Installation of lighting & Improvements to existing lighting

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Please note: The studies included in this synopsis were selected from those identified by a systematic literature search of specific databases (see supporting document). The main criterion for inclusion of studies in this synopsis and the DSS was that each study provides a *quantitative effect estimate*, preferably on the number or severity of crashes or otherwise on road user behaviour that is known to be related to the occurrence or severity of a crash. Therefore, key studies providing qualitative information might not be included in this synopsis.

1 Summary

De Ceunynck, T., Focant, N., October 2017

1.1 COLOUR CODE: GREEN

The vast majority of results show that the installation of road lighting and improvements to existing road lighting have favourable effects on the number of occurring crashes.

1.2 KEYWORDS

Road lighting; installation of road lighting; improvement of road lighting; switch off lighting; part-night lighting

1.3 ABSTRACT

The aim of the installation of road lighting and improvements in existing road lighting is to increase visibility, mostly to help reduce nighttime crash frequency. A meta-analysis is available that covers both the installation of road lighting and improvements in existing road lighting (Høye, 2014).

Based on the combined results of 53 individual studies, the meta-analysis shows that the **installation of road lighting** significantly reduces the number of fatal crashes in the darkness by 52%, and the number of injury and unspecified crashes in the darkness by 26%. Fatal pedestrian crashes in the darkness decrease by 78%, while pedestrian injury crashes in the darkness decrease by 51%. The effects of installation of road lighting are generally larger for fatal crashes than for less severe crashes, and more favourable for crashes involving pedestrians than for other types of crashes.

Based on the results of 26 studies, the meta-analysis indicates that **improvements to existing road lighting** generally have a favourable effect on road safety as well. Increasing the lighting by two to five times the previous level reduces the number of injury crashes by 13%. Increasing the lighting to five times the previous level or more reduces injury crashes by 32%. A reduction of the lighting level to half of the previous level was found to significantly increase the number of injury crashes by 17%. Three more recent papers on changes to existing road lighting were coded that showed mixed results and could therefore not confirm the results of the meta-analysis.

In general, it can be concluded that the vast majority of research available suggests that both installation of and improvements to road lighting have a **favourable effect on road safety**. The effect on crashes of improving existing road lighting seems smaller than the effect of installing road lighting on previously unlit locations. It also seems that improvements to existing road lighting need to be quite strong (more than doubling the previous level of lighting) in order to have a significant effect on the number of crashes. Transferability of the results may, however, be somewhat uncertain due to the substantial differences in effect size that were found in different studies. Some evidence suggests that effects differ between different types of road users and types of locations.

1.4 BACKGROUND

1.4.1 Rationale

Most of the information drivers use in traffic is visual. In darkness, the human eye picks up contrast, detail and movements to a far lesser extent than in daylight. Visual conditions could therefore strongly affect the level of safety of the transport system (Elvik et al., 2009). Mäkelä and Kärki (2004) estimated that the risk of getting involved in an injury crash is approximately 1.5 times as high in darkness as in daylight. Johansson et al. (2009) found that the risk of getting involved in an injury crash in darkness increases by almost 30% in urban areas and about 50% in rural areas compared to the risk during daylight. A number of studies indicate an increased crash risk during the night for cyclists and pedestrians as well (Lauwers, 2010; Twisk & Reurings, 2013; Walter, Cavegn, Allenbach, & Scaramuzza, 2005).
Road lighting is defined as all artificial lighting of roads, streets, intersections and pedestrian crossings. The aim of road lighting is to reduce the number of crashes during darkness by making it easier to see the road, other road users, potentially hazardous obstacles and the immediate surroundings of the road.

1.4.2 Description of the main research methods

The safety effects of installation of and improvements to road lighting have been studied quite extensively. A recent meta-analysis (Høye, 2014) was found that covers both the installation of road lighting on previously unlit roads and improvements to existing road lighting. Three more recent studies are included that examine the effects of changes to existing road lighting; no additional more recent studies on new installations of road lighting were found. Two of these studies apply a cross-section design, one applies an observational design. Only studies that provide estimates on the number of crashes have been included; studies that only looked at non-crash measures (e.g. driving speed) were not included.

1.5 OVERVIEW OF RESULTS

Most research towards road lighting suggests that the installation of, as well as substantial improvements to, road lighting **significantly improve road safety**.

A meta-analysis by Høye (2014) indicates that the **installation** of road lighting significantly reduces the number of fatal crashes in the darkness by 52%, and the number of injury and unspecified crashes in the darkness by 26%. The number of fatal pedestrian crashes in the darkness reduces by 78%, while the number of pedestrian injury crashes in the darkness reduces by 51%. In other words, the reduction in the number of crashes as a result of the installation of road lighting seems stronger for the most severe crash types, and also for crashes involving pedestrians, in comparison with all crash types. The author mentions that the results of the individual studies that were included in the meta-analysis are very heterogeneous. Therefore, the true size of the effect remains somewhat uncertain.

