New methods for assessing the impact of traffic safety countermeasures.

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Abstract

This paper investigates new methods for assessing the impact of traffic safety countermeasures on the number of accidents or injuries. The primary aim of this paper is to show in general how statistical methods that take development over time into account may be used when assessing the impact on traffic safety data. A secondary aim is to specifically investigate the effect of a change in the police accident reporting routine in 1997 on the injury classification.
A salient characteristic in most monthly traffic safety data is a fluctuating trend and seasonal pattern. Some of the fluctuation can be explained, but in order to have a reliable assessment of the countermeasures the evaluation methods have to capture this fluctuation. So-called State Space models provide a framework, where these characteristics can be investigated and modelled explicitly. The change in the police reporting practice lead in 1998 to a 49% [35%; 60%] decrease in the reported number of head injuries in Copenhagen and in 1997 to a 37 % [27%, 46%] decrease outside Copenhagen. An estimate of the actual traffic safety in 1998 measured in the number of serious injuries could be the reported number corrected by an additional 670 injuries due to this change in the reporting.

Key words: Traffic accidents; safety countermeasures; reporting practice; intervention analysis; state space models;

Introduction

There is a general need to assess the impact of political and regulatory decisions. Within traffic safety work this is also important in order to comply with the national Danish traffic safety action plan (Færdselssikkerhedskommissionen (2000)). Continuous monitoring and evaluation can contribute to more efficient prioritization of funding. It is vital that the limited resources to improve road safety are spent as efficiently as possible. The Danish traffic safety action plan lists specific countermeasures and an evaluation of the effect of these countermeasures is needed and specifically requested.

Nearly all studies that evaluate the effects of road safety measures are observational, that is non-experimental studies in which allocation of the treatment cannot be controlled. Evaluations of countermeasures cannot be examined as simple laboratory experiments, where the researchers are able to control all major sources of variations of the measured outcome. Traffic safety, often measured in number of accidents or in number of casualties, is influenced by many different factors, which the traffic safety researchers are not able to control during the experiment. Therefore, the methods for evaluation of the countermeasures should be able to take into account that variations in the traffic safety can be caused by such factors and not only the countermeasure in question. An important example of such factors is the long-term trend affecting the number of accidents or injured road users. Other examples are changing traffic volume and reporting practise.

This paper summarizes some of the conclusions from a PhD thesis, which general purpose was to improve the insight into the traffic safety methodology. The aim was to analyze contemporary statistical methods, which were designed to study developments over time including effects of interventions. This aim has been achieved by investigated variations in aggregated Danish traffic accident series and by applying *state of the art* methodologies on specific case studies.

This paper is organized as follows: Section 2 provides an introduction to models that take development over time into account. In section 3 and 4 case studies are analyzed to exemplify different issues when assessing the impacts on traffic safety series. Section 5 summarizes the major results.

2. Statistical models

To gain insight into the causal relationship governing the accident generation process, one may use statistical models that take development over time into account. Models that essentially describe repeated observations of the same physical or institutional object over time. The unit of observation is a point or period in time (hour, day, month, year).

Peltzman (1975) gave one of the first examples of a traffic safety analysis on the basis of accident risk, taking development over time into account. Yearly observations were analyzed in a model on the log scale. It was clear from the study that when analyzing data over a long period of time, changes over time should be accounted for.

Models that take development over time into account can be divided into two major classes: models that use time as regression variables (non-dynamic models) and models in which development of processes over time are described (dynamic models). Both non-dynamic and dynamic modelling techniques are widely used in the analysis of traffic safety data and provide reliable evaluation of countermeasures at an aggregated level and at the site-specific environment e.g. black spots traffic safety work.

The time series shown in figure 1 consists of monthly observations of traffic accidents with killed or seriously injured in Denmark. The series is typical for many series of traffic safety data. Its salient characteristics are a trend, which represents the long-run tendency in the series, and a seasonal pattern, which repeats itself more or less each year. An adequate model of the series will need to capture these characteristics

Figure 1 visualizes a general decreasing trend, which changes over time. Much of the variations in the trend can be explained by socio-economic variables, most important variables that measures traffic volume. But as often seen in series of monthly safety data explanatory variables cannot capture the total variation in the trend and thereby reduce the trend to a simple global trend. An explanation for this changing trend may be that unobserved factors that influence accidents series are similar in adjacent months.

