically be expected to respond to a treatment that would affect the mean speed by a given amount (with an associated change in the spread of speeds).

Roads similar to those in group 1 offer the greatest potential for accident reduction for each 1mile/h reduction in mean speed. They typically already have low speeds, associated with a high density of minor junctions and a high level of pedestrian activity. They tend to have high accident frequencies. Conversely, roads similar to those in group 4 offer the least potential for accident reduction per 1mile/h reduction in mean speed. They already have relatively low accident frequencies but have higher speeds, associated with longer link length, fewer minor junctions and lower pedestrian activity. The reductions in speed that are in practice *achievable* on these different types of road are clearly also relevant in determining where measures should best be targeted. For example, it may be easier to reduce speeds by a greater amount where speeds are high than where they are low. These issues will be discussed further in Section 5.6 where accident reductions are considered with respect to achievable speed reductions.

The urban speed-accident models strictly speaking do not extend to very minor roads, but we know that the *observed* effect on roads where 20miles/h zones have been installed (Webster and Mackie, 1996) is a reduction in mean speed from 25.2miles/h to 15.9miles/h, with a reduction in accident frequency of 60%. Part of this accident reduction was attributed to concurrent reductions in traffic flow on these roads, but it is estimated that about three quarters of the 60% (ie. 45%) was due to the speed change alone. The predicted accident reduction arising from the same reduction in mean speed – that is 25 to 16miles/h - now taken from the speed-accident model (see Figure 9) is of similar magnitude. This suggests that the model results may have wider applicability to more minor, residential roads.

5.3.2 The consequences according to accident type

Speed-accident models were also developed for different accident types (pedestrian/vehicle accidents and junction/non-junction accidents). The relatively small number of accidents in each of these sub-groups means that these results are only indicative. They suggest, however, that for a unit change in speed:

- overall (on links including the minor junctions), both pedestrian and vehicle accidents are reduced when speed is reduced, but the effect on the frequency of accidents involving vehicles only is the greater;
- in contrast, the percentage reduction in pedestrian accidents at minor junctions is greater than the percentage reduction in vehicle-only accidents;
- the percentage reduction in pedestrian accidents is similar *at* minor junctions and *between* minor junctions, whereas vehicle-only accidents are reduced more between junctions than at junctions.

5.4 The accident consequences of changing speeds on rural single-carriageway roads

5.4.1 The consequences on all types of accident by road type

Different sub-groups of rural roads, distinguished by their differing speed characteristics, were identified in the sample used to develop the EURO model (see Section 3.3.3). For illustrative purposes, the English links are divided here into 4 groups using a simple classification based on a 10miles/h speed band in which the highest number of drivers fall (ie. the most ‘popular’ speed band). The 4 groups are defined in Table 4. The effect on accidents of a reduction in mean speed (predicted by the EURO model as illustrated in Figure 9) is different on these four road types. Table 4 summarises these effects and Table 5 shows the *average* characteristics of the roads that were in each of the groups 1-4 in the English study sample of 63 A and B class roads. Together these tables show how the accident frequency on a road with known speed, flow and accident characteristics might typically be expected to respond to treatment that would affect the mean speed by a given amount (with an associated change in the proportion of speeders).

Table 4 The effect on the accident frequency of a reduction in the mean speed, for different types of rural road

Speed group	Description	Speed band (miles/h)	Percentage accident change per 1mile/h change in mean speed
1	Very low speed	30 – 40	4.2
2	Low speed	35 – 45	3.8
3	Medium speed	40 – 50	3.4
4	High speed	45 – 55	3.0

Table 5 The average characteristics of links in Speed Groups 1-4

Speed group	1	2	3	4
Speed band (miles/h)	30 – 40	35 – 45	40 – 50	45 – 55
Flow AADT	6406	6479	9671	9472
Mean speed (miles/h)	36.3	40.3	45.8	50.6
Proportion of speeders (%)	0.2	2.2	3.4	10.0
Accidents per km per year	1.37	0.84	1.20	0.63
Accident rate per 100 million vehicle-km	45.3	40.5	38.5	21.4
Fatal/serious accident rate per 100 million veh-km	14.1	8.7	8.0	6.8

Roads similar to those in group 1 offer the greatest potential for accident reduction for each 1mile/h reduction in mean speed. They typically already have low speeds. They tend to have high accident *rates* (ie. accidents per vehicle-km driven), particularly of the most serious accidents. Conversely, roads similar to those in group 4 offer the least potential for accident reduction. They already have relatively low accident rates but higher speeds. However, the range in the size of the effect between group 1 and group 4 is smaller (4.2 to 3.0% per 1mile/h) than for urban roads (6.2 to 2.2% - see Table 2).

It should again be recognised that these are best estimates which are subject to statistical uncertainty (Appendix A (Section A1.6)). The issues of what reductions in speed are achievable in practice, mentioned earlier in this Section, is also again relevant.

5.5 Speed management strategies

This sub-section looks at some of the key ways in which attempts could be made to influence speeds, and how priorities for implementing these might be determined.

5.5.1 Changing speed limits

The prediction of the effects of different speed limit policies is limited by the range of links which formed the basis of the model development – in fact, all of the English rural road data related to roads with a 60miles/h speed limit. However, because these data were then supplemented by data from other countries with different speed limits, and a consistent model determined, it was possible to specify a model in which speed limit was a category variable. The urban link data related primarily to roads with a 30miles/h speed limit, and although a small number of roads with a 40miles/h limit were included, the speed *limit* – in contrast to the vehicle speeds themselves – did not emerge as a significant factor in the accident prediction model.

Rural roads

For rural A and B class single-carriageway roads, the EURO model (together with the models developed for predicting mean traffic speed, V and the proportion of speeders, P) allow estimates to be made of the effects on accident frequency of differences in the speed limit between otherwise similar roads. As explained in Section 4.3.2 there are assumptions implicit in doing this that need to be borne in mind, but what follows illustrates the magnitude of the effects that might be expected.

Section 4.3.2 and Table 1b show that the effect of applying a 50miles/h speed limit to 60miles/h roads has been estimated to be a reduction in the accident frequency of about 8 per cent. Of course, the reduction for an *individual*

link section would depend on its characteristics in respect of speed, flow and geometry. Using the model link by link allows those links likely to give the maximum reduction in accident frequency from such a policy to be identified.

By way of example, this process has been applied to the English rural links in the road-based studies, using the EURO model given in Appendix A (Section A4). Figure 20 shows the proportion of speeders that would be expected on each link resulting from the new (50miles/h) speed limit. The links are ordered 1-63, with link 1 being that which would be predicted to yield the greatest benefit in terms of the reduction in accident frequency and link 63 being that which would be predicted to yield the least benefit. The cumulative benefit that would be expected to be achieved by applying the policy progressively to these 63 links, starting with link 1, is shown in Figure 21. The effect would be that priority for treatment would be given to those links with high speed *and* high accident frequency.

For links in speed groups 1 and 2, speeds are already low and the implementation of a 50miles/h limit would be unlikely to have much effect (fewer than 10 per cent of drivers were observed above that limit now on most of these links).

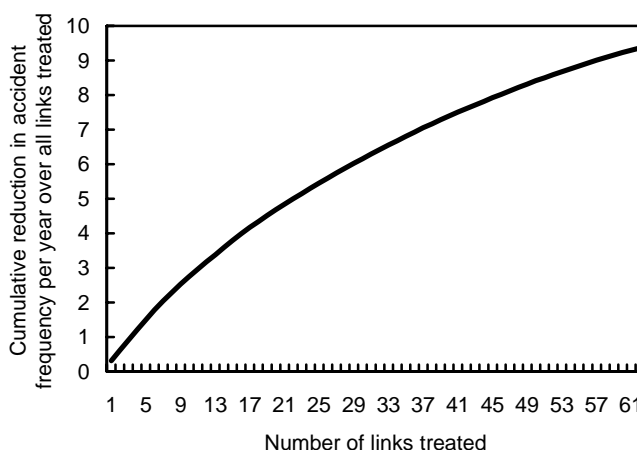


Figure 21 Estimated cumulative accident reduction from applying a 50miles/h speed limit to the sample of English links

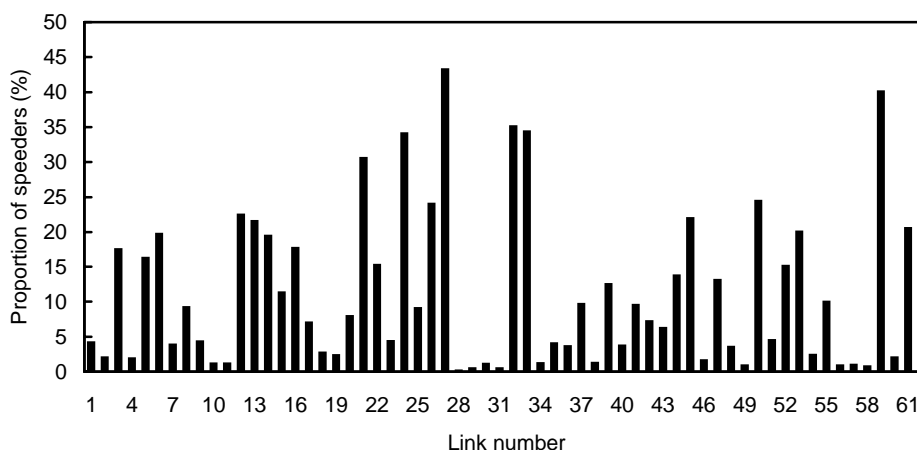


Figure 20 Estimated proportion of speeders on each of the English links after the introduction of a 50miles/h speed limit

Figure 20 shows that some of the links yielding the highest benefit in terms of accident reduction (ie. those at the left hand end of the graph) would still have a substantial proportion of speeders after the lower limit was applied, while others would have a very low proportion of speeders. Clearly the speed limit reduction would be more acceptable in cases where the resulting proportion of speeders would be low. Where the resulting proportion is high, additional enforcement measures might be needed to ensure acceptable levels of compliance - which in turn might yield further accident reduction. This may be an important factor in assessing public acceptability.

5.5.2 Increasing compliance with speed limits

In this Section we consider the effects of a range of other measures, including engineering and signing/marketing measures, which may be used to modify speeds. The models for both urban and rural links demonstrate the relationship between changes in accident frequency and changes in certain measures of speed (Sections 4.2 and 4.3). Where speed reduction measures have a known effect on speed, or where this can be estimated, the results can be used to rank links by the accident reduction expected to result from the introduction of such measures. This requires an understanding of those measures that might be applicable to each link, which will depend on many aspects of its design, traffic characteristics, and function.

The level of non-compliance with the existing 60miles/h limit on the English rural links in the study was relatively low. On the urban links, however, particularly those with a 30miles/h limit, there was considerable non-compliance. This indicates that there would be greater benefits from measures designed to achieve compliance with speed limits on urban roads than would be the case for rural roads. The model results also suggest (Section 4) that the accident frequency is more sensitive to a change in the proportion of speeders on urban roads than on rural roads (the coefficient of P is higher) although this difference is not statistically significant. In the sample of urban links studied, 36% had more than 30% speeders - if the proportion of speeders on each of these links was reduced to 10%, there would be roughly an 8 per cent reduction in the accidents in the sample as a whole.

The models indicate that for urban roads, targeting excessive speeds will often be more effective than addressing speeds overall. For example, in the sample of urban links studied, the mean *excess* speed was 4.4miles/h. If this were to be reduced to, say, 1mile/h, an average reduction in accidents of around 50% might be expected, even if we assume little change in the proportion of speeders. In contrast, an accident reduction of this size could only be achieved through a reduction of about 10miles/h in the *mean* speed of the traffic. Again whether these changes in speeds are achievable is a factor which also needs to be considered.

Different *types* of speed reducing measure are likely to affect the different characteristics of the speed distribution by different amounts. A number of research studies have been published which show the extent to which traffic calming features such as road humps reduce average traffic

speeds (and 85th percentile speeds) – for example Webster and Layfield (1996). But less is known about how these features affect the variation in speeds or the proportion of speeders. Other measures, such as those involving signing and marking, may influence the speed distribution in different ways and a greater understanding of these effects is very much needed.

In fact, what has been said in the earlier paragraphs about speed control measures in general is equally true of the enforcement of existing limits. Substantial research has been undertaken on the effectiveness of police enforcement of speeds and the application of technology such as speed cameras. In such studies additional enforcement has usually been shown to have resulted in lower speeds and fewer accidents. However, the role of the various characteristics of the speed distribution in achieving these accident reductions is not well understood, and further research exploring this issue in the light of the model results reported here would provide a sounder basis for targeting limited enforcement resources.

5.5.3 The relative effectiveness of site-specific measures and general 'blanket' measures

Measures intended to reduce the accident frequency can be applied in two ways: they can be employed over the whole network of roads or 'targeted' on specific links. The overall objective of a satisfactory speed policy is similar in each case – to achieve appropriate speeds over the whole of the network, and thus provide a general change in traffic behaviour in relation to road design and function so as to reduce accidents. In particular, where a high accident frequency is associated with a specific site on a link it is likely to be more cost-effective to introduce a speed-reducing measure at that site. Figure 22 suggests some general principles for a structured speed management strategy.

