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FACULTEIT BEDRIJFSECONOMISCHE WETENSCHAPPEN
master in de mobiliteitswetenschappen

Masterproef

Voor-Na studie: Het doven van verlichting op Vlaamse autosnelwegen en de impact op de verkeersveiligheid

Promotor :
dr. Stijn DANIELS

Olivier Bervoets
Proefschrift ingediend tot het behalen van de graad van master in de mobiliteitswetenschappen

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ABSTRACT

On July 15th 2011 the Flemish motorway lighting changed, introducing nine types of lighting changes to the motorway network. The goal of this study is to measure the effects of this new so called “Flemish Lighting Vision”. This goal will be achieved in this study by using a before-after study with as comparison group daytime accidents. The main analysis techniques used here are correction for the trend analysis and meta-analysis of crash data. The accident data was provided through police records of injury accidents that occurred on Flemish motorways between the beginning of 2006 and the end of 2012. The study mainly indicates that the number of crashes between before and after the introduction of the lighting changes did not significantly increase or decrease, taking into account general traffic trends. Yet there is a noticeable crash reduction on dynamically lit parts of the motorway network of 23%. On the same parts the number of rear-end crashes is reduced by 41%. From the analysis it also becomes clear that the unlit parts of the motorway network are equally as safe as during the before period.

INTRODUCTION

Recently Flanders decided to reduce motorway lighting at night to a minimum. This was in accordance to a general ecological trend in Europe. Before 2007 motorway lights were switched off between 0:30 AM and 5:30 AM. Only interchanges and large ring motorways were lit the entire night. From July 2007 this state of non-lighting was lengthened by an hour, stretching the time period between 0:00 AM and 6:00 AM. (EMIS 2007)*(1)* The next big Flemish motorway lighting change took place on July 15th of 2011. On this date the new "Flemish Light Vision" was introduced at the motorways.

This new lighting vision started from the principle: "Turn off the lights when possible, turn them on when needed for traffic safety" (Crevits 2011)*(2)*. The vision also stated three principles of lighting: permanent lighting, dynamic lighting and no lighting. Permanent lighting is only applied on interchanges, on- and off-ramps, ring motorways and motorway locations with high traffic intensities during the peak hours. On specific parts of the Flemish motorways dynamic lighting is applied. At these locations lights are switched off in normal situations but can be turned on when a high traffic intensity is detected, whenever the average speed drops below 70 km/hour or in the case of bad weather and calamities (e.g. stationary vehicle on the motorway). In the third case, lights will be permanently turned off, irrespective of the traffic situation. The lighting vision also stated some accompanying measures like road markings with a higher reflection rate and more reflectors on the roadside (Agentschap Wegen en Verkeer 2011) *(3)*. With the introduction of this vision, only 827 km of the total of 1728 km of motorways in Flanders remains (dynamically or permanently) lit. This means that 901 km of Flemish motorway is now completely unlit since the summer of 2011. Figure 1 gives an overview of the current Flemish Lighting Vision.

