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Are speed enforcement cameras more effective than other speed management measures?
The impact of speed management schemes on 30 mph roads

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Abstract

This paper presents the results of an evaluation of the impact of various types of speed management schemes on both traffic speeds and accidents. The study controls for general trends in accidents, regression-to-mean effects and migration, separately estimating the accident changes attributable to the impact of the schemes on traffic speed and on traffic volume. It was found that, when judged in absolute terms, all types of speed management scheme have remarkably similar effects on accidents, with an average fall in personal injury accidents of about 1 accident/km/year. In terms of the percentage accident reduction, however, engineering schemes incorporating vertical deflections (such as speed humps or cushions) offer the largest benefits: at 44%, the average reduction in personal injury accidents attributable to such schemes, is twice that at sites where safety cameras were used to control speeds (22%) and they were the only type of scheme to have a significant impact on fatal and serious accidents. Other types of engineering scheme (with a fall of 29% in personal injury accidents) were on average less effective in reducing accidents than schemes with vertical features but more effective than cameras. All types of scheme were generally effective in reducing speeds, with the largest reductions tending to be obtained with vertical deflections and the smallest with other types of engineering schemes.

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Keywords: Road safety; Speed management; Safety cameras; Regression-to-mean; Trend in risk

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1. Introduction

Considerable controversy surrounds the relationship between traffic speed and the frequency and severity of road accidents. The laws of physics support the view that, all else being equal, higher speeds will increase both the probability that an accident will occur and the severity of its consequences. Certainly, increased speeds result in increased stopping distances so that the likelihood of a driver being able to stop safely will fall with increased speed: according to the UK Highway Code typical stopping distances are 23 m at 30 mph and 36 m at 40 mph. The severity of any injuries arising from a crash will depend, at least in part, on the energy dissipated on impact and this is proportional to the square of the impact speed. This will be a particularly important factor for pedestrians and cyclists who do not have the protection afforded by the structure of a vehicle: the energy dissipated in an impact with a vulnerable road user hit by a car travelling at 40 mph is 78% higher than at 30 mph. These points are not controversial. Where controversy arises is in the fact that it is not speed itself that is normally the primary cause of an accident: some other factor is needed which requires a driver to stop to avoid a collision. The contribution of speed lies in the fact that, given a particular set of circumstances, an accident might be avoided (or its consequences might be less severe) if drivers' speeds had been lower (Stone, 2004). From this standpoint vehicle speed becomes at least a secondary causal factor in every road accident. Accepting that road transport is both necessary and must necessarily carry some element

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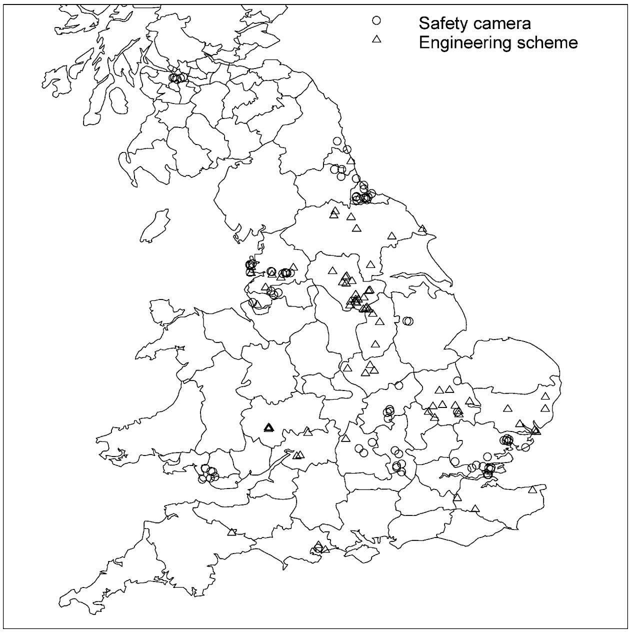

Fig. 1. Map showing the locations of the speed management schemes.

of risk, the controversial question is then where the balance should be struck. “Appropriate” speeds should provide both an adequate level of mobility and an acceptable level of safety for a particular set of road conditions.

Further controversy then arises in deciding how best drivers can be persuaded not to drive faster than the speed judged, by others, to be appropriate. More general agreement on what constitutes an appropriate speed would undoubtedly help to improve compliance but this is not easy to achieve: what constitutes a “safe” traffic speed for the occupants of a four-wheeled drive vehicle will inevitably be rather higher than that for a child cycling to school. In the longer term better driver education concerning the potential consequences of excessive speed and more variation in speed limits according to the risk levels associated with specific road layouts might help. The more immediate solution is to improve compliance with existing speed limits through the use of speed enforcement cameras, vehicle-activated signs and engineering measures such as speed humps, chicanes and narrowing. While available evidence suggests that all of these measures can effectively reduce mean speeds and accidents, they are not always successful in these aims and their comparative effectiveness in road safety terms and the relationship between their impact on speed and safety is not well understood.

The aim of the research on which this paper is based was to compare the impact of the various types of scheme on accidents and vehicle speeds and to establish the nature of any relationship between speed changes and accident changes. This paper deals with the first of these issues, examining the *average* effect of various types of speed management scheme on accident frequencies and speeds using data for some 150 speed management schemes implemented on 30 mph roads at various locations throughout Great Britain (Fig. 1). In a second, linked paper (Hirst et al., 2005) a description is given of the models that were developed to enable a prediction of how the impact of treatment on accidents varies both with speed changes and with site and scheme characteristics.

2. Background

Numerous studies have been published on the effects of speed management schemes on safety. Such safety studies are, however, by no means straightforward and the extent to which the study methodologies have addressed potential analysis problems must be borne in mind when considering their findings. It is now generally accepted that before-and-after observations of changes in accident frequencies will include not only changes attributable to the impact of the scheme but also changes which would have occurred in any case: changes arising due to general trends in accidents and regression-to-mean (RTM) effects (see, for example, Hirst et al., 2004a). The magnitude and direction of any trend effects will vary with location and the timing of the observations. For example, Fig. 2 shows accident frequencies in the UK between 1980 and 2002. There is a general downward trend in both personal injury accidents (PIAs) and in fatal and serious accidents (FSAs). Thus, the effects of trend alone mean that accident frequencies at any location in the UK would normally be expected to fall over time, with or without the implementation of a speed management scheme or any other form of intervention. (Although it is perhaps worth noting that, in the case of all PIAs, there are some years when national annual accident totals vary sufficiently from the underlying trend that the impact of trend for some study periods could be an increase in observed accidents.) RTM effects give rise to analysis difficulties when a high observed accident frequency in a particular time period is at least one of the criteria for site selection: RTM effects will then tend to result in a fall in observed accidents in a subsequent time period even if no scheme is implemented. A high

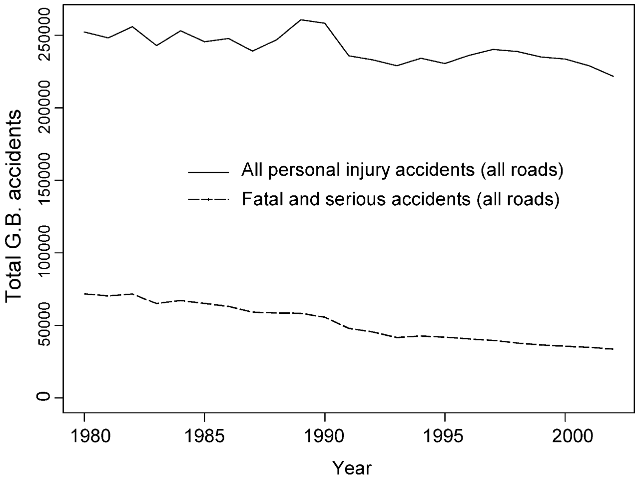

Fig. 2. National trends in accidents for Great Britain 1980–2002.