	Excessive speed	Inappropriate speed
High risk sites	Fixed cameras Engineering remedial measures Targeted police activity	Vehicle-activated signs
General sites	Mobile cameras Police presence Camera signing	Innovative marking Fixed warning signs Low-cost vehicle-activated signs

Figure 22 Speed management strategies for high risk sites and general treatment

The effect of reducing speeds at sites with a consistently poor accident record would be expected to result in larger accident reductions than the average effects shown by the models. It is known for example from accident investigations on rural roads, that speed is more likely to be a contributory factor on bends than elsewhere. The assessment of accident

patterns on rural roads (Barker et al, 1999; IHT, 1999) has provided a basis for judging when accident frequencies at bends (and junctions) are sufficiently high to warrant intervention with accident remedial treatments.

5.5.4 Other considerations

The models show that if average speeds of below 20 miles/h in urban areas and below 40 miles/h in rural areas could be achieved there would be substantially fewer accidents than occur at present on these roads. However, a reduction in average speeds to these levels may impact on journey times. In urban areas there is also the potential for environmental disbenefits. In assessing the overall benefits of different speed management techniques it will be necessary to take such effects into account. The DETR Speed Policy Review has considered these issues (DETR, 2000). On motorways in Great Britain (Harbord, 1998) and abroad, controlled speeds have actually been used to *sustain* traffic throughput, so the use of measures to influence speeds clearly depends on the circumstances.

The present report has been confined to the accident consequences of potential changes in speed, and has not considered trade-offs against these other factors.

5.6 The overall impact of different speed management strategies

Reductions in accident frequency could be achieved on most types of road if traffic speeds were reduced. But the most effective way of influencing the key characteristics of the speed distribution will vary according to circumstances, and the expected safety benefits will differ from one location to another. A consideration of the scope for speed reductions on different roads provides some indication of the potential reduction in accident numbers nationally.

5.6.1 Summary of accident numbers by road type, nationally

To set the context, consider first the national accident picture in outline.

Some 70 per cent (about 175,000) of all injury accidents occur in urban areas - more than 50 per cent of them on main roads. About 20 per cent of injury accidents (46,500) are on rural single-carriageway roads, and 4 per cent of these are on roads with a 50 miles/h limit. Fatal and serious accidents occur proportionately more frequently on rural roads, but are still far more numerous in absolute terms in urban areas. Table 6 summarises injury accidents by road type and severity for Great Britain.

5.6.2 Potential speed and accident reductions, nationally

Table 7 shows for roads of each type:

- the total number of injury accidents occurring nationally in a year;
- assumed values of reductions in the mean speed that are potentially achievable;
- the predicted average percentage reduction in accident frequency for each 1 mile/h reduction in average speed (at typical average speeds for these road types); and
- the resulting total predicted reduction in accidents.

Table 6 Accident distribution by road type (1998)

Road type	Speed limit (miles/h)	Total number of accidents	Number	
			of fatal + serious accidents	% (fatal + serious) of total
Urban	20	289	47	16
Minor urban (non-A or B roads)	30	74,390	10,832	15
Main urban (A+B roads)	30	80,173	10,265	13
Main urban	40	19,109	3,126	16
Rural	50	3,818	653	17
Rural single-carriageway (A road)	60	23,217	5,553	24
Rural single-carriageway (other)	60	21,494	4,652	22
Rural dual-carriageway	60/70	8,378	1,580	19
Motorway	70	8,055	1,062	13
All		238,923	37,770	

Table 7 Overall potential accident reductions obtained from mean speed reductions on different road types, nationally (based on 1998 data)

Road type	Speed limit (current - miles/h)	All accidents per year (AF)	Assumed mean speed reduction (miles/h) (V)	% reduction in AF per 1 mile/h reduction in V	Total reduction in accidents (per year)
					Total reduction in accidents (per year)
Urban	20	289			
Minor urban	30	74,390	10	6	44,634
Main urban	30	80,173	5	4	16,035
Main urban	40	19,109	3	2	1,147
Rural	50	3,818			
Rural single-carriageway (A)	60	23,217	4	3	2,786
Rural single-carriageway (other)	60	21,494	2	4	1,720
Other	60/70	16,433			
All		238,923			66,322

No reduction in speed is assumed on dual-carriageways/motorways or on rural roads with a 50 miles/h limit or in 20 miles/h zones. An assumption implicit in the accident savings shown in Table 7 is that the accident frequency at major junctions will be reduced by the same percentage as it is on the links between them. This seems broadly reasonable, given that accident reductions achieved in West London as a result of the deployment of speed cameras along links were proportionally at least as large at the junctions as they were on the links (Winnett, 1994).

The overall accident reduction taking all road types together is 28% of all accidents, but this is heavily influenced by the assumption that all minor urban roads could be treated with the same degree of success as has resulted from the introduction of 20 miles/h zones. The implications of a range of alternative (more realistic) assumptions can in principle be considered. Two examples are given here.

Firstly, if it were assumed that only 30 per cent of accidents on minor urban roads could be influenced through a 10 miles/h reduction in mean speed, with perhaps another 30 per cent subject to a speed reduction of 5 miles/h, the accident reduction from minor urban roads would

reduce to about 20,000 (more similar to the total main urban road reduction), and the overall reduction would be 41,773 (ie. 17% rather than 28%). Even with this more conservative assumption about what could be achieved on urban roads, it is clear that speed policies which target urban areas are likely to result in overall accident reductions that are considerably greater than those achievable in rural areas.

Secondly, if it were assumed that: only 30 per cent of accidents on the main urban and rural single-carriageway road types targeted in Table 7 could be influenced through speed reductions of the size given in Table 7 (and only 15 per cent on minor urban roads) – and that another 30 per cent on each type were subject to speed reductions of half these amounts; then an overall reduction of some 23,000 injury accidents (about 10% of the national total) is implied, resulting from an average reduction in mean speeds of about 2 miles/h. A fuller analysis of this estimate is given in Appendix C; we return to it again in Section 5.7.

An alternative approach to the estimation of accident savings would be to use assumed *target values* for the proportion of speeders (P) and an associated reduction in the mean speed of the speeders – at least for those road types for which this information is available. Table 8 shows the average proportion of speeders on road types where these are recorded nationally (DETR, 1999b); the table also shows the assumed target for P and the resulting expected reduction in accidents, nationally.

Table 8 Overall potential accident reductions achievable if the proportions of speeders could be reduced by prescribed (target) amounts, according to road type

Road type	Speed limit (current)	Proportion of speeders (current)	Proportion of speeders (target assumed)	Total reduction in accidents (per year)
Urban	20			
Minor urban	30			
Main urban	30	72	15	26,202
Main urban	40	28	15	2,291
Rural	50			
Rural single-carriageway (A)	60	10	10 (ie. no change)	
Rural single-carriageway (other)	60			
Other	60/70			

These particular assumptions imply a two-thirds greater reduction in the number of accidents on urban roads than shown in Table 7. The low percentage of speeders on rural roads means that on these roads, accident benefits would only be achieved by targeting those individual links which were carrying a significant proportion of speeders. For example, in the sample of English links used to develop the EURO model, 18% of the links had more than 10% speeders. If the proportion of speeders on these links was reduced to 10%, there would be a 2 per cent reduction in the accidents in the sample as a whole.

5.7 Casualties: the effects of different severity levels

In Section 1.2, we pointed out the distinction between accident numbers and the numbers and severities of casualties. The analyses and models in this report provide estimates of accidents.

When the results are being carried through to application, the distinction between accidents and casualties needs to be taken into account. If on average the number of casualties per accident, and their severity, did not differ according to the circumstances of the accident, the distinction would not matter. But in practice there are sometimes important differences.

In particular, casualties involving vehicle occupants on rural roads tend on average to be more severe than those on urban roads (the last column in Table 6, Section 5.6.1, illustrates this point). But injuries to pedestrians, which are more frequently serious or fatal than those involving vehicle occupants, are much less frequent on rural roads.

An approximate estimate of the casualty numbers by severity can be made by applying national multipliers (DETR, 1999a) to the predicted accident numbers according to the circumstance (urban or rural etc) of the accident. Using this technique it can be shown that the reduction of 23,000 injury accidents which was estimated in Section 5.6.2 to be achievable nationally would involve about 3,500 severely injured casualties and more than 200 fatalities (see Appendix C).

The assumption implicit in applying multipliers in this way (eg. n serious injuries to vehicle occupants per rural road accident, m fatalities etc) is that they do not depend on the factors which have been shown to influence the frequency of accidents. In particular it is assumed that the speed characteristics which influence accident frequency do not influence the multipliers. Clearly in practice the multipliers *will* depend on a range of factors – and speed in particular must influence them strongly. The difference in the effect of speed on total accident numbers compared to the number of fatal and serious accidents is implied in the findings of Andersson and Nilsson (1997), based on Swedish data. In deciding on casualty-reducing strategies some account will need to be taken of these effects. The consequence of linking fatal and serious accidents to speed through a cubic power law rather than a square law (as suggested by the Swedish work), would be to give a percentage reduction in fatal and serious accidents per 1 mile/h change in mean speed which is about half as much again as the figure for all accidents.

There is insufficient data from the studies reported here to investigate this in more detail but some further evidence is provided by looking at changes in accidents after the introduction of remedial measures. The monitoring of 20 miles/h zones (Webster and Mackie, 1996) shows that an overall 60% reduction in all accidents and a 70% reduction in fatal and serious accidents have been achieved by this approach. This suggests that, on these minor urban roads, the percentage change in fatal and serious accidents is not very much higher than the change in the overall accidents. In comparison, the data from the West London speed camera study on 40 miles/h urban roads (Winnett, 1994) suggested a

percentage change in fatal and serious accidents which is almost double that for all injury accidents. Not surprisingly, the impact on accident severity of speed reductions is considerably greater on high speed roads than on low speed roads.

Table 9 estimates the possible change in fatal and serious accidents if the percentage accident reduction per 1mile/h reduction in mean speed (applied to all sites on the 5 types of road targeted) is assumed to vary from:

- 7% for residential roads with a 30miles/h speed limit (compared with 6% for all accidents) to
- 4% for main urban roads with a 40miles/h speed limit (compared to 2% for all accidents).

Again we are assuming that the accident frequency at major junctions is reduced by the same proportion as it is on the links between them.

Table 9 Potential reductions in fatal and serious accidents obtained from mean speed reductions on different road types, nationally (based on 1998 data)

Road type	Speed limit (current – miles/h)	Fatal + serious accidents per year (AF)	Assumed mean speed reduction (miles/h) (V)	% reduction in AF per 1mile/h reduction in V	Total reduction in fatal + serious accidents (per year)
Urban	20	47			
Minor urban	30	10,832	10	7	7,582
Main urban	30	10,265	5	6	3,079
Main urban	40	3,126	3	4	375
Rural	50	653			
Rural single-carriageway (A)	60	5,553	4	5	1,111
Rural single-carriageway (other)	60	4,652	2	5	465
Other	60/70	2,642			
All		37,770			12,612

The overall accident reduction is about one-third of fatal and serious accidents on all roads, but the percentage reduction for rural roads (15%) is half as much again as the percentage reduction for all accidents on these roads (almost 10% based on Table 7). In contrast, the percentage reduction of fatal and serious accidents on urban roads is 45% - not so much more than the 35% reduction (based on Table 7) for all accidents. Despite this re-distribution, the greater contribution to overall accident reductions from speed management policies would nonetheless still come from policies focusing on urban roads.

5.8 Changing drivers' attitudes to speed

Regardless of decisions about which roads to treat and the choice of treatments, there will remain a continuing need to use public awareness campaigns and education and training techniques to influence drivers' attitudes to speeding. The message from both the road-based and the driver-based studies is clear: that the presence of faster drivers in the traffic stream is associated with a higher frequency of accidents. It is therefore important to develop ways of modifying the behaviour of those drivers who adopt the higher speeds and who thereby generate higher

accident frequencies. However, persuading the lower speed drivers to reduce their speeds still further should not be neglected; all drivers need to be made aware of the extent of speeding amongst the population of drivers as a whole, and its role in generating accidents.

Providing convincing evidence of the link between speed reduction and accident reduction will be vital in underpinning and motivating these activities, which depend strongly on the authority and credibility of the message. The evidence base is crucial. General messages such as 'speed kills' and 'just a 1mile/h reduction in the speed of all drivers will reduce accidents by 5%' have been used to date. The results of the analyses reported here provide a much more extensive and structured basis on which to consider publicity messages and to develop well-targeted education and publicity programmes.

Conclusions relevant to publicity messages include:

- Speed reduction reduces accidents on links and at minor junctions, and is effective in reducing both vehicle and pedestrian accidents.
- The 5% figure for the reduction in accident frequency per 1mile/h reduction in mean traffic speed remains a useful and robust overall rule.
- The higher levels of accident reduction are most likely to be achieved on residential roads, and on more highly congested urban roads where the variability in speeds is considerable.
- Drivers who adopt speeds above the average for the road have significantly higher accident involvement than those adopting the average speed and this involvement rises sharply for those drivers adopting the highest speeds.

