Title

Development of an index to measure Police traffic enforcement effectiveness

Names of Authors

Diamantopoulou K., Monash University Accident Research Centre

Cameron M. H., Monash University Accident Research Centre

Abstract

The aim of the research was to develop a procedure that would measure traffic enforcement effectiveness levels for each Victoria Police Region. The development of this measure of effectiveness referred to as the Police Effectiveness Index or the Output Performance Index was achieved using structural time-series regression modelling techniques. Relationships were developed that connected monthly crashes in each of the five Police Regions with monthly variations in variables representing exposure, enforcement activity and other factors for 1989-1997. Crash and enforcement data were obtained from the Victoria Police. The models developed for each Region revealed the relative contribution of an increase in each enforcement operation to reducing the risk of casualty crashes. The reductions were found after the effects of exposure changes and other factors had been accounted for.

A monthly output performance index for each Region was developed for January-December 1998. There was some variation found in the monthly indices both between and within Regions. Relative to the previous year, 1997, the Police performed better than expected on average during the first quarter of 1998, but decreased their output performance for the rest of the year.

The value of the output performance index to Police is that it specifies which enforcement operations Police should increase their resources in per Region to reduce the risk of casualty crash. The index also allows for the assessment and comparison of the effect on road safety of different enforcement activities both within and among Police Regions. The application of a relatively new statistical analysis technique, structural time-series modelling, has offered increased power and flexibility in the modelling of crashes compared to traditional multivariate regression methods.

Keywords

Enforcement, Police region, crash, structural time-series ('state-space') model

Body of Paper

Introduction

The Victoria Police requested the Monash University Accident Research Centre (MUARC) to develop a procedure by which it could measure the Police's effectiveness in reducing road trauma. The purpose of the research was to develop a method that would measure traffic enforcement (output) levels against expected levels of enforcement for each of the five Victoria Police Regions.

The development of this new measure of effectiveness followed a MUARC review of a previous index that had been developed by the Police in order to measure the effectiveness of Police Districts in meeting their road safety objectives (Cameron, (1)).

The aim of the research was to develop relationships connecting monthly casualty crashes in each of the five Police Regions with monthly variations in variables representing the exposure, enforcement activity and other factors. The analysis was expected to reveal the relative contribution of an increase in each enforcement operation to reducing the risk of casualty crashes, after the effects of exposure changes and other factors had been taken into account for that Region. Greater detail of the research and the findings is given in the report of the study (Diamantopoulou et al, (2)).

Previous research in this area has included an evaluation of the Queensland Random Road Watch (RRW) Program (Newstead et al, (3)). This evaluation aimed to link Police outcomes with Police outputs by considering percentage crash reductions in each Police region attributable to the Queensland RRW Program. Similarly, Elvik (4) investigated the relationship between the levels of police enforcement (outputs) and the effects of the enforcement on crash outcomes by reviewing a number of European and American studies concerned with this area of research.

Methods

i. 'State-space' modelling

The development of the Police Effectiveness Index was based on 'state-space' or structural time-series regression modelling techniques. 'State-space' models were probably first used in a road safety context by Harvey & Durbin (5), who used the-then new approach to evaluate the effects of the British seat belt wearing legislation on road casualties. They modelled monthly casualties from 1969 to 1984 using a state equation including level, trend, seasonality and an intervention effect due to the law.

Scuffham (6) developed 'state-space' models for quarterly variations in fatal crashes and fatal crash rates per kilometre travelled in New Zealand from 1970 to 1994. His models included terms representing level, trend, seasonality, interventions (speed limit increase, oil crises, seat belt law) and a range of socio-economic variables (e.g. unemployment rate, income per capita, beer consumption per capita, and alcohol and petrol tax rates). The most satisfactory models were those obtained for the fatal crash rate series rather than the frequency of fatal crashes.

The Dutch SWOV Institute for Road Safety Research has experimented with the application of 'state-space' models to data on fatalities and hospital admissions (two sources: police reports and hospital records) of car occupants aged 25 to 49 at the quarterly level (Bijleveld & Oppe, (7)). The models appear to be very adaptive to short-term changes in the casualty series and hence appear suitable for short-term forecasting (one to two years). 'State-space' models have the advantage that it is possible to decompose the model into components representing the separate contributions of each term in the model. This attribute is valuable if the models are established for explanatory purposes.

