MASTER

Enlighting the roads of tomorrow

exploring road users' preferences of road lighting along highways in the Netherlands

van Kampen, M.

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2015

ENLIGHTING THE ROADS OF TOMORROW

Exploring road users' preferences of road lighting along highways in the Netherlands.

MASTER GRADUATION THESIS
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Figure 1 - Netherlands and Belgium and its public lighting as seen from the International Space Station somewhere 2014. Note that the public lighting in the Netherlands has been dimmed to only light what needs to be lighted. Source: Platform Lichthinder, 2014

COLOPHON

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I have learned lots about researching, road lighting and more specifically about myself. I am ready to take on new, exciting challenges with the knowledge and life lessons I derived during this graduation period. I enjoyed working at Heijmans Infra B.V., studying at Eindhoven University of Technology and writing my graduation thesis. I hope you are able to experience my enthusiasm and enjoy reading the results,

Mark van Kampen
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MANAGEMENT SUMMARY

Road lighting is an integral aspect of infrastructure in general, and in specific highways. Road lighting is vital for driving, as the road users' visual perception is key in acquiring the necessary information for driving. Road lighting aids the visual perception when natural light sources are not sufficient, so that road users can detect any objects or other road users in timely fashion and are guided along the course of the road. Besides driving advantages, road lighting also enhances the feelings of safety and comfort for road users, especially at night.

Current road lighting comes with several downfalls. First, financial costs for placement, maintenance and energy form a burden for the road lighting owners. Second, road lighting needs energy to function, and therefore CO_2-emission and global warming are results of road lighting as well. Third and final disadvantages is light pollution, the effect lighting has on nature and on the sky.

Measures to cope with these disadvantage are taken by the government, such as dimming of shutting down road lighting completely. More strict legislations are created to decrease the effects of road lighting, while maintaining the benefits. Companies within the lighting industry are coming up with new kinds of lighting, in order to cope with these measures. However, the effects of road lighting on road users is yet to be determined. The road user, the main actor in road lighting, is often overlooked at this moment. Current practice in construction is aimed at fulfilling the legislations, without looking to the needs of road users.

The rise in vehicle automation and smart mobility will change the identity of the road users, and may present new opportunities for road lighting enhancements. However, understanding on the relation between road lighting and the effects for the road users is very scarce. More insights in the perceptions of the road users are crucial for future lighting development and application as well as decision-making processes for legislative parties.

The preferences of road users will provide more understanding in the effect of road lighting. Road users preferences are based on four variables, namely safety, guidance, detection, and comfort. In order to determine which aspects are influential for the perceptions of road users, and provide stepping-stones for future research, road lighting is divided in several aspects. These aspects are categorized in lighting aspects, situational, aspects and driver aspect. Using available literature and expert knowledge, a number of aspects are fixed and a set of aspects is highlighted to analyzed. Within these aspects, a limited number of level is distinguished. Besides current forms of lighting, new kinds of lighting are added so that current and future road lighting can be studied.

ASPECT	LEVELS		
Lighting type	SON	LED	EL
Lighting placement	Above	Below	
Lighting uniformity	Low	Medium	High
Road conditions	Straight lane	Bend	Exit lane
Weather conditions	Fine weather	Rainy weather	Foggy weather
Driver assistance	No assistance	Full assistance	

Determining the preferences of road users in the Netherlands will be done using a stated choice experiment. Several hypothetical lighting alternatives are randomly created using the aspects from the study. This includes the possibility to test the preferences of road users regarding present forms of lighting, primarily SON lighting applied from above, and include new types of lighting, LED and EL lighting, as well as alternative placement and uniformity of lighting.

These alternatives are presented visually and verbally using an online survey from Berg Enquête System. A respondent is asked to rate the alternatives on four variables, namely safety, guidance, detection, and comfort and eventually choose one of the alternatives in one choice-task. This combination of rating and choice will provide not only the preference but also extensive information on the perceptions of road users and the performance of individual lighting aspects and corresponding levels. The survey exists out of three parts, the first determines the experience of road users. The second part of the survey presents the stated choice experiment, including a trial question, extensive explanation, and three choice-tasks. The third and final part of the survey concerns several personal questions. A total of 280 respondents participated in the survey, all aged 18 and above, and they represent the population of the Netherlands well.

The analysis of the rating and choice data is done by creating four ordinal regression models and a multinomial regression model. The models together provide detailed information about the performance of road lighting under different circumstances, the interaction of the road user with road lighting and the driving environment as well as the determination of most influential aspect of road lighting.

The results of the experiment show that new forms of lighting are preferred over the current form of lighting. Alternative placement, lighting uniformity and lighting types were rated higher on the aspects of safety, guidance, detection and comfort, under different circumstances. This indicates that not only new lighting types, such as LED and EL, are viable opportunities for future road lighting, also complete new concepts involving new placement and uniformity have potential. As lighting type, LED lighting is preferred, EL is considered second-best and SON lighting is rated worst. Lighting placement from below is preferred over lighting from above and a high level of uniformity is preferred over medium and low uniformity. The most important aspect, according to road users in this experiment, is lighting uniformity, followed by lighting type and lighting placement. It is concluded that preferences of road users regarding road lighting are strongly related to the context. Different weather conditions and road conditions account for a different need of road lighting.

It is recommended for governmental institutes and legislative parties to look at opportunities besides dimming or shutting down road lighting, and take the needs of road users into consideration in decision-making processes. For companies in the road lighting industry recommendations feature the need for new lighting solutions, incorporating the most important aspects for road users. New lighting types and alternative ways of lighting should be designed and created to cope with the challenges and measures set by the government. Collaboration and integral approaches during the design and construction of road lighting along highways, taking the needs of road users into consideration is key for the development of future road lighting.

MANAGEMENT SUMMARY DUTCH

Openbare verlichting is een onlosmakelijk verbonden onderdeel van infrastructuur, met name rondom de snelwegen. Openbare verlichting is cruciaal voor het verkeer. Visuele waarneming van de weggebruiker is voor het waarnemen van de noodzakelijke verkeersinformatie van groot belang. Openbare verlichting ondersteunt de weggebruiker wanneer natuurlijke verlichting niet meer voldoende is, zodat weggebruiker op de juiste momenten objecten en verkeersdeelnemers kunnen detecteren en het verloop van de weg kunnen volgen. Naast deze voordelen voor het verkeer heeft openbare verlichting ook een positief effect op het gevoel van veiligheid en comfort van weggebruikers, met name bij nacht.

De huidige openbare verlichting heeft echter enkele nadelen. Allereerst de financiële kosten, met betrekking tot het plaatsen, onderhouden en laten functioneren van verlichting. Daarnaast betekent de energie consumptie van verlichting ook CO_2 uitstoot en dus een bijdrage aan het broeikaseffect. Een derde en laatste nadeel is lichtvervuiling, voortkomend uit de effecten van verlichting op de natuur en op de hemel.

De overheid heeft maatregelen tegen deze nadelen genomen, zoals het dimmen of uitschakelen van verlichting. Daarnaast is de wet en regelgeving aangepast, zodat nadelen geminimaliseerd worden zonder de effecten van verlichting weg te nemen. Verschillende bedrijven in de verlichtingsindustrie komen met nieuwe manieren van verlichten, met nieuwe lichtsoorten of nieuwe toepassingen. Echter, dit gebeurt met weinig kennis over de effecten op de weggebruiker. De weggebruiker wordt over het hoofd gezien in de praktijk, terwijl verlichting toch echt is gericht op het ondersteunen van deze doelgroep.

De opkomst van geautomatiseerde voertuigen en slimmere mobiliteitsoplossingen zullen deze doelgroep ongetwijfeld beïnvloeden en daarmee indirect zorgen voor nieuwe kansen voor verbeteringen aan de openbare verlichting. Echter, hiervoor is wel inzicht in de relatie tussen verlichting en de weggebruiker noodzakelijk. Op het moment is er bijzonder weinig actuele kennis over deze effecten voorhanden om de besluitvormingsprocessen en de ontwikkeling van openbare verlichting te ondersteunen.

Onderzoek naar de voorkeuren van weggebruikers zal meer inzicht geven in de effecten van openbare verlichting. De voorkeuren worden in vier variabelen verdeeld: veiligheid, begeleiding, detectie en comfort. Openbare verlichting is gecategoriseerd in diverse aspecten, waarin met behulp van literatuur en experts een selectie is gemaakt voor verder onderzoek. Deze aspecten hebben een aantal niveaus toegekend gekregen, om zowel huidige als toekomstige manieren van verlichting te kunnen omschrijven.

ASPECT	NIVEAU		
Verlichtingssoort	SON	LED	EL
Verlichtingswijze	Van boven	Van beneden	
Uniformiteit	Laag	Gemiddeld	Hoog
Wegsituatie	Rechte weg	Bocht	Uitrit
Weerssituatie	Goed weer	Regen	Mist
Rij-assistentie	Geen assistentie	Volledige assistentie	

Het vaststellen van de voorkeuren van weggebruikers in Nederland uitgevoerd worden met behulp van een keuze-experiment. Dit experiment zal verschillende hypothetische verlichtingsalternatieven vergelijken. Elk alternatief is willekeurig samengesteld uit de niveaus van de aspecten. Deze aanpak biedt de mogelijkheid om naast de huidige, standaard SON verlichting vanaf boven, ook nieuwe vormen van verlichting te vergelijken.

Alle alternatieven zijn in woord en beeld gepresenteerd in een online enquête via Berg Enquête System. Een respondent wordt gevraagd om elk alternatief te beoordelen op de vier variabelen, veiligheid, begeleiding, detectie en comfort, en daarna een van de drie alternatieven in een keuzetaak te kiezen die zij het meest prefereren. De combinatie van beoordelen en kiezen geeft niet alleen de voorkeur van de weggebruiker weer, maar biedt geeft veel informatie over de beleving van weggebruikers en de prestatie van de individuele verlichtingsaspecten. De enquête bestaat uit drie delen. Het eerste deel onderzoekt de wegervaring van de respondent, het tweede deel beslaat het keuze experiment. Het keuze-experiment beslaat een introductievraag, uitgebreide uitleg en drie keuzetaken. Het derde en laatste deel van de enquête heeft betrekking op persoonskenmerken. In totaal hebben 280 respondenten deelgenomen, met minimale leeftijd van 18. Zij vertegenwoordigen de Nederlandse bevolking.

De analyse van de beoordeling en de keuze wordt middels vier ordinale regressie modellen en een multinomiaal regressie model gedaan. Deze modellen samen geven gedetailleerde informatie over de prestatie van openbare verlichting onder verschillende omstandigheden, alsmede de interactie tussen de weggebruiker, wegverlichting en de context en de invloed van de verschillende aspecten van verlichting.

De resultaten van het experiment geven aan dat nieuwe vormen van verlichting worden geprefereerd over de huidige vormen. Nieuwe wijze, uniformiteit en types worden hoger beoordeelt op de aspecten van veiligheid, begeleiding, detectie en comfort, onder verschillende omstandigheden. Dit duidt niet alleen op de mogelijke ontwikkeling van nieuwe lichtsoorten, zoals LED en EL, maar geeft ook de potentie van nieuwe manieren van verlichten aan. Er is ruimte in de ogen van de weggebruiker voor verlichting vanaf het wegdek en met andere uniformiteiten. LED heeft de voorkeur als verlichtingstype, boven EL en SON. Verlichting toegepast van onderen wordt beter gewaardeerd dan verlichting boven de weg. Een hoger niveau van uniformiteit geniet de voorkeur. Het belangrijkste aspect van verlichting is de uniformiteit van verlichting, daarna de lichtsoort en als laatst de wijze van verlichting. Het blijkt dat de context sterk samenhangt met de voorkeuren van de weggebruiker. Weersomstandigheden en wegsituaties resulteren in aangepaste voorkeuren van verlichting.

Voor de overheid wordt aanbevolen om de resultaten van dit onderzoek mee te nemen en toe te passen door de behoeften van de weggebruikers mee te nemen in het besluitvormingsproces. Bovendien kunnen er alternatieve vormen van verlichting mee worden genomen om beter om te gaan met de nadelen, in plaats van meteen het licht te dimmen of uit te schakelen. Voor bedrijven in de industrie wordt aangeraden om naast verlichtingstypen ook naar alternatieve vormen van verlichting te kijken. De meest invloedrijke aspecten kunnen in het ontwerpproces worden meegenomen en worden gebruikt om efficiëntere en effectievere verlichting te creëren. Een integrale aanpak en samenwerking tijdens het ontwerp van snelwegen, waarbij de belangen van de weggebruikers concreet worden meegenomen zijn essentieel voor het verlichten van de weg van morgen.

LIST OF ABBREVIATIONS

AVV	a former Dutch advisory institute, DVS: *Adviesdienst Verkeer en Vervoer.*
CBS	a Dutch research institute for statistics: *Centraal Bureau voor de Statistiek.*
CROW	a Dutch research institute: *Kennisplatform voor Infrastructuur, verkeer, vervoer en openbare ruimte.*
DVS	an advisory-part of the Dutch Ministry of Infrastructure and Environment, *Dienst Verkeer en Scheepsvaart.*
I&M	the Dutch Ministry of Infrastructure and Environment, *Infrastructuur en Milieu.*
IGOV	a Dutch Innovation Platform: *Intergemeentelijk Overleg Openbare Verlichting.*
ITS	*Intelligent Traffic Systems.*
KiM	a Dutch research institute, *Kennisinstituut voor Mobiliteitsbeleid.*
NSVV	a Dutch institute for lighting: *Nederlandse Stichting voor Verlichtingskunde.*
RWS	an operations-part of the Dutch Ministry of Infrastructure and Environment, *Rijkswaterstaat.*
SWOV	a Dutch research institute: *Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.*
TNO	a Dutch research institute: *Nederlandse Organisatie voor toegepast natuur-wetenschappelijk onderzoek.*

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1 INTRODUCTION

This study begins with a short introduction of lighting in general, after which road lighting is presented as an essential part of the driving environment. It will briefly cover interesting trends and relevant issues in the lighting industry, before presenting the research objectives and the outline of the study.

1.1 Lighting

Lighting is all around us. Lighting has lots of different forms and functions, but in general it is essential for the world of today. Lighting enables us to extend the day beyond daytime (roughly between sunrise and sunset) and use spaces which are not sufficiently lighted by daylight.

An activity of life where lighting is of great importance is driving. Lighting for driving consists of road lighting, vehicle lighting, road signs and traffic signals. The principles of road lighting have changed little since the 1930s, and a review is “necessary and timely” (Boyce, 2009).

Functional road lighting is essential in ensuring the safety of road users. Especially at night-times or whenever daylight is not able to light sufficiently due to circumstances. Lighting aids the visual perception of road users, so that they are able to drive safely to their destinations in all sorts of conditions.

Much of road lighting research is focused on more sustainable forms of lighting and financial discussions, instead of determining how to make road lighting more effective for the road user. Furthermore the application of road lighting nowadays seems to be focused on meeting the requirements, instead of creating the best lighting solutions for the end-goal: a safe road. These developments are definitely not beneficial for the safety of road users.

Based on these kinds of researches, the Dutch ministry has decided to push a ‘sober down’ strategy since autumn 2013 and actually turns off the lights at times at night in order to save money (I&M, 2015). Although they claim road safety is not being harmed, turning down the lights surely is not beneficial for the perception of the road and the driving task. It is necessary to bring back the focus of road lighting to its original purpose: aiding the road user.

1.2 Focusing on the environment

In the search for lighting solutions, several trends have been developed over the year. New forms of technologies and applications, such as new applications of LED in road lighting, account for more variability, and an increase in sustainability and durability. Since the 1990s the environment has become more of a subject for lighting solutions (AVV, 2006). From then on, new technologies needed to have less harmful emission, less energy consumption and use less materials, in order to keep a safe environment. In 1997, the Netherlands signed the Kyoto Agreement, which is designed to reduce greenhouse gas emissions, and it was agreed that the CO_2 emissions lighting installations should be reduced by 20 % by 2020 and at least 10 % use of sustainable energy by the same year (AVV, 2006). Another environmental trend in road lighting is the influence of lighting on nature. Under influence of several institutes such as Platform Lichthinder, the use of lighting and its environmental pollution is under discussion. According to research of AVV (2006), the natural behavior of animals can be disrupted by light.

Different lighting strategies have been developed by the Dutch government in order to cope with these trends, making sure that road safety is maintained while consequences are kept to a minimum. Several companies, such as Heijmans Infra and Philips adopted these challenges and try to find new ways to light roads without the harm of the environment. Innovations like the Glowing Lines and Interactive Light (Visscher, 2013) are specifically designed to be energy efficient and highly functional. These developments and ideas incorporate the perspectives of the politics while holding on to the main objective of road lighting.

1.3 New kinds of driving

Simultaneously with the developments of lighting solutions, the vehicle industry is innovating towards smarter and safer vehicles. These trends are captured in the general term 'Smart Mobility'. The identity of the road user is changing, mainly due to technological improvements on vehicles. In-car systems are ready to take over driving duties and make fully automated vehicles possible. Some researchers even say that these Intelligent Traffic Systems, ITS in short, make a large part of the road infrastructure redundant (KPMG and Car, 2012). Different roadmaps on Smart Mobility have been drawn (AutomotiveNL, Connekt, DITCM, 2012; TNO, 2014), and they agree on the fact that the driver's role is undergoing changes. Different levels of automation require different driver solutions, however they all have in common that the driver will act more passively than current drivers. The decrease of driving duties together with the automation of driving even questions the need for road lighting, as technology does not need light to be able to see.

1.4 Problem definition

In the creation of successful roads and road lighting, both the technological possibilities as well as the road users' demands have to be taking into account. Although researchers have tried to gain insights on the demands, knowledge about the preferences of road lighting of road users is lacking. Especially when circumstances start changing researchers are in the dark. In order to prevent a potential mismatch in between technology and perception, now and in the future, it is essential that understanding of the demands of road lighting of the road users is derived.

As mentioned throughout this chapter, the governmental institutes as well as the lighting industry cope with the same problem, which has been defined in the problem definition:

There is a lack of knowledge about the preferences of road users regarding current and future road lighting.

This research is an attempt to fill that gap, examining the preferences of the current road users on various forms of road lighting under different circumstances. This will aid in the creation of future perspectives on road lighting and roads of tomorrow, and provide valuable insights in the needs of road users concerning their future driving experiences. The insights derived during this research can be used to support the decision-making of governmental institutes and lighting companies.

As we are on the brink of automated vehicles, now is the time to evaluate the way road lighting is used and what is preferential, so that we can meet tomorrow's demands. The time between now and the potential full implementation of automated vehicles may offer opportunities for new road lighting techniques to gradually take over, alongside the implementation of vehicle automation. For now, experts are in the dark on the needs of road users, especially when the driving task is changing over time.

The current practice often overlooks the end-user and create lighting plans that fulfil the requirements as legislated, instead of addressing user-based lighting needs. In an attempt to design new kinds of lighting plans, the user must be investigated carefully in order to determine current needs of the road users.

1.5 Research questions

In order to find a solution for the existing problem, a main question (MQ) has been set up.

MQ: Which kinds of road lighting do road users prefer and which circumstances are influential on road users' road lighting preference?

The objective of this research is to gain understanding of the way road lighting contributes to the perception of driving, from the road users' point of view and generate a preferential situation. It will help to determine which aspects of road lighting are necessary in the future, by developing understanding of the importance of different aspects. Therefore a set of four sub questions (SQ) has been created, in order to better help understand and answer the main question.

SQ1: What is road lighting and what are current and expected technologies?

SQ2: Which circumstances influence the preferences of road users regarding road lighting?

SQ3: What are the current preferences of road users regarding road lighting?

SQ4: How do road lighting, circumstances, and the road user interact?

The knowledge gained throughout this research will be used as input for Heijmans Infra B.V. for the development and implementation of road lighting technologies. It is of great importance to stay ahead of the competition and that they can be trend leaders instead of trend followers. Understanding the way road-users perceive the roads, might provide the edge for Heijmans Infra B.V. to design better road lighting solutions.

