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A Meta-analysis of the methodologies practiced worldwide for the identification of Road Accident Black Spots

Shawon Aziz[a*], Dr. Sewa Ram[b]

[a]*Research Scholar, School of Planning and Architecture, New Delhi 110002, India*

[b]*Professor, School of Planning and Architecture, New Delhi 110002, India*

Abstract

An accident Black spot (often synonymously known as a crash hotspot) is a section of road where the frequency of occurrence of several types of road accidents or a particular type of road accident is comparatively higher than other similar sections on the road. Accidents may occur on such sections of a road due to several factors such as faults in engineering design, failures in traffic rule enforcement, rash driving etc. but road accidents repeatedly occur at a location due to faults and inconsistencies in design which lead creation of an ambiguous road environment that fails to provide a positive guidance to road users. For rectifying of such road sections, it is important to identify such locations based on likelihood of occurrence of road accidents and past accident history. This paper intends to conduct a critical appraisal of the various methodologies practiced worldwide for the identification of road accident black spots and discusses their merits and demerits. The paper summarizes the key elements in the definitions of road accident Black spots and black road sections of different countries that are a part of protocol of their respective government policies. The paper at last discusses a meta-analysis of the inferences drawn out from these definitions for road accidents.

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Keywords: Road; Black spot; accident; fatalities; safety

1. Introduction

There are many definitions of accident black spots available worldwide. However; there is no comprehensive and universally accepted definition of an accident black spot (Guerts & Wets, 2003). In general, when several road accidents frequently occur in close proximity to a location, it is described as a hazardous location, more commonly known as an accident black spot (Elvik, 2007). As described in the RiPCORD-iSEREST study by Rune Elvik on State-of-the-art approach to road accident black spot management, a road accident black spot has been defined as, "any location that has a higher expected number of accidents than other similar locations as a result of a local risk factor". This paper presents a critical review of the accident black spot definitions and protocols practiced worldwide. The scope of the paper is limited to 34 Countries spread across different Continents where Researchers have worked in the recent past on accident black spot rectification and have given a reference to the protocol practiced in their respective Country for black spot identification. Scholarly articles since 1975 and up to the year 2020 that mainly focused on black spot identification have been reviewed to draw out analytical inferences from the different black spot definitions/protocols. Based on the inferences, the paper gives a way forward towards attainment of a rational approach for identification of road accident black spots.

2. Principles of Identification of Road Accident Black Spots

As shown in Fig.1, the principles for identification of accident black spots can be broadly classified into accident based and non-accident-based principles (Sørensen, 2007). The accident-based principles can be further classified into number based, statistics based, model based & accident specific principles. The non-accident-based principles can be classified into Qualitative and Quantitative principles (Taylor, J; Thompson, H.T;, 1977). The accident-based principle is based on the traditional approach of relying on past accident history for identifying Black spots (Elvik, 2007) i.e., when accidents frequently occur around a location occur over a period of time; it is declared as a black spot. Thus, it is retrospective in nature (Sørensen, 2007). It can be further classified into number based, statistics based, model based, and accident specific principles.

* *Corresponding Author : Shawon Aziz , 4 Block B , IP Estate New Delhi 110002 Telephone +919140560837 shawonaziz786@yahoo.in*

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The number-based definitions do not make any reference to the traffic volume or to the normal number of accidents, nor does it specify the type of location considered (Elvik, 2008). Thus, when the magnitude of an accident attribute (such as accident number, rate, frequency, cost etc.) is higher than the average at any location, it is regarded as a black spot. A statistical definition of an accident black spot relies on the comparison of the recorded number of accidents to a normal number for a similar type of location (Elvik, 2007). Thus, in a statistical definition, a comparison is made of an accident attribute with a threshold value for similar locations. Network screening methods such as sliding window method is generally used in combination with statistical methods to identify the start and end points of Black spots. A sliding window moves across the entire road section to identify segments that meet the threshold value and when the criterion is met, a Black spot is identified (Ghadi & Török, 2017).

