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Pedestrian fatality and natural light: Evidence from South Africa using a Bayesian approach

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ABSTRACT

In this paper we use a Bayesian approach to investigate the relationship between pedestrian fatality records from Tshwane and time of fatality. Time of fatality is used as a proxy to reflect the presence of effective lighting, not precluding the presence of any other lighting intervention. In South Africa, for a large proportion (60%) walking is a primary means of transport, with about 45% of all deaths on South African roads being pedestrian. Such reports call for attention to be devoted to analyzing pedestrian fatalities records to locate possible directions of intervention. Results from this analysis reveals that not only does time of day influence pedestrian fatality counts, but also within road types, Municipal roads were the most prone to pedestrian fatalities followed by National roads, while the Regional roads were the least prone to pedestrian fatalities.

1. Introduction

This paper examines one infrastructure improvement that could reduce the incidence, and possibly severity, of pedestrian accidents, namely lighting. Bayesian modeling is used to show the significance of lighting on pedestrian fatalities. Lighting to improve visibility, is an intervention that can more easily be implemented than other interventions such as behavioral changes or large infrastructure setups. For a large proportion (60%) of the South African population, walking is a primary means of transport (DEAT, 2004). With 45% of all deaths on South African roads being pedestrian (Road Traffic Management Corporation), it is evident that attention be given to the problem of reducing pedestrian fatalities. Pedestrian facilities may be an important influencing factor on pedestrian fatalities, such as street infrastructure furniture (e.g. traffic control devices) and infrastructure such as curb ramps, grade passes, crosswalks, traffic calming devices and center refuge islands.

There have been studies that have examined pedestrian facilities, however not all have examined the issue of lighting. Roberts et al. (1995), LaScala et al. (2000) and Agran et al. (1996) examined pedestrian environments and facilities, not including lighting. Some of the factors that were identified were demographics, parked vehicles, city design and traffic. It is possible that in the countries where these studies were conducted lack of lighting is not an issue. A study conducted by Braddock et al. (1994) used GIS to plot child pedestrian accidents, in which various characteristics were examined, including time of day. The authors created four time groups (6 AM–10 AM, 10 AM–2 PM, 2 PM–6 PM, 6 PM–10 PM), with the group 2 PM–6 PM being the most prominent time for child pedestrian accidents to occur. Rivara and Barber (1985) conducted a study on demographic analysis of childhood pedestrian injuries and showed how for children, majority of accidents occurred after school hours, however in the light hours. In a study conducted by Brysiewicz (2001), the author notes that majority of the pedestrians involved in a pedestrian accident were wearing dark clothes at the time of the accident. This is significant in that with better lighting these pedestrians may be more visible and thus reducing their risk of being involved in a pedestrian accident. The author also comments how a large percentage of these incidents occur in and around informal settlements. The author further comments on how lack of specific facilities such as pedestrian crossings has influence on this problem. Cottrell and Pal (2002) examined pedestrian data, and explained how night time pedestrian activity should be better accommodated since over 50% of fatal crashes in Utah in the year 2000 occurred at night. The authors advise that in order to more fully understand this, an assessment of lighting and pedestrian visibility needs to be undertaken. A study conducted by Odera et al. (1997) examining road traffic injuries in developing countries showed that majority of accidents occur between 6 in the evening and mid night. Further, the authors comment how with less traffic the risk and probability of injury is much higher than during the day. In this backdrop, we present below the motivation for conducting this study in the context of South African roads and pedestrian fatalities.