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observed accident frequency is normally one of the primary reasons for implementing a speed management scheme.

With speed management schemes there is a further complication in that there is also a real possibility that an "accident migration" effect may arise. There are at least two mechanisms by which such an effect could occur. First, drivers may attempt to find alternative routes to avoid the scheme so that some of the beneficial effects of a scheme may be eroded by increases in accidents on diversionary routes: the true scheme effect should be estimated with the inclusion of any such increases. With area-wide traffic calming schemes the specific objective is indeed, not only to reduce speeds on residential streets, but also to divert traffic away from such streets onto more suitable traffic routes (upgraded if necessary to avoid a corresponding increase in accidents). If traffic diversion does occur then it is also worth noting that any accident reduction within the speed-managed sections will include both the effects of a decrease in accident risk (due to reduced speeds or other changes in driver behaviour) and the effects of a decrease in exposure to risk. Any attempt to establish a relationship between the speed and safety effects of a scheme should then of course exclude the reduction in accidents attributable to reductions in flow. With speed cameras, there is anecdotal evidence of a second mechanism by which an accident migration effect could arise. It has been claimed that drivers may brake abruptly on their approach to the camera, or attempt to compensate for reduced speeds at the camera by rapidly accelerating after passing it, so that accidents could then increase upstream or downstream of the camera.

Few studies have attempted to deal with these issues and most of these have been confined to studies of speed cameras. A randomised controlled trial is arguably the best approach although in safety studies a comparison group approach is more common (Hauer, 1997). However, even a randomised controlled trial cannot distinguish between accident changes attributable to the effect of a scheme on traffic speed and its effect on the volume of traffic (Hirst et al., 2004a). The Empirical Bayes (EB) approach with a comparison group and flow correction (Hirst et al., 2004a) can overcome this difficulty but the estimates then depend on the quality of the accident prediction models used. It must, for example, be noted that declining trends in accident risk will mean that any accident prediction model will become outdated. With an outdated accident prediction model the estimated treatment effect will still be exaggerated (even using an EB approach) unless an appropriate correction of the type described by Hirst et al. (2004b) is applied. Ideally the accident prediction model should also include as explanatory variables all those measured site characteristics that are used for site selection (Allsop, 2004; Mountain et al., 2004a,b).

Table 1 summarises the findings of some recent studies of the impact of speed management schemes on accidents and speeds. It should be stressed that the variability in the findings is attributable, both to the extent to which confounding factors have been controlled and to the variation in the nature of the treated sites, as well as the differences in scheme type. A number of studies have attempted to estimate the effect of speed cameras free of RTM and trend effects (Table 1). The first of these (Elvik, 1997) was based on data for 64 cameras in Norway: a statistically significant reduction of 20% in the number of PIAs was found but there was insufficient data to establish whether accident migration occurred. More recently, a study based on 49 cameras in one UK county (Cambridgeshire) studied accidents within circles of varying radii of the camera. After allowing for trend and RTM effects, the reduction in PIAs in the immediate vicinity of the camera (250 m radius) was estimated to be 46% while over a 2 km radius there was an estimated reduction of 21% (Hess, 2003). These results thus suggest that, rather than inducing a migration effect due to rapid braking or sudden acceleration, cameras can actually reduce accidents over a wide area. Another UK study of 101 mobile cameras in South Wales (Christie et al., 2003) concluded that a route-based approach (i.e. using only data for accidents occurring on the route with the camera), although methodologically more difficult, is preferable to the circles based approach used by Hess (2003). Using route-based data it was found that the cameras reduced PIAs within 500 m of the cameras by 51% and pedestrian acci-

Table 1
Summary of the results of some recent studies of speed management schemes

Author	Scheme type (monitored distance from cameras)	Confounding variables controlled	Estimated change in		Change in mean speed (mph)
			All PIAs (%)	FSAs or KSIs (%)[a]	
Elvik (1997)	Cameras (variable)	Trend; RTM	−20	–	–
Hess (2003)	Cameras (250 m)	Trend; RTM	−46	–	–
	Cameras (2 km)		−21	–	–
Christie et al. (2003)	Cameras (500 m)	Trend; RTM	−51	–	–
Mountain et al. (2004a,b)	Cameras (500 m)	Trend; RTM; migration	−19	−6	−4.4
	Cameras (1 km)		−19	−9	
Gains et al. (2004)	Cameras (mainly 500 m)	Trend	−33	−40	−2.4
LAAU (1997)	Cameras (variable)	Trend	−9	−12	–
Winnett and Wheeler (2002)	Vehicle-activated signs	Trend; RTM	−31	–	−4
Webster and Mackie (1996)	Speed humps	–	–	–	−10
Webster and Mackie (1996)	Area traffic calming	–	−58	–	−9.3
Elvik (2001)	Area traffic calming	Meta-analysis—variable	−25	–	–

[a] Fatal & serious accidents or killed and seriously injured casualties.

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dents by 78%. (Although an average accident reduction of 10% was observed in the region 500–1000 m from the cameras, it was concluded that there was insufficient data available to properly assess treatment effects beyond 500 m.) In both of these studies, however, while trend and RTM effects were allowed for, the absence of traffic flow data meant that it was not possible to assess the effects of diversion of traffic to other routes. The authors of this paper have recently published (Mountain et al., 2004a) the results of a route-based study of 62 fixed speed cameras on 30 mph roads in the UK for which flow data were available. This study found that the cameras reduced PIAs over a distance of up to 1000 m. Over this distance there was an average reduction in PIAs of 24%, of which a fall of 19% was attributable to the effect of the cameras on vehicle speeds, with a fall of 5% due to diversion of traffic to other routes. While the actual size of the accident reduction that can be achieved with cameras appears to be rather variable, as does their apparent area of influence, these studies all point to cameras having beneficial effects on road safety over a wider area than the immediate vicinity of the camera: there is no evidence of any negative effects due to sudden changes in speed upstream or downstream of the camera site.

