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An Applied Assessment of the Procedures and Criteria for Black Spot Determination

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Abstract

Traffic accidents are the number one worldwide cause of death among youths and one of the major causes of death for all ages. Black spots are high risk locations where road accidents have been concentrated. Herein, a literature review of black spots determination methods is conducted. Certain broad approaches are used to identify them: crash numbers, crash rates related to exposure and gravity of accidents and quantitative methods. Generally, the threshold value of a safety indicator is first determined and in a subsequent phase, it is investigated whether the value of this indicator along a road subsection significantly exceeds that predetermined value. The various approaches adopted by some key countries are also presented. Turkey is one of them and as a country presents similarities with the relevant Greek road safety reality. Then, a comparison is made between the broad approaches and the method which is being used in Turkey along a section of the national road Athens-Thessaloniki. It is concluded that to obtain balanced results, road black spots should be determined as a coupling of both a statistical method at a relevant low confidence interval (90%) together with an accident severity index method.

Keywords: *black spots, safety indicators, threshold values, traffic safety*

1. Introduction

Road accidents are one of the major causes of death worldwide. According to World Health Organization (WHO), road accidents will globally be the ninth cause of death in 2015 and seventh in 2050; this figure shows the importance of the issue of road safety [29, 30]. It should truly become common belief that the act of driving itself constitutes the most complex and dangerous daily action which is executed by most people. Furthermore, the socioeconomic cost of road accidents is classified by far as the most significant among all the other human activities [10]. Therefore, every action for road safety improvement should be considered as important and notable. Particularly in Greece an average of 13.000 road accidents is taken place during the last five years; the average number of deaths during this period is 1.000 and the injuries reach an average number of almost 16.400 people (Table 1) [25, 28]. Despite the overall progress in the field of road safety during the last years, Greece still own the devastating privilege of the first position in number of road accidents in European Union (in this country, the rate of deaths is 10 deaths/100.000 inhabitants, whilst in Sweden, a country-pioneer in road safety, is only 3 [27]).

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Table 1. Number of Road Accidents by Casualty Type and Number of Deaths and Injuries in Greece, [28]

Accident / Year	With deaths	With serious injuries	With light injuries	Total accidents	No. of Deaths	Serious injured	Light injured	Total casualties
2000	1458	2037	13261	16756	2103	4213	26166	32482
2001	1712	2512	15446	19670	1911	3251	22758	27920
2002	1458	2037	13261	16756	1655	2581	19625	23861
2003	1409	1824	12514	15747	1613	2345	18218	22176
2004	1374	2032	11993	15399	1547	2521	17254	21322
2005	1311	1861	13488	16660	1470	2327	19133	22930
2006	1351	1681	12620	15652	1493	2056	19898	23447
2007	1292	1462	11872	14626	1449	1812	18223	21484
2008	1414	1542	12035	13577	1550	1886	16685	20121
2009	1314	1389	12072	13461	1463	1669	16683	19815
2010	1162	1454	12456	15072	1281	1754	17024	20059
2011	1011	1395	11222	13628	1092	1672	15126	17890
2012	899	1192	10226	12317	976	1443	13675	16094
2013	802	1107	10145	12188	865	1315	13510	15690
2014	747	895	10037	11679	801	1068	13216	15085

It is well known that three parameters and their combinations, contribute to a road accident, in a variable rate: human factor, vehicle and the road infrastructure with the road environment. From these factors, road infrastructure and road environment is the second most important cause of accidents, contributing from 3% (alone) to 27% (in connection with human factor) (Figure 1, [4, 19]). Locations in which the accidents concentration (recorded number) is higher than the stochastic expected during a certain period of time, are known as black spots (also: hot spots, hazardous locations, high accident concentrations, sites with promise); this concentration is occurred for a variety of reasons connected to infrastructure problems and local risk factors and may be related to geometric design and traffic factors. In international fieldwork, there is no common unanimity about the definition and the ways of finding for black spots [5, 9, 13, 21]. As a result, there is a research interest in the investigation of the outcomes which each one of the ways of determining black spots results in. According to [9], the main factors which are taken into account in order to evaluate the performance of road safety are: Average Annual Day Traffic (AADT), curvature (length and radius), tangent length, lane width, shoulder width, accesses density, roadside hazards, sight distance, road gradient, pavement condition and speed limit.

