Using satellite images to asses the effect of road lighting on the number of road accidents

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1 Introduction

Traffic safety represents an important research topic in transportation. The correlation between the risk of accident and road lighting is well known in literature. For example, Per Ole Wanvik estimated that on average the reduction of injury accident during darkness is around 30% in areas with road lighting [1]. Some other studies analyzed the influence of road lighting on traffic safety on highways [2] or in intersections [3]. A common approach in such evaluations is to compare the number of accidents occurring in the daytime with the ones occurring in the nighttime.

The presented work is not limited to a particular road type and consider most of the roads in Denmark. The analysis is based on a comparison of the number of nighttime accidents occurring in roads with different light intensity levels, accounting also for road type and flow. Moreover, this study introduces a new method to evaluate the intensity of road lighting throughout the use of satellite images. In literature, the use of satellite image in traffic safety is limited on analyzing road design [4] [5] or traffic volume [6].

2 Data

2.1 Accident

VejMan, a road management system operated by the danish road directorate (Vejdirektoratet), collects detailed information of police-reported traffic accidents occurring in Denmark. The data contain information about location, time, light condition, person, vehicle and road characteristics of the accident. The observations are categorized by severity: accident causing only material damage, light injury, severe injury or death. The period taken into consideration is between the 1st of January 2012 and the 31st of December 2016. In this period and in the municipalities that are part of the study, a total of 21.224 accidents during nighttime have been registered. *VejMan* indicates the light condition of the accident such as dark, twilight or daylight. An accident occurred in the first two cases is considered as a nighttime accident. In case the indication was missing, it is considered as nighttime the time interval between 18 and 6 from November to April and between 22 and 4 from May to October, according to the sunrise and sunset time in Copenhagen [7].

2.2 Light intensity

The Earth Observation Group of the National Oceanic and Atmospheric Administration and of the National Centers for Environmental Information, provides satellite images showing the intensity of artificial light on earth [8]. These images are obtained through the Visible Infrared Imaging Radiometer Suite which is an instrument onboard the Suomi National Polar-Orbiting Partnership spacecraft. The images available have a size of 355 x 445 kilometers which contain the surface of Denmark with the exception of Bornholm. The images contain units of size 260 x 460 meters indicating the average radiance value observed at nighttime during one month. Given that the quality of an image depends on the cloud coverage, our analysis has been based solely on cloud-free observations. For this reason, the data set has been filtered removing the images regarding the first nine months of 2012; June, July and August 2013 and June of 2014, 2015 and 2016. These images have been used to calculated average radiance level over the 5 years for each season (summer, fall, winter, spring). Figure 1 shows an example of a satellite image.

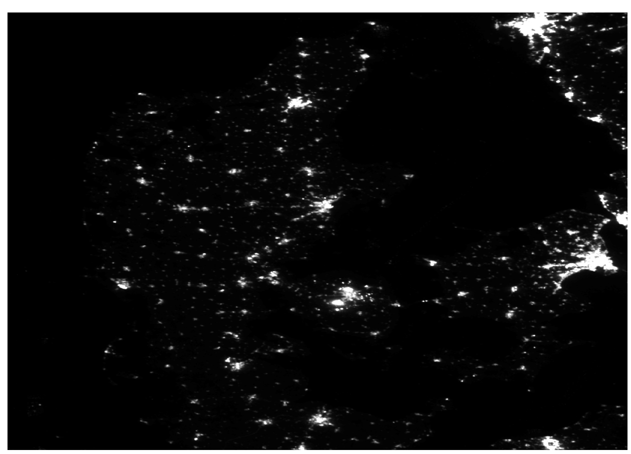

Figure 1. Example of a satellite image indicating the radiance values

2.3 Road type and traffic volume

Since the relationship between traffic volume and risk of accident is well known, it is assigned to each road the indi-

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cation of the workday annual average daily traffic volume. These indications are obtained from the Danish National Transport Model which states the traffic volume of the main roads of Denmark, for the roads not included it is assumed a value lower than 2000 vehicle per day.

In order to account the effect of road type in the analysis, it is also included the indication of whether the road is a motorway or an expressway or a regular road. These information are retrieved from *VejMan*.

2.4 Grouping

Both the satellite and accidents observations are grouped by road sections, as defined by *VejMan*, and by seasons. Given that not all the municipalities are part of *VejMan*, for 32 municipalities, out of 99, only the main roads are available. The missing municipalities are evenly distributed over the country; therefore it is assumed that the lack of municipalities does not affect the general analysis results. Consequently, the accidents occurring in roads that are not included in the data set are not considered in the analysis. The reason why the observations are also grouped by seasons is because it is assumed that the intensity of light is likely to considerably vary over the seasons (summer, fall, winter, spring).