1.6 Research limitations

Certain boundaries have been set, in order to make this research possible in the limited timeframe. The research will focus on road lighting in the Netherlands, and more specific along the highway. The highway only facilitates one kind of vehicle-users, whereas other road types may combine different users, i.e. pedestrians and cyclists. Only lighting technologies in the pilot-phase or further will be taken into account, as the research focusses on the preferences of current lighting possibilities to prepare for the future.

1.7 Research outline

The research is done in three parts. First of all, during the context orientation, literature studies and expert interviews will be held in order to identify important aspects of road lighting and road users. Literature about road lighting from several research institutes in the Netherlands, such SWOV and TNO, will be combined with literature from RWS and other parts of the government in order to examine the current practice. Several experts in the field of lighting and perception, such as PhD. R. Elvik, PhD. P.O. Wanvik & PhD. P.R. Boyce, provide the necessary perspectives on the use of road lighting (section 2 Road lighting unveiled). Interviews will be held with experts from governmental parties as well as consultancy agencies, to gain background information on different lighting trends (section 3 Trends in road lighting).

Then the important aspects of lighting and road users are identified (section 4 Aspects of road lighting). Which feature in a field study that is held among road users in the Netherlands. In order to test road users' preferences, a stated choice experiment is set up (section 5 Choice-experiment). Data for this experiment will be collected by means of an online survey, using the Berg Enquête system, a tool developed in 2007 by the group Design Systems of Eindhoven University of Technology. Data is analyzed using regression analysis and choice model analysis (section 6 Road users' preferences)

The third and final part of this research consists of an evaluation of the experiment and an interpretation of the results. Conclusions are drawn about the preferences of the respondents (section 7 Conclusions) and recommendations are made for future research and development of lighting technologies (section 8 Recommendations). After which the experiment is critically analyzed and discussed (section 9 Discussion).

The expected result of this research is mainly the increase in knowledge about the road users' preferences. It will provide insights into the ways current road users perceive their driving environment and how lighting possibilities are experienced under different circumstances. It will support the decision-making of governmental institutes and lighting companies concerning future road lighting.

PART 1: CONTEXT ORIENTATION

2 ROAD LIGHTING UNVEILED

In this chapter the aspect of lighting will be analyzed. Light has many forms and before one is able to understand the applications for road lighting, it is necessary to familiarize with light, the benefits and its limitations. Furthermore, the current state of road lighting and the current practice will be reviewed. Finally, different lighting sources are quickly assessed.

2.1 Understanding lighting

Light is an electromagnetic phenomenon, according to the Commission Internationale de l'Eclairage (2015). In the eyes of physicists, the full electromagnetic spectrum is considered light. The human eye however is not able to absorb the whole spectrum. Only light with a wavelength between 380 and 780 nanometer can be transformed into stimuli by the human eye. Light within that region of the spectrum is called 'visible light' (CIE, 1931). The electromagnetic spectrum can be seen in Figure 2-1 below. Every wavelength has its own characteristics, i.e. color and sensitivity. The CIE-1931 system is used to review those wavelengths and describe their color using the tri-stimuli coordinates *x, y and z* (CIE, 1931).

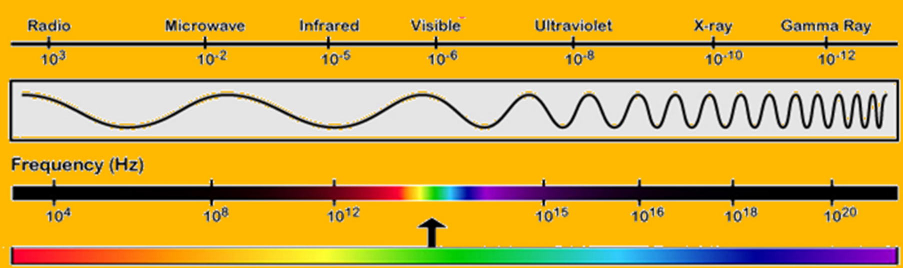
As described by Fors & Lundkvist (2009), a light-source emits radiant flux, *Φ* [watt, W], which when weighted according to the spectral response of the human eye, is called luminous flux, *Φw* [lumen, lm]. The luminous flux emitted by a light source within a certain angle, is named light intensity, *I* [candela, cd].When the light lands on a surface, *A* [square meter, m^2] at a certain distance from the source, *r* [meter, m] the light intensity implies an illuminance, *E* [lux, lx]. Dependent of the reflective characteristics of a surface, the illuminance results in a luminance, *L* [candela per square meter, cd/m^2]. The human eye makes things visible by detecting differences in luminance between the visible object and its background. This concept is called "contrast" and is essential in road lighting (Fors & Lundkvist, 2009).

Different lighting conditions, i.e. daylight or dusk, trigger different responses from the eye. The CIE has divided these types of vision into three categories, photopic, mesoptic and scotopic vision. The eye consists of different light sensitive cells, two of which are the rods and cones. Rods are responsible for the scotopic vision. The rods are very sensitive to light (with a maximum at 500 nanometer) and are able to function at low light conditions such as night-time. They are less able to distinguish colors, but are highly sensitive to motion.

The cones are responsible for photopic vision, they are less sensitive to light, and need brighter lighting conditions in order to function. They are however very good at perceiving colors. Cones are maximally sensitive at 560 nanometer, but also have peaks at 420 and 530 nanometer. The mesoptic vision, also known as the transitional range, is the range between scotopic and photopic. Neither the rods nor the cones function optimally in this range.

Figure 2-1
The electromagnetic spectrum with the visible region accentuated.

Source: NASA, 2012



2.2 Lighting in the driving environment

Vision is vital for driving, as the driver is required to continuously be aware of its environment. CROW (2013) states that about 90% of the necessary information for driving is acquired by vision. Thus making sure the driving environment is sufficiently lighted is essential in the search for safe mobility.

The human eye is not capable to perform optimally in low lighting conditions, even without visual impairments. Low light conditions account for a decrease in contrast and visual sensitivity. This results in a difficulties for the road user on the spotting of movement, distinguishing colors, estimating distances and looking ahead. Failing to gather the necessary information may result in (fatal) accidents.

In order to provide in this basic need of the driver, road lighting has been developed. Road lighting is a form of public lighting, which is considered 'all artificial lighting on roads and streets, intersections and crossings' (Elvik, Vaa, Hoye, Erke, & Sorensen, 2009), specifically altered to enhance the visibility on roads. The NSVV (2011) even provides a broader definition: 'all artificial lighting with the purpose of enlightening the public space to the enhancement of quality of life, the traffic- and social safety of the public safety'.

The role of road lighting is to enable drivers to communicate with their environment, obtaining information from their environment either direct or indirect (Boyce, 2009). Direct communication occurs when the information is a light-source, which can be a vehicle headlight or a traffic sign. Indirect communication exists when a light-source is used to illuminate a surface, making it more visible for the driver. In daylight conditions, most of the time the environment is illuminated sufficiently by the sun. However, when bad weather occurs, road lighting might be needed to enhance visibility for road users.

The main objective of road lighting can thus be summarized to 'to aid the visual perception of drivers, when natural sources are not sufficient', as stated by the SWOV (2011).

Road lighting has two primary functions:

1) Detection of objects on and around the road
2) Guidance of road users along the course of the road

2.2.1 Detection

Road lighting aids the road user in detecting the layout of the road, its objects, signs and other road users. In the Netherlands we use the so-called 'Luminance contrast' principle (Boyce, 2009) for the detection of objects on and around the road. Road lighting is used to light the road surface and the objects on the road. The target and the background are on a different distance from the light source, which gives the object a different level of illumination. Taking the reflective properties into account, road surface absorbs the illumination, resulting a dark road surface. The lighted target will seem brighter (a positive contrast) and will stand out according to the darker background, a principle called luminance contrast. By continuously lighting the road surface, all objects on the road surface can be detected more effective.

2.2.2 Guidance

Lighting the surface of the road, so that objects become detectable, is only one function of road lighting. The other function of road lighting is making sure that road users, travelling about 40 meters every second, are able to see the course of the road. The luminance of the road surface can be seen at close-range, but is less or not visible further along the road.

The light sources currently used in road lighting need to have a high level of light intensity to generate the necessary amount of luminance on the road surface. This light source, due to its intensity, is in fact visible at long range, leaving the road user with a trail of light sources along the course of the road. This trail enables the user to look ahead and see the direction of the road at long distances.

2.3 Effect of road lighting

Road lighting has a number of advantages for the road user. First, it eases the driving task by simplifying the perception of road- and traffic information. In other words, driving becomes more comfortable due to road lighting, as it becomes easier for the road user to gather the necessary information for driving (Wanvik, 2009b). The driving task becomes easier, and road users are less tired after driving. An example of road lighting aiding the road users is the road lighting used to accentuate exit lanes. Lighting installations around exit lanes are applied in such a manner that road users are able to detect the exit lanes, be able to determine which exit lane this is and safely be guided along the exit lane (CROW, 2013). Another aspect that benefits the level of comfort for road users is the fact that road lighting takes the darkness away, which gives a comfortable feeling as well (Boyce, Eklund, B.J., & Bruno, 2000).

A second benefit of road lighting, and perhaps more vital advantage, is its effect on road safety (Wanvik, 2009b). The feeling of safety on the road is closely related to the aspect of “see and be seen”, as mentioned by CROW (2012). The feelings of safety on the road is very personal, therefore it is very difficult to understand and interpret the effects of measures on the feelings of safety (RWS, 2010). However, it is clear that road lighting has an improving effect on the

Road lighting enhances the safety on the road, by aiding in the communication of objects, signs and markings on the road. Making sure that road users are able to timely detect objects and other road users is critical for the increase in safety of the road users, as this increases the time a road user has to react. Road lighting also enhances the visibility of the course of the road and the roadsides, which adds to the road users’ feelings of safety as well (RWS, 2010).

Another benefit is the increase in mobility, which closely relates to the increased levels of safety. Not only are road users more prepared to also travel at night when roads are lit (Wanvik, Road Lighting and Traffic Safety, 2009b), road users also travel faster (Assum, Bjornskau, Fosser, & Sagberg, 1999). A study by Assum, Bjornskau, Fosser & Sagberg (1999) proves that the average speed during darkness is increased by road lighting by an amount up to 5 percent, depending on the road conditions (e.g. straight lane, bends, exit lanes). An increase in speed also leads to an increase in traffic flow, and an overall decrease in travelling time (Beyer & Ker, 2009). Thus, it is argued that road lighting benefits the mobility of road users.

All these benefits have a common factor, they are all influenced by the perception of safety of road users. Therefore, the ultimate purpose of road lighting is "to enhance the safety by increasing the visibility of the road and the objects on and around it" (Wanvik, 2009b).

The effects of road lighting are estimated in several studies by for example Beyer & Key (2009), Boyce (2009), Elvik, Vaa, Hoye, Erke & Sorensen (2009), Martens (2005), Plainis & Murray (2002), Wanvik (2009a) and Weijermans, Goldenbeld, Bos & Bijleveld (2008) and proves difficult due to the large amount of influences affecting the aspect of road lighting. Factsheets from SWOV (2011) and CROW (2013) also accentuate this complexity in their reports. Regardless, the work of Elvik, Vaa, Hoye, Erke & Sorensen (2009) is often used to showcase the positive effects of road lighting on safety, by assessing the number of accidents.

Elvik, Vaa, Hoye, Erke & Sorenson (2009) have performed a meta-analysis including studies from several countries on the number and nature of crashes. Comparing the data of crashes of an previously unlit road to a lit road provides valuable insights in the effects of road lighting. Although it can be argued that these results also are dependent on lots of different factors, such as changing weather conditions or even the mental state of road users (alcohol level for example), the outcomes provide an indication on the effects of road lighting. It is estimated that the mean effect of road lighting on accidents during darkness was found to be -30% (Elvik, Vaa, Hoye, Erke, & Sorensen, 2009), with results up to -49% on motorways in the Netherlands. It is clear that road lighting offers great benefits for the road user, there are however also a number of disadvantages of road lighting.

2.4 The dark side of lighting

Road lighting offers benefits but also comes with several downfalls. The first is the financial aspect, divided in the placement costs, maintenance costs, and energy costs. The placement of road lighting along roads is an costly investment that has to made in addition to the infrastructure itself. Light poles, potential reflectors or lighting in the road and the armatures have to be bought, as well as the light sources. Additional maintenance costs for the use of road lighting installations and electric grid also add to the sum of costs. The placing of lighting is an addition to the placement costs as well.

Besides the placement and maintenance costs, energy is necessary for road lighting to function. Therefore, either connections to the electric grid or other means of collection and storing energy have to be installed. Energy costs are growing and have become an issue for governments and municipalities.
There are almost 4 million light poles in the Netherlands, according to RWS (2015), which collectively make up almost 10 % of the energy consumption in the Netherlands. As Taskforce Verlichting (2008) estimated, the costs of road lighting can take up to 70% of the energy costs of municipalities.

Rather than the large disadvantage of costs, a more serious downfall of road lighting is its effect on the environment. The energy consumption of road lighting, the energy necessary to function, build and maintain these installations, is closely related to the CO_2 emission, which is one of the greenhouse gasses causing global warming.

Besides the CO_2 emission as a result of energy consumption, another downfall of lighting is the effect of light on the biological clock of both humans and animals, according to Platform Lichthinder (2015). Light can be desired during driving, but troublesome for the close surroundings affected by lighting. The life of animals is disoriented by road lighting. This is addressed as light trespass by Wanvik (2009) and Boyce (2009). This aspect is mainly due to the fact that light diffuses on its close surroundings, while being directed to the road. This has benefits for the driver, as they are able to see objects in close vicinity of the road, but affects the biological clock of the animals.

Platform Lichthinder (2015) mention that road lighting can be regarded as light pollution, polluting the surroundings and the air. Besides light trespass, sky glow is also a form of light pollution. Sky glow is a direct result of the way lighting is applied along roads in the Netherlands, as the light diffusion from light poles also lights the air. This results in a decreased visibility of stars, which is an issue for astronomers and casual viewers.

Another danger of road lighting is glare. This is mainly the result of either bad placing or too much luminaires of lighting. Glare causes a blinding effect on the road user, which may lead to dangerous situations and discomfort (Boyce, 2009). The increased feelings of safety due to lighting may also be taken advantage of by for example driving too fast or recklessly.

Because of these dark sides of road lighting, road lighting needs to be applied with care. Otherwise road lighting may cause more problems than it solves. Nevertheless, the importance of road lighting is clear, and currently outweighs the downfalls. The current state of lighting might be improved, in order to perform better and take away the dark sides.

2.5 Current state of road lighting in the Netherlands

As mentioned before, road lighting in the Netherlands is well developed and widely applied. About 20% of all highways is lighted, according to Platform Lichthinder (2015), which is approximately 1000 kilometers of lit highways (CBS, 2014). However, it is estimated that about 40% of these lighting installations is outdated, energy-inefficient, and subject to costly maintenance and another of road lighting 30% could be improved according to the current legislations (van den Brink, 2014). The outdated installations have to be manually controlled, information has to be gathered manually and real-time information exchange or interactive communications are scarce. This illustrates the old-fashioned approach of road lighting in these modern days. The current legislation is updated by Rijkswaterstaat in collaboration with several advisory institutes, but is very conservative (CROW, 2012).

The owner of the road is responsible for the correct application of road lighting (CROW, 2012), although roads are built by project-teams or road construction companies. In the Netherlands the road network is owned by either the municipalities, Rijkswaterstaat, the provinces or the waterways. About 85% of the road lighting is owned by the municipalities, making them responsible for most of the lighting decisions (CROW, 2012). Rijkswaterstaat owns approximately 10% of the road lighting and is responsible for the main highway network (the A-roads in the Netherlands).

A guideline is developed by the NSVV, the Dutch part of the CIE, in order to assist in road lighting decisions. This guideline has been written down in “Richtlijn Openbare Verlichting” or ROVL in short (NSVV, 2011) and is based upon the international recommendation CIE 115-2010. This guideline features traffic intensity and speed (equal to the type of road) as determinants for the necessary lighting characteristics on a road, as seen in Table 2-1: each road class has certain minimum specifications regarding road lighting.

In current practice lighting plans are evaluated during the road construction or the reconstruction of existing roads, mainly by the contractors. Different parties are involved in road (re)construction, such as traffic experts, urban designers, landscape architects and civil engineers. Sometimes even lighting experts are involved in the creation of roads. These parties will provide input for the road owner about which situations require lighting. Specific situations, such as junctions, exits or bends require special attention, as they might become dangerous when lighted insufficiently.

Road lighting has an expected lifetime of 15 years, which means lighting should still be sufficient in 15 years and decisions have to be examined thoroughly. CROW (2012) mentions that road lighting needs to be designed as an integral part of the road, taken along all these aspects. However, the current practice is different.

In current practice, the design and creation of road lighting along highways is done by simply following the guidelines and making sure every box is ticked, instead of integrally approaching an optimal solution (CROW, 2012). The guideline of NSVV, is not meant as strict norms, but they seem to be used as such (NSVV, 2011). This approach is considered to provide decent, but primarily old-fashioned ways of lighting, instead of taking advantage of technological improvements. An example is the use of consistent use of certain types of lighting, where others may perform better.

Table 2-1 Overview of regulations for highways according to Richtlijn Openbare Verlichting (NSVV, 2011).

TRAFFIC INTENSITY	PAE/h	% of CAPACITY %	SPEED LIMIT km/h	CLASS M	C	#	Lgem cd/m^2	Egem lx	U_L [-]
Dense	≥3255	≥70%	≥110	3	2	3	1.00	15	0.60
			90 -110	4	3	4	0.75	10	0.60
Medium	2325 - 3255	50-70%	≥110	4	3	4	0.75	10	0.60
			90 - 110	5	4	5	0.50	7.5	0.40
Low	≤2325	≤50%	≥110	5	4	5	0.50	7.5	0.40
			90 - 110	6	5	6	0.30	7.5	0.40

Capacity is based on the lane capacity of two lanes as 4650 PAE/h or vehicles/h according to NOA (AVV, 2007)
Category is based upon Richtlijn Openbare Verlichting (NSVV, 2011) by using the determination tables “M” & “C”. As the determined class must feature the highest of the two classes.
Both L_{gem}, E_{gem} & U_L provide the minimal values that have to be reached.

Road lighting in the Netherlands along highways is almost always applied directly on the road surface using light poles. These light poles may differ in height from 5 up to 7 meters, providing different kinds of light diffusion on the road (RWS, 2010). The poles can be placed in multiple ways, either on the sides of the road or in the middle whenever two-way traffic is present. Light poles are bearing the armatures with the light sources. The armatures are of particular importance as they are direct the light onto the road and may cancel out certain directions of diffusion and potential light pollution. There are a lot of different armatures being used along the highway, as this is one of the aesthetic aspects of road lighting that can be altered, without compromising really harming the performance of road lighting. Besides light poles, reflectors on road sections, for example sharp bends, are used to emphasize the road ahead or dangerous points.

2.6 Lighting types

Different light sources have been used to lit roads through the years. Different light sources have been used to lit roads through the years. In the early days, gas-powered light sources were used to light the roads. At a certain point in time, the lighting industry took initiative and produced better light sources, based on effectiveness and efficiency. Most of the current road lighting features High-pressure sodium, and less common light emitting diodes or metal halide light sources. Every light source has its own characteristics, such as color, energy- and cost-efficiency, and light-intensity.

2.6.1 High-pressure sodium lighting

High-pressure sodium light source is the most common light source used for road lighting in the Netherlands (Boyce, 2009; RWS, 2010). High-pressure sodium, or commonly known as SON, is a gas-discharge lamp, which uses sodium to produce light. SON lighting needs time to run up, before it reaches the full lighting intensity.