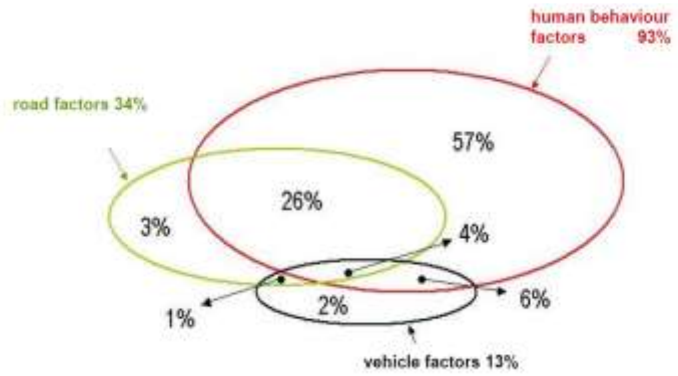

Figure 1. Road Accidents Contributing Factors [4, 19]

In this article, the most tested and widespread methods of finding black spots are presented. Then, these methods are implemented on a road section of New National Road Athens-Thessaloniki, which administratively belongs to Regional Unit of Fthiotida in Central Greece; data are referred to a period prior to transform this section from a single carriageway to a motorway. Certain methods have been implemented as a way to determine the number of black spots and to compare the number of these spots each method results (also to find out how many and which type of black spots are common among all these methods); finally, to propose an alternative combination of different methods.

2. Methods & Procedures of Finding Black Spots on Road Networks

According to Hayer [3], some investigators detect black spots towards the exposure of drivers (accidents per vehicle-kilometers), some rank them based on per-entering vehicles, some use accident frequency (accidents per year or accidents per km-year), some use accident gravity and others use a combination of the aforementioned methods. According to Geurts and Wets [13], the ranking of a road subsection as a black spot should be defined by a comparison of accident rate or accident frequency with a critical value (threshold); this value should be exceeded by the above rate or frequency for this road section, in order to be defined as a black spot. In order to take a relevant decision, quality statistical tests make up a fundamental tool. As an inextricable part of the process, in situ inspections should be taken into consideration; in these inspections all the elements which contribute in the rise of road risk should be recognized, such as faults in construction, faulty road design, lack of maintenance, inappropriate or deficient traffic signs, lack of visibility, slippery road, faulty invocation etc. Following this procedure, unitary road sections for which ways of finding black spots show as hazardous but nothing in road infrastructure suggests as dangerous, are excluded from black spots.

In short, in order to define black spots, all the following steps should be followed:

1. data collection about traffic and accidents,
2. data procession,
3. finding places with a high number of accidents by using a vigorous method,
4. accident's analysis in each one of these places and
5. in-situ inspection in these points, as referred before.

In case of finding the cause of these accidents, then these positions are named as black spots and ways of treatment in each location are proposed in order to improve road traffic safety. Finally, hazardous positions are classified and are assessed by the way and the cost of restoration, as a way to order the necessary interventions [14].

Based on bibliography, the most common and premier methods of finding black spots (hazardous places) are the following:

- crash frequency,
- random Poisson distribution,
- accident rate R, or number,
- gravity rate (index) Gr,
- quality control,
- the empirical Bayes method and
- potential for improvement.

In general, all the above methods should be applied in road sections with similar geometric and traffic features. Each one of the road section is divided into unitary sections with specific length. Inevitably, this elementary length constitutes a function of the accurate recording of road accidents; this length is usually around 1 km for interurban roads.

2.1. Methods of Black Spots Identification

Crash frequency

Crash frequency is the simplest hot spots identification method. A road section is divided in similar unitary length and then they are ranked in descending order of crash frequencies.

Poisson distribution

According to the random Poisson distribution, for a certain confidence level, firstly the critical number of accidents for a unitary road section is estimated; this number makes up the threshold, the overrun of which means that the number of accidents which takes place in the section of the road is not statistically random and the section is hazardous. Despite the fact that this method is statistically excellent, it doesn't take into account the traffic volume and the gravity (significance) of accidents; these elements are the main disadvantages of this method [12].

Accident rates

Accident rates could be implemented in order to define black spots. In general, accident rates are the deduction of number of accidents in relation to a specific parameter (denominator). Such parameters could be the number of vehicle-kilometers travelled (VKT), the number or cost of accidents per vehicle-kilometer or per registered vehicle, the number of inhabitants, the length of the road network or the total number of vehicles. The most common index takes into consideration the exposure in possible accident, as this is expressed by the vehicle-kilometers travelled (index R). Index R is calculated as shows in formula (1).

$$R = \frac{Z * 10^6}{Q * L * T} \tag{1}$$

where:
R is accident rate (*i.e.*, accidents per million VKT),
Z: number of accidents,
Q: yearly main traffic volume,
L: length of the tested section of road (in km) and
T: period of time under which accidents are taken place.

In this method, there is a comparison between the number of accidents in each unitary road section and the total accident rate of the road, multiplied by a coefficient (usually 1,2 or 1,5). The main disadvantage of this method is that it doesn't take into consideration the severity of road accidents, so for this reason it receives criticism.

In general, accidents in a few defective unitary road sections could very often be serious (serious injuries or deaths), due to serious problem in road infrastructure and objective conditions (*i.e.*, high V_{85}). This fact should play an important role in the ranking of these unitary road sections as black spots; so, accident gravity should be a parameter which is being used to define these spots.