The meta-analysis also indicates that **improvements of existing road lighting** generally have a favourable effect on road safety as well. Higher levels of illumination result in fewer crashes. The effect of doubling the lighting level on injury crashes is not statistically significant, but increasing the lighting two to five times the previous lighting level reduces the number of injury crashes by 13%. Increasing the lighting level to five times the previous lighting level or more reduces the number of injury crashes by 32%, but no significant effect on the number of fatalities was found.

A recent study by Bhagavathula et al. (2015) found favourable effects of road lighting improvements on crashes as well, hence confirming the results from the meta-analysis, but Steinbach et al. (2015) did not find a significant effect. On the contrary, Nabavi Niaki et al. (2016) found higher numbers of pedestrian and cyclist crashes at locations with better road lighting. The authors of the latter study, however, acknowledge that they find these results rather unexpected, and that these could possibly result from the underlying non-randomness of the decision to add or increase road lighting at certain locations.

A **reduction of the lighting level** to half of the previous level was found to significantly increase the number of injury crashes by 17% in the meta analysis by Høye (2014). Reducing road lighting in multiple forms (permanently switch off, reduce the number of hours that lamps are switched on at night and dimming the output of lamps) was, however, not found to be statistically significant in the study by Steinbach et al. (2015).

1.6 BIASES AND TRANSFERABILITY

The body of available literature towards the safety effects of road lighting is quite large. Transferability of the results may, however, be somewhat uncertain due to the substantial differences in effect size that were found in different studies. Some evidence suggests that effects differ between different types of road users and types of locations. The cross-sectional studies by Bhagavathula et al. (2015) and by Nabavi Niaki might be prone to some differences between the treatment group and the control group that remain unaccounted for.

2 Scientific overview

2.1 ANALYSIS OF STUDY DESIGN AND METHODS

Table 1 provides information on the sample and the design of the coded studies on the effects of installation of road lighting and changes to existing road lighting. The number of studies of good quality on the effects of road lighting is relatively high. A recent meta-analysis is available that summarizes the results of a large number of individual studies on both the installation of road lighting and changes (mostly improvements) to road lighting (Høye, 2014). The meta-analysis combines the results of 52 individual studies on the installation of road lighting and 27 studies on changes to the road lighting. Three more recent papers were found that assess the road safety effects of different levels of road lighting. No more recent papers were found that investigate the effects of installation of road lighting.

Out of the three additional studies on differences in the level of road lighting, two papers applied a cross-sectional design in which the outcome indicators are related to differences in illuminance at different locations (Bhagavathula et al., 2015; Nabavi Niaki et al., 2016), while one paper applies an observational study in which the effects of changes to the lighting on crashes are directly observed (Steinbach et al., 2015). The two former studies assess the effect of a 1 lx increase in illuminance, while the latter study assesses the measures switching off road lighting, switching to part-night lighting, dimming the road lighting and upgrading the lighting to whiter light.

The meta-analysis by Høye (2014) looks into injury and fatal crashes of all road users, and of injury and fatal crashes involving a pedestrian. The study by Nabavi Niaki et al. (2016) looks at bicycle crashes and pedestrian crashes, while the studies by Bhagavathula et al. (2015) and Steinbach et al. (2015) look at crashes involving all types of road users. There are major differences in the types of locations that were investigated in the included studies, and not all publications report a sufficient level of detail about the study sites. There are major differences in sample sizes, ranging from a relatively small sample of 99 intersections (Bhagavathula et al., 2015) to a very large sample of tens of thousands of km of roadway (Steinbach et al., 2015).

Table 1: Information on sample and design of coded studies.

Author(s), year, country	Measure description and sample	Study design	Types of sites included	Outcome indicators
Høye, 2014, several countries	- Effects of installation of road lighting from 53 individual studies; - Effects of different changes to road lighting from 26 studies	Meta-analysis, some of the included estimates are corrected for RTTM	- For installation of lighting: separate estimates for pedestrian crossings, two-way urban road sections and intersections on urban roads - Few additional details about individual sites of included studies provided - Likely differences between studies	- Number of injury crashes - Number of fatal crashes - Number of pedestrian injury crashes - Number of pedestrian fatal crashes
Bhagavathula, Gibbons, and Edwards, 2015, United States	Effects of illuminance level at 99 intersections	Cross-sectional study; negative binomial regression	Lighted and unlighted intersections	- Day-to-night crash ratio
Nabavi Niaki, Fu, Saunier, Miranda-Moreno, Amador, and Bruneau, 2016, Canada	Effects of illuminance level at 1422 road links	Cross-sectional study ; negative binomial regression	Downtown locations (Montréal)	- Number of bicycle crashes - Number of pedestrian crashes
Steinbach, Perkins, Tompson, Johnson, Armstrong, Green, Grundy, Wilkinson, and Edwards, United Kingdom	Effects of different changes in lighting in 62 municipalities: - Switch off lighting (15,833 km) - Part-night lighting (12,101 km) - Dimming (10519 km) - White light (946 km)	Observational study; conditional Poisson models	Not specified	- Number of crashes - Number of KSI crashes

2.2 OVERVIEW OF STUDY RESULTS

A recent meta-analysis is available that combines the results of multiple scientific studies concerning the effects on crashes of installation of road lighting and improvements to road lighting (Høye, 2014). A review-type analysis has been made that departs from this meta-analysis, supplemented by a number of more recent studies on the topics that have been published in peer-reviewed journals. The meta-analysis is supplemented with three more recent studies about the safety effects of changes to road lighting. No additional more recent studies about the effects of installing road lighting were found.

