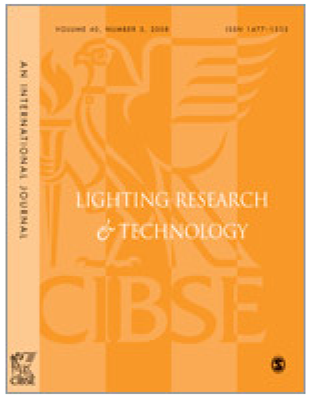

The Role of Lighting in Road Traffic Collisions

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The Role of Lighting in Road Traffic Collisions

Abstract

The paper reports a study that examines how to determine if a road traffic collision took place in daylight or in the dark. An innovative method was developed, based on solar altitude, to establish cut off points of daylight and darkness determined from a study of daylight availability in England and Scotland. This approach provides a rigorous method to differentiate the daytime and night time collisions. The criteria were used in a study of the collisions reported in the STATS19 dataset for the weeks either side of the clock changes that are necessary between Greenwich Mean Time and British Summer Time. By comparing periods with the same clock time either side of the time change, using the aforementioned method, it was possible to isolate collisions within the same time period that during one week occurred in darkness and in the other week in daylight. The initial finding was that there are 19.3% more collisions in the dark periods and there is an even greater increase (31.7%) in pedestrian injuries.

Introduction

It has long been argued that road lighting can reduce road traffic collisions[1]. However, studies in this area tend to treat road traffic collisions as a homogenous collection of incidents and thus provide little information on how to improve road lighting to reduce collisions[2]. Clearly lighting may have an impact in a collision when a driver does not see a hazard in the road at night, but it will be a less important factor in a collision that occurs due to a mechanical failure.

The causation and consequences of road traffic collisions are complex as there are many contributory factors in which light may play a role. However, due to the complex nature of the interactions it is difficult to isolate those collisions where lighting is the primary cause. Consider a driver pulling out of a side road on to a major high-speed road without checking if there was any traffic coming. It could be argued that better lighting conditions may have made it more likely that he would have noticed any traffic; however, the act of pulling out without due care does not cause a collision in the absence of traffic. Thus, the probability of a collision happening is also a function of traffic density. Figure 1 shows traffic density based on data collected and published by the Institution of Lighting Professionals (ILP)[3] for England. The ILP data set was for 164 locations and a total of 2,452 days involving a total of 34,619,159 vehicle movements. Out of the 164 locations, 98 were within Essex and of the 2,452 days of data, 1,262 were from Essex, 980 from Northern Ireland with 210 days of data from the rest of the UK. Dates varied between 7 days of information per site up to 70 days' worth. The average number of vehicle movements for each hour of the day is presented as a percentage of the total traffic flow for a whole day.

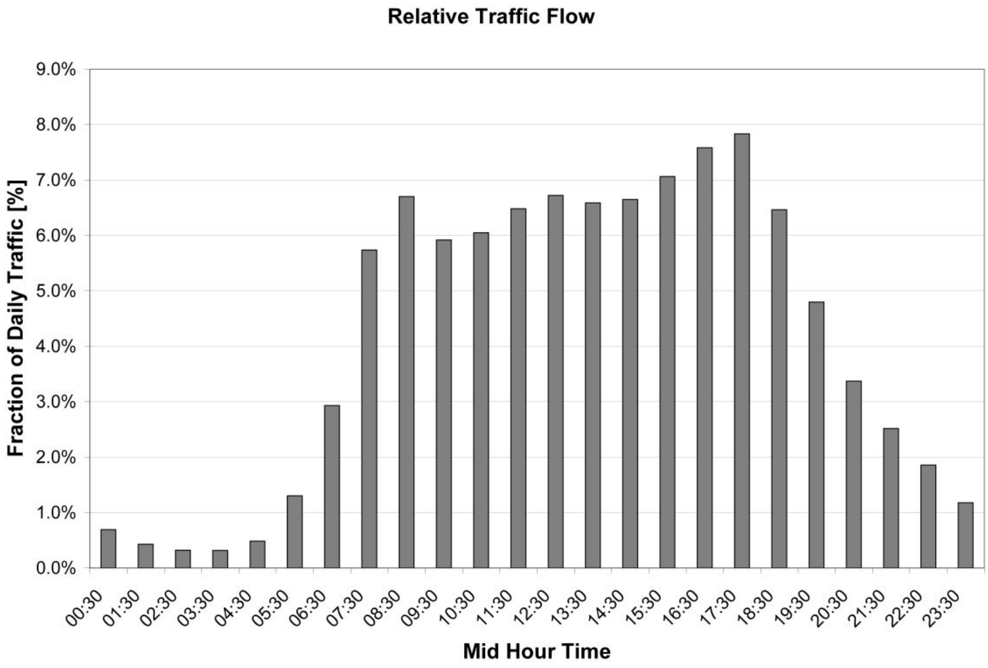

Figure 1 Relative traffic flow in England[3]