Gravity Rate

Gravity is often determined by the financial evaluation of the road accidents consequences, which is damages, injuries and deaths. A typical formula which is used in order to calculate gravity rate shows in equation (2),

$$Gr = \frac{(N*p_1 + T*p_2)*10^6}{365*Q*L*t} \tag{2}$$

where:
N: number of deaths,
T: number of injuries, p_1 and p_2 gravity coefficients,
Q: main traffic volume,
L: length of the tested section of road (in km) and
t: period of time under which road accidents are taken place.

In the numerator, the evaluation of the severity of road accidents can be represented with the intended accuracy. A gradation among deaths, serious injuries, light injuries and possible damages can be introduced; so, these parameters can be differentiated. As the description of the consequences of road accidents is more detailed, more reliable and analytical accident data are required. In Greece such detailed and reliable data are usually not provided. Whereas the above statement and based on financial features, a gravity coefficient p_1=45 for deaths is typically used; respectively, the coefficient which is often used for the injuries is p_2=5. Following the estimation for gravity rate for each unitary section and the mean for the whole road sections, the threshold is estimated by multiplying the mean gravity rate with an incremental coefficient (usually 1,2 or 1,5). The road sections in which their gravity rate is greater than the incremental mean value for the whole road are referred as black spots. This method uses the severity of road accidents, so it gives an answer to the critical thoughts for the previous methods. However, there is a possibility a position, where a single random event of a serious road accident, with a certain number of deaths, has been occurred, to be named as hazardous. Hence, the objective dangerousness (*i.e.*, road features) should be taken into account as well.

Quality Control

A very common method which is used to determine hazardous road positions is named quality control. In this method for each road section with same traffic volume and geometric features, the mean of accidents per kilometer is calculated. Afterwards, based on table of the Poisson probabilities, the lowest level for a certain confidence interval (*i.e.*, 95%) is found; after that, the critical rate of accident is calculated (3),

$$R_i = R_a + k*\sqrt{\frac{R_a}{M} + \frac{1}{2M}} \tag{3}$$

where:
R_i is the critical accident rate (*i.e.*, accidents per million VKT),
R_a: mean average accident rate for all the road sections with similar features,
K: probabilistic parameter set by the desirable statistical confidence interval for R_i and
M: number of vehicle-kilometers.

In this method, also, if the number of accident on a road section is equal to or higher than the critical rate, then this is not considered a random incident, but is due to the objective infrastructure hazardousness. Severity of the accidents isn't taken into account in the quality control method, too.

The empirical Bayes

The empirical Bayes approach to road safety [6, 17] makes it possible to provide unbiased estimates of the expected number of accidents for individual elements of the road system. This is attained by combining the recorded number of accidents with the model estimate for that site. In Bayesian statistics anything about which is uncertain, including the true value of a parameter (such as the true accident frequency at a location), can be thought of as being a random variable to which we can assign a probability distribution, whilst, in frequent statistics, critical parameters are fixed quantities. The difference to other methods is that Bayes approach has the aspiration to identify hazardous road locations that have an abnormally high expected number of accidents and not just a recorded one, which may attributed to data randomness. Furthermore, the Bayes approach, through before-and-after studies, can offer evaluation of black spot treatment.

More specifically, Bayes model parameters are expressed by placing a probability distribution (most commonly a negative binominal regression model) on the parameters, called the prior distribution ($p(\theta)$), that represents additional information that is available; and the dependent variable is expressed in the "likelihood," which is proportional to the distribution of the observed data given the model parameters, written as $p(y|\theta)$. All Bayesian inference is based on the posterior distribution, which is produced by a combination of (θ) and $p(y|\theta)$. In Bayes' theorem, the posterior is proportional to the prior times the likelihood, or more precisely:

$$P(y|\theta) = \frac{p(y|\theta) * p(\theta)}{\int p(\theta) * p(y|\theta)\, dx} \tag{4}$$

It is commented that the empirical Bayes approach is not widely applied in Europe, as much as in North America [2].

Potential for Improvement

Rather than using overall accident frequencies at sites, what is really of importance is the potential of accident reduction [1, 7]. These methods rest on the premise that only ‘excess’ accidents over those expected from sites with similarities can be prevented by applying appropriate treatments. The potential for improvement is the difference between the recorded number of accidents and that predicted by models like Poisson or empirical Bayes. When the potential for improvement is greater than zero, the site experiences more crashes than expected and this may be worth improving.