Most research towards road lighting suggests that the installation of, as well as substantial improvements to, road lighting **significantly improve road safety**.

The meta-analysis by Høye (2014) shows that the **installation** of road lighting significantly reduces the number of fatal crashes in the darkness by 52%, and the number of injury and unspecified crashes in the darkness by 26%. The number of fatal pedestrian crashes in the darkness reduces by 78%, while the number of pedestrian injury crashes in the darkness reduces by 51%. In other words, the reduction in the number of crashes as a result of the installation of road lighting seems stronger for the most severe crash types, and also for crashes involving pedestrians in comparison with all crash types. Injury crashes in crosswalks in darkness reduce by 53%. Crashes at intersections in urban areas lower by 36%, but no significant effect on urban road sections outside intersections was found. The author mentions that the results of the individual studies that were included in the meta-analysis are very heterogeneous. Therefore, the true size of the effect is somewhat uncertain. The

results do not seem to be affected by publication bias. The author also mentions that results suggest that road lighting has a greater impact in rural areas than in urban areas, but this is not directly apparent from the numerical estimates because results are too heterogeneous. The meta-analysis also reports that many of the included studies are quite old, but that no systematic differences in results were found between older and newer studies.

The meta-analysis also indicates that **improvements of existing road lighting** generally have a favourable effect on road safety as well. Higher levels of illumination result in fewer crashes. The effect of doubling the lighting level on injury crashes is not statistically significant, but increasing the lighting level by two to five times the previous lighting level reduces the number of injury crashes by 13%. Increasing the lighting level to five times the previous lighting level or more reduces the number of injury crashes by 32%, but no significant effect on the number of fatalities was found.

A recent study by Bhagavathula et al. (2015) found favourable effects of road lighting improvements on crashes as well, hence confirming the results from the meta-analysis, but Steinbach et al. (2015) did not find a significant effect. On the contrary, Nabavi Niaki et al. (2016) found higher numbers of pedestrian and cyclist crashes at locations with better road lighting. The authors of the latter study, however, acknowledge that they find these results rather unexpected, and could possibly result from the underlying non-randomness of the decision to add or increase road lighting at certain locations.

A **reduction of the lighting level** to half of the previous level was found to significantly increase the number of injury crashes by 17% in the meta analysis by Høye (2014). Reducing road lighting in multiple forms (permanently switch off, reduce the number of hours that lamps are switched on at night and dimming the output of lamps) was, however, not found to be statistically significant in the study by Steinbach et al. (2015).

In general, it can be concluded that the vast majority of research available suggests that the installation of road lighting and improvement of existing road lighting have a favourable effect on road safety. The effect of improving existing road lighting on crashes seems to be smaller than installing road lighting on previously unlit locations. It also seems that improvements to existing road lighting need to be quite strong (more than doubling the previous level of lighting) in order to have a significant effect on the number of crashes.

2.3 TRANSFERABILITY

The body of available literature towards the safety effects of road lighting is quite large. Transferability of the results may, however, be somewhat uncertain due to the substantial differences in effect size that were found in different studies. Some evidence suggests that effects differ between different types of road users and types of locations, which would imply that the expected effects of the installation of road lighting or changes to existing road lighting are likely to depend on the types of locations where the measures will be executed and on the traffic composition.

A limitation of cross-sectional designs, such as those applied by Bhagavathula et al. (2015) and Nabavi Niaki et al. (2016), is that they could be prone to some differences between the treatment group and the control group that remain unaccounted for. This would imply that the found effects (i.e. differences in crash records) are not necessarily caused by the variable that is studied (i.e. road lighting treatments), but might be explained by some other systematic differences between both groups.

Table 2: Summary of study results.