The key features of 'state-space' modelling techniques that make them potentially more powerful for the purpose of developing models of casualty crashes at the Police Region level are:

?? The parameters of the 'state-space' models can have stochastic variation that can represent real variation over time. The 'fixed-effects' models used by MUARC to date may suffer by their implicit need to average the estimation of the model parameters over the full period of the data, which has been 1990-1996 in the most recent analysis.

?? The 'state-space' models are capable of representing time-series data, which is also cross-sectional in nature, in one unified model structure. MUARC work to date in general has developed models independently for each crash sub-set (by region, time of week and/or road user group) without capitalising on the possibility of common relationships with explanatory variables, and the additional statistical power which such a framework may provide. However, it was not possible to consider one unified model structure in this study because of the computer memory limitations of the statistical software STAMP 5.0 used for the modelling procedures. It is hoped that this limitation will be overcome in the near future.

'State-space' models (with random effects) are thus considered to produce better estimators of time series data than 'fixed-effects' models.

For each Police region two multivariate 'state-space' models were fitted to the data. The first model considered monthly casualty crashes that occurred during High Alcohol Hours (HAH) of the week[1], and the second model considered crashes that occurred during Low Alcohol Hours (LAH) of the week.

The explanatory factors included in each model for each Region were:

?? Monthly number of random breath tests (RBTs) – conducted through both patrol car and Booze bus operations.
?? Monthly number of speed camera Traffic Infringement Notices (TINs)
?? Monthly number of Penalty Notice offences[2]
?? Speed-related advertising awareness per month (measured by Adstock[3])
?? Drink-driving[4] advertising awareness per month (measured by Adstock)
?? Monthly unemployment rate
?? Monthly alcohol sales in Victoria
?? Monthly vehicle kilometres of travel in Victoria.

The following 'lagged' variables were also included in the models to correct for possible auto-correlation in the residual observations.

?? The previous month's number of RBTs (car and bus), i.e. RBTs 'lagged' by one month;
?? The previous month's number of speed-camera TINs, i.e. speed camera TINs 'lagged' by one month;
?? The previous month's unemployment rate, i.e. the unemployment rate 'lagged' by one month.

The models developed revealed the relative contribution of an increase in each enforcement operation to reducing the risk of casualty crashes in each Region after the effects of exposure changes and other factors had been taken into account. The coefficients (obtained fom the regression models in most cases) measured the relative contribution of each enforcement operation, specific to each Region, and formed the basis of an "output performance index" that allowed the overall contribution to traffic safety produced by the mix of enforcement activities in each Region to be assessed and compared between Regions.

ii. Form of the Index

The relationship between casualty crashes and explanatory factors during time *t* was assumed to have the following form:

$$Crashes_t = a*(exposure\ factor_t)^b *(enforcement\ factors_t)^c *(other\ factors\ affecting\ risk_t)^d.$$

However, the only terms in this equation that were relevant to the calculation of the "output performance index " were the enforcement factors (i.e., Police outputs). This is because the other

---

1 High alcohol hours (HAH) of the week are those periods when illegal drink-driving is more likely to occur, and have been based on the definitions of Harrison (8). The remaining hours of the week are described as low alcohol hours (LAH).

2 Penalty Notice Offences consist of 'speeding' offences, 'unsafe action' offences, 'headlight' offences, 'failing to stop or give-way offences', 'signal offences', 'restraint/helmet' offences, 'drink-drive' offences and 'licence/registration' offences.

3 Adstock (Broadbent, (9)), a function of Television Audience Ratings Points represents the audience's retained awareness of current and past levels of road safety television advertising.

4 Drink-driving Adstock was considered to be relevant only during HAHs of the week. Hence it was only included as a potential explanatory factor in the HAH crash models.

variables or factors represent either the total potential for crashes (i.e. exposure such as population or vehicle travel) or represent the effects of other, non-enforcement factors on risk (i.e. unemployment rate, road safety advertising, alcohol sales) that are beyond the control of traffic police management.

