STATISTICAL ADVICE: SCOTTISH SAFETY CAMERA PROGRAMME

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1. EXECUTIVE SUMMARY

1.1 The Scottish Safety Camera Programme has, since 2010, produced an annual bulletin *Key Scottish Safety Camera Programme Statistics* summarising and analysing the data from the more than 400 camera sites in Scotland. This has generally compared the numbers of accidents and casualties in a three-year baseline period with the most recent three-year period post-installation. So far these comparisons have not made any allowance for trend or regression to the mean. It has been of some concern that the methodology may be open to criticism as the results do not provide a reliable estimate of the effect of the cameras.

1.2 National data from *Reported Road Casualties Scotland 2011* show that over the decade 2001 – 2011 the number of fatal and serious collisions fell by 4% per year and the number of all injury collisions fell by around 3% per year, on average. There seems no reason to doubt that the same trend would have occurred at camera sites. Therefore any estimate of the effect of cameras should take account of trend.

1.3 When the decision to install a camera is based on a high number of collisions in the preceding period (typically three years), and this same period is used to provide the “before” data in a before-after comparison, there is the danger of regression to the mean, as has been amply demonstrated in previous studies (see, for example, Hauer, 2002). Ideally the baseline period should be a three-year period that follows the making of the decision as then the period would provide a true, unbiased estimate of the before camera collision rate. This happens only rarely in practice.

1.4 If regression to the mean cannot be ignored, then it is necessary to allow for it. The commonly accepted way to do this is through the Empirical Bayes method, as was employed on a subset of the data in the DfT 4-year evaluation report (Gains *et al*, 2005). This requires an independently developed predictive accident model which, using data on the flow, length and design of the site, predicts the expected number of accidents. This prediction is then combined in a weighted average with the observed number of accidents in the baseline period to give an unbiased estimate of the true accident rate. This adjusted value can then be used in place of the observed value in a before-after comparison to estimate the effect of the cameras in reducing accidents.

1.5 It is recommended therefore that in future both trend and regression to the mean should be allowed for in the comparison of accident numbers in baseline and after periods at Scottish safety camera sites.

2. BACKGROUND TO THE WORK

2.1 Since its establishment in 2003, the Scottish Safety Camera Programme has been collecting accident, casualty and speed data relating to safety camera sites across the country. In October 2010 the Scottish Government produced the first bulletin in the statistical series *Key Scottish Safety Camera Programme Statistics,* and the second bulletin was published in July 2011. These publications have generally been well received but there has been some criticism of the methodology used to produce the reports and some elements of presentation.

2.2 As the Scottish Government continually aims to improve the statistics it produces, it was felt that some external, independent evaluation of the statistical methods used in the publication should be carried out to determine their suitability and robustness and to provide advice where necessary as to how these might be improved.

2.3 From the 2011 report it can be seen that there are currently in excess of 400 safety cameras being enforced across the country, with around 40% being fixed, 50% mobile and the remaining 10% being red-light cameras. These have varying 3-year baseline periods, ranging from 1997-99 to 2006-08. Overall, when the most recent 3-year average figures are compared with the average in the baseline period, the percentage reduction in numbers of fatal and serious collisions is 66% whilst the percentage for all severities is 48%. However, set alongside this, it is seen from *Reported Road Casualties Scotland 2011* that, across all Scotland's roads, the number of fatal and serious accidents fell by 41% between 2001 and 2011 whilst the number of accidents of all severities fell by 32%.

3. METHODOLOGICAL ISSUES IN BEFORE-AFTER STUDIES OF SAFETY REMEDIAL TREATMENTS

3.1 It is natural to want to estimate the effectiveness of treatments that have been applied, whether in road safety or other areas of study. This is tackled through before-to-after comparisons, with the aim being to estimate by what percentage the "performance" of the system has been improved by the application of the treatment. In road safety work the performance is generally measured by the number of accidents or casualties at the sites, or some subset such as the number of fatal and serious accidents. More precisely, what is required is a comparison of the number of accidents in some after period with the number of accidents that would have been the expected in that after period *if the treatment had not been applied*.