SON lighting is regarded as very energy-efficient among the electrical forms of lighting, measured by the luminous efficacy level. The use of sodium is the cause of SON’s characteristic yellowish light color, which performs well on the perception of safety, guidance, detection, and comfort according to RWS (2010). A downside of SON lighting is that due to its’ color road users have limited color perception. However, color perception is not immediately necessary for road safety purposes, which makes SON suitable for highway lighting. SON lighting has high investment costs, but it also comes with a long lifetime, as mentioned by (Boyce, 2009).

2.6.2 Metal halide lighting

Metal halide lighting, or HID, is another form of lighting using gas-discharging. Instead of sodium, other metal halide are used to generate light. HID lighting is little used along the highways in the Netherlands, it is more frequently used in urban areas and, in another form, for vehicle headlamps (Boyce, 2009).

The characteristic color of HID lighting is bright white, which improves the visibility of objects significantly (Boyce, 2009). HID lighting also take a few minutes for run-up time, before they reach the desired lighting intensity. In comparison to SON lighting, HID lighting has better color perception, and is more energy-efficient than SON, but has a lower life time expectancy. Another downfall of HID is that there color properties shift slightly over time.

2.6.3 Light emitting diodes

A reasonably new alternative for road lighting are light emitting diodes, or LED in short. LED lighting uses a semiconductor that emits light when an electric current is passed through it. The current and the temperature of the light source determine the color of LED lighting, which makes it very widely usable. Whenever LEDs are used for road lighting, often the bright white kind is used. The choice of white results in improved color perceptions, in comparison to SON.
An advantage of LED lighting over other forms of lighting is that it has no run-up time, which makes it ideal to use in intelligent light sources, being able to take on multiple colors and switch on and off in an instant.

LED lighting is still under development as the lighting industry regards LED as the future form of road lighting slowly taking over from SON. The energy-efficiency is already far better than SON and HID, and its' lifetime expectancy also outperforms SON and HID. LED lighting us a very narrow-band source of light, which is an advantage for directing the light on the road. These characteristics lower the necessary light intensity and benefit the energy-efficiency, as the light can be directed better and less light is 'lost'. However, the intensity of LED is often perceived quite harsh and cold, as analyzed by Agentschap NL (2010).

An overview of the mentioned lighting types and a brief summary has been described in Table 2-2. The overview clearly indicates that LED offers great benefits over the currently most used lighting type SON. Besides the ongoing development on light sources for road lighting like LED, the lighting industry is continuously looking for more effective, efficient ways of lighting. That and more trends in the road lighting industry are going to determine the road lighting of tomorrow. Several parties are subject of these trends and try to cope with the changing society and pressure on the environment.

Table 2-2 An overview of different lighting sources and characteristics (Boyce, 2009)

LIGHTING TYPE	LUMINOUS EFFICACY[1] Lumen/watt	COLOUR TEMPERATURE Kelvin	COLOUR INDICATION	LAMP LIFE Hours	RUN-UP TIME Minutes
SON	53-142	1,900-2,100	Bright yellow	10,000 -20,000	3-7
HID	60-98	3,000-6,000	Bright white	2,000 – 10,000	0.5-8
LED	30-55	3,000-6,500	Bright white	Up to 50,000	Instant

[1] Luminous efficacy is the ratio of luminous flux produced to the supplied power.

3 TRENDS IN ROAD LIGHTING

This chapter focusses on several trends in society, mobility and the world of lighting. The influences of the government and measures taken to cope with these trends are discussed, after which several reactions of companies and the road users are presented.

3.1 Societal challenges and mobility

Mobility is essential for society. A regularly mentioned statement says: "Without transport everything stagnates" (TLN, 2004) which covers the importance of mobility for the society: it is crucial for our day-to-day life and will remain so. It is said that mobility in the Netherlands has been increasing over the years and is expected to keep on growing at least until 2050 (TNO, 2014).

In order to cope with the growing demand for mobility, a dense road network has been established in the Netherlands. However, at peak moments this road network is often not able to handle the intensity of the moving population with traffic congestions and accidents as direct consequences. Besides these traffic issues, the rise of mobility also creates more emission and thus pollution of the environment.

These challenges demand smarter, more sustainable mobility: smart mobility. In current times, much attention has been given to the development of cleaner, safer and smarter cars, for example in drivers' assistance. Car manufacturers like BMW and Volkswagen are working on the development of semi-autonomous driving systems, where the drivers is assisted with the driving task. Companies like Google even intend to bring fully-autonomous vehicles to the market. It is necessary for these kinds of innovations that the driving environment communicates with the vehicles, in order for technology to successfully take-over control. Besides the communication aspect, the driving environment is currently left the way it is.

A lot can be gained by applying this intelligent approach onto road lighting. New lighting technologies need to have less energy consumption, less materials and perform smarter than the current road lighting. Different approaches can be taken, as governmental parties and companies all take on these challenges in their own way. The following section will address some of the measures and trends that these parties developed within the aspect of road lighting.

3.1.1 The government and road lighting

The first party in the road lighting industry is the government, in specific the Ministry of Infrastructure and the Environment or Rijkswaterstaat. As mentioned in section 2.5 Current state of road lighting in the Netherlands, the government is responsible for the legislation on road lighting in the Netherlands. According to KiM (2014) the government is subject to three key societal challenges:

1. Increase traffic safety;
2. Improve traffic flow;
3. Increase environmental savings.

Road lighting is subjected to these key challenges as well. Rijkswaterstaat is continuously evaluating ways of lighting, different types of armatures, lighting types and placing, in order to determine the best applications of lighting for traffic safety and ultimately an improved traffic flow. An example of these researches is the "Eindreportage LED oplossingen voor openbare verlichting (Agentschap NL, 2010), checking whether LED lighting solutions are viable for road lighting in the Netherlands.

Current lighting is responsible for up to 70% of the energy costs of municipalities, which is clearly in conflict with the third challenge. RWS has addressed this issue by setting targets for the following 15 years in "Energieakkoord: openbare verlichting" (RWS, 2015). Road lighting has to save at least 20% in comparison to the energy consumption in 2013 and at least 50% in 2030. RWS has even mentioned the try and decrease the energy-consumption of highway lighting with 80 % in 2017, in comparison to 2006. Simultaneously, the outdated road lighting installations will be updated, so that eventually in 2030 a minimum of 40 % of all road lighting is equipped with smart energy-utilities and more energy-efficient light sources.

In order to find a balance between the three key challenges, Rijkswaterstaat and Agentschap NL, formulated a new strategy for road lighting; "only light what needs to be lighted" (Taskforce Verlichting, 2008; NRC, 2013). Four different implementations of this strategy can be derived from Taskforce Verlichting (2008):

1. Leaving away road lighting whenever possible;
2. Using alternatives for road lighting;
3. Reducing the lighting time of road lighting;
4. Shifting and dimming the lights potentially in combination with management systems.

An effect of these measures on the road lighting along the highways is the shifting and dimming of the light. Current road lighting is shifted and dimmed to a lower light intensity and thus a lower level of lighting, based upon the traffic intensity and weather conditions. As the highest safety level is to be maintained, no matter what measures are implemented. Whenever bad weather, such as heavy rains or fog, is present, the lights will be on as before. When there is little traffic, and weather conditions justify as well, the road lighting may be dimmed to about 20% of its original intensity, in order to still maintain sufficient traffic safety.

An eye-catching measure, which the government started using in 2013, is shutting down of all road lighting along highways during nighttime (23:00 – 5:00) except lighting on dangerous locations. This rather radical measure will provide the government with energy savings, while trading off for comfort and safety levels for the road users. It also will benefit the environment by diminishing the light pollution, sky glow and light trespass. In short, road users have to rely on their vehicle lighting and road lighting at exit lanes for example. Not surprisingly this measure has led to resistance from road users.

3.1.2 Companies and road lighting

Road construction companies like Heijmans Infra B.V. and expert lighting companies such as Philips are also coping with the key challenges as mentioned by KiM (2014). Energy-efficient lighting sources such as LED with new armatures might also fulfill the brief. An example of the companies innovating and trying to come up with solutions for highway lighting is the Smart Highway project (Heijmans B.V., 2015). Smart Highway is a collaboration between Heijmans B.V. and Studio Roosegaarde and has been awarded with “Best Future Concept” by the Dutch Design Awards as well as winning the INDEX Award 2013, indicating the potential of this project.

The Smart Highway project features divers ideas and concepts on but not only road lighting. The goal is to “make roads that are more sustainable and interactive by using light energy and road signs that automatically adapt to the traffic environment and people” (Studio Roosegaarde, 2014). One of the ideas is the use of electroluminescence as a light source, incorporating that into road markings so that the road user is guided along the roads properly without any additional lighting from above. This idea is referred to as “Glowing lines” and a prototype of this technology is currently placed at the “Snelweg van de Toekomst” (or the “highway of the future”) in the municipality of Oss in the Netherlands (Visscher, 2013).

This technology is innovative on a couple of aspects, including in all of the key challenges of KiM (2014) as well as the desired targets of the government. First of all, it uses a different way of lighting, namely lighting from below. The glow of the lines provides just enough luminaires to detect obstacles and see the road ahead. Second, the type of lighting, electroluminescence, is extremely energy-efficient and requires almost no run-up time, making it comparable with LED lighting on these aspects. Electroluminescence, or EL in short, differs from LED in the way that the light source emits light. And finally, EL features a more glowing kind of light, with a cool bright green glow, diminishing the effect of light pollution, light trespass and sky glow to a minimum. As mentioned by Platform Lichthinder (2015) and Boyce (2009), green-colored lighting is less harmful for the environment.

However, as with most of the lighting solutions, it is very difficult to evaluate the performance of the Glowing Lines on safety and other aspects. The prototype will inevitably provide insights in the performance of this alternative method of lighting, which will be applicable on all safe parts of highways. Additional lighting on dangerous parts such as exit lanes might be necessary. Nevertheless, more understanding in the way EL lighting from below is perceived by road users is needed in order to properly evaluate the Glowing Lines.

Another concept, which is not only featured by the Smart Highway, is “Interactive Light” (Heijmans B.V., 2015) or Adaptive Smart Lighting systems (Ghazwan, 2014). This dynamic way of lighting uses existing light poles and light sources with instant run up times. and equips them with management systems in order to detect traffic and weather conditions. Interactive Light aims to change the lighting levels to suit each situation, dimming the lights when traffic is low and turning on whenever traffic is coming. Interactive Light is a concept that uses a management system in order to turn on lighting exactly on the right time, so that a road user does not perceive any discomfort. This concept, especially in combination with LED lighting, might provide an extremely energy-efficient system. These concepts and many more incorporate the perspectives of the politics, respect the environment while holding on to the main objective of road lighting: aiding the road user.

3.1.3 Road users and road lighting

The road user is the end user of road lighting. Without road users, there would be no need for road lighting. As the main objective is 'to aid the visual perception of drivers' as stated by SWOV (2011), it is only reasonable to evaluate road lighting from the perspective of the road user. New concepts of lighting as well as measures implemented by the government should therefore be evaluated not only by their increase in energy-energy, decrease in energy-consumption or overall costs and performance, but also on their influence on the perception of road users.

The perception of road users is mainly formed by the visibility of the road ahead and their environment. Several aspects of lighting such as the intensity and color of light, the way of integrating lighting installations along the road and the reflection of the road surface influence this perception (Boyce, 2009; O'Donnel, Colombo, & Boyce, 2011). However, as Wanvik (2009) mentions, there is simply little knowledge about the specific influences of road lighting on these perception. For now, it is only possible to comment on the relations that exist between road lighting and perceptions, basically by combining the results from old studies and logic.

In the current practice of road lighting, the needs of the road users are often overlooked as creators tend to only "tick the boxes" and follow the guidelines. The guidelines as set up by the outdated studies and have changed little since their introduction. Following the guidelines is sufficient for now, as the road users' identity has not changed over the years (RWS, 2010). However, the car-industry is rapidly improving their vehicles, which in time will influence road users. The driving task will simply not be the same, as technology will slowly assist the driver and may take over eventually (AutomotiveNL, Connekt, DITCM, 2012; TNO, 2014).

Fundamental for this 'technologically improved' mobility is the interaction between drivers, vehicles and the driving environment. The rise of automated driving, already available in certain systems in cars such as lane departure warning systems, adaptive cruise control and intelligent speed adaption, has already set in. Experts doubt if we ever will drive fully automated vehicles, as road users potentially have the tendency to maintain driving control (KPMG and Car, 2012) But in-between forms of automation, such as releasing control at certain parts of roads are likely to become the new standard, perhaps as soon as 2020, according to roadmaps of AutomotiveNL, Connekt & DITCM, (2012) and TNO (2014).

Different levels of automation require different driver solutions, however they all have in common that the driver will act more passively than current drivers. The decrease of driving duties together with the automation of driving even questions the need for road lighting, as technology does not need light to be able to see.

Simply shutting down all lighting, either because of energy reduction or the disappearing need of lighting for driving, might be a solution for the government and several parties. Inevitably, this will alter the perceptions of road users, again stressing the need to research the effects of road lighting. The conclusion is simple, the current measures of the government, the new lighting concepts in the lighting industry and the rise of automated driving together make this the time to take a step back and carefully asses road lighting the way it should be done: as an aid to the road user.

4 ASPECTS OF ROAD LIGHTING

This chapter focusses on the large number of aspects influencing road lighting and deriving the most influential and important ones, in the eyes of the road users.

4.1 Evaluation of current and new applications of road lighting

The evaluation of road lighting is difficult, even experts are unsure and many researches have conflicting or ambiguous conclusions as seen in the many literature sources used throughout this review. It is of great importance however to evaluate the existing road lighting alternatives as well as new concepts, forms of lighting and even the measures, so that the quality of road lighting is maintained and the road user does not become the victim of reckless innovating or downgrading. While the evaluation of road lighting as a whole is very difficult, other methods might provide help and understanding.

Many kinds of road lighting and circumstances exist and affect the road users. It is possible to distinguish a number of aspects that are commonly recognized in literature studies and use these to classify the different kinds of lighting and contexts. A brief summary of the distinguished aspects is provided in Table 4-2. The aspects have been grouped into lighting aspects, situational aspects, and road users aspects. By evaluating those aspects from the road users' perspective, a better understanding on the aspects of road lighting and their influence is gained. This will be a steppingstone for further and more precisely aimed research, as the aspects will indicate where to look for rather than just evaluate the complete lighting plan.

Evaluating from the road users' point of view might be a pretentious task as well, as every road user and every circumstance is unique. Once again, within the evaluation of the road users, different subjects can be distinguished and perhaps used to aid the evaluation. These subjects are derived from Langers, de Boer & Buijs (2005), Martens (2005), AVV (2006), Elvik et al. (2009), Boyce (2009), Wanvik (2009) and SWOV (2011), and are described in Table 4-1.

Table 4-1 An overview of subjects that road users use to evaluate the performance of road lighting

SUBJECTS	EXPLANATION	SOURCE[1]
Traffic safety	The perception of being safe on the road, closely related to the aspect of see and be seen.	(Wanvik, 2009b; Martens, 2005)
Social safety	The perception of being safe from criminal activities on the road, such as gas stations.	(Martens, 2005; NSVV, 2011; SWOV, 2011)
Comfort	The level of comfort as derived from the kind of road lighting used, such as the brightness and placement of lighting.	(Martens, 2005; NSVV, 2011; SWOV, 2011)
Guidance	The ability of road users to determine where the road is, on what part of the road they are and how the road proceeds.	(AVV, 2006)
Detection	The ability of road users to detect obstacles, i.e. physical barriers, animals and other road users, on time, so they have the opportunity to adjust and prevent collisions.	(AVV, 2006)
Aesthetics	The overall appreciation of the armatures and lighting are based on beauty.	(Martens, 2005) (Langers, de Boer, & Buijs, 2005)

[1] the distinguished subjects of road users' evaluation on road lighting have been described in many researches, the sources noted provide sufficient information on the aspects for this research.

Table 4-2 An overview of aspects that together classify road lighting

ASPECT	EXPLANATION	SOURCE[1]
LIGHTING		
Lighting type	The type of light sources used, such as LED or SON.	(Boyce, 2009; Wanvik, 2009b)
Lighting placement	The way lighting is incorporated along the road,	
Light source intensity	The intensity of the applied light source.	
Lighting color	The color of the applied light source	
Luminance	The amount of light that lights the road surface and the objects on the road.	
Distance between lighting sources	The distance between the light sources, resulting in differences in lighting uniformity	
Lighting uniformity	The distribution of lighting on the road ahead	
Lighting character	The character of lighting, such as dynamic or static	
SITUATIONAL		
Road type	Type of road, for example highway	(AVV, 2006; RWS, 2010; NSVV, 2011)
Number of lanes	The number of lanes in a single direction	
Road situation	The situation of the road in its environment, such as rural or urban areas.	
Road condition	The course of the road, for example straight, an exit lane, a junction or a bend.	
Traffic intensity	The density of traffic on the road	
Permitted speed limit	The speed limit as communicated by the road type, road situation or signs.	
Light of surroundings	The light which interferes with road lighting from secondary light such as bill-boards or buildings.	
Darkness conditions	The level of darkness, such as dusk or nighttime	(Langers, de Boer, & Buijs, 2005) (Fors & Lundkvist, 2009)
Weather conditions	The weather circumstances, such as rainy, foggy, or snowy.	(Wanvik, 2009b; SWOV, 2012)
Surface conditions	The conditions of the road	
ROAD USER		
Level of assistance	The level of technological assistance in the vehicle.	(van Driel & van Arem, 2005)
Length of trip	The distance of a trip.	(RWS, 2010)
Duration of trip	The duration of the trip.	
Familiarity of trip	The familiarity of the driver with a road.	
Secondary activities	The activities a driver is doing besides driving, such as navigating or calling	(Eyben, et al., 2010)
Mentality of driver	The reason behind driving, i.e. as pleasure or work.	
Level of fatigue	The mental condition of the driver	
Average annual mileage	The distances a driver covers in a period of time	(Boyce, 2009; RWS, 2010)
Frequency of driving	The frequency of driving by a road user	
Experience of driving	The time a road user has its drivers' licence	
Visual capabilities	The visual impairments of the road user	
Kind of car	The type of car used by the road user	

[1] the distinguished subjects of road users' evaluation on road lighting have been described in many researches, the sources noted provide sufficient information on the aspects for this research.

4.1.1 Safety
The safety aspect of road lighting is a combination of both social safety and traffic safety. Social safety regards the feelings of safety in situations where people might become victim of criminality (Haans & de Kort, 2012). This is more an issue on urban roads, parking lots and gas stations than it is on the highway. Therefore this aspect is left out of the research.

Traffic safety is regarded as the most important of subjects. The perception of road safety comes from the ability to see and expect to be seen, as mentioned by CROW (2012). Road lighting aids by providing means to increase visibility. Usually the presence of road lighting has positive effects on the perception of safety, as the amount of accidents is decreased (Wanvik, 2009a) by 30 % on average. The precise relation between road lighting and safety has not been determined yet, as results are indecisive (Wanvik, 2009b).

However, when lighting is incorrectly applied, road lighting might actually have a negative effect on safety as well. This occurs for example when the light is too bright or reflection of the road surface is too high. The right applications of road lighting in specific situations is therefore essential for feelings of safety of road users.

4.1.2 Comfort
Road lighting has a positive effect on comfort (CROW, 2012). Road lighting, whenever applied correctly, eases the visual aspects of driving and thus eases the driving task. The result is that road users can drive longer with a lower level of fatigue. Important aspects that benefit the feelings of comfort are the use of the right colors, the correct placing of lighting and the intensity of light sources (CROW, 2012).

Comfort used to be an important aspect in road lighting evaluation, as mentioned by AVV (2006). Comfort is an aspect is difficult to express in value or cost. The increased attention on the environment and the cost perspectives of lighting have led to a change in the importance of comfort. Nowadays, comfort is an aspect that is often traded off against energy reduction or other environmental savings (AVV, 2006). Comfort remains one of the most important aspects of lighting for the road users.

4.1.3 Guidance and detection
Whenever the actual functional performance of lighting is evaluated, the guidance and detection functions of road lighting are checked. As mentioned in section 2.1 Lighting in the driving environment, guidance and detection rely on the luminance of the road surface and the reflective properties of the background.

