Black Spot Analysis Methods: Literature Review

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Samenvatting

In dit rapport wordt een literatuurstudie gegeven van de methoden en technieken die gebruikt worden om zwarte punten en zwarte zones te onderzoeken. Alhoewel de internationale literatuur geen algemeen aanvaarde definitie geeft voor zwarte punten en zwarte zones, wordt algemeen gesproken over lokaties met een verhoogd risico op ongevallen. In deze context worden in de literatuur verschillende statistische modellen beschreven om de ongevallenfrequentie en de ernst van een ongeval te modelleren. Deze studie geeft een overzicht van deze modellen. Verder wordt een overzicht gegeven van de verschillende alternatieve methodes die worden voorgesteld in de literatuur om zwarte punten te identificeren en te rangschikken. Daarnaast worden een aantal technieken beschreven die gebruikt worden om deze ongevallenlokaties te profileren. Ook het uitvoeren van voor-en na studies om het effect van een maatregel op deze lokaties in te schatten wordt besproken. Tot slot wordt een overzicht gegeven van de methoden en technieken die momenteel gebruikt worden in het zwarte punten beleid van België, Denemarken en Australië

Summary

In this text, a literature review is given of the methods and techniques that are used to analyse black spots and black zones. Although, no universally accepted definition of a black spot or black zone is given, these locations will in general be described as high risk accident locations. In this context, several statistical models are described in literature to model the accident frequency and accident severity. This study gives an overview of these models. Additionally, several alternative methods that are used to identify and rank black spots are described. Furthermore, some techniques that are used to profile these accident locations and the use of before- and after studies to estimate the effect of treatment on these sites are discussed in this text. Finally, an overview of the methods and techniques that are used in Belgium, Denmark and Australia to analyse black spots is presented.

Contents

1. INTRODUCTION

In literature there is no universally accepted definition of a black spot. According to Hauer (1996) some researchers rank locations by accident rate (accidents per vehicle-kilometres or per entering vehicles), some use accident frequency (accidents per km-year or accidents per year) and some use a combination of the two. More recently, the proportion of accident types considered susceptible to treatment is also used for ranking. Another dimension of diversity in practice is that rank may be determined by the magnitude (of either of rate or of frequency) or, as is more common, by the amount by which the rate or frequency exceed what is normal for such sites. According to The Bureau of Transport and Regional Economics of Australia (2001) locations are in general classified as black spots after an assessment of the level of risk and the likelihood of a crash occurring at each location. At certain sites, the level of risk will be higher than the general level of risk in surrounding areas. Crashes will tend to be concentrated at these relatively high-risk locations. Locations that have an abnormally high number of crashes are described as crash concentrated, high hazard, hazardous, hot spot or black spot sites. Sites with potentially hazardous features are sometimes described as grey spots.

In general, the number of crashes is affected by three factors (see e.g. Sayed and Abdelwahab (1995)):

- the road environment
- the condition of vehicles using the road system
- the skills, concentration and physical state of road users.

As will be discussed in the following section, several models of crash causation are proposed in the road safety literature. These models generally explain crashes as being a consequence of driver behaviour that is not correctly matched with the demands of the road environment or to vehicle characteristics, or to both. The demands of the road environment vary due to factors such as traffic flow rates, geometric features of the road and type of road. Drivers normally adapt their performance level to the demands of the road system. A crash occurs when the driver's performance level is insufficient to meet the performance demands of the road environment. Most of the time, driver capabilities exceed performance demands. Black spots are points of peak performance demand. Engineering improvements in the road network lower performance demands on the driver. This increases the safety margin between the driver's performance level and the performance demands of the road environment, and reduces the probability of a crash.

The remainder of this literature review is organised as follows. First, we will outline the different models that are described in literature to model variation in accident frequencies. Then, we give an overview of the models used in the different phases of black spot safety work. This will be followed by a discussion of the different models that researchers have investigated to profile accident black spots. Next we will present the different models that are described in literature related to the concept of a black zone. Subsequently, a description is given of the state of the art in Belgium concerning black spot analysis. Following this, some examples of the use of black spot analysis models in foreign countries will be discussed. Finally, this literature review will be completed with a summary of our conclusions.

2. Modelling Variation In Accident Frequencies

2.1 Statistical Models

A number of statistical models have been used to estimate accident rates and/or accident frequencies at a specific location over a given interval of time. The following models can be discerned. A more detailed description of these models can be found in Nassar (1996).

Foldvary (1979) and Jovanis and Delleur (1983) have used simple models using mean and variance. These models are used to study variations in accident rates for different levels of exposure. These models are not able to incorporate the effect of risk factors on accident involvement.

In Oppe (1979) and Ceder and Livneh (1982) multiple linear regression models are used. In these models the dependent variable (either number of accidents or accident rate) is a function of a series of independent variables such as speed or traffic volume. Accident occurrence in these models is assumed to be normally distributed. These models generally lack the distributional property that is necessary to describe adequately the random and discrete vehicle accident events on the road and they are inappropriate for making probabilistic statements about accident occurrence.