Conclusions from the driver-based studies particularly relevant to the development of education and training programmes include:

- Drivers who choose higher-than-average speeds tend to do so habitually and on all roads.
- Drivers who choose higher-than-average speeds tend to be young, high mileage drivers who have a greater tendency than others to violate traffic regulations (although inevitably this does not mean that *all* drivers who speed have these characteristics or that *all* drivers with these characteristics speed).

5.9 Section summary

The key implications of the road-based models for setting priorities for speed management have been presented. They can be summarised as follows:

- The potential for reducing accidents through speed management on urban roads is greater than on rural roads, both in terms of the percentage accident reduction and in terms of the numbers of accidents that can be influenced.
- The results relate to the total number of injury accidents occurring; different speed-accident relationships may apply for accidents involving serious or fatal casualties but it is unlikely that the implications for speed management will be much affected.

- The potential for reducing accidents through speed management on urban roads is greatest on highly congested roads in towns.
- The results for urban classified roads appear to be applicable to minor residential roads.
- Applying reasonable assumptions about the speed reductions achievable on different road types, it can be shown that an annual saving of about 23,000 injury accidents could be expected, involving more than 200 fatalities and about 3,500 serious casualties.
- Speed reductions on urban roads can be expected to lead to reductions in both pedestrian and vehicle-only accidents and to reductions in accidents both at, and away from, the minor junctions within links.
- Speed management measures need to be carefully targeted on rural roads, with priority given to those with high accident frequencies and a high proportion of speeders; particular consideration should be given to site-specific treatment (for example at bends).
- The benefits in accident terms from reduced traffic speeds need to be set against potential disbenefits in journey times and (in urban areas) against environmental disbenefits.
- The results can be used to inform the development of public awareness campaigns and education and training programmes.

6 Summary and conclusions

6.1 Summary

TRL has undertaken a major programme of research in which the relationship between speed and accidents has been investigated. This programme comprised road-based studies for both urban and rural roads, and driver-based studies. Extensive data have been collected and statistical modelling methods used to determine the influence of many factors so that the impact of the key speed variables on accidents could be detected and quantified.

The statistical models relating speed and injury accidents which were developed in the road-based studies show that no *single* measure of speed is fully effective as a predictor of accidents.

For **urban roads**, two alternative models were derived from British data, enabling accident frequencies to be predicted for classified roads on road links between major junctions. Both models predict the effects on accident frequency of:

- i traffic speeds;
- ii traffic flows, pedestrian activity, the numbers of minor road junctions, and the percentage of large vehicles.

The higher values of each of the measures in (ii) are all associated with higher accident frequencies. Links on B class roads have higher accident frequencies than links on A or C class roads and links in London have higher accident frequencies than links elsewhere.

Speeds are represented in the models in two ways:

- The first model (Model U1) uses the *average speed of vehicles* and the *coefficient of variation* - a measure of the spread of individual speeds about the average speed.
- The second model (Model U2) uses the *proportion of vehicles exceeding the speed limit* and the *average speed in excess of the limit of those doing so*.

For each of these measures of speed, higher values are associated with more accidents. If each measure could be varied *independently*:

- The faster traffic moves on average, the more accidents there are – the accident frequency rises approximately with the square of the average traffic speed; thus a 21% increase in accidents would result from a 10% increase in mean speeds.
- The bigger the spread of speeds around the average speed, the more accidents – the accident frequency rises exponentially as the coefficient of variation of speed rises. The accident frequency rises by 15% if the coefficient of variation rises by 0.025.
- The higher the proportion of drivers speeding, the more accidents – the accident frequency rises by 10% if the proportion of speeders doubles.
- The higher the average speed of those drivers who speed, the more accidents – the accident frequency rises by 19% if the average speed of the speeders increases by 1mile/h.

In practice, the pair of speed variables in each model are likely to be correlated (that is, as one varies, so does the other). In each model, the combined effect of the pair of variables on accidents is approximately linear. Between one end of the range of values of the speed variables observed in the data and the other end of that range the accident frequency roughly doubles.

The statistical model developed for **rural roads** was based on data from links in England, Sweden, and the Netherlands.

The EURO model predicts accident frequencies using the average speed and the proportion of drivers exceeding the speed limit. The model also contains the speed limit as a category variable. A higher speed limit and a higher proportion of speeders are each associated with more accidents but the effect of average speed on accidents could not be directly determined. Other factors associated with increased accidents were: traffic flow, link length, and the number of minor junctions. Wider roads were associated with fewer accidents.

The analyses for both urban and rural roads also allowed the objective classification of links into separate sub-groups, reflecting their operational characteristics.

The driver-based studies showed that those individuals who choose to drive at speeds above the average on some roads tend also to do so on all roads, and at different times. They tend to be young, to drive high mileages and to be more inclined than others to violate traffic regulations. They also have a significantly higher accident involvement than average.

6.2 Conclusions

The results have been drawn together to reach the following conclusions:

- 1 In a given situation, higher speeds are associated with more accidents.
- 2 Reducing the speed of the fastest drivers (relative to the average speed for the road) is likely to bring greater accident benefits than reducing the overall average speeds for all drivers, particularly on urban roads. This demonstrates the value of engineering and enforcement measures which target the fastest drivers.
- 3 To allow more effective targeting for accident reduction, the routine speed monitoring used by authorities in the formulation of speed management strategies needs to include measures of the *distribution* of speeds about the average speed, particularly for example, the proportion of drivers exceeding the speed limit.
- 4 The scope for reducing accidents by means of speed management depends on the operational characteristics of the road. The often-quoted broad result that a '5% reduction in accident frequency results per 1mile/h reduction in average speed' has been investigated carefully; although it remains a robust general rule, a much fuller picture is now available. The percentage reduction in accident frequency per 1mile/h reduction in mean speed has been shown to vary according to the road type and the average traffic speed. It is:
 - about 6% for urban roads with low average speeds;
 - about 4% for medium speed urban roads and lower speed rural main roads;
 - about 3% for the higher speed urban roads and rural main roads.

In urban areas the potential for accident reduction (per one mile/h reduction in average speed) is greatest on those roads with low average speeds. These are typically busy main roads in towns with high levels of pedestrian activity, wide variation in speeds, and high accident frequencies.

These results will be fundamental in deciding which speed reduction policies would achieve the greatest safety benefits. Even if the higher severity of accidents on rural compared to urban roads is taken into account, the pattern will remain broadly unchanged, as well as the implications for prioritisation.

- 5 Speed reductions on urban roads will reduce both pedestrian and vehicle accidents and will reduce accidents at minor junctions along the links. It seems likely (on the basis of studies of the effect of speed cameras in West London) that accidents at major junctions will be reduced as well. Minor (residential) roads appear to offer similar accident reduction potential to other urban roads, per one mile/h reduction in average speed, at equivalent levels of speed.
- 6 A reduction in the national speed limit on rural A and B class roads, to 50miles/h, is likely to be effective in

reducing accidents only on a modest proportion of roads. Targeting 'problem' roads would be a more effective strategy. Priority would best be given to roads which combine high speeds with a high accident frequency. The reduction in speed limit could itself lead to an increase in the proportion of speeders; in such cases the new limit would require additional enforcement.

- 7 A consideration of:
 - (i) the effect of different accident remedial measures on the characteristics of the speed distribution;
 - (ii) national accident numbers;
 - (iii) the accident reductions that can be expected to result from different reductions in speed;
 - (iv) the reductions in speed that are likely to be achievable in different circumstances; and
 - (v) the proportion of the network to which these reductions could be applied,suggests that the overall potential for reducing accidents by means of general engineering and enforcement strategies aimed at speed restraint is:
 - greater for urban roads than rural roads;
 - greater for residential than major urban roads (making reasonable assumptions about the number of residential areas suitable for cost-effective treatment).
- 8 It is well established that speed is a contributory factor in a large number of accidents. The key question is by how much the national accident toll could be reduced by moderating speed. Of course, widespread behavioural changes and a consequently large decrease in average speeds would be required to eliminate *all* accidents in which speed is a contributory factor. But on the basis of the results in this Report we can estimate what might be a reasonable *minimum* accident reduction to aim for. This represents only a proportion of the accidents in which speed is a contributory factor, but provides a guide to the sensitivity of the accident numbers to a small change in average speed.

Thus, applying reasonable but modest assumptions about the speed reductions achievable on the various road types, it can be shown that an annual saving of about 23,000 injury accidents could be expected, resulting from a reduction in average speeds (averaged across the whole network) of just 2miles/h. This would mean that each year more than 200 deaths and about 3,500 serious casualties would be prevented.

The value of restraining speeds in terms of saving unnecessary death and injury is clearly great.
- 9 The results can also be used to inform the development of public awareness campaigns and education and training programmes.
- 10 To obtain a comprehensive understanding of the impact of speed management policies, greater knowledge is required in a number of areas. These include:
 - the effect of speed on accidents in different driving conditions (wet/dark) and at different times of the day;
 - the effect of measures designed to modify speeding behaviour on the characteristics of the speed distribution;
 - methods of establishing what speeds are appropriate on different roads and in different conditions.

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8 References

- Alvey N G et al (1977).** *GENSTAT A General Statistical Program*. Rothamsted Experimental Station, Harpenden.
- Andersson G and Nilsson G (1997).** *Speed management in Sweden*. Swedish National Road and Transport Institute VTI, Linköping.
- Allsop R E (1998).** *Summary of research area 1: Basis for appraisal of effects of different levels of speed*. MASTER working paper R 1.3.1. European Commission.
- Baker R J and Nelder J A (1978).** *Generalised Linear Interactive Modelling*. The GLIM System. Rothamsted Experimental Station, Harpenden.
- Barker J, Farmer S and Nicholls D (1998).** *Injury accidents of rural single-carriageway roads, 1994-95: an analysis of STATS19 data*. TRL Report TRL304. Transport Research Laboratory, Crowthorne.
- Barker J, Farmer S and Taylor M (1999).** *The development of accident-remedial intervention levels for rural roads*. TRL Report TRL425. Transport Research Laboratory, Crowthorne.
- Baruya A (1998).** *MASTER: Speed-accident relationship on European roads*. MASTER working paper R 1.1.3. European Commission, Brussels.
- Baruya A and Finch D J (1994).** *Investigation of traffic speeds and accidents on urban roads*. Proc. 22nd PTRC Summer Annual Meeting, 13-16 September 1994. PTRC, London.
- Baruya A, Finch D J and Wells P A (1999).** *A speed-accident relationship for European single-carriageway roads*. Traffic Engineering & Control, 40(3), 135-139.
- Broughton J, Markey K A and Rowe D (Supt.) (1998).** *A new system for recording contributory factors in road accidents*. TRL Report TRL323. Transport Research Laboratory, Crowthorne.
- Coleman J A et al (1996).** *FWHA Study tour for speed management and enforcement technology*. FWHA-PL-96-006. Federal Highway Administration, US Department of Transportation.
- Department of Transport (1980).** *Circular Roads 1/80*. London.
- Department of Transport (1993).** *Circular Roads 1/93*. London.
- DETR (1999a).** *Road Accidents Great Britain 1998 The Casualty Report*. Stationery Office, London.
- DETR (1999b).** *Vehicle Speeds in Great Britain: 1998*. Transport Statistics Report. DETR Statistics Bulletin (99) 17.
- DETR (2000).** *New Directions in Speed Management – A Review of Speed Policy*.
- European Commission (1999).** *DUMAS: The Research Report*. D10.3. Brussels.
- Evans L and Wasielewski P (1983).** *Do accident-involved drivers exhibit riskier everyday driving behaviour?* Accident Analysis & Prevention, 14, 57-64.
- Finch D J, Kompfner P, Lockwood C R and Maycock G (1994).** *Speed, speed limits and accidents*. Project Report PR58. Transport Research Laboratory, Crowthorne.
- Garber N J and Gadirau R (1988).** *Speed variance and its influence on accidents*. AAA Foundation for Traffic Safety, Washington, USA.
- Grayson G B (Ed.) (1997).** *Behavioural research in road safety VII*. Transport Research Laboratory, Crowthorne.
- Hall R D (1986).** *Accidents at four-arm single carriageway urban traffic signals*. Contractor Report CR65. Transport Research Laboratory, Crowthorne.
- Harbord B (1998).** *M25 Controlled Motorway – Results of the first two years*. Proc. 9th International Conference on Road Transport Information and Control, 21-23 April 1998, 149-154. Institution of Electrical Engineers, London.
- Hughes W and Amis G (1996).** *Accidents on Rural Roads: Single Carriageway 'A' Class Roads*. AA Foundation for Road Safety Research, Basingstoke.
- Institution of Highways and Transportation (1990).** *Guidelines for: Urban Safety Management*. Institution of Highways and Transportation, London.
- Institution of Highways and Transportation (1999).** *Guidelines for: Rural Safety Management*. Institution of Highways and Transportation, London.

International Road Federation (1999). *World Road Statistics 1999.*

Kennedy J V, Hall R D and Barnard S (1998). *Accidents at urban mini-roundabouts.* TRL Report TRL281. Transport Research Laboratory, Crowthorne.