The better road lighting functions, the easier the driving task for the road user becomes and the more safe traffic becomes. Evaluation of guidance and detection functions therefore seem logically, not only for the sake of the road user but also to cope with the key challenges of KiM (2014)

4.1.4 Aesthetics
The aesthetics of road lighting may influence the evaluation of road users as well. However as this is primarily the subject of individual taste, aesthetics of lighting are left out of this research.

4.2 Lighting aspects

Arguably the most important aspect concerning road lighting is lighting itself. Several aspects have been distinguished and are used to classify existing and new forms of lighting. One of those aspects is the type of lighting used, which immediately implies the color of lighting. As Taskforce Verlichting (2008) mention, different types of lighting and different light source intensities and luminances are evaluated differently under certain circumstances. An example is the color definition of SON lighting, in comparison with LED lighting. Whenever detection of colors is desirable, LED lighting will be evaluated better by road users than the currently used SON lighting, as SON lighting has a very low level of color definition.

The placement of lighting might also change the valuation of road lighting, however this is quite a new subject as the standard placement of lighting is from above, from light poles. Lighting from above will light the road as a whole, and using the luminance contrast principle will provide guidance along the road and detection of objects for the road users. Changing the way lighting is placed along highways will change the perception of detection, but may offer benefits regarding the guidance of road users.

It is argued that the perception of safety and comfort primarily depends on the lighting intensity, the lighting color and the lighting uniformity (Boyce, 2009; Fors & Lundkvist, 2009). Unlit highways, which features no lighting color and a very low lighting intensity but a high level of lighting uniformity, cause discomfort (Boyce, 2009), and road lighting features changes in luminance, a low level of lighting uniformity, also causes discomfort. Which combinations of uniformity, color and intensity increase the perception of safety and comfort is yet to be determined.

As for this research, the emphasis will be put on the level of uniformity (immediately incorporating distances between light sources), the lighting type (including their generic color, intensity and luminance), and the placement of lighting. These aspects seem to be determining the overall application of road lighting and are therefore prioritized over aspects such as the character of lighting The lighting types included in this research will be SON and LED, as described in section 2.6.1. And the experimental EL lighting will be added as well, in order to evaluate new forms of lighting. These aspects will feature their generic colors and characteristic lighting intensities. Electroluminescent lighting will be regarded as glowing instead of shining form of light, in order to emphasize the differences between the lighting sources.

The aspect of lighting placement is added to check whether road lighting is evaluated differently when road lighting is applied from the road itself rather than from above. This will provide insights in the feasibility of new lighting concepts such as the “Glowing lines” as mentioned in section 3.1.2 Companies and road lighting.

The last aspect which will be emphasized is lighting uniformity. The uniformity of lighting is derived from legislation from the ROVL (NSVV, 2011) and is applied onto the existing forms of lighting as well as variants on the new lighting concepts of the glowing lines. Three levels of lighting uniformity will be distinguished, namely low, medium and high uniformity. Low lighting uniformity will feature less than 40 % uniformity, medium levels of uniformity will be regarded to have an uniformity in between 40% and 70% and high levels of lighting uniformity will feature an even distribution of lighting of at least 70%.

4.3 Situational aspects

There are a lot of situational aspects involved in road lighting. Road lighting can be seen as an integral part of infrastructure, adjusted specifically on the situation. These road characteristics vary from the type of road, a highway in this case, to a specific road condition, such as a bend or an exit lane. According to NSVV (2011) these conditions might influence the valuation of road lighting. As road users approach dangerous situations the requirements of road users on road lighting increase.

Current road lighting adapts to the traffic intensity, the darkness conditions and the location in where it is placed. These aspects are deemed to effect the necessary levels of lighting as stated by AVV (2006) and NSVV (2011). These aspects will also influence the perceptions of road users, as dense traffic or no traffic will surely alter the perception of comfort for example. The surroundings of the road, for example an urban area in comparison to a rural area, and the lighting of surroundings that interferes with the road lighting is also influential on road lighting.

Weather conditions are another situational aspect, subjecting not only the visibility levels of road users during fog or heavy rains but also the surface of the road. Specific weather conditions may cause dangerous situations by itself and require road users to alter their behavior. Several researches have tried to determine the effects of weather on road lighting, as mentioned by SWOV (2012). However, instead of determining the importance of weather conditions on the perceptions of road users, they rather focus on the effects on safety measured by the decrease or increase of accidents. Experts have proven that rainy weather decreases the feelings of safety and comfort of road users, as mentioned by Wanvik (2009b), often resulting in a decrease in speed (Assum, Bjornskau, Fosser, & Sagberg, 1999). Experts also proved that fine weather increases the feelings of safety and comfort. But it is yet unknown how road lighting, and in specific the necessary levels of lighting, relates to these situational conditions and how road lighting could adapt to these situations so that road users maintain their perception of safety and comfort (Wanvik, 2009b).

Many aspects are in need of new research. However, the effects of weather conditions as well as the road conditions can be prioritized for research. This is based upon the current trends on road lighting and measures, as well as future forms of lighting and driving. Adaptive, smart forms of lighting might benefit most from the emphasis on weather conditions and the road conditions. It will also be very interesting to determine how new lighting sources and alternative ways of placing lighting perform under certain weather circumstances and in certain road situations. As mentioned by Boyce (2009) and Wanvik (2009), there are lots of different weather conditions possible. The most occurring and influential for driving are rainy circumstances, foggy weather and fine weather conditions. Snowy weather is also influential, but is a very specific weather condition, which is not occurring as often as rain or fog. Therefore rainy, foggy and fine weather have been prioritized over for example snow.

Many different road conditions exist on highways in the Netherlands Besides the general bend and straight lanes, different kinds of junctions, bridges, tunnels and exit lanes can be emphasized. According to SWOV (2011), bridges and tunnels require very specific lighting installations, and are excluded from this research as the objective is to keep this as general as possible. Therefore, straight lanes, bends are prioritized and exit lanes are taken along in the research as a ‘dangerous situation’.

4.4 Individual characteristics of road users

When the perceptions of road users on road lighting are evaluated, the road users' individual characteristics are of influence. Experienced drivers, who drive more frequently, feel more secure on the road and therefore will probably evaluate road lighting more positive than new, inexperienced drivers will (RWS, 2010). The familiarity of a trip, the duration and the length of a trip, as well as the level of fatigue and the mentality of a driver will also influence the perception of comfort of a road user. Longer trips in distance and time, and less familiar trips, will ask more of a road user than short, familiar trips will in terms of comfort, for example.

Even the type of car and the level of driving assistance influences the perceptions of the road user (Eyben, et al., 2010; RWS, 2010). The level of driving assistance is becoming more important, as the driving task is changing and this might have specific effects on the requirements of road lighting. Therefore, this aspect will be emphasized in the following sections of this research.

Experimenting with driving assistance, and making this understandable for others is difficult, as not everyone is familiar with driving assistance and automated driving. Simply asking whether the evaluation road lighting would be different whenever the vehicle is fully automated will not provide the desired results. In order to gain understanding in potential differences caused by the level of driving assistance, another method of experimenting needs to be applied.

Using the general thought that partially assisted or fully assisted driving changes the driving task from active to a more passive level, an approach is taken where an active driving task ('being the driver') is compared to a passive driving task ('being the passenger'). It can be argued that being the passenger is not equal to being assisted while driving. However, the aim of this division is not to determine exactly what the effects of driving assistance are on the perception of road lighting, it is merely testing whether differences might arise whenever the role of the road users is changed.

This concludes the aspects used to classify different forms and situations regarding road lighting. Using the emphasized aspects, it is possible to quickly compare different forms of road lighting and perhaps check which aspects are most influential on either the perceptions of safety, comfort, guidance and detection. A research into the preferences and evaluations of road users will be set up, eventually trying to determine which aspects are most important in certain situations and under certain circumstances. The research will not be aimed at determining the exact effects, it will rather be directed to gain insights into the aspects and be able to provide stepping stones for further research.

4.5 Conclusion

Benefits of road lighting for the road user have been established. As mentioned throughout the study, there is very little expert knowledge about the effects of road lighting on the perception of road users. In order to gather more insights in the perceptions of the road users in relation to the applied road lighting, an experiment will be held. This experiment will feature several of the more important aspects of lighting and the lighting context. The experiment will be set up to determine the preferences of road users regarding road lighting. The experiment will indicate which aspects should be decisive in decision-making and design processes, and which should be neglected, from a road users' perspective. The study is future-oriented, not only current forms of lighting, but also new, future forms of lighting will be included in the experiment. The experiment will use the four most important road user' variables, namely safety, guidance, detection and comfort, to rate and determine the most preferential lighting alternatives. More information about the experiment will be provided in section 5 Choice experiment. These lighting aspects will be put in perspective by the addition of context variables and road user' characteristics as mentioned in 5.1.2.

The first lighting aspect that will be present in the experiment is the lighting type. The lighting type will indicate the kind of lighting is applied and which characteristics go along with that lighting type, such as the lighting color. Three types of lighting are included, the first is SON lighting (section 2.6.1), which represents the current type of lighting. To include future forms of lighting in the experiment, LED lighting is presented as a second, more upcoming type of lighting will be assessed. LED lighting is most likely to substitute SON lighting as the next standard lighting type, according to experts. Third, a more future oriented form is lighting included in the research is EL. EL lighting differs from SON and LED, EL features a glowing instead of a shining light. It is assumed that road users will prefer LED lighting, as this aids the color detection most and thus will probably provide feelings of safety, comfort and a high level of detection. EL is assumed to score high on the guidance aspect, because of the high frequency of glow lights that can be used without discomfort in relation to the SON and LED lighting. SON lighting is expected to score high on all factors, but lower than LED due to the color detection aspect.

The second aspect of lighting included is the placement of lighting. Lighting placement on current roads features lighting attached from light poles, thus from above. A future form of lighting placement is to apply road lighting directly from the road. It is expected that road users prefer road lighting from above, especially on the aspects of safety, detection and comfort, where lighting from below is more likely to be preferred for guidance.

The third and final aspect of lighting included is the uniformity of lighting. In order to determine the preferences of road users on the frequency of road lighting installations, three levels are set: low, medium and high lighting uniformity. On current roads, the road lighting is on a medium level, being intense in close vicinity of the light source, but decreasing in between. A high level of uniformity features (almost) no decrease in lighting intensity, due to an increased amount of lighting installations. A low level of uniformity will represent large differences in lighting intensity and a large distance between road lighting installations. It is expected that road users tend to prefer high levels of uniformity, although certain situation (such as straight lanes) might be sufficiently lit from a road users' perspective using lower levels of road lighting. This concludes the introduction and theory on road lighting.

PART 2: FIELD RESEARCH

5 CHOICE-EXPERIMENT

In this chapter the methodology used during this study is described. First a theoretical understanding on the modelling of choice is established, after which the theory of stated choice is presented and followed to set up the necessary models. Meanwhile, throughout the theory, different advantages and disadvantages are discussed.

5.1 Modelling of choice

This research is set up to gather knowledge about the preferences of road users regarding road lighting. Understanding the preferences means understanding the behavior of road users in different road lighting circumstances.

An approach that provides clarity in the behavior of individuals is discrete choice experiment, also known as conjoint analysis. Discrete choice experiments are also described as the “modelling of choice and preference behavior of individuals” (Molin, Oppewal, & Timmermans, 1997). Discrete choice experiments state that every product, activity, service and more can be described as a combination of attributes (Kuhfeld, 2010). As mentioned by Louviere (1988) the underlying theory on individual preference and choice behavior assumes that this behavior is the result of an individuals’ cognitive decision-making process. This behavior is based on the subjective perception and evaluation of their physical, functional and socio-economic attributes. The objective of discrete choice modelling is to determine what combination of attributes is perceived as most important, in order to understand what drives the preferences of individuals.

Hensher, Greene & Rose (2005) have established guidelines to properly design a discrete choice experiment. These guidelines will be followed for the rest of the chapter. First of all, the problem statement is refined in section 5.1.1, so that a focus on specific parts of the problem is established. Secondly, attributes and attributes-levels will be defined. After which the measurement task is chose. Fourth, an experimental design is generated and choice-sets are established. So that finally a survey instrument can be set up and the data can be collected. Ultimately, the data will be analyzed using several methods.

As mentioned by Louviere, Flynn and Carson (2010) discrete choice modelling, which follows from the data collection, is in origin a psychological research method, in which different ways are represented to mathematically represent human behavior. Discrete choice modelling is about understanding and predicting choices between alternatives (Train, 2009). Discrete choice modelling can take inter-linked behavior into account, interactions that may exist which road users may not realize themselves. Discrete choice modelling is well-tested and is particularly well applicable to determine choice behavior and thus preferences under different circumstances.’

5.1.1 Problem focus

As discussed in section 1.4, the objective of this research is to gain understanding in the way road lighting contributes to the perception of driving from a road users' point of view. Therefore a main research question has been defined:

MQ: Which kinds of road lighting do road users prefer and which circumstances are influential on road users' road lighting preference?

However, many kinds of road lighting and circumstances exist and affect the road user as elaborated throughout the literature review. Therefore, a focus has to be established on several aspects of road lighting, as not everything can be included in the experiment. Road lighting has not been the subject of a discrete choice experiment yet, this experiment will be used to provide understanding in basic situations so that attention points for further research are derived. To take future lighting trends into account, the policy boundaries will be stretched, so that new lighting technologies can be included in the research as well. More information on legislation and new lighting technologies can be read in section 2.6 Lighting types.

5.1.2 Selection of attributes and attribute-levels

Variables of influence to road lighting have been the subject of many researches, in particular from the specialized researches of Langers, de Boer & Buijs (2005), Martens (2005), AVV (2006), Elvik et al. (2009), Boyce (2009), Wanvik (2009) and SWOV (2011). Important aspects have been recognized and collected in Table 4-2.

Taking the problem focus into account, different attributes and corresponding attribute-levels are selected based on the literature study of previous researchers and input of experts in the road construction industry. As mentioned before, the experiment will be set up so that further research can be directed more accurately. Therefore more attention is given to 'ordinary attributes', such as the weather conditions, than to 'extra-ordinary attributes', calamities and accidents for example. A number of aspects have also been set in advance:

- The road is a generic two lane highway in the Netherlands outside the city;
- The permitted speed is 130 km/h;
- There is some traffic present, but the road is not crowded;
- It is night-time.

The selected attributes and attribute-levels have been defined so that they can easily be interpreted. Respondents are meant to identify themselves with the situation, therefore attribute-levels will be labelled (Klojgaard, Bech, & Sogaard, 2012). A pilot test was used to determine whether every aspect was understood correctly. If something was ambiguous or confusing, it was changed by either changing the label, or leaving it out. An example is the attribute "Driver assistance", which was initially described as "Level of vehicle automation", with corresponding levels:

- Fully assisted;
- Partly assisted;
- Not assisted.

Pilot testing proved that not all respondents were able to understand the concept of vehicle automation, as well as being "partly assisted" in the driving task. Therefore, the attribute was renamed to "Driver assistance", only dividing full assistance and no assistance. In the experiment, full assistance is presented as "passenger" instead of "driver".
An overview of the selected attributes and attribute-levels is presented in Table 5-1 below. The first three of attributes in Table 5-1 consider the context of the experiment, representing the situation in which the road lighting is subjected. Special attention was given to the last three attributes that make up the lighting possibilities. The road lighting possibilities are made up by combining three different attributes:

1. Lighting type – which involves the type of lighting is used;
2. Lighting placement – which involves the placing of light along the road;
3. Lighting uniformity – which involves the intensity and frequency of lighting along the road and the distance in between.

The main advantages of this method of categorizing lighting are the possibility to incorporate both existing and new lighting possibilities, being able to easily compare them on the basis of the included attributes, and begin able to identify the most influential attributes in lighting technologies. It does provide difficulties, as some existing lighting possibilities may not be easily categorized with the use of the three attributes. Therefore, not every kind of lighting will be represented in the experiment, which is a clear restriction of the experiment. Once all the included attributes and attribute-levels have been established, the experimental design is constructed.

Table 5-1
Attributes and attribute-levels.

The first three attributes are considered context-attributes and the second three are considered lighting-attributes.

These attributes and their levels are described in section 4 Aspects of road lighting

NAME	ABBREVIATION	LEVEL	LABEL
Road conditions	RC	2	Bend
		1	Exit lane
		0	Straight lane
Weather conditions	WC	2	Rainy weather
		1	Foggy weather
		0	Fine weather
Driver assistance	DA	1	Full assistance
		0	No assistance
Lighting type	LT	2	EL
		1	LED
		0	SON
Lighting placement	LP	1	Below
		0	Above
Lighting uniformity	LU	2	High
		1	Medium
		0	Low

5.1.3 Measurement task

Discrete choice experiments can be conducted in numerous ways, one of which is a revealed preference experiment. Revealed preference experiments present real-life situations, so-called alternatives, to the respondents and the respondents are asked to either choose, rate or rank the presented situations, dependent on the experimental design (Louviere, Flynn, & Carson, 2010). It is often used to observe the actual choices and trade-offs made by respondents. As this research aims to include future lighting possibilities, a revealed choice set up will not satisfy the research objective. Stated preference experiments, another way of conducting choice experiments, uses hypothetical situations as alternatives to identify the preferences of the respondents and is able to include all kinds of lighting possibilities. Furthermore, as it does not require observing real-life choices, it is less expensive and less time-consuming.

It allows for a basic understanding on how individuals value the situations, by presenting multiple questions to an individual and observing the results. Stated preference experiments are often questioned on its reliability, as it is uncertain on how the respondents react to the hypothetical situations and whether their reaction is equal in the experiment as in real-life. A keynote is to make sure that the hypothetical situations fully represent the attributes in the experiment while being as realistic as possible.

Stated preference experiments have not been used yet for determining the preferences of road users concerning road lighting. However, it has been used multiple times to determine the needs and willingness of drivers concerning Advanced Driver Assistance Systems and other subjects concerning drivers' behavior (Marchau, Wiethoff, Penttinen, & Molin, 2001).

Stated experiments can be conducted using a preference approach, asking respondents to rate or rank hypothetical alternatives, or a choice approach, asking respondents to choose between multiple profiles. In this experiment, both a rating and a choice approach are applied. The choice approach will provide the importance of attributes in the decision-making process. Every respondent will be confronted with a number of choice-sets and asked to choose between two presented lighting alternatives and a third 'no-lighting'-alternative during the experiment. Rating will provide detailed information on the thoughts of the respondents on three presented alternatives. Respondents will rate the alternatives on a scale of 1 to 5, where 1 equals 'disagree' and 5 equals 'agree', on four different variables, which have come up in the literature study as being of importance for road users:

- Safety;
- Detection;
- Guidance;
- Comfort.

Usually, a stated choice experiment either focusses on choosing or rating, rather than choosing and rating. Combining choice data with ratings of road users will provide not only information about the preferences of road lighting of road users but also insights in the aspects they rate most important in the forthcoming of this preference. It indicates which relations between the dependent variables and the attributes prefered exist and what their influence is on the actual choice of the road users. The choice data together the rating data will provide more than sufficient input for further, in-depth research.

5.1.4 Generation of choice-sets

In this experiment, a respondent will be confronted with a choice between three alternatives. In order for the discrete choice theory to be applicable, the presented choice-sets need to meet three conditions, as mentioned by Train (2009):

1. Exclusiveness;
2. Exhaustiveness;
3. Finiteness.

The first condition regards the exclusivity of alternatives within a choice situation. When a decision maker chooses an alternative, it implies not choosing any of the other alternatives. The second condition, exhaustiveness, regards the fact that all possible alternatives must be included. The third and final condition is that the number of presented alternatives must be finite, in other words a set amount of alternatives is included in the research.