Authors	Dependant / outcome type	Further specification of sites or measure	Best estimate of effect [95% CI]	Impact on road safety
INSTALLATION OF ROAD LIGHTING				
Høye, 2014 (meta-analysis), several countries (53 studies included)	**Fatal crashes in darkness – all road users**	/	**-52% [-59; -45]**	↗
	Injury crashes in darkness – all road users	/	**-26% [-33; -19]**	↗
		Pedestrian crossings	**-53% [-66; -37]**	↗
		Two-way urban road sections (outside intersections)	**-10% [-41; +36]**	/
		Intersections on urban roads	**-36% [-51; -18]**	↗
	Fatal pedestrian crashes in darkness	/	**-78% [-88; -62]**	↗
	Injury pedestrian crashes in darkness	/	**-51% [-63; -36]**	↗
CHANGES TO EXISTING ROAD LIGHTING				
Høye, 2014 (meta-analysis), several countries (26 studies included)	**Injury crashes in darkness**	**50% reduction in lighting**	**+17% [+9; +25]**	↘
		Increasing lighting to twice the previous level	**-8% [-20; +6]**	/
		Increasing lighting to 2-5 times the previous level	**-13% [-17%; -9%]**	↗
		Increasing lighting to more than 5 times the previous level	**-32% [-39%; -25%]**	↗
	Fatal crashes in darkness		**-50% [-79; +15]**	/
Bhagavathula, Gibbons, and Edwards, 2015, United States	Day-to-night crash ration (effect of a 1 lx increase in illuminance)	All intersections	0.93	↗
		Lighted intersections	0.91	↗
		Unlighted intersections	0.79	↗
Nabavi Niaki, Fu, Saunier, Miranda-Moreno, Amador, and Bruneau, 2016, Canada	Number of bicycle crashes in darkness	/	+0.02 [+0.00 ; +0.03]	↘
	Number of pedestrian crashes in darkness	/	+0.02 [+0.01 ; +0.03]	↘
Steinbach, Perkins, Tompson, Johnson, Armstrong, Green, Grundy, Wilkinson, and Edwards, 2015, United Kingdom	Number of crashes in darkness (relative risk)	Switch off lighting (=reduction)	0.97 [0.82; 1.15]	/
		Part-night lighting (=reduction)	0.95 [0.84; 1.07]	/
		Dimming (=reduction)	1.00 [0.91; 1.10]	/
		White light (=improvement)	1.01 [0.93; 1.09]	/
	Number of KSI crashes (relative risk)	Switch off lighting (=reduction)	0.96 [0.67; 1.35]	/
		Part-night lighting (=reduction)	0.95 [0.71; 1.25]	/
		Dimming (=reduction)	1.05 [0.83; 1.33]	/
		White light (=improvement)	0.97 [0.80; 1.17]	/

2.4 DESCRIPTION OF ANALYSIS

A recent meta-analysis is available that combines the results of multiple scientific studies regarding the effects of the installation of road lighting and improvements to existing road lighting on crashes (Høye, 2014). A review-type analysis has been made that departs from this meta-analysis, supplemented by the main effects of a number of more recent studies on the topic that have been published in peer-reviewed journals. The meta-analysis is supplemented with three more recent papers that investigated the effects of changes to existing road lighting (Bhagavathula et al., 2015; Nabavi Niaki et al., 2016; Steinbach et al., 2015). No additional studies about the installation of road lighting were found. The results are included in Table 2. Effects on road safety are coded as: positive (favourable) (↗), negative (unfavourable) (↘) or not statistically significant (/).

Installation of lighting & Improvements to existing lighting

The number of studies on the topic is large; 53 studies on the road safety effects of installing road lighting and 26 studies on changes to existing road lighting were included in the meta-analysis by Høye (2014). The meta-analysis and one of the added individual studies found significant reductions in crashes resulting from the installation of road lighting or improvements to existing road lighting, one study found no statistically significant effects and one study found that better road lighting correlated with a higher number of pedestrian and bicycle crashes. Given the substantial importance of the meta-analysis and the fact that the authors of the only study suggesting a negative effect of road lighting on road safety acknowledge that these findings might result from other differences between the treatment group and the control group that remain unaccounted for, it is decided that a green colour code is justified here.

2.5 CONCLUSION

In general, it can be concluded that the vast majority of research available suggests that both installation of and improvements to road lighting have a **favourable effect on road safety**. According to a meta-analysis by Høye (2014), the **installation** of road lighting significantly reduces the number of fatal crashes in darkness by 52%, and the number of injury and unspecified crashes in darkness by 26%. The number of fatal pedestrian crashes in the darkness reduces by 78%, while the number of pedestrian injury crashes in the darkness reduces by 51%.

The effect of **improving existing road lighting** on crashes seems somewhat smaller than the effect of installing road lighting on previously unlit locations. It also seems that improvements to existing road lighting **need to be quite strong** (more than doubling the previous level of lighting) **in order to have a significant effect on the number of crashes**. Increasing the lighting to two to five times the previous level reduces the number of injury crashes by 13%, and increasing it to five times the previous lighting level or more reduces injury crashes by 32%. Transferability of the results may, however, be somewhat uncertain due to substantial differences in effect size that were found over different studies. Some evidence suggests that effects differ between different types of road users and types of locations.

3 Supporting document

A literature search for studies that assessed effects of section control and speed fixed cameras was carried out in three databases (ScienceDirect, TRID, Scopus) with combinations of search terms and operators. These studies were assessed and checked for their relevance. Coding has focused on the most recent available meta-analysis (Høye, 2014), and articles in peer-reviewed scientific journals that are more recent than the meta-analysis (and that were therefore not included in it). Only articles that provide effect estimates on the number or severity of crashes are included; papers that only applied non-crash measurements such as driving speed have not been included.