It is more difficult to find published studies of the safety effects of other types of speed management schemes which incorporate corrections for trend and RTM, or which take account of the effects of the scheme on flow. In a recent study of vehicle-activated signs (Winnett and Wheeler, 2002) data were available to permit corrections to be made for both trend and RTM at 21 of the 27 sites studied. The corrected estimate of the accident reduction attributable to the signs was 31%: the impacts of any flow changes were not investigated. Webster and Layfield (1996), demonstrate that road humps on 20 and 30 mph can lead to reductions in flow of the order of 25% and reductions in mean speed of the order of 10 mph but no data were available to assess the impact on accidents. In a study of humps in 20 mph zones (Webster and Mackie, 1996) the observed fall in accidents was 60% with an average fall in mean speeds of 9.3 mph and an average fall in flow of 27% for the schemes where flow data were available. Webster and Mackie (1996) suggest that there is a progressive relationship between accident and speed changes (a 6.2% reduction in accidents for each 1 mph reduction in vehicle speed) but the evidence for this has been questioned (Stone, 2004) and no account is taken of the effects of trend, RTM or flow changes on accidents within the scheme. The effects of flow changes on accidents in the areas surrounding 40 of the schemes were, however, investigated and although there was no significant change overall, annual accident rates increased in 17 of the surrounding areas suggesting that the possibility of accident migration should at least be borne in mind. Elvik (2001) conducted a meta-analysis of 33 studies of area-wide traffic calming schemes from eight countries and noted that none of the studies explicitly controlled for RTM or long-term trends in accident occurrence. This study found that on average area-wide urban traffic management schemes reduce the number of injury accidents by about 15%, with larger reductions on residential streets (about 25%) and smaller reductions on main roads (about 10%).

Few systematic studies have been carried out into the impact of speed management schemes on accident severity or the accident involvement of vulnerable road users. Of these, some have controlled for trend effects but none for RTM and the results are variable. For example, a recent evaluation of speed and red light cameras in the UK suggests that the average reduction in PIAs was 33% below the long-term trend, with a fall of 40% in killed and seriously injured (KSI) casualties and a fall of 35% in the number of pedestrians killed or seriously injured (Gains et al., 2004). However, given that the site selection guidelines included threshold levels of fatal and serious accidents (for example, for fixed cameras, 4 or more FSAs per km in the most recent 3 years) it seems likely that part of the apparent reduction in KSI casualties was actually attributable to RTM effects. In an earlier study of speed and red light cameras in London (LAAU, 1997) similar observed reductions in KSI casualties (30%) and in FSAs (31%) were reported but comparison with control group data showed that a reduction in FSAs of only 12% was directly attributable to the cameras (and any RTM effects). LAAU (1997) also considered the impact of cameras on casualties to vulnerable road users but no control data were available for these: the observed reductions were 41% for pedestrian casualties and 13% for cyclists as compared with 11% for car occupant casualties.

This brief review of some of the recent studies of the impact of speed management schemes is by no means comprehensive but it does serve to illustrate the variation in study methodologies and the consequent difficulty in comparing the impact of the various speed management measures on accident frequencies and vehicle speeds. In this paper the results of a unified study of a range of speed management methods are presented with a view to comparing their impact on accidents (including any migration effects), free of RTM and trend effects.

3. Data

The data for this study relate to some 150 speed management schemes at various locations throughout Great Britain as indicted in Fig. 1. All of the schemes were on roads with 30 mph speed limits. These roads were selected both because speeding is a significant problem on them (58% of cars and 54% of motorcycles were estimated to have exceeded the 30 mph limit on UK roads in 2003—the corresponding percentages for 40 mph limits were 27 and 36% (DfT, 2004)) and because a wide range of speed management measures are used to enforce 30 mph limits.

The schemes included in this study comprised 79 speed enforcement cameras (17 mobile and 62 fixed) and 71 engineering schemes of various types. Initially mobile and fixed cameras were analysed separately. As the number of mo-

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bile cameras was too small to allow any general conclusions about their effectiveness to be drawn and no significant differences were detected between fixed and mobile cameras in terms of their impact on either speeds or accidents, all cameras were considered together as a single treatment type. Evidence from schemes on roads with 20 mph limits (Mackie, 1998) suggests that, of the various types of engineering measures that can be used to reduce speeds, vertical deflections are the most effective and thus engineering schemes were grouped into those which included any form of vertical deflection (with or without narrowing or horizontal deflections) and those with narrowing or horizontal deflections only. "Vertical deflections" include any measure that alters the vertical profile of the carriageway such as road humps and speed cushions. "Narrowing" here includes any measure used as part of a speed management scheme to reduce the carriageway width available to moving traffic: pinch points, central hatching, traffic islands and so on. "Horizontal deflections" include measures that alter the horizontal alignment of the carriageway such as mini-roundabouts, build outs and chicanes (with either one- or two-way working). There were four schemes which used speed-activated signs to control speeds and one site with 30 mph speed warning roundels painted on the carriageway that were initially assessed separately. As the effects of the four speed-activated signs were found to be similar to horizontal deflections and narrowing, these were grouped together for subsequent analysis. There were a total of 31 schemes with horizontal deflections, narrowing or speed-activated signs (referred to as schemes with horizontal features in the remainder of this paper) and 39 schemes with vertical deflections. The scheme with painted roundels on the road was not successful in reducing accidents and, as it does not fit naturally into any other group, was excluded from the analysis.

Various local authorities and police forces supplied the data required for the study. These data comprised details of all accidents occurring at the schemes during the 3 years prior to scheme implementation and for up to 3 years after implementation (an average after period of 2.5 years), together with before and after traffic flows and speeds. The accident data for engineering schemes included all accidents occurring within the treated section. Similarly, for mobile cameras, the accidents were those occurring within the full section over which the cameras could be deployed as indicated by the relevant police authority. For fixed cameras the choice of a monitoring length for accidents was more difficult as there has, until recently, been very little information available concerning the likely area of influence of cameras and there is no standard monitoring length. Different authorities use different lengths although 500 m either side of the camera has probably been most common (Gains et al., 2004). In this study, accident data was requested for a section of 2 km centred on the camera (although this was not available for all sites). An analysis of the accident changes over various distances (Mountain et al., 2004a,b) indicated that although the largest percentage accident reductions were observed closest to the cameras, the overall percentage accident reductions observed over 500 m and 1 km distances from the camera were similar. Since fixed cameras appear to improve safety over a distance of 1 km, and the longer monitoring length gives a larger absolute accident reduction, the data for fixed cameras in this paper include all available recorded accidents up to 1 km either side of the camera.

Various measures of before and after speed were obtained (mean, 85th percentile, standard deviation, percentage exceeding the speed limit and the mean speed of speeders) although not all measures of speed were available for all sites. At least one measure of traffic flow was also obtained during the periods before and after the start of operation of each speed management scheme. While accident data was readily available, the sample size was limited by the availability of sufficiently detailed before and after speed and flow data as this information is not routinely collected for all speed management schemes. Site surveys were carried out to obtain supplementary information: this included the number and type of junctions within the treated section and details of the features included in the engineering schemes.

4. Analysis

The approach to the accident analysis is described in detail elsewhere (Hirst et al., 2004a,b) and will only be briefly summarised here. To control for RTM effects, an estimate of the true mean number of accidents per year in the before period was obtained using an Empirical Bayes (EB) approach. In this the underlying mean accident frequency is estimated as a weighted average of two sources of information: the observed number of accidents in the period before treatment, X_B, and a predictive model estimate of expected accidents given the nature of the site and the level of traffic flow (see, for example, Hauer, 1997). In this study the predictive models derived by Mountain et al. (1997) were used. The parameters of this model depend on the road class, speed limit and carriageway type. For example, for a 30 mph, single carriageway, A-road the model for annual PIAs is:

$$\hat{\mu} = 0.9 q_B^{0.6} L \exp\left(\frac{0.08n}{L}\right)$$

where $\hat{\mu}$ is the predicted annual PIAs, q_B the annual flow in the before period (in million vehicles per year), L the section length (km) and n the number of minor intersections.