During the night there is a much-reduced traffic flow, so the chances of a collision may be reduced. However, as the road is less congested it is possible that the speed of vehicles may be higher[i] and so if a collision occurs it may be more severe. A further problem is that the way reported collision and casualty data is captured may also be a function of the daylight available. Consider a minor collision where a person has been in a vehicle and has been shaken slightly. During the daytime a paramedic attending the scene may well be able to assess that the person has no significant injuries; however, at night that assessment will be harder and acting on the precautionary principle, it may be decided that the person needs to go to hospital to be checked[ii]. This decision to send someone to hospital is likely to change the recorded severity of the collision. Given the above considerations, it is difficult to compare collision rates for different times of day and, thus, establish patterns of collisions associated with light and dark.

One approach to the problem has been to examine the weeks either side of the clock change that happens twice each year with the introduction and removal of daylight saving time. The advantage of this approach is that it permits the comparison of collisions during particular time windows, in pairs of similar weeks where one week the period is dark and the other week it is light. This approach has been used by Ferguson et al [4] and also by Uttley and Fotios[5] and a number of other studies, for example, Sullivan and Flanagan[6]. These studies compared recorded collisions that took place when it was nominally light in one week and it was nominally dark at the same time in the other week, with Ferguson et al categorising a period of one hour as twilight. The problem with most previous studies is the way of assessing when it is light and when it is dark. Ferguson et al based their limit of the light period at solar altitude 0° and then treated the period of one hour with

[i] It is a fundamental principal of highway design that traffic speed is a function of the ratio of traffic flow to the design capacity of the road. For further details see for example: DBRB Volume 13 Economic Assessment of Road Schemes Section 1 The COBA Manual Part 5 Speed on Links (COBA). Available at: https://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/pgr/economics/software/coba11usermanual/part0theappofthecoba3152.pdf

[ii] The relationship between light colour and quantity clinical diagnosis is complex, however, poor lighting has the potential to reduce diagnostic confidence. See P A Lovett, M B Halstead, A R Hill, D A Palmer, T S Sonnex & M R Pointer, The effect on clinical judgements of new types of fluorescent lamp: I Experimental arrangements and clinical results. Lighting Res. Technol 23(1) 35-51 (1991)

the sun just below the horizon as being twilight. The work of Uttley and Fotios used the point at which the solar altitude was 0° to mark the boundary between light and dark.

Clearly, during the transition between light and dark it would be reasonable to expect that the rate of collisions may change. Both Ferguson et al, and Uttley and Fotios found significant changes in collisions; however, without an accurate definition of when it is dark and when it is light it is not possible to study the recorded collisions in order to identify what types of incidents are more common in the dark. The objective of this paper is to investigate methods of isolating collisions that happen after dark and perform an initial examination of the record of traffic collisions for England, Scotland and Wales using a proposed new quantitative method.

It should be noted that the approach of this paper is to seek conditions that can be defined either as light or as dark. However, between these 2 conditions there is a period of twilight. During twilight, conditions gradually change from natural to artificial lighting or visa versa. The relationship between vehicle lights and daylight on the road was studied by Andre et al[7] and they used the concept of a twilight illuminance of 3.3 lx as criteria for vehicle head lamp performance. However, the complex nature of lighting conditions during twilight means that for the sake of simplicity a study of collisions during twilight is not included in this report, as the paper focuses purely on light and dark conditions.

Collision Data

The STATS19[8] data set gives information on road traffic collisions that have taken place in England, Scotland and Wales. For this paper data for the years 2005 to 2015 have been studied, in which there are a total of 1,780,653 recorded collisions involving 3,262,270 vehicles which caused 2,402,909 casualties. One of the fields in the data set provides the lighting condition at the time of the collision. There are several options that may appear in the field including *Daylight* or *Darkness* with a number of variations covering the presence or not of street lighting. If this field gives accurate information, then it could be used to determine which collisions took place after dark.

To check the accuracy of values in this field, the solar altitude all of collisions in the STAT19 dataset were calculated using the NOAA[9] method. The collisions were checked to see if they had taken place when solar altitude was in the range -8.5° to +5.5° and 253,755 were found within the range. This range was selected on the basis that it was expected to include the whole of the transition between light and dark. It was expected that solar altitude would be a good predictor of daylight availability, and the probability of a collision being reported as taking place in daylight would be a function of solar altitude at the time of the collision. The results of this analysis are plotted in Figure 2 with separate columns for the morning and afternoon results. If the lighting condition field was accurate, the column heights at each solar altitude would be approximately the same. However, the analysis showed that this is not the case and it seems that the afternoon data lags the morning data by about 5° of solar altitude. A potential explanation of this is that in many cases the daylight condition reported is not for the time of the collision but for some time afterwards, in the morning this means that solar altitude had increased before arrival and in the afternoon the sun would be setting, by the time the Police Officer arrived at the scene. Further analysis of the data was carried out and it was found that difference between morning and afternoon daylight probability was slightly less if a Police Officer did not attend the scene.