Evaluation

From all the above statements, it can be deducted, that the number of black spots would depend on the method which a researcher/an agency follows: different number and hazardous places would result by different methods. Methodology of black spots identification varies from simple to complex and sophisticated combination of methods, whilst simplicity would always be an advantage. To evaluate these methods, certain quantitative criteria [1, 7] have been proposed, like the site consistency test, measuring the ability of a method to identify high-risk sites over different observation periods, the method consistency test, evaluating the repeatability of the results, the total rank difference, taking into account the safety rankings of various road sections during two time periods and the false identification test, where the actual hot spots are known and the methods are evaluated against how few false identifications predict. The simple accident rate method performs better on site consistency test as well as predicts fewer false identifications. The rather complicated empirical Bayes method outperforms in the rest two tests and ranked second in the others, thus being the most consistent and reliable one for hot spots identification. However, a road section causing fewer traffic accidents but with consistent serious casualties may be missed, unless the gravity of the accidents taken into consideration. A typical hazardous site definition may be that where the observed number of accidents exceeds either the accident prediction Poisson model estimate or the empirical model estimate by at least one standard deviation. By that definition, the empirical Bayes estimate yields fewer hot spots than Poisson model [8]. Also, a real supremacy of the Bayes method occurs where sample sizes are small [17].

2.2. Criteria for Black Spots Identification in Various Countries

National traffic safety Agencies prefer to propose, instead, a clear set of criteria and definitions to detect hazardous road locations. A great variety is also identified in these approaches. Even in the simplest but crucial parameter of road subsection unit length, one can meet a variety of definitions, from 100 m to 1 km. It is of research interest to present and summarize in a Table the different methods followed by certain countries.

Australia

In Australia, there is no universally common definition for black spots; sites are nominated as black spots after an assessment of the level of risk and the likelihood of a crash occurring at each site. Each State follows different programs to nominate a black spot area (Table 2, [23]).

Table 2. Fundamental Black Spot Identification Criteria in Australia

<table>
<tr><td>County</td><td colspan="4">Western Australia Black spot program</td><td>Federal Black Spot Program</td><td>South Australia Black Spot Program</td><td>Tasmania Black Spot Program</td></tr>
<tr><td rowspan="2">Crash criteria for intersection or mid-block or short road section (length <3 Km)</td><td>State metro roads</td><td>State rural roads</td><td>Local metro roads</td><td>Local rural roads</td><td rowspan="2">3 casualty crashes over a 5-year period</td><td rowspan="2">3 casualty crashes over a 5-year period</td><td rowspan="2">3 casualty crashes over a 5-year period</td></tr>
<tr><td>10 crashes over 5 years</td><td>3 crashes over 5 years</td><td>5 crashes over 5 years</td><td>3 crashes over 5 years</td></tr>
<tr><td>Crash criteria for road length (≥ 3 Km)</td><td>Average of 3 crashes /km over 5 years</td><td>Average of 1 crash /km over 5 years</td><td>Average of 2 crashes /km over 5 years</td><td>Average of 1 crash /km over 5 years</td><td>Average of 0,2 crashes /km/year over 5 years or top 10% of sites having the highest crash rate / region</td><td>Average of 0,2 crashes /km/year over 5 years or top 10% of sites having the highest crash rate / region</td><td>At least 1 reported crash/km within 5 years</td></tr>
<tr><td>Benefit/Cost Ratio</td><td colspan="4">≥1</td><td>≥2</td><td>≥1</td><td>Not stated</td></tr>
</table>

Austria

According to [14], scenes of accidents are distinguished in black spots and hazardous locations, depending on their recorded crash history. A hazardous location is classified as a black spot, if one of the following two criteria has to be met:

1. Three or more similar injury accidents within 3 years and a relative coefficient A of at least 0,8. The value of this coefficient is calculated as follows (5),

$$A = \frac{U}{0{,}5 + 7 * 10^{-5} * AADT} \tag{5}$$

where:
AADT is the Annual Average Daily Traffic and
U the number of injury accidents within 3 years.

2. At least 5 accidents (including property damage only) of similar type within a year.

For the above purpose, a sliding window with a length of 250 m is being used.

The critical value of 0.8 of the relative coefficient A will be reached for example if there are 3 injury accidents in 3 years and the AADT is up to 10,700 vehicles/24 hours or 4 injury accidents in 3 years and the AADT is up to 16,700 vehicles/24 hours *etc*.

Croatia

In Croatia, as happens in many other countries, a unique methodology to determine black spots is not being developed; in this country, black spots are identified based on the ranking of the number of traffic accidents on specific location. [26]. This method does not take into account all relevant parameters nor a systematic identification characteristics of black spots. There are some criteria only for roads which are supervised by the authority of the Croatian Roads. In these roads, black spot is an intersection or a road segment 300 m length or part of a road length of 300 to 1000 m, satisfying one of the following criteria:

- 12 or more accidents with injuring in the past 3 years,
- 15 or more recorded accidents regardless to consequences during a 3-year period,
- 3 or more identical accidents, with the same group of participants, same moving direction and same conflict area.