3.2 In road safety work, remedial treatments are generally applied at sites that have been previously identified as being in need of treatment, typically by having a high number of accidents in some before period. This applies to the installation of safety cameras as well as to other remedial measures.

3.3 It is now well-known (*eg* Hauer, 2002) that when sites have been selected for treatment on this basis, there is the danger that *regression to the mean* (RTM) will cause the estimated treatment effectiveness to be exaggerated. This happens if the period used to select the sites for treatment is the same as (or overlaps) the before period used in the before-to-after comparison. The magnitude of this bias by selection depends, of course, on the criteria used for site selection and on the length of the before period, but many studies have shown that RTM can quite easily account for 20 – 30% of the reduction from before to after.

3.4 RTM can be avoided if, following site selection, application of the treatment is delayed to allow the collection of the data in the intervening baseline period (or “lag” period). Then the comparison is made of after and baseline periods, as the baseline period provides an estimate of the true before-treatment average accident rate, free from contamination by RTM. Mountain *et al* (1998) analysed data from 906 sites where there was a lag period of at least 6 months and found that whilst a comparison of after with before gave an estimate of treatment effectiveness of 43%, a comparison of after with lag gave an estimate of 23%, implying that the remaining 20% was due to RTM.

3.5 If RTM cannot be avoided, then in some circumstances the Empirical Bayes (EB) method can be used to estimate and allow for the effect of RTM. The EB method requires the use of an independently developed predictive accident model to allow the expected mean number of accidents to be calculated for that type of site (ie of that design and carrying that flow). Then a weighted average of this prediction and the observed number of accidents in the before period gives an unbiased estimate of the true before mean. This can then be compared with the observed after number of accidents to estimate the treatment effectiveness. This approach was used by Maher and Mountain on a subset of the data analysed in Appendix H of the 4-year evaluation report of the DfT camera partnership study (Gains *et al*, 2005). This showed that the estimate of camera effectiveness in reducing the numbers of KSIs was 19% rather than the 50% value if RTM were not allowed for.

3.6 A simple baseline to after comparison may be affected by trend as well as RTM. As mentioned earlier, the number of fatal and serious accidents per year on Scottish roads has fallen by 41% between 2001 and 2011: an average of approximately 4% per year. These national reductions may be attributed to a variety of factors: improved driver training, improved highway and vehicle design, national road safety campaigns, legislation, and better enforcement amongst others. Hence, in the time from the baseline period to the after period, it could have been expected that the number of accidents at any site would reduce in line with the national trend, even if no treatment were applied at the site. Therefore, in trying to isolate the effect of the treatment, an allowance for trend should be made: either on the basis of a national trend for all road types or a local trend (eg for that region or for that road type). Again in Appendix H of the DfT 4-year evaluation report, it was found that, for fatal and serious collisions, the 54% overall reduction could be broken down into 10% due to trend, 34% due to RTM and the remaining 10% due to the camera.

3.7 To summarise, in order to estimate the effectiveness of the treatment, allowance should be made for both RTM (if appropriate) and trend in before to after comparisons. Otherwise, there is the danger that the reduction claimed to be attributable to the treatment will be exaggerated and the methodology will be open to criticism.

4. THE DATA

4.1 The data used for the preparation of the 2011 report is contained in an Excel spreadsheet consisting of 429 rows (one per camera site). The columns contain: site ID; camera type (fixed, mobile, red-light); speed limit; camera partnership; roads authority; site length (km); baseline period; date operational; PIAs, FSAs, KSIs and all severity injuries in the baseline; annual PIAs 2002-2011; annual all severity injuries 2001-2011; annual FSAs 2002-2011; annual KSIs 2002-2011; summary speed statistics in the baseline and most recent periods; flows in the baseline and most recent periods; and finally eastings and northings of the start and end of the site. All sites had three-year baseline periods.