The estimate of *total* before accidents in a before period of t_B years is then

$$\hat{\mu}_B = t_B \hat{\mu}$$

As the predictive model was derived from data for the 12-year-period 1980–1991 a correction was applied to allow for the fact that the model will be outdated due to trends in accident risk between the modelled period and the period of observation at the speed management schemes (Hirst et al.,

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2004b). The corrected estimated is given by

$$\hat{\mu}_{\mathrm{B\,CORRECTED}} = \gamma^{\mathrm{t}}\hat{\mu}_{\mathrm{B}}$$

where γ is the average factor by which risk changes from year to year (estimated to be 0.98 for all PIAs and 0.95 for FSAs) and t the elapsed time between the middle of the modelling and study periods. Thus, for example, for a scheme that became operational in January 2001 (with a before period from January 1998 to December 2000) $t = 13.5$ and thus, for all PIAs, $\gamma^{t} = 0.76$.

Normally predictive accident models assume that the random errors are from the negative binomial (NB) family. If K is the shape parameter for the NB distribution (K is estimated to be 1.9 for the above model), the EB estimate of total accidents in the before period, $\hat{M}_{\mathrm{B}}$, is calculated as

$$\hat{M}_{\mathrm{B}} = \alpha\hat{\mu}_{\mathrm{B\,CORRECTED}} + (1-\alpha)X_{\mathrm{B}}$$

where

$$\alpha = \left(1 + \frac{\hat{\mu}_{\mathrm{B\,CORRECTED}}}{K}\right)^{-1}$$

To allow for the trend in accidents between the before and after periods, the expected accidents in the after period were estimated using a comparison group approach. The comparison group for this study comprised UK national accident totals during the relevant before and after period for each scheme. The estimate of after accidents allowing for trend, $\hat{M}_{\mathrm{A}}$, is then

$$\hat{M}_{\mathrm{A}} = \left(\frac{A_{\mathrm{A\_NAT}}}{A_{\mathrm{B\_NAT}}}\right)\hat{M}_{\mathrm{B}}$$

where $A_{\mathrm{B\_NAT}}$ is the total national accidents in the before period, t_{B} years and $A_{\mathrm{A\_NAT}}$ the total national accidents in the after period, t_{A} years.

The use of a comparison group ratio implicitly assumes that flows at the study site have changed in line with national trends. To take account of the effects of any flow changes due to the implementation of the scheme, while avoiding double counting, it is necessary to have a representative measure of traffic flow at the scheme in the after period, q_{A}, together with flow data for the comparison group. If

$Q_{\mathrm{B\_NAT}}$ = total national flow in the before period, t_{B} years,
$Q_{\mathrm{A\_NAT}}$ = total national flow in the before period, ,
t_{A} years

then the expected flow in the after period if flows at the study site had changed in line with general trends, q'_{A}, can be estimated using

$$q'_{\mathrm{A}} = \left(\frac{Q_{\mathrm{A\_NAT}}/t_{\mathrm{A}}}{Q_{\mathrm{B\_NAT}}/t_{\mathrm{B}}}\right)q_{\mathrm{B}}$$

If the observed flow in the after period, q_{A}, differs from q'_{A} then there have been local changes in flow at the site other than those attributable to trend. The estimate of expected after accidents allowing for local changes in flow, $\hat{M}'_{\mathrm{A}}$, can then be estimated as

$$\hat{M}'_{\mathrm{A}} = \hat{M}_{\mathrm{A}}\left(\frac{q_{\mathrm{A}}}{q'_{\mathrm{A}}}\right)^{\beta}$$

where β is the power of flow in the accident prediction model (0.6 in the example of the model for a 30 mph, single carriageway, A-road given above).

It would be a matter of local knowledge to assess whether these changes were as a result of the scheme or due to other causes. In this study there were no schemes where a change in flow due to other causes was anticipated: all local changes in flow were attributed to the impact of the scheme. The change in accidents attributable to the impact of a scheme on flow, S_{F}, was thus estimated as

$$\hat{S}_{\mathrm{F}} = \frac{\hat{M}'_{\mathrm{A}}/t_{\mathrm{A}} - \hat{M}_{\mathrm{A}}/t_{\mathrm{A}}}{X_{\mathrm{B}}/t_{\mathrm{B}}}$$

and the estimate of the change attributable to the effect of the scheme on traffic speed (and possibly other aspects of driver behaviour), S_{R}, was

$$\hat{S}_{\mathrm{R}} = \frac{X_{A}/t_{\mathrm{A}} - \hat{M}'_{\mathrm{A}}/t_{\mathrm{A}}}{X_{\mathrm{B}}/t_{\mathrm{B}}}$$

The overall scheme effect, S, is then estimated as $\hat{S} = \hat{S}_{\mathrm{R}} + \hat{S}_{\mathrm{F}}$.

The non-scheme effects (i.e. the changes which would have occurred with or without speed management measures) are the changes due to national accident trends over the before and after periods, N_{T}, and RTM effects, N_{R}. These are estimated as

$$\hat{N}_{\mathrm{T}} = \frac{\hat{M}_{\mathrm{A}}/t_{\mathrm{A}} - \hat{M}_{\mathrm{B}}/t_{\mathrm{B}}}{X_{\mathrm{B}}/t_{\mathrm{B}}}$$

$$\hat{N}_{\mathrm{R}} = \frac{\hat{M}_{\mathrm{B}}/t_{\mathrm{B}} - X_{\mathrm{B}}/t_{\mathrm{B}}}{X_{\mathrm{B}}/t_{\mathrm{B}}}$$

The observed proportional change in observed accidents, B, which can be written

$$B = \frac{X_{\mathrm{A}}/t_{\mathrm{A}} - X_{\mathrm{B}}/t_{\mathrm{B}}}{X_{\mathrm{B}}/t_{\mathrm{B}}}$$

is thus made up of four elements, each of which was estimated separately

$$B = \hat{S}_{\mathrm{R}} + \hat{S}_{\mathrm{F}} + \hat{N}_{\mathrm{T}} + \hat{N}_{\mathrm{R}}$$

The estimates of the average scheme and non-scheme effects were obtained by using summations over all sites in the category of interest (the 79 cameras, the 39 schemes with vertical deflections and the 31 schemes with horizontal features). Thus, for example, the proportional change in observed annual accidents over all sites in a treatment category was calculated as

$$B = \frac{\sum X_{\mathrm{A}}/\sum t_{\mathrm{A}} - \sum X_{\mathrm{B}}/\sum t_{\mathrm{B}}}{\sum X_{\mathrm{B}}/\sum t_{\mathrm{B}}}$$

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Standard errors and confidence intervals were calculated using the bootstrap (Efron and Tibshirani, 1993).