Moreover, it is assumed that the road lighting might have different impact on the number of accidents depending on the location. For this reason, the observations are also divided between urban and rural areas.

In conclusion, the final data set indicates for each road and for each season the number of accidents occurred, the traffic volume, the light intensity and the road type. It counts 123,337 roads sections and 11,614 accidents in the urban area and 48,991 road sections and 9,610 accidents in the rural area.

3 Methodology

Negative binomial (NB) regression model is estimated in order to evaluate the impact of light intensity on the number of accident. NB is a common approach for analysing count data (non-negative and integer) and it is a generalization of Poisson regression which does not assume that the variance and the mean are equivalent. Indeed, NB assumes that the variance is a function of its mean and has an additional parameter called dispersion.

The fundamental NB regression model for an observation *i* is written as:

$$Pr(Y = y_i|\mu, \alpha) =$$

$$\frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(\alpha^{-1})\Gamma(y_i + 1)} \left(\frac{1}{1 + \alpha\mu_i}\right)^{\alpha^{-1}} \left(\frac{\alpha\mu_i}{1 + \alpha\mu_i}\right)^{y_i}$$

Where μ represent the mean incidence rate of y per unit of exposure t_i.

$$\mu_i = t_i\mu$$

However, in this case the exposure is consistent for all the observations; therefore, it take a value equal to 1 for all the observation.

The mean of the distribution, μ is assumed to be a liner function of a series of input features X and β

$$\mu_i = exp(\beta_0 + X_i\beta)$$

The dispersion parameter namely α is contained in the formula to estimate the variance of the dstribution.

$$Var[Y] = \mu + \alpha\mu^2$$

The model considers as dependent variables y_i the number of accidents occurred in a given road and in a given season while the independent variables X_i are:

- *Radiance*, road light intensity.
- *AADT*, Annual Average Daily Traffic.
- Road type, *motorway* or *expressway* or *regular road*.

The input features are all included as categorical variable which means that the value is one, if the observation is within the given category, or zero otherwise.

4 Results

In this section, the results of the analysis are presented. Table 1 shows the estimated values of the independent variables coefficients.

Table 1
Estimated coefficients

Features	Rural Area		Urban Area	
	Coefficients	*P>|z|*	*Coefficients*	*P>|z|*
AADT < 2000	-	-	-	-
AADT 2001 - 5000	3.6	0	3.2	0
AADT 5001 - 10000	4.1	0	3.9	0
AADT 10001 - 25000	4.4	0	4.5	0
AADT > 25000	4.6	0	5.1	0
Radiance < 5	0.5	0.007	-1.4	0
Radiance 6 - 10	0.6	0.002	-1.1	0
Radiance 11 - 30	0.6	0.002	-0.5	0
Radiance > 30	-	-	-	-
Motorway	1.4	0	-0.3	0.005
Expressway	0.5	0	1.6	0
Regular road	-	-	-	-

The variables namely *AADT <2000*, *Radiance >30* and *Regular roads* are used as reference.

Firstly, it can be noticed that all the coefficients estimated are significant different from 0.

As expected, the coefficients of the light intensity observations are smaller than the one associated with the traffic volume meaning that the traffic volume has a larger impact on the number of accident compared with the intensity of light.

Noteworthy, the *Radiance* effect changes between the two cases, which means that in the countryside, poor road lighting increase the number of accidents, while the opposite is observed in urban areas.

In addition, results show motorway in rural area positively influence the number of accidents. This might happen because of the high level of traffic and the high speed limit that characterize the motorway. The same reasons could explain the effect on the number of accident of Expressway in urban area. However, the different impact of motorway and expressway between urban and rural area can be a possible future research topic.

5 Discussion

In this work, accident data and nighttime light intensity observations obtained through satellite images are merged together in order to analyze the effect of road lighting on the number of road accidents during nighttime. Negative Binomial regression model is estimated and the results show that poor road lighting increase the number of accidents in rural areas. While, intense road lighting increase the number of accidents in urban areas.

The increment of the number of accidents due to poor road lighting in rural area can be explained by the low visibility and, therefore, the lower capability to perceive dangerous situations. On the other side, the opposite trend occurring in the urban area can be due to the fact that drivers tent to drive faster when the road is illuminated; increasing, so, the risk of having and accident. However, the urban area are know to be complex environment where the risk of accidents is affected by multiple factors.

Moreover, this study suggests that the road lighting in the rural area in Denmark should be enhanced in order to decrease the number of accidents.

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