4.2 Of the 429 sites, 289 had a baseline period that ended before the date of installation, and were referred to as “programme sites”. One had been installed in 2011 and therefore had as yet no post-installation accident data, leaving 288 sites. The remaining 140 sites were referred to as “legacy sites”. As the baseline period for these sites did not precede the camera installation, no comparison of before to after could be made, and so these “legacy” sites were excluded from further consideration.

4.3 The discussion and analysis that follows concerns these 288 programme sites, and is focussed on trying to estimate the effect of the cameras by comparing the accident numbers (PIAs and FSAs) in the baseline period with those in all the available post-installation years.

5. ALLOWING FOR TREND

5.1 From *Road Casualties Scotland* the numbers of PIAs (personal injury accidents) and FSAs (fatal and serious accidents) on all Scottish roads are given in Table 1 below for each year from 1997 to 2011. Trend factors *f*, with 1997 as the base year, are also shown. These indicate that, over the 14 year interval from 1997 to 2011, the number of PIAs per year has fallen by 40% and the number of FSAs by 50% in a roughly uniform manner (see Figure 1). It seems reasonable to assume that the same trend would have applied at the camera sites even if the cameras had not been installed.

Table 1: Annual PIAs and FSAs, and trend factors

	PIAs	f_{PIA}	FSAs	f_{FSC}
1997	16646	1.000	3652	1.000
1998	16519	0.992	3657	1.001
1999	15414	0.926	3492	0.956
2000	15118	0.908	3303	0.904
2001	14724	0.885	3149	0.862
2002	14343	0.862	2958	0.810
2003	13917	0.836	2796	0.766
2004	13919	0.836	2614	0.716
2005	13438	0.807	2516	0.689
2006	13110	0.788	2550	0.698
2007	12506	0.751	2304	0.631
2008	12158	0.730	2487	0.681
2009	11556	0.694	2195	0.601
2010	10295	0.618	1901	0.521
2011	9974	0.599	1847	0.506

5.2 If, for a set of camera sites, we have a baseline period (B) of, say, 2000 - 2002 and an after period (A) of 2004 - 2011, and we compare the numbers of FSAs in B and A then *if the cameras had no effect*, the ratio of the expected number falling in A to the expected number falling in B is (0.716 + 0.689 + 0.698 + 0.631 + 0.681 + 0.601 + 0.521 + 0.506) / (0.904 + 0.862 + 0.810) = 1.96. So, taking account of the different lengths of the periods (3 years in B and 8 years in A) as well as trend, we would expect almost twice as many FSAs in A as in B. In general if we denote by F_B the sum of the trend factors over the baseline period and by F_A the sum of the trend factors over the after period, then if the cameras had no effect the ratio of the number of accidents in the after period to that in the baseline period would be $r = F_A/F_B$.

5.3 Hence if the baseline period is free from the effects of regression to the mean, so that the number of accidents occurring in the period X_B is an unbiased estimate of the true mean, and the number of accidents in the after period is X_A then a simple estimate of the effect of the camera is given by $\hat{\theta} = X_A/(rX_B)$ For example, if a site had 10 FSAs in the baseline period 2000 – 2002 and 12 FSAs in the period 2004 – 2011 after installation of a camera, then the estimate of the effect of the camera would be $\hat{\theta} = 12/(1.96 \times 10) = 0.612$: that is, a reduction of 39%.