3.1 METHODOLOGY

3.1.1 Literature search strategy

Principles

Excluded:

- Excluded:
- Tunnels
- Impact on health
- Railway level crossings
- Workzones, toll stations, roundabout
- Environmental issues, Energy consumption issues, energy performance
- Impact on traffic capacity/flow
- Guidelines, standards
- Lighting under fog, rain, etc.
- Working of driving assistance systems in low illumination conditions

Research terms and hits

Database: ScienceDirect **Date:** 6th January 2017

Limitations/ Exclusions:

- Search field: TITLE-ABS-KEY
- Published: 1990 to current
- Document Type: ALL

search no.	search terms / operators / combined queries	hits
#1	TITLE-ABSTR-KEYlighting) and TITLE-ABSTR-KEY"road safety").	115
#2	TITLE-ABSTR-KEY"road light*").	44

Database: Scopus **Date:** 4th January 2017

Limitations/ Exclusions:

- Search field: Abstract, title, keywords
- Published: 1990 to current

- Document Type: ALL
- Subject Area: ALL

search no.	search terms / operators / combined queries	hits
#1	TITLE "road light*" OR illumin*) AND TITLE-ABS-KEY "road safety" OR accident* OR crash*)) AND PUBYEAR > 1989	108

Database: TRID **Date:** 4th January 2017

Limitations/ Exclusions:

- Published: 1990 to 2017
- Document source : ALL, Document Type: ALL, Subject area : ALL
- Language: English and French

search no.	search terms / operators / combined queries	hits
Not selected	lighting and road	2438
#1	"road lighting"	208

Database: iRAP toolkit, iRAP website and CEDR website **Date:** 09th January 2017
No additional relevant studies

Results Literature Search

Database	Hits
ScienceDirect	159
TRID	208
Scopus	108
Total number of studies to screen title	475

Screening

Total number of studies to screen title in order to evaluate the relevance to the topic)	475
Number of articles remaining after screening of the title = Total number of studies to screen abstract	77
Remaining studies after abstract screening	- 32 selected + 1 review - 18 excluded - 25 excluded duplicates, outside search field, etc.) ➔ Impact of lighting on road safety/crashes/behaviour, as main topic of the article ➔ Among other Visual detection and recognition of objects under low-illuminance

Added articles, based on the reference list of different papers	7 + meta-analysis from The handbook of Road Safety Measures (Norwegian online version, 2014)
Total number studies to screen full-text :	41

Prioritizing Coding

Prioritization:

1. Paper's availability
2. Most recent meta-analysis available, or individual study more recent than latest meta-analysis
3. Peer-reviewed journal articles only

Following these prioritization criteria, the full-text screening of the studies has allowed to select 4 publications to be coded, including 1 meta-analysis.

Table 3 Final list of coded studies about section control.

Authors	Title	Year	Country
Høye, A.	Trafikksikkerhetshåndboken, kapittel 1.18: Vegbelysning [in Norwegian]	2014	Multiple countries (meta-analysis)
Bhagavathula, R., Gibbons, R. B., & Edwards, C. J.	Relationship Between Roadway Illuminance Level and Nighttime Rural Intersection Safety	2015	United States
Nabavi Niaki, M. S., Fu, T., Saunier, N., Miranda-Moreno, L. F., Amador, L., & Bruneau, J.-F.	Road Lighting Effects on Bicycle and Pedestrian Accident Frequency - Case Study in Montreal, Quebec, Canada	2016	Canada
Steinbach, R., Perkins, C., Tompson, L., Johnson, S., Armstrong, B., Green, J., Grundy, W., Wilkinson, P., & Edwards, P.	The effect of reduced street lighting on road casualties and crime in England and Wales: controlled interrupted time series analysis	2015	United Kingdom

3.2 FULL LIST OF CODED STUDIES

Bhagavathula, R., Gibbons, R. B., & Edwards, C. J. (2015). Relationship Between Roadway Illuminance Level and Nighttime Rural Intersection Safety. Transportation Research Record: Journal of the Transportation Research Board, 2485, 8–15.

Høye, A. (2014). Trafikksikkerhetshåndboken, kapittel 1.18: Vegbelysning [in Norwegian]. Handbook of Road Safety Measures-Norwegian (online version). Oslo, Norway.

Nabavi Niaki, M. S., Fu, T., Saunier, N., Miranda-Moreno, L. F., Amador, L., & Bruneau, J.-F. (2016). Road Lighting Effects on Bicycle and Pedestrian Accident Frequency - Case Study in Montreal, Quebec, Canada. Transportation Research Record: Journal of the Transportation Research Board, 2555, 86–94.

Steinbach, R., Perkins, C., Tompson, L., Johnson, S., Armstrong, B., Green, J., Grundy, C., Wilkinson, P., & Edwards, P. (2015). The effect of reduced street lighting on road casualties and crime in England and Wales: controlled interrupted time series analysis. J Epidemiol Community Health. doi:10.1136/jech-2015-206012

3.3 EXTRA REFERENCES IN SYNOPSIS

Elvik, R., Høye, A., Vaa, T., & Sørensen, M. (2009). Handbook of Road Safety Measures (2nd Edition). Bingley, UK: Emerald Group Publishing Limited.