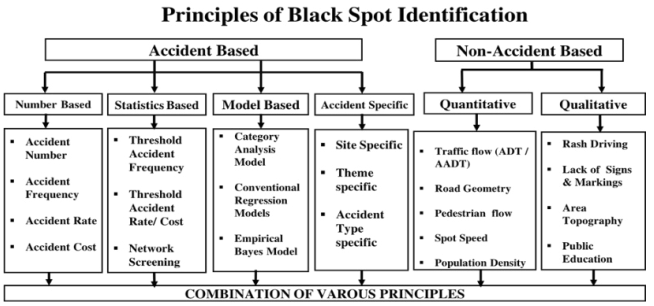

Fig1: Principles and Methods of Identification of Accident Black spots (Sørensen, 2007)

In a model-based approach, the numbers of accidents that have occurred on a location are compared with an expected number of accidents on such similar locations which have common built environment attributes and risk factors on the road (Sørensen & Elvik, 2007). An accident prediction model is, in essence, a mathematical equation that expresses the average accident frequency of an entity as a function of traffic flow and other road characteristics (Mitiku Dinsamo, 2018). A few examples of accident prediction models include regression models, accident category specific models and empirical Bayes model (Sørensen & Elvik, 2007). An example of accident prediction model is empirical Bayes model which was developed by Ezra Hauer and is extensively used in North America (Elvik, 2007).

The non-accident principle here is to identify sites with higher degree and likelihood of accidents before the actual occurrence of it. Thus, unlike the accident-based principle, this principle has a proactive approach (Laughland, Haefner, & Clough, 1975). A Researcher need not rely on past accident data on a site as this principle is based on data pertaining to road geometry, surrounding land use, road user beheaviour etc. The methods for identification of accident black spots under this principle can be based on either a quantitative or a qualitative assessment (Taylor, J; Thompson, H.T;, 1977) . The quantitative assessment of the black spot is based on quantifiable parameters such as sight distance, coefficient of friction, radius of curvature, traffic volume etc. The existing value of such parameters is compared against a threshold value. The qualitative assessment of the black spot is based on parameters such as driving skills, road user education level, cognitive capacity and expectations of the road users (Laughland, Haefner, & Clough, 1975). The advantages and disadvantages of the principles of identification of road accident black spot are illustrated in Table 1

Table 1: Advantages and Disadvantages of Blackspot Identification principle

Principle	Advantages	Disadvantages
Number based & Statistics based principles	1. Easy to interpret and apply at all places. 2. The analysis is possible without detailed road and traffic data thus analytical methodology is undemanding 3. The focus is on hazardous locations with more number of accidents	1. Results are biased towards roads with higher traffic flow 2. Road design and Traffic characteristics are not taken into account 3. Attention is not paid to random and systematic fluctuations in the data 4. Dependent on imprecise accident data from secondary sources 5. The methods are not Proactive i.e., approach is reactive and retrospective
Model based principle	1. Road design and traffic volume is taken into consideration 2. The approach is proactive and prospective 3. Systematic variation in the accident data is taken into consideration	1. Detailed data on accident, road geometry attributes and traffic data is necessary 2. Best method from theoretical point of view, its ground implementation is difficult 3. Attention is not paid to random fluctuations in data
Accident specific principle	1. Special focus on accident sites/ sub set of accident type/ theme of accident 2. Local risk factors are taken into account	1. Detailed data for such analysis is not always available 2. Approach is reactive and retrospective 3. A new method of identification needs to be adopted at every place due to varying local risk factors
Not Accident based principle	1. Proactive approach and method prospective in nature 2. The method is independent of detailed accident data	1. There is a risk of biased identification because of the use of indirect indicators 2. Detailed secondary data collection is necessary to supplement the identification methodology

3. Definition of Accident Black Spots in Various Countries

The key elements in the definitions of accident black spots which are followed in various countries for black spot management have been enlisted in Table 2. The table also shows the corresponding principle, identification method, period of observation and source of the information.