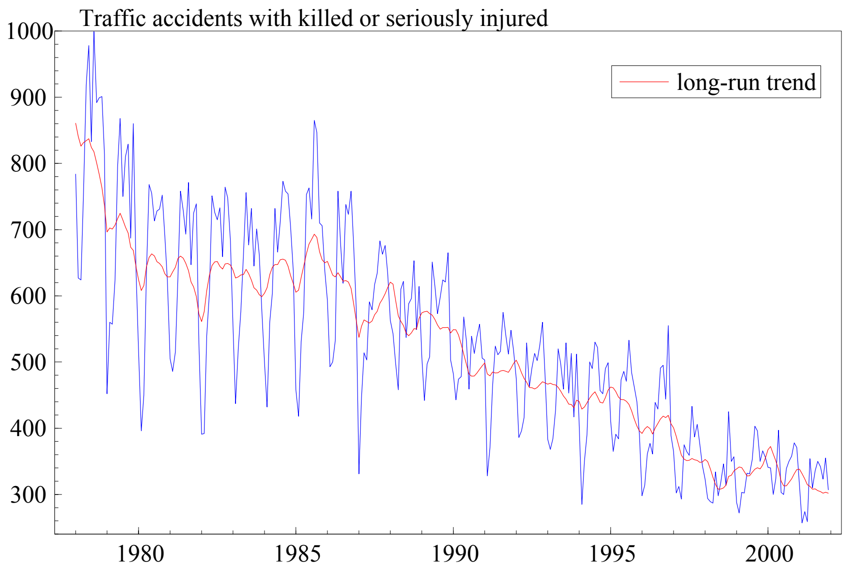

Figure 1. Monthly number of traffic accidents with killed or seriously injured from 1978 to 2001.

In order to have a reliable evaluation of the effect of countermeasures or other factors that may explain variations in the series, it is important that the model can capture this fluctuating trend. A changing seasonal pattern is also sometimes seen in safety series and should as well be captured by the model. So-called State space models provide formulations, where such patterns can be taken into account.

State space models provide an alternative to the ARIMA models, which form the basis of classical dynamic modeling. State Space models are formulated in terms of unobserved components such as trends and seasonals, which have direct interpretation, and hence have many methodological advantages:

$$\text{Observed series} = \text{trend} * \text{seasonal} * \text{irregular},$$

where the "irregular" components reflects all non-systematic movements in the series. The model is multiplicative and is easily handled in the classical additive framework by taking logarithms.

Harvey and Durbin (1986) are considered first to use such models in traffic safety research. Applying those models Harvey and Durbin gave a convincing evaluation of the effects of the British seat belt legislation from 1983.

3 Assessing the impact of safety countermeasures through the use of time series models.

This section has two aims. The primary aim is to show how statistical methods that take development over time into account may be used when assessing the impact on traffic safety data. A secondary aim is to investigate the effect of a change in the police accident reporting routine on the classification of injuries.

Unfortunately, there was an imprecise description in the police accident-reporting manual updated in 1997. According to the new reporting routine, injured people with concussions were to be classified as having suffered a minor injury. Previously, this injury was classified as a serious injury.

The effect of this change is particularly interesting regarding the observed traffic safety measures for 1998, since this year serves as the reference level for the national safety plan Færdselssikkerhedskommisionen (2000), where target values are specified. This effect is also interesting from a traffic safety research point of view, because the accident series with killed or serious injured (AKSI) also serve as an important tool in assessing the effect of different countermeasures on as well an aggregated as a disaggregated level. The two other relevant accident series accidents with killed (AK) and accidents with injured (AI) suffer from either having too few observations or being recorded too inconsistently.

A natural starting point for assessment of the effect of the changing police reporting practice is inspection of the accident data themselves. Valuable insight can be gained by simply plotting the time series of the number of accidents or number of victims along a time axis.