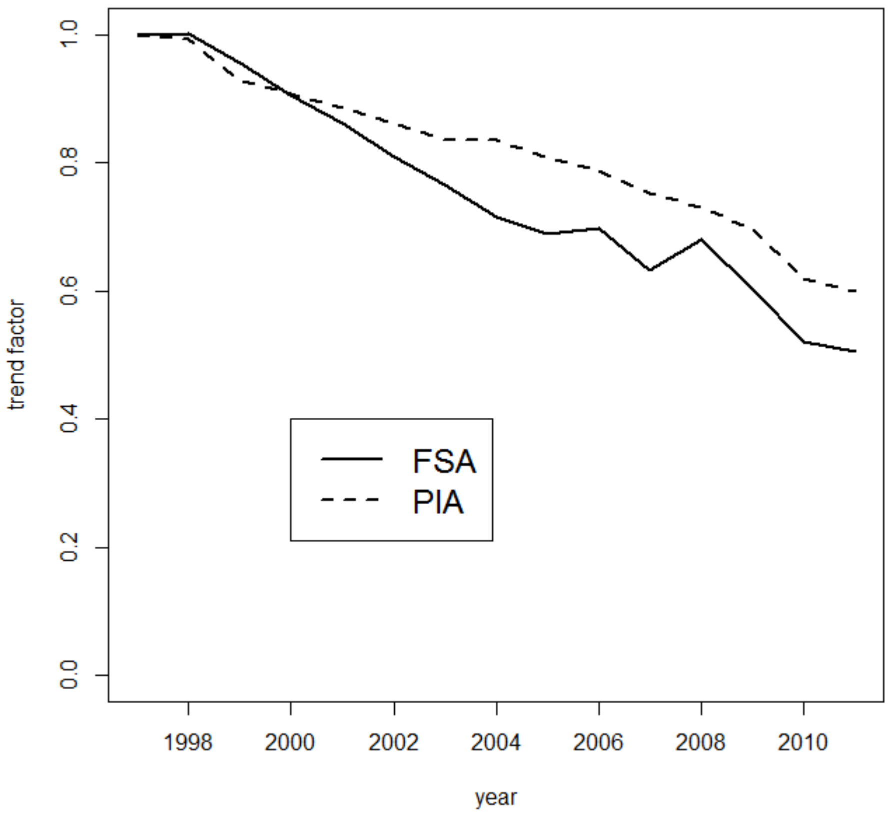

Figure 1: trends in FSAs and PIAs on all Scottish roads 1997-2011

5.4 When there is data from a set of N camera sites, each possibly with a different baseline period and after period, then each will have its own factor r_k. Then if the observed numbers of accidents in the baseline and after periods are respectively X_{Bk} and X_{Ak} at site k (k = 1, ... N) the overall estimate of the camera effect is:

$$\hat{\theta} = \sum_k X_{Ak} \,/\, \sum_k r_k \; X_{Bk}$$

5.5 To illustrate,consider the 288 “programme sites” each of which had a three-year baseline period, ranging from 1997-1999 to 2007-2009, and after periods ranging in length from one year to eleven years, with a mean of 7.5 years, The total number of FSAs in the baseline periods was 743 and the total number of FSAs in the after periods was 726. When each baseline frequency was adjusted by the site r value, and these were summed, the result was $\sum_k r_k \; X_{Bk}$ = 1358.8. Hence $\hat{\theta} = \sum_k X_{Ak} \,/\, \sum_k r_k \; X_{Bk}$ = 726 / 1358.8 = 0.534. This indicates that the effect of the cameras was to reduce FSAs on average by 47%. (However, note that this is on the assumption that the baseline FSA values are unbiased estimates of the true means; that is, free from the effect of RTM, which will be considered in the next section).

6. ALLOWING FOR REGRESSION TO THE MEAN

6.1 When the baseline accident frequencies are *not* believed to be free of the effect of regression to the mean (RTM), typically because the decision to install a camera at that site was based on a high number of accidents in all or part of that baseline period, then it is necessary to allow for RTM. One way to do this is through the Empirical Bayes Method (EBM) as was done in Appendix H of the DfT 4-year evaluation report (Gains et al, 2005). For this, a predictive accident model is required that has been fitted using a sample of relevant sites quite unconnected with the camera sites.

6.2 The model used for PIAs in Appendix H was:

$$\mu = a \, L \, T_B \, q^{0.626} \, exp\left(\frac{0.083\,n}{L}\right)(0.76)$$

where q_B is the flow (two-way flow in millions of vehs/year) in the baseline period, L is the length of the site (in km), T_B is the length of the baseline period (in years) and n/L is the density (per km) of minor intersections in the site. The factor of 0.76 is to adjust the original model to 2000 (see Gains *et al*, 2005 or Mountain *et al*, 1997 for details). If it is an urban site (speed limit = 30 or 40 mph), the constant a = 0.913, whereas if it is rural site (speed limit = 50, 60 or 70 mph), then a = 0.440.