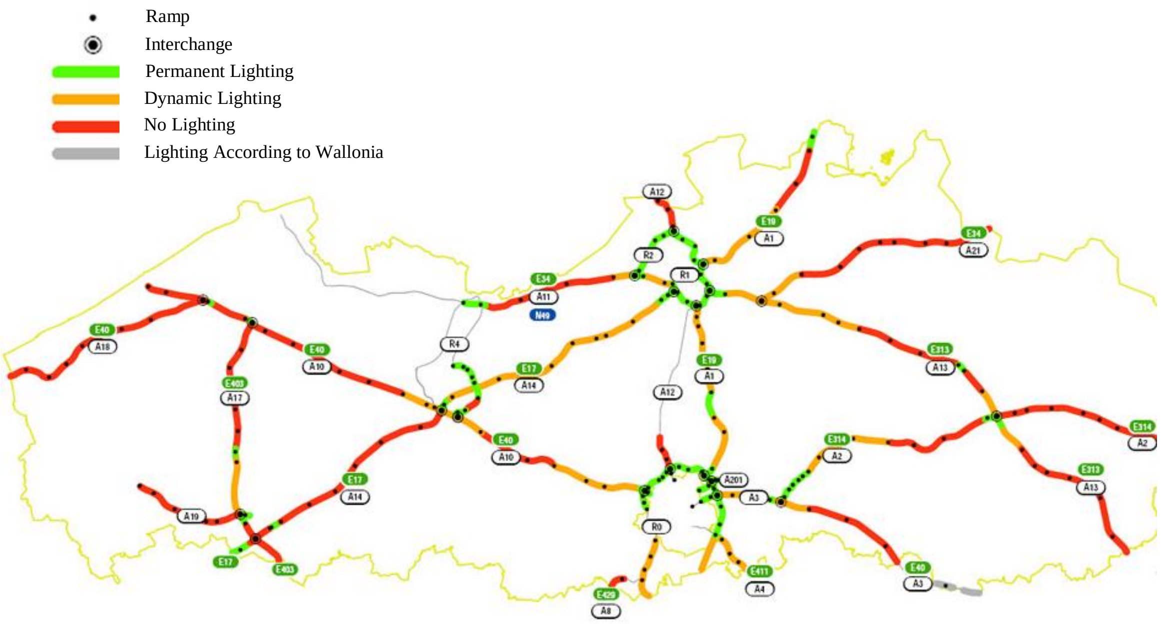


FIGURE 1 Flemish Lighting Vision (Crevits 2011).

Because these lighting changes were introduced from an ecological and budgetary view, no real preliminary traffic safety studies preceded the introduction of this Flemish Lighting Vision. Therefore a study was applied in order to study the traffic safety effects of this measure.

PROBLEM STATEMENT AND OBJECTIVES

The main stimulus for this case-study is that the Flemish Lighting Vision still has to be proven (in)-effective on the field of traffic safety. Up to now no studies have been applied comparing the traffic incidents before and after the implementation of this measure. Therefore no scientific proof is in place to agree or disagree with the growing public opinion that driving on motorways in pitch black is more dangerous than driving with the lights well lit.

This leads to the main objective for this paper: finding out if the road safety has decreased or increased on Flemish motorways after the introduction of this new lighting vision. Through further analysis of this main objective, other traffic safety related subjects will be reviewed. This study contains deeper analysis of crash types, the effects of weather on motorway accidents and a number of other road safety related statistics.

LITERATURE STUDY

Motorway lighting and prevention of accidents

Byer and Ker (2008) *(4)* of the New-Zealand based Cochrane Collaboration made a before-after analysis to study whether roadside lighting can effectively prevent traffic accidents. For their study they applied a meta-analysis of seventeen before-after studies that comprised accident data. These seventeen studies all compared day- and nighttime accidents. They concluded that an improvement of the motorway lighting could result in a decrease in the number of motorway crashes. The backbone of their study was the work of Vis (1994) *(5)*. He defined the function of roadside lighting as: “A tool that increases the safety and speed of transport”. Vis’ study tried to determine the relationship between the lighting level and the number of accidents. For this he used accident data of 2000 km of Dutch motorways between 1989 and 1991. He concluded that a relatively high share of the nightly accidents took place on unlit motorway sections. Furthermore he stated that the risk-ratio night/day for lit sections of motorway was generally lower. Vis’ work also stated that the average speed on lit motorways was slightly higher than on unlit motorways. The main conclusion of his work was that motorway lighting had an all-round favorable effect on the road safety at night.

Elvik (1995) *(6)* also conducted a meta-analysis, using 37 studies from 11 countries between 1948 and 1989. These studies all dealt with the effect of roadside lighting as a tool to prevent traffic accidents. From this meta-analysis Elvik concluded that roadside lighting reduced the fatal accidents at night by 65%, reduced the nightly accidents by 30% and reduced the accidents with material damage by 15%. These results were not specifically applicable to motorways but give a rather astonishing view on the effectiveness of roadway lighting. Elvik continued this work in The Handbook of Road Safety Measures (2004) *(7)*. Here Elvik concludes that, when roadway lighting was placed on previously unlit motorways, the amount of accidents with injuries would overall decrease with 4%. In general consensus this 4% is also taken as the increase in accidents whenever a motorway becomes unlit. In his handbook Elvik also concludes that motorway lighting reduced the amount of rear-end collisions by 20%, increased the amount of one-sided accidents by 44% and reduced the accidents on on- and off-ramps by 41%. In an updated version of The Handbook of Road Safety Measures (2009) *(8)* Elvik continued his research once more. Here he stated that a doubling of the lighting intensity could reduce the amount of accidents with injured by 8%. When this lighting rate would be increased with a factor of 5, the number of accidents with injuries would be reduced by 13%. From these findings it can be stated that motorway lighting has a positive effect on road safety. This is confirmed by Wanvik (2009) *(9)* who did multiple analyses about the effectiveness of roadside lighting. He concluded that motorway lighting has an overall reducing effect on the number of severe motorway accidents of 50% (deaths and heavy injuries).