Figure 2 shows the monthly observations of all Danish head injuries occurred in traffic accidents from January 1st, 1990 to December 31st, 2001. A relatively long series enables one to investigate the variation in the accident processes and it enables one to adjust more precisely for other explanatory variables, for example the amount of traffic, which is known to affect the variation in accident series.

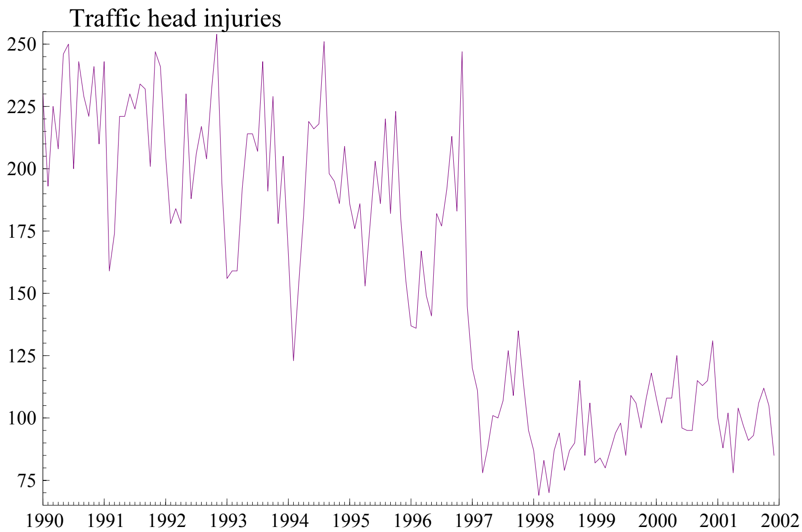

Figure 2. Monthly head injuries from 1990 to 2001.

Figure 2 shows again a general decreasing tendency and seasonal variation. There is a clear reduction in the number of reported head injuries in 1997. This is also found in other studies Lund and Hemdorff (2002). In Christens (2003) the estimated reduction was found to differ in size across different urban areas. In addition, the effect was immediate in most areas, whereas the effect in Copenhagen was delayed one year. Hence, it was chosen to separate the head injuries from Copenhagen from the rest of Denmark and analyze the series separately.

The assessment of the changing reporting practice may be thought of as an intervention analysis. Intervention analysis is concerned with making inferences about the effect of known events. These effects are measured by including intervention, dummy variables to the dynamic model.

If the model contains trend and seasonal components then the effect of the intervention may assume four different shapes: 1) a transitory effect as an impulse, 2) a structural break in the level of the series, 3) a structural break in the slope of the series (e.g. a change in the gradually movement in the series), 4) or a change in the seasonal pattern.

It is conceivable for an intervention to influence the pattern of the series in a combination of the forms listed above. In addition the intervention may also give a dynamic response where for example the effect gradually decreases. According to Harvey (1989) it is extremely difficult to determine whether the result of the intervention is a transitory, a step or a slope change.

In the non-dynamic models the coefficient associated with an intervention may be estimated consistently and the variance of coefficients decreases when the sample period increases. However, in dynamic State Space models only observations recorded immediately after the intervention took place can be used to measure the effect. This is because in the State Space formulation the trend is modelled stochastically to absorb the fluctuation in the trend. The relative variance of the trend (measured as the ratio of the trend variance and the measurement variance) determines how quickly the series will move on to a new level. When the relative variance of the trend is approximately 0.05, as it is for this model, then the estimated effect is only influenced by the first 10 observations recorded succeeding the time of intervention Harvey (1989).

Since assessment of an intervention variable in dynamic modelling is only based on few observations, one should model a form of intervention based on as much a priori knowledge as possible and then submit it to diagnostic checking of the model. The form of the intervention effect in a specific countermeasure is highly dependent on the traffic users willingness to change behaviour and the awareness of the coming intervention. In such situations a logit function may be a better description of the road users response to the intervention than a simple step-function (e.g. a logit function of the road users speed may be a well-specified intervention for analyzing changes in safety due to speed reduction countermeasures). Unfortunately, such informative data are often not available and one has to rely on a priori assumptions.