Denmark

In Denmark the definition of black spots relies on a detailed classification of the road system into different types of road sections (motorways, other dual carriageways in urban/interurban environment) and various types of intersections. In this country, data refers to a period between 3 and 5 years, and Poisson distribution is used in order to define black spots (confidence interval is 95%). The AADT volume is the major factor in order to calculate the normal expected number of accidents. In Denmark, black spot is a site with a reported number of accident which is higher than both a fixed minimum number (4 accidents during a five-year period) and much higher than the normal expected number of accidents for a similar type of roadway element.

Flanders

In this region of Belgium, hazardous segment is called a road section maximum length of 100 m where there are observed at least 3 accidents during a three-year period. These segments are called as black spots if their severity index (S) is greater than (or equal to) a fixed number (*i.e.*, 15), for a three-year period. This index is calculated as shown in equation (6),

$$S=LI+3*SI+5*DI \tag{6}$$

where:
LI is the total number of slightly injured,
SI the total number for serious injured and
DI the number of deaths for this three-year period.

Germany

In Germany, there is a definition of black spots, black sections and black areas (the last one mainly refer to urban areas); these positions are defined by a comparison between the number of accidents on them and critical thresholds, depending on the period of time (1, 2 or 3 years usually). There is an identification of spots with similar types of accidents and similar level of accident severity (fatal, serious injured, lighter injured, serious material damage, other damage), Severity is taken into account in defining black spots by reducing the critical values in serious injured accidents and injury accidents.

Hungary

In this country, there is a distinction between urban and interurban areas: the unit road section should be no longer than 1 km for outside built-up areas and no longer than 100 meters in inside-built areas. Black spots are sites where at least 4 accidents are recorded during a period of 3 years. Traffic volume is taken into account in the ranking of black spots.

Malaysia

According to Royal Malaysia Police [23], black spots are sites where more than 5 accidents are taken place within 50m radius over 3 consecutive years or more than 3 accidents of the same time within 30m radius over 3 consecutive years. However, according to the Malaysian Public Works Department, hot spots are sites with 9 or more injury accidents within 50 m of a junction (or on 200 m on a road section) over the past 3 years. An accident point weighting system was adopted by the Malaysian Highway Planning Unit; in this system the following ratio is being used for the accidents: fatals/serious injuries/slight injuries/damages only 6/3/0,8/0,2 [23].

New Zealand

In New Zealand, a threshold of 3-5 accidents over 5 years has been suggested.

Norway

In this country there is a separation between black spots and black sections. A black spot is defined as a section of road with a maximum length of 100 m, in which at least 4 injury accidents are occurred during the last 5 years and black section is a road section with a maximum length of 1 km, where at least 10 injury accidents are recorded during the last 5 years. Hazardous spots and hazardous sections are identified by applying a sliding window. Hazardous sections are often consist of several hazardous spots which are located near one another.

Poland

In Poland as a black spot section is treated a road section 1 km in length or less on which during the last 5 years has taken place 12 or more accidents.

Portugal

In Portugal, there are two ways of defining black spots. In the first one, black spots are the road sections with maximum length of 200 m, where at least 5 or more accidents are taken place; in addition to this, the severity index should be greater a fixed value (20), in the period of analysis. This severity index is calculated as shows in equation (7),

$$SI=1*LI+10*SI+100*F \tag{7}$$

where:
LI the number of slight injured,
SI the number of serious injured and
F the number of fatalities.

In the second method, a hazardous location is a geographical area where the expected accident frequency is higher than in similar areas, because of the road characteristics. In the second approach, there is a differentiation between intersection and non-intersection places. In the first case, the minimum length should be 250 m for single carriageway roads and 500 m for dual carriageway roads; furthermore, road network is classified in 6 classes and in each class a different unique accident prediction model is fitted. In these models, the most significant variable is AADT.

Switzerland

In Switzerland, a black spot is called a road subsection where the number of accident is significantly higher than the number of accident in comparable sites. There is a certain procedure in order to find these comparable sites individual for road subsections and intersections. The length of a subsection varies according to the type of road (between 100 m and 500 m, depending on the importance of the road). Accident sites are those where the number of accidents exceeds the estimated expected number of accidents based on normal accident rates. These sites are compared to threshold values in order to find out whether they are black spots or not. The threshold values vary, depending on the road type, and they refer to a period of 2 years.

United Kingdom

In Scotland, black spot is a position where 3 or more casualty accidents are taken place within 3 years in a 100 m radius. In England these criteria are set by local authorities.