Every choice set will contain two lighting alternatives, together with a base situation, without any form of road lighting. Respondents will be asked to rate each of the three alternatives as presented in the context, after which they are asked to choose their preferred lighting alternative for that specific context. The context of each set is generated by the three context-attributes and is the same for all alternatives within a choice-set. This set-up can be reviewed as a structured comparison method, in which the alternatives within a choice-set are generated to be easily compared to one-other, as the context is equal. Each of the lighting alternatives is generated by the three lighting-attributes, and obviously, the base situation without lighting involves no lighting alternatives at all. This results into nine attributes (three for the context and six in total for the lighting alternatives) and corresponding levels used to construct the experiment. Using this method, there is no complete randomization, as the choice-sets all feature the same context-variables.

It is considered that decision makers have their own preferences on the presented attributes which leads to specific behavior, and they provide insights into their preferences by providing their choices in different choice sets. The importance of different attributes per individual can be observed by combining their choices over different choice sets. Asking respondents to evaluate all different combinations of attributes, a full-factorial design of $3^6 \times 2^3$ thus 5832 sets, will take too much time. The task size for respondents will be too large, and response errors are expected to occur, such as respondents ignoring attributes or adopting response patterns (Kemperman, 2000).

Therefore a fractional factorial design has been applied. Using fractional factorial design, only a subset of the factorial design has to be evaluated to be able to estimate the effects independently (Louviere, 1988). A reduction in the number of sets can be done by assuming that the respondents answer in a structured manner, that their answers can be combined as if they answered the full-factorial set. As less choice data means less information, a fractional factorial design leads to the fact that only main effects and first-order interactions can be interpreted, instead of all main effects and interaction effects as in a full-fractional design (Louviere, 1988). Using SPSS, a fractional factorial design is generated of 27 profiles, the minimal amount used for nine attributes with a maximum of three levels each (Addelman, 1962).

In this experiment, three attributes have two instead of three levels. For these attributes, a simple translation of one of the present levels on the missing level can be used to complete the design. An overview of the generated choice-sets can be seen in Table 5-2. As mentioned, the two alternatives within a choice-set constructed out of the three lighting-attributes are reviewed besides the no-lighting alternative, and a choice will be made. This requires the presented alternatives to differ on at least one attribute-level. The design of the choice-sets of Addelman (1962) and the set-up in this experiment conflict in one of the 27 sets, namely set 18: the lighting-alternatives are the same. In order to create a choice-opportunity in set 18, one of the attribute-levels has been translated, so that a total of three unique alternatives are presented.

Asking each respondent to evaluate all 27 choice-sets will make the choice-task too large. Groups of three choice-sets are established, numbered 1-9, and are randomly distributed. Now that the choice-sets have been established, the instruments for data collection can be designed.

Table 5-2
Overview of the choice-sets.

The table can be read as follows:

A group consists of three sets, each covering two lighting alternatives A and B, as well as a base variable without lighting. The context in these three alternatives is equal.

So, group 1 exists out of choice-sets 2,6 and 18.

SET	CONTEXT			ALTERNATIVE A			ALTERNATIVE B			GROUP
	RC	WC	DA	LT	LP	LU	LT	LP	LU	
1	2	0	0	1	0	0	0	0	2	3
2	2	0	1	2	1	1	0	1	0	1
3	0	0	0	0	1	0	1	0	1	4
4	1	2	0	1	0	0	1	1	0	6
5	1	2	1	0	1	2	1	0	2	5
6	0	2	0	1	1	2	0	0	0	1
7	1	2	0	2	1	1	1	1	1	4
8	2	2	0	1	1	1	2	1	0	8
9	0	2	1	0	0	1	0	1	2	3
10	1	0	1	2	1	0	2	0	0	8
11	0	1	0	2	1	1	2	0	2	7
12	0	1	0	0	1	2	2	1	0	8
13	2	1	0	0	0	1	1	0	0	6
14	0	1	1	1	0	0	2	1	1	9
15	0	2	0	2	1	0	0	1	1	2
16	1	0	0	0	0	1	2	1	1	9
17	1	0	0	1	1	2	2	1	2	7
18	1	1	0	0[1]	1	0	2	1	0	1
19	2	1	1	1	1	2	1	1	1	4
20	0	0	0	1	1	1	1	1	2	5
21	1	1	1	1	1	1	0	0	1	2
22	1	1	0	2	0	2	0	1	2	3
23	2	2	0	2	0	2	2	0	1	9
24	2	2	1	0	1	0	2	1	2	7
25	2	0	0	0	1	2	0	1	1	2
26	0	0	1	2	0	2	1	1	0	6
27	2	1	0	2	1	0	1	1	2	5

[1] *has been changed from 2 (EL) to 0 (SON) to create two different alternatives*

5.1.5 Presentation of choice-sets

Presenting the choice-sets can be done by verbally describing the context and the alternatives, as is done in most choice-experiments (Train, 2009). However, presenting the alternatives in 2D (visuals), or even in 3D (virtual reality) might offer better interpretation, and thus more realistic results. Especially when the respondents are asked to comprehend the context and the lighting alternatives, visual stimuli can be used. Visual stimuli, rather than words and numerical information, are increasingly seen as the most effective way to promote comprehension (Bateman, Day, Jones, & Jude, 2009). However, they may also introduce experience bias, as the respondent has prior experiences that influence the decision making. In order to get the right results, visuals should be done as realistic as possible so that respondents can relate to the visual and the situation (Couper, 2005).

In this experiment, the alternatives will be presented graphically as well as verbally. The visuals are created using Adobe Photoshop, a program specially used for editing photos and ideally for making realistic images and added in Appendix B Visuals. The basis for the different visuals were real-life highway pictures taken by Google (2014) at the A2 around the city of Maarheeze, Noord Brabant. The A2 can be seen as a generic highway, without road lighting at the area of Maarheeze, which makes it suitable for the design of the visuals. All attributes available in the experiment are incorporated in the visuals, making sure everything is interpreted correctly. To create realistic images, the visuals were created in collaboration with road lighting experts at lighting innovations at Heijmans and tested among a pilot group, accompanied by an extensive explanation of the choice-task. The pilot group argued that the visuals seemed realistic, lighting alternatives were understandable and thus sufficient for this experiment. Together with the verbal descriptions of the alternatives, and the rating & choice part, the result is the choice-set as a total, as seen in Figure 5-1.

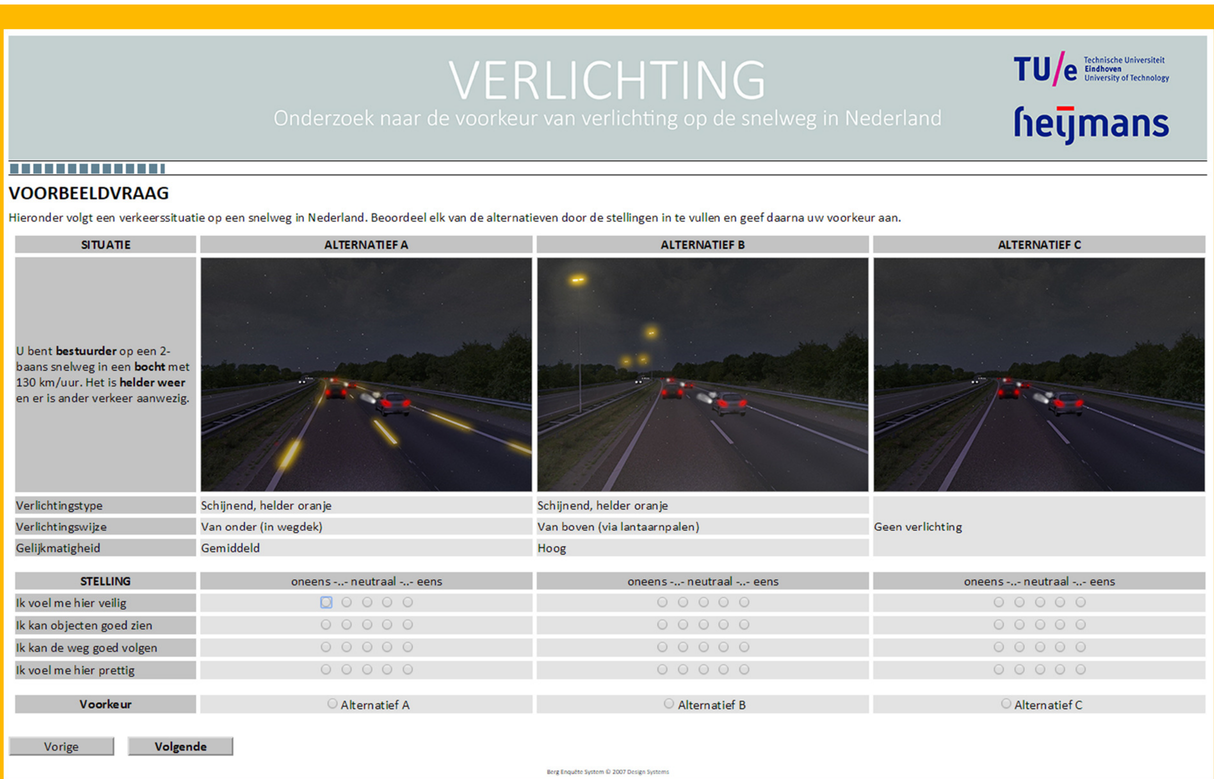


Figure 5-1 An example of a choice-set as presented in the Dutch survey. In the survey, visuals could be enlarged by clicking on them. The enlarged pictures have been added in Appendix B Visuals.

5.2 Survey development

The instrument for data collection in this choice-experiment is a survey. The choice-sets will be presented to respondents with the use of an online-survey program “Berg Enquête System”, developed by the group of Design Systems of Eindhoven University of Technology. Using the internet to gather respondents is a fast and effective way to reach many people in little time period, and respondents can determine when they fill in the survey. It does rely on the respondents actually taking the survey, without supervision (Couper, 2005). An important requirement for survey is that they don’t take too much time, a rule of thumb is that a survey should not take longer than 15 minutes to fill in completely (Galesic & Bosnjak, 2009) as the length of the choice-task mainly determines the start and completion rate of surveys. Age is the only restriction for respondents to take the survey, respondents need to be 18 years or older in order to participate. Having a driving license is not necessary. The survey will be spread among the social and work environment of the modellers. The survey is only available in Dutch.

The objective of this experiment is to gain insights into the choice preferences of road user. Hensher, Greene & Rose (2005) argue that besides the attributes of the experiment, the individual characteristics also influence choice behavior. Individual characteristics include socio-demographic variables as well as prior experience (Marchau, Wiethoff, Penttinen, & Molin, 2001). To gain understanding on the choice behavior as a whole, the survey also includes background questions aimed at determining the individials’ characteristics and their experiences on road usage.

Galesic & Bosnjak (2009) state that questions need to be ordered correctly, due to the fact that the concentration and focus of respondents changes throughout the survey. To prevent answering biases uniform, general questions should be positioned in the beginning, the most difficult questions in the middle and again general questions in the end.

The survey consists of three parts. The first part of the survey regards the driving experience of the respondents. The experience of respondents in driving and especially highway familiarity are also important to understand before data is analyzed. Besides driving experience or frequency of travelling on the road as passenger or as driver, information about the visual capabilities of respondents are included. Rijkswaterstaat (2010) have conducted research into the effect of visual impairments of drivers and passengers, which influences the perception of lighting along the highway. Questions derived from this research are included in the experiment. An overview of included questions on experience and visual capabilities is provided in Table 5-3 on the next page.

The second part of the survey covers the choice-task as described in sections 5.1.3 Measurement task, 5.1.4 Generation of choice-sets, and 5.1.5 Presentation of choice-sets. It first introduces the included attributes, and provides an explanation on the choice-task. In order to improve the respondents’ understanding of the questions, a trial question has been added. After the example question, one of the groups of choice-sets will be presented at random to the respondents. In each choice-set, the respondent is asked to rate each of the alternatives and make a choice between the alternatives, indicating their preference.

Table 5-3 Overview of the driving experiences of respondents as included in the experiment, mainly based on previous researches of RWS (2010) and van Driel & van Arem (2005).

NAME	LEVEL	LABEL
Driving license (van Driel & van Arem, 2005)	1 2	Yes No
Driving experience (van Driel & van Arem, 2005)	1 2 3 4 5 0	5 years or less 6 – 10 years 11 – 20 years 21 – 30 years 31 years or more I do not know
Highway familiarity (van Driel & van Arem, 2005)	1 2 3 4 5	Unfamiliar Reasonably unfamiliar Neutral Reasonably familiar Familiar
Highway usage (RWS, 2010)	1 2	Yes No
Frequency of driving (van Driel & van Arem, 2005)	1 2 3 4 5	0 days per week 1 – 2 days per week 3 – 4 days per week 5 – 6 days per week 7 days per week
Frequency of passenger (van Driel & van Arem, 2005)	1 2 3 4 5	0 days per week 1 – 2 days per week 3 – 4 days per week 5 – 6 days per week 7 days per week
Average annual mileage (van Driel & van Arem, 2005)	1 2 3 4 5 0	Less than 5,000 kilometers 5,000 – 9,999 kilometers 10,000 – 19,999 kilometers 20,000 – 29,999 kilometers 30,000 kilometers or more I do not know
Visual capabilities[1] (RWS, 2010)	1 2 3 0	Yes, but I do not use visual aid Yes, and I do use visual aid No, I do not have issues with sight I do not know

[1] *This question is accompanied by three statements so that more information about possible visual impairments can be derived. These statements cover distraction, estimation of distances and fear of darkness.*

The third and last part of the questionnaire is made up with questions about the socio-demographics of the respondent. Besides the actual choices, the background of respondents also provides vital information. The so called socio-demographic variables, such as gender, age and household-type provide insights in the prejudice of individuals (Hensher, Greene, & Rose, 2005). Marketing and research agency "Motivaction" developed a tool to determine what mentality a respondent has in life, which influences their decision-making (Motivaction, 2012). This model is included in the survey by a set of sentences derived from Drijver & De Boer (2013). Together these questions will provide sufficient background information on the respondents for further in-depth research. An overview of included socio-demographic variables with their corresponding levels and labels can be seen in Table 5-4. This concludes the survey instrument. The survey is added in the Appendix A Survey. The sample of the survey will include everyone above 18 years old, with or without license as mentioned in section 5.2 Survey development.

Table 5-4 Overview of the socio-demographic variables in the experiment based on literature from Langers, de Boer, & Buijs (2005) and van Driel & van Arem (2005)

NAME	LEVEL	LABEL
Age	1	Under 18 years
(van Driel & van Arem, 2005)	2	18 – 24 years
	3	25 – 39 years
	4	40 – 64 years
	5	65 years and older
Gender	1	Male
(Langers, de Boer, & Buijs, 2005)	2	Female
Household situation (van Driel & van Arem, 2005)	1	One-person
	2	Multiple person household without children
	3	Multiple person household with children
	4	Other
Education	1	Primary education
(Langers, de Boer, & Buijs, 2005)	2	Secondary education
	3	Lower education
	4	Higher education
	5	University
	6	No education
Mentality in life (Motivaction, 2012; Drijver & Broer, 2013)	1	Traditional bourgeoisie
	2	Modern bourgeoisie
	3	Convenience-oriented
	4	Social climbers
	5	Post-materialists
	6	Post-modern hedonists
	7	New conservatives
	8	Cosmopolitans

5.3 Data analysis

Once the experiment is generated and data is collected, the data needs to be analyzed to ensure correct interpretation of the results. The theory behind data analysis in this experiment will be explained in the following section. The data analysis for this experiment consists of two parts, namely interpretation of the rating and the choice experiment, as described in section 5.2 Survey development.

5.3.1 Ordinal regression model

The objective of data analysis is to be able to predict the preferences, determining the relationships among attributes and identify importance of attributes. For the rating data, regression analysis can be used to determine the influence of the attributes, the independent variables, on safety, guidance, detection or comfort, the dependent variables (Hensher, Greene, & Rose, 2005).

SPSS Statistics, version 22, will be used to perform the regression analysis. The dependent variables are of ordinal nature, as the distances between the ratings are not defined as equal and the distances are in fact unknown (Long & Freese, 2003). Because of this ordinal nature, ordinal regression is the method to use.

The dependent variables, as mentioned in section 5.1.3 Measurement task, are categorized from 1 to 5, with the distances between those ratings unknown. An ordinal regression model can be used to determine the influences of independent variables on a dependent variable, being able to predict the ratings of road users on the basis of the existing independent variables. This will provide insights in the valuation of road users on different road lighting installations under different circumstances. Eventually, the best rated lighting alternative can be determined for every situation.

In order to estimate the effects of attributes on the dependent variables and to standardize the levels across the attributes, the attributes have to be coded, as Marchau, Wiethoff, Penttinnen et al (2001) mention, so that they are easily interpreted.

As mentioned by Long & Freese (2003) the "ordinal regression model is commonly presented as a latent variable model, defining y* as a latent variable ranging between -∞ to ∞. The equation for the ordinal regression model is given in equation 1 below.

Equation 1: Ordinal regression, for observation i = 1, … n (based upon Long & Freese, 2003)

$$y*_i = \beta_i x_i + \varepsilon_i$$

Where
- $y*_i$ is the predicted outcome of dependent, latent variable for observation *i.*
- β_i is the vector of regression coefficients for observation *i.*
- x_i is the vector of independent variables as included in the model to predict $y*$ for observation *i.*
- ε_i is the error-component for the residual between the actual and the predicted value for observation *i.*

The ordinal regression model divides y* in a number of categories, where several thresholds are determined. Whenever a predicted outcome crosses a threshold, it is considered to be in that particular category.

With *n* of attribute-levels, at most *n* − 1 attribute-levels can enter the model, with one of the attribute-levels normalized to zero, which can be seen in Table 5-5. The normalized level can be calculated as the negative sum of all other levels, as the total is equal to zero, by definition (Marchau, Wiethoff, Penttinen, & Molin, 2001).

Table 5-5 Effect coding for two-level and three-level attributes, based on Marchau, Wiethoff, Penttinnen et al. (2001)

ATTRIBUTE-LEVEL	TWO LEVELS		THREE LEVELS		
	Indicator	Utility	1st indicator	2nd indicator	Utility
0	1	β_1	1	0	β_1
1	-1	$-\beta_1$	0	1	β_2
2			-1	-1	$-(\beta_1 + \beta_2)$
Parameter	β_1		β_1	β_2	

5.3.2 *Multinomial logit model*

The choice-part of the experiment, the actual stated preference relies on the theory of the Random Utility Model, in short RUM, and was proposed by Thurstone (1927). Train (2009) explains that RUM provides an explanation of the choice behavior of humans. It states that any individual *n* considers a set of alternatives in a choice situation *t* and chooses an alternative *j*, consisting of attributes *k* with levels *l* out of the total of alternatives *J*. The decision maker judges every alternative to a certain value, a "utility" (*U)* and it is assumed that the decision maker will always opt for the alternative with the greatest utility.

Observing the utilities of alternatives of each individual directly is not possible. When presenting alternatives to decision makers in a systematic manner, it is possible to observe the effects of their weights attributes. These attributes, combined with characteristics of the decision maker provide the observable component of utility: *V* often called the "structural utility" (Train, 2009). An error term has been set up, capturing all factors that affect utility but are not included in the attributes per se. This term is ε, and is not defined for every specific choice situation. It is defined as "relative to the researcher's representation of the choice situation". As ε is unknown it is often treated as random, by doing so, the researcher can make probabilistic statements about the preference of individuals (Train, 2009).
This can be summarized in the following equation:

Equation 2: The Random Utility Model (Thurstone, 1927, in Train, 2009)

$$U_{nj} = V_{nj} + \varepsilon_{nj}$$

Where U_{nj} is the utility of alternative *j* of individual *n*

V_{nj} is the structural utility, which is an observable component of utility and includes the attributes of the alternatives *j*, the socio-demographic characteristics of the individual *n* and the context of the choice set.

ε_{nj} is the unobservable component of utility, an error-term that captures the factors that are not in the model for individual *n* with alternatives *j*.