Here the most straightforward model, that the introduction of the new police-reporting manual in January 1997 induced a once and for all downward shift in the level of the series of head injuries, was investigated. An assessment of the changing reporting practice found that the reported number of head injuries decreased by 39.5 % [28.2 %; 51.0 %]. This decrease is illustrated in figure 3, which shows the reported number of head injuries on a logarithmic scale and the estimated number of head injuries if the change in reporting practice had not been instuted and assuming that all other influential factors are alike.

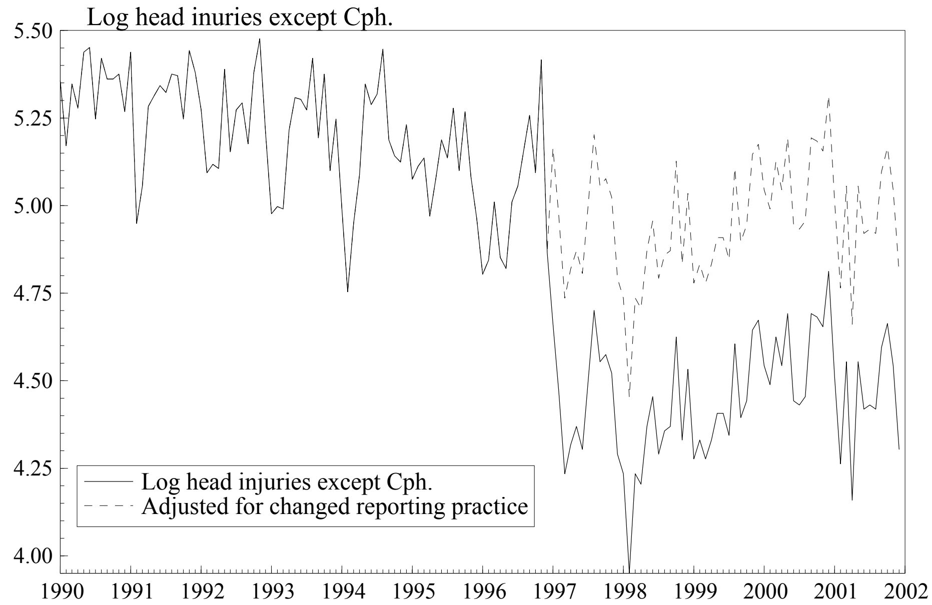

Figure 3. Log number of traffic head injuries except head injuries from Cph. The dotted line illustrates the estimated log number of injuries if the police reporting practice change would not have happened.

A similar modelling scheme was applied when analyzing head injuries from traffic accidents in Copenhagen. In Christens (2003) it was found that the change in police reporting practice did not effect the injury classification till 1998. A possible explanation for this may be that the reporting of accidents in Copenhagen was administrated centrally till 1998. Through State space modeling, one finds that the changing police reporting practice led to a 48.6 % [34.7 %; 59.5 %] decrease in the reported number of head injuries.

4. Assessing the impact of safety countermeasures through the use of control groups.

Control groups play a fundamental role in many areas of scientific investigations. If observations are available on another safety series, which is influence by the same factors as the series of interest, but is not affected by the countermeasure, it is possible to obtain a more precise measure of the effect of the countermeasure.

Traditionally, traffic safety countermeasures are evaluated through the use of before-and-after studies with a control group. Such design investigates the relative change in the number of injuries or accidents in the treatment group from the before period to the after period and compare this change to the analogous change for the control group. To determine whether the change is significant test statistic based on the ratio of the relative changes is calculated. (Elvik et al. (1997))

The following example is from a traffic calming experiment where five urban areas were selected for the treatment in 1999 and all other urban areas served as control group. Figure 4 illustrates the indexed number of accidents with injuries in the urban areas where the experiment was conducted and indexed accidents from all other urban areas. The average number of accidents from 1994-1996 was selected as reference (or the before period). The relative decrease is for the control group 13 % in 1999 whereas the relative decrease is 20 % in the treatment group. Hence, one would assume that the traffic calming had significantly reduced the accidents by approximately 1-(0.80/0.87) = 8 %. From looking at the treatment series (figure 4) it is, however difficult to argue that a significant difference can be explained by the traffic calming experiment.