United States (certain States)

In United States there is not a common approach of the issue. In Kentucky, for instance, the minimum number of crashes is 14 over 3 years in urban areas and 5 crashes over 3 years in interurban areas. The critical risk factor is calculated by dividing the actual crash rate by the average statewide crash rate for the particular type of road or intersection; this factor should be clearly greater than 1 in order to nominate a black spot. In Colorado, the weighted hazard index should be equal or greater than zero; in this index crash frequency, severity, traffic volume and statewide weighted crash average for the particular class of road or intersection are taken into account. The fundamental criteria in this state is 7 damage only or casualty crashes or 3 fatal accidents over three years [16].

Turkey

Turkey has been intentionally left as the last country, outside the above alphabetical presentation. In this country, the quality control method is used [20], together with three parameters, for each unitary road section with a length of 1 km. This statistical method is called rate-quality-control method and uses the three following indexes in order to determine black spots: 1) accident rate, 2) accident frequency and 3) severity index; each one of these indexes is compared to critical values. Black spot is a section where all these three indexes are higher than the critical values for each one respectively. In Turkey, the number of deaths per 100.000 inhabitants is comparable to Greece [19]. For this distinctiveness, Turkey approach is presented in more details.

The first index, which is accident rate, a ratio R_j is defined as shown in equation (8),

$$R_j = \frac{A_j}{m_j} \qquad (8)$$

where:
Aj is the number of accidents on section j during a certain period of time and
m_j is the number of vehicle-kilometers (in millions), on this section j during the same period of time
R_c is a threshold (critical value) for the accident rate, which is defined as follows (9),

$$R_c = \hat{\lambda} + k_a \sqrt{\frac{\hat{\lambda}}{m_j}} - \frac{0,5}{m_j} \qquad (9)$$

where:

$$\hat{\lambda} = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} m_i} = \frac{1}{n}\sum_{i=1}^{n}\frac{m_i}{\bar{m}} R_i \tag{10}$$

In these equations, λ is the estimated average accident rate for section belonging to the same population, and k_a is a constant the choice of which is based on statistical significance check. This constant is selected by the normal distribution and can take the following values:

-for significance level a=0,1%, k_a=2,576

-for significance level a=5%, k_a=1,645

-for significance level a=10%, k_a=1,282

In the accident frequency method, a section is defined as black spot only if the accident frequency A_j of this section is greater than a threshold A_c (expressed in number of accidents). The value of this threshold is defined as shown in (11),

$$A_c = F_{ave} + K_a * \sqrt{\frac{F_{ave}}{L_j}} - \frac{0,5}{L_j} \tag{11}$$

where:
L_j is the length of the road sections,
F_{ave} is the average accident frequency for the whole road (for all road sections).

A position can be a black spot if accident frequency A_j is greater than (or at least equal to) the threshold A_c.

In the third method, the gravity index, a relative gravity 3:1 between deaths and injuries, as well as between injuries and damaged vehicles is used. The severity is calculated as in (12),

Severity $S_j = 9 * I_{f,I} + 3 * I_{b,j} + 1 * I_{d,j}$ (12)

where:
$I_{f,I}$: number of fatals,
$I_{b,j}$ number of injured and
$I_{d,j}$ is the number of damaged vehicles.

After that, the following quotient is calculated (13a), as well as the variance (13b),

$$Q_{ave} = \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} A_i} \tag{13a}$$

$$\hat{\sigma}^2 = \frac{1}{n-1}\sum_{i=1}^{n}(Q_i - Q_{ave})^2 \tag{13b}$$

A road site is considered to be a black spot, if the following condition $Q_j > Q_c$ is valid. The threshold Q_c is calculated as in (14),

$$Q_c = Q_{ave} + K_a * \sqrt{\hat{\sigma}^2} - 0,5 \tag{14}$$

the variables are as previously defined.

It is noteworthy the relative low gravity for the fatal accidents which is used in this method. In addition to this, the complexity of this method should also be noticed. Furthermore, due to lack of data about the number of damaged vehicles in road accidents, the factor $I_{d,j}$ is difficult to be estimated (there are accidents with only damages for example which are not systematically recorded by police agencies).

Commenting

In the following Table 3 the European approaches to black spot definition are outlined and compared. Many variations are obvious, most distinct one, the simplest one, that of road unit length, which greatly affects accident threshold values. It seems that along interurban roads a 0,5 km unitary road length should be adopted. A 3 year analysis period seems long enough for hot spots identification. As far as the actual accident threshold, this should depend on the road type and on the traffic safety level of the country as well. It also worth's commenting a tendency to simplicity and the complete absence of more complicated yet more precise methods, like the empirical Bayes.

3. Implementation of Methods and Criteria for Black Spot Detection

For research purposes, the most widespread method for black spots identification are applied to a Greek national road section with high traffic volumes and high accident rates. This road section has recently been upgraded from a single carriageway to a dual 2-lane motorway. This is considered as an advantage, both from the road safety point of view, (due to the sharp decrease of accident risk) and having less legal and administrative complications.