In this research, ε_{nj} is assumed to be independent and identically distributed (IID), which means there is no correlation throughout the attributes. For this to be applicable, the attributes need to be uncorrelated, otherwise they would influence each other. This is checked by performing a correlation analysis in SPSS Statistics, and added in Appendix C SPSS output – correlation matrix.

Because the correlations between attributes are diminishable and the error-term is independent and identically distributed (IID), each alternative is unaffected by the presence of other alternatives in a choice set. This independence from irrelevant alternatives (IIA) makes that the choice model can be described as a multinomial logit model (Train, 2009). A multinomial logit model can be used in model with a dependent variable, nominally distributed in more than two categories. The choice-experiment covers one dependent variable, "Choice", which is a nominal variable.

In a multinomial logit model, it is possible to predict the possibility that an individual chooses an alternative from the choice set. In order to determine the probability of an individual *n* to choose alternative *i* over all other alternatives *j* is described in the following equation 3 below.

Equation 3: Choice Probability (McFadden, 1974, in Train, 2009)

$$P_{ni} = Prob(V_{ni} + \varepsilon_{ni} > V_{nj} + \varepsilon_{nj})$$
$$P_{ni} = Prob(\varepsilon_{nj} < \varepsilon_{ni} + V_{ni} - V_{nj})$$

Which can be rewritten into equation 4 below, given the random nature of the error-term:

Equation 4: Logit Choice Probability (McFadden, 1974, in Train, 2009)

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_j e^{V_{nj}}}$$

Where P_{ni} the probability that an individual *n* to choose alternative *i.*
V_{ni} is the structural utility of alternative *i* for individual *n.*
V_{nj} is the structural utility of all alternatives *j* for individual *n.*

In words, the probability that a decision makers opts for a certain alternative out of the presented choice set can be calculated by determining the structural utilities of all alternatives in the model.

The structural utility of an alternative can be derived in a systematic manner and specified as linear parameters with a constant, as shown in equation 5 below.

Equation 5: Structural Utility (Train, 2009)

$$V_{nj} = \beta_0 + \beta_{nj}x_{nj}$$

Where V_{nj} is the structural utility of alternative *j* for individual *n.*
β_0 is a constant indicating the average profile rating, often called the alternative-specific constant.
β_{nj} is the regression coefficient corresponding to alternative *j* for individual *n.*
x_{nj} is the matrix attributes and the socio-demographic characteristics of decision maker *n* corresponding to alternative *j*.

First, x_{nj} is a matrix of the attribute-levels that in combination form an alternative and the socio-demographic characteristics of the individual and the context of the choice set. This matrix can be regarded as the total of independent variables, providing information about the decision maker, the context and the attributes with regard to the specific alternative.

Second, β_{nj} is a vector of parameters corresponding to the attribute-levels of x_{nj} and the individual *n* and the influence to the utility for alternative *j*. They are not different for alternatives, they represent general coefficients for the overall attributes and characteristics in the model.

Third, the constant β_0 or the alternative-specific constant is equal to the mean of the observed alternative ratings, and provides understanding in the average attitude of the decision makers towards a certain alternative. Therefore β_0 can be both positive or negative and is used to compensate for this base-effect. It captures the average effects on utility of all factors that are not included in the model. By adding the regression intercept, the structural utilities are expressed as a deviation from the mean (Marchau, Wiethoff, Penttinen, & Molin, 2001).

The multinomial logit model and these constants can be easily estimated in NLOGIT 5, a statistical program of Econometric Software designed to run several logit models and analyses. In this research, the calculation-method of “DISCRETE CHOICE” is used to determine all utilities and constants. The exact procedure is added in Appendix D Procedure NLOGIT – multinomial logit model.

5.4 Evaluation of model quality

To determine whether the models fit the observed data and if the models are able to predict correctly, the model's goodness of fit can be calculated. The goodness of fit provides insights in the performance of the model, different tests can be done to determine whether the proposed model is an improvement of a model without any estimations (Train, 2009). In this experiment the model's goodness of fit will be evaluated by R-square, R^2, which is sufficient to determine the performance of a multinomial logit model (Hensher, Greene, & Rose, 2005). For the evaluation of the regression analysis Chi-square will be used to determine the goodness of fit.

5.4.1 Log likelihood

Most of the analyses of the goodness of fit use the log likelihood of a model. The log likelihood is based on a set of parameters that produce the observed sample most often, as mentioned by Train (2009). The log likelihood, or LL_β, can be calculated using equation 6.

Equation 6: Log likelihood for an alternative model (Train, 2009)

$$LL_\beta = \sum_{n=1}^{N} \sum_{i} f_{ni} \, (P_{ni})$$

Where LL_β is the log-likelihood for the proposed model with the estimated parameters of β.
N is the total sample of individuals.
f_{ni} is the choice of an individual *n* for alternative *i,* and equals either 1 or 0.
P_{ni} the probability of an individual *n* to choose alternative *i.*

Using the log likelihood of the proposed model, further analyses can be conducted in order to determine the goodness of fit for the proposed model. The loge likelihood of the null-model, a model with all parameters set to zero as a reference. This can be calculated using equation 7.

Equation 7: Log likelihood for null-model (Train, 2009)

$$LL_0 = \sum_{n=1}^{N} \sum_{t} \ln \frac{1}{J}$$

Where LL_0 is the log-likelihood for the null-model model with the estimated parameters of β set to zero.
N is the total sample of individuals.
J is total amount of alternatives in choice-set *t* for individual *n.*

5.4.2 Likelihood ratio

The log-likelihood ratio statistic explains the performance of the proposed model in comparison to a null-model, a model with all parameters set to zero. It is used to determine whether the optimal model is an improvement over the null-model. The log-likelihood ratio can be compared to the critical Chi-square ratio with the according amount of degrees of freedom, to check whether the probability of the model performing better is significant.

Equation 8: Log-likelihood ratio, D (Train, 2009)

$$D = -2\,(LL_0 - LL_\beta)$$

Where D is the log-likelihood ratio, indicating the improvement of the proposed model over the null-model.
LL_0 is the log-likelihood for the null-model, with all parameters set to zero
LL_β is the log-likelihood for the proposed model with the estimated parameters of β.

5.4.3 R-square

Another statistical method to determine the goodness of fit is R-square, described as R^2 and is found by comparing the proposed model, the null-model. The R^2 is calculated using equation 9 below and will always be somewhere between 0 and 1, where 1 is the optimal value. It provides insights in the fitting of the actual data to the predicted data. According to Louviere (1988) and Hensher, Greene and Rose (2005) the R^2 should be 0.1 at least, in order to indicate a decent fit. A value between 0.2 and 0.4 indicates a good fit.

Equation 9: R-square, R^2 (Train, 2009)

$$R^2 = 1 - \frac{LL_\beta}{LL_0}$$

Where R^2 is the R-square, which determines the level of improvement of the proposed model over the null-model.
LL_0 is the log-likelihood for the null-model, with all parameters set to zero.
LL_β is the log-likelihood for the proposed model with the estimated parameters of β.

5.4.4 Chi-square

The chi-square, or χ^2, statistic provides understanding of the similarity of the predicted and the observed data. The lower the χ^2, the better, according to Franke, Ho, & Christie (2012). It is used to evaluate the difference of observed and predicted data and whether the difference between the sets arose by chance. Interpreting the χ^2- statistic is done by comparing the outcome of equation 10 below to the critical Chi-square value in a Chi-square distribution table.

Equation 10: Chi-square, χ^2 (Franke, Ho, & Christie, 2012)

$$\chi^2 = \sum_{i=1}^{N} \frac{(O_i - E_i)^2}{E_i}$$

Where χ^2 is the chi-square.
O_i is the observed data for the i^{th} observation.
E_i is the expected data for the i^{th} observation.

These three model evaluation methods are sufficient to judge whether the models are fitting to predict the data and produce valid results.

PART 3: RESULTS & EVALUATION

6 ROAD USERS' PREFERENCES

In this chapter the results of the choice-experiment are discussed and set into perspective.

6.1 Required sample size

In order for the results of the experiment to be valid, the sample size of the stated choice experiment should meet the size requirements. Rose & Bliemer (2013) have stated that using a rule of thumb by Orme can determine the desired amount of respondents.

Equation 8: Rule of thumb by Orme (Rose & Bliemer, 2013)

$$N \geq \frac{500 * L_{max}}{J * S}$$

Where N is the desired sample size.
L_{max} is the largest number of levels of any of the attributes in the experiment.
J is the number of alternatives included in a single choice-set.
S is the number of choice-sets in the experiment.

As for this experiment, the largest number of levels of any of the attributes equals 3, the number of alternatives in each choice-set is 3 and the number of choice-sets in the experiment equals 27. In any normal experiment, the desired sample size with these characteristics equals at least 18.51 respondents. However each respondent only fills in three choice-sets instead of 27, which requires nine times the amount respondents to gather enough filled in choice-sets. Therefore, the desired sample size equals at least 166.67 or 167 respondents.

The choice-sets are randomly divided among the respondents. However, not everyone that starts the survey will finish it, therefore differences in the amount of filled in choice-sets need to be taken into account as well.

6.2 Descriptive analysis

The results of this stated preference experiment are based upon the answers of 280 respondents, which is more than the rule of thumb as suggested by Orme. Therefore, we have gathered sufficient respondents to perform the analysis and create a model. Due to the random nature of dividing the choice-sets in the online-survey program Berg Enquête System, which is random with replacement, the frequencies of are not equally spread over the nine groups. Every starting respondent will be randomly given a group number with , whenever this respondent does not finish the survey differences in the frequency of groups arise. This may influence the results, more of which will be described in section 8 Recommendations. However, every group has been answered at least 15 times, which is sufficient to proceed.

Table 6-1 A frequency table each of the group. Every group has been answered at least 15 times.

Group	1	2	3	4	5	6	7	8	9	Total
Frequency	41	33	15	27	41	19	34	32	38	280
Percent	14.6%	11.8%	5.4%	9.6%	14.6%	6.8%	12.1%	11.4%	13.6%	100.0%

As mentioned in section 5.2 Survey development the respondents have answered several personal questions, so that characteristics of the sample group can be determined and taken along in the analysis. An overview can be seen in Table 6-2 below.

Table 6-2 The sample group and its characteristics, as mentioned in section 5.2 Survey development.

CHARACTERISTICS	Frequency	Percent		Frequency	Percent
Gender			**Frequency of driver**		
Male	176	62.9%	0 days	6	2.1%
Female	104	37.1%	1 - 2 days	52	18.6%
			3 - 4 days	31	11.1%
Age			5 - 6 days	118	42.1%
18 – 24 years	46	16.4%	7 days	68	24.3%
25 – 39 years	87	31.1%	No license	5	1.8%
40 – 64 years	133	47.5%			
>= 65 years	14	5.0%	**Frequency of passenger**		
			0 days	112	40.0%
License			1 - 2 days	147	52.5%
Yes	275	98.2%	3 - 4 days	14	5.0%
No	5	1.8%	5 - 6 days	7	2.5%
Driving experience[1]			**Education**		
<= 5 years	45	16.1%	Primary education	2	0.7%
6 – 10 years	39	13.9%	Secondary education	14	5.0%
11 – 20 years	62	22.1%	Lower education	66	23.6%
21 – 30 years	67	23.9%	Higher education	132	47.1%
>= 31 years	64	22.9%	University	66	23.6%
			Household situation		
Kilometers per year[1]			One-person household	41	14.6%
< 5,000	25	8.9%	Multi-person household without children	87	31.1%
5,000 - 9,999	43	15.4%			
10,000 - 19,999	54	19.3%	Multi-person household with children	137	48.9%
20,000 - 29,999	43	15.4%			
>= 30,000	106	37.9%	Other	15	5.4%
Highway familiarity			**Mentality in life**[1]		
Fairly unfamiliar	1	0.4%	Traditional bourgeoisie	2	0.7%
Neutral	9	3.2%	Modern bourgeoisie	76	27.1%
Fairly familiar	47	16.8%	Convenience-oriented	106	37.9%
Familiar	223	79.6%	Social climbers	12	4.3%
			Post-materialist	21	7.5%
			Post-modern hedonist	6	2.1%
			New conservatives	5	1.8%
			Cosmopolitans	33	11.8%

[1] sum of percentages does nog equal 100% as several respondents indicated that they did not know.

The characteristics of the sample are compared to those of the population in the Netherlands, to check whether this sample is comparable and valid for the population of adults or drivers of the Netherlands as a whole. The comparing data are presented in Statline, an online module to assess data from the CBS, and in particular from the “Bevolking” (CBS, 2014) and “Mobiliteit in Nederland” (CBS, 2014) statistics and the statistics of “Mobiliteitsbeeld” (KiM, 2014). A few characteristics will now be explained.

Comparing the characteristics of the respondents, several aspects stand out. First of all, in the experiment the gender proportion is different to the population. The population of the Netherlands is divided as 49% men, 51% women and in this experiment, the men representing almost 63%. Looking to the distribution method of the survey, the assumption can be made that most of the respondents from the working network are male, as Heijmans Infra employees are primarily male.

Second, the age distribution is slightly different than the population of the Netherlands as well. The amount of people older than 65 is larger (approximately 18 %) in the Netherlands, than in the sample (5%). This can also be explained by the distribution method, the personal and work-network are primarily younger adults and the employees of Heijmans Infra are mostly younger than 65. Although the sample might slightly differ from the population of the Netherlands, the general conclusion is that the sample does account for the working part of the population of the Netherlands, and .

The driving experience of the sample seems to be higher than the population of the Netherlands, almost everyone owns a drivers’ license, is familiar with the highway and uses the road frequently (mostly as a driver instead of a passenger). Combining the fact that the sample contains mostly experienced drivers and frequently drive, with the household situation, the level of education and their age, the assumption is made that the sample consists for a large part of working class people.

Now that the sample has been identified, the analysis is continued and the sample description might be used to explain certain values.

6.3 The multinomial logit model

The middle part of the questionnaire involved evaluating a choice-set, rating all alternatives and choosing any of the alternatives and thus sharing their preference. The analysis of the choices of the respondents is done by creating a multinomial logit model. Therefore the software package of NLOGIT is used with the procedure as described in Appendix D Procedure NLOGIT – multinomial logit model

The program uses the theory described in section 5.3.2 Multinomial logit model to create a model which will be evaluated on its performance before conclusions will be drawn on the outcome.

The goodness of fit of the multinomial logit model is evaluated by the likelihood ratio The results of the log likelihood ratio and the R-square are described in Table 6-3. The log likelihood of the model, as well as its significance are derived directly from NLOGIT. The number of degrees of freedom equals the number of estimated parameters, which is 31 in this experiment and can also be derived directly from NLOGIT.

The log likelihood ratio is determined by subtracting the log likelihood of the null model from the log likelihood of the proposed model and multiplying this by -2. This results in the log likelihood ratio, D, of 231.117. Comparing the log likelihood ratio to the critical chi-square value describes whether the proposed model is an improvement over the null –model. The critical chi square value can be looked up, based upon the degrees of freedom and the desired significance, which in this case are 31 degrees with a significance of 0.001. The critical chi-square value for this model equals 61.098 at a confidence level of 0,999. The log likelihood ratio exceeds the critical chi-square by a large margin, thus the proposed model is an improvement over the null-model.

The R-square of the proposed model is determined by dividing the log likelihood of the null model by the log likelihood of the proposed model, and subtracting the outcome from 1. The R-square indicates the rate of improvement, this must be at least 0.1 and the higher the better (Hensher, Greene, & Rose, 2005). This model has an R-square value of 0.442, which indicates that the model is a good fit for the data and the model performs well. Concluding, the model is proven to be a significant improvement, and may be used to subtract conclusions from the experiment.

Table 6-3
An overview of the model characteristics as calculated following the theory presented in section 5.4 Evaluation of model quality

MODEL'S GOODNESS OF FIT INFORMATION		
Log likelihood – null-model		-931.277
Log likelihood – model		-519.493
Significance		0.001
Degrees of freedom		31
Log likelihood ratio	D	231.177
R-square	R^2	0.442
Critical χ^2 value		61.098

6.3.1 *Interpretation of the multinomial logit model*

The modelled data has been split over four different tables, the first (Table 6-4) will focus on the lighting attributes, which vary over the alternatives within a choice-set. The next three tables (Table 6-5, Table 6-6 & Table 6-7) all focus on one of the context attributes, which are calculated by determining their interaction effects with the lighting attributes on the preference of road users. This is due to the nature of context attributes being consistent throughout the alternatives within a choice-set. The results will be discussed in the following sections, and examples will be provided to clarify the outcome. The lighting attributes are most important for the interpretation of this research. It explains how road users' evaluate different kinds of lighting under a set of circumstances. The preferences of the road users regarding road lighting is illustrated in Table 6-4 below.

The preferences of the road users are indicated by the β-coefficient, which shows information about the amount as well as the direction. The higher the β-coefficient, the more a level is preferred. The alternative specific constant is added in the model to correct for the utility of the base alternative of "no lighting". The constant is used to normalize the utility of the base model to 0.

An example is "lighting placement" which is an attribute with two levels. Out of the two ways of lighting, either below on or above the road, road users slightly prefer lighting that is placed on the road itself, below. This can be visualized clearly in a graph, as done in Figure 6-1. Because the levels included in this model are of ordinal nature, a trend line does not have to be fluent. However, as for the attribute of lighting uniformity, it is expected that medium uniformity performs better than low uniformity in most cases. This is not the case in this experiment. This and more conclusions will be discussed in section 7.2
Results of the experiment.

Table 6-4 The results of the multinomial logit model regarding the main effects of lighting attributes only.

ATTRIBUTE	LEVEL		β	ρ	Rank of levels	Range	Rank
Alternative specific constant			4.830	0.000*			
Lighting type	EL	LT1	0.077	0.843	2	1.275	2
	LED	LT2	0.599	0.011*	1		
	SON	LT0	-0.676		3		
Lighting placement	Below	LP1	0.185	0.339	1	0.371	3
	Above	LP0	-0.185		2		
Lighting uniformity	High	LU1	1.685	0.005*	1	2.589	1
	Medium	LU2	-0.904	0.021*	3		
	Low	LU0	-0.782		2		

** indicates a significance level of at least 90 %. Several variables have been constructed using the summation method as described in Table 5-5 and therefore a significance indication is left out.*

Based on these data, it is possible to determine the most influential attribute for road users preferences by calculating the range between the highest and lowest coefficient of the attribute. This equals the impact that a change in levels has for the overall utility, which can be regarded as the importance of an attribute relative to the others. As calculated in Table 6-4 and visualized in Figure 6-1, road users find lighting uniformity the most important out of the three lighting alternatives, followed by lighting type and lighting placement.