Kloeden C N, McLean A J, Moore V M and Ponte G (1997). *Travelling speed and the risk of crash involvement.* Federal Office of Road Safety, CR172. Canberra.

Layfield R E, Summersgill I, Hall R D and Chatterjee K (1996). *Accidents at urban priority crossroads and staggered junctions.* TRL Report TRL185. Transport Research Laboratory, Crowthorne.

Lynam D A, Baruya A, Taylor M C and Finch D J (1999). *Managing speeds to reduce accidents in UK.* Proc. 2nd European Road Research Conference, 7-9 June 1999. Brussels.

Maycock G and Hall R D (1984). *Accidents at 4-arm roundabouts.* Laboratory Report LR1120. Transport Research Laboratory, Crowthorne.

Maycock G, Brocklebank P J and Hall R D (1998). *Road layout design standards and driver behaviour.* TRL Report TRL332. Transport Research Laboratory, Crowthorne.

Maycock G, Lockwood C R and Lester J F (1991). *The accident liability of car drivers.* Research Report RR315. Transport Research Laboratory, Crowthorne.

McCullagh P and Nelder J A (1989). *Generalized Linear Models (2nd edition).* Monographs on statistics & applied probability. Chapman and Hall, London.

Pickering D, Hall R D and Grimmer M (1986). *Accidents at rural T-junctions.* Research Report RR65. Transport Research Laboratory, Crowthorne.

Quimby A, Maycock G, Palmer C and Buttress S (1999a). *The factors that influence a driver's choice of speed – a questionnaire study.* TRL Report TRL325. Transport Research Laboratory, Crowthorne.

Quimby A, Maycock G, Palmer C and Grayson G B (1999b). *Drivers' speed choice: an in-depth study.* TRL Report TRL326. Transport Research Laboratory, Crowthorne.

Reason J T, Manstead A S R, Stradling S G, Parker D and Baxter J S (1991). *The social and cognitive determinants of aberrant driving behaviour.* Contractor Report CR253. Transport Research Laboratory, Crowthorne.

Rogerson P S, Newstead S and Cameron M (1994). *Evaluation of speed programme in Victoria 1990-91, Phase 3 and 4. Report 54.* Accident Research Centre, Monash University, Victoria, Australia.

Silcock D, Smith K, Knox D and Beuret K (1999). *What limits speed? Factors that affect how fast we drive.* Interim report, July 1999. AA Foundation for Road Safety Research, Basingstoke.

Solomon D (1964). *Accidents on main rural highways related to speed, driver and vehicle.* Bureau of Public Roads, Department of Commerce, Washington, USA.

Summersgill I and Layfield R E (1996). *Non-junction accidents on urban single carriageway roads.* TRL Report TRL183. Transport Research Laboratory, Crowthorne.

Summersgill I, Kennedy J V and Baynes D (1996). *Accidents at three-arm priority junctions on urban single carriageway roads.* TRL Report TRL184. Transport Research Laboratory, Crowthorne.

Taylor M C, Hall R D and Chatterjee K (1996). *Accidents at 3-arm traffic signals on urban single-carriageway roads.* TRL Report TRL135. Transport Research Laboratory, Crowthorne.

Taylor W C (1995). *Speed zoning – a theory and its proof.* Traffic Engineering, 34(12). USA.

Transport Research Laboratory (1999). *SafeNET User Manual.* Application Guide AG34. Transport Research Laboratory, Crowthorne.

Walmsley D A and Summersgill I (1998). *The relationship between road layout and accidents on modern rural trunk roads.* TRL Report TRL334. Transport Research Laboratory, Crowthorne.

Wasielewski P (1984). *Speed as a measure of driver risk: observed speeds versus driver and vehicle characteristics.* Accident Analysis and Prevention, 16, 89-103.

Webster D C and Layfield R E (1996). *Traffic calming – road hump schemes using 75mm high humps.* TRL Report TRL186. Transport Research Laboratory, Crowthorne.

Webster D C and Mackie A M (1996). *Review of traffic calming schemes in 20miles/h zones.* TRL Report TRL215. Transport Research Laboratory, Crowthorne.

West R, Erlander J and French D (1992). *Decision making, personality and driving style as correlates of individual accident risk.* Contractor Report CR309. Transport Research Laboratory, Crowthorne.

Winnett M A (1994). *A review of speed camera operations in the UK.* Proc. 22nd PTRC Summer Annual Meeting, 13-16 September, 264-276. PTRC, London.

Appendix A: Technical details

A1 The modelling methodology

A1.1 Introduction

In Section 3 of the main report some of the factors that are associated with accidents were outlined – factors such as mean speed, traffic flow, pedestrian flow and the number of junctions. Since these factors are to some extent inter-dependent it is not possible simply to relate accidents to one factor alone – eg. the mean speed – and ignore the interacting effects of the other variables. An accident relationship is multidimensional and it requires a multidimensional analytical technique to explore the dependencies. The Generalised Linear Modelling approach explained below is such a technique, which helps us to answer the question: *what would happen to the accident frequency if we altered speed, but kept all other factors constant?*

A1.2 Generalised Linear Modelling (GLM)

The Generalised Linear Modelling technique (McCullagh and Nelder, 1989) is a multivariate regression method which enables a dependent variable (in this case accident frequency) to be related to a set of independent or explanatory variables. The method used is to search for those mathematical relationships which best describe the data. The resulting mathematical description is termed a statistical ‘model’, and the search for the best model is referred to as ‘fitting the model’. Models will vary in how well they ‘fit’ the data and a ‘goodness of fit’ statistic is used as a guide to how effective any particular model is. Because the models are multivariate – that is, they account for many factors simultaneously - the model may be taken to represent the ‘true’ effects of the individual explanatory variables, providing that all the relevant explanatory variables are included in the model, and that the functional forms of these variables are appropriate.

The GLM method used in the present study is the same as that employed in a number of previous road-based accident studies - particularly those for junctions (see for example: Maycock and Hall, 1984; Summersgill et al, 1996; Taylor et al, 1996). Reference should be made to these reports for fuller details of the method. The technique has also been used for the analysis of individual driver accident risk as a function of speed. These driver-based models, together with the associated methodological and analytical issues are described in the original TRL publications (Maycock et al, 1991; Maycock et al, 1998; Quimby et al, 1999a; Quimby et al, 1999b). The remainder of this appendix focuses on the road-based models only.

A1.3 Fitting the models

Multivariate accident models consist of three components:

- 1 a systematic component - the relationship between the dependent variable (accident frequency) and those explanatory variables (flow, speed etc) which prove to be significant;
 - 2 the sampling or measurement error associated with the dependent variable; and
 - 3 residual errors due to the lack of fit of the model.
- (The term ‘error’ is used here in the strict statistical sense.)

As far as the systematic component of the model is concerned, the objective of the analysis is to relate the accident frequency (the average number of accidents per year) to a range of ‘explanatory variables’. For the road-based studies, the ‘explanatory’ variables are functions of the traffic and pedestrian flows, traffic speed, and the geometric and other characteristics of the roads.

The sampling error appropriate to the modelling is determined by the characteristics of the independent variable - in this case the accident frequency. Accidents are infrequent events, and as such are more satisfactorily represented by a Poisson distribution than by a normal distribution. Because accidents are not normally distributed and the variance of the accident frequency is not constant across the range of the data, a least squares regression cannot be used. Instead the Generalised Linear Modelling method available in the computer programs GENSTAT (Alvey et al, 1977) and GLIM (Baker and Nelder, 1978) has been used. This method allows the dependent variable in the regression analysis to be drawn from one of a family of distributions, including the Poisson distribution.

As in all statistical modelling, the aim is to obtain a ‘parsimonious’ model – ie. one which provides the best trade-off between the number of variables included in the model (keeping the number as small as possible to make interpretation and application easier) and the ability of the model to represent the data (keeping the fit as good as possible). Each model is developed using a step-by-step procedure, starting with the ‘null’ model – one without any independent variables included, which therefore simply fits the mean value of the dependent variable. Explanatory variables are then added one by one as independent variables - tried in various functional forms - seeking the best model fit. At each step, to determine whether the new variable added to the model is statistically significant, a statistic called the ‘scaled deviance’ is calculated. The scaled deviance is a maximum likelihood statistic; it is the deviance of the model – a function of the observed and predicted values - multiplied by a scale factor. For a pure Poisson model, the scale factor is 1. Generally, the difference in scaled deviance between two nested models with degrees of freedom df_1 and df_2 will be a chi-squared distribution (χ^2) with $(df_1 - df_2)$ degrees of freedom. Thus for the addition of one term to the model, a reduction in scaled deviance in excess of 3.84 is required for statistical significance at the 5% level.

As regards overall goodness of fit, provided the predicted mean value of accidents in the study period is greater than about 0.5 (see Maycock and Hall, 1984), the scaled deviance of a Poisson model is asymptotically distributed as χ^2 with $(n-p-1)$ degrees of freedom. Here, n is the number of data points and p the number of independent variables fitted. Thus a perfectly fitting Poisson model would have a scaled deviance equal to the number of degrees of freedom. However, for reasons given in the following paragraph, a perfectly fitting Poisson model is not expected, and a scale factor other than 1 has to be estimated for the purpose of testing the significance of adding terms to the model.

The Poisson assumption takes account only of the within-site variation of accidents, that is, the variation that occurs because the observed number of accidents occurring at a particular site in the observation period is a sample from a Poisson distribution whose mean is the 'true' accident frequency at that site. The accidents in the road-based studies, however, occur at a large number of sites with between-site variations in the 'true' mean accident frequencies, not all of which will be allowed for by the explanatory variables in the model. Thus, there will be an additional component of 'error' variation in the data over and above the Poisson variation which arises from this between-site unexplained variation; compared to pure Poisson data, the data will appear to be over-dispersed.

A quasi-likelihood method has been used to allow for this over-dispersion. The procedure is as follows: each model is initially estimated assuming a Poisson distribution of accidents and a scale factor (used in calculating the scaled deviance) of one. The amount of over-dispersion is then determined by calculating a revised scale factor which is the ratio of the generalised Pearson X^2 statistic to the number of degrees of freedom (df) for that model. When the model is re-run using this revised scale factor (now greater than 1), the model parameters themselves remain unchanged, but the scaled deviance is reduced and the standard errors of the parameters are increased by an amount equal to (scale factor)^{0.5}. This means that to reach significance using the revised scaled deviance, the size of the effect under consideration has to be larger than would have been the case in a Poisson model. In all of the results presented in this report, the standard errors shown have been adjusted by the revised scale factor.

A1.4 Application of GLM in the road-based studies

In almost all of the accident modelling work carried out at TRL over the past decade or so, exploration of alternative model forms has shown that a multiplicative model has generally proved to be the most satisfactory. The work reported here has the same property. The simplest functional forms for the individual terms in such a model are:

The power form..... X^α

The exponential form..... $e^{\beta Y}$

where X and Y are explanatory variables in the model. It is found in practice, given the nature of the accident data, that one or other of these simple functional forms generally gives a satisfactory fit, so that more complex terms are not required.

Thus if AF represents the accident frequency to be predicted, and X_i and Y_j are the explanatory variables ($i = 1, 2, \dots; j = 1, 2, \dots$), the accident models take the form:

$$AF = k X_1^{\alpha_1} \times X_2^{\alpha_2} \times \dots \times \exp(\beta_1 Y_1) \times \exp(\beta_2 Y_2) \times \dots$$

or if natural logarithms are taken of both sides:

$$\ln(AF) = \ln k + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \dots + \beta_1 Y_1 + \beta_2 Y_2 + \dots$$

To achieve a regression relation with this structure, a GLM is fitted using a log link (in which the natural

logarithm of the accident frequency becomes the dependent variable) and the explanatory variables are fitted in logged form, $\ln X_1, \ln X_2$ etc, to give power functions, or simply as Y_1, Y_2 etc. to give exponential terms. The regression process then estimates the values of the coefficients α_1, α_2 etc and β_1, β_2 etc, by a maximum likelihood process.

The procedure used in building the models was to fit the layout variables to the null model first and retain those which were individually significant and which in combination provided the best model fit. Once a satisfactory first stage model was achieved, the various flow variables were added in the second stage. In the final stage the speed variables were added. It will be appreciated that interaction between variables can lead to variables in the first and second stages becoming non-significant in the later stages and thus being superseded by the later additions. Hence, at each stage of model development a 'stepwise' method of variable selection was used to obtain a parsimonious model which included the smallest number of statistically significant variables.

As a secondary check on model development a backwards elimination approach was also used in which all viable variables were initially included in the model, and the non-significant variables eliminated one by one until only those that were statistically significant remained. The use of a stepwise approach to the selection of variables for inclusion in the models is essential in a situation where the speed variables are correlated both with themselves and with the flow and geometric variables, and in which the number of potential explanatory variables is large.

The procedure outlined above led to the formulation of three aggregate level models - two for British urban roads (models U1 and U2), and a third for European rural roads (EURO model). These models are presented below.

Although the presentation of other models is outside the scope of the present report, it is worth noting that during the course of the study, models were formulated to explore among other things:

- speed effects for different time periods;
- speed effects for different accident types;
- directional speed-flow effects.