The data were collected by the police agency of the Regional Unit of Fhtiotida [11, 15]; these data referred to a road section with a total length of 144 km. This section is divided into two sub-sections; the first one is a section with a length of 65 Km between the positions 117+000 Km and 181+000 Km and the second one between the positions 182+000 km and 260+000 km (Figure 2). In these subsections, the number of accidents are referred to a different timebase; in the first one the time base is 5 years (time period from 2007 to 2011) and in the second one 7 years (time period from 2005 to 2011), (Table 4). In Table 5, the road risk of these subsections is shown, as well as, the critical thresholds of the accident rates and their gravity rates.

Table 3. Overview of European Procedures & Criteria to Identify Black Spots

Country	Reference to method	Sliding window applied	Minimum number of accidents	Accident severity considered	Length of identification period
Austria	Accident rate, formula (5)	250 m	3 injuries or any 5	Yes	3 years
Croatia	Road sections ranking	300-1000 m	12 injuries or any 15 or 3 identical	Yes	2 years
Denmark	Poisson	variable length	4	No	5 years
Flanders (Belgium)	Gravity rate, formula (6)	100 m	3 and gravity > 15	Yes	3 years
Germany	Gravity indexes	accident maps	3 or 5	Yes, by different critical values	1 year (all accidents) – 3 years (injuries)
Hungary	Accident rate	1 km, urban: 100 m	4	No	3 years

Norway	Statistical test, Poisson	100 m (spot) or 1 km (section)	higher than normal 4 (spots) or 10 (sections)	via accident costs and potential savings	5 years
Poland	No	1 km	12	No	5 years
Portugal	Gravity rate, formula (7)	200 m	5	Yes	5 years
Scotland	No	200	3	No	3 years
Switzerland	Accident rate	100-500 m	set of critical values	Yes, by different critical values	2 years

Table 4. Basic Data for the Subsections of New National Road Athens-Thessaloniki

Section of PATHE (Km place)	Length (Km)	Yearly Mean Traffic Volume	Period of time	Number of accidents	Direction
117-181	65	30.000	2005-2007	150	Athens
				152	Thessaloniki
182-260	79	25.000	2005-2011	416	Athens
				442	Thessaloniki

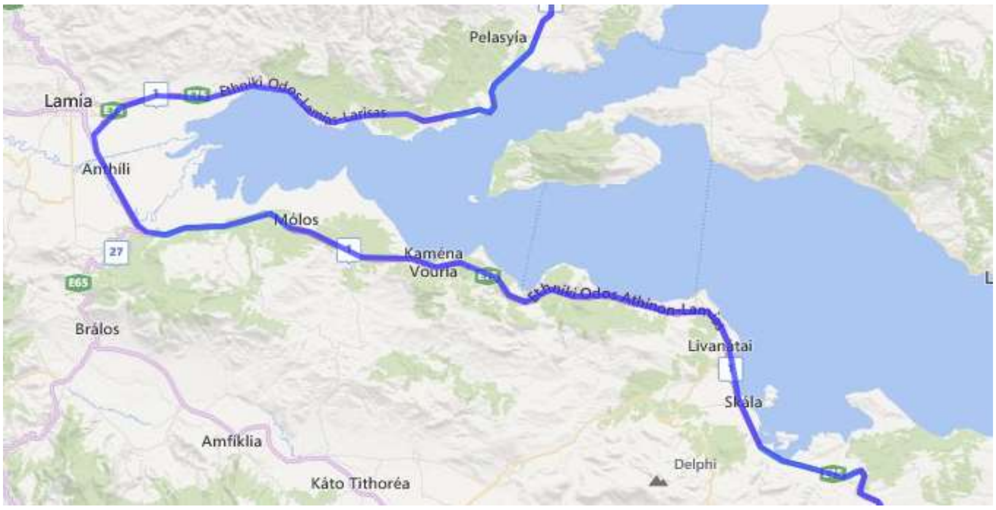

Figure 2. Section of New National Road Athens-Thessaloniki

Table 5. Number of Injuries and Rates for each One of these Subsections

Section of PATHE (Km)	Direction	Accidents /Km	Deaths	Injuries	Accident rate R	Gravity rate Gr	Accident gravity
117-181	To Athens	2,31	7	16	0,04	0,11	2,54
	To Thessaloniki	2,34	8	27	0,04	0,13	3,15
182-260	To Athens	5,27	13	73	0,08	0,18	2,22
	To Thessaloniki	5,59	18	73	0,09	0,23	2,58

The results which come from the implementation of the above methods are outlined in Table 6.