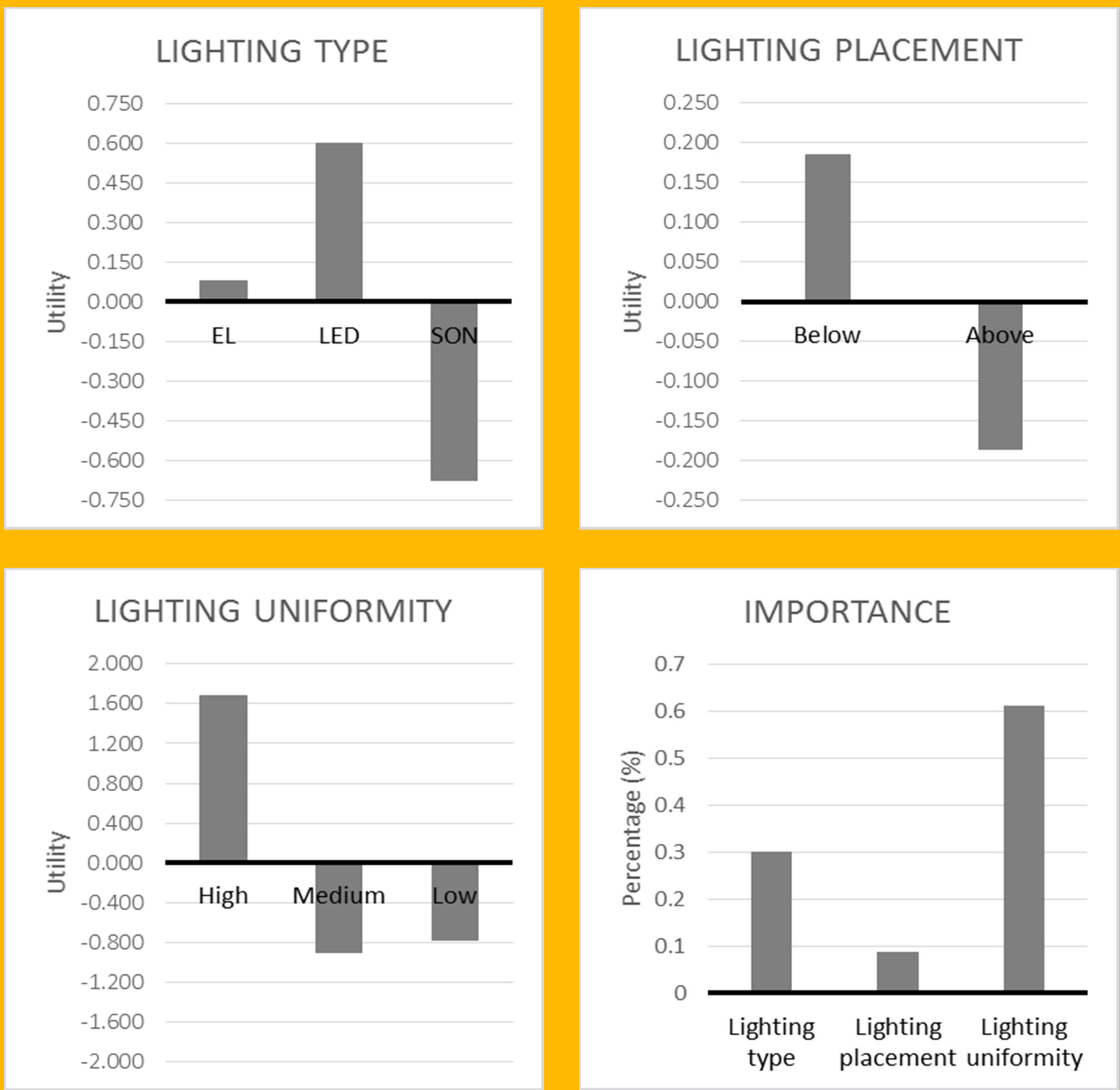


Figure 6-1 Four graphs illustrating the relation between different levels or the importance of several attributes.

6.3.2 *Preferences into perspective*

However, the preferences of road users' regarding lighting attributes cannot be estimated correctly without perspective. The circumstances in which the lighting attributes are implemented are determined by the context attributes, which are equal for all alternatives within a choice-set. Therefore, not the main effects, but the interaction effects are calculated and included in the model. For each of the three context attributes, the interaction effect on the lighting attributes is derived and displayed in Table 6-5, Table 6-6 & Table 6-7.

First, Table 6-5 below shows the interaction effects of "Road conditions" on the lighting attributes. Using the fact that the total of the effects equals zero, all interactions can be determined.

An example is the combination of EL lighting and road conditions on the preferences of the road users. The presence of an exit lane in combination with EL lighting has a negative effect on the preference of road users namely an decrease in structural utility of 2.009. However, EL lighting in combination a straight lane has a increasing effect of 0.555. EL in combination with a bend also has a positive effect on the preferences of the road users, namely an increase of 1.454 on the utility. As illustrated, the context in which lighting is applied influences the preferences of road users. The results can be explained with logic and the knowledge gained in the literature review, EL is a glowing form of lighting, which works very well in situations where guidance is essential, such as bends and straight lanes. Whenever detection is more important, in potentially dangerous situations such as exit lanes, EL scores fairly low.

Several interaction effects are not significant, such as the effect of a bend in combination the a high lighting uniformity. The result is that these interactions effects are not established with confidence and therefore are regarded as 0. It can be questioned whether the presence of a bend in the road combined with a high level of lighting uniformity has a negative effect on the preference of lighting and a bend in combination with a medium level of lighting uniformity has a positive effect on the preference of lighting.

Table 6-5 The results of the multinomial logit model regarding the interaction effects of the context attribute "Road conditions" on the lighting attributes.

INTERACTION EFFECTS OF ROAD CONDITIONS ON LIGHTING ATTRIBUTES								
		LEVEL	Bend	RC1	Exit lane	RC2	Straight lane	RC0
ATTRIBUTE	LEVEL		β	ρ	β	ρ	β	ρ
Lighting type	EL	LT1	1.454	0.003*	-2.009	0.031*	0.555	
	LED	LT2	1.123	0.047*	0.215	0.635	-1.338	
	SON	LT0	-2.577		1.794		0.783	
Lighting placement	Below	LP1	-0.642	0.075*	0.657	0.004*	-0.015	
	Above	LP0	0.642		-0.657		0.015	
Lighting uniformity	High	LU1	-0.339	0.538	1.211	0.263	-0.871	
	Medium	LU2	0.873	0.073*	-1.672	0.086*	0.799	
	Low	LU0	-0.534		0.462		0.073	

** indicates a significance level of at least 90 %. Several variables have been constructed using the summation method as described in Table 5-5 on page 44 and therefore a significance indication is left out.*

Besides the road conditions, the weather conditions as well as driving assistance have interaction effects with the lighting attributes. These have been collected in a similar manner as the effects of road conditions and therefore can be analyzed and used in the same way. The interaction effect of weather conditions on the preferences of road users regarding lighting attributes are described in Table 6-6 and the interaction effects of driving assistance are described in Table 6-7.

Table 6-6 The results of the multinomial logit model regarding the interaction effects of the context attribute "Weather conditions" on the lighting attributes.

INTERACTION EFFECTS OF WEATHER CONDITIONS ON LIGHTING ATTRIBUTES								
ATTRIBUTE	LEVEL	Level	Rainy weather β	WC1 ρ	Foggy weather β	WC2 ρ	Fine weather β	WC0 ρ
Lighting type	EL	LT1	-0.555	0.010*	0.492	0.088*	0.063	
	LED	LT2	0.442	0.039*	-0.223	0.314	-0.218	
	SON	LT0	0.114		-0.269		0.155	
Lighting placement	Below	LP1	0.098	0.664	0.315	0.160	-0.413	
	Above	LP0	-0.098		-0.315		0.413	
Lighting uniformity	High	LU1	-0.447	0.017*	0.190	0.297	0.258	
	Medium	LU2	-0.328	0.146	0.781	0.005*	-0.453	
	Low	LU0	0.775		-0.970		0.195	

** indicates a significance level of at least 90 %. Several variables have been constructed using the summation method as described in Table 5-5 and therefore a significance indication is left out.*

Table 6-7 The results of the multinomial logit model regarding the interaction effects of the context attribute "Driving assistance" on the lighting attributes.

INTERACTION EFFECTS OF DRIVING ASSISTANCE ON LIGHTING ATTRIBUTES						
ATTRIBUTE	LEVEL	LEVEL	Full assistance β	DA1 ρ	No assistance β	DA0 ρ
Lighting type	EL	LT1	-1.684	0.042*	1.684	
	LED	LT2	1.016	0.040*	-1.016	
	SON	LT0	0.668		-0.668	
Lighting placement	Below	LP1	-0.066	0.615	0.066	
	Above	LP0	0.066		-0.066	
Lighting uniformity	High	LU1	-0.169	0.643	0.169	
	Medium	LU2	-0.871	0.030*	0.871	
	Low	LU0	1.040		-1.040	

** indicates a significance level of at least 90 %. Several variables have been constructed using the summation method as described in Table 5-5 and therefore a significance indication is left out.*

6.3.3 *Scenario analysis*

Once all coefficients and effects have been estimated, the structural utility of a scenario can be calculated by summing the utilities of the included attribute-levels and interaction effects, as seen in equation 5. As an example, randomly chosen choice-set 6 as presented in the choice-experiment will be examined. The lighting attribute-levels form two alternatives, which together with the base alternative provide the choice-options for the road user in a fixed context. The attribute levels all have corresponding coefficients, summing them will provide the structural utility for each of the alternatives. The base alternative is normalized to 0 and this is corrected by adding a constant to the other alternatives. An overview of the alternatives of choice-set 6 as well as their corresponding coefficients, the total structural utility per alternative have been described in Table 6-8.

The conclusion that can be drawn from this comparison is that a road lighting with LED lighting, placed from below with a high uniformity is preferred over a lighting installation with SON, from above with a low level of uniformity when the road user is driving without driving assistance on a straight road under rainy circumstances.

Using the theory of multinomial logit, as explained in section 5.3.2 Multinomial logit model, the structural utilities of alternatives can be used to calculate the probability of a road user to prefer and choose an alternative over another, as seen in equation 4. This calculation has been done in the example in Table 6-8, resulting in a probability of 79% that a road user will choose the first alternative over alternative 2 (20%) and the alternative without lighting (1%). This concludes the first part of the evaluation.

Table 6-8 An overview of the calculation of the structural utility per alternative in choice-set 6 of the experiment, as described in Table 5-2. The calculation method used to determine the probability is described in 5.3.2 Multinomial logit model.

ATTRIBUTE	ALTERNATIVE 1	UTILITY	ALTERNATIVE 2	UTILITY
Constant		4.830		4.830
Lighting type	LED	0.599	SON	-0.676
Lighting placement	Below	0.185	Above	-0.185
Lighting uniformity	High	1.685	Low	-0.782
Road conditions	Straight		Straight	
- on lighting type		-1.338		0.783
- on lighting placement		0.015		-0.015
- on lighting uniformity		-0.871		0.073
Weather conditions	Rainy weather		Rainy weather	
- on lighting type		0.442		0.114
- on lighting placement		0.098		-0.098
- on lighting uniformity		-0.447		0.775
Driving assistance	No assistance		No assistance	
- on lighting type		-1.016		-0.668
- on lighting placement		0.066		-0.066
- on lighting uniformity		0.169		-1.040
Total structural utility		4.417		3.045
Probability of choice		0.790		0.200

6.4 Evaluation of the ordinal regression model

Besides the choice-experiment, a rating-experiment was also included in the survey. The rating-experiment involved road users to rate the alternatives presented in the choice-sets on four dependent variables:

- Safety;
- Detection;
- Guidance;
- Comfort.

After all data have been collected and analyzed in SPSS, using the ordinal regression command, models for each of the dependent variables have been created. Before interpreting the regression models, each of the models is evaluated based on their improvement over their respective null-models and their goodness of fit.

The goodness of fit of the ordinal regression model is evaluated by the χ^2, Pearson's χ^2 and Nagelkerke's R^2. These statistics can be derived directly from SPSS and have been described in Table 6-9. All four models, named after their dependent variable, are significant improvements over their null models. For example, the χ^2 value of the "Safety" – model, 383.890 exceeds the critical χ^2 value at 10 degrees of freedom with a confidence level of 95% of 29.588. Pearson's χ^2 also proves that the model predicts the observed data well for all four regression models.

Nagelkerke's R^2 is a measure similar to the likelihood to predict the fit of the model. The outcome of Nagelkerke's R^2 varies between a maximum of 1 and a minimum of 0. Nagelkerke's R^2 explains to what extend the model predicts the influence of the independent variables on the dependent variables. In the case of the "Safety" – model, about 13 percent of change of the dependent variable is accounted for, a decent percentage. The other models perform equally good, with R^2 –values of 20, 11.4 and 15.4 percent respectively. Therefore, the models perform sufficient for the predictions to be used and interpreted.

Table 6-9 An overview of the ordinal regression model characteristics as calculated following the theory presented in section 5.4 Evaluation of model quality

MODEL'S GOODNESS OF FIT INFORMATION	SAFETY	GUIDANCE	DETECTION	COMFORT
Log likelihood – base	-2,268.519	-2,706.268	-2,209.468	-2,398.031
Log likelihood – model	-1,932.629	-2,171.355	-1,917.493	-1,993.012
χ^2 value	385.890	534.913	291.975	403.019
Degrees of freedom	10	10	10	10
Critical χ^2 value	29.588	29.588	29.588	29.588
Significance	0.000	0.000	0.000	0.000
Pearson's χ^2 value	1,082.225	1,335.797	1,034.998	1,138.000
Pearson's degrees of freedom	298	298	298	298
Significance	0.000	0.000	0.000	0.000
Nagelkerke's R^2	0.130	0.200	0.114	0.154

The ordinal regression model, as mentioned in section 5.3.1 Ordinal regression model, can be used to determine the influence on the ratings of each of the attributes on the dependent variables. The estimated influence is described in Table 6-10.

While examining the influences of levels the outcome should be treated as vectors, both the direction and the magnitude are of importance. The direction indicates whether a level has a positive of negative effect on the rating of a dependent variables, the magnitude provides insights in the relative amount of increase or decrease of the rating.

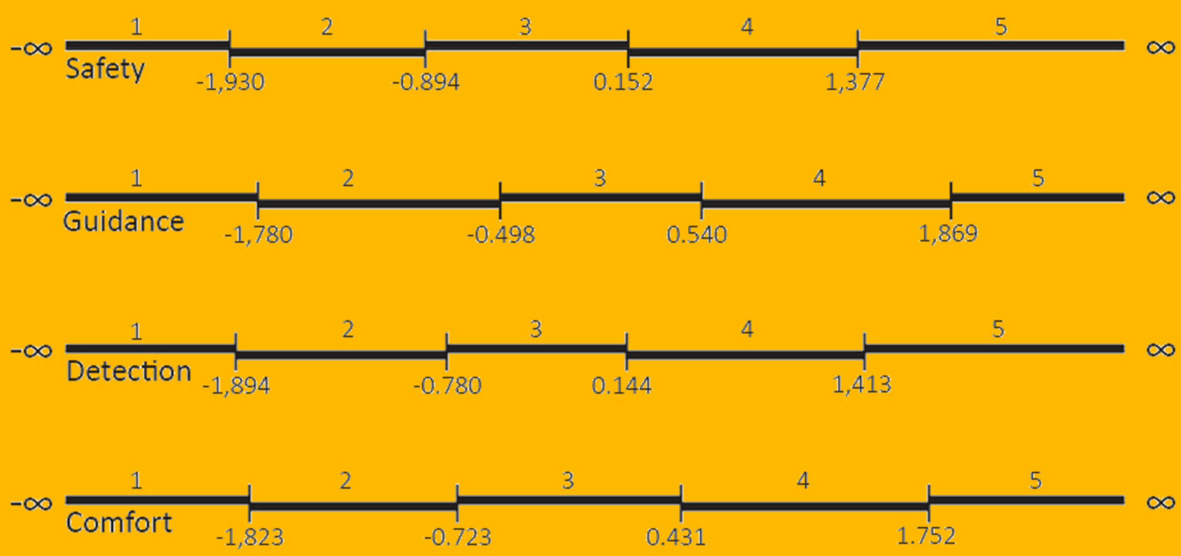
An example is LED, a level of the attribute "lighting type". The application of LED as a lighting type increases the feeling of safety of a road user, namely an increase of 0.167. Where SON-lighting has a negative effect (-0.173) on the feelings of safety, according to this experiment. Therefore, the outcome of the regression model can be used to determine that kinds of lighting should be applied to provide the road user with feelings of safety, or to provide the road user with feelings of guidance, detection or comfort.

Table 6-10 An overview of the ordinal regression model characteristics as calculated following the theory presented in section 5.4 Evaluation of model quality

ORDINAL REGRESSION MODEL		SAFETY		GUIDANCE		DETECTION		COMFORT	
ATTRIBUTE	LEVEL	β	ρ	β	ρ	β	ρ	β	ρ
Lighting type	EL	0.006	0.926	-0.007	0.857	0.011	0.902	0.068	0.264
	LED	0.167	0.009*	0.177	0.019*	0.152	0.005*	0.173	0.007*
	SON	-0.173		-0.169		-0.163		-0.241	
Lighting placement	Below	0.591	0.000*	0.496	0.000*	0.963	0.000*	0.663	0.000*
	Above	-0.591		-0.496		-0.963		-0.663	
Lighting uniformity	High	0.081	0.198	0.118	0.001*	0.217	0.059*	0.201	0.001*
	Medium	0.080	0.195	0.061	0.737	0.021	0.318	0.012	0.846
	Low	-0.161		-0.179		-0.238		-0.213	
Road conditions	Bend	0.032	0.522	0.027	0.733	0.017	0.594	0.008	0.880
	Exit lane	-0.023	0.649	-0.042	0.242	-0.060	0.410	-0.039	0.441
	Straight lane	-0.009		0.015		0.042		0.031	
Weather conditions	Rainy weather	0.068	0.181	0.051	0.852	0.009	0.315	0.000	0.994
	Foggy weather	-0.579	0.000*	-0.562	0.000*	-0.441	0.000*	-0.576	0.000*
	Fine weather	0.511		0.511		0.432		0.575	
Driving assistance	Full assistance	0.006	0.883	-0.061	0.738	0.013	0.106	-0.021	0.574
	No assistance	-0.006		0.061		-0.013		0.021	
Threshold 1		-1.930	0.000*	-1.780	0.000*	-1.894	0.000*	-1.823	0.000*
Threshold 2		-0.894	0.000*	-0.498	0.000*	-0.780	0.000*	-0.723	0.000*
Threshold 3		0.152	0.001*	0.540	0.002*	0.144	0.000*	0.431	0.000*
Threshold 4		1.377	0.000*	1.869	0.000*	1.413	0.000*	1.752	0.000*

** indicates a significance level of at least 90 %. Several variables have been constructed using the summation method as described in Table 5-5 and therefore a significance indication is left out.*

Figure 6-2 The thresholds of each of the regression models as derived from SPSS via the ordinal regression command. The thresholds provide information on the predicted rating of road lighting under certain circumstances.



As can be seen in Table 6-10, the effects of attribute-levels are consistent throughout the four models, the LED-type of lighting has a positive effect on guidance, detection and comfort similar to the positive effect on safety for example. This can be determined by comparing the magnitudes and directions of the estimated influences of each of the models.

It can also be said that the effects of LED lighting on safety, guidance, detection and comfort are greater than the effects of for example EL lighting. The magnitudes of the estimates of LED exceed the estimates of EL, therefore it can be concluded that LED is rated over EL in this experiment.

Although these individual estimates tell something about the importance of separate levels relative to one another, this does not provide insight in the rating of the dependent variables by the road users. Illustrating, a positive effect of LED lighting on safety does not immediately translate into a high rating of safety, this is dependent on the summation of coefficients of the situation and the thresholds of the dependent models.

As mentioned, each of the dependent variables has a 1 to 5 scale, every category has a boundary characteristic for that dependent variable. These threshold values are derived from SPSS directly and are visualized in Figure 6-2.

The thresholds can be used to predict the rating of a dependent variable. By comparing the summation of the influences of the attribute-levels to thresholds, a predicted rating can be derived. For example, a combination of factors with a value of -1,950 on safety is likely to represent a rating of 1 out of 5. Whenever this value is improved to -1,900, the rating on safety is more likely to be rated a 2 out of 5. Using this method, it is possible to determine both the importance of different lighting attributes under different circumstances for different purposes and predicted how this will be rated by the road users.

7 CONCLUSIONS

This chapter presents an conclusion of the theory and research in this report. The research questions will be answered and the preferences regarding road lighting will be discussed.

7.1 Conclusion

The objective of this research is to gain understanding in the way road lighting contributes to the perception of road lighting, from the road users' point of view in order to generate preferential road lighting situations for the road user. There is lack of knowledge available on the subject of road lighting and its effects on road users, and with the industry innovating, now research into the needs of road users concerning road lighting is crucial, by answering the main question:

MQ: Which kinds of road lighting do road users prefer and which circumstances are influential on road users' road lighting preference?

In order to do so, each of the sub questions will be answered:

SQ1: What is road lighting and what are current and expected technologies?