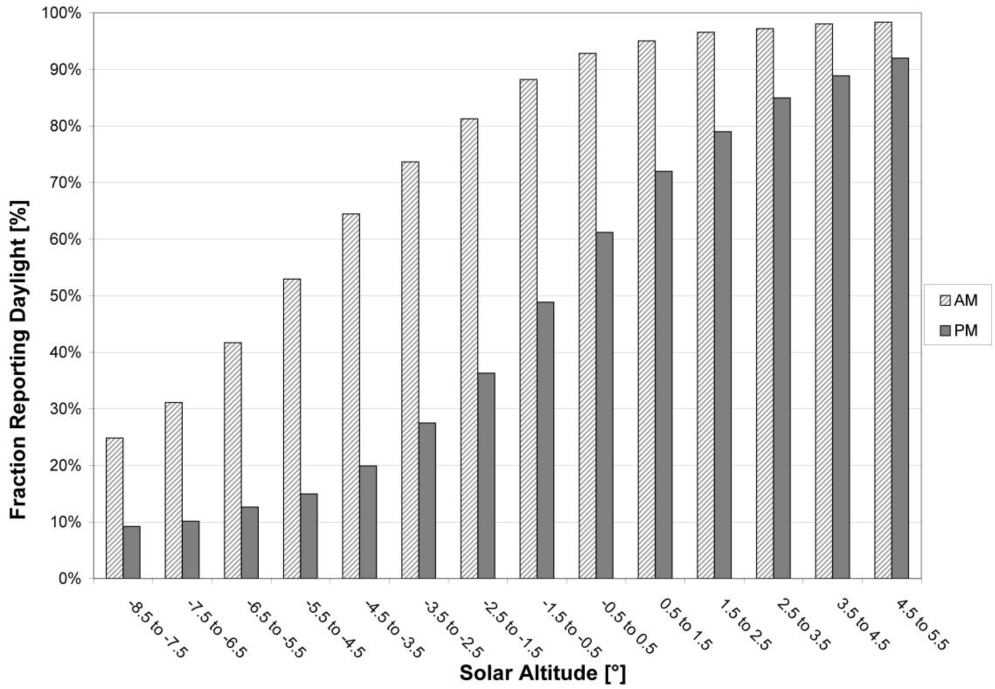

Figure 2 Percentage of collisions reported as daylit for varying solar altitude

This analysis shows that it is not possible to rely on the lighting condition field in the STATS19 dataset.

Daylight Availability and Solar Altitude

As mentioned in the previous section, it is expected that solar altitude would be a good predictor of daylight availability. To investigate this point, the daylight availability data set from Public Health England (PHE) was used. PHE run solar monitoring network[10] stations around the UK and for this study we used illuminance data for the years 2015 and 2016 from the 8 PHE sites in England, Wales and Scotland. The locations used are listed in Table 1.

Location	Latitude	Longitude
Camborne	50.2185	-5.3271
Chilton	51.5750	-1.3180
Glasgow	55.8625	-4.3447
Inverness	57.4734	-4.1939
Leeds	53.8451	-1.6146
Lerwick	60.1390	-1.1848
London	51.4988	-0.1183
Swansea	51.6094	-3.9849

Table 1 Locations of the data collection points

PHE records the average external illuminance for 5-minute intervals thus the section of data studied had over 1,600,000 records of illuminance. The resolution of the measurements is 0.01 klx (10 lx). The measuring equipment at the sites, with the exception of Lerwick, are mounted on the roofs of buildings, to ensure that as far as possible the sensors have an un-obscured view of the sky. In the dataset for the 8 locations over 2 years there were 19,270 illuminance values within the solar altitude range of -8.5° to +2.5°. The calculation of solar altitude used the NOAA method using the time at the middle of the 5-minute interval over which the illuminance was averaged. To study daylight availability as function of solar altitude in the given range, the results were binned into 1°

intervals and the average illuminance and a range of percentiles for each bin were calculated. The results of this analysis are shown in Table 2.