Thus the developed index consisted of a combination of Police outputs per Region, i.e., the number of random breath tests; the number of speed camera traffic infringement notices; the number of penalty notice offences; the number of hours of mobile radar enforcement and the number of hours of laser enforcement. Pragmatically, therefore, the output performance index was expressed as:

$$Index_t = (\text{random breath tests}_t)^a * (\text{speed camera traffic infringement notices}_t)^b * (\text{penalty notice offences}_t)^c * (\text{mobile radar hours}_t)^d * (\text{laser hours}_t)^e.$$

The parameters relating to random breath tests (RBTs), speed camera traffic infringement notices (TINs) and Penalty Notice offences were found by regression methods (i.e. using 'state-space' modelling techniques) because there was sufficient historical data to allow for this type of estimation. However, the parameters relating to mobile radar and laser hours of operation were estimated from independent evaluation studies since the data for these types of operations covered a period of one year (for laser operations) and under three years (for mobile radar operations).

There was also a need to make the index independent of scale so that Regions could be compared. This involved re-expressing the index in terms of *ratios* of Police activity. The enforcement activity (hours or offences) achieved during a particular month was divided by the monthly average of a base period (e.g. the previous year) so that the output indices developed for each Region would be on the same scale and therefore be comparable.

Although the index developed for each Region indicates the relative Police performance of that Region in terms of outputs, the bottom-line criterion for measuring the effectiveness of traffic law enforcement is the potential savings in road crashes and injuries due to the magnitude and mixture of the various outputs achieved by the enforcement operations. For this evaluation, the measure of road safety 'outcome' used was the number of Police-reported casualty crashes per Region.

iii. Testing the Index Against Crash Outcomes

Whilst the indices developed for each Region indicated the relative performance of that Region per month there was a need to test each index against actual road safety outcome performance (casualty crashes) achieved during 1998. A comparison against actual road safety performance per month for each Region relative to the expected crash levels was made.

The expected crash levels were found by projecting each of the 'state-space' regional models developed ahead into the months of 1998. The models 'ignored' the enforcement activity achieved during 1998 by keeping the monthly enforcement levels at a constant value (i.e. the monthly average of the previous year, 1997, was used). This method assumed that there had been no change in enforcement levels from the previous year. The actual levels of all other relevant factors achieved per month during 1998 were included in the projected models. These factors included time, seasonality and non-enforcement factors such as advertising levels and unemployment rates.

These projections then gave the number of casualty crashes expected to have occurred per month assuming there had there been no change in the levels of enforcement during 1998 for each Region. The projected crashes were based on the time-series models developed for 1989-1997. The actual crashes observed per month were then compared with the expected levels (projected from the estimated models) for January-December 1998. This comparison was expressed in terms of a percentage crash change of the ratio of observed crashes to expected crashes. This percentage crash change defined the outcome performance measure for each Region.

If the developed index does in fact reflect the relative road safety contribution of a mix of Police operations in each Region, then the differences between the expected and observed crashes should be reflected in the index.

Results

i) Output Performance

An output performance index for each Region was developed for the months January-December 1998 using the monthly average during 1997 as the base period (Figure 1). The monthly indices depicted in Figure 1 define Police performance in terms of outputs for each type of enforcement. Each index is expressed as a percentage. An index value above 100% represents an increase in Police output performance compared to the previous year. For example, a Regional index value of 106% indicates that there has been a 6% increase in enforcement effectiveness for that Region compared to the previous year.

There was some variation found in the monthly indices both between and within Regions (Figure 1). For example, during January 1998 each Region performed better than what would have been expected on average during 1997, with Region 2 and Region 5 performing best amongst all Regions. However, during April, June, October and December each Region performed below what was expected on average for 1997. For the other months, some regions performed above average in a particular month whilst others performed below average. When considering the overall index (i.e. for all regions combined – based on the five regions' average), the estimated output performance index has shown that relative to the previous year (1997), the Police performed better than average during the *first quarter of 1998*, but decreased their output performance for the rest of the year (Figure 2). It should be noted, however, that some regions performed better than average during some of the later months of 1998.

Figure 1 Monthly OUTPUT Performance Index for each Police Region, January-December 1998