Effect of roadway lighting on driving behavior

Martens (2005) *(10)* conducted research in The Netherlands towards driving behavior on lit and unlit roads. Here he used vehicles equipped with sensors and thirty-two test subjects to find out if driving on unlit roads increases the pressure on the driver. He used a lit road as a control site to compare the results of the unlit road. The sensors in the vehicles detected speed, lateral position, weaving, braking- and steering behavior. The pressure on the driver was measured with a short questionnaire. His research concluded that drivers did not behave differently on an unlit road, compared to a lit road. The only thing that was slightly increased, was the weaving. The same conclusions were formed by Elvik in The Handbook of Road Safety Measures (2009) *(8)*. Though Elvik states that the main reason for increased traffic safety on lit motorways is due to higher visibility.

The findings of Martens (2005) *(10)* were partially confirmed by Assum et al. (1999) *(11)*. These researchers did a study about vehicle speeds before and after the installation of roadway lighting. They concluded that the mean speed will not change after the introduction of roadway lighting compared to before the installation. Their study however found that there was a higher number of extreme speeds at the lit roads compared to the unlit roads. The averages did not show these extreme speeds because they got countered by the vast majority of slower road users. Assum et al. addressed these higher speeds through the theory of risk compensation (also known as the Peltzman Effect or Risk Homeostasis). This theory stated that someone is less careful when he feels safe. In general a driver would take more risks when the road was lit, due to the better visibility, which results in a higher speed and delayed breaking.

As stated by Murray and Plainis (2002) *(12)* there is a significant correlation between reaction time and road lighting. Their study showed that reaction time on unlit roads was significantly higher than the reaction time on lit roads. The total stopping distance at unlit motorways increased with 10 to 15 meters compared to lit motorways. This was due to a higher reaction- and processing time. For an unlit motorway the stopping distance quickly became 135.4 meters at a speed of 120 km/hour.

Other effects of roadway lighting

As stated before it is clear that motorway lighting mainly has a positive effect on traffic safety in regard to increased visibility. The main downside to lit highways are increased speeds. But there are yet some other effects that should be stated here, before completing this literature research.

SWOV (2011) *(13)* stated that the installation of light poles can create an increase of the number of single vehicle crashes on motorways. This problem can however be reduced through the use of crash friendly light poles according to a study of Elvik in The Handbook of Road Safety Measures (2009) *(8)* and the CROW (1999) *(14)*. Their studies showed that the use of these crash friendly light poles can reduce the number single vehicle crashes by 50%.

Lighting will also have a certain impact on the human and its surroundings. Shaflik (1995) *(15)* studied the phenomenon of “Light Trespass”. This is the light that penetrates outside of the domain that has to be lit. (E.g. light pole also lights a house/garden) This amount of unwanted light can ruin the sleeping patterns of animals or neighbors. Another effect Shaflik studied was blinding light or “glare”. He stated that a lot of drivers could be blinded by badly covered roadway lighting.

METHOD

Selection of the research period and locations

The main focus of this study is to find out the effects of the Flemish Lighting Vision. Therefore the before and after periods selected in this case should be focused on the introduction date of the new vision. Even though there was a slight change to the motorway lighting in 2007, this will not be a target focus of this study. This is due to the fact that the motorway lighting was only extended by 30 minutes in the evening and 30 minutes in the morning. The main changes however were applied on the 15th of July 2011. On this date the new light vision was introduced. Due to the fact that accident data was only available before 2012 (Federal Public Service Economy, Department statistics), the before period was set from January 2006 up until June 2011. The after period will run from August 2011 up until December 31st 2012. July 2011 will not be included in the analysis due to possible road user adaptation issues.