In South Africa there has been some research on pedestrian fatalities and facilities, for instance, Ribbens (2002) examined strategies to promote the safety of vulnerable road users. Within this work there is a section promoting pedestrian visibility especially school children. It was noted that a large percentage of pedestrian injuries occur between 6 and 10 in the evening, or in bad weather, both conditions that have compromised visibility. Moeketsi (2002) explains how different interventions for pedestrians have been attempted in South Africa, one such being bettering the roadside environment, however, lighting was not specifically mentioned. In the paper by Mabunda et al. (2008) it is noted how in developed countries the most vulnerable pedestrian group is that of the elderly and the very young while in developing

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countries the most vulnerable group is the economically active sector namely working adults. The authors then examined the recorded fatalities according to month, day and time when they occurred, and observed that September and June had the highest number of fatalities while January had the lowest recorded number. Most fatalities occur on Saturdays followed by Sundays and Fridays. For time of day the authors note how over 45% occur between 18:00 and midnight. For people younger than 20 years the most occurred in the afternoons. The authors of the paper explain how engineering interventions such as sidewalks, road side barriers, pedestrian bridges, crossings and street lighting are some measures that might be particularly effective in reducing pedestrian fatalities.

Ribbens (1996) notes how the highest incidence of pedestrian accidents occurs in the late afternoon and early evening, weekend days being particularly frequent. The author also noted how a large proportion of pedestrian accidents involve an adult. Ribbens (1996) explains some problems that may have a large impact on pedestrian accidents and fatalities such as lack of walkways, lack of signs, lack of guardrails and lack of lighting. In the draft national non-motorized transport policy (2008) there is mention of the Engineering manual to plan and design safe pedestrian and bicycle facilities which was published in August of 2003, and how there was no supportive legislation to make it enforceable. Within this policy it is explained how pedestrian facilities do not only include walkways or pavements but also traffic calming features underroad passes and over road passes. They talk of the importance of street lighting, surveillance and pavements as well as safety and security on pavements.

In this paper we focus on investigating the effect visible lighting conditions on pedestrian fatality. We analyze the pedestrian fatality data as an outcome of a Poisson process and evaluate the Poisson process parameter separately for the light condition and non-light condition, and we further do the same for the three road types. The purpose is to use empirical results to obtain possible hotspots for lighting intervention to reduce pedestrian fatalities. The rest of the paper is structured as follows: in Section 2 we discuss the method used; in Section 3 we discuss the pedestrian fatality data from Tshwane; in Section 4 we discuss the results obtained from the analysis; while Section 5 concludes.

2. Methods

The objective in this paper being to investigate the pedestrian fatality pattern in the natural light and non-natural light conditions at the accident site, irrespective of whether any other source of illumination existed, we categories each reported fatality into one of the two types, with $\mathcal{L}$ denoting the natural light condition, and $\mathcal{L}^c$ denoting the non-natural light condition. Since the day-light hours in Tshwane differ from winter to summer, a judgment was done when categorizing the time of fatality into the $\mathcal{L}$ and $\mathcal{L}^c$ as follows: for summer months (January, February, March, April, September October, November and December) the day-light natural visibility times ($\mathcal{L}$) were taken as between 06:00–20:59; for winter months (May, June, July and August) the day-light natural visibility times ($\mathcal{L}$) were taken as between 09:00–17:59. The rest of the accident times were categorised as $\mathcal{L}^c$.

The layout of the Tshwane three major road types are depicted in Fig. 1. 450 pedestrian fatalities were reported to the nearest police station from where it occurred during the period considered. These records contained the month, road type and time of the accident. The months spanned January-2007 to April-2009, road types were one of three, namely, National, Regional or Municipal, and the time of accident. In the next section, we present the model description used to analyze the data.

3. Model

Without considering the Bayesian setup, the exact $100(1-\alpha)\%$ confidence interval of the Poisson parameter using the formula that