Table 2: Key Elements of Accident Blackspot Definitions practiced World wide

S. No.	Continent	Country	Total Accidents	Fatal Accidents	Injury Accidents	Spread of Black spot	Period of observation	Type of Road	Type of Area	Remark on the Definition / Protocol	Identification Principle	Identification Method	Source of Information
1	Asia	India	5	--	--	500m	3 year	National Highways	--	• 5 Road Accidents in 3 Years • Or 10 Fatalities in 3 years	Statistics Based	Accident Frequency	Govt. of India - Ministry of Road Transport and Highways (MoRTH), Circular Number- RW/NH-29011/2/2015/P&M (RSCE) dated 07.12.2015
2a	Asia	China	6 / 9	2	--	--	1 year / 5 year	--	--	• 6 Pedestrian Accidents • Or 9 injury accidents • Or 2 Fatal Accidents in 5 Years	Statistics Based	Accident Frequency & Type	The Government of China (South China Morning Post, 2010)
2b	Asia	China (Urban Area)	3	--	--	150m / 500m	1 Year	--	Urban	• Minimum 3 accidents in a year • 150m spread for Intersection • 500m spread for Road Section	Statistics Based	Accident Frequency	(Yuan, Zeng, & Shi, 2020)
3	Asia	Thailand	3	--	--	300m /500m / 1Km	1 year	High ways	--	The total length is divided into 300, 500, and 1,000-meter road sections.	Statistics Based	Accident Frequency	Department of Highways, Thailand (Mungnimi, Jierranaitanakit, & Chayanan, 2009)
4	Asia	Singa-pore	12	--	--	--	3 year	--	--	A minimum 12 accidents at the same location within 3 years	Statistics Based	Accident Frequency	Land Transport Authority Singapore (asiaone, 2015)
5	Asia	Banglad esh	--	--	--	30m	3 year	--	--	• Road Intersections are treated as black spots. • Accidents occuring within 30m of an intersection are considered • Period of Observation – 3 Years	Number Based	Accident Frequency	(Road and Highways Department Bangladesh, 2018)
6	Asia	Turkey	3	--	--	1 Km	5 year	--	--	Long road lengths with an average 3 causality accidents per km length in 5-year period	Statistics Based	Accident Frequency	SweRoad - Road Improvement and Traffic Safety Project, (Black Spot Manual, 2001)
7	Asia	Indo-nesia	--	--	--	100m / 500m	2 year	--	--	A black spot is defined as a road section or route location where the accidents have historically been concentrated • 100m spread for Intersections • 500m spread for road sections	Number based	Accident number	(Sandhyavitri, Zamri, Wiyono, & Subiantoro, 2017)
8	Africa	Tunisia	10	--	--	1 Km	5 year	--		A hotspot is any part of the road having 1000m of length and recording 10 causality crashes in 5 years	Statistics Based	Accident Frequency	(Ouni & Belloumi, 2019)
9	Africa	Tanzania	Black spot is an area which has got above average road crashes.(Note: In the source report the maximum number of crashes in a black spot is 90 road crashes and the minimum is 7 crashes.)								Number Based	Accident Number	(Tanzania. Ofisi ya Taifa ya Ukaguzi., 2012)
10	Africa	Kenya	5	--	--	--	1 year	--	--	The Kenya Traffic Police considers a black spot as a location that experiences at least five crashes per year and of related causes	Statistics Based	Accident Frequency	(Abira, Nancy; Oketch, Dr. Eng. Timothy;, 2018) 2018)
11A	North America	USA (Highways)	As per the Highway safety Manual (HSM), for an accident black spot of average window length of 0.3 miles, the number of accidents (x_i) must be greater than :- $xi > \bar{x} + \frac{CI \times SD}{n}$ Where, x_i = No. of accidents at any location , $\bar{x}$ = Average Number of accidents for similar location CI = Confidence Interval (95% to 99%) SD = Standard Deviation								Statistics Based	Sliding Window	(AASHTO, 2010) Highway Safety Manual 1st Edition 1st Edition