During the before period there were 3 lighting regimes in place: (1) permanently lit motorways, (2) motorways lit between the fall of dark till 00:00 AM and from 06:00 AM till the break of dawn and (3) unlit motorways. These lighting regimes changed across the entire motorway network with the introduction of the Flemish lighting vision towards: (1) permanently lit motorways, (2) unlit motorways and (3) dynamically lit motorways. Table 1 based upon data of the Roads and traffic agency (2013) shows the main changes on the lighting regimes on Flemish motorways.

TABLE 1 Overview of the Lighting Changes

Lit during evening/morning -> Unlit		**Lit during evening/morning -> Dynamic**		**Lit during evening/morning -> Permanent**	
Motorway	**Between road markers**	**Motorway**	**Between road markers**	**Motorway**	**Between road markers**
A1	53-66	A1	38-53	A1	12-19
A2	40-61	A1	3-12	A1	66-70
A2	0-38	A1	19-34	A2	38-40
A3	25-44	A2	61-79	A10	81-84
A10	95-104	A3	19-25	A10	93-95
A10	20-34	A3	7-15	A13	48-52
A10	84-93	A4	5-13	A13	56-58
A10	52-81	A10	34-52	A14	97-100
A11	12-22	A10	1-20	A14	49-53
A12	3-11	A11	8-12		
A13	31-48	A13	3-31		
A13	52-56	A13	58-62		
A13	68-100	A13	64-68		
A14	4-48	A21	10-21		
Total Km	**608**	**Total Km**	**428**	**Total Km**	**66**
Permanent -> Unlit		**Permanent -> Dynamic**		**Permanent -> Permanent**	
Motorway	**Between road markers**	**Motorway**	**Between road markers**	**Motorway**	**Between road markers**
A11	22-37			A11	37-41
Total Km	**30**	**Total Km**	**0**	**Total Km**	**8**
Unlit -> Unlit		**Unlit -> Dynamic**		**Unlit -> Permanent**	
Motorway	**Between road markers**	**Motorway**	**Between road markers**	**Motorway**	**Between road markers**
A17	18-27	A17	30-39	A17	27-30
A17	42-67			A17	39-42
A18	6-47			A19	0-3
A19	3-23				
Total Km	**190**	**Total Km**	**18**	**Total Km**	**34**

Table 1 clearly indicates that the largest part of the highways were converted from lighting during evening and morning to no lighting (608 km) or to dynamic lighting (428 km). Nevertheless all the locations are thoroughly investigated during the data analysis. In order to control for the trend effects, two groups of comparison locations were selected. The first group includes highways where no highway lighting was installed in both before and after period. Another group of comparison locations are the treated locations during the daytime. In this study all nightly data was collected between 10:00 PM and 6:00 AM. The daytime data collection happened between 9:00 AM and 4:00 PM. It should be noted that no peak hours are included in the research. Furthermore due to the lack of lighting change on ring motorways around large cities and the higher traffic intensities, these will not be included in the analysis, resulting in a low total length of permanent lit motorways.

Data collection and accident database

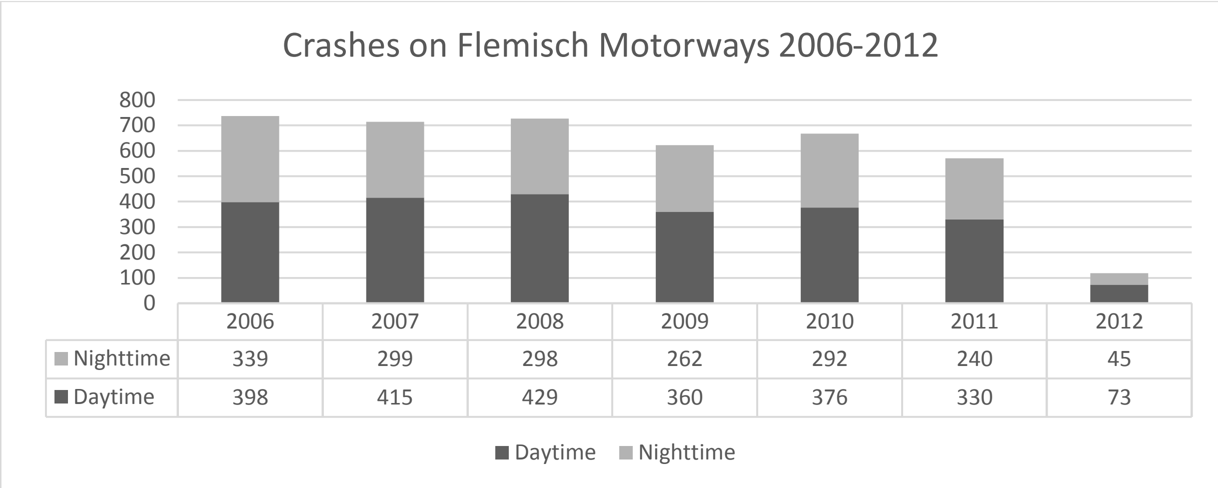
The data used for this study was provided by the Federal public service Economy, Department Statistics. The main database contained all injury crashes in Flanders for the period between the beginning of 2005 and the end of 2012. The crash data in the database was collected by the police at the scene of the accident using a crash form.