A before-and after design with a control group assumes that the accident counts in the control group have a similar pattern to the ones in the treatment group. In other words the indexed control series should almost be parallel with treatment series up to the time of intervention, which is not the case in figure 4. Elvik (2002) has recently investigated some pitfalls when using before-and-after studies.

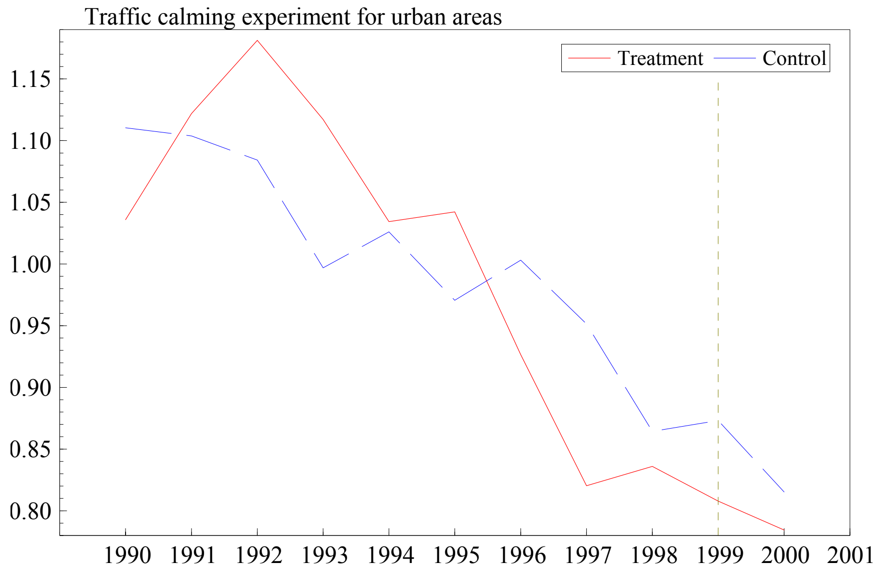

Figure 4. Index number of accidents with injuries in urban areas with and without traffic calming. The traffic calming experiment in 1999 is highlighted with a dotted vertical line.

A more sophisticated method is to construct a bivariate time series model, where the treatment series is modelled simultaneously with the control series. If the control series is highly correlated with the treatment series one obtains a more precise and realistic measure of the countermeasure (Harvey 1996). By modelling the treatment series and control series simultaneously one also achieves measures for correlation between the two series.

When applying bivariate time series modelling on the traffic calming experiment one cannot demonstrate a significant change in number of accidents due the traffic calming in 1999 and one finds that the treatment series are not correlated with the control series. These findings are also in line with the previous simple visual inspections of figure 4.

In the following advantages from using a control group in a bivariate time series model is exemplyfied. The example, illustrated in figure 5, consists of the head injuries discussed in the previous section and a control group. The control group is in this example other serious traffic injuries. Visual inspection shows that the long-term trends and the seasonal patterns seem similar in two groups and that the control group is not affected by the change in the police reporting practice. Estimation of the changing police reporting practice in a bivariate model changes the estimated effect slightly to 37.3 % [27.3 %, 45,8 %], but the precision (measured in standard error of the estimate) is improved by approximately 15 %.