Solar Altitude Bin		-8°	-7°	-6°	-5°	-4°	-3°	-2°	-1°	0°	1°	2°
Lower Angle		-8.5°	-7.5°	**-6.5°**	-5.5°	-4.5°	-3.5°	-2.5°	-1.5°	-0.5°	0.5°	1.5°
Upper Angle		-7.5°	-6.5°	**-5.5°**	-4.5°	-3.5°	-2.5°	-1.5°	-0.5°	0.5°	1.5°	2.5°
Av Illuminance [lx]		0.70	1.03	**2.33**	7.04	21.98	62.14	145.4	289.4	508.7	812.1	1216
Illuminance Percentiles [lx]	1%	0	0	**0**	0	0	0	10	20	50	80	130
	10%	0	0	**0**	0	0	10	40	80	140	230	350
	50%	0	0	**0**	0	20	50	120	260	460	760	1160
	90%	0	0	**10**	10	40	120	270	530	920	1450	2120
	99%	10	10	**10**	40	100	240	470	850	1380	2070	3002

Table 2 Illuminance values at different solar altitudes

Selection of Criteria for Light and Dark

Based on the values in Table 2 for the analysis of road traffic collisions it would be reasonable to assume that it is dark at solar altitudes of -6° and below. At these low solar altitudes, the illuminance will be less than or equal to 10 lx more than 99% of the time and thus any street lighting present should have been switched on and the luminance of the road would be less than 0.3 cd m^{-2}[iii]. The choice of -6° as a starting point for darkness ties into the existing notion that the period of *Civil Twilight* stops at this point as well.

It is debatable which value of solar altitude to take as the start of reliable daylight on the road. Arguments could be made for the altitudes 0° or 1°. At 0° the illuminance is below 50 lx less than 1% of the time and this value rises to 80 lx at 1°. At both of these illuminance levels it would be normal for street lighting to be switched off; both values are higher than the illuminance at less than 1% of the time at below -6°. For simplicity, a 0° of solar elevation was used for the lower limit of the condition termed light. This choice aligns with the value used by most previous studies. See Table 3 for a summary of the choices made.

Light Condition	Altitude
Light	Above 0°
Dark	Below -6°

Table 3 Lighting Conditions in Relation to Solar Altitude

To confirm that -6° and 0° boundaries for dark and light were valid, each site was then checked individually to find that the top one percentile value of the -6° bin for all sites was 10 lx, except for Swansea where 10 lx occurred at the top third percentile. Likewise, percentile data were extracted from the bottom percentile of the 0° bin for all sites and found all values to be above or equal to 50 lx, except for Swansea, where 50 lx occurred at the second percentile. The full list of values mentioned above, by city, can be found in Table 4.

[iii] The 0.3 cdm^{-2} assumes the use of a Q_0, the bulk reflection factor for the road surface, of 0.1 which is higher than average for the UK.

	-6° bin percentiles			0° bin percentiles	
City	**97th***	**98th**	**99th**	**1st**	**2nd****
Camborne	10 lx	10 lx	10 lx	50 lx	68 lx
Chilton	10 lx	10 lx	10 lx	60 lx	80 lx
Glasgow	10 lx	10 lx	10 lx	50 lx	60 lx
Inverness	0 lx	10 lx	10 lx	60 lx	80 lx
Leeds	10 lx	10 lx	10 lx	50 lx	70 lx
Lerwick	10 lx	10 lx	10 lx	50 lx	70 lx
London	10 lx	10 lx	10 lx	70 lx	81 lx
Swansea	10 lx	20 lx	20 lx	30 lx	50 lx
*	**Note all illuminance values are ≤10 lx.**				
**	**Note all illuminance values are ≥50 lx.**				

Table 4 Comparison of city illuminance by threshold solar altitude bin.

Most previous studies have not used definitions for light and dark based on a study of available daylight illuminance. The study of daylight availability above suggests that Ferguson et al[3] may have included significant periods of darkness in the twilight category.

Initial Analysis of Collisions in Weeks Either Side of the Clock Change

The weeks for which collisions were studied are given in Table 5. The dates are in four groups, before and after the spring change and before and after the autumn change. The actual clock change takes place at 01:00 AM on Sunday mornings (the first date in *after* columns).

Spring Before		Spring After		Autumn Before		Autumn After	
Start	End	Start	End	Start	End	Start	End
20/03/05	26/03/05	27/03/05	02/04/05	23/10/05	29/10/05	30/10/05	05/11/05
19/03/06	25/03/06	26/03/06	01/04/06	22/10/06	28/10/06	29/10/06	04/11/06
18/03/07	24/03/07	25/03/07	31/03/07	21/10/07	27/10/07	28/10/07	03/11/07
23/03/08	29/03/08	30/03/08	05/04/08	19/10/08	25/10/08	26/10/08	01/11/08
22/03/09	28/03/09	29/03/09	04/04/09	18/10/09	24/10/09	25/10/09	31/10/09
21/03/10	27/03/10	28/03/10	03/04/10	17/10/10	23/10/10	24/10/10	30/10/10
20/03/11	26/03/11	27/03/11	02/04/11	16/10/11	22/10/11	23/10/11	29/10/11
18/03/12	24/03/12	25/03/12	31/03/12	14/10/12	20/10/12	21/10/12	27/10/12
24/03/13	30/03/13	31/03/13	06/04/13	20/10/13	26/10/13	27/10/13	02/11/13
23/03/14	29/03/14	30/03/14	05/04/14	19/10/14	25/10/14	26/10/14	01/11/14
19/10/15	24/10/15	29/03/15	04/04/15	19/10/15	24/10/15	25/10/15	01/11/15