It was also possible from this data set to estimate regression relations between:

- the mean speed;
- the proportion of speeders;

each as the dependent variable, and the flow and geometric variables as explanatory variables. Such relations are the equivalent of the more traditional speed/flow/geometry relations; they were used here in Section 4.3 in the estimation of the effect on accident frequency in the EURO model (taking account of the concurrent effect on mean speeds and the proportion of speeders) of a change in the speed limit and differences in the road width.

A1.5 The problem of masking

Sometimes the relevant variables interact in such a way that the effect of interest (in this case the association between speed and accidents) is masked. Consider for example the associations

between accident frequency (accidents per year), mean speed and pedestrian flows on a sample of road sections. On busy urban sections, accident frequencies are high and are associated with high pedestrian flows. But these high pedestrian flows are also associated with lower speeds. Thus, if the interacting effect of pedestrians is not properly allowed for in the statistical modelling, high accident frequencies can appear to be associated with low speeds. What we need is the relationship between speed and accidents on road sections on which the pedestrian flows are held constant.

Masking such as this arises when two or more variables are highly inter-correlated with a third, and one of these dominates or *masks* the association of the other with the dependent variable. Masking of the speed variables was explicitly found to occur in the urban data and implied in the rural data. For example, at the simplest level of analysis the relationship for urban roads between accidents and mean speed appears to be *negative* – higher speeds, lower accident frequencies. This is because the mean speed is itself affected by differences in traffic flow and pedestrian activity. The negative relationship appears because the effects of traffic and pedestrian flows have not been taken into account properly - ie. traffic and pedestrian flows have masked the true effect of the mean speed. When traffic and pedestrian flows have been included in the urban model, the relationship between speed and accidents becomes positive (Section 4.2).

Similarly, when the rural data from which the EURO model was developed are examined as a 'raw' relationship, there is a negative speed effect – higher speeds appear to be associated with lower accident frequencies. It seems likely that the negative speed effect arises as a result of a masking variable or variables in the rural data as well, though in this case, pedestrian flows do not provide the required explanation. Masking is an important issue in the interpretation of the rural model, and it will be considered further when discussing that model.

A1.6 Statistical uncertainty

The statistical processes described above (A1.2 - A1.4) have resulted in models which relate a dependent variable (in this case the accident frequency) to a range of explanatory variables, based on observed data. These models are used to predict the accident frequency from known values of the explanatory variables. Such predictions are always subject to some statistical uncertainty. In complex models of the type developed here, where there are a number of explanatory variables and extensive interactions between them, estimating the *size* of this uncertainty is difficult. The range of statistical error associated with predictions of accident numbers tends to be wide because of the relatively low rate at which accidents occur at any individual site and the consequent need for very large studies to provide sufficient numbers of accidents for deductive purposes.

It should be strongly emphasised that the results given in this report derive from the *best estimates* available of predicted accident frequencies. These are *unbiased, central estimates* of what can be expected to occur in a given situation. Moreover, the data from which the models were

developed in the road-based studies were indeed extensive – a total of 5095 accidents from 271 sections of road (and some 2 million observations of vehicle speed). Only a considerable increase in the volume of data would secure an appreciable reduction in the statistical error associated with the predictions.

A2 The variables used in the models and the range of the data

A2.1 The variables

The generalised model structure for the road-based studies is, as explained above, multiplicative in form. It can be summarised as follows:

$$AF = k \cdot (\text{SPEED}) \cdot (\text{FLOW}) \cdot (\text{GEOMETRY}) \cdot (\text{OTHERS}) \cdot (\text{Residual})$$

where:

AF = accident frequency (accidents/year)

k = a constant determined by regression

SPEED = a set of speed variables

FLOW = a set of flow variables

GEOMETRY = a set of geometric variables

OTHERS = a set of other variables

Residual = the error term

The actual variables used in the urban models are as follows:

SPEED

V	mean traffic speed (miles/h)
C _v	coefficient of variation of the speed distribution – ie. the standard deviation of the distribution (SD) divided by the mean
V _{ex}	mean excess speed (miles/h): the mean speed of drivers <i>in excess</i> of the speed limit.
P	percentage of drivers exceeding the limit

V and C_v are used in Urban Model U1; they are correlated with one another (C_v is SD/V), so that they should be regarded primarily as a complementary pair of speed variables in this model. Similarly V_{ex} and P are associated, and should be regarded as a complementary pair in Urban Model U2.

FLOW

Q	Annual Average Daily two-way Traffic along the link (AADT)
PED _n	a four level categorical variable with values of (0,1) representing different levels of pedestrian activity as measured by hourly movements across the link, including movements across its side roads at minor junctions
PED1	= 1 if count is very high: >1,800 crossings/hour; otherwise =0
PED2	= 1 if count is high: 600-1,800 crossings/hour; otherwise =0

- PED3 = 1 if count is low: 200-600 crossings/hour; otherwise =0
- PED4 = 1 if count is very low: <200 crossings/hour; otherwise =0

The traffic flow variable is straightforward, normally being obtained using automatic traffic counters and scaled to the annual average daily total (AADT).

The original database for urban roads contained detailed measurements for pedestrian activity and vehicle mix that would be difficult to obtain, if not prohibitively expensive for most practitioners. These variables have thus been converted to categorical and binary variable equivalents, to enable the models to be used more easily in subsequent applications. Comparison of models with raw and categorical data indicates that the latter perform just as well in predicting accident frequencies.

GEOMETRY

- NJ number of minor junctions along the link (counted as side roads, both sides)
- W road width at speed survey point (metres)
- D link length (km)

OTHERS

- L a dummy variable (0,1) representing:
0 = link is outside the Greater London area
1 = link is inside the Greater London area
- B-ROAD a dummy variable (0,1) representing:
0 = link is on an A or C class road
1 = link is on a B class road
- DHGV a dummy variable (0,1) representing:
0 = proportion of heavy goods vehicles and buses in flow ≤ 1 in 8
1 = proportion of heavy goods vehicles and buses in flow > 1 in 8
- S speed limit (miles/h)

A2.2 The ranges of the data

Data ranges for the key continuous explanatory variables as used in models U1 and U2, are given in Table A1, and those for the EURO model in Table A2. It should be further noted that urban models U1 and U2 were developed using data from A, B or C class two-way, single-carriageway roads between 0.4 and 1.8km in length, of uniform speed limit (either 30 or 40miles/h) and overall character; the range of pedestrian crossing flows observed was from 30 to 5600 per hour and the proportion of heavy goods vehicles and buses in the flow ranged from 5 to 33%. The EURO model was developed from data from the Netherlands, Sweden and England. In the UK context, this model applies to A class or B class two-way single-carriageway roads between 1.0 and 3.4km in length of uniform speed limit and overall character. Because the link length (D) is explicitly accounted for in the EURO model it will be possible to apply this model to link lengths outside the data ranges quoted. Link length was not explicitly accounted for in urban models U1 and U2 because all links were of roughly

similar length (between 0.4 and 1.8km), and junction frequency (NJ) was found to be an excellent proxy for length. Consequently, *urban models U1 and U2 should not be used to predict accident frequencies outside this range.*

Table A1 Data ranges for use with urban models U1 & U2

Explanatory variable	London	Outside London
	Mean (Range)	Mean (Range)
NJ	6.0 (1 – 14)	6.6 (2 – 20)
Q (AADT)	11000 (780 – 32000)	9100 (1500 – 27000)
P (%)	25 (4 – 73)	29 (2 – 82)
V _{ex} (miles/h)	4.3 (3.0 – 6.0)	4.4 (3.2 – 6.7)
V (miles/h)	25.5 (19.5 – 33.1)	27.4 (19.0 – 34.7)
Cv	0.25 (0.18 – 0.33)	0.23 (0.17 – 0.31)
Link length (km)	0.70 (0.4 – 1.3)	0.74 (0.4 – 1.8)

Table A2 Data ranges for using the EURO model on UK roads

Explanatory variable	A class roads	B class roads
	Mean (Range)	Mean (Range)
S (miles/h)	60	60
W (metres)	7.5 (5.4 – 10.0)	7 (5.7 – 10.2)
NJ	2.7 (0 – 5)	3 (0 – 6)
D (km)	2.1 (1.0 – 3.4)	1.8 (1.0 – 2.6)
Q (AADT)	8800 (3600 – 27000)	5900 (2500 – 11000)
P (%)	5.3 (0.2 – 18.3)	3.8 (0.3 – 16.9)
V (miles/h)	45.2 (33.2 – 53.8)	44.0 (37.4 – 52.9)

A3 The Urban models

A3.1 Model U1

Table A3 gives the regression coefficients and associated statistics for Urban Model U1 – which uses V and Cv as the key speed variables.

Table A3 Coefficients for model U1: Urban links mean speed model

Variate	b	se(b)	t	Sig-t (P)	Accident effect size
L	0.326	0.080	4.04	<0.001	1.39
ln(V)	2.252	0.584	3.85	<0.001	3.88
Cv	5.893	2.030	2.90	<0.01	2.57
ln(Q)	0.450	0.079	5.64	<0.0001	5.32
PED1	1.532	0.249	6.15	<0.0001	4.63
PED2	0.973	0.211	4.63	<0.0001	2.65
PED3	0.714	0.191	3.73	<0.001	2.04
NJ	0.057	0.011	4.76	<0.0001	2.95
B-ROAD	0.343	0.343	4.11	<0.0001	1.41
DHGV	0.377	0.116	3.27	<0.001	1.46
Constant	-13.20	2.264	-5.83	<0.0001	

b = the estimated coefficient

se(b) = the standard error of the coefficient

t = studentised t-value

Sig-t(P) = significance level of t (Probability)

Accident effect size – see text

The initial deviance of the above model was 1598.4 (df 97) and the residual deviance 225.2 (df 87). This model therefore explains 92% of non-Poisson variation in accident frequencies.

The ‘accident effect size’ in the final column of Table A3 is the factor by which the accident frequency would change if the associated variable changed from the lowest value in its range to the highest (Table A1 – all data together). Thus for example in the case of the number of junctions (side roads) (NJ) the range outside London shown in Table A1 is from 1 to 20. Since NJ is in the model as a simple exponential term, the ratio of accidents for a road section with 20 junctions will be $\exp((20-1) \cdot 0.057) = 2.95$ times that on a road section with only 1 junction. In the case of the category variables (eg. the pedestrian flow categories or the DHGV factor) the effect size is simply the ratio of the number of accidents with the relevant factor in play to that without the relevant factor in play. For example, the average accident frequency on roads on which the percentage of heavy goods vehicles is greater than 12.5% (DHGV=1) is $\exp(0.377) = 1.46$ times the accident frequency on roads on which the percentage of such vehicles is less than 12.5% (DHGV=0). These factors therefore give some idea of the relative impact of the various variables on accidents.

It will be seen that the largest accident effects arise from flow variations – both vehicle and pedestrian flows. In both cases as flows increase, accidents increase – by a factor of about 5 from the smallest to the largest. The London factor, the B-road factor and the goods vehicle factor are all of similar size – about 1.3 to 1.4. The speed factors (V and Cv) are of particular interest, and although Table A3 suggests that both mean speed and Cv are associated with a positive effect of some magnitude (higher speeds, higher Cv, more accidents), there is a strong interaction between the two (Cv involves the reciprocal of V) which needs to be taken into account and which determines the overall functional form of the relationship between accidents and mean speed.

Table A3 shows that both the mean speed (V) and the coefficient of variation of speed ($Cv=SD/V$) are statistically significant components of the model. In fact, when V is included in the model on its own (as a power function), accidents appear to be approximately proportional to V – ie. the speed-accident relation is linear (see Table A4, column 2). The addition of Cv involving as it does the reciprocal of V will result in a model which will be non-linear in V and which implies that accident frequency ‘flattens off’ at higher speeds. The overall speed-accident relation (ie. when both V and Cv change together) is illustrated in Figure A1. The figure has been obtained by entering pairs of values of V and Cv averaged over a number of adjacent data points into the model of Table A3 with L=0 (outside London), PED2=1 (between 600 and 1,800 pedestrian crossings per hour), B-ROAD=0 (A or C class road), DHGV=0 (percentage of goods vehicles < 12.5%), and NJ and Q set at their average values of 6 and 10,000 respectively. It will be seen that the overall relation is indeed essentially linear. The fact that Cv is in statistical terms a significant addition to the model indicates

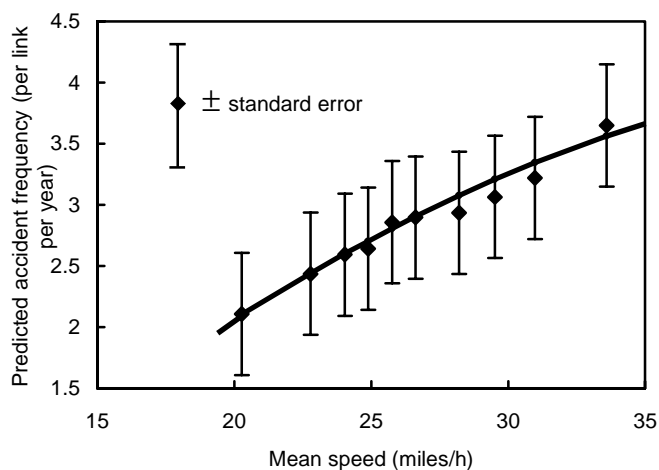


Figure A1 Accident frequency against mean speed (Urban Model U1)

that Cv is providing some additional explanation of site-to-site differences in accidents in addition to the overall trend. (Incidentally, in the modelling, Cv was a far better explanatory variable than either SD or 1/V on their own.)