To account for the probabilistic nature of accident occurrence Saccomanno and Buyco (1988) and Blower et al (1993) have used a Poisson loglinear model to explain variations in accident rates. This Poisson regression model is especially suitable for handling data with large numbers of zero counts. However, this model could be inappropriate for road accident counts, since it fails to account for extra-Poisson variation (the value of the variation could exceed the value of the mean) in the observed accidents counts.

To solve this problem of extra-Poisson variation, several authors such as Maycock and Hall (1984), Hauer and Persaud (1987), Persaud (1990), Miaou (1994), Shankar et al (1995), Maher and Summersgill (1996), Kulmala (1995), Hauer (1997), Tunaru (1999), Abdel-Aty and Radwan (2000) have used negative binomial regression models. Miaou (1994) developed two types of negative binomial models, one using a maximum likelihood method and one using a method of moments. The maximum likelihood model was found to be more reliable than the Poisson regression model in predicting accidents where overdispersion is present. Persaud incorporated an empirical Bayesian adjustment in his negative binomial model arguing that adjusting historical data by statistical estimates yields improved predictability.

The issue of extra-Poisson variation in road accident data was addressed further by Hauer and Persaud (1987). They extended the generalized linear model of Maycock and Hall (1984) who allowed for systematic differences in accident frequencies between locations by relating the mean in the Poisson distribution to a number of location characteristics such as traffic flow and various geometric variables. In their model, the Poisson mean was allowed to vary between locations beyond what may be explained by differences in characteristics. The Poisson-gamma generalized linear model set up in Hauer and Persaud (1987) has been supported by Maher and Summersgill (1996), and is now widely accepted (see e.g. Kulmala (1995) and Hauer (1997)). A few extensions to this model have been pursued. As an example, in Tunaru (1999), the parameter in the gamma distribution as well as the regression variables are modelled as random variables themselves, thus adding several levels to the model. However most modelling of traffic accidents use a generalized linear model with negative binomial error structure, and no specific modelling of dispersion effects (see e.g. Abdel-Aty and Radwan (2000)).

In the models described above, only the reported number of accidents in the observation period is used and location characteristics are thus modelled as constant within this period. In practice, these characteristics (in particular traffic flows) often change over time. In order to account for such changes, one may wish to divide the observation period into sub-periods. However, because accident counts, in different sub-periods at the same location, depend on the same site-specific conditions not reflected in the location characteristics, they are not independent (see Maher and Summersgill (1996)). This poses difficulties in estimating the models, as accident counts no longer are independently negative binomially distributed. For example, in Persaud (1994) each year accident's count is used as separated records. However, Persaud made the unrealistic assumption of independence between yearly accident counts at the same time. In Vistisen (2002), disaggregated accident models on sub-periods of one year are used with the assumption that yearly accident counts at the same location are dependent. The random variation in accident frequencies is described by a hierarchical Poisson-gamma distribution, but the Poisson mean is separated into a fixed and a dispersion part (a parameterisation also used in Hauer (2001)).

Finally, Jovanis and Chang (1989) have used survival theory models. These models predict the probability of a vehicle being involved in an accident at time t given that the vehicle had survived until that time. Since the use of these models requires specifically collected data, this approach has not been widely adopted by other researchers in this field.

2.2 Scope Of Analysis

A review of the scope of analysis in accident involvement models indicated that most researchers have chosen to analyse specific accident models. For example, Saccomanno et al (1989), Saccomanno and Buyco (1988), Jovanis and Delleur (1983) and Mountain et al (1998) have analysed specific accident locations such as links or intersections. Other researchers such as Saccomanno et al (1989), Saccomanno and Buyco (1988), Jovanis and Delleur (1983), Blower et al (1993), Miaou (1994), Chirachavala and Cleveland (1985), Glauz and Harwood (1985), Wood and Simms (2002) and Valent et al (2002) have studied specific vehicle types such as large trucks.

Very few researchers studied general accident involvement models. For example, Shankar et al (1995), Persaud (1990), Hadi et al (1995), Wood and Simms (2002) and Valent et al (2002) have analysed all vehicle models. Other researchers such as Blower et al (1993), Persaud (1990) and Hadi et al (1995) have combined link and intersection accidents in their research.

3. BLACK SPOT SAFETY WORK

Black spot safety work can be described as the task of improving road safety through alterations of the geometrical and environmental characteristics of the problematic sites in the existing road network. More specifically, this task involves targeting and treating intersections and road sections with an unusual high number of accidents, the so-called black spots. Vistisen (2002) explains that this work may be divided into three phases. These phases will be further described in the following sections.

1. Targeting hot spots on the road network.
2. Prioritising the hot spots to treat with safety improving measures.
3. Before and after studies of the effect of treatment.