Table 5 Dates for the start and end of summertime in the study years

For each clock change pair of weeks, the STATS19 dataset was searched to find collisions that occurred when the solar altitude was less than -6° (calculated using the NOAA method) and that if the collision had taken place the exact same time in the other paired week, the sun would have had an altitude greater than 0°. Similarly, collisions that happened when the sun was above the horizon (altitude greater than 0°) that would have had an altitude below -6° if they had taken place in the other week were identified. It should be noted that this approach means that the timing of each collision window will vary with location, day and year. Collisions in both the mornings and evenings of the relevant weeks were found. The conditions are summarised in Table 6.

CODE	Season	Time of Day	Week	Light Condition	Approx length of window [min]
SMB	Spring	Morning	Before	Light	5
SMA			After	Dark	
SEB		Evening	Before	Dark	32
SEA			After	Light	
AMB	Autumn	Morning	Before	Dark	7
AMA			After	Light	
AEB		Evening	Before	Light	33
AEA			After	Dark	

Table 6 Summary of study periods (shaded cells denote dark periods)

For each of the time windows in Table 6 the STATS19 data set was searched and the collisions that happened during each of the periods were noted. A summary of these findings is given in Table 7.

CODE	Number of Collisions	Number of Vehicles Involved	Casualties		
			Vehicle Occupants	Pedestrians	Cyclists
SMB	24	41	31	0	1
SMA	26	52	27	2	5
SEB	931	1678	895	220	120
SEA	754	1322	702	179	121
AMB	155	280	130	23	29
AMA	124	222	110	20	17
AEB	1493	2794	1407	302	240
AEA	1745	3390	1676	415	256

Table 7 Summary of collisions and their impacts

Note: in Table 7, the column "vehicle occupants" includes all casualties that are not pedestrians or cyclists, thus it includes motorcyclists, as well as passengers in buses.

It is possible that the change in the number of collisions that occurred during the week of the clock change occurred due to factors not associated with daylight. To study the extent to which other factors could be causing changes in the collision rates, control periods either side of dawn and dusk where the whole period in both weeks was either light or dark in all areas studied were counted. For each of the control periods the number of collisions, vehicles involved and casualties caused were counted. No breakdown of casualty type was conducted as these periods were only being used to provide an overall check to ensure other major factors were not influencing the results during the clock change periods. Table 8 shows the time of the control periods.

Code	Condition			Times	
				Start	End
SAD	Spring	AM	Dark	04:10	05:10
SAL	Spring	AM	Light	07:30	08:30
SPL	Spring	PM	Light	16:50	17:50
SPD	Spring	PM	Dark	20:50	21:50
AAD	Autumn	AM	Dark	04:50	05:50
AAL	Autumn	AM	Light	08:30	09:30
APL	Autumn	PM	Light	14:40	15:40
APD	Autumn	PM	Dark	18:40	19:40

Table 8 Times of the control periods

Table 9 gives the results of the control periods analysis.

	Before			After		
Code	No. of collisions	No. Vehicles	No. Casualties	No. of collisions	No. Vehicles	No. Casualties
SAD	161	255	214	204	305	286
SAL	2381	4601	3036	1923	3648	2396
SPL	2646	4937	3485	2967	5625	3975
SPD	1050	1827	1504	1131	1982	1662
AAD	281	473	346	312	502	390
AAL	2628	4933	3349	2533	4800	3257
APL	2753	5041	3659	2584	4730	3524
APD	2313	4311	3144	2245	4088	3040

Table 9 Summary of the collisions during the control periods

Discussion

The study has investigated various methods to determine if collisions take place in the light or the dark and chosen to use solar altitude to determine light condition. The choice of solar altitude greater than 0° for being light and less than -6° for being dark provides a simple way of selecting comparable collisions from either side of the biannual clock changes. This selection means that the study excludes collisions that occur during twilight. Twilight accidents have already been looked at by Ferguson et al; however, their sample probably included lots of collisions that happened in darkness. This does not mean that collisions during twilight are not important. The variable nature of light during this period means it is challenging to analyse this time window.