Figure A1 also shows that the overall change in accident frequency arising from both V and Cv varying together across the range of data observed in this study is about 2.

In relation to speed, the urban model can be written in simplified form as:

$$AF_{U1} = K_{U1} V^{2.252} e^{5.893Cv} \quad (A1)$$

where AF_{U1} is the accident frequency and K_{U1} is a site-specific constant incorporating all the variables in Table A3 other than the speed terms. In Section A5 below, an alternative formulation of the above accident-speed relation will enable the accident savings per mile/h reduction in mean speeds to be estimated.

The U1 model (equation A1) suggests that if it were possible to change the mean speed on a section of road without changing the coefficient of variation, then accidents would be proportional to $V^{2.25}$ – approximately a square law. A square law relating the probability of occurrence of an accident to speed has often been suggested as arising from the kinematics of a vehicle engaged in emergency braking. The Newtonian laws of motion indicate that at constant deceleration, the distance required to reduce the speed of a vehicle from an initial speed V to a lower one is a function of the square of V. In a given set of circumstances – ie. for a given vehicle, tyres and road surface – the assumption of constant deceleration under maximum braking is likely to be a good one. In some simple accident situations – like rear end shunts – the distance-speed square law may well suggest that the probability of becoming involved in an accident is a speed square law also, though there will be many other situations (single vehicle accidents for example) where this argument would not hold. The kinetic energy of a moving vehicle is also proportional to V^2 and this bears on collision severity when an accident takes place, V here being the impact velocity.

A3.2 Model U2

The driver-based studies suggest that, averaged over all roads, drivers who travel faster than the average speed for the road have a higher-than-average accident liability. This in turn suggests that on a given section of road, it is likely to be the higher speed drivers who are contributing more than others to the overall accident frequencies on these sections. Clearly in the road-based dataset, neither the speeds of individual drivers nor their accidents are individually identified. It is not therefore possible to associate particular accidents with particular drivers. However, from both a theoretical and practical standpoint, and for the reasons explained in Section 3.3.2, it seemed important to investigate the association between accident frequencies and the proportion of drivers in the upper part of the speed distribution.

We define a threshold speed $u(n)$ miles/h to refer to a speed of n miles/h in excess of the speed limit. Hence $u(0)$ will mean the speed limit itself and $u(5)$ will mean 35miles/h for 30miles/h zones and 45miles/h for 40miles/h zones, etc. If we define $P(n)$ as the percentage of drivers exceeding an excess speed threshold of $u(n)$ miles/h, an exploratory regression model can be written in the following form :

$$\ln(AF) = F(\underline{x}) + \lambda(n) \cdot \ln P(n) \quad (A2)$$

where:

$\ln(AF)$ is the natural logarithm of the yearly accident frequencies;

$F(\underline{x})$ is the function of the set of eight explanatory variables $L, Q, PED1, PED2, PED3, NJ, B-ROAD$ and $DHGV$ as included in the Urban Model U1 (Section A3.1);

$\lambda(n)$ represents the coefficient of the effect of $\ln P(n)$, the value of which depends on the threshold $u(n)$.

The accident model of equation A2 includes $P(n)$ as a power function – ie. $AF = K(P(n))^\lambda$. The alternative exponential model in which $AF = k \exp(\gamma P(n))$ was also tried. At low values of n – ie. $P(0)$ and $P(5)$, the exponential form was marginally better, but at higher values of n , the power form was significantly better. Thus although the power form gives an improbable result at $P(n) = 0$, namely that when there are no drivers exceeding the speed limit, there are no accidents, the power function would appear to give a generally better representation of the way excess speeds relate to accidents, providing the limits of P (especially the lower limit) are specified and observed. The power function model also has some subjective validity in that $P(n) \cdot Q$ is a traffic flow term, and in accident models traffic flows (Q) have normally been found to be better incorporated as power terms.

If we now consider a range of values for $u(n)$ of 0, 5, 10, 15, 20 and 25miles/h in excess of the speed limit, then six different power models can be considered, one for each value of $u(n)$, and each model will yield an estimate for λ . The results are summarised in Table A4 (columns 3-8), where the estimated values of the regression coefficients at different values of $u(n)$ are presented. The parameter values are presented as those of $C(\underline{x} | u)$ - the symbol ‘|’ is used here to indicate that the value is conditional on $u(n)$.

The initial deviance for the null model prior to fitting the 8 explanatory variables was 1682.1 (df 99). When $F(\underline{x})$ was fitted for the base model the residual deviance reduced to 292.83 (df 91). The addition of $\ln V$ to this base model is shown in column 2 of Table A4; it shows that $\ln V$ added to the model – to give a power function of V (without C_v) - provides a significant improvement to the model, but yields an approximately linear effect of mean speed on accidents (cf. Figure A1). The table shows that the addition of each $\ln P(u)$ term (with a small constant [0.1] added to P to avoid taking logs of the zeros in the data) causes a further reduction in the residual deviance by an amount indicated by ‘ ΔDev ’ in Table A4. The coefficients $\lambda(u)$ of the $\ln P(u)$ terms are highly significant as predictors of accident frequencies. Moreover, once P is added to the model, V ceases to be significant as a predictor of accidents – this will be an important point to note when interpreting the EURO model (Section A4).

This analysis indicates therefore that the proportion of (excess) speeders in the driving population $P(u)$ is a better predictor of accidents than mean speed alone, and that the higher the excess speed threshold over the speed limit ($u(n)$), up to at least $u(20)$, the better the fit. This almost certainly means that the functional form of the $P(n)$ -accident relation (across sites) is a better representation of the accident data than that involving mean speed. This itself suggests that the proportion of high speeders in the population of drivers is closely related to the accident potential of the road section (though it does not necessarily indicate a causal effect of itself).

The inference drawn in the previous paragraph is in agreement with a number of other studies which demonstrate the association between high speeders and greater accident frequencies. The driver-based studies (Maycock et al, 1998; Quimby et al, 1999a, 1999b) show that drivers who habitually drive at speeds well in excess of the mean have high accident liabilities. Some recent road-based studies carried out on urban roads in Australia (Kloeden et al, 1997) have shown that drivers driving in excess of the speed limit (60km/h) are at considerably greater risk than those driving at or below the speed limit. In fact, Kloeden et al’s study shows that the risk of involvement in an injury accident approximately doubles for every 5km/h increase in speed. Other studies show that a positively skewed speed distribution implies higher accident frequencies than a symmetrical one – for example, Taylor as long ago as 1965 showed that accident savings could result from introducing speed zones which had the effect of making the speed distribution more symmetrical.

For simplicity and practicality, a speed model using a threshold of the speed limit $u(0)$ was developed as an extension of the models of Table A4. $P(0)$ will simply be referred to as P – the proportion of drivers over the speed limit. In addition, exploration of this model showed that the inclusion of V_{ex} (the mean speed of the speeders in excess of the speed limit) significantly improved the model. This excess speed model is called U2, and Table A5 gives the regression coefficients and associated statistics for the model.

Table A4 Coefficients of $C(\underline{x} | u)$ and the power $\lambda(u)$ of $P(u)$ in equation A2

Covariate	Base + $\ln(V)$ 1	Base + $\ln(c+P(0))$ 2	Base + $\ln(c+P(5))$ 3	Base + $\ln(c+P(10))$ 4	Base + $\ln(c+P(15))$ 5	Base + $\ln(c+P(20))$ 6	Base + $\ln(c+P(25))$ 7	Base + $\ln(c+P(30))$ 8
L(0,1)	0.348	0.338	0.335	0.333	0.326	0.323	0.352	
(se)	0.050	0.050	0.050	0.050	0.050	0.050	0.049	
Ln(Q)	0.495	0.504	0.499	0.476	0.406	0.337	0.335	
(se)	0.050	0.049	0.049	0.049	0.052	0.056	0.062	
NJ	0.048	0.048	0.049	0.049	0.047	0.046	0.051	
(se)	0.0073	0.0071	0.0070	0.0070	0.0070	0.0070	0.0070	
PED1	1.751	1.557	1.559	1.559	1.535	1.548	1.507	
(se)	0.154	0.132	0.131	0.130	0.129	0.129	0.129	
PED2	1.123	0.929	0.935	0.948	0.937	0.070	0.958	
(se)	0.131	0.116	0.116	0.117	0.116	0.117	0.117	
PED3	0.846	0.650	0.642	0.643	0.632	0.642	0.664	
(se)	0.120	0.114	0.114	0.114	0.114	0.114	0.114	
B-Road	0.355	0.354	0.365	0.365	0.362	0.367	0.348	
(se)	0.052	0.052	0.052	0.052	0.052	0.051	0.051	
DHGV	0.411	0.397	0.408	0.408	0.415	0.397	0.366	
(se)	0.070	0.068	0.068	0.068	0.068	0.068	0.067	
Ln(V)	1.017	—	—	—	—	—	—	
(se)	0.242	—	—	—	—	—	—	
$\lambda(u)$	—	0.180	0.160	0.200	0.325	0.473	0.539	
(se)	—	0.038	0.030	0.033	0.046	0.068	0.101	
Constant	-8.267	-5.395	-5.091	-4.683	-3.757	-2.778	-2.492	
(se)	0.841	0.432	0.433	0.441	0.476	0.554	0.670	
ΔDev	-17.76	-22.93	-28.00	-37.37	-49.36	-48.72	-28.82	
Res. Dev	275.06	269.90	264.22	255.46	243.46	244.11	264.01	

Table A5 Coefficients for model U2: Urban links excess speed model

Variate	b	$se(b)$	t	$Sig-t(P)$	Accident effect size
L	0.338	0.085	3.99	<0.001	1.40
Ln(Q)	0.480	0.083	5.77	<0.001	5.95
PED1	1.524	0.224	6.81	<0.001	4.59
PED2	0.932	0.197	4.74	<0.001	2.54
PED3	0.627	0.193	3.25	<0.01	1.87
NJ	0.051	0.012	4.21	<0.001	2.63
Ln(P)	0.141	0.065	2.17	<0.05	1.69
V_{ex}	0.175	0.074	2.37	<0.05	1.91
B-ROAD	0.373	0.087	4.26	<0.001	1.45
DHGV	0.411	0.117	3.52	<0.001	1.51
Constant	-5.850	0.764	-7.74	<0.0001	

b = the estimated coefficient
 $se(b)$ = the standard error of the coefficient
 t = studentised t -value
 $Sig-t(P)$ = significance level of t (Probability)
 Accident effect size – see text

The initial deviance of this model was 1682.1 (df 99) and the residual deviance 253.9 (df 89). Thus, the model explains 90% of non-Poisson variation in accident frequencies. The effect size (the factor by which accidents would change if the associated variable changed from the lowest value in the data range to the highest) is shown in the final column of Table A5. For the variables in the U2 model which are common to the U1 model (Table A3), these effect sizes are reasonably consistent.

The power of P in this model is 0.141 – a little lower (but not significantly so) than that in the corresponding model without V_{ex} , shown in column 3 of Table A4 (0.18). This suggests that the correlation between these variables is not so high that they cannot both provide additional explanatory power in the model. The accident effect size in Table A5 shows that both P and V_{ex} contribute about equally to the model.

Of course, the speed variables P and V_{ex} are likely to be inter-related. Taking this into account by using the approach described for the case of the U1 model, Figure A2 illustrates the effect on accidents of the two speed variables in combination, corresponding to the U2 model (for fixed $Q = 10000$; Non-London; $PED2 = 1$; $NJ = 6$; Non-B-road; $DHGV=0$). In this case accidents have been plotted against P – but they might equally well have been plotted against V_{ex} .

It will be seen, as expected, that the relationship in Figure A2 is approximately linear over the observed range of P . The figure shows that the overall change in accident frequency arising from P and V_{ex} varying together across the range of data observed in this study is very similar to that given by the U1 model (Figure A1) at about 2.

In simplified form, the urban equation U2 becomes:

$$AF_{U2} = K_{U2} P^{0.141} e^{0.175 V_{ex}} \quad (A3)$$

where AF_{U2} is the accident frequency and K_{U2} is a site-specific constant incorporating all the variables in Table A5 other than the speed terms.