S. No.	Continent	Country	Total Accidents	Fatal Accidents	Injury Accidents	Spread of Black spot	Period of observation	Type of Road	Type of Area	Remark on the Definition / Protocol	Identification Principle	Identification Method	Source of Information
11 B (i)	North America	USA Kentucky State	14 / 5	--	--	--	3 Year	--	Urban / Rural	• Black spots in Urban Areas: 14 Accidents in 3 Years. • Black spots in Rural Areas: 5 Accidents in 3 Years	Statistics Based	Accident Frequency	(Meuleners & Fraser, 2008)
11 B (ii)		USA Kentucky	Critical Rate Factor (CRF) > =1 CRF is calculated by dividing the actual accident rate by state level average accident rate for that particular type of road or traffic exposure. Then all such CRFs with value above 1 are prioritized based on Benefit Cost Ratio (BCR)								Model Based	Accident Rate	(Green, E.R; Agent, K.R;, 2003)
11 C (i)	North America	USA Colorado	--	3	7	--	3 Year	--	--	• 7 Physical Damage Only (PDO) accidents • Or 7 Injury Accidents • Or 3 Fatal Accidents	Statistics Based	Accident Frequency	(Meuleners & Fraser, 2008)
11 C (ii)		USA Colorado	Weighted Hazard Index (WHI)>=0 & Binomial Probability >= 90% The model considers accident frequency, traffic volume, and a state level accident average for a particular type of road or intersection. A WHI greater than or equal to 0 with binomial probability more than 90% indicates highway sections with an accident pattern and accident frequency greater than state average.								Model Based	Category Analysis Model	(Colorado Department of Transportation , 2007)
12 A	Europe	Austria	--	--	3	250m	3 year / 1 Year	--	--	A Blackspot is either a 250m road stretch where 3 or more injury accidents have occurred in 3 years and has a risk coefficient R_K of at least 0.8. $R_K = \frac{\text{Total } injury\ accidents in\ 3\ year}{0.5 + 7 \text{ x } 10^{-5} \text{ x } AADT}$	Statistics Based	Accident Frequency & Sliding Window	(Austrian Guideline Code for Planning, Construction and Maintenance of Roads, 2002)
12 B	Europe	Austria	5	--	--	250m	1 Year	--	--	Or a Black spot is a Road stretch with at least 5 similar type of accidents (Including Property damage accidents) in 1 year	Statistics Based	Accident Frequency	(Austrian Guideline Code for Planning, Construction and Maintenance of Roads, 2002)
13	Europe	Belgium	3	--	--	100m	3 Year	--	--	The 100m sites with minimum 3 accidents in 3 years and having a Priority score above 15 are termed as Black Spots. Priority score =Light Injuries + (3 x Serious Injuries) + (5 x Fatal Injuries)	Statistics Based	Accident Frequency & Sliding Window	(Geurts & Wets, 2003)
14	Europe	Germany	5 / 3	--	3	--	1 / 3 Year	--	--	Accident points are plotted on accident pin boards on a map which exceed the critical values in any of the following: • 1 Year Map – 5 similar type of Accidents. • 3 Year Map – 5 Injury Accidents. • 3 Year Map – 3 Grievous Injury Accidents	Statistics Based & Accident Specific	Accident Frequency & Accident Type	(Andreas, Brannolte, Tanneranon, & Koren, 2007)
15	Europe	Norway	--	--	4 / 10	100m	3 / 5 Year	--	--	• Black Spot: 4 Injury accidents in 3 years in 100m road stretch • Black Section: 10 Injury accidents in 5 years in 100m road stretch	Statistics Based	Accident Frequency & Sliding Window	(Sørensen & Elvik, 2007)
16	Europe	Hungary	--	--	4	1000m / 100m	5 year	--	Built-up / Non-Builtup Area	• The length of the road sections is less than or equal to 1000m in Non-built-up areas • For Built-up areas the length of the road sections is less than or equal to 100m	Statistics Based	Accident Frequency & Sliding Window	(Sørensen & Elvik, 2007)
17 A	Europe	Portugal	5	--	--	200m	1 year	--	--	At least 5 accidents in a year and Severity Index greater than 20	Statistics Based	Accident Frequency & Severity Index	(Sørensen & Elvik, 2007)