Comparing the number of collisions and casualties between all four sets of light and dark periods it is clear that there are more collisions during the dark periods. Table 10 shows the relative increases of various outcomes associated with the number of collisions for the whole period examined.

Parameter	Percentage increase in the dark	Percentage change during corresponding control periods
Number of Collisions	19.3%	-6.8%
Number of Vehicles Involved	23.3%	-8.0%
Casualties: Vehicle Occupants	21.2%	*
Casualties: Pedestrians	31.7%	*
Casualties: Cyclists	8.2%	*
Casualties: Total	21.3%	-7.3%
* The breakdown of casualty types was not calculated for the control periods		

Table 10 Increases in collisions and their outcomes during the dark periods

Table 10 also shows a summary of the results from the control periods. To generate the data in the right-hand column the values from Table 9 were summed for the values corresponding to light and dark periods. Thus, for spring mornings the before values were added to the values for the light side and the after values to the dark. The control value changes were much smaller than the light to dark changes and in the opposite direction. It should be pointed out that the total values for the control period hide a lot of variation across the 4 periods sampled.

There are two standout numbers in Table 10. Firstly, that casualties among cyclists increase far less than any other category; this will need further investigation to explore whether this is perhaps a function of a cyclist's conspicuity or if this can be explained by the reduced number of cyclists on the road after dark. The other interesting number is the increase in the number of pedestrian casualties, relative to other increases.

It is noted that Unwin et al[11] found that there were fewer pedestrians on the streets after dark and Fotios et al[12] showed that walking and cycling is less common in the hour after sunset compared to the hour before sunset. This indicates that the risk factor to pedestrians is much higher in the dark. However, it is unclear why the number of cyclists in collisions does not increase after dark to the same extent as incidents involving pedestrians.

Conclusion

This paper has made the case for the use of solar altitude at the time of a collision to determine if the incident took place in the light or the dark. Using the criteria proposed, the road traffic collision record for England, Scotland and Wales (2005 - 2015) has been examined for collisions taking place in the weeks either side of the spring and autumn clock change during weeks when the light condition at the time of the collision would be different if it was on the other side of the clock change. As expected, this revealed higher rates of collisions and injuries during the dark periods.

This initial review of collisions during equivalent light and dark periods demonstrates that the method works and further work studying the incidents in more detail is planned so that the cause of the additional night time collisions can be better understood.

Acknowledgement

This work was partly funded by EPSRC grant number EP/N509577/1

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Ref No	Reviewer	Comment	Action	Justification
1.	1	There are other potential factors that may contribute towards changes in collision frequencies before and after a clock change, that may not be directly linked to the light levels. First, weather conditions may vary. Weather variations occur on a daily basis and there is no guarantee that the weather is the same on one side of a clock change as on the other side. There may also be a systematic trend aligned with changes in light condition that could contribute towards increased collision risk. For example, in the Spring clock change, the light condition at an appropriately-selected time of day will change from darkness to daylight as a result of clocks moving forward one hour. The general trend is also for weather conditions to be improving, in terms of temperature and precipitation. With the Autumn clock change, the reverse is true. The shift from daylight to darkness coincides with a systematic worsening of weather conditions. The worsening of weather conditions may contribute towards collision risk. The second potential confounding factor is changes in exposure levels before and after a clock change, brought about by national events. An example of this is school holidays – these can often occur around the same time as the Spring and Autumn clock changes, and this could lead to differences in exposure levels in the weeks before and after, due to fewer / greater people being out on the roads. A final potential confound related to the clock change is the potential changes in fatigue levels and general alertness that may be caused by the one hour shift and the effect this has on sleep and waking times (for example, see Harrison, Y. (2013). The impact of daylight saving time on sleep and related behaviours. Sleep medicine reviews, 17(4), 285-292). The authors need to account for these potential confounding factors in their analysis. One possible way to do this would be to use 'control' collisions, or times of the day, that occur over the same period of time (i.e. before and after a clock change) but with no change in light condition. See Johansson, Ö., Wanvik, P. O., & Elvik, R. (2009). A new method for assessing the risk of accident associated with darkness. Accident Analysis & Prevention, 41(4), 809-815.	The study now reports data for control periods close to the times assessed in the study but compares light with light and dark with dark periods	The intention of the paper is to propose a potential method to sort light from dark accidents, however the referee feels we need to go a bit further in the validation of the approach. The additional material is spread through the paper, key information is in Table 8
2.	1	The article would benefit from greater referencing of literature to support the points being made. Some examples: On lines 22-23, page 1, the authors state: "studies in this area tend to treat road traffic collisions as a homogen[e]ous collection of incidents" – some examples of such studies would be useful. On line 3 of page 2, the authors suggest the speed of vehicles may be higher at night due to less congestion, but no evidence in support of this is provided. On lines 7-12 of page 2, the authors suggest paramedics may have greater difficulty assessing an injury at night than during the day and this may change the severity of injury recorded. Some evidence to support this would be useful.	3 actions needed to address this:	
			Reference the comment on P1:L22-3 to papers already used	Existing papers listed cover this but point is now explicit
			Footnote added to cover this point	Address point for readers not familiar with highway design
			Footnote added with reference to Lovett et al	Reference is a bit old and but covers the variation in diagnostic confidence in lighting conditions that are quite similar and all in the photopic. We are not aware of work that looks ate diagnostic confidence in the mesopic, but it would be reasonable to infer that if it varies with light source in the photopic then going to the mesopic is going to be a greater change.
3.	1	Figure labels are small and difficult to read	Labels made larger	
4.	1	Figure 1 – it would be helpful to be more explicit about where this data is derived from. Is this data for a whole year and averaged, or for a more specific period of the year? How was the data collected? Is it based on the statistics published by DfT?	Add the reference to the figure caption as well (it is already been referenced in line 37 page 1) Add text from the reference regarding this data as per reviewer's 1 comment	Data source was clearly stated in the reference, but now text from the reference has been added to the paper, to address the point
5.	1	The authors use the biannual clock change to compare daylight and after-dark conditions, but do not clearly explain the benefit of this approach, e.g. why not choose more distant parts of the year to compare, when there is a clearer distinction between daylight and darkness, and a greater number of collisions may be included in the analysis?	Additional text to address this: *The advantage of this ... ...week it is light.* In the introduction.	