A first filter was applied to the general injury crash database to remove all non-motorway accidents. This resulted in the main database used in this study, containing 17984 motorway crashes between the beginning of 2005 and the end of 2012. Further filters and queries were applied to the database to gather all data in accordance with the before-after periods, comparison locations and research locations. Table 2 gives a brief overview of the core numbers on which further and more detailed analysis was performed for the part of the study where daytime was registered as a comparison group.

TABLE 2 Overview of Crash Data during Before- and After Period (Comparison Group: Daytime Accidents)

Location	Length	Nighttime crashes Before	Nighttime crashes After	Daytime crashes Before (comparison group)	Daytime crashes After (comparison group)
Lit during evening/morning-> Unlit	608	685	69	835	86
Lit during evening/morning -> Dynamic	428	704	54	956	95
Lit during evening/morning -> Permanent	66	74	7	183	14
Permanent -> Unlit	30	9	0	23	1
Permanent -> Dynamic	0	0	0	0	0
Permanent -> Permanent	8	5	0	1	3
Unlit -> Unlit	190	105	12	136	8
Unlit -> Dynamic	18	7	0	18	1
Unlit -> Permanent	34	21	0	25	0
Totals	**1382**	**1610**	**142**	**2177**	**208**

The same table can be created for nighttime crashes where the comparison group is composed of crashes on motorways that remained unlit throughout the entire research period. More important to note is the low number of crashes in the after period. This is mainly attributable to the fact that the after period is only 1.5 years compared to the 5.5 year long before period. Figure 2 will show an overall picture of the motorway crashes during the research period.



	2006	2007	2008	2009	2010	2011	2012
Nighttime	339	299	298	262	292	240	45
Daytime	398	415	429	360	376	330	73

FIGURE 2 Overview of Flemish motorway crashes 2006-2012.

This graph clearly indicates a problem with the data of the year 2012. This is due to an input error in the crash database. Not all highways were coded correctly into the database, thus making it impossible to link some crashes with a certain location on the motorway network. This should not cause any problem for the data analysis because this database error appeared network wide and all year round.

Correction for the trend, Empirical Bayes and meta-analysis

There are multiple methods available to perform a before-after analysis. (Austroads Research Report, 2012) *(16).* Most common are correction for the trend and the Empirical Bayes method. The Empirical Bayes method is one of the most used techniques for estimating the effectiveness of traffic safety measures or identifying high risk sites. It is also used to correct for regression to the mean. But in this case the introduction of the lighting changes was not caused by an elevation in the number of crashes and due to the long length of the motorway sections, it also seems unlikely that there will be any effect of regression to the mean present. Therefore correction for the trend was chosen as a primary method of analysis. This method gives an indication of the effectiveness of the lighting changes, taking common traffic trends like driving behavior, vehicle safety systems or even increasing traffic intensity into account. Due to the fragmentation of the different lighting regime changes in nine categories, a second analysis technique in the shape of a meta-analysis can provide an answer to the more network wide effects of the introduction of the Flemish lighting vision.