S. No.	Continent	Country	Total Accidents	Fatal Accidents	Injury Accidents	Spread of Black spot	Period of observation	Type of Road	Type of Area	Remark on the Definition / Protocol	Identification Principle	Identification Method	Source of Information
										(Severity Index = 100 x No. of Fatalities + 10 x No. of Serious Injuries + No. of Slight Injuries)			
17 B	Europe	Portugal	The roads are classified based on carriageway widths and for each class of road accident prediction model is fitted to accident data for a 5-year period.				5 year	--		Model is developed using following equation :- $E(\lambda) = \beta 1 \times ADT^{\beta 2} \times CW^{\beta 3} \times e^{(\beta 4 \times \mathrm{ADT}/1000)}$ Where: E(λ) is expected number of accidents in the five year period. ADT =Average Daily traffic, CW=Carriageway width, βi Parameters estimated with model fitting	Model Based	Empirical Bayes Model	(Sørensen & Elvik, 2007)
18 A	Europe	Switzerland	10	2	4	--	2 year	Motorways	--	Black Spots are defined as any location where recorded number of accidents is well above the mean number of accidents at comparable sites. Such comparable sites are defined by classifying the road system into various sections and intersections	Statistics Based	Accident Frequency	(Sørensen & Elvik, 2007)
18 B	Europe	Switzerland	10	2	4	--	2 year	Entrance/ Exit ramps	--				
18 C	Europe	Switzerland	8	2	4	--	2 year	Intersection & Open area road	Rural				
18 D	Europe	Switzerland	8	2	5	--	2 year	Open area road	Urban				
18 E	Europe	Switzerland	10	2	6	--	2 year	Intersection	Urban				
19	Europe	England	--	--	12	300m	3 year	--	--	Black spots are defined as Road Sections of length 300m with a minimum off 12 injury accidents in 3 years	Statistics Based	Accident Frequency	(Mungnimi, Jierranaitanakit, & Chayanan, 2009)
20	Europe	Scotland	3	--	--	100m	3 year	--	--	Black spots are defined as geographical areas of radius 100m with at least 3 casualty accidents in 3 years	Statistics Based	Accident Frequency	(Transport Scotland, 2007)
21	Europe	Czech Republic	3	--	--	250m	1 year	--	--	Black spots are identified by a sliding window of 250 m length, which meets a condition of at least three injury accidents in one year	Statistics Based	Accident Frequency & Sliding Window	(Ambros, Havránek, Valentová, Křivánková, & Striegler, 2016)
22	Europe	Denmark	4	--	--	--	5 Year	--	--	The expected number of accidents is estimated through regression analysis and compared with registered number of accidents. Minimum 4 Number of accidents must be recorded during a period of 5 years. The level of significance of statistical test must be 5%.	Model Based	Regression Analysis Model	(Sørensen & Elvik, 2007)
23 A	Australia	New Zealand	3 to 5	--	--	30m	5 Year	--	Rural	Historically five (sometimes three) injury accidents have been adopted as a trigger level for clusters	Statistics Based	Accident Frequency	(Land Transport NZ, 2004)