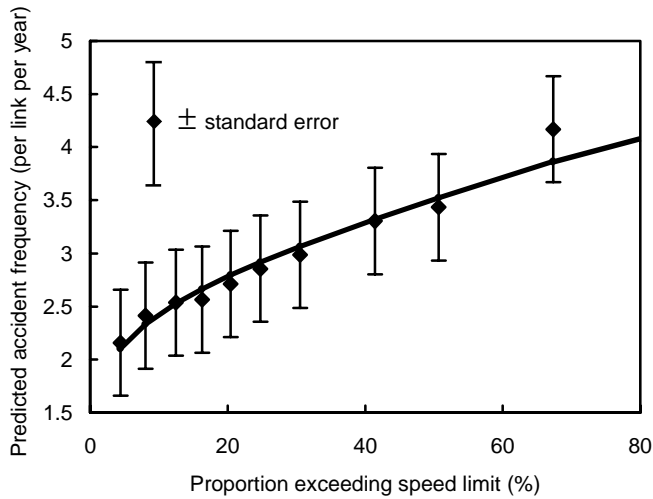


Figure A2 Accident frequency against proportion of speeders (Urban Model U2)

A3.3 A worked example using the U2 model

The following example is designed to illustrate how the U2 model described above can be used to predict the number of accidents expected to occur on a given link, based on its speed, flow and geometric characteristics.

Let us suppose we have an urban link that is 1km in length with the following characteristics:

- the link is outside London;
- AADT = 9,000;
- pedestrian crossing activity is judged to be high – between 600 and 1,800 crossings/hour;
- the total number of minor junctions is 6;
- the proportion of drivers exceeding the limit is 30%;
- the mean excess speed of non-compliant drivers is 4.5 miles/h over the limit;
- the link is on an A class road;
- the percentage of large vehicles in the traffic stream is judged to be less than 12.5%.

The model written out in full in multiplicative form is:

$$AF = 0.00288 e^{0.338 Q} e^{0.480 P} e^{1.524 PED1} e^{0.932 PED2} e^{0.627 PED3} e^{0.051 NJ} \times P^{0.141} e^{0.175 V_{ex}} e^{0.373 B-ROAD} e^{0.411 DHGV} \quad (A4)$$

Table A6 sets out the required calculations. The first column is the variable name, and the second is the value of the coefficient. Column 3 – labelled ‘Data’ – provides the values of the variables that are needed in the calculation (as listed above). The exponential terms are evaluated in column 4 – ie. each entry in this column is $\exp(b \cdot \text{Data})$, and the final column evaluates the power terms – ie. the entries are $(\text{Data})^b$. All that remains is for the terms in the final two columns to be multiplied together. When this is done, we arrive at the value of 2.79 accidents per year for the link section in question.

Should we now wish to consider the effect of, for example, a change in one or more of the variables in the model, then we would reapply the model with the revised values.

Table A6 Worked example for model U2

Variate	b	Data	Exponential terms	Power terms
L	0.338	0	1	
Q	0.480	9,000		79.074
PED1	1.524	0	1	
PED2	0.932	1	2.540	
PED3	0.627	0	1	
NJ	0.051	6	1.358	
P	0.141	30		1.615
V ^{ex}	0.175	4.5	2.198	
B-ROAD	0.373	0	1	
DHGV	0.411	0	1	
Constant	-5.850		0.00288	

A4 The EURO (rural) model

The EURO model was developed from data from the Netherlands, Sweden and England. The variables included in the model and the ranges of the data available have already been given in Section A2 above. The model is shown in Table A7.

Table A7 Coefficients for EURO model: Rural links European model

Variate	b	se(b)	t	Sig-t (P)
Ln(Q)	0.748	0.0613	12.21	<0.0001
Ln(D)	0.847	0.0653	12.98	<0.0001
NJ	0.0379	0.0156	2.42	<0.02
Ln(V)	-2.492	0.5174	-4.82	<0.001
Ln(P)	0.1143	0.0563	2.03	<0.05
W	-0.0563	0.0242	-2.32	<0.02
S	0.0382	0.0102	3.74	<0.0001
Constant	0.549	1.962	0.88	<0.4

b = the estimated coefficient

se(b) = the standard error of the coefficient

t = studentised t-value

Sig-t(P) = significance level of t (Probability)

The initial deviance of the EURO model was 837.0 (df 138), and the residual deviance 305.6 (df 131). This model therefore explains 75% of non-Poisson variation in accident frequencies.

The variables available for explaining the variations in accident frequency in the rural dataset were not as extensive as were those for the urban data. Flow (AADT), the number of junctions (side roads) (NJ), mean speed (V) and the proportion of drivers exceeding the speed limit (P) were available and were included, as in the case of the urban model U2. In addition, link length (D), road width (W) and speed limit (S) were included in the EURO model. The coefficient of link length (D) is somewhat less than 1, reflecting the presence of the number of minor junctions (NJ) in the model. However, other than the speed-related variables, there were no variables (other than road width) which reflected the geometric design standards of the roads.

It will be seen from Table A7 that accidents are positively related to P (the proportion exceeding the speed limit) and to the speed limit itself (S). Speed limit is effectively a category variable in that the data relate to five values of the

limit – 70km/h, 80km/h, 90km/h, 100km/h and 110km/h. Examination of the within-category representations of P and V show that the overall coefficients in Table A7 are a good representation of those obtained within each of the five speed limit categories separately.

Table A7 also shows that accident frequency is inversely related to mean speed (actually proportional to $V^{-2.5}$) – this means that the higher the mean speed, the lower the number of accidents. This situation corresponds to that found in the urban data before the masking effect of pedestrian flow was taken into account, and almost certainly arises from a similar effect. It is not difficult, however, to see how a negative speed accident relation could arise on rural roads. It is well known that high quality roads have low accident rates, because they are wider, have fewer (or no) junctions, have more accommodating verges, and have generous sight-lines and curvatures. But it is these very same ‘design standards’ which themselves are linked to ‘design speed’ and which result in high actual speeds. Thus in a cross-sectional ‘between roads’ sense (ignoring any masking of variables), high speeds correspond to low accident frequencies. And if the design standard features are not adequately represented as explanatory variables in the model, the masking remains and a negative speed-accident relation results.

This appears to be what is happening in the EURO model - differences in design standards between roads (differences not included in the model) have generated an accident effect which it appears is proportional to $V^{-2.5}$. However, the effect of P is positive, and does seem to be reflecting the effect of the excess speeders on accidents, as was the case for the urban models shown in Table A4 (which included P only). Moreover, these excess speed models showed that P was a better predictive variable than V and that when P was included in Urban Model U2 (which did avoid masking effects by including other relevant variables – notably pedestrian flows) the effect of V was not statistically significant. It is also a fact that the coefficient of P in the EURO model, although smaller than that in the excess speed model of Table A4 (column 3), is not significantly different in statistical terms. It seems reasonable, therefore, to take the P term in the EURO model as representing the effect on accidents of changes in speed and to take the remaining terms – including S, and the inverse V term – as representing the changes in accidents arising from differences in road design and operating characteristics. Moreover, since the safety interest in speed and accidents normally focuses on what can be achieved on a particular stretch of road – ie. it is the before-after or ‘within road’ effect which is of concern – the accident-P relation of the EURO model (Table A7) will be interpreted as a ‘within road’ effect as well as a ‘between road’ effect.

Thus the basic predictive equation for the change in the accident frequency on rural roads as the proportion of drivers exceeding the speed limit varies becomes:

$$AF_R = K_R P^{0.1143} \quad (A5)$$

where AF_R represents the accident frequency predicted by the model, and K_R is assumed to be a site-specific constant incorporating all of the variables in Table A7 other than P. In view of the fact that the power of P in this equation

(0.114 ± 0.056) is lower than that found in the urban analysis (0.141 ± 0.065), and that unlike model U2 the EURO model does not include the term V_{ex} which provided additional explanatory power to that model, it is suggested that the value of 0.114 in equation (A5) is probably conservative – underestimating the true effect.

A5 Accident savings per 1 mile/h reduction in speed

A5.1 On urban roads

It has been previously pointed out that in Urban Model U1, the two speed terms V^α and $e^{\beta C_v}$ are inter-related in the sense that as the mean speed varies from site to site, so does the coefficient of variation of speed. If then some measure is taken on a particular road section which results in the reduction of the mean speed, the most likely consequence, within present circumstances, judging by the cross-sectional data available in this study, is that the coefficient of variation will change also. On this basis Figure A1 illustrated the association between accidents and mean speed taking account of the corresponding changes in C_v .

It is now necessary to quantify the changes illustrated in Figure A1, and to do this we need an algebraic relationship between V and C_v . Figure A3 shows how the mean speed V is related to C_v across the sites in the study. Because the standard deviation of speed (SD) is only weakly correlated with mean speed, and $C_v = SD/V$, the relationship is inverse – but a linear relationship seems adequate to represent it. Consideration was given to whether the relationship used should be a regression fit to the data in Figure A3 or a functional one (which would take account of the errors in both V and C_v). In the event, since the error variance of V is considerably greater than that in C_v , there was little difference in the two relationships, and the regression relation between V and C_v has been used. This is:

$$C_v = 0.448 - 0.0078 V \quad (A6)$$

Substituting this expression in equation (A1), Urban Model U1 becomes:

$$AF_{U1} = 14.01 K_{U1} V^{2.252} e^{-0.046V} \quad (A7)$$

Differentiating with respect to V and considering small changes $\Delta(AF_{U1})$ and ΔV gives:

$$\Delta(AF_{U1})/AF_{U1} = [2.252 / V - 0.046] \cdot \Delta V \quad (A8)$$

Thus the percentage change in accident frequency resulting per 1mile/h change in mean speed is $225.2/V - 4.6$. This result is plotted in Figure 9 in the main report over the range of mean speeds observed on the sample of urban roads (19miles/h – 35miles/h). It is worth bearing in mind that the coefficients of both V and C_v , and of equation (A8), are subject to statistical uncertainty. The standard error of the coefficient of $1/V$ in equation (A8) is estimated to be ± 0.584.

It should be realised that equation (A8) is based upon cross-sectional empirical evidence; it represents the way in which accidents change from road section to road section as the mean speed and the coefficient of variation of the speed distribution changes – all other factors affecting speed (in particular, geographical area and road type, traffic and pedestrian flows, the number of junctions and the proportion of goods vehicles) remaining constant. The

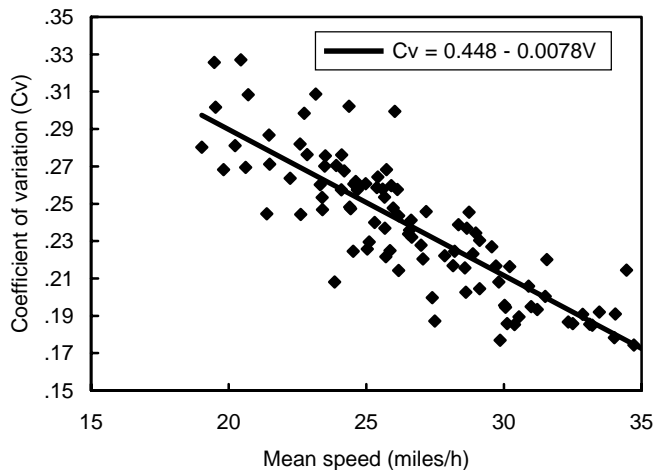


Figure A3 Coefficient of variation of speed against mean speed (urban roads)

application of this result to a before-and-after change in speeds amounts to assuming that within-site changes in the mean speed and the coefficient of variation will follow the same pattern as the observed between-site variation. Since the model has taken into account many of the cross-sectional characteristics of the roads which do influence speed, we believe it is reasonable to interpret equation (A8) as being the ‘within-road section’ effect of speed.

A5.2 On rural roads

The analysis of the European rural road data has led to a predictive equation relating accident frequency to the proportion of speeders, the mean speed, speed limit and a number of other site-specific variables. Because of the problem of masking, this model is not straightforward to interpret. However, on the basis of a comparison with Urban Model U2 (which includes the proportion of speeders and the mean excess speed) it was concluded that the EURO model can be

interpreted as a simple power law model in P (equation A5), with the other variables – including V (mean speed) and S (speed limit) as reflecting site-specific design characteristics.

To determine the change in accidents resulting for each 1mile/h change in mean speed, we need a relationship between P (the proportion of speeders) and the mean speed, V. Figure A4 shows a log-log plot of these two variables from the rural data. It will be seen that for each speed limit value the plot can be approximated by a straight line with a similar slope. The power law relationship between the two variables is:

$$V = k P^{0.0744} \quad (A9)$$

where the value of k would be different for each of the speed limit groups.

Substituting for P from equation (A9) into the rural model equation (A5) gives:

$$AF_R = [K_R/k^{1.536}] V^{1.536}$$

Differentiating with respect to V, and substituting for the constant term gives:

$$\Delta(AF_R)/AF_R = [1.536 / V] \cdot \Delta V \quad (A10)$$

This equation indicates that for every 1mile/h reduction in the mean speed (V) on European rural roads, the accident frequency will be reduced by 153.6/V per cent. The result is plotted in Figure 9 in the main report over the range of mean speeds observed on the sample of English rural roads (33miles/h – 54miles/h).

It is worth noting that the figure 1.536 is derived from the ratio of two regression coefficients – 0.1143/0.0744 – both of which are subject to statistical error. An estimate of the standard error of the ratio 1.536 is ± 0.760 . Moreover, it was suggested in Section A4 that the EURO model could be underestimating the effect of speed on rural roads. It is worth bearing in mind therefore that the rural road speed effect could be as high as a 200/V per cent change in accident frequency per 1mile/h change in mean speed.