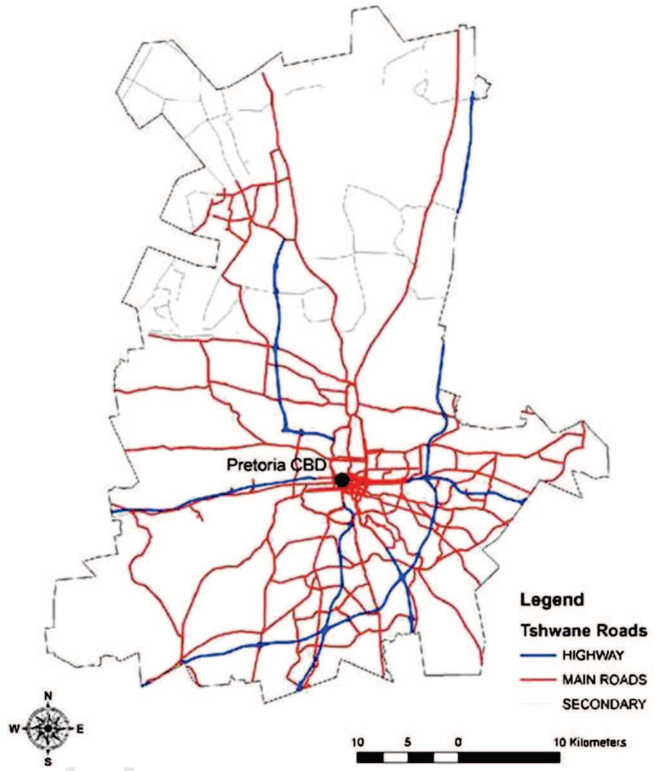

Fig. 1. Road network in Tshwane Municipality. Highways, Main Roads and Secondary legends correspond to the National, Regional and Municipal types respectively. Source: CSIR.

Table 1
Number of pedestrian fatalities in the study period, by road type and natural light condition.

Month	National (1)			Regional (2)			Municipal (3)			All		
	$\mathcal{L}^c$	$\mathcal{L}$	Total	$\mathcal{L}^c$	$\mathcal{L}$	Total	$\mathcal{L}^c$	$\mathcal{L}$	Total	$\mathcal{L}^c$	$\mathcal{L}$	Total
Jan-07	0	0	0	0	1	1	6	5	11	6	6	12
Feb-07	0	1	1	0	1	1	9	5	14	9	7	16
Mar-07	2	0	2	2	0	2	12	8	20	16	8	24
Apr-07	1	1	2	1	1	2	10	13	23	12	15	27
May-07	1	2	3	2	0	2	9	5	14	12	7	19
Jun-07	5	1	6	0	0	0	2	6	8	7	7	14
Jul-07	4	2	6	1	1	2	6	13	19	11	16	27
Aug-07	0	0	0	2	0	2	6	11	17	8	11	19
Sep-07	0	0	0	0	0	0	10	3	13	10	3	13
Oct-07	1	1	2	0	0	0	12	4	16	13	5	18
Nov-07	2	1	3	0	0	0	5	10	15	7	11	18
Dec-07	3	0	3	1	0	1	11	9	20	15	9	24
Jan-08	2	0	2	0	0	0	3	5	8	5	5	10
Feb-08	2	0	2	0	1	1	6	4	10	8	5	13
Mar-08	4	0	4	2	1	3	5	8	13	11	9	20
Apr-08	3	2	5	0	0	0	7	5	12	10	7	17
May-08	0	1	1	4	0	4	7	3	10	11	4	15
Jun-08	1	1	2	2	3	5	6	1	7	9	5	14
Jul-08	2	1	3	2	2	4	3	3	6	7	6	13
Aug-08	2	0	2	4	0	4	6	5	11	12	5	17
Sep-08	2	0	2	1	1	2	8	1	9	11	2	13
Oct-08	1	0	1	2	1	3	3	4	7	6	5	11
Nov-08	0	0	0	0	3	3	1	2	3	1	5	6
Dec-08	4	1	5	3	0	3	5	4	9	12	5	17
Jan-09	0	0	0	2	0	2	2	2	4	4	2	6
Feb-09	1	0	1	2	0	2	8	7	15	11	7	18
Mar-09	1	1	2	1	1	2	5	3	8	7	5	12
Apr-09	7	0	7	2	2	4	3	3	6	12	5	17
Total	51	16	67	36	19	55	176	152	328	263	187	450