Furthermore, there are four basic approaches to reducing crashes by applying engineering treatments or countermeasures (The Bureau of Transport and Regional Economics of Australia (2001)):

- single sites or black spots-treating specific sites or short sections of road;
- route action-applying known remedies on a route with an abnormally high crash rate;
- area-wide action-applying several treatments over a wide area; and
- mass action-applying a known remedy to locations with common crash problems or causal factors.

However, jurisdictions do not rely solely on crash history to identify black spots and prioritise them for treatment. Local knowledge and judgment are used as well as statistical information.

3.1 Targeting And Ranking Black Spots

As described by Virtisen (2002), locations were ranked at first according to their reported number of accidents. Locations with a number exceeding a chosen threshold value were targeted as hot spots (see e.g. Jorgensen (1966)). This method is very sensitive to random variation in accident counts and to the regression to the mean problem (see e.g. Hauer (1986), Elvik (1997)). Therefore, the expected number of accidents, estimated from a model was used instead. However it is well established that, in general, there are considerable differences between the expected number of accidents at different types of intersections and road sections. This may be inexpedient, as the most effective solution will end up altering the location into a different road type. Such alterations are often too expensive and/or impossible.

Instead, McGuigan (1981) suggested ranking sites according to their potential for accident reduction (PAR), which is the difference between the reported number of accidents at a location and the expected number at locations with similar characteristics. Persaud et al. (1999) suggested using an empirical Bayes estimate instead of the accident count in PAR. Persaud et al. used a Poisson-gamma generalized linear model with characteristics such as traffic flow and various geometric variables. In Saccomanno et al (2001) the results of a multivariate Poisson regression models and Empirical Bayesian methods are compared for establishing the potential for accidents and designating safety black spots along a highway. The Empirical Bayes model was found to yield fewer black spot locations than the Poisson regression model.

The task of targeting black spots may be viewed as a ranking and selection problem (see e.g. Dudewicz and Koo (1987)) and parallel with the PAR-method, Gupta and Hsu (1980) introduced the so-called probability of correct selection (PCS). In a group of locations a subset is targeted as hot spots, if the probability of hereby selecting the site with the largest expected number of accidents (the 'worst' location) is above a chosen threshold value. Later Hauer and Persaud (1984) derived the probability of correct selection for a Poisson-gamma model. However the PCS in Hauer and Persaud was used as a measure of the overall efficiency of the targeting method and not directly used for targeting hot spots. Schlütler et al (1997) derived the PCS for an individual site as the posterior probability of being 'worst' in a Poisson-gamma model with no location characteristics. Heydecker and Wu (2001) later extended the PCS measure in Schlütler et al to include location characteristics and defined PCS as the probability of the Poisson rate exceeding a chosen threshold.

A few alternative methods for targeting black spots have been proposed. For a given treatment measure, Heydecker and Wu (1993) suggested ranking sites according to the posterior probability that accidents occurring at the location involve the feature the measure is aimed at. Heydecker and Wu assumed a Poisson-beta model with no location characteristics. In Persaud and Kazakov (1994) locations are ranked depending on the way in which the estimated economical benefits of treating the location exceed a threshold value based on the allocated budget.

In Van den Bossche et al (2002) investigation is done on the question whether a ranking alone can give enough evidence for the selection of dangerous sites. More specifically, Bayesian hierarchical modelling techniques are used to identify and rank hazardous intersections for bicycles in Leuven, a small university town in Belgium. The authors conclude that ranking hazardous sites is an interesting means to get insight in dangerous locations, but there is no such thing as "the" correct ranking.

3.2 Prioritising

Virtisen (2002) describes that high-risk sites are targeted with the aim of improving safety on the road network through remedial treatment of the sites. Any achieved positive effects of safety measures at accident hot spots are denoted the benefits of the implemented measures. Implementing safety measures is costly, but in theory, all measures generating a positive net-benefit should be implemented. However, the restricted funding for hot spot safety work does put a limit to the number of sites that may be treated. Therefore, it is necessary to prioritise between sites and safety measures in order to utilize the limited funds as effectively as possible.

The general aim of prioritising may be described as:

$$\underset{Y}{Max} \; \frac{B(Y)}{C(Y)}$$

where Y represents a portfolio of safety measures and C(Y) and B(Y) denote the corresponding overall cost and benefit of Y.

The objective is to improve safety as much as possible with the funds allocated, but without a given target level of safety. This approach is known as the 'as low as reasonable practicable' (ALARP) principle (see Melchers (2001)). Here reasonable practicable refers to within the budget.

When expressing the benefit and costs of a treatment in objective measures such as saved number of accidents, saved accident costs etc. two important problems can be discerned. First, the problem of pricing injury accidents is that no market prices are stated for e.g. a human life and instead the pricing of injury accidents is done indirectly (see Dasgupta and Pearce (1972)).

In general, there are basically three methods for estimating the costs of injury and death to society (see T10 (2000)). Using Implicit Values the accidents are priced according the average cost of the given medical treatment in trying to avoid a person dying, divided by the probability of the treatment being successful. With the method of Human Capital, the major part of the cost of an injury is the discounted present value of the victim's future output or income lost due to the injury. The additional cost contributors are involving medical treatment, police, property damage and administration costs. Finally, the Willingness To Pay (WTP) method calculates the price of accidents from people's trade-off between road safety and other commodities, e.g. deciding between different modes of transportation with different safety levels. The advantage of this approach is that it reflects the public's concern for safety. Also because WTP values tend to be higher than implicit or human capital values, estimated benefits of remedial work are increased, which may increase the priority given to road safety. In practice, the actual cost of injury accident is dependent on the number of people involved in the accident. However, because this number is independent of the site of the accident, the average cost of an accident type is used.

In addition to the problem of pricing accidents, the obtained accident reduction from implementing a safety measure is uncertain. This uncertainty may be divided into:

- the uncertainty concerning the reduction rate in accidents due to the treatment portfolio
- the uncertainty concerning the extent to which the accident types, the measure is aimed, are in fact present at the site
- the uncertainty concerning whether or not a site is in fact a hot spot.

The last two uncertainties are site-related, while the first uncertainty is linked to the safety measure. It is assumed that sites with a high certainty of being a black spot have relatively higher potential for accident reduction than sites with a low certainty (see Persaud et al. (1999)). Also, a safety measure aimed at a particular type of accident is assumed to have a relatively higher effect at sites where such types are predominant. To increase knowledge in the uncertainty related to the safety measure, additional before and after studies of the effect of treatment are needed.

3.3 Before And After Studies

Treating a site may lead to changes in traffic volume, road geometry and other site characteristics thus affecting the accident frequency at the site. However the literature on before and after studies has pointed out a number of other observable and non-observable elements affecting the change in reported accident count before and after the implementation of preventive safety measures (e.g. Elvik et al. 1997)). A more detailed description of these elements can be found in Virtisen (2002).

For example, different safety measures may be aimed at the same type of accidents thus creating an effect overlap if implemented at the same site. If the purpose of the before and after study is to estimate the individual effects of the measures, one needs to account for effect overlap.

Accident treatment measures may, beside positive effects, also have negative effects on safety. In a before and after study of the total number of accidents at a site only the net-effect will show.

Another element is the problem of road user behavioural adjustment. This is the problem of road users adjusting their behaviour to a safety measure in such a way that the actual effect of the measure deviates from what was expected. Behavioural adjustment leading to an unchanged level of safety after treatment is known as risk homeostasis (see Wilde (1986)). This phenomenon is strongly connected to the road user's subjective perception of safety.

A statistical effect on before and after studies is the regression to the mean effect. In the area of traffic safety, this effect may be explained as follows. Sites with accidents counts above (or below) the expected at sites with similar traits one year, will in the following year have accident counts which on average are closer to the expected number of accidents at sites with similar traits. In other words, the accident counts have regressed to the mean (see Davis (1986) for a general description).

The migration effect is the phenomenon that the accident frequency apparently rises at sites that are untreated but adjacent to treated sites. Boyle and Wright (1984) proposed a hypothesis that migration effect was due to behavioural mechanism based on the idea of road user behavioural adjustment. However, the existence of a migration effect has not been verified (see Elvik (1997)), and a study by Maher (1990) indicates that the apparent migration effects may to a large extent be explained by a regression to the mean effect caused by a bias-by-not-selection. In other words, sites are not targeted as hot spots because of unusually low (below the expected at sites with similar traits) accident counts. In addition, incorrect coding of the location of accidents as well as changes in traffic flow due to treatment of adjacent sites may be contributing factors.

A next element that is often revealed in a study of time series of accident counts is a trend in the accident development over a period of time. There are many factors influencing general increases or decreases in accident counts. For instance road users are changing their choice of modes and attitude in traffic. A before and after study needs to account for the effect of such trends that are otherwise attributed to the treatment.

Finally, incomplete reporting of accidents leads to a general underestimation of the road safety problems. A change in the level of reporting at a site will also change its estimated level of safety.

In Hauer (1997) the central role that prediction plays in the estimation of the safety effect of treatments is discussed. For example, the shortcomings and adaptations of conventional approaches such as the Naïve Before-After study are investigated. In this method the count of 'before' –period accidents is used to predict what would have been the expected count of after-period accidents had the treatment not been implemented. This way of predicting reflects a naïve and usually unrealistic belief that the passage of time was not associated with changes that affected the safety of the entity under study. Adaptations that are approached concern the factors that are measured and interpreted and the use of a comparison group. Furthermore, the author discusses some approaches that better fit the realities of observational Before-After studies. It is shown that the Empirical Bayes approach to estimation not only solves the regression to the mean problem but also yields more precise estimates. Next, estimation will be freed from the constraint of a fixed-duration before period. The key roles played by multivariable models, which express the safety of an entity as a function of its observable traits, are examined. Finally, the author returns to the central issue of the before and after study, that of estimating what the effect of some intervention is and how this approach has been used to estimate the effect of resurfacing rural roads. Hauer concludes that the subject of how to interpret observational before-after studies has certainly not reached closure. Compared with the number of books on the statistical design and interpretation of experiments, very little is written on observational studies and a great deal needs to be done before a maturity of method and routine of application can be attained or claimed.

4. PROFILING ACCIDENT BLACK SPOTS

The rules for targeting black spots described above are based on the total number reported accidents at a site. However, road accidents are connected with a number of features, which may be considered to analyse the occurrence in variance between accident frequencies on different locations:

- the severity of the accident, e.g. fatal, injury or property damage only
- the accident contributory factors present in the accident, e.g. ice on the road. These factors may be assigned to the driver, the location or the vehicle.
- the accident category, e.g. pedestrian, left-angle, left-turn, rear-end, head-on, and various run-off-road collisions (see e.g. Hamaoka et al (1999), Valent et al (2002)).

In literature, several models have been investigated including the first two of these features: accident severity and accident risk factors. A more detailed description of these features can be found in Nassar (1996).

4.1 Modelling Road Accident Severity

Several researchers, such as Zaremba (1980), Hobbs (1981), Gimotty and Chirachavala (1982), Evans (1985), Hutchinson (1986), Laberge-Nadeau et al (1992), Nassar et al (1994), Latimer (1992) and Wood and Simms (2002) have investigated models for accident injury severity. A few researchers investigated severe injury involvement models, for example Jovanis and Chang (1989) and Blower et al (1993). The following description of these models was taken from Nassar (1996).

Statistical models of injury severity were undertaken by Evans (1985a) and Hobbs (1981). Other researchers such as Gimotty and Chirachavala (1982) and Nassar et al (1994), have used accident data to study the effect of changes in risk factors on occupant injury severity.

Evans (1985a, b and c) used the fatal Accident Reporting System data in the US to estimate the effectiveness of risk factors such as seat belt use and vehicle mass in preventing road accident fatalities. The approach adopted by Evans, which is referred to as the Double Pair Comparison, involves the comparison of the probability of fatality for an occupant with and without set belt for a similar set of risk factors.

Gimotty and Chirachavala (1982) investigated the relationship between occupant injury severity and accident conditions. Using a binary logit model to differentiate between severe and non-severe injuries, models were fitted for different impact types.

Nassar et al (1994) proposed a series of sequential disaggregate multivariate logit models of road accident severity. In principle, the models are similar to those used by Gimotty and Chirachavala (1982), although the former uses a sequential model structure for five levels of injury. The purpose of road accident severity models is to explore factors that affect the level of injury sustained by individuals involved in road accidents.

Nassar (1996) states that since injury is sustained by occupants of vehicles, an accident severity model should focus on occupants and their characteristics at the time of accident. Accident type (i.e. single-vehicle, two-vehicle and multi-vehicle) and accident dynamics play a major role in predicting injury severity. An accident severity model should be able to integrate with an involvement model to account for the expected number of injuries and fatalities in an accident.

Models similar to those developed by Nassar et al (1994) predict injury severity using accident dynamics and occupant characteristics for different accident types. These models could be easily integrated with accident involvement models provided information on the number of occupants per vehicle involved in an accident is available.

4.2 Integrating Road Accident Severity And Accident Involvement

In Nassar (1996) an integrated Accident Risk Model (ARM) for policy decisions is developed using risk factors affecting both accident involvements on road sections and injury severity of occupants involved in the accidents. Again, the accident involvement model is based on a negative binomial regression. This model is able to provide estimates of the number of vehicle involvements on road sections by region, road type, vehicle type and accident location. The accident severity model is developed and evaluated using a sequential binary logit formulation. The model is able to provide occupant specific injury profiled by region, road type, accident type and vehicle type. The integrated structure of ARM permits an estimate of road accident risk in terms of the number of vehicles involved, and fatalities and major injuries to occupants. It also permits the identification of risk factors explaining both accident involvement and severity. However, the model application for policy is limited.

4.3 Risk Factors

Risk factors are used to explain accident involvement and accident severity. Risk factors in road accident models play two roles (Nassar, 1996):

- improve overall model fit and reduce the amount of unexplained variation. Care must be taken that these models and are not over-specified (i.e. do not include unnecessary variables).
- provide a means for evaluating the effectiveness of alternative safety measures.

The following risk factors have been elaborately adopted in the literature for explaining accident involvement and accident severity. A more detailed description of these risk factors can be found in Nassar (1996):

- course of the accident: vehicle manoeuvre, driver action
- traffic conditions: traffic volume, dynamics, speed regulation
- environmental conditions: light condition, road surface condition, road geometry
- human conditions: driver age, occupant age, driver sex, driver condition (alcohol, fatigue, illness), seating position, seat belt use
- vehicle conditions: vehicle mass, vehicle size

In Geurts et al. (2002) an association algorithm is used to identify accident factors that frequently occur together at high frequency accident locations. Furthermore, these patterns are analysed and compared with frequently occurring accident characteristics at low frequency accident locations. The strength of this approach lies within the identification of relevant variables that make a strong contribution towards a better understanding of accident circumstances and the discerning of descriptive accident patterns from more discriminating accident circumstances to profile black spots and black zones.

In general, risk factors related to traffic and road section characteristics were found to be essential in analysing accident injury severity. Risk factors such as accident dynamics/speed, seat belt use, and occupant age were found to be most important in explaining accident severity.

5. BLACK ZONES

Recently, identification of black zones has been considered in the literature, as arising from the awareness of the evident spatial interaction existing between contiguous accident locations. The existence of black zones reveals concentrations and hence may suggest spatial dependence between individual occurrences. Spatial concentrations may be due to one or several common cause(s). The following review is described in more detail in (Flahaut et al., 2002).

The most appropriate level of spatial aggregation for road accidents is the road section, but in most studies its length is not justified and not controlled (see Thomas, 1996 for a review). No clear indication exists of what the best length of a dangerous road segment should be, nor or whether an optimal length can be defined. Deacon et al (1975) make a distinction between 'short' and 'large' highway segments, respectively called spots and sections. The lengths are chosen in order to limit the heterogeneity within each road segment, but the authors recommend the use of a constant length because the interpretation of accident data would be more complicated for sections of variable length. Okamoto and Koshi (1989) propose seven ways of defining road segments: some are based on fixed lengths and other on variable length. Stern and Zehavi (1990) divide the road studied into 1-km-long sections, without any particular justification for this length. Elvik (1988) suggests defining dangerous road sections of a fixed length, by moving a 'glider' of a specific length along the road. However results are not found to be satisfactory with this method.

In Flahaut et al (2002) the concept of black zone is used to tackle the problem of the length as well as the location of road sections, taking into account the contiguity structure of the basic individual spatial units. A black zone is here defined as a set of contiguous spatial units taken together and characterized by a high number of accidents. No attempt is made to find out which factors explain the occurrence of accidents, or which countermeasures should be taken to reduce their number. The research focuses on an exploratory spatial data analysis problem: defining the location and the length of black zones. Two methods are compared: the use of local spatial autocorrelation indices (a decomposition of the global Moran index) and kernel estimation. Both methods differentiate local dangerousness and generate a smoothing of the empirical process. Although each method starts from different conceptual approaches, both may provide quite similar results under a specific choice of parameters and lead to a definition of non-contiguous black zones.

6. STATE OF THE ART IN BELGIUM

In the Design Mobility Plan Flanders (2001), the Flemish government states that a long term increase in traffic safety can only be achieved by means of an integrated approach towards vehicle safety, road safety (and its environment) and the required behaviour of the road user. Especially the interaction of these three factors will cause an accident to occur or not. Therefore, ideally traffic safety measures should aim at the interaction of these three factors.

To determine the most 'dangerous' accident sites, the Flemish government analyses the accident data that are obtained from the Belgian "Analysis Form for Traffic Accidents". This form should be filled out by a police officer for each traffic accident that occurs with injured or deadly wounded casualties on a public road in Belgium. Based on these data, the following criterion is used. First, each site where in the last three years three or more accidents have occurred, is selected. Then, a site is considered to be dangerous when its priority value (P), calculated using the following formula, equals 15 or more:

$P = X + 3*Y + 5*Z$, where

X = total number of light injuries

Y = total number of serious injuries

Z = total number of deadly injuries

Based on this criterion, in Flanders currently approximately 800 sites should still be considered as 'dangerous'. The Flemish minister of Traffic, Steve Stevaert, will each year, starting in 2003 for a period of 5 years, invest 100 million EURO to redesign these dangerous locations.

When evaluating the trends in accident figures, the Design Mobility Plan (2001) concludes that their policy aimed at the reduction of the number of accidents on these 'dangerous' or black spots certainly has been successful so far. However, these trends also point out that accidents tend to occur less concentrated in space, which in future will limit the effectiveness of similar infrastructure safety measures.

Furthermore, being able to determine where crashes occurred is vital for the analysis of Black Spots. There are two issues associated with this:

correctly identifying the location of the crash; and

consistently recording the location in the road crash database so that details of all crashes at that location are readily accessible

As mentioned in the Design Report of the Status Questionis Flanders (2002), the accident data for Flanders are located in a Geographical Information System (GIS). When necessary, this pinpointing is done with the help of official police reports.

The GIS tools allow for the local authorities to analyse the located accident data in Access databases. However, this research is usually limited to the analysis of the evolution of accident data in relation to certain infrastructure parameters such as the number of accidents in the built-up area or the number of accidents on numbered roads. After the black spots are identified by means of the priority value criterion (see 7.1), the GIS software is also used to map these locations on the Belgian road network (see e.g. the Design Mobility Plan Flanders (2001)).

Steenberghen et al (2002) show the usefulness of GIS and point pattern techniques for defining road accident black zones within urban agglomerations. The location of road accidents is based on dynamic segmentation, address geocoding and intersection identification. One-dimensional (line) and two-dimensional (area) clustering techniques for road accidents are compared. Advantages and drawbacks are discussed in relation to network and traffic characteristics. Linear spatial clustering techniques appear to be better suited when traffic flows can be clearly identified along certain routes. For dense road networks with diffuse traffic patterns, two-dimensional techniques make it possible to identify accident-prone areas. The use of these techniques enables suggestions for causal dependence, which is illustrated through the analysis of spatial shifts of accident concentrations by introducing traffic calming measures in a Belgian town (Mechelen). Traffic safety is the result of a balance between the type and the road and neighbourhood characteristics. The imbalance results in statistically significant differences in concentrations of accidents. The importance of the environmental factors in relation to the traffic characteristics needs to be further researched to better identify which combinations generate higher concentrations.

7. STATE OF THE ART IN FOREIGN COUNTRIES: TWO EXAMPLES

7.1 Hot spot safety work in Denmark

On the Danish road network the national Road Directorate is the primary developer of the theoretical foundation of the hot spot safety work. The Road Directorate has classified the state and regional road network into road sections, roundabouts and intersections. Road sections are further classified into a number of groups, defined by geographical-, geometrical- and environmental (site) characteristics. For each group, a model describing variation in accident counts within the groups is used. These accident models are fairly simple (few parameters) because environmental characteristics, other than traffic flow, are not directly included as traits in the model.

Research (Vistisen 2002) has pointed out that Poisson-gamma hierarchical generalized linear models better describe the variation in accident counts on the Danish roads and accordingly provide better estimates of site safety than the models currently at use in Denmark. The proposed accident models are disaggregated on time periods of one year, which assures that yearly changes in traffic as well as in other traits may be accounted for. In these models not only general trends in accident counts may be included, but also the so-called dispersion effects. These effects represent the site-specific conditions not included as traits in the model. In addition a dispersion effect models interdependence between yearly accident counts at the same location. Since this dispersion effect expresses how the expected accident frequency at a location deviates from the expected accident frequency at locations with similar traits, it may be used for targeting black spots in the road network. In general, this results in a marginally higher sensitivity than the method used on the Danish road network today.

In Vistisen (2002) also a new method for estimating the effect of hot spot treatment work is proposed. The model is based on the site safety estimates provided by the accident models, and takes into account the regression to the mean effect as well as changes in traffic flow and other traits. The proposed method is found to give better estimates of the effect of treatment than the method currently used in Denmark. In addition, the researchers claim that it outperforms the methods as yet suggested in the international literature. The improved estimates of treatment effect will improve the foundation for prioritising of black spots and safety measures.

7.2 Hot spot safety work in Australia

For over a decade, the Federal Government of Australia has operated programs to improve the physical condition or management of hazardous locations with a history of crashes involving death or serious injury. This evaluation relates to the Capital Funding for Black Spots Roads Programme, more generally known as the Federal Road Safety Black Spot Program, which commenced in 1996–97 and is scheduled to conclude in 2001–02. In total, 983 black spot projects had been implemented under the Program as at 30 June 1999. The Australian Transport Safety Bureau (2001) administered the Program. A sample of 608 black spot projects around Australia undertaken between 1 July 1996 and 30 June 1999 was analysed. The total cost of these projects was approximately $59.5 million.

This study adopted a before and after treatment approach. This methodology was chosen because of its compatibility with the nature of the data available for analysis. The evaluation compared the number and severity of crashes after the black spots were treated with the number and severity of crashes that would have been expected with no treatment. The expected crash history was estimated using the actual crash history of the black spots before treatment and data on other variables expected to affect crashes at black spots after treatment. A Poisson regression model was used to determine whether black spot treatments had a statistically significant effect.

Overall, the evaluation provides very strong evidence that the Program achieved its aim of improving safety at locations with a history of crashes involving death or serious injury. Nevertheless, the Program was not uniformly effective in reducing the number of casualty crashes. Not all road engineering treatments had a statistically significant effect.

In the capital cities, sealing road shoulders, edge lines, pedestrian facilities, and signs had no statistically significant effect on road safety. The lack of a statistically significant result on road safety from sealing road shoulders in capital cities is particularly interesting, as this was the fifth most popular treatment in expenditure terms, and accounted for nearly seven per cent of expenditure on urban black spot treatment. Attempts to improve lighting in the capital cities appear to have had a counterproductive effect. In regional areas, traffic islands on approach, indented right and left turn lanes, non-skid surfaces, and pedestrian facilities had no statistically significant effect on road safety.

On the other hand, there were many areas in which the Program had a dramatic effect in reducing the number of casualty crashes, and some engineering treatments were consistently very successful. Roundabouts and new traffic lights with no turn arrows appeared to be very successful in improving safety in both capital cities and regional areas, with the probability of such large improvements being due to chance being less than one in ten thousand. There was very strong evidence that installing roundabouts successfully improved safety regardless of how expensive, and presumably how large, the roundabouts were. New traffic lights with turn arrows, medians and non-skid surfaces were similarly successful when used in capital cities. In regional areas, there is very strong evidence that signs and new traffic lights with turn arrows improved safety, and moderate evidence that medians, shoulder sealing, edge lines, and improved lighting increased safety. In capital cities, there is very strong evidence that traffic islands on approaches and indented right and left hand turns improved safety.

Overall, the Black Spot Program appears to have been highly effective in reducing the number of casualty crashes. It is estimated that the Program prevented around 32 fatal crashes and 1 539 serious crashes between 1996–97 and 1998–99. The Program is therefore estimated to have saved at least 32 lives and prevented a large number of injuries over these three years. Further benefits will continue to accrue over the life of the black spot treatments that were applied.

8. CONCLUSIONS

A number of statistical models have been used to estimate accident rates and/or accident frequencies at a specific location over a given interval of time. The Poisson-gamma generalized linear model, in which the Poisson mean is allowed to vary between locations beyond what may be explained by differences in location characteristics, is currently widely accepted as the best model. Furthermore, when modelling accident frequencies, most researchers have chosen to analyse specific accident models such as specific accident locations or vehicle types. Very few researchers studied general accident involvement models.

In literature there is no universally accepted definition of a black spot. Locations are generally classified as black spots after an assessment of the level of risk and the likelihood of a crash occurring at a location. Black spot safety work can be described as the task of improving road safety through alterations of the geometrical and environmental characteristics of the problematic sites in the existing road network. Accordingly, this work may be divided into three phases.

In the first step, black spots are targeted with the aim of improving safety on the road network through remedial treatment of the sites. This task may also be viewed as a ranking and selection problem. In Belgium, each site where in the last three years three or more accidents have occurred, is selected. Then, a site is considered to be dangerous when its priority value (P), calculated using the following formula, equals 15 or more:

P = X + 3*Y + 5*Z, where

X = total number of light injuries

Y = total number of serious injuries

Z = total number of deadly injuries

Researchers have proposed several alternative methods for targeting and ranking black spots. However, there is no such thing as "the" correct ranking.

Restricted funding for hot spot safety work does put a limit to the number of sites that may be treated. Therefore, it is necessary to prioritise between sites and safety measures in order to utilize the limited funds as effectively as possible. This is the second step of black spot safety work. Two important problems can be discerned when calculating the costs and benefits of a treatment. First, no market prices are stated for e.g. a human life and instead the pricing of injury accidents is done indirectly Secondly, the obtained accident reduction from implementing a safety measure is uncertain.

The third step of black spot safety work involves the realisation of before and after studies of the effect of treatment. Important elements when analysing the change in reported accident count before and after the implementation of preventive safety measures are overlap in effects, negative effects, road user behavioural adjustment, regression to the mean effect, migration effect, general trends and change in the level of reporting. Accordingly, conventional approaches such as the Naïve Before-After study have a number of shortcoming which could be partly solved with some adaptations. Furthermore, it is shown that the Empirical Bayes approach to estimation not only solves the regression to the mean problem but also yields more precise estimates than the traditional estimation methods. However very little is written on observational studies and the subject of how to interpret observational before-after studies has certainly not reached closure.

Besides the analysis of the total number of reported accidents at a site, several models have been investigated including the severity of the accident and the accident contributory factors present in the accident. Risk factors, such as course of the accident, traffic, environmental, human and vehicle conditions have elaborately been adopted in the literature for explaining accident involvement and accident severity. and the accident category to profile these high frequency accident locations. In general, risk factors related to traffic and road section characteristics were found to be essential in analysing accident injury severity. Risk factors such as accident dynamics/speed, seat belt use, and occupant age were found to be most important in explaining accident severity.

Recently, identification of black zones has been considered in the literature, as arising from the awareness of the evident spatial interaction existing between contiguous accident locations. The use of Geographical Information Systems and point pattern techniques has proven to be very useful when identifying such zones However, no attempt is made to find out which factors explain the occurrence of accidents, or which countermeasures should be taken to reduce their number. The research focuses merely on an exploratory spatial data analysis problem: defining the location and the length of black zones.

In conclusion, analysis of the accident figures of Belgium, Denmark and Australia show that black spot safety work has been effective in reducing the number of casualty crashes. However, as road and traffic authorities will tend to treat the worst sites first, the benefits from treating remaining sites reduce progressively. This means that ongoing evaluation is necessary to help governments determine if the benefits from further treatment of black spot sites justify the treatment costs.

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