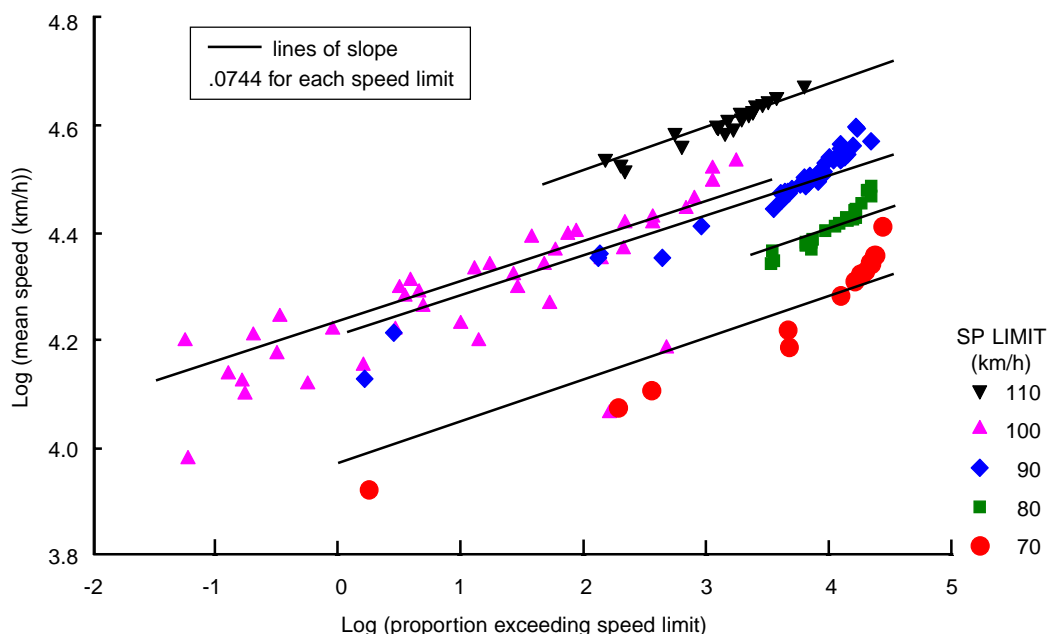


Figure A4 Mean speed against proportion of speeders (rural roads)

A6 Practical issues

A6.1 Use of the 85th percentile speed

Practitioners have traditionally used the 85th percentile speed as the sole speed measure on which to base action plans and policy. DoT Circular Roads CR1/80 (Department of Transport, 1980) stated the importance of the 85th percentile in determining local speed limits, and this approach is reflected to a lesser extent in DoT Circular Roads CR1/93 (Department of Transport, 1993), which embodies current regulation. In paragraph 7.2 of CR1/93 it is stated that: *if the observed 85th percentile speed is within 7mph or 20 per cent of the proposed limit, the limit may be introduced.*

It should be noted though that this is part of an *advisory* procedure, rather than a mandatory method for determining the suitability of a local speed limit. The rationale for use of the 85th percentile, as outlined in CR1/93, is in providing a realistic local limit that will be obeyed by the majority of drivers. In this respect the 85th percentile is a useful tool for the highway engineer. However, it is clear from the work reported here that a single measure of speed is not in itself adequate for predicting the benefits of measures designed to improve safety. Three basic characteristics of the speed distribution – the mean, the variability and excess (high) speeds – need to be addressed in order to benefit from the results presented in this report. The 85th percentile, being a hybrid somewhere between mean and variance, is unlikely to address either of these two characteristics adequately. In urban situations, speed distributions are usually asymmetric and this in itself renders 85th percentile much less relevant.

A6.2 Speed surveys

The use of models U1, U2 or the EURO model for accident prediction will require practitioners to undertake different surveys of vehicle speeds from those traditionally carried out, to provide the necessary information describing speed distributions. It will be imperative to capture speed data as accurately and comprehensively as possible, using automatic techniques. The use of equipment that provides ‘per vehicle record data’ (PVR) will be preferable to that which uses speed ‘bins’. Where the use of bins is necessitated, the configuration of those bins will be important; the optimum configuration will depend on which models are to be used.

Appendix B: Areas where more knowledge is needed

The report has highlighted a number of areas where a greater understanding would be useful. These are summarised as follows.

B1 Improved representation of design features in the model for rural roads

As discussed in Appendix A, it appears that differences in design standards between roads act as masking variables in the EURO model and the available data have not included variables that can explicitly penetrate the masking. A more

extensive study is warranted, concentrating on UK roads and adequately covering the range of design standards found, in which data covering a much broader range of geometric variables and layout characteristics are collected.

B2 Variation in the speed-accident relationship under different conditions

The speed surveys in the road-based studies on rural links were carried out in conditions which included both wet and dry weather, but did not discriminate between these conditions, although for urban links, wet weather was avoided as far as possible. For the urban links, speeds were measured only between 07:00 and 19:00. Although models for urban links were developed for different time periods, these were based on only a limited amount of data and do not provide robust tools for practical application. Similarly, differences in the speed-accident relationship for wet roads, or in winter for example, cannot be assessed.

The DETR Vehicle Speed survey (DETR, 1999b) shows that speeds during peak hours are only about 1 mile/h lower than daytime off-peak speeds, although speeds can be 2-3 miles/h higher later in the evening and in the early morning. Simple comparison of accident frequency suggests that proportionately 20-30% more accidents occur in the dark than would be expected in daylight (comparing equivalent hours of the day). But both alcohol and fatigue are likely to influence these differences, and the true difference in accidents due to the light/dark effect alone may be nearer half this (ie. 10-15%).

A similar 20-30% increase in accidents has been suggested during wet periods. The implication from the current studies might be that if average speeds were to be reduced during wet weather to counter this and bring risk down to the level associated with dry weather, then the reduction would need to be of the order of 5-8 miles/h on urban roads, and more on rural roads. But this topic requires more detailed study as the increased risk may be much higher at sites such as junctions and bends, where braking is required.

B3 Variation in the speed-accident relationship for different accident types

The relations between speed and accidents developed in the road-based studies relate to *total* accidents (ie. including all accident types). It is possible that different relationships apply for different accident types. This is particularly so for accidents of different *severity* because of the direct role that speed plays in contributing to accident severity. This point is discussed in more detail in Section 5.7 of the main report. Similarly, the effect of traffic speed may be different for accidents involving different classes of road user – for example pedestrians and cyclists, or for accidents involving only single vehicles. In the road-based studies, models were developed which suggested that the effect of traffic speed on pedestrian and vehicle-only accidents differed (see Section 5.3.2 of the main report) but the data limitations mean that this can only be regarded as an indicative result at this stage.

B4 Extension of the road-based models to other road types

The road-based models developed to date are applicable to classified urban roads and to A and B class rural single-carriageway roads. Accident risk curves are therefore available for these two types of road (as shown in Figure 9). However, the models do not extend to more minor urban or rural roads, or to dual-carriageway roads or motorways. Separate risk curves are needed for these road types to provide a family of risk curves corresponding to the whole network.

Urban roads with a 40 miles/h speed limit were also not well-represented in the sample of roads studied. Furthermore, it may be desirable, for the road types that have been studied, to extend the coverage to values of the parameters outside the ranges observed. This is particularly true of the urban link models where the range of link length was between 0.4 km and 1.8 km.

B5 The effect of speed on accidents at major junctions

The road-based models can be used to quantify the effect of speed on accidents within links, including minor junctions. They do not provide any measure of the effect of speed changes on the accident frequency at the major junctions (ie. those where the main road no longer has priority) at the end of each link. However it may be noted that accident reductions achieved in West London as a result of the deployment of speed cameras along links were proportionally at least as large at the junctions as they were along the links (Winnett, 1994).

B6 Appropriate speed

An understanding of what speeds are 'appropriate' to what road types and conditions is needed in order to establish what measures will be necessary or applicable to achieve them.

There is no clear definition of appropriate speed, or in other words, what level of speed it is necessary or desirable to achieve. This would involve deciding on a level of accident risk which is considered to be 'acceptable'. One way of choosing an appropriate speed reduction would be to consider the disbenefit to mobility from speed reductions at each level of speed and compare it with the benefits from accident savings. If achieving average speeds as low as 10 miles/h is considered, environmental disbenefits can also result.

B7 Distribution of speeds

Greater knowledge is required of the changes that occur in speed distributions (and particularly the speeds of the fastest drivers) when different measures are applied, in order to predict the impact of those measures on accident frequency. This includes different traffic calming measures, automatic enforcement measures (both within and outside the vehicle) and changes in speed limits.

B8 The impact on speed of changes in traffic flow

The road-based models presented in this report include traffic flow and can be used to estimate the effect on

accidents of small changes in this flow. However, speed management or other traffic and safety management strategies might result in more substantial re-distribution of flow across a network, and practitioners will also wish to know the impact of proposed strategies in years to come when flows may have increased. Hence a knowledge of how speed distributions are affected in different circumstances by changes in flow is needed for a complete appraisal.

B9 Speed as a contributory factor

There is scope for improving understanding of speed as a contributory factor in driver errors. A new system developed at TRL (Broughton et al, 1998) allows contributory factors to be collected on a more consistent basis. The factors include 'excessive speed', defined here as speed which is inappropriate for the conditions. However, speed is compounded with many other factors – for example 'following too close' and 'aggressive driving'. Higher speeds are likely to increase the likelihood of these other factors being included as contributory factors in driver errors. Hence the true magnitude of the influence of speed as a contributory factor is likely to be greater than suggested by the contributory factor 'excessive speed' alone.

Appendix C: Potential national accident reductions - assumptions

In Section 5.6.2 it was shown that, making certain reasonable assumptions about:

- the numbers of accidents on different types of road that could potentially be addressed in a cost-effective way through speed management;
- the speed reductions potentially achievable on these roads; and
- the accident reduction achievable per 1 mile/h reduction in mean speed on each road type,

it could be expected that 23,000 injury accidents per year could be saved nationally. Table C1 details the assumptions.

In 1998 (DETR, 1999a) the average number of serious casualties in an urban accident was 0.145 and the average number of fatalities was 0.008. For rural accidents the average number of serious casualties was 0.254 and the average number of fatalities was 0.033. Applying these figures to the accident savings on urban and rural roads respectively in the last column of Table C1 gives:

- an annual reduction of 3,144 serious casualties on urban roads;
- an annual reduction of 429 serious casualties on rural roads;
- an annual reduction of 173 fatalities on urban roads;
- an annual reduction of 56 fatalities on rural roads.

The assumptions imply a reduction in mean speeds nationally, averaged across all road types, of 2.1 miles/h, using the figures in the 'assumed mean speed reduction' column of Table C1, weighted by the numbers of accidents to which they each apply.

Table C1 Assumptions made in estimating national accident reductions (based on 1998 data)

<i>Road type</i>	<i>Speed limit (current: miles/h)</i>	<i>All accidents per year (AF)</i>	<i>Proportion of accidents addressed</i>	<i>Assumed mean speed reduction (miles/h) (V)</i>	<i>% reduction in AF per 1mile/h reduction in V</i>	<i>Total reduction in accidents (per year)</i>
Urban	20	289	0	-	-	0
Minor urban	30	74,390	0.15* 0.3	10 5	6 6	6,695 6,695
Main urban	30	80,173	0.3 0.3	5 2.5	4 4	4,810 2,405
Main urban	40	19,109	0.3 0.3	3 1.5	2 2	344 172
Rural	50	3,818	0	-	-	0
Rural single-carriageway (A)	60	23,217	0.3 0.3	4 2	3 3	836 418
Rural single-carriageway (other)	60	21,494	0.3 0.3	2 1	4 4	516 258
Other	60/70	16,433	0	-	-	0
All		238,923				23,149

* *the physical treatment applied in existing 20miles/h zones, which is likely to be necessary to give mean speed reductions of 10miles/h, is relatively costly. Therefore a smaller potential for the proportion of accidents which can be addressed cost-effectively is assumed, compared to other road and treatment types. This assumption still implies a very large increase in the existing number of 20miles/h zones.*

Abstract

TRL has undertaken a major programme of research for the Department of the Environment, Transport and the Regions (DETR) to investigate the impact of traffic speed on the frequency of road accidents. This has built on results from a comprehensive review of relevant research, published by TRL in 1994. The evidence then available indicated a 5% increase in injury accidents per one mile/h increase in average speed.

Extensive road-based and driver-based studies have been used to address the complex task of understanding the speed-accident relationship more fully. Statistical modelling has been used to develop relationships between:

- the accident frequency on urban and rural roads, and how it depends on the speed of traffic, the volume of traffic movement and characteristics of the road layout;
- the speeds at which individuals choose to drive and how often they have accidents.

The report describes the collection and analysis of data and the models developed. These models allow accident changes to be predicted from the speed changes that might result, for example, from the introduction of speed management measures. The report illustrates the effect of the speed (and other) variables that determine accident frequency. The application of the results to the identification of priorities for speed management is then discussed. The overall potential for accident reduction from measures to restrain speed is large.

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