5. Results

5.1. Impact on accidents

Table 2 summarises the observed percentage reductions in various types of accident at cameras and engineering schemes, including those to vulnerable road users. These observed changes in accidents will, of course, include not only the change attributable to the effect of the speed management schemes on traffic speeds and flows but also changes arising due to RTM and trend. The absence of predictive models for cyclist and pedestrian accidents or data for control sites, meant that it was not possible to correct the observed changes in accidents involving vulnerable road users for RTM effects. Thus only observed changes in these accidents are presented in this paper. Clearly these results must be treated with caution and almost certainly give exaggerated estimates of the mean change attributable to treatment. At the same time we have no reason to suppose that the effects of confounding factors will vary appreciably with treatment or accident type and thus the relative sizes of the observed accident changes are of interest. It will, for example, be noted that engineering schemes tend to result in larger percentage reductions in all accident categories. On the basis of the average observed accident changes, the greatest beneficiaries of speed management schemes appear to be pedestrians.

In Table 3 the results of the detailed analysis of PIAs and FSAs are presented, with separate estimates of the changes in accidents attributable to scheme and non-scheme effects. The estimates of the scheme effects (Table 3, columns 6–8) confirm the superior effectiveness of engineering schemes in terms of the average percentage accident reductions. Schemes incorporating vertical deflections resulted in the largest reductions. With a fall in all PIAs of 38% attributable to reduced speeds and a further fall of 6% due to reduced flows, the overall average percentage accident reduction attributable to the schemes with vertical deflections (44%) is twice that at sites with cameras (22%) and comparison of the confidence intervals suggest that the difference is significant. The average effect of engineering schemes with horizontal features on all PIAs (a reduction of 29%) suggests that these are on average less effective than schemes with vertical features but more effective than cameras. However, the larger standard errors and broader confidence intervals for schemes with horizontal features also suggest that these schemes are less consistent in terms of their safety effect perhaps reflecting the broad range of scheme types included in this category. The boxplots of the percentage accident change due to speed reductions (Fig. 3(a)) confirm the variability of the impact of schemes with horizontal features and the superior and more consistent safety effects of schemes with vertical deflections, with the majority of them (more than 75%) successfully reducing accidents. A similar picture emerges for the effects on FSAs (Table 3, columns 6–8) where the average reduction with vertical deflections (35%) is over three times that at cameras (11%) and over twice that at schemes with horizontal features (14%). Indeed the confidence intervals suggest that it is only schemes with vertical deflections that have a significant impact on FSAs.

The estimates of the impact of flow changes on accidents (Table 3, column 8) suggest that both cameras and schemes with vertical deflections do, on average, result in a significant diversion of traffic to other routes. There is an average accident reduction of around 6% attributable to the effects of these schemes on traffic flow which, although small, is statistically significant. For schemes with horizontal features the effects of flow changes did not have a significant impact on accidents. This would suggest that flows before and after scheme implementation should be routinely monitored to assess the extent of any changes in route choice. If changes in flow do occur, accidents on likely diversionary routes should

Table 2
Summary of observed accidents

Type of accident	Type of scheme	Number of sites[a]	Observed accidents (years of observation)		Percentage change in observed annual accidents (95% confidence interval)
			Before	After	
All PIAs	Safety cameras	79	1461 (236)	943 (192)	−20% (−30%, −10%)
	Engineering schemes	71	699 (218)	356 (184)	−40% (−52%, −27%)
FSAs	Safety cameras	79	232 (236)	143 (192)	−24% (−41%, −4%)
	Engineering schemes	68	121 (203)	59 (173)	−43% (−63%, −19%)
All cyclist accidents	Safety cameras	75	163 (224)	123 (180)	−6% (−33%, 23%)
	Engineering schemes	61	103 (182)	59 (157)	−34% (−56%, −7%)
All child cyclist accidents	Safety cameras	74	49 (221)	39 (179)	−2% (−42%, 43%)
	Engineering schemes	56	39 (167)	21 (142)	−37% (−69%, 8%)
All pedestrian accidents	Safety cameras	79	337 (236)	199 (192)	−27% (−43%, −11%)
	Engineering schemes	64	157 (191)	63 (166)	−54% (−67%, −38%)
All child pedestrian accidents	Safety cameras	74	134 (221)	94 (179)	−13% (−39%, 15%)
	Engineering schemes	56	77 (167)	25 (142)	−62% (−75%, −43%)

[a] Not all sites have details of severity, road user type or age of road user.

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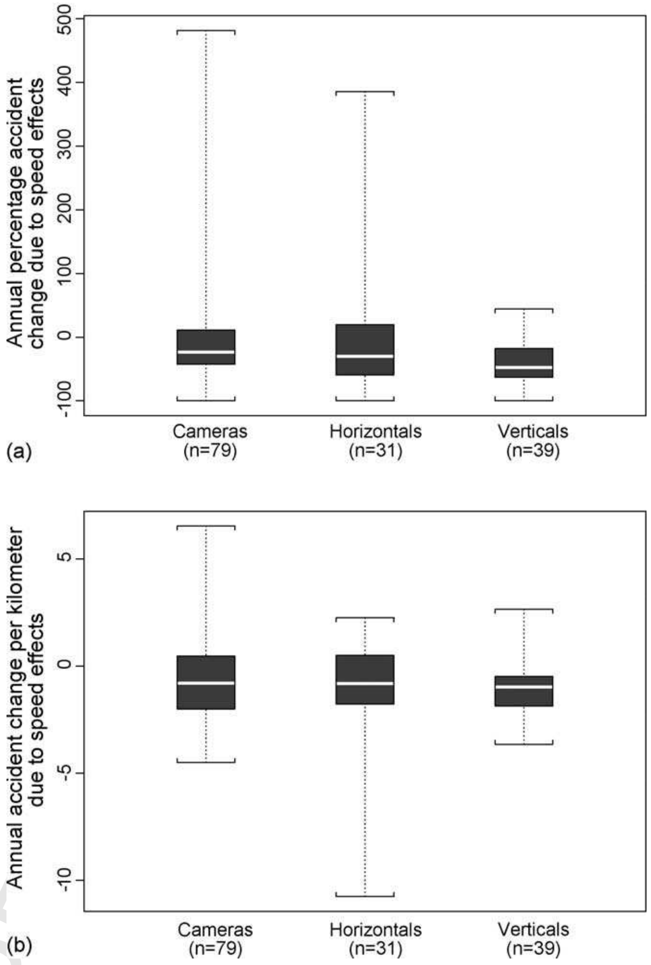
Table 3
Impact of speed management schemes on accidents