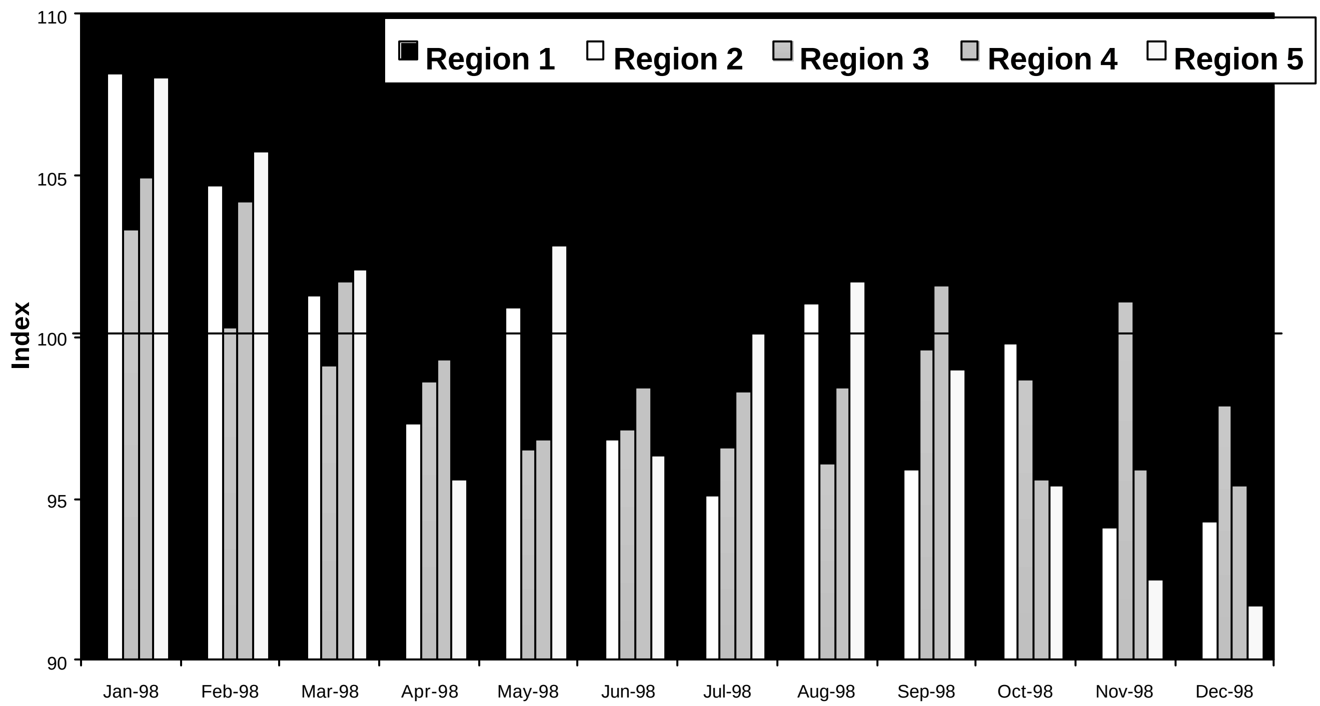
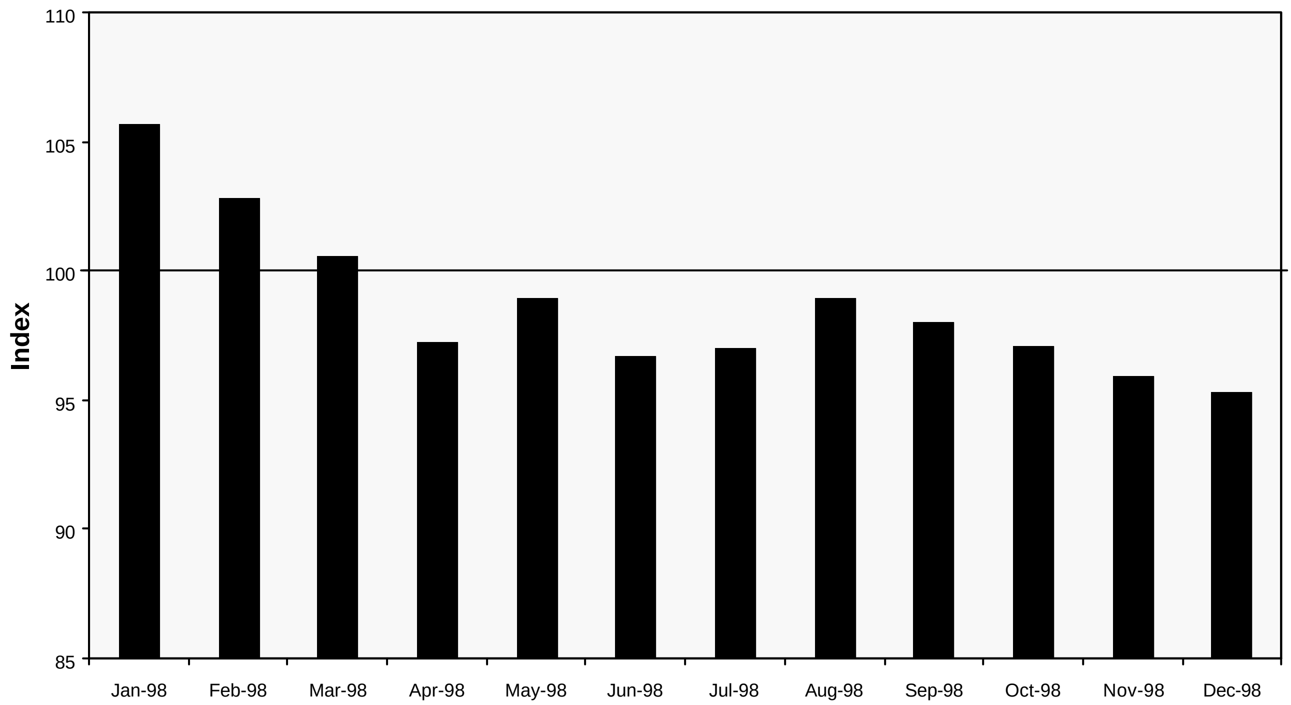