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6.	1	Lines 6-8, page 3. The authors suggest the difference between am and pm seen in Figure 2 may be due to police officers arriving at a collision scene sometime after the actual collision occurred, and judging the light condition at that time rather than at the time of the collision. This seems a reasonable explanation, but there may be other explanations too, e.g. the perceived quality of the light at sunrise and sunset may be different, leading to different interpretations of whether it is 'dark' or 'daylight'. E.g. refraction of light is different at sunrise and sunset, Sampson, R. D., Lozowski, E. P., Peterson, A. E., & Hube, D. P. (2003). Variability in the astronomical refraction of the rising and setting Sun. Publications of the Astronomical Society of the Pacific, 115(812), 1256. It would be interesting to compare collisions that were attended by police and those that were not (this is a variable within STATS19) - does this difference between am and pm disappear?	The data on which figure 2 was based was expanded to cover all collisions that happened with solar altitude in the range and analysis was carried out to see the impact of Police Officer attending the scene. Figure 2 was updated and is now based on the 253,755 collisions found. Comments about the analysis with regard to officer attendance added to the text. Text now includes the words *potential explanation*	The referee clearly was not happy with this point of our paper. To put the matter to rest we calculated the solar altitude for all collisions in the database and found 253,755 with solar altitude in the range and all necessary fields filled. We carried out analysis of the sample based on Police attendance and generated a series of plots of similar form to figure 2. The changes between the various charts were small, however, in the cases where there was no police attendance there was less difference between morning and afternoon results. This is a bit of a side issue for the paper so we chose not to add all of the extra figures to the paper
7.	1	Lines 38-41 page 3 – it would be helpful to have further explanation about the illuminance recording at the sites described. E.g. are these sites located in rural or urban areas? How many other sites are there and why were these 8 selected?	Text has been added to cover the location and choice of sites	These locations were not selected from a list of others, they are the only locations where England, Scotland and Wales collect this data. Therefore all the available information has been taken into consideration. PHE does have sites in Ulster but these were not used a STATS19 has no data from there
8.	1	Lines 21-22 page 5 – the authors state that comparisons of the illuminance measurements across the 8 sites did not find any significant differences, but the results of any statistical comparisons should be reported. It would also be useful to provide descriptive statistics related to the illuminance measurements at the 8 sites – how much variation is there between sites, and between different time-points?	A more detailed comparison of percentiles has been added to address this point. The statistical analysis suggested has not been completed for the following reasons: - A comparison of all illuminance values, across sites is not valid in this case, as the sites are in different geographical locations, therefore expected to be different. The same applies to time points. - Daylight data are not normally distributed, therefore means and variances are not appropriate in this case. - Statistical methods used throughout the paper are descriptive rather than inferential (Bayesian). Bayesian statistical methods do not apply because we are not making predictions based on analysis of the datasets. This would be inappropriate because the datasets used are non-homogeneous. - It could be argued that the percentile approach used to support the cut off decision, is more robust than the 0.05 confidence interval often used in Bayesian statistics. This is because we are using the third percentile at the extremes to explain the choice of cut off altitude. This is well within the five percentiles at either extremes, therefore the approach employed is considered rigorous.	
9.	1	Table 4 – the final dates for Spring Before are actually for Autumn Before	Error fixed	
10.	1	Lines 30-31 page 6 – the authors state that collisions with solar altitudes below -6 degrees were identified. However, it is not clear how the solar altitude at the time of each collision was calculated – the solar altitude will vary as a function of time of day and longitude / latitude, so using the same time window for all collisions, to identify the solar altitude at the time of those collisions, may not be appropriate if that was done.	Text added to say that the NOAA method was used	This should clarify the text, as the NOAA method requires date, time, latitude and longitude
11.	1	Table 5 – final column, it would be useful to state what these time windows actually were	Text added to explain this point *It should be noted that this... ...day and year.*	It is not possible to give exact lengths of the windows due to variations between locations, years and days
12.	1	Line 56 (page 7) – the Fotios et al analysis used a whole-year approach and will therefore have included collisions that occurred greater than an hour before or after sunset (although within the same hour of the day throughout the year).	Delete Fotios reference	Simplest way to resolve the issue as an in depth analysis of Fotios et al would take up a lot of space