Accident type	Scheme type	No. of sites	Total observed accidents [accident/km/year in before period]	Observed change in accidents (% change (S.E.){95% CI}), B	Accident change attributable to scheme effects (% change (S.E.) {95% CI})			Accident change attributable to non-scheme effects (% change (S.E.) {95% CI})	
					Overall effect, $\hat{S}$	Change in speed, $\hat{S}_R$	Change in flow, $\hat{S}_F$	Trend in accidents, $\hat{N}_T$	RTM, $\hat{N}_R$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
All PIAs	Cameras	79	2404 [4.4]	−20% (5) {−30, −11}	−22% (4) {−30, −13}	−17% (4) {−25, −9}	−6% (1) {−9, −3}	+5% (2) {+1, +9}	−3% (1) {−4, −2}
	Horizontal[a]	31	478 [2.6]	−33% (12) {−53, −9}	−29% (11) {−48, −8}	−27% (11) {−47, −4}	−2% (2) {−5, +1}	+1% (2) {−3, +6}	−5% (2) {−9, 0}
	Vertical[b]	39	542 [2.3]	−49% (5) {−60, −38}	−44% (5) {−54, −34}	−38% (5) {−48, −27}	−6% (2) {−10, −3}	+1% (3) {−6, +7}	−6% (1) {−9, −3}
	All engineering	70	1020 [2.5]	−42% (6) {−53, −29}	−37% (6) {−48, −25}	−33% (6) {−44, −22}	−4% (1) {−7, −2}	+1% (2) {−3, +5}	−6% (1) {−8, −3}
FSAs	Cameras	79	375 [0.70]	−24% (9) {−41, −5}	−11% (8) {−26, +6}	−6% (8) {−20, +10}	−5% (1) {−8, −3}	−4% (2) {−7, 0}	−10% (4) {−17, 0}
	Horizontal[a]	31	81 [0.43]	−25% (26) {−63, +37}	−14% (19) {−44, +32}	−12% (18) {−41, +30}	−2% (1) {−4, +1}	−7% (2) {−11, −3}	−5% (10) {−21, +19}
	Vertical[b]	39	98 [0.49]	−57% (9) {−75, −39}	−35% (9) {−54, −18}	−30% (9) {−50, −14}	−5% (2) {−9, −2}	−5% (2) {−9, 0}	−16% (6) {−27, −3}
	All engineering	70	179 [0.46]	−44% (11) {−63, −21}	−26% (9) {−42, −6}	−23% (9) {−39, −4}	−4% (1) {−6, −1}	−6% (2) {−9, −3}	−12% (6) {−21, +1}

S.E. = standard error of the estimate, {95% CI} = 95% confidence interval of the estimate.

[a] Horizontal = schemes with horizontal features.

[b] Vertical = schemes with vertical deflections with or without horizontal features.



ig. 3. Annual accident change by scheme type. (a) Percentage change (b) absolute change per ilometre.

also be monitored to assess whether these changes give rise to any accident migration effect.

The estimates of the non-scheme effects (trend and RTM) are given in Table 3, columns 9 and 10. What is perhaps most striking about these estimates is their variability in both size and direction. On average RTM effects result in a significant reduction in both PIAs and FSAs for cameras and vertical deflections but have no significant effect for schemes with horizontal features. (Again it is striking that, for the schemes with horizontal features, the confidence intervals are broader than for the other scheme categories.) While the average fall in all PIAs due to RTM effects is comparatively small, for FSAs the average fall attributable to RTM is rather larger. At cameras, almost a half of the observed reduction in FSAs is attributable to RTM effects and, at schemes with vertical deflections, RTM effects account for more than a quarter of the observed reduction.

The estimates of the effects of trend are shown in column 9. As expected, there is a small but significant fall in FSAs due to trend for all scheme types. There is no significant effect of trend on PIAs for engineering schemes but for cameras

Table 4
Estimates of absolute accident changes (annual accidents per km)

Accident type	Scheme type	Observed change in accidents (accident/km/year) (S.E.) {95% CI}	Accident change attributable to scheme effects (accident/km/year) (S.E.) {95% CI}		
			Overall scheme effect	Change in speed	Change in flow
(1)	(2)	(3)	(4)	(5)	(6)
All PIAs	Cameras	−0.90 (0.2) {−1.4, −0.5}	−1.00 (0.2) {−1.4, −0.6}	−0.74 (0.2) {−1.1, −0.3}	−0.25 (0.1) {−0.4, −0.1}
	Horizontal[a]	−0.88 (0.4) {−1.7, −0.2}	−0.78 (0.4) {−1.6, −0.2}	−0.72 (0.4) {−1.4, −0.1}	−0.06 (0.04) {−0.2, 0}
	Vertical[b]	−1.15 (0.2) {−1.6, −0.8}	−1.03 (0.2) {−1.4, −0.8}	−0.89 (0.1) {−1.2, −0.6}	−0.15 (0.05) {−0.3, −0.1}
	All engineering	−1.03 (0.2) {−1.5, −0.7}	−0.92 (0.2) {−1.3, −0.6}	−0.82 (0.2) {−1.2, −0.5}	−0.11 (0.04) {−0.19, −0.1}
FSAs	Cameras	−0.17 (0.1) {−0.3, 0}	−0.10 (0.1) {−0.2, 0}	−0.08 (0.1) {−0.2, 0}	−0.02 (0.01) {−0.04, 0}
	All engineering	−0.20 (0.1) {−0.3, −0.1}	−0.16 (0.04) {−0.2, −0.1}	−0.14 (0.04) {−0.2, −0.1}	−0.02 (0.01) {−0.03, 0}

S.E. = standard error of the estimate, {95% CI} = 95% confidence interval of the estimate.
[a] Horizontal = schemes with horizontal features.
[b] Vertical = schemes with vertical deflections with or without horizontal features.

trend effects result in an average increase in PIAs between the periods before and after implementation. This somewhat unexpected result is a consequence of the range of implementation dates for the schemes included in this study. Fig. 1 shows the national trends in accidents. While the underlying trend is downwards and FSAs decline fairly consistently year-on-year, total PIAs tend to fluctuate with several year-on-year increases. Thus for PIAs, depending on the implementation date, the effects of trend between the periods before and after implementation, can be up or down or there may be no effect. Although the effects of trend over before and after periods of the order of 3-years would not normally be expected to be large, the variability in both the magnitude and direction of the effect means that it is advisable to estimate its value.

Although it is common to consider accident reductions in percentage terms it is also of interest to consider the size of the absolute accident reduction achieved. Indeed it could be argued that it is the absolute accident saving which is more important than the percentage reduction: a 100% reduction in accidents at a site with only 1 accident is clearly less effective in real safety terms than a 50% reduction at a site with 10 accidents. The use of percentage accident reductions as a comparator presupposes that initial observed accident frequencies are similar. In fact the observed accidents before treatment at the camera schemes included in this study were on average almost twice those at engineering schemes, with average values of 13.2 and 7.5 PIAs/km respectively in the 3-years prior to treatment. In Table 4 the scheme effects (corrected for trend and RTM) are given in terms of the average annual accident reduction per kilometre while Fig. 3(b) shows the absolute annual accident change per kilometre for individual schemes. When judged in average absolute terms, all speed management schemes have remarkably similar effects, with mean reductions of some 1 accident/km/year for both cameras and engineering schemes with vertical deflections (Table 4, column 4). Although the mean reduction for schemes with horizontal features is somewhat smaller (0.78 accidents/km/year) comparison of the confidence intervals suggests that the difference is not significant but rather that the impacts of schemes with horizontal features are more variable. Fig. 3(b) highlights the variation in the impact on accidents within each scheme type. In particular it can be seen that none of the scheme types are consistently successful in reducing accidents although schemes with vertical deflections have the largest proportion of successful outcomes. The impact of schemes with horizontal features is most variable but they do result in the largest absolute accident reductions.