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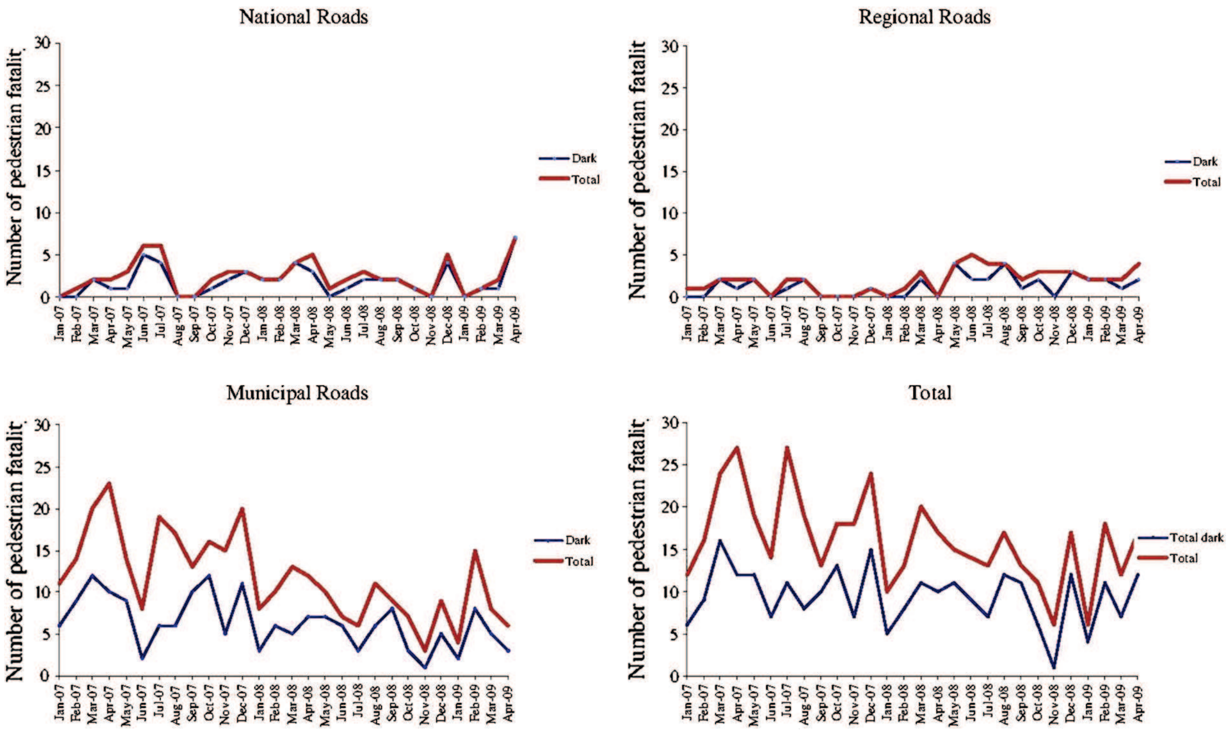

Fig. 2. Pedestrian fatality by road type between January 2007 and April 2009 in Tshwane.

relates the chi-square and Poisson distributions (Johnson and Kotz, 1969; Stuart and Ord, 1994) is given by:

$$l = \frac{\chi^2_{\frac{\alpha}{2},\ 2T}}{2} \tag{1}$$

$$u = \frac{\chi^2_{1-\frac{\alpha}{2},2T+2}}{2}. \tag{2}$$

Here, T is the number of blocks, or months, during the data period, and $\chi^2_{a,v}$ is the $(100 \times \alpha)$th centile of the Chi-square distribution with v degrees of freedom. (l, u) are the exact confidence interval around the point estimate of the Poisson parameter, which is the simple sample mean. However, we proceed with a Bayesian approach because we believe that the Poisson parameter itself can have a distribution, and thus develop a Bayesian model to capture the process generating the pedestrian fatalities under different natural light conditions. Let x_{ij} denote the number of pedestrian fatalities in the jth time-block from the ith group, where $j = 1, \ldots, T$, the total number of time-blocks in the data period, and $i = 1,2$ corresponding to the two groups $\mathcal{L}^c$ and $\mathcal{L}$ respectively. Since x_{ij} are discrete events, we assume that they follow a Poisson probability distribution $P(\lambda_i)$, with corresponding expected values of the distribution being λ_i. We use Jeffreys' non-informative reference prior (Jeffreys, 1961) for the Poisson parameter. The Jeffreys' prior, though improper (as it does not integrate to 1), results in the posterior distribution to be a Gamma distribution. The non-informative Jeffreys prior for the Poisson parameter is given by

$$\pi(\lambda) \propto \frac{1}{\sqrt{\lambda}}. \tag{3}$$

Let $Data_i = \{x_{ij}, j = 1,\ldots,T\}$, for $i = 1,2$. Using Bayes's theorem, the posterior distribution of λ_i is given $\pi(\lambda_i \,/\, Data_i) \propto L(Data_i \,/\, \lambda_i) \times \pi(\lambda_i)$, where $L()$ denotes the likelihood function of the Poisson events. Assuming that the number of accidents in the time-blocks are independent of each other, the complete form of the posterior distribution for $i = 1,2$ is

$$\begin{aligned} \pi(\lambda_i|Data_i) &= L(Data_i|\lambda_i) \times \pi(\lambda_i) \\ &\propto \prod_{j=1}^{T} e^{-\lambda_i} \lambda_i^{x_{ij}} \times \frac{1}{\sqrt{\lambda_i}} \\ &\sim \mathrm{Gamma}\left(\sum_{j=1}^{T} x_{ij} + \frac{1}{2}, T\right). \end{aligned} \tag{4}$$

Since the Gamma distribution is not symmetric, we will obtain the $100(1-\alpha)\%$ highest posterior density (HPD) credible interval (CI) around the posterior estimates of the λ_is. The $100(1-\alpha)\%$ HPD for any parameter *heta* is the subset of values C of Ω such that

$$C = \{\theta \in \Omega : \pi(\theta|Data) \geq ka\}.$$

where k_a is the largest constant satisfying $P(C \,/\, Data) \geq 1 - \alpha$. The algorithm to calculate HPD is called the *Chen–Shao* algorithm (Chen and Shao, 1999; Chen et al., 2000). When the posterior is symmetric, the HPD is the same as the equal tailed CI. If the $100(1-\alpha)\%$ HDP of λ_1 and λ_2 are non-overlapping, it would indicate that the underlying processes driving pedestrian fatalities (irrespective of the road type) in the $\mathcal{L}$ and $\mathcal{L}^c$ groups are significantly different. We can do similar analyses at a more refined scale by road types.

4. Data

Pedestrian fatality data was obtained through the Road Traffic Management Corporation that contained the following information: crash number, date and time, the police station it was reported to, the route that it occurred on, what type of accident it was, vehicle registration, number of the vehicles involved, vehicle types involved, gender, population group and road user status of the various people involved and

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Table 2
Proportion of accidents by road type and natural light condition.

	National			Regional			Municipal			All		
	$\mathcal{L}^c$	$\mathcal{L}$	Total	$\mathcal{L}^c$	$\mathcal{L}$	Total	$\mathcal{L}^c$	$\mathcal{L}$	Total	$\mathcal{L}^c$	$\mathcal{L}$	Total
Total proportion	51	16	67	36	19	55	176	152	328	263	187	450
	0.11	0.04	0.15	0.08	0.04	0.12	0.39	0.34	0.73	0.58	0.42	1

who was killed. Only police stations from Tshwane Metropolitan Area were used. Data from January 2007 to April 2009 was used, in which time 450 pedestrian fatalities were recorded for Tshwane. The distribution of the reported pedestrian fatalities in the data period, categorized by time of accident is presented in Table 1, and corresponding graphical representation is in Fig. 2.