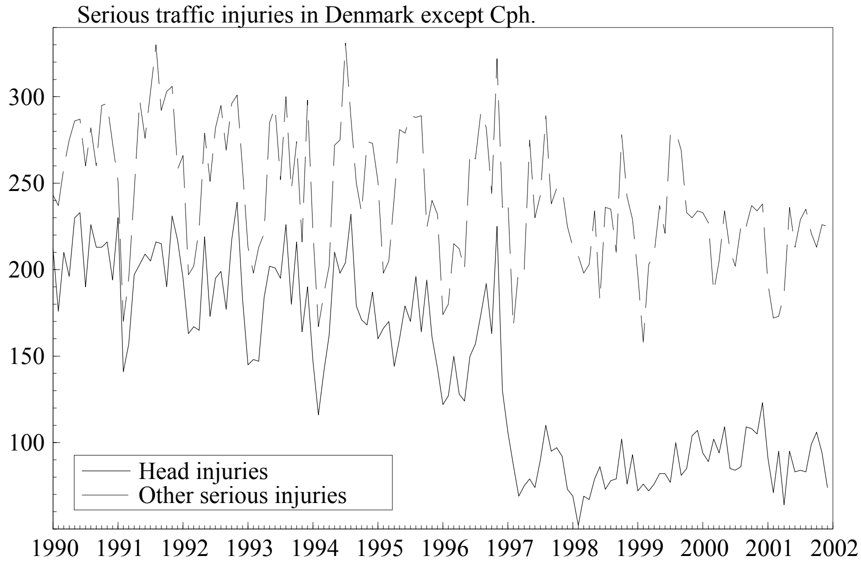

Figure 5. Serious traffic injuries separated into head injuries and other injuries.

Conclusion

One of the key issues in safety research is monitoring the number of injured road users by looking at the change over time in order to assess the effectiveness of the national policy. Often valuable insight can be gained by simply plotting the time series of the number of accidents or number of victims along a time axis.

A salient characteristic in most monthly traffic safety data is a fluctuating trend and a seasonal pattern. Some of the fluctuation can be explained by changes in the number of kilometers driven, but in order to have a reliable assessment of the effect of countermeasures or other factors that may explain variations in traffic series, the evaluation methods have to capture the conceivable remaining fluctuation. The state space models provide a framework, where these characteristics can be investigated, visualized and modelled explicitly.

Assessment of the effects of a specific countermeasure can be troublesome and should be based on as much a priori knowledge as possible. This is because the effective number of observations used to estimate the effects is highly dependent on the dynamic in the accident series. Extending the post intervention period does not necessarily improve the estimated effect associated with the countermeasure.

The change in the police reporting practice lead in 1998 to a 49 % decrease in the reported number of head injuries in Copenhagen and in 1997 to 37 % decrease in the reported head injuries outside Copenhagen. An estimate of the actual traffic safety in 1998 measured as the number of serious injuries could be the reported number corrected by an additional 670 injuries, due to this change in the reporting. During the summer of 2003 the police is to alter the reporting practice to be consistent with the routine prior to 1997. This study suggests, that the reported number of head injuries would increase by some approximately 65 % if the accident generating processes were equivalent.

Even though sudden known changes may appear in an accident series, it is possible to use the series to describe the effect of a given countermeasures or exposure, when one adjusts for the changes. Even if changes are not accounted for by observable explanatory variables, then one can still utilize the series if the changes are modelled by a dynamic model structure.

References

Christens, P.F. (2003). Evaluation of the Danish Automatic Mobile Speed Camera Project Experiment: A State-space intervention analysis. Symposium i anvendt statistik

Elvik, R. Mysen, A.B. and Vaa, T.(1997). Trafikksikkerhetshandbok. transportøkonomisk Institut.

Elvik, R. (2002). The importance of confounding in observational before-and-after studies of road safety measures. *Accident Analysis and Prevention*.

Færdselssikkerhedskommisionen (2000). Hver ulykke er en for meget - Trafiksikkerhed starter med dig: Mod nye maal 2001-2012.Technical report, The Danish Ministry of Transport.

Harvey, A. C. and Durbin, J. (1986). The Effects of Seat Belt Legislation on British road Casualties: A case study in structural Time Series Modeling. *J.R. statist. Soc.*, 149(3): 187-227.

Harvey, A.C. (1989). Forecasting, structural time series models and the Kalman filter. Cambridge.

Harvey, A.C. (1996). Intervention Analysis with Control Groups. *International Statistical Review*. (64) 313-328

Lund, H. and Hemdorff, S. (2002). Betydning af ændring af definitionen på hjernerystelse i 1997.The Danish Road Directorate's website.

Peltzman, S. (1975).The effects of automobile safety regulation. *Journal of Political economy.*