5.2. Impact on speed

Table 5 summarises the observed speeds prior to the implementation of the speed management schemes and the changes in speed following implementation. This table indicates that the mean characteristics of the speed distributions prior to the implementation of the schemes do not generally vary significantly with scheme type. For all scheme types, the mean speed of drivers prior to implementation was some 31–34 mph with an 85th percentile speed of some 36–40 mph. Of the order of 60% of drivers exceeded the speed limit although, on average, the highest percentage exceeding the speed limit was at sites where cameras were subsequently deployed (67%) while the smallest percentage (56%) was at sites where vertical deflections were used.

On average, all measures of speed were reduced following the implementation of the speed management measures. The average reductions in mean speed, 85th percentile speed and the percentage of drivers above the speed limit are all large and significant. However, the schemes seem to have little impact on the standard deviation of speeds or the mean speed of speeders: only cameras resulted in a significant reduction in the standard deviation of speeds and, for all scheme types, the average fall in the mean speed of speeders, although significant was small (1.3 mph). It seems that drivers who continue to speed after a scheme is in place do not adjust their speed as much as drivers who drive within the speed limit and an increase in the number of drivers driving at very low speeds may be responsible for a similar (or, for some schemes, an even greater) spread of speeds before and after scheme implementation.

Schemes that include vertical deflections have the greatest average impact on the mean, 85th percentile speed and the percentage of drivers speeding. With average reductions of

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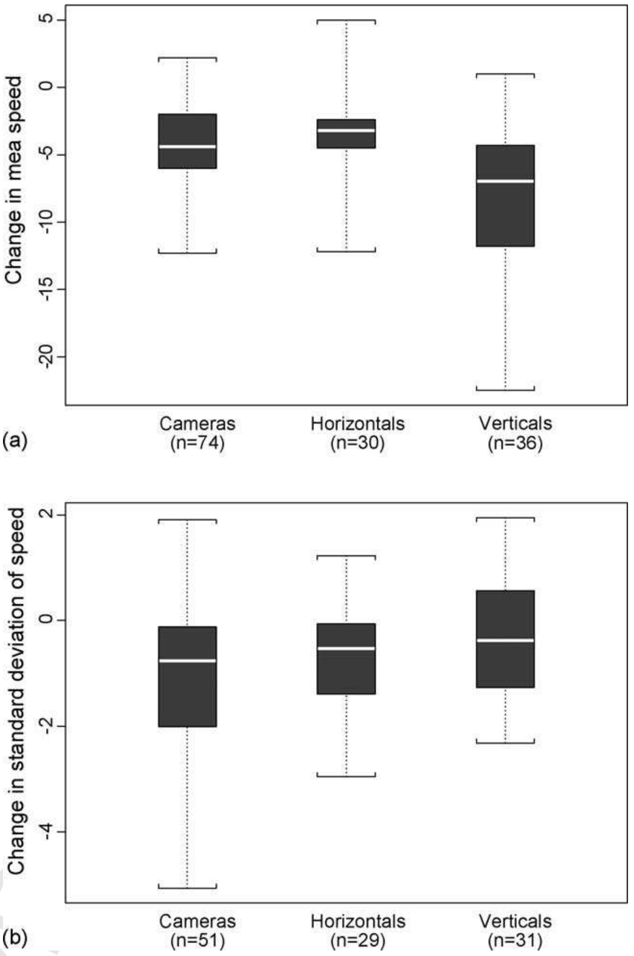
Table 5
Summary of observed speeds

Scheme type		Mean speed (mph)	85th percentile speed (mph)	Standard deviation (mph)	% above speed limit	Mean speed of speeders
Cameras	No. of sites[a]	74	78	51	78	49
	Mean before (S.E.) {95% CI}	33.0 (0.47) {32.1, 34.0}	38.9 (0.46) {37.9, 39.8}	6.5 (0.19) {6.1, 6.9}	67.1 (2.28) {62.5, 71.6}[b]	36.8 (0.39) {36.1, 37.6}
	Mean change (S.E.) {95% CI}	−4.1 (0.32) {−4.7, −3.4}[b]	−5.3 (0.40) {−6.1, −4.5}[b,c]	−1.1 (0.20) {−1.5, −0.7}[b]	−32.9 (2.29) {−37.5, −28.3}[c]	−1.3 (0.25) {−1.8, −0.8}
Horizontal[d]	No. of sites[a]	30	31	29	29	29
	Mean before (S.E.) {95% CI}	32.3 (0.64) {31.0, 33.6}	38.4 (0.81) {36.7, 40.0}	6.3 (0.30) {5.7, 7.0}	63.1 (4.24) {54.4, 71.8}	36.0 (0.30) {35.4, 36.6}
	Mean change (S.E.) {95% CI}	−3.3 (0.53) {−4.4, −2.3}[b]	−3.8 (0.53) {−4.9, −2.7}[b,e]	−0.8 (0.19) {−1.2, 0.4}	−23.3 (3.19) {−29.8, −17}[b,e]	−1.3 (0.25) {−1.8, −0.8}
Vertical[f]	No. of sites[a]	36	39	31	32	32
	Mean before (S.E.) {95% CI}	31.8 (0.67) {30.5, 33.2}	37.3 (0.69) {35.9, 38.7}	5.9 (0.31) {5.2, 6.5}	56.2 (3.98) {48.1, 64.3}[e]	35.8 (0.37) {35.0, 36.6}
	Mean change (S.E.) {95% CI}	−8.4 (0.94) {−10.3, −6.5}[c,e]	−8.8 (0.91) {−10.6, −6.9}[c,e]	−0.3 (0.19) {−0.7, 0.1}[e]	−40.3 (4.49) {−49.5, −31}[c]	−1.3 (0.52) {−2.3, −0.2}

[a] Number of sites: not all sites have data for all measures of speed.
[b] Significantly different from vertical ($p < 0.05$).
[c] Significantly different from horizontal ($p < 0.05$).
[d] Horizontal = schemes with horizontal features.
[e] Significantly different from cameras ($p < 0.05$).
[f] Vertical = schemes with vertical deflections with or without horizontal features.



ig. . Impact on speed by scheme type. (a) Change in mean speed (b) change in standard deviation of speeds.

8.4 and 8.8 mph in the mean and 85th percentile speed respectively these reductions are significantly larger than those achieved with any other scheme type. The mean reduction of 40% in the percentage of drivers exceeding the speed limit is significantly better than the reduction for schemes with horizontal features. Cameras are, on average, more effective in reducing speeds than schemes with horizontal features. Although there is no significant difference in the reduction in mean speed achieved, the mean reductions in the 85th percentile speed (5.3 mph) and in the percentage of drivers exceeding the speed limit (33%) is significantly better than the reductions achieved using schemes with horizontal features.

The boxplots in Fig. 4 highlight the variability of the impact of individual schemes on vehicle speeds. Fig. 4(a) shows the distributions of the impact of the three scheme types on mean speed. The plots confirm that schemes involving vertical deflections tend to have the greatest impact on mean speed and schemes with horizontal features the least. It can be seen that, while the schemes were not always successful in reducing accidents, most are successful in reducing mean

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speeds. Fig. 4(b) confirms that the impact of the schemes on the standard deviation of speeds is generally small, and many schemes with vertical deflections result in an increase rather than a decrease in standard deviation. It may be that (with vertical deflections in particular) the most cautious drivers tend to drive very slowly, while the most reckless largely ignore the scheme, so that the spread of speeds is not necessarily reduced.