Lauwers, B. (2010). Pedestrian Death Review. Ontario, Canada: Office of the Chief Coroner for Ontario.

Mäkelä, O., & Kärki, J. L. (2004). Tievalaistuksen vaikustus liikenneturvallisuuteen yes ajonopeuksiin (No. Tiehallinnon Selvityksiä 18). Helsinki, Finland.

Twisk, D. A. M., & Reurings, M. (2013). An Epidemiological Study of the Risk of Cycling in the Dark: the Role of Visual Perception, Conspicuity and Alcohol Use. Accident Analysis & Prevention, 60, 134–140.

Walter, E. M., Cavegn, M., Allenbach, R., & Scaramuzza, G. (2005). Fahrradverkehr–Unfallgeschehen Risikofaktoren und Prävention [in German]. Bern, Switzerland: Beratungsstelle für Unfallverhütung.

3.4 PAPERS INCLUDED IN META-ANALYSIS BY HØYE (2014)

3.4.1 Installation of road lighting papers

Andersen, KB (1977). Uheldsmønsteret on ordinary 4-tracked Veje. RFT report 20. Council Trafiksikkerhedsforskning (RFT), Copenhagen.

Austin, BR (1976). Public lighting the deadly reckoning. Traffic Engineering and Control, 17, 262-263.

Bauer, KM & Harwood, DW (2000). Statistical models of at-grade intersection Accidents - addendum. Report FHWA-RD-99-094.

Billion, CE & Parsons, NC (1962). Median accident study - Long Island, New York. Highway Research Board Bulletin, 308, 64-79.

Borel, P. (1958). Accident prevention and public lighting. Bulletin des Schweitzerisches ELEKTROTECHNISCHE Verband, 49, 1, 8-11, 1958 (quoted by Ketvirtis 1977).

Box, PC (1972a). Freeway Accidents and Illumination. Highway Research Record, 416, 10-20.

Box. PC (1989). Major Road Accident Reduction by Illumination. Transportation Research Record, 1247, 32-38.

Brüde, U. & J. Larsson. (1981). Vägkorsningar the countryside inom huvudvägnätet. Olycksanalys. VTI report 233. State Swedish National Road och trafikinstitut (VTI), Linköping.

Brüde, U. & J. Larsson. (1985). Korsningsåtgärder vidtagna inom vägförvaltningarnas trafiksäkerhetsarbete. Regressions- och åtgärdseffekter. VTI report 292. State Swedish National Road och trafikinstitut (VTI), Linköping.

Brüde, U. & J. Larsson. (1986). Trafiksäkerhetseffekter of korsningsåtgärder. VTI report 310. State Swedish National Road och trafikinstitut (VTI), Linköping.

Bullough, JD, Donnell, ET, & Rea, MS (2013). Two illuminate or not to illuminate: Roadway lighting as it Affects traffic safety that Intersections. Accident Analysis & Prevention, 53, 65-77.

Christie, AW (1962). Some investigations Concerning the lighting of traffic routes. Public Lighting, 27, 189-204.

Christie, AW (1966). Street Lighting and Road Safety. Traffic Engineering and Control, 7, 229-231.

Cleveland, DE (1969). Illumination. Chapter 3 of Traffic Control and Roadway Elements - Their Relationship to Highway Safety, Revised. Automotive Safety Foundation, Washington DC.

Cobb, J. (1987). Light on Motorway Accident Rates. The Journal of The Institution of Highways and Transportation, October 1987, 29-33.

Cornwell, PR & GM Mackay. (1972). Lighting and road traffic. Part 1. Public lighting and road Accidents. Traffic Engineering and Control, 13, 142-144.

Daniels, S., Brijs, T., Nuyts, E., & Wets, G. (2010). Externality of risk and crash severity that Roundabouts. Accident Analysis & Prevention, 42 (6), 1966-1973.

Fisher, AJ (1971). A review of street lighting in relation to road safety. Report Ranked 18th Australian Department of Transport, Australian Government Publishing Service, Canberra.

Fisher, AJ (1977). Road lighting as an accident Countermeasures. Australian Road Research, 7, 4, 3-15.

Griffith, MS (1994). Comparison of the Safety of Lighting Options on Urban Freeways. Public Roads, Autumn 1994, 8-15.

Gross, F., & Donnell, ET (2011). Case-control and cross-sectional methods for Estimating crash modification factors: Comparisons from roadway lighting and lane and shoulder width safety effect studies. Journal of Safety Research, 42 (2), 117-129.

Hogema, JH, & Van der Horst, ARA (1998). Dynamische Openbare Verlichting (DYNO). Fase 4: Synthese [Dynamic Public Lighting. Phase 4: Synthesis] (Report TM 98 C065). Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Institute of Traffic Engineers and the Illuminating Engineering Society. (1966). Joint Committee of Public Lighting. Public Lighting Needs. Special Report two US Senate, 1966 (quoted by Ketvirtis 1977).