Road lighting can be defined as 'all artificial lighting with the purpose of enlightening the public space to the enhancement of quality of life, the traffic- and social safety of the public safety'. Road lighting is vital for driving, as the road users' visual perception is key in acquiring the necessary information for driving. Road lighting aids the visual perception when natural light sources are not sufficient, so that road users can detect any objects or other road users in timely fashion and they are guided along the course of the road. Besides these advantages for driving, road lighting enhances the feelings of safety and comfort while driving at night. Road lighting is estimated to decrease the number of accidents by an astonishing 30%.

However, road lighting comes with a number of downfalls. The first of which concerns financial costs, covering placement costs, maintenance costs and energy costs. Second, the fact that energy input is necessary for current road lighting to function also results in environmental issues, indirectly road lighting has high levels CO_2 emission, due to the energy consumption, causing global warming. Third, road lighting also affects nature (light trespass & sky glow).

Current measures taken by the government try to decrease the impact of lighting pollution and other downfalls, setting up three key challenges: increase traffic safety, improve traffic flow, and increase environmental savings. The result is that road lighting is simply shut down during night-time, as this will not lead to an increase in accidents according to RWS. This however does influence the perceptions of road users at night-time, experiencing decreases in the perception of safety and comfort.

Companies in the lighting industry try to come up with environmental-friendly, sustainable concepts that feature new kinds of lighting, involving better armatures, new lighting sources, new ways of placing lighting. The influences of new and expected road lighting on the road users' perceptions is yet to be determined. In order for the development of viable road lighting for the roads of tomorrow, it is necessary to gain understanding of these effects.

Besides the trends in the lighting industry, the car industry is rapidly introducing smart mobility solutions, also based upon the key challenges as set by the government. The rise of automated driving has already started and is going to influence the way we drive. The driving task of road users will be altered, depending on the level of automation in vehicles, which results in even more pressure on road lighting. Technology does not need road lighting to see, making road lighting redundant for driving when fully automated vehicles have taken over. However, the road users, either driving or being driven, might still need forms of lighting in order to feel comfortable and safe. We have very little knowledge about the relationship between road lighting and the perceptions of road users, resulting in the following research question.

SQ2: Which circumstances influence the preferences of road users regarding road lighting?

In order to gain more understanding in the effects of road lighting, different aspects of road lighting and circumstances have been distinguished and described. These lighting aspects describe different lighting alternatives. This research approach makes it possible to identify important factors, so that research on the effects of road lighting can be focused correctly. Also situational aspects and driver characteristics have been described, as they are closely related to the performance of road lighting. The preferences of road users will indicate which of the circumstances of driving is most important and therefore has to be investigated closely .

It is concluded that the type of lighting used, the way lighting is placed and the resulting uniformity of lighting together make up for the lighting alternatives. Where the road conditions, the weather conditions and the level of driver assistance make up for the context of road lighting.

At the moment, it is unknown how much light and what kind of light we need during different conditions. Potential consequences of new kinds of road lighting or measures such as dimming the light are unknown as well. Without insights in these factors, optimizing the lighting and the experiences of road users is simply impossible.

In an attempt to fill this gap, knowing the preferences of road users will be a step in the right direction. An experiment has been set up, using the distinguished aspects of lighting in order to determine the preferences of road users on the current form of road lighting as well as several upcoming forms. The experiment is set to find an answer for the following questions:

SQ3: What are the current preferences of road users regarding road lighting?

SQ4: How do road lighting, circumstances, and the road user interact?

Answers to these question are found by performing a discrete choice experiment using an online survey, in which road users are asked to rate different lighting alternatives within a fixed context and choose which one they prefer. The road users where shown visuals of the situation and the lighting alternatives, and there was textual explanation on the alternatives as well. The data collected from this experiment is analyzed using multinomial logit modelling and ordinal regression analysis.

7.2 Results of the experiment

The results of this experiment show that new forms of lighting, using alternative placing of lighting and lighting types such as LED or EL, are rated higher over current road lighting by road users on the aspects of perception of safety, perception of comfort, guidance and detection. The rating of ‘lighting from below’ and ‘high level of uniformity’ indicate that not only new types of light sources are viable, but new concepts of lighting under certain circumstances, such as “Glowing lines” as well.

The multinomial model also emphasizes that the LED lighting, EL lighting are preferred by road users over the current lighting type SON. Also lighting placement on the road is slightly favored over lighting placement from above. Both outcomes strengthen each other, which leads to the conclusion that road users are open to the application of new sources of road lighting along the highways of the Netherlands.

The interaction of the context with road lighting is crucial for the evaluation of lighting. As for road conditions, road users tend to favor the current form of lighting in combination with straight lanes, namely SON type lighting applied from above with a medium level of uniformity. Whenever other situations arise, in the experiment bends and exit lanes have been included, road users rather see lighting placed from below instead of from above.

Looking into the preferences of road users regarding road lighting under different weather conditions, it is clear that road users driving in fine weather are satisfied with the current forms of road lighting. They even indicate that the uniformity of road lighting might be lower than usual, which is no surprise in fine weather. However, once again when ‘special conditions’ are analyzed, road users tend more to other forms of lighting. During rainy weather, road users value shining forms of lighting (like LED and SON) over glowing EL. It is expected this has something to do with the need to detect objects in rainy circumstances rather than being guided properly. The exact opposite is happening whenever foggy weather conditions are present. During foggy conditions, EL lighting from below is preferred over others. This is in line with the expected results, as foggy weather conditions diminish the effects of road lighting from above, as often their light does not reach the course of the road.

Overall, it can be concluded that the preferences of road users regarding road lighting are related to the context. There seems to be a slight preference for road lighting placed from below rather than from above and the inclusion of new lighting types. LED lighting seems to be preferred over other lighting types, with high levels of uniformity. Road users have indicated that they do not like the inconsistent forms of lighting, as this is rated lowest in the ordinal regression model.

Because of the nature of the models and the attribute having two levels, it is concluded to be difficult to evaluate any differences on the aspect of driving assistance. The outcomes of the regression model show very little differences and therefore, this aspect is left aside.

Translating these results into real-life scenarios will still remain difficult. Therefore the results of the experiment should be used as stepping stones for further research, emphasizing on the effects of new lighting aspects. The knowledge gained by this experiment can be used by parties in the lighting industry to revise their strategy, also benefitting the road user in the end.

8 RECOMMENDATIONS

This chapter will focus on the research findings in an attempt to tie the findings to real-life. Additionally, this chapter will emphasize limitations and opportunities for further research.

8.1 Recommendations for governmental institutes

The preferences of road users have been derived. These preferences indicate which aspects should be pursued from the road users' point of view in order to create road lighting that performs adequately under certain circumstances.

As the government is the legislative power, they are usually the last to adapt to innovations. However, it is crucial for the development of new lighting technologies as well as for the renovation of outdated lighting applications that space is given to innovation. Creating places where lighting can be tested in real-life, so that in-depth studies can be done on the variables derived from this research. The conservative attitude of the government on the one hand and the increasing technological improvements in the other, might lead to dangerous situations. The victimizing of road users, putting safety and comfort on the line, could have disastrous outcomes. Therefore, it is necessary that governmental institutes, advisory organs and the government itself become open-minded towards future road lighting and give it space to improve.

The current challenges of the government, involving the increasing traffic safety, improving the traffic flow, while increasing environmental savings, can go hand in hand with the development of future lighting. In order to save energy, new lighting types such as LED and EL could be investigated and implemented in current lighting installations. Their effects on the perceptions of safety and comfort are better than the current lighting, so it is argued that traffic safety is also increased. These new lighting types also are far more energy-efficient than SON, and are able to be included in smarter systems such adaptive and interactive lighting due to their low run-up time. The placement of lighting along highways is also an opportunity worth exploring, as this research indicates that lighting from below offers benefits in certain circumstances.

The current measure of simply shutting down lighting at places where it is not necessary, so that energy can be saved, is not received well by road users. Road users indicate that all forms of lighting outperform non—lighted alternatives and low levels of uniformity are least preferred. Low levels of uniformity arise when road lighting is dimmed or shut down at certain places and still on at for example exit lanes. This causes discomfort by road users, and creates feelings of insecurity when leaving the lighted areas. Therefore a recommendation for the government is to rather look at other opportunities to cope with the key challenges, instead of simply shutting down the lights.

This research should be regarded by the government as an indication of the current state of lighting, providing understanding of the way measures are perceived by road users and offering several opportunities to take on the challenges in a way that seems to be more beneficial than the current practice. It can be used as an aid in the decision-making process regarding road lighting. Ultimately, it would be ideal if the perceptions of safety, comfort, guidance and detection of the road users become a part of lighting legislation, next to the performance, cost and environmental aspects.

8.2 Recommendations for companies

Besides recommendations for the governmental parties, other parties in the lighting industry also benefit from this research. The identification of important aspects from the road users' point of view offers clear direction for innovation.

Taking road users' preferences into consideration for further development of future road lighting will lead to more effective and efficient ways of lighting. The outcome of this research identifies the aspects most important for road users, in regard to the perception of safety, comfort, guidance and detection. Incorporating these aspects in new ways of lighting will create better road lighting from the users' perspective. As the results of the experiment indicate, the potential for thinking outside the box, outside the guidelines of the ROVL and the current road lighting possibilities, is supported by the road users. This research could also aid in the decision-making processes of companies regarding the application of future road lighting on projects.

Newer, alternative ways of lighting are preferred in many situations over the current road lighting installations, providing opportunities and stepping stones for innovation. It is clear that lighting companies should investigate the importance of aspects in road lighting carefully to make sure that future road lighting fulfills the needs of road users and tackles the challenges of the government simultaneously.

Especially looking into different types of light sources and alternative ways of placing lighting seem opportunities for companies in the lighting industry. Collaboration and integral approaches of during the designing and construction of road lighting along highway is a recommendation to companies as well.

8.3 Recommendations for further research

Experimenting and evaluating lighting with before-and-after studies might be difficult due to the changing circumstances, therefore other methods for evaluation have to be found. This research provides direction in the aspects that are influential and thus should be covered in these researches. This research has proven that using modelling techniques such as stated choice experiments are useful in the development for future lighting. Multinomial Deriving attention points and influential circumstances offers great benefits for future research.

The results of old studies have been used for many years now, and are still valid due to the little change in mobility and the driver. The lack of knowledge is documented throughout this study and these gaps have to be filled in order for road lighting to be optimized. However, as influential trends in mobility, the environment and the lighting industry are originating, the time has come to review road lighting once again. It is recommended that especially the trends of vehicle automation and technological improvements regarding lighting systems are regarded and taken along in future lighting research.

The experiment and the data derived contain much more information than is regarded at this moment in time. Only a small part of the data have been used, in order to determine the preferences of road users in general. The data of this experiment can be used perfectly to determine which types of road users exist and whether their preferences differ. Also aspects as driving experience and researches specifically based on weather conditions for example are worth examining for future research.

9 DISCUSSION

This chapter will critically evaluate the research method and discuss benefits and downfalls of the chosen research method.

9.1 Research method

Little research has been done on preferences regarding road lighting from the road users' point of view. The road user is the reason that lighting is applied along highways. However due to the current energy- and environmental issues, road lighting is simply being shut down, without looking towards the effects on the perceptions of the road user. Simultaneously. technological trends in the lighting industry and the driving industry, result in changes in road lighting and the identity of driving. These developments create a situation in which the road users is left aside. In order to stand up for the road user, more research is necessary into the preferences of road users and the way lighting effects the perception of road users. So that the preferences of the road users are taken along in the developments of future road lighting.

This research provides understanding of these preferences, by examining a number of aspects of lighting in a discrete choice experiment. A discrete choice experiment has not been conducted concerning this subject. However, this method of research is perfectly suited for investigation of important aspects, especially stated preference. The clear benefit is that it is possible to fully control the variables included in the model, and create hypothetical situations rather than relying on real-life situations. These situations are described both verbally and graphically, so that respondents can relate to the hypothetical situations and compare them more effectively.

A risk of stated preference is that situations might not seem realistic. This is potentially very influential in this research, as the visuals added in the survey are created in Photoshop together with experts. Although they have been tested amongst a pilot group, the visuals still might be subjective and therefore effect the quality of the research. As not every aspect of lighting is included in the research, unforeseen effects or relations may influence the quality and the outcomes of the research as well. A fractional factorial design is used to minimize the amount of choice-sets, to make the research manageable within the limit period of time. A full fractional design might offer more insights, as then all attributes are compared.

The survey containing the choice experiment is a quick and easy way to collect data. Especially when the internet is used to spread the survey amongst road users. However, the sample will only reach people that use internet, understand Dutch and probably are somehow connected to the personal network of the researchers. This might result in a subjective sample, for example if many colleagues have taken the survey.

In order for the survey to be comprehensible and manageable for respondents to fill in without biases, the choice-sets have been grouped and distributed at random. As seen in the research, the frequency of each group is quite different. Which is the result of people starting but not finishing the survey and the type of randomization (drawing with replacement) used by the Berg Enquête system. The result is that potentially attributes are not evenly distributed throughout the data, as some attributes might be represented more than others. This is an aspect that might influence the outcomes and quality of the model as well.

All models estimated in the research performed better than the null-models, and were significant improvements. It is concluded that the model used for this research will perform adequately to determine the preferences of road users and answer the research questions properly.

9.2 Results

The results of this experiment can be considered quite revolutionary, as new and hypothetical lighting situations are preferred over current road lighting. Most researches as less outspoken and often indecisive, rather than the results of this experiment. The experiment has been done with the utmost care and precision, is carefully set up and is explained with the existing literature. Therefore, the results are actually representative for the sample.

However, there may be a couples of aspects that influence the outcomes of the experiment. The first is that the sample is biased. The survey amongst personal and work networks, which may result in similar thinking people that might have been prejudiced towards these new lighting alternatives and therefore more likely to prefer those over the current road lighting.

Another scenario is that the visuals created for this survey are biased. They might be subjective and favor the new lighting alternatives, as these might be considered more exciting. An example of this subjectivity is that LED lighting seems to be preferred over other lighting types, which may have something to do with the enhanced color definition under white light. This is added in the visuals by adjusting the colors of the environment and the cars slightly brighter than those with other forms of lighting. This is based upon the effects of the lighting types on the visibility. However, this might be overdone, slightly influencing the respondents and triggering them to simply prefer the visual with the brightest colors.

This is a common downfall whenever visuals are used in these kinds of experiments. Although the creation of the visuals has been done with the utmost precision, creating all lighting alternatives similarly and applying the same templates for weather conditions, the visuals might still favor the ‘new and exciting’ alternatives.

A third and last scenario is the fact that these results are actually representative for the sample, and that road users actually prefer the new concepts of road lighting over the current forms of road lighting.

The experiment also included a differentiation between driver and passenger, in order to determine if potentially the automation of vehicles might influence the needs of the road user regarding road lighting. The results of this attribute are not decisive enough to interpret correctly. Therefore, the differentiation between driver and passenger is left out of the results and the influences are not taken into consideration. Further research, more respondents or perhaps another research method are necessary in order to determine whether differences exist and what implications for road lighting are.

The results of this experiment have potential to change the way roads are lighted. There are many roads to follow, and many opportunities for the lighting industry to take advantage of trends and make an impact on road lighting. Let’s start enlightening the future.

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LIST OF APPENDICES

A SURVEY

VERLICHTING

Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

TU/e Technische Universiteit Eindhoven University of Technology

heijmans

Welkom!

Hartelijk dank voor uw interesse in mijn enquête.

Deze enquête gaat over verschillende vormen van **verlichting rondom de Nederlandse snelweg** en wordt uitgevoerd in opdracht van Heijmans Wegen N.V. en de Technische Universiteit van Eindhoven. Deze enquête heeft als doel om inzicht te krijgen in **uw voorkeur** van verlichting op de Nederlandse snelweg. Uw input wordt gebruikt om de snelweg van morgen vorm te geven.

Het invullen van de vragenlijst neemt ongeveer 10 minuten in beslag. De vragenlijst bestaat uit drie delen. Eerst stellen we u enkele achtergrondvragen om een indruk te krijgen van uw rijgedrag en ervaring. In het tweede deel vragen we u diverse situaties met elkaar te vergelijken en een voorkeur aan te geven. Tot slot volgen nog enkele persoonlijke vragen.

Alvast bedankt voor uw medewerking, succes bij het invullen!

Mark van Kampen

Afstudeerder Construction Management & Engineering - TU/e
Afstudeer-stagiair Smart Highway - Heijmans Wegen N.V.

Al uw gegevens worden anoniem en met zorg verwerkt. Op geen enkel wijze worden uw gegevens gebruikt voor commerciële doeleinden.

[Begin enquête]

VERLICHTING

Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

TU/e Technische Universiteit Eindhoven University of Technology

heijmans

DEEL 1: ACHTERGROND VRAGEN

Het eerste deel van de enquête bestaat uit enkele achtergrond vragen met betrekking tot uw achtergrond en rijervaring.

Heeft u een autorijbewijs (tenminste rijbewijs B)?

- Ja
- Nee

Bent u bekend met de snelweg in Nederland?

- Bekend
- Redelijk bekend
- Neutraal
- Redelijk onbekend
- Onbekend

Maakt u, als passagier/bestuurder, gebruik van de snelweg in Nederland?

- Ja
- Nee

[Vorige] [Volgende]

VERLICHTING

Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

De volgende vragen hebben betrekking op uw ervaring op de weg.

Hoelang bezit u een rijbewijs?

- 5 jaar of minder
- 6 - 10 jaar
- 11 - 20 jaar
- 21 - 30 jaar
- 31 jaar of meer
- Weet ik niet

Hoevaak bent u gemiddeld per week bestuurder in de auto?

- 0 dagen
- 1-2 dagen
- 3-4 dagen
- 5-6 dagen
- 7 dagen

Hoevaak bent u gemiddeld per week passagier in de auto?

- 0 dagen
- 1-2 dagen
- 3-4 dagen
- 5-6 dagen
- 7 dagen

Hoeveel kilometer legt u per jaar gemiddeld af in de auto in totaal, als bestuurder én passagier?

- Minder dan 5000 kilometers
- 5.000 - 9.999 kilometers
- 10.000 - 19.999 kilometers
- 20.000 - 29.999 kilometers
- 30.000 kilometers of meer
- Weet ik niet

Vorige | **Volgende**

VERLICHTING

Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

Nu volgen nu enkele vragen over de mate van eventuele problemen die u ervaart tijdens het reizen.
Geef aan in hoeverre u het eens bent met de volgende stellingen.

Heeft u last van beperkingen met uw zicht?

- Ja, ik zie niet altijd goed
- Ja, ik maak gebruik van visuele hulpmiddelen tijdens het rijden (bijvoorbeeld lenzen of een bril)
- Nee, ik heb geen visuele beperkingen
- Weet ik niet

Ik heb problemen met reizen in de auto in het donker.

- Eens
- Gedeeltelijk eens
- Neutraal
- Gedeeltelijk oneens
- Oneens

Ik heb problemen met het schatten van afstanden in de auto.

- Eens
- Gedeeltelijk eens
- Neutraal
- Gedeeltelijk oneens
- Oneens

Ik ben snel afgeleid door mijn omgeving in de auto.

- Eens
- Gedeeltelijk eens
- Neutraal
- Gedeeltelijk oneens
- Oneens

Vorige | **Volgende**

Berg Enquête System © 2007 Design Systems

VERLICHTING
Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

DEEL 2: KEUZE-EXPERIMENT

In het tweede deel van de enquête vergelijken we verlichtingsmogelijkheden in verschillende situaties.
U dient drie keer een voorkeur aan te geven tussen de mogelijkheden en elk alternatief te beoordelen op de volgende aspecten:

Veiligheid - *Ik voel me hier veilig*

Detectie - *Ik kan objecten goed zien*

Geleiding - *Ik kan de weg goed volgen*

Comfort - *Ik voel me hier prettig*

Per situatie vergelijken we drie alternatieven.
De situatie is in woorden beschreven, waarna elk alternatief is uitgewerkt in een afbeelding met beschrijving.
De beