# THE EVOLUTION OF CRITERIA FOR IDENTIFYING BLACK SPOTS AND RECOMMENDATIONS FOR DEVELOPING COUNTRIES

Huy Huu Nguyen
PhD Student
EU-Asia Road Safety Centre of Excellence
Department of Civil Engineering
Prince of Songkla University
Hat Yai 90112, Thailand
E-mail: huycongtrinh@yahoo.com

Pichai Taneerananon
Professor
Centre for Road Safety Research
Department of Civil Engineering
Prince of Songkla University
Hat Yai 90112, Thailand
E-mail: breathislife@yahoo.com

Csaba Koren
Professor
Department of Transport Infrastructure and Municipal Engineering
Szechenyi Istvan University
Egyetem ter 1, 9026 Gyoer, Hungary
E-mail: koren@sze.hu

Paramet Luathep
Lecturer
Centre for Road Safety Research
Department of Civil Engineering
Prince of Songkla University
Hat Yai 90112, Thailand
E-mail: paramet007@hotmail.com

## ABSTRACT

The general purpose of black spot identification is to identify high accident frequency locations on a road network to improve road safety. The next task is to sift through these locations to select the particular locations based on whose analysis the safety treatment is established. Thus, black spot treatment is a two-stage process: *identification* and *safety analysis*, with the former producing the enriched data for the detailed analysis done in the latter. Such analysis is to determine the true black spots, the safety aspects to improve, the cost of treatment, and the extent of the efficiency. Accordingly, the object of identification stage is to select sites that have a good chance of being in need of remedial action and also capable of being cost-effectively improved. This paper reviews the evolution of criteria for black spot identification in terms of scope and aspects. On the basis of this review, a number of suggestions are made for the cases of developing countries in terms of black spot identification aspects.

**Keywords**: Black spot identification, hot spot identification, hazardous location identification

## 1. INTRODUCTION

An accurate identification of black spots prevents the waste of resources that may result if such locations are less accurately identified. In particular, treating locations that are not truly black spots may be ineffective and lead to a decrease in available resources for treating the truly black spots. However, the identification of black spots has been in different directions due to the variation of the criteria employed. Actually, there has been almost no standard definition of black spot (Elvik, 2008). Hauer (1996) is of the opinion that a variety of terms can be used to referred to a black spot; namely, hot spot, hazardous location, site with promise, and accident-prone location. Moreover, each of these terms employs different criteria for the identification of the location it denotes. Therefore, it is necessary to determine how black spots should be locally identified and treated. That is why this paper aims (1) to review the criteria employed in each term, and (2) suggests the aspects which help select the right black spots to treat as well as establish better corresponding treatment process according to the local conditions of a particular region.

The scope of this paper is black spot only. However, it is also important to acknowledge that recently there appears to be a number of related terms to black spots; namely, black sections and black zones or black area.

## 2. THE EVOLUTION OF CRITERIA FOR IDENTIFYING BLACK SPOTS

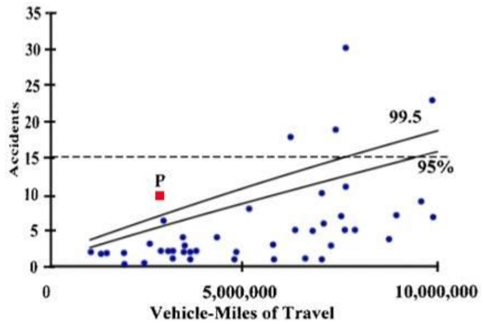
This section gives a historical sketch of the main ideas and conceptual developments in what is usually called the identification of black spots, or hazardous locations, or hot spots, or sites with promise, or accident-prone locations. To make this review easier, the following notation will be used:

- $X$ = observed accident count for a road section and period,
- $m$ = expected accident count $(E\{X\})$ for the road section and period,
- $E\{m\}$ = mean of m's for similar road sections,
- $D$ = length of road section,
- $Q$ = number of vehicles passing road section during period to which X pertains,
- $R$ = observed accident rate (e.g., accidents/vehicle-kilometer) [note that $R = X/(DQ)$],
- $R_{EB}$ = accident rate estimated by empirical Bayes method,
- $\overline{R}$ = average value of R for the similar road sections,
- $UCL_x$ = upper control limit for observed accident counts $(X)$,
- $UCL_R$ = upper control limit for observed accident rate $(R)$,
- $t$ = number of years of accident data to be used, and

Norden *et al.* (1956) suggested using methods of industrial statistical quality control for highway safety. What is being monitored is the observed accident rate *R*. They assume that if some road section served $D \times Q$ *(vehicle×miles)* in a certain time period, it would be expected to have $\overline{R} \times D \times Q$ (accidents) in that period. One can now find an accident count *X*, called the upper control limit $(UCL_X)$, such that the probability $X \geq UCL_X$ is less than 0.5 percent. Equivalently, $UCL_R = UCL_X/(DQ)$ is the upper limit on the observed accident rate *R*. Using an approximation of the Poisson distribution and 0.5 percent probability, they suggest that $UCL_R = \overline{R} + 2.576\sqrt{[\overline{R}/(DQ)]} + 0.829/(DQ) + (DQ)/2$.

Similar approaches were used by Rudy (1962) gives $UCL_R = \overline{R} + z\sqrt{[\overline{R}/(DQ)]} + 0.829/(DQ) + 1/(2DQ)$ where z is said to be 2.576 for 1 percent false detection, 1.960 for 5 percent false detection, and so forth.

Morin (1967) suggested that the term $0.829/(DQ)$ be deleted and that $UCL_R = \overline{R} + z\sqrt{[\overline{R}/(DQ)]} - DQ/2$. These errors should have ended when Baker (1976) provided the correct expression $UCL_R = \overline{R} + z\sqrt{[\overline{R}/(DQ)]} + 1/(2DQ)$.




Source: Hauer, 1996

Figure 1: Sample plot of exposure and accident count

The same can be written more simply as $UCL_X = \bar{R}DQ + z\sqrt{(\bar{R}DQ)} + 1/2$. In this, $\bar{R}DQ$ is the mean number of accidents for a road section if $\bar{R}$ was its accident rate and *DQ* its exposure. If accidents are Poisson distributed, $\sqrt{(\bar{R}DQ)}$ is standard deviation. Thus, $UCL_X$ is the sum of what would be expected normally + z standard deviations. The addition of ½ to this is unimportant.

It is important to stress that use of the equation for $UCL_R$ is identical to the use of equation for $UCL_X$. To illustrate, suppose that $\bar{R} = 1.077 \times 10^{-6}$ injury accidents/vehicle×mile of travel and that a road section recorded 10 injury accidents in 2,932,000 vehicle miles of travel. For this road section the normal number of accidents would be $1.077 \times 10^{-6} \times 2{,}932{,}000 = 3.16$ and thus standard deviation is $\sqrt{3.16} = 1.77$. Clearly, $10 > UCL_X = 3.17 + 1.77$. Plotting exposure as the abscissa and the accident count as the ordinate, this road section is shown in Figure 1 as Point *P*. Also shown in Figure 1 are 44 additional road sections based on data from Flowers and Griffin (1992). It is evident which road sections are above the curves for a $UCL_X$.

Tamburri and Smith (1970) introduced the notion of the safety index. This was later incorporated into practice of black spot identification based on the idea that sites with severe accidents deserve prior attention. In principle, each road type was said to have a characteristic mix of accident severity. Thus, for example, for a rural two-lane road the mix was 2.9 percent fatal, 43.0 percent injury, and 54.1 percent property damage only (PDO) accidents. They also suggested using costs weight by accident severity and road type. If a property damage accident on a rural road was given the weight of 1, fatal and injury accident on such roads had weights of 95 and 3, respectively. If so, an accident of average severity on a rural two-lane road could be said to be equivalent to $95 \times 0.029 + 3 \times 0.430 + 1 \times 0.541 = 4.6$ PDO accidents. Thus the main idea is to express all accident severities as equivalent PDO (EPDO) accidents.

Deacon *et al.* (1975) considered the difference between spots and sections and how long spots should be. The also present an analysis of the optimal *t*. The outcome is a compromise between the desire to detect reliably and the need to detect adverse change quickly. Use of safety index (EPDO) is recommended with 9.5 as the weight for fatal and A-injury accidents and 3.5 for B and C injury accidents.

Jorgensen (1972) introduced two new ideas. First, *E{m}* should be estimated by a multivariate model. Second, the ranking should be by the difference between the observed accident frequency of a road section or spot and the expected frequency for such road sections or spot as estimated by the multivariate model.

Taylor and Thompson (1977) suggested that a hazardousness index be defined for each road section as a weighted sum of a mix of accident frequency, rate, severity, volume-to-capacity ratio, sight distance, conflicts, erratic maneuvers, and driver expectancy. There is a recognition here that there are clues to hazardousness other than accident occurrence.

Renshaw and Carter (1980) recognize that questions about the length of sections *(D)*, duration of accident history *(t)*, amount of traffic *(Q)*, and detection accuracy must all be considered jointly.

McGuigan (1981, 1982) suggests that for each road section and intersection one calculate the difference between the actual number of accidents and the number of accidents expected for such a class of road or intersection given the same traffic. This difference, in McGuigan's opinion, represents the size of the potential accident reduction. Whereas in methods emulating statistical quality control the aim is to identify sites with unlikely accident counts, the idea here is to identify by promise of improvement. Like Jorgensen (1972), McGuigan, suggested that a regression equation be estimated for each category of road or junction, thus linking the expected number of accidents with traffic. The

potential annual accident reduction is then the difference between the observed and the expected accident frequency.
Mahalel *et al.* (1982) also suggest estimating a multivariate model for $E\{m\}$. A road section is deemed to be a black spot if, with $E\{m\}$ as the mean, the probability of observing $X$ or more accidents is smaller than some value, say 0.05 or 0.005. This is the same idea as expressed by Norden *et al.* (1956) except that $E\{m\}$ is now estimated by a multivariate model [as by Jorgensen (1972)] not as an average accident frequency.

Hauer and Persaud (1984) examined how an identification procedure performs in terms of proportions of correctly identified deviant road sections, proportion of falsely identified road sections, and proportion of deviant road sections not identified. The empirical Bayes (EB) method was used to calculate these proportions.

Higle and Witkowski (1988) use the EB approach and focus on the identification of road sections with unusually large accident rates (rather than frequencies). They show how the probability distribution function of the accident rate at a specific road section can be obtained. A road section is then said to be hazardous if the probability that its accident rate exceeds a certain value is sufficiently large.

Hauer (1990, 1992) illustrates how the Empirical Bayes approach can be used for the identification task. The first step is to fit a multivariate model to road sections of a certain kind – the reference population. Using this information one obtains the distribution of *m's* in the reference population. In this distribution one selects an $m^*$ such that road section with $m > m^*$ may be considered deviant and therefore deserving of further attention. Next, by using the accident history of the road section under scrutiny, the probability density function for its $m$ is obtained. How this is done is shown by Hauer *et al.* (1989). Now one can determine the probability that the $m$ of road section under scrutiny exceeds the selected $m^*$ in the reference population. If this probability is large, the road section is said to deserve further examination.

Persaud (1990), recognizing that when a short accident history is used the observed accident frequency is an unreliable estimate of the accident frequency $m$, suggests using the Empirical Bayes estimate of the $m$ of road sections and ranking them accordingly.

Hauer and Quaye (1990) and Hauer *et al.* (1993) define as the time to trigger the time until a road section or intersection meets some specified detection criterion. The time to trigger is a random variable that depends on what the detection criterion is and on $m$, $D$, or $t$. Based on some analysis it proves possible to find what proportion of the identified road sections is correct and false positives. Guidance is given on how to best choose $D$, $t$, and the detection criterion.

Heydecker and Wu (1991) pursue ideas that are similar to those of Flak and Barbaresso (1982). A site is to be flagged for attention if the proportion of accidents of some kind (wet weather, nighttime, rear-end, fatal, etc.) is unusual. The idea is that this then provides information for engineers in assessing the nature of any problems that might have arisen at the site and hence in devising appropriate accident remedial measures. The EB approach is used to this purpose.

Flowers and Griffin (1992) consider the statistical quality control method and the EB method for the former, with a 5 percent probability of exceedance, they recommend using $UCL_X = \bar{R}DQ + 1.65\sqrt{(\bar{R}DQ)}$. Unlike Norden *et al.* (1956) here the upper limit is stated in terms of accident counts rather than accident rate. The authors point out that gross inaccuracies would result if the observed accident severity for a road section was used for prioritization. This is the result of the randomness in the count of fatal accidents and the large weight attached to them. In short, they suggest that EPDO should not be used for ranking. To obviate this problem expected cost is to be estimated by the EB procedure. The idea is to rank road sections by expected cost.

Pioneering work by Hauer and Persaud (1984) who pointed out difficulties in identifying black spots by using the recorded number of accidents as the only criterion. Since all the different criteria used have merit and shortcomings, it is not clear what path to steer (Hauer, 1996). Madsen (2005) discusses in detail criteria for identifying black spots. He proposes that an adequate definition of a hazardous road location should satisfy three or possible four criteria:

(1) It should control for random fluctuations in the number of accidents.
(2) It should account for as many of the factors that are known to influence road safety as possible.
(3) It should identify sites at which fatal and serious injury accidents are over-represented.
(4) It should identify sites at which local risk factors related to road design and traffic control make a substantial contribution to accidents.

The first of these criteria suggests that the identification of a black spot should rely on the expected number of accidents, not the recorded number. In practice, this would appear to be difficult, since the expected number of accidents cannot be observed, but has to be estimated. However, a method has now been developed that permits the expected number of accidents to be estimated for a single location: the EB method. By applying this method, it is in principle possible to identify hazardous road locations in terms of the number of accidents expected to occur in the long run at each such location. The second and fourth criteria also suggest that the identification of road accident black spots should rely on the EB method, supported by a multivariate accident prediction model. By developing an accident prediction model, it is possible to account for a number of factors that explain systematic variation in the number of accidents, including traffic volume, various characteristic of road design and element of traffic control (like speed limits). It is not realistic to expect an accident prediction model to include and accurately estimate the effects of all factors that influence the number of accidents; the factors that are not include in such models will typically be local risk factors, which due to their site-specific nature, cannot be detected statistically in a multivariate model. These local factors may cause a site to have a higher expected number of accidents than predicted by an accident prediction model. The third criterion implies that the identification of black spots should either rely on fatal or serious accidents only, or assign a greater weight to these accidents than slight injury accidents or PDO accidents. This criterion is relevant to the extent that road safety policy seeks to prevent the most serious accidents.

Elvik (2008) evaluated five common criteria used to identify hazardous road locations as follows:

(1) Upper tail accident count;
(2) Upper tail accident rate;
(3) Upper tail accident count and high accident rate;
(4) Upper tail expected number of accident (EB estimate); and
(5) Upper tail EB dispersion criterion.

The research concluded that of the five criteria, EB estimates of safety provide the most reliable identification of hazardous road locations than the other criteria.

In fact, there have been three approaches in common use so far. The first approach is to set a more stringent critical value for the number of serious injury accidents than for all injury accidents when identifying black spots. The second approach is to apply weights to accidents at different levels of severity (using weighting factors). The third approach is to estimate the costs of accidents. When analyzing accidents of different categories together, the numbers of accidents are weighted by the accident severity. Accident costs are, therefore, used to describe the combined effect of number and severity of the accidents. These costs vary according to injury severity; hence, cost will be higher at sites that have a high proportion of fatal or serious injury accidents.

In order to improve the safety of road networks as well as black spot identification and treatment, Bast and Sétra (2005) suggested using the safety potential (SAPO) in black spot identification. The SAPO can be defined as the amount of accident costs per kilometre of road length (cost density) that could be reduced if a road section would have a best-practice design . The higher the safety potential, the more societal benefits can be expected from improvements to the road. In favor of what Bast and Sétra (2005) had concluded, the European Parliament and The Council (2008) promulgated the Directive 2008/96/EC on road infrastructure safety management suggesting that the number of fatal accidents in proportion to the traffic flow should be considered when identifying black spots of the road networks.

To enhance the efficiency of black spot management, it is necessary to discriminate between true black spots and false black spots. Such discrimination can rely on the classification of black spots suggested by Elvik (2008), which can be briefly presented as follows.

- True positives: if $E \geq [c]$ and $R \geq [c]$;
- False positives: if $E < [c]$ and $R \geq [c]$;
- True negatives: if $E < [c]$ and $R < [c]$;
- False negatives: if $E \geq [c]$ and $R < [c]$.

(E denotes the expected number of accidents, [c] denotes the selected critical value, and R denotes the recorded number of accidents at a site during a given period of time)

Nguyen *et al.* (2013) proposed a black spot safety management approach called SAPO-Based BSM, which relies on expected number of accidents as an additional parameter in identifying true black spots. That means in its identification of black spots, SAPO-Based BSM makes use of three parameters: recorded number of accidents (R), expected number of accidents (E), and critical value ([c]).

In the SAPO-Based BSM approach the expected number of accidents of (E) a spot can be estimated by Formula (1), and The SAPO [$10^3$USD/(km.year)] can be calculated by the formula (2) as follows.

$$E = \frac{365 \cdot \overline{AR} \cdot ADT \cdot t}{10^6} \quad (1)$$

Where: $\overline{AR}$ = Average accident rate [A/($10^6$ veh.km)], ADT = Average daily traffic in t years [veh/24h], L = Length of road section [km], t = Period of time under review [years].

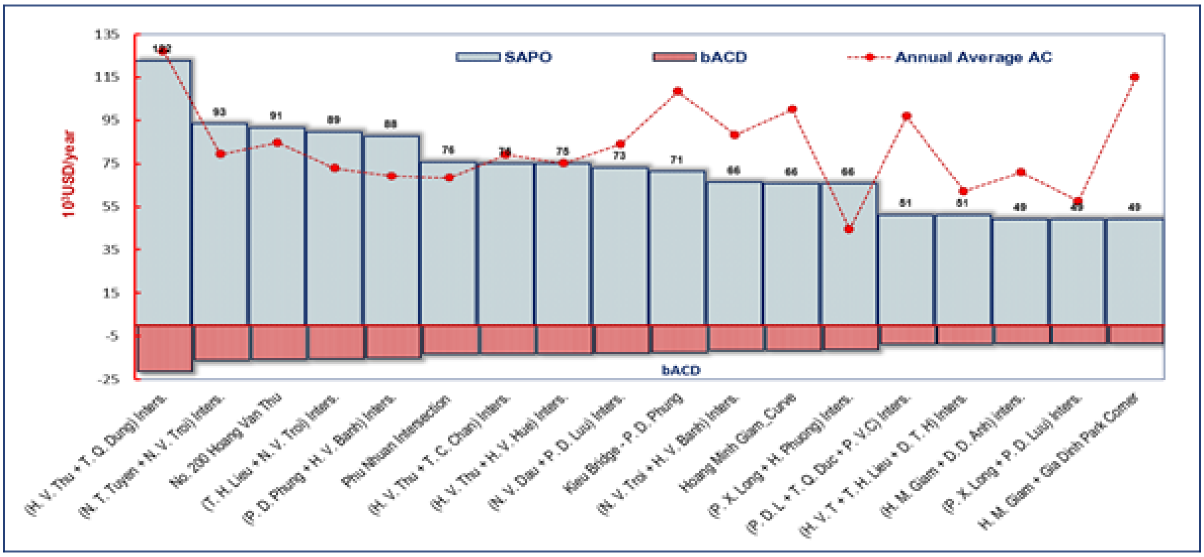
$$SAPO = ACD - bACD \quad (2)$$

The basic accident cost density (bACD) represents the anticipated average annual number and severity of road accidents (represented by the accident costs) per kilometer, which can be achieved by a best-practice design at the given average daily traffic (ADT). It can be calculated as the product of basic accident cost rate (bACR) and the average daily traffic as formula (3).

$$bACD = \frac{bACR \times ADT \times 365}{10^6} \quad (3)$$

In ideal circumstances the basic accident cost rate (bACR) required for determining the safety potential contains no influence from the infrastructure on the accidents. Rather, it represents the accident cost rate caused only by the other two components of the transport system: vehicles and road users.

With its application of formula (2) and formula (3) it is easy to realize that SAPO-Based BSM approach incorporated all of the three contributing factors – accident number, accident severity, and traffic volume – in identifying and ranking black spots. Such incorporation generates the so-called SAPO – a new indicator in black spot management, whose application allows assessing different road types and roads with different traffic volumes at the same time. Furthermore, as an accident-cost-based indicator, SAPO is related to the cost of the improvement measures. Figure 2 illustrates particular calculation of SAPO of 18 identified black spots in Ho Chi Minh City done for and reported in Nguyen *et al.* (2013).




Source: Nguyen, 2013

Figure 2: The ranking of the 18 identified black spots by SAPO

Jorgensen (1972) asks what *t*, the number of years of accident data to be used, should be. He found that a 13-year average could be adequately estimated from 3 years of accident counts. From this may concluded there is little to be gained by using a longer study period than three years. The length of the period used to identify black spots varies from 1 year to 5 years, a period of 3 years is used frequently (Elvik, 2008). Research by Cheng and Washington (2005) shows that the gain in the accuracy of black spot identification obtained by using a longer period of three years is marginal and declines rapidly as the length of the period is increased. There is little point in using a longer period than 5 years.

Furthermore, it is useful to explicitly recognize three interdependent motives that appear to be far behind the black spot identification methods as Hauer (1996) presented.

- Motive 1 – Economic efficiency
  This motive focuses on the identification of sites at which remedial action would prove cost-effective.

- Motive 2 – Professional and institutional responsibility
  This motive focuses on the recognition and rectification sites that are deficient either because of how they were built or because they have deteriorated while in use.

- Motive 3 – Fairness
  This motive focuses on the identification of sites that pose an unacceptably high hazard to the user.

In fact, the number of and servility accidents vary considerably between developed and developing countries [See the Status Report on Road Safety 2013, WHO (2013)]. For each particular country or region, such variation makes it necessary to determine particular methods of identifying and analyzing black spots which best suit the local conditions.

## 3. CHALLENGES OF BLACK SPOT SAFETY MANAGEMENT IN DEVELOPING COUNTRIES

Generally, road planners and engineers in the highly motorized countries have learnt from the mistakes made in the past and realized the potential of road safety in planning and design. However, most of their counterparts in developing countries are often still preoccupied with the problems of road construction and maintenance and increasing the network capacity. Thus, all too frequently, roads and road systems are being built or upgraded with little consideration given to road safety. As a result, black spots and black links are created and many road users are being killed or injured regrettably. Consequently, the developing world has been facing a numbers of challenges in terms of black spot safety management which can be described as follows.

### 3.1 Challenges associated with the road traffic accident database system

Developing countries have been experiencing a seriously insufficient road traffic accident database system which cannot meet the requirements of the road network safety management. Such insufficiency can be felt in such aspects as poor systemization, low accessibility, low reliability and poor adequateness of data. Another important aspect is the under-reporting of road accidents. Specifically, approximately 50 percent of fatal accidents are under-reported such as Vietnam, Thailand *(see* WHO, 2013). Thus, one of the major challenges of road safety improvement in developing countries is how to improve the road traffic accident database system efficiently.

### 3.2 Challenges associated with the road environment

The first challenge is that of road design and planning. Motorcycles are considered the majority vehicle in developing countries but most of the existing road networks in these countries were designed in compliance with the standards employed in developed countries where motorcycles are considered a minority vehicle. As a consequence, many motorcycle accidents have occurred in the developing world (WHO, 2013). Motorcycle users are relatively more affected by characteristics of the road environment in terms of crash causation and severity of injury outcome than other road users (Hawoth, 2012).

Another challenge for countries with high aspirations for road safety is how to provide – in an affordable and feasible manner – a road infrastructure that is forgiving for motorcycle riders and still functions well for other road users.

### 3.3 Challenges associated with the safety work budget

Implementing safety measures is costly, but in theory, all measures generating a positive net-benefit should be implemented (Geurts and Wets, 2003). Moreover, in developing countries there are so many requirements for road network safety improvement, especially for the black spot treatment. However, the funds available for safety work are always scarce. This leads to a limitation of sites which can be effectively treated. Thus, there is a challenge of how to use the limited funds effectively to both treat all of the black spots and solve other related road safety issues.

### 3.4 Challenges associated with the knowledge constraints

Motorcycle accidents made up a large proportion of the total number of road accidents in developing countries. The cases of Thailand (60%) and Vietnam (approximately 70%) are good cases in point. There should be more incorporation of motorcycle safety into the black spot safety management program of such countries. Such incorporation requires good knowledge about motorcycle safety, mobility and a number of local factors to which motorcycle accidents are attributable. However, most of the research into the safety and mobility of motorcycles comes from the developed world (ACEM, 2004; Hurt et al., 1981), with the exception of some studies of helmet use from Asia (Haworth, 2012) and a large-scale motorcycle crash study from Thailand (Kasantikul, 2002). Furthermore, much of the research focuses on aspects of motorcycles as a minority vehicle, with much riding being for recreation (Haworth, 2012). While motorcycles serve as the means of transport in developing countries. This fact suggests that there is a severe shortage of research into motorcycles as a majority vehicle in the developing world.

## 4. CONCLUSIONS AND RECOMMENDATIONS

The evolution of the methods for identifying black spots points out that recorded number of accidents, expected number of accidents, accident severity, and traffic volume are the four main parameters used in the process of identification. Unlike the other three parameters which are of quantitative nature, accident severity is more of qualitative nature. Therefore, weighting factors and/or accident costs were employed so that accident severity can be evaluated more accurately. Weighting factors describe the severity of accidents; and, accident costs describe the combined effect of number and severity of the accidents. The analysis of both accident number and traffic volume enables the safety assessment of different types of road with different traffic volumes. Due to this fact, accident rate is used more often than accident frequency. Accident rate is the average number of accidents at a traffic volume of one million vehicles and one kilometre section length (for spots only one million vehicles). Accident rate represents a road user's risk of being involved in an accident.

Initially, recorded number of accidents was used as the main parameter for black spot identification. This practice led to the existence of false positive black spots in the set of identified black spots. In order to solve this problem, expected number of accidents was employed. The expected number of accidents cannot be observed, but has to be estimated by multivariate accident prediction model. This model makes it possible to account for a number of factors that explain systematic variation in the number of accidents, including traffic volume, various characteristic of road design and element of traffic control.

In addition, safety performance function is also used to identify locations that experience more accidents than expected, thus exhibiting a potential for accident reduction. Safety performance functions reflect the complex relationship between exposure, usually measured in annual average daily traffic, and accident count for a unit of road section over a unit of time.

There are three independent aspects behind the black spot identification methods which can be recognized. They are: (1) economic efficiency; (2) professional and institutional responsibility; (3) identification of sites that pose an unacceptably high hazard to the user. Hence, there arises the question of which is the first priority in identifying black spots to suit the local traffic conditions in developing countries in general.

In theory, every identification method always contains advantages and disadvantages. In practice, the local conditions or specific situation of each country should be considered first in the use of a black spot identification method.

In order to deal with the shortage of fund and poor accident database system in developing country, a simple technique of black spot identification should be used and more attention should be paid to the aspect of economic efficiency when choosing safety countermeasures. For this purpose, it is highly recommended to use the method of black spot safety management based on safety potential or potential savings in accident costs. The methodology in such method focuses on the traffic volume and the severity of accidents at spots and the evaluation of the accidents on the basis of accident cost rates. The comparison of actual accident cost with a hypothetically-estimated-based accident cost provides information on safety potential of spots. The advantage of the safety potential compared to the traditional accident parameters is that it allows assessing different road types and roads with different volumes at the same time. Furthermore, as the safety potential is given in accident cost, it can be related to the cost of the improvement measures. The safety potential is the most important parameter to identify black spots on which safety improvement measures are expected to have the greatest effects.

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