6. Discussion

The appropriateness of the predictive models used and the impact of this on the accuracy of the EB estimates is an issue recently raised by Allsop (2004) and responded to by the authors of this paper (Mountain et al., 2004b). The issue is worthy of some further discussion here. Theoretically, the predictive accident models should include any quantifiable, non-accident site selection criteria as explanatory variables. The aim is to ensure that the estimate, $\hat{\mu}_B$, is an *unbiased* estimate of the expected accident frequency for a “reference population” that is similar to the study site in terms of all measured characteristics. It is important to stress that the problem here is to do with possible bias rather than the diversity of the reference population. The reference population may include a wide range of sites or only rather similar sites; the accident prediction model may include many explanatory variables or only a few. The EB method can deal with this since the diversity of the reference population is reflected in the weight used (a greater weight is given to models with smaller variance-to-mean ratios) and in the confidence intervals of the resulting estimates. Indeed, the advantage of using predictive model estimates (rather than means and variances for reference populations matched for appropriate combinations of characteristics) is that measured continuous characteristics (notably traffic flow) can be matched precisely (Hauer, 1997).

There is, however, a potential for bias if study sites are selected on the basis of some measured characteristic in addition to observed accidents which is not included in the model but which is thought to affect accident frequencies. In the UK, for example, there are currently formal site selection guidelines for potential speed camera sites which, for 30 mph sites of the type considered here, include not only threshold accident frequencies (specifically, at least 8 PIAs and 4 FSAs per km in the last three calendar years) but also an 85th percentile speed of at least 35 mph and at least 20% of drivers exceeding the speed limit (see, for example, Gains et al., 2004). Sites are initially identified on the basis of observed accidents and then speed measurements are made to check whether these criteria are also met. While such formal criteria are not used for other types of safety scheme, it is common to initially identify sites for possible road safety intervention on the basis of their recent accident history and then to carry out an assessment of secondary factors (excessive speed, inadequate skid resistance, inadequate visibility and so on) at sites with particularly large numbers of accidents to assess the underlying cause of accidents and the appropriate form of treatment. Thus it could be argued that, for most types of safety intervention, sites are selected using variables that could theoretically have been included in the models but were not. If the distribution of these secondary variables is different for the treated sites than for the reference population used to derive the predictive accident models there is a possibility of bias in the EB estimates.

The practical difficulty is that models which include secondary factors are often unavailable since predictive models can only be developed using variables for which data are readily available at *all* sites: data are often not routinely collected for the secondary selection criteria. For example, for UK roads, speed data are normally only obtained for sites which are under investigation for some form of remedial action. Although models which incorporate speed variables have been derived for total accidents on UK roads (Taylor et al., 2000) the speed variables do not match those used in the secondary selection criteria for speed camera sites and no models including speed variables are available for fatal and serious accidents. The question that then arises is whether, when the predictive model used does not include all the explanatory variables that theoretical should have been included, the EB method is still likely to give better estimates of underlying mean accident frequencies than observed accident frequencies alone.

The models used in this study were based on data for some 3400 km of road throughout Great Britain for which no speed data were available (Mountain et al., 1997). These roads can, however, be reasonably assumed to be representative of the typical speed distributions throughout Great Britain. National data suggests that, for typical 30 mph roads, speed distributions are in fact extremely similar to those at the sites included in this study (DfT, 2004). Nationally, in 1998 (which is close to the middle of the period when our sample of cameras were installed), an average of 70% of cars on 30 mph roads in GB exceeded the speed limit with a mean speed of 33 mph. These values correspond closely with the mean values for the speed management sites included in this study (Table 5), most notably for speed cameras where before treatment an average of 67% of vehicles exceeded the speed limit and the mean speed was 33 mph. Thus there is no reason to suppose that the models used in this study would lead to any significant bias. It could be argued that this is because speeding is endemic on 30 mph roads and the speed criteria for camera installation are not particularly restrictive: since the speed criteria would be met on most 30 mph roads, it is the observed accident frequency which is the over-riding factor in decisions relating to the implementation of speed management measures.

More generally, however, it is worth stressing that the primary criterion for any form of road safety treatment, on any type road, will normally be the observed number of accidents. Other criteria are very much secondary criteria based on detailed site investigation of pre-selected sites. As a conse-

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quence, any bias arising from the use of variables not included in the models, is likely to be small and very much smaller than any evaluation which takes no account of RTM. This issue is, indeed, discussed in some detail by Hauer (1997) in the endnote to chapter 11 of his book. While further investigation of the effects of the omission of potential explanatory variables from accident prediction models may be worthwhile, we would concur with the views expressed by Hauer. He points out that "for any specific entity it always possible to think of it as having some relevant trait which sets it apart from all available reference populations" but that the use of accident counts alone is likely to lead to significant errors. His conclusion is that safety scheme evaluation will inevitably require a level of judgement but the EB method is the appropriate methodology: "It ought to be obvious that it is better to use both kinds of clues: those which derive from traits [accident prediction models] and also those which derive from the count of accidents."

7. Conclusions

The main conclusions that can be drawn from this analysis of the effects of speed management schemes on roads subject to a 30 mph speed limit can be summarised as follows:

- The mean characteristics of the speed distributions prior to the implementation of the speed management schemes do not vary significantly with scheme type but cameras are used at locations with the highest accident frequencies: on average the observed accident frequencies at locations where cameras were deployed were twice those where engineering measures were implemented.
- In terms of average percentage accident reductions, engineering schemes incorporating vertical deflections offered the largest and most consistent safety benefits. The average reduction in all PIAs attributable to schemes with vertical deflections (44%) is twice that at sites with safety cameras (22%), and this was the only scheme type found to have a significant impact on FSAs. Engineering schemes with horizontal features resulted in a 29% fall in PIAs on average and were less consistent in their safety effect than schemes with vertical deflections, perhaps reflecting the broader range of scheme types included in this category.
- When judged in average absolute terms, all speed management schemes have remarkably similar effects on accidents, with a mean fall in PIAs attributable to the schemes of the order of 1 accident/km/year.
- There is evidence that speed management schemes can affect route choice and this can have a significant effect on accidents within the scheme. Thus, it is advisable to routinely monitor before and after traffic volumes at speed management schemes. Where traffic diversion is detected, accident frequencies on diversionary routes should be monitored to assess whether this gives rise to any "migration" of accidents.
- The effects of RTM and trend on observed accidents are variable but can be large and should always be estimated.
- On the basis of changes in observed accidents, there is some evidence to suggest that the greatest beneficiaries of speed management schemes are pedestrians.
- All types of speed management scheme are normally successful in reducing mean speeds, 85th percentile speeds and the percentage of vehicles exceeding the speed limit.
- The schemes generally have little impact on the speeds of drivers who continue to speed and engineering schemes have no significant effect on the standard deviation of speeds, possibly reflecting an increase in the number of drivers driving at very low speeds.

Uncited reference

Finch et al. (1994).

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