6.3 The predictive model then tells us how many PIAs we would expect there to be at each site in the baseline period, given its flow, the site length, the length of the baseline period (3 years), and the type of site (urban / rural etc). We then calculate, for each site, the empirical Bayes estimate of the true mean in the baseline period, by taking a weighted average of the predicted and the observed:

$$m = \alpha \mu + (1 - \alpha)\, X_B$$

where the weight is given by $\alpha = \left(1 + \frac{\mu}{K}\right)^{-1}$. K, the shape parameter for the fitted model (which defines the precision of the predictive model) is 1.92. So the m value is an adjusted baseline value: a compromise between the observed and the predicted.

6.4 For example, suppose that at a particular site there were 8 PIAs in the 3-year baseline period 2000-2002, and 10 in the 8-year after period (2004-2011). The length L = 3.3 km, the site is rural, with a 60 mph limit, and in the baseline period the AADT is 7312 or 2.67 million vehs/year. Hence, μ = 6.12. The weight $\alpha = \left(1 + \frac{6.12}{1.92}\right)^{-1}$ = 0.24. Hence m = 0.24 x 6.12 + 0.76 x 8 = 7.55. It is this m value that is then used, instead of the observed frequency X_B as the estimate of the true mean accident frequency in the baseline period in the comparison of after with baseline to obtain the camera effect.

6.5 The sum of trend factors over the baseline period is 2.65 (F_B), whilst the sum of the trend factors over the 8-year after period is 5.82 (F_A), so r, the ratio of F_A to F_B is 5.82/2.65 = 2.19. Hence, if the camera had had no effect, we would expect there to be 2.19 x 7.55 = 16.53 PIAs in the after period, whereas there were actually 10. So the estimate of the effect of camera *at this site* is $\hat{\theta}$ = 10/16.53 = 0.605, indicating a 39.5% reduction in PIAs.

6.6 When there are N camera sites, the EB method above is applied at each site k (= 1, .. N) in order to calculate the adjusted baseline mean m_{Bk} . The estimate of the camera effect is then given by:

$$\hat{\theta} = \sum_k X_{Ak} \,/\, \sum_k r_k\, m_{Bk}$$

6.7 To summarise: to apply the EB Method to allow for RTM, a current predictive accident model is required for each separate site type (link or junction), including the shape parameter K (which measures the accuracy of the model). In addition, the relevant data for the model is required for each camera site (*eg* flow, site length etc). Of the 288 programme sites, 255 are fixed or mobile sites that have a value for baseline period flow in the spreadsheet, and are therefore amenable to the use of the EB method. The red-light camera sites, being junctions rather than links, would require a different predictive accident model. Before the EB method could be applied to the 255 sites, however, it would need to be established that the baseline flow value was reliable and represented the two-way AADT for the site. Additional data would need to be collected to provide the number of minor junctions n within the site in order to be able to put the junction density n / L value into the predictive model.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 To allow for trend it is recommended that national annual statistics for PIAs and FSAs should be used to provide trend factors *f* with respect to a base year of 1997, so as to calculate for each site a factor r_k to enable a comparison to be made of baseline accident numbers with all available "after" years for all 288 programme sites, and hence estimate the cameras effect using the method in section 5.4.

7.2 It is clear that, even for the 288 programme sites, the baseline period cannot be relied upon to provide an unbiased estimate of the true mean before the installation of the camera. Therefore regression to the mean is likely to be present. To allow for (and remove) RTM, it is recommended that the Empirical Bayes method be used, following the approach adopted in Appendix H of the DfT 4-year evaluation report (Gains *et al*, 2005). This can only be applied to sites for which there is an appropriate predictive accident model, and the required data (on flow in the baseline period and junction density) is available or can be acquired.

8. REFERENCES

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