S. No.	Continent	Country	Total Accidents	Fatal Accidents	Injury Accidents	Spread of Black spot	Period of observation	Type of Road	Type of Area	Remark on the Definition / Protocol	Identification Principle	Identification Method	Source of Information
										worthy of consideration for rural clusters or small urban centres. PDO accidents can be considered if injury accidents are sparse			
23 B	Australia	New Zealand	10 to 15	--	--	250m	5 Years	--	Urban	Traditionally 30 m and 250 m radii have been adopted for urban and rural sites respectively. On a busy urban network 10–15 accidents may be an appropriate trigger level	Statistics Based	Accident Frequency	(Land Transport NZ, 2004)
24 A (i)	Australia	Australia (Western Australia State)	10 / 3	--	--	<= 3Km Or >= 3Km	5 Year	State Metro Road	Urban	• Black Spots: 10 Accidents in 5 Years and spread less than 3Km • Black Sections: A Minimum average of 3 accidents per Km for over 5 year period	Statistics Based	Accident Frequency	(Meuleners & Fraser, 2008)
24 A (ii)	Australia	Australia (Western Australia State)	3 / 1	--	--	<= 3Km Or >= 3Km	5 Year	State Rural Roads	Rural	• Black Spots: 3 Accidents in 5 Years and spread less than 3Km • Black Sections: A Minimum average of 1 accident per Km for over 5 year period	Statistics Based	Accident Frequency	
24 A (iii)	Australia	Australia (Western Australia State)	5 / 2	--	--	<= 3Km Or >= 3Km	5 Year	Local Metro Roads	Urban	• Black Spots: 5 Accidents in 5 Years and spread less than 3Km • Black Sections: A Minimum average of 2 accidents per Km for over 5 year period	Statistics Based	Accident Frequency	
24A (iv)	Australia	Australia (Western Australia State)	3 / 1	--	--	<= 3Km Or >= 3Km	5 Year	Local rural roads	Rural	• Black Spots: 5 Accidents in 5 Years and spread less than 3Km • Black Sections: A Minimum average of 2 accidents per Km for over 5 year period	Statistics Based	Accident Frequency	(Meuleners & Fraser, 2008)
24 B	Australia	Australia Southern Australia State	3 / 0.2	--	--	<= 3Km Or >= 3Km	5 Year	--		• Black Spots: 3 Accidents in 5 Years and spread less than 3Km • Black Sections: A Minimum average of 0.2 accidents per Km for over 5 year period	Statistics Based	Accident Frequency	(Meuleners & Fraser, 2008)
24 C	Australia	Australia Tasmania State	3/ 1	--	--	<= 3Km Or >= 3Km	5 Years	--		• Black Spots: 3 Accidents in 3 Years and spread less than 3Km • Black Sections: A Minimum average of 1 accident per Km for over 5 year period	Statistics Based	Accident Frequency	(Meuleners & Fraser, 2008)
25	10 TRACECA Member Countries		--	4	--	300m	3 Year	--		Countries : Armenia, Azerbaijan Georgia, Kazakhstan, Kyrgyzstan, Moldova Tajikistan, Turkmenistan , Ukraine, Uzbekistan	Statistics Based	Accident Frequency	(TRACECA, 2015)

4. Inferences from Accident Black Spot Definitions

Several inferences can be drawn from the Table 2 of the paper regarding definitions of accident black spots of various countries. A few notable inferences are enumerated as follows: -

(i) As shown in Fig 2, 32 countries (94% of the sample size under review) use accident frequency as a method to identify black spots followed by 6 countries adopting Sliding window method in combination with accident frequency.

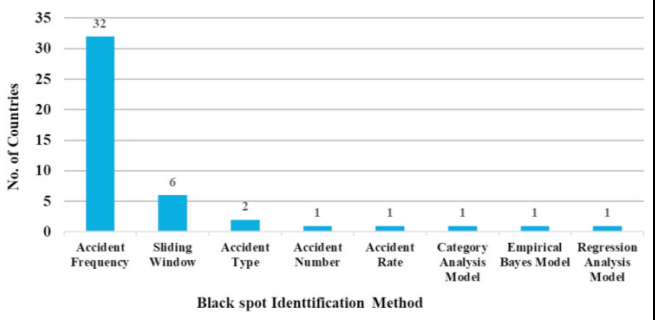

Fig 2: Classification of Countries based on identification method

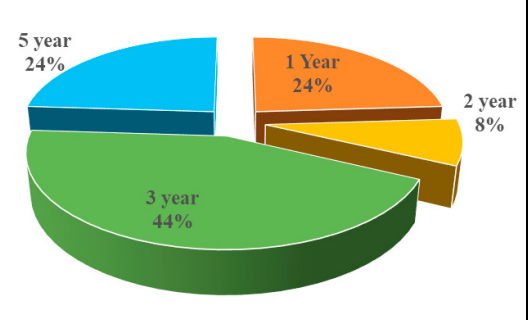

Fig 3: Period of Observation (in Years)