Correction for the trend

For the before-after analysis with correction for trend the following formulas were used:

$$\theta = \frac{L/K}{N/M}$$

Here θ is the effectiveness of the road safety measure. L is the observed number of crashes at the treated sites in the after period and K is the observed number of crashes at the treated sites in the before period. N equals the observed number of crashes at the comparison sites in the after period and M is the observed number of crashes at the comparison sites in the before period.

To check if the effectiveness θ is significant, the following formulas for the 95% confidence interval were applied to the data:

$$95\%\ CI\ \theta_l = exp\ [\ ln\ (\theta_l) \pm 1.96 * S_l]$$

The standard deviation (s) can be calculated as the root of the variance S^2:

$$S_l^2 = \frac{1}{L} + \frac{1}{K} + \frac{1}{N} + \frac{1}{M}$$

Whenever 1 is not part of the confidence interval, θ will be significant on 95% confidence level. When the upper limit is lower than 1 there will be a significant decrease in traffic accidents, if the lower limit is higher than 1 there will be a significant increase of traffic accidents. To calculate the 90% confidence interval, the same formula can be used, only with a slight adaptation:

$$90\%\ CI\ \theta_l = exp\ [\ ln\ (\theta_l) \pm 1.645 * S_l]$$

Meta-analysis

For the meta-analysis another set of formulas was applied to the collected data. The overall effectiveness θ can be calculated by:

$$\theta = exp\left[\frac{\sum_{l=1}^{n} w_l * ln(\theta_l)}{\sum_{l=1}^{n} w_l}\right]$$

To calculate w, the weight of each location in the meta-analysis, the following formula can be used:

$$w_l = \frac{1}{S_l^2}$$

Once again a confidence interval should be made to test the significance of the effectiveness indicator θ. The formula used for this is:

$$95\%\ CI\ \theta = \left[\frac{\sum_{l=1}^{n} w_l * ln(\theta_l)}{\sum_{l=1}^{n} w_l} \pm 1.96 * \frac{1}{\sqrt{\sum_{l=1}^{n} w_l}}\right]$$

RESULTS

Before-after study with trend correction

All data retrieved from the motorway accident database was subjected to previously mentioned methods of before-after analysis. Both daytime crashes and continuously unlit roads were used as 2 separate comparison groups. The analysis with daytime crashes as a comparison group showed the most significant results. Therefore only these results will be shown. Significant results will be indicated with a star symbol.

TABLE 3 Effectiveness of Flemish Lighting Vision on Motorway Crashes (Comparison Group: Daytime Crashes)

Measure	L	K	N	M	θ	95% CI	90% CI
Unlit -> Dynamic lighting	0	7	1	18			
Unlit -> Unlit	12	105	8	136	1.94	[0.77;4.92]	[0.89;4.24]
Unlit -> Permanent lighting	0	21	0	25			
Permanent lighting -> Unlit	0	9	1	23			
Permanent lighting -> Permanent lighting	0	5	3	1			
Lit during evening/morning -> Dynamic lighting	54	704	95	835	0.77	[0.55;1.09]	[0.58;1.03]*
Lit during evening/morning -> Unlit	69	685	86	835	0.98	[0.70;1.36]	[0.73;1.29]
Lit during evening/morning -> Permanent lighting	7	74	14	183	1.24	[0.48;3.19]	[0.56;2.74]
Network wide	142	1610	208	2177	0.93	[0.74;1.15]	[0.77;1.11]

Table 3 shows that there was not enough data available to do a before-after analysis for some of the lighting changes. As previously mentioned this was caused by a short after period and short sections of motorway where these changes took place. Therefore these categories will not be discussed any further. Even though some results were found for the research groups “unlit to unlit motorways” and “lit during evening/morning to permanently lit motorways”, wider confidence intervals show that not enough data was available to perform a clear analysis. This leads the study to focus further upon 2 regime changes: “lit during evening/morning to dynamic lighting” and “lit during evening/morning to unlit motorways”. When motorway sections were switched to dynamic lighting from the lit during evening and morning regiment, numbers seem to indicate a decrease in the number of crashes by 23% on confidence level 90%. No significant changes were found for all crashes when lit highways during evening and morning became unlit in the after period. Network wide the analysis does not indicate any significant change between the before and after situation.