Isebrands, H., Hallmark, S., Hans, Z, McDonald, T., Preston, H. & Storm, R. (2004). Safety impacts of street lighting that isolated rural Intersections - Part II, Year 1. Iowa State University: Report.

Isebrands, H., Hallmark, S., Li, W., McDonald, T., Storm, R., & Preston, H. (2010). Roadway Lighting Shows Safety Benefits the Rural Intersections. Journal of Transportation Engineering, 136 (11), 949-955.

Ives, HS (1962). Does Highway Illumination Affect Accident Occurrence? Traffic Quarterly, 16, 229-241.

Jacoby, RG & Pollard, NE (1995). The lighting of rural Roundabouts. Lighting Journal, 149-159.

Janoff, MS (1988). Effect of Bridge Lighting on Nighttime Traffic Safety. Transportation Research Record, 1172, 88-92.

Jorgensen, E. (1980). Examples of effect studies from SSV. Vejdirektoratet, Secretariat for Sikkerhedsfremmende Vejforanstaltninger (SSV), Næstved.

Jorgensen, NO & Z. Rabani. (1971). Fodgængeres certainity in and by fodgængerovergange. RFT report 7. Council Trafiksikkerhedsforskning (RFT), Copenhagen.

Ketvirtis, A. (1977). Road Illumination and Traffic Safety. Prepared for Road and Motor Vehicle Traffic Safety Branch, Transport Canada. Transport Canada, Ottawa.

Lamm, R., JH Klöckner & EM Choueiri. (1985). Freeway Lighting and Traffic Safety - A Long Term Investigation. Transportation Research Record, 1027, 57-63.

Lipinski, ME & RH Wortman. (1976). Effect of Illumination on Rural At-Grade Intersection Accidents. Transportation Research Record, 611, 25-27.

Mäkelä, O. & Kärki, JL (2004). Tievalaistuksen vaikustus liikenneturvallisuuteen yes ajonopeuksiin. Helsinki: Tiehallinnon Selvityksiä, 18.

National Board of Public Roads and Waterways. (1978). Traffic Safety Effects of Road Lights. Swedish National Road och Vattenfall Byggnads Agency, Helsinki.

Pegrum, BV (1972). The application of certainties traffic management techniques and Their effect on road safety. National Road Safety Symposium. Canberra, Australian Department of Transport, 1972 (quoted by OECD 1979). Canberra.

Pfund, K. (1986), Strassenbeleuchtung und Verkehrssicherheit. Strassenverkehrstechnik, Heft 1, 1-9.

Polus, A. & A. Katz. (1978). An analysis of nighttime pedestrian Accidents that specially illuminated crosswalks. Accident Analysis and Prevention, 10, 223-228.

Preston, H. & Schoenecker, T. (1999). Safety Impact of Street Lighting that Isolated Rural Intersections. Final Report MN / RC-1999-17. Minnesota Department of Transportation, April.

Richards, SH (1981). Effects of Turning Off Selected Roadway Lighting as an Energy Conservation Measure. Transportation Research Record, 811, 23-25.

Sabey, BE & HD Johnson. (1973). Road lighting and Accidents: before and after studies on trunk road sites. TRRL Report LR 586. Transport and Road Research Laboratory, Crowthorne, Berkshire.
Sasidharan, L., & Donnell, ET (2013). Application of propensity scores and potential outcomes two estimate effectiveness of traffic safety Countermeasures: Exploratory analysis overusing intersection lighting data. Accident Analysis & Prevention, 50 (0), 539-553.
Schwab, RN et al (1982). Roadway Lighting. Chapter 12 of Synthesis of Safety Research Related to Traffic Control and Roadway Elements, Volume 2. Report FHWA-TS-82-233. US Department of Transportation, Federal Highway Administration, Washington DC.
Seburn, TC (1948) Relighting A City. Proceedings of the Institute of Traffic Engineers Nineteenth Annual Meeting, 58-72, 1948 (quoted by Ketvirtis 1977).
Tamburri, TN, Hammer, C, J .; Glennon, JC & Lew, A. (1968). Evaluation of Minor Improvements. Highway Research Record, 257, 34-79.
Tanner, JC & AW Christie. (1955). Street Lighting and Accidents - A Study of some New Installations in the London Area. Light and Lighting, 48, 395-397.
Tanner, JC (1958). Reduction of Accidents city Improved Street Lighting. Light and Lighting, 51, 353-355.
Taragin, A. & BM Rudy. (1960). Traffic Operations as Related to Highway Illumination and Delineation. Highway Research Board Bulletin, 255, 1-22
Tennessee Valley Authority. (1969). A Study of the Benefits of Suburban Highway Lighting. Illuminating Engineering, April, 359-363.
Transportforskningskommissionen. (1965). Swedish National Road och gatubelysningens inverkan on Trafiksäkerhet. Meddelande No. 60. Transportforskningskommissionen, Stockholm.
Walker, FW & SE Roberts. (1976). Influence of lighting on accident frequency that Highway Intersections. Transportation Research Record, 562, 73-78.
Wanvik, PO (2009a). Road lighting and traffic safety. Do we need road lighting? Doctoral theses at NTNU 2009: 66, Trondheim, NTNU.
Wanvik, PO (2009b). Effects of Road Lighting on Motorways. Traffic Injury Prevention, 10 (3), 279-289.