5. Results

In Table 2 we convert the observed pedestrian fatality counts of Table 1 into proportions to get a feel of the relative representation in each category. We observe that the proportion of pedestrian fatalities under the absence of natural light ($\mathcal{L}^c$) are always higher than in the corresponding period with availability of natural light ($\mathcal{L}$). Also, the most dominant pedestrian fatality figures at 0.73% occurred on Municipal roads during the data period, and within that, proportion under $\mathcal{L}^c$ and $\mathcal{L}$ conditions were very similar at 0.39% and 0.34% respectively. This was followed by the National roads at 0.15%, where the proportion of pedestrian fatalities was almost three times more under the $\mathcal{L}^c$ condition as compared to the $\mathcal{L}$ condition. Finally, the least proportion, 0.12%, of pedestrian fatalities during the data period occurred on Regional roads, with twice as many occurring under the $\mathcal{L}^c$ condition as compared to the $\mathcal{L}$ condition.

We next proceed with the Bayesian inference on the Poisson process parameter. Based on Eq. (4), we have $T = 28$, as the data spans 28 months from January-2007 to April-2009. The HPD for the Poisson parameter under the $\mathcal{L}^c$ and $\mathcal{L}$ conditions at the aggregate level, and separately for the three road types is given in Table 3. The $100(1-\alpha)$% HPD intervals in Table 3 not only corroborate the observations from Fig. 2, for all the road types, as well as the aggregate (All), but also establish that the Poisson parameters under the two light conditions do not overlap. This lends credence to the hypothesis that in fact the underlying Poisson process driving the pedestrian fatality pattern is significantly affected by visibility. Moreover, the Poisson parameter driving pedestrian fatalities in the presence of the natural light condition is significantly smaller than when natural light is absent. Recall that 'absence of natural light' does not preclude the absence of any other artificial illumination source at the sight of the fatality.

Table 3
Bayes estimator (BE), Bayes standard error (BSE) and $100(1-\alpha)$% HPD intervals for the Poisson parameter by road type. Here $\boldsymbol{\alpha} = 0.05$.

Road type	$100(1-\alpha)$% HPD	
	$\mathcal{L}^c$	$\mathcal{L}$
All		
BE	9.375	6.661
BSE	0.018	0.016
95% HPD	(9.339, 9.411)	(6.630, 6.691)
National		
BE	1.804	0.554
BSE	0.008	0.005
95% HPD	(1.787, 1.820)	(0.545, 0.563)
Regional		
BE	1.268	0.661
BSE	0.007	0.005
95% HPD	(1.255, 1.281)	(0.651, 0.670)
Municipal		
BE	6.268	5.411
BSE	0.015	0.014
95% HPD	(6.238, 6.298)	(5.383, 5.438)

6. Discussion

The purpose of this investigation was to find whether natural lighting conditions influence pedestrian fatality patterns. Measures to curb pedestrian fatalities can be of many kinds such as enforcing stricter traffic regulations as well as more physical interventions. The former measure is related to human behaviors which is difficult to measure while the latter can range over a large cost frame from very cost intensive (overhead pedestrian footwalks, separate roads, refuge islands) to low cost intensive options (street lights). Effective lighting is a fairly easy intervention. Results from this study reveal that low pedestrian fatalities occur during effective lighting conditions, which equates to proper visibility. For a decision maker with limited funding and in the interest of influencing policy making, allocating resources for effective lighting can be an immediate and effective, as well as cost effective measure. Although this study was a preliminary investigation, none the less, it provides impetus to perform similar analysis over time and across other regions to get a temporal as well as a spatial pattern of pedestrian fatality records. Any informed intervention that can reduce pedestrian fatality events can result in a life saved.

7. Uncited reference

Road Traffic Management Corporation, 2008

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