TABLE 4 Effectiveness of Flemish Lighting Vision on Crash Severity (Comparison Group: Daytime Crashes)

Severe and fatal injury crashes							
Measure	**K**	**L**	**N**	**M**	**θ**	**95% CI**	**90% CI**
Lit during evening/morning -> Dynamic lighting	15	200	30	261	0.65	[0.34:1.25]	[0.38;1.12]
Lit during evening/morning -> Unlit	20	210	29	252	0.83	[0.454;1.51]	[0.50;1.37]
Slight and heavy injury crashes							
Measure	**K**	**L**	**N**	**M**	**θ**	**95% CI**	**90% CI**
Lit during evening/morning -> Dynamic lighting	48	612	79	822	0.82	[0.56;1.19]	[0.60;1.12]
Lit during evening/morning -> Unlit	61	583	72	711	1.03	[0.72;1.48]	[0.76;1.40]

Table 4 shows the analysis results of the change in the number of slight, heavy or fatal injury crashes before and after the lighting changes. No significant effect was found on the number of injury crashes. However, the results indicate that the number of crashes decreased after the introduction of dynamic lighting.

TABLE 5 Changes in the Flemish Lighting Regimes and Weather (Comparison Group: Daytime Crashes)

Lit during evening/morning -> Dynamic lighting							
Weather	**K**	**L**	**N**	**M**	**θ**	**95% CI**	**90% CI**
Dry	47	642	91	877	0.71	[0.49;1.02]	[0.52;0.96]*
Rain	6	53	3	69	2.60	[0.62;10.90]	[0.78;8.66]
Lit during evening/morning -> Unlit							
Weather	**K**	**L**	**N**	**M**	**θ**	**95% CI**	**90% CI**
Dry	60	613	79	768	0.95	[0.67;1.35]	[0.71;1.28]
Rain	7	54	6	58	1.25	[0.40;3.96]	[0.48;3.29]

To determine if the changes to the motorway lighting had positive or negative effects during different weather situations, another correction for the trend analysis was performed, for which the results are shown in table 5. On motorway segments where the lighting changed from evening and morning lighting towards dynamic lighting, the number of crashes during dry weather was reduced by 29% on a significance level of 90%. For motorway sections where evening and morning lighting changed towards unlit motorways, no significant change was noticeable in the number of dry weather crashes. The same lighting changes did not seem to influence the number of rainy weather crashes negatively or positively.

TABLE 6 Effect of Flemish Lighting Changes on Crash Type (Comparison Group: Daytime Crashes)

Lit during evening/morning -> Dynamic lighting							
Type	**K**	**L**	**N**	**M**	**θ**	**95% CI**	**90% CI**
Rear-end	19	293	48	435	0.59	[0.34;1.02]*	[0.37;0.93]*
Side impact	1	51	9	134	0.29	[0.03;2.36]	[0.05;1.69]
Single-sided	32	333	29	307	1.01	[0.60;1.72]	[0.65;1.58]
Lit during evening/morning -> Unlit							
Type	**K**	**L**	**N**	**M**	**θ**	**95% CI**	**90% CI**
Rear-end	28	285	48	352	0.72	[0.44;1.18]	[0.48;1.08]
Side impact	1	33	7	87	0.38	[0.04;3.18]	[0.06;2.26]
Single-sided	34	343	24	342	1.41	[0.82;2.34]	[0.89;2.23]

Table 6 shows that there is a significant decrease in the number of rear-end crashes of 41% at 90% confidence level for locations where dynamic lighting was introduced. Side impact and single-sided crashes were also analyzed. Yet no other significant results are found, not even for the introduction of unlit motorways.

Meta-analysis

Using previously mentioned techniques for meta-analysis the network wide effects of the introduction of the Flemish light vision were calculated. For the analysis of all crashes, data from all research locations was used, except for the "unlit to unlit" and "permanently lit to permanently lit" motorways, on the grounds that no lighting change took place here. The other meta-analysis results found in table 7 were obtained using data from the groups: "lit during evening/morning to dynamic lighting", "lit during evening/morning to unlit" and "lit during evening/morning to permanent lighting".