Figure 2 Monthly Output Performance Index for all Regions combined, January-December 1998



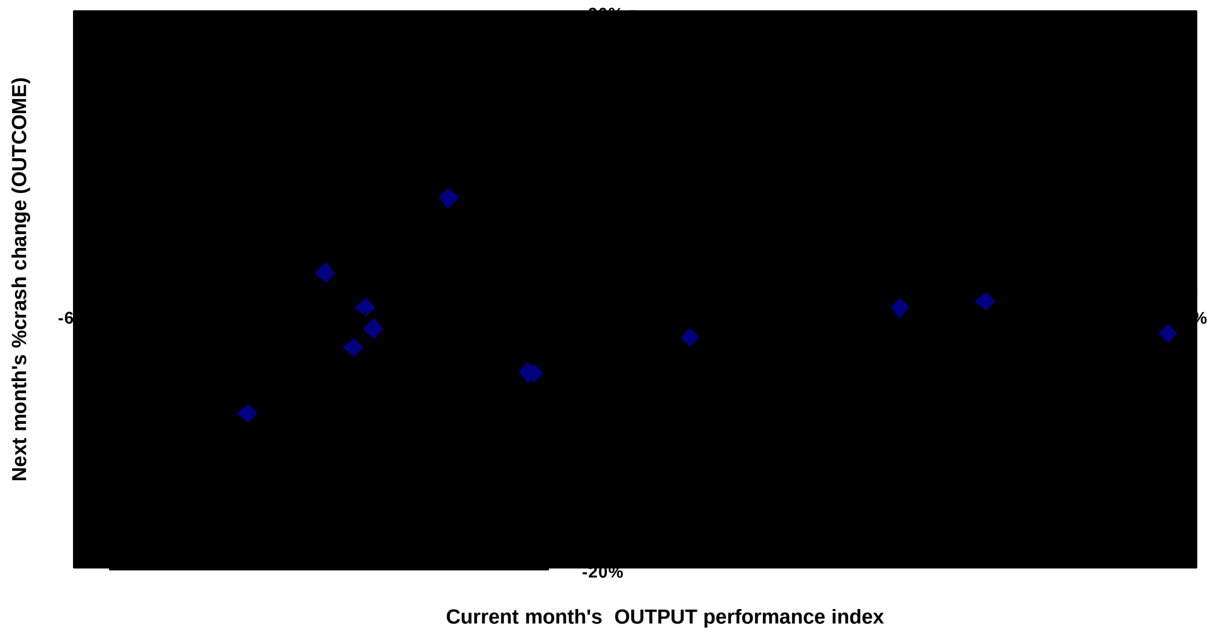
ii) Comparing Police outcomes with Police outputs

Even though the indices developed for each Region had face value in that they could be assessed and compared, they needed to be tested against actual road safety performance. This was achieved by comparing the observed casualty crash frequencies per month during January-December 1998 with the expected levels (projected from the estimated models) to give a percentage crash change (as described in the Methods section). This percentage crash change defined the outcome performance for each Region. The outcome performance measure was then compared with the output performance index for each Region and for all Regions combined

The testing procedure appeared to work best when Police were performing better than average (as measured by the output performance index), with reductions in casualty crash risk (the measure of outcome performance) occurring in most cases. This was even more evident when the current month's output performance index was compared with the *next month's* crash risk outcomes (an alternative outcome measure). However, when Police were performing below average, the index did not reflect casualty crash outcomes as well as it did when the performance was above average – both increases and decreases in casualty crash risk occurred.