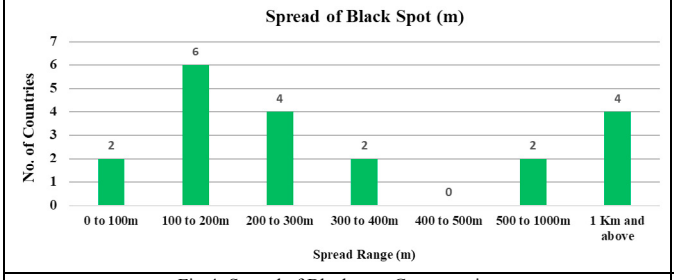

Fig 4: Spread of Black spot Country wise

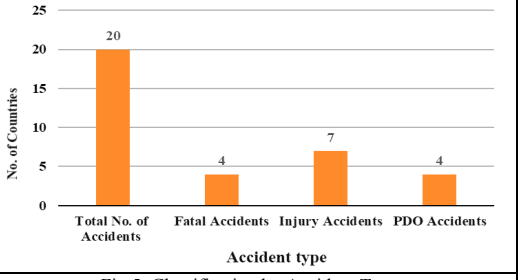

Fig 5: Classification by Accident Type

(ii) As shown in Fig 3, 44% of the countries have a period of observation of 3 years for past accident history followed by 24% of the countries having a period of observation of 5 years and 1 year each. Only 8% of the countries were found to have a period of observation of 2 years.

(iii) As shown in Fig 4, 6 countries were observed to be have defined their linear spread of a black spot in the range of 100-200m followed by 4 countries having spread in the range of 200 to 300m and 4 other countries with spread beyond 1Km. Two countries each were observed to have a spread of black spot in the ranges of 0 to 100m, 300 to 400m and 500 to 1000m respectively.

(iv) As shown in Fig 5, 20 Countries have been found using total number of accidents (fatal + injury) as a criterion for identifying black spots followed by 7 countries using injury accidents. 4 countries have been found using Fatal accidents as the identifying criterion while there are 4 countries that also take into consideration the physical damage only (PDO) accidents while defining black spots

5. Conclusion

Accident black spot definitions that are practiced in about 34 countries worldwide have been reviewed in this paper. A critical review suggests that 94% of the countries that have been studied use accident frequency method to identify black spots. Most of the countries have not taken into account the notable features such as road hierarchy, land use and area type (Urban/Rural) into consideration while defining black spots. Few countries such as USA, Australia, China, Switzerland, Hungary and New Zealand classify black spots based on area type. In Australia and Switzerland, in addition to area type, black spot definitions also take into account the hierarchy and functional classification of roads. While defining black spots, the physical damage only accidents (PDO) have not been taken into consideration by most of the countries except for USA Australia, New Zealand and Austria. In case of China, a special attention has been given to accidents that involve causality of Pedestrians. In European countries like Belgium and Portugal, black spots are identified based on a cumulative score of fatal, serious injury, minor injury and property damage accidents taking place at a spot. The scores to such accidents are assigned based on their severity and damage caused to life and property. Furthermore, a differentiation between black spots and black road sections is also performed by only two countries namely Australia and Norway (longer road segments). A unique feature in the black spot protocol of India (applicable on National Highways) is that the magnitude of fatalities as a result of road accidents at a location has also been taken into account while framing the accident black spot definition.

Hence, it can be seen that there is a very little consensus in the methodologies and criteria practiced in different countries. The sole purpose of defining a black spot is to efficiently implement an accident blackspot management program run by various government organizations. Thus, keeping in mind the vision of a country towards attainment of safer roads, a rational approach is

required to be developed for identifying black spots owing to the diverse and dynamic characteristics of traffic, land use, topography, hierarchy and the geometric attributes of a road. Thus the methodology for identifying Black spots should address the following issues:

1. The attributes such as traffic volume, land use, topography, road design elements etc. must be taken into account in order to identify the local risk factors.
2. The random fluctuations in recorded data should not affect the identification criteria.
3. The hierarchy of road and its functional classification must be considered while identifying the local risk factors
4. The methodology should explore spatial relation between accidents (if any) at a black spot and recognize any formation of spatial clustering pattern of accidents.
5. The identification methodology must be practical and easy to implement and it should not require very detailed data which may not be available at all places

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