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13.	1	Line 2-3, page 8 – the authors suggest the reduction in cyclist numbers due to darkness, as evidenced by Fotios et al, may account for the relatively low increase in collisions involving cyclists after-dark. However, Fotios et al found that the reduction in pedestrian numbers due to darkness was even greater than cyclists, so by the authors' theory, we should also have expected a low increase in collisions involving pedestrians. This was not the case however.	Reword the last sentence to leave the point open	There is clearly something of interest going on with a large difference in the rates of change for pedestrians and cyclists, however, a great deal of further analysis is going to be needed to make much of the point and this is beyond the scope of this paper
1.	2	This paper reviews the role of light level in crash occurrence. The first half of the paper explores the artifacts in the manner light level is reported in crashes, examining the correspondence between sun elevation and reported light level. It appears that morning reports of crashes are biased toward reporting daylight, while evening reports of crashes are biased toward darkness. The authors then redirect their analysis to empirical measures of darkness based on known sun position at eight geographic locations. At the conclusion of this analysis, they choose to identify darkness to occur when the sun angle is 6 degrees below the horizon. While they cite several previous studies' definition of darkness, they seem to have missed other studies that specifically identify Civil Twilight as a benchmark definition of darkness (see Andre, J. and D. A. Owens (2001). "The twilight envelope: A user-centered approach to describing roadway illumination at night." Human Factors 43(4): 620-630.)	Paragraph added to point out that were are deliberately not planning to study twilight conditions	Paper a bit confusing as on page 621 figure 1 shows more that 2 log units of variation in luminance during twilight but text suggests log units of variation in illuminance. Moreover, the paper goes on to use a value of 3.3 lux for twilight with no good reason and uses the value to assess the performance of vehicle headlights
2.	2	Moreover, follow-up published dissections of the kinds of crashes that are significantly reactive to light level seem to have also been overlooked (see Sullivan, J. M. and M. J. Flannagan (2007). "Determining the potential safety benefit of improved lighting in three pedestrian crash scenarios." Accident Analysis and Prevention 39(3): 638-647.) In these studies, Civil Twilight is used as the benchmark definition of darkness.	No Change	The Sullivan, J. M. and M. J. Flannagan work has not been overlooked. In their paper they suggest that the twilight is one hour after the sunset and therefore it is independent of solar altitude and this is why it has not been taken into consideration as the whole point of this paper is the suggested method based on solar altitude.
3.	2	The authors offer a breakdown of the percentage of crashes occurring in darkness that is comparatively coarse and with little statistical rigor--it would be useful to report confidence intervals.	This is an important point. However, the paper only presents the difference in collision numbers to show that the method of solar altitude works and be may be used to assess the number of collisions at different times. To do more with this information would require a deeper knowledge of the type of causation mechanisms associated with what must be treated as a series of catastrophic failures. Any attempt to treat the data as a homogenous set of incidents is doomed to failure. The objective of the paper is to get the method of using solar altitude to determine night from day when doing collision analysis accepted so that it can be applied in further studies. The results stated apply to the periods sampled. No claim is made to infer that the differences to day and night time collision rate might apply to different time windows within the full dataset or any other dataset.	
4.	2	To summarize, I do not think the authors provide a sufficient review of the literature covering this area and, as a consequence, may have misrepresented the prior work; they also ignore more comprehensive breakdowns of the crash analysis literature that identify light-sensitive crash characteristics in greater detail; and finally, they provide weak statistical support for their conclusions.	Table 7 shows some results that are just an indication of the changes to a population. The point of this paper is to describe the method. We then want to use it to study collisions in more detail to try to find common features of incidents that are more common at night than during the day. This point echo's the comment to the point above.	