TABLE 7 Results Meta-analysis

Factor	θ	95% CI
All crashes	0.93	[0.75;1.17]
Crashes with Deaths or heavy injuries	0.76	[0.38;1.21]
Crashes with injuries	0.98	[0.74;1.22]
Weather		
• Normal	0.88	[0.64;1.11]
• Rain	1.67	[0.68;4.10]
Type of crashes		
• Rear-end	0.70	[0.34;0.87]*
• Side impact	0.57	[0.75;1.90]
• Single-sided	1.19	[0.81; 1.19]

Yet the meta-analysis resulted in only one significant network wide effect. With the new lighting regimes in place the number of rear-end crashes significantly decreased network wide by 30%. Furthermore numbers indicate an overall status quo or even slight reduction in the number of crashes on Flemish motorways.

DISCUSSION

The previous results give a clear indication that, during the entire research period, not much has changed for the traffic safety on the Flemish motorway network. In total nine different lighting changes occurred on the motorway network. But not all of these changes could be evaluated properly due to their limited length and the short after period. Nevertheless, the largest portions of the motorway network were analyzed. Some effects became clear from the analyses.

The first main effect is the increased traffic safety on motorways that switched to dynamic lighting from evening and morning lighting. From the analyses it was found that there is a nearly significant decrease of the number of crashes by 23% on these parts of the motorways. Furthermore the amount of rear-end crashes significantly decreased by 41% These effects can be mainly explained by the fact that the dynamic lighting will be turned on during the nighttime when traffic intensities are high, when accidents happen or even when the weather is bad. Previously the motorways were only lit during the evening and morning, dynamic lighting did not occur. In a way the introduction of dynamic lighting can be linked to Elvik's theories in The Handbook of Road Safety Measures (2009) *(8)* because it can be seen as an introduction of new motorway lighting on points and places in time when the lighting is needed most. Although Elvik stated a reduction of rear-end crashes by 20% when motorway lighting was introduced, the 41% reduction in this case indicates a positive traffic safety effect of dynamic motorway lighting.

Secondly, at large parts of the motorway network, lights were switched off where they were previously turned on during the evening and morning. However, no significant effects are found at these locations. Therefore it can be concluded that turning off the motorway lights at night did not have a negative impact on the traffic safety. This effect can be explained by the Peltzman effect that Assum et al. (1999) *(11)* described. Due to the new darkness on these motorways people feel more unsafe, lowering their speed and increase their attention.

The meta-analysis confirms these findings by resulting in mainly insignificant effectiveness. Therefore this study concludes that the traffic safety on Flemish motorways has stayed roughly the same as before the introduction of the new light vision, with the big exception the improved traffic safety on dynamically lit parts of the motorway.

As a control to both results of the correction for the trend analyses and meta-analyses, Empirical Bayes analyses were conducted on the same database. These analyses closely matched the previously described results.

Yet one can question the quality of the data used for this study. Because of the input errors in the data of 2012, a lot of potential results were lost for all lighting regime changes. But due to the usage of a trend correction method, the validity of the study remained intact. Yet it can be said that the main goal of this study was achieved: calculating the effects of the introduction of the new Flemish Lighting Vision.

For future research and studies on this topic it is strongly advisable to re-evaluate this traffic measure in the future when the lighting vision has been applied for 5 to 10 years. At that moment the accompanying measures like reflectors and better road markings will be installed and more accident data will be available for the after period. Another point of further research may lay in the analysis of the effects of the Flemish Lighting Vision on the demographic characteristics of the road users or the inclusion of accidents with only material damage.

CONCLUSION

During the course of this study it was the goal to study the traffic safety effects of the new Flemish Lighting Vision introduced in July 2011. The main changes of this new lighting system were the introduction of dynamic lighting and shutting down motorway lighting on a large portion of the network. During the course of this study nine research location groups were determined where the lighting regiment changed or remained the same. Using comparison groups, before-after analyses with correction for the trend and meta-analyses the effects on nightly motorway traffic safety were calculated.

In general the nightly traffic safety remained on par with the safety before the introduction of the new system. Yet it became clear that the dynamic lighting has a reducing effect on the total number of crashes happening on motorways at night by 23%. It even reduces the number of rear-end collisions by 41%. Yet due to a short after period and the shortness of some motorway sections where the lighting changed, not enough data was present to perform all analyses. Therefore it’s advisable that this study will be repeated in the future when the after period stretches a longer period of time.

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