As an example of the testing procedure, Figure 3 depicts a plot of the current month's output performance index against the next month's casualty crash risk outcomes for all Regions combined during each month of 1998. This chart shows that for 4 months of 1998 when Police output performance was better than average, their outcome performance was reflected in a reduction in the next month's crashes.

Figure 3 All Regions Combined: Comparison of current month's OUTPUT performance with the next month's %change in casualty crash OUTCOMES, January-December 1998



Conclusions

The output performance index developed for each Region for the months January-December 1998 found some variation both between and within Regions. During January, each Region performed better than what would have been expected on average during 1997. However, during April, June, October and December each Region performed below what was expected on average.

When considering the overall index (i.e. for all regions combined – based on the five regions' average), the estimated index has shown that relative to the previous year (1997), the Police performed better than average during the first quarter of 1998, but decreased their output performance for the rest of the year.

Although the Police performance, as reflected by the index, was below average for most of 1998, the index should still be considered as a valuable tool for Police. This is because each Region's developed index consists of negative parameters relating to all or some of the following enforcement operations – the number of random breath tests, the number of speed camera TINs issued, the number of penalty notice offences issued, the hours of mobile radar operations and the hours of laser operations. Because the parameters were, in most circumstances, negative, then this suggests that Police should *increase* their operations of that type of enforcement in a particular Region to reduce the risk of casualty crashes. For example, an increase in the levels of a particular type of enforcement (e.g. the number of RBTs) in a specific Region (e.g. Region 4) is associated with a reduction in casualty crash risk.

Thus, the value of the index to the Police is that it specifies which enforcement operations our outputs Police should increase their resources in per Region to reduce the risk of casualty crash in that Region.

The indices developed for each Region during January-December 1998 were tested against actual road safety performance. This was achieved by comparing the observed casualty crash frequencies per month during January-December 1998 with the expected levels (projected from the estimated models) to give a percentage crash change. This percentage crash change defined the outcome performance for each Region. The outcome performance measure was then compared with the output performance index for each Region and for all Regions combined. This testing procedure appeared to work best when Police were performing better than average (as measured by the output performance index), with reductions in casualty crash risk occurring in most cases. This was even more evident when the current month's output performance index was compared with the next month's crash risk outcomes.

References

1. Cameron, M. (1997). *"Review of Road Safety and Traffic Enforcement Effectiveness Index",* Monash University Accident Research Centre, Clayton, Victoria, 1997.

2. Diamantopoulou, K., Cameron, M. & Shtifelman, M. *"Index to Measure Traffic Enforcement Effectiveness in each Police Region of Victoria"*, Report No. 172, Monash University Accident Research Centre, Clayton, Victoria, 2000.

3. Newstead, S.V., Cameron, M.H., & Leggett M.W. (2001). "The crash reduction effectiveness of a network-wide traffic police deployment system". Accident Analysis and Prevention, 33 pp. 393-406.

4. Elvik, R. (2001). "Cost-benefit analysis of Police Enforcement", Working Paper for The European ESCAPE Project – available at the world-wide-web page, http://www.vtt.fi/rte/projects/escape/.

5. Harvey, A.C. & Durbin, J. "The effects of seat belt legislation on British road casualties: a case study in structural time series modelling". *Journal of Royal Statistical Society, Series A (General), Vol. 149, Part 3,* pp. 187-227, 1986.

6. Scuffham, P. *"An econometric analysis of motor vehicle traffic crashes and macroeconomic factors",* Thesis submitted for the degree of Doctor of Philosophy, University of Otago, Dunedin, New Zealand, 1998.

7. Bijleveld, F. & Oppe, S. *"New approach to the time-ordered analysis of disaggregated road safety data"*, Unpublished SWOV report, 1998.

8. Harrison, W. A. *"Update of alcohol times as a surrogate measure of alcohol-involvement in accidents"*. Research Note, Monash University Accident Research Centre, Victoria, 1990.

9. Broadbent, S. "One way TV advertisements work". *Journal of the Market Research Society, Vol. 21, No. 3.* London, 1979.