3.4.2 Changes to existing road lighting papers

Andersen, KB (1977). Uheldsmønsteret on ordinary 4-tracked Veje. RFT report 20. Council Trafiksikkerhedsforskning (RFT), Copenhagen.
Box, PC (1972a). Freeway Accidents and Illumination. Highway Research Record, 416, 10-20.
Box, PC (1972B). Comparison of Accidents and Illumination. Highway Research Record, 416, 1-9.
Box, PC (1976). Effect of Lighting Reduction On an Urban Major Route. Traffic Engineering, October 1976, 26-27.
Christie, AW (1966). Street Lighting and Road Safety. Traffic Engineering and Control, 7, 229-231.
Danielsson, S. (1987). Trafiksäkerhetseffekter vid one Attenuation of gatubelysningen. VTI report 315. State Swedish National Road och trafikinstitut (VTI), Linköping.
Fisher, AJ (1977). Road lighting as an accident Countermeasures. Australian Road Research, 7, 4, 3-15.
Foyster, MJ & M. Thompson. (1986). The effect of road lighting improvements in Westminster on road Accidents. Proceedings of the Seminar P held that the PTRC Summer Annual Meeting, University of Sussex, England, 14-17 July 1985, 161-172. PTRC, Sussex, England.
Friis, A., NO Jørgensen & I. Schiøtz. (1976). Færdselsuheld and vejbelysning under oliekrisen. A undersøgelse af about the neddæmpede vejbelysning under oliekrisen in winter 1973/74 havde any effect on færdselsuheldstallet. RFT note 129. Council Trafiksikkerhedsforskning (RFT), Copenhagen.

Huber, MJ & JL Tracy. (1968). Effects of Illumination on Operating Characteristics of Freeways. National Cooperative Highway Research Program Report 60. Highway Research Board, Washington DC.

Janoff, MS (1988). Effect of Bridge Lighting on Nighttime Traffic Safety. Transportation Research Record, 1172, 88-92.

Lamm, R., JH Klöckner & EM Choueiri. (1985). Freeway Lighting and Traffic Safety - A Long Term Investigation. Transportation Research Record, 1027, 57-63.

Ludvigsen, HS & K. Sorensen. (1985). Natreduktion af vejbelysning - the sikkerhedsmæssige effect. Vejregelforberedende report 1. Vejdirektoratet, Secretariat for Sikkerhedsfremmende Vejforanstaltninger (SVV), Copenhagen.

Pfund, K. (1986), Strassenbeleuchtung und Verkehrssicherheit. Strassenverkehrstechnik, Heft 1, 1-9.

Richards, SH (1981). Effects of Turning Off Selected Roadway Lighting as an Energy Conservation Measure. Transportation Research Record, 811, 23-25.

Schreuder, DA (1989). The relationship between the level of street lighting and the traffic safety. R-89-55. SWOV Institute for Road Safety Research, Leidschendam.

Schreuder, DA (1993) Relation between lighting, Accident and crime in urban streets. The VIIth European Lighting Conference, April 4 to 7, 1993, Heriot-Watt University, Edinburgh, Scotland. Proceedings, Volume 1, 117-123.

Seburn, TC (1948) relighting A City. Proceedings of the Institute of Traffic Engineers Nineteenth Annual Meeting, 58-72, 1948 (quoted by Ketvirtis 1977).

Sielski, MC (1967). Relationship of Roadway Lighting and Traffic Accidents. In: Highway Research Board Special Report 93, Improved Street Utilization Thru Traffic Engineering, 172-177. Highway Research Board, Washington DC.

Tamburri, TN, Hammer, C, J .; Glennon, JC & Lew, A. (1968). Evaluation of Minor Improvements. Highway Research Record, 257, 34-79.

Tanner, JC & AW Christie. (1955). Street Lighting and Accidents - A Study of some New Installations in the London Area. Light and Lighting, 48, 395-397.

Tanner, JC (1958). Reduction of Accidents city Improved Street Lighting. Light and Lighting, 51, 353-355.

Turner, HJ (1962). Influence of road lighting on traffic safety and service. Proceedings of the Australian Road Research Board, Volume 1, Part 1, 596-611.

Uschkamp, G., Hecker, R .; Thasler, HU. & Breuer, D. (1993). Zusammenhang zwischen Beleuchtungsgüte und Strassenverkehrsunfällen. FE 70300/89. Schlussbericht 08/31/1993. ISV Ingenieurgruppe Stadt + Verkehr.

Wyatt, FD & E. Lozano. (1957). Effect of Street Lighting on Night Traffic Accident Rate. Highway Research Board Bulletin, 146, 51-55.

Yin, T. (2005). Effects of highway illumination reduction on Highway Safety performance. Portland State University.