Table 6. Number of Black Spots Identified by each Implemented Method

Section of PATHE (Km)	Direction	Rate R	Accident Gr	Poisson (95%)	Section of Poisson and Gr rate	Versions applied in Turkey: Accident rate	Accident Frequency	Accident gravity	Section of the three criteria
117-181	To Athens	16	10	9	5	15	14	6	3
	To Thessaloniki	21	12	6	3	16	14	5	1
182-260	To Athens	20	12	9	7	12	10	6	4
	To Thessaloniki	24	13	9	8	16	14	8	5

Specifically, in Table 6 the number of black spots estimated by three major methods is presented (accident rate, accident gravity rate and Poisson distribution); for all these methods, the level of significance which is used was a=0,05 (confidence interval 95%). Apart from that, the number of black spots which are resulted by the section between Poisson distribution and accident gravity rate also shown (the confidence interval is still 95%). Also, an implementation of the method used in Turkey, in this section of the National Road Athens-Thessaloniki is comparatively presented. Differentiations are observed among similar methods, which are attributed to changes in probabilistic factors and gravity factors; the conclusion is that any change in probabilistic and gravity factors can result in markedly different outcomes (different number of hot spots). In the last column, the results from the section of all the three indexes (accident rate, accident frequency rate and accident gravity rate) are shown (as Turkey method requires). This last column operates as a powerful filter, significantly reducing the number of black spots. In Turkey, the number of blackspots is diminished by using a complex and erudite approach.

In Table 7 the number of black spots identified by criteria set in certain European countries are compared against those identified by major methods previously described. Available data refer to 1 km unitary road length and are, in general, impossible to be reduced to shorter subsections, hence only those country's practices at Table 3, refer to 1 km unitary road section can be used.

Table 7. Number of Black Spots Identified by Typical Methods versus Criteria Set in Certain European Countries

Section of PATHE (Km)	Direction	Method: Rate R	Rate Gr	Poisson (95%)	Section of Poisson and Gr rate	Method/criteria applied in Europe: Croatia	Denmark	Hungary	Norway	Poland
117-181	To Athens	16	10	9	5	0	8	6	2	1
	To Thessaloniki	21	12	6	3	0	6	4	2	1
182-260	To Athens	20	12	9	7	0	8	7	3	2
	To Thessaloniki	24	13	9	8	1	10	8	4	2

The great diversion of the results is obvious. Croatia set very strict criteria (combination of high number of accidents with a short reference period). Poland's criteria are also strict and filter out most potentially dangerous road sections. Hungary's black spot identification procedure is both simple and yields results quite near to the section between Poisson distribution (with 95% confidence interval) with accident gravity rate.

4. Conclusions

The identification and ranking of hazardous locations is very important towards being able to apply priority treatment, given limited budget. In the analysis preceded, the obvious conclusion that emerged is that the number of black spots constitutes a function of the followed methodology or set criteria. However, the differences which were found, have quite an important extent and that was a surprise. Generally, any change in probabilistic and gravity factors can result in different number of black spots. This magnitude of the above differentiations (sensitivity) is attributed to two reasons.

The first one refers to the different philosophy of the methods for locating black spots, either probabilistic, or taking into account mainly the accident gravity rate. The probabilistic theory is fundamentally more correct, so the gravity of accidents should be taken into account in order to reduce and rationalize the differentiations, but not in that extent that a single serious accident (with fatalities) can make a point hot by itself.

The second reason pertains to the different level of uncertainty that we accept, for a road section to be defined as hazardous. Probably for this reason, specific numbers are defined as thresholds in several countries (if these thresholds are exceeded, the unitary road section can be considered as hot), instead of a statistical overview of every similar road axis which would result in different critical values for each road section.

The answer to the first topic is probably based on the differentiation of the gravity consideration of road accidents. Gravity should be emerged, not from the grade of the social and financial consequences of each incident (evaluation of deaths, injuries and vehicle damages), but through a much milder gradation of the severity of accidents. The sense which is applied in Turkey’s methods, whereas in the first approach it seems to underestimate the value of human life, finally responds to attribute a suitable coefficient on accidents gravity, but not so decisive, that even only one fatal accident can define a black spot.

The answer to the second concern could be coped reversely: in a road section, such as for example the examined ones, of 60 and 80 km of length, which number of black spots is considered normal and manageable? The fact that 20 or even 24 (for one direction only) road points to be considered as black spots from a sole applied method, isn't it an exaggeration? Such a pragmatistic approach of black spots identification issue, would define, in an axis coarsely and depending on the overall riskiness and the Regional available budget, a target-number for the necessary spots to be treated; on these frame, the confident intervals of the analysis could be, in a rationalized way, properly adjusted.

It seems to be that a balanced approach yields as a conjunction between the clearly probabilistic methods and the methods in which gravity of accidents is taken into account. Thus, all fundamental parameters of influence could be evaluated.

If, finally, black spots are resulted from a cross-section between, for example, the Poisson distribution (or quality control) having a lower confident interval (like 90%) and accident gravity rate (with low gravity factors), then a manageable number of reliable defined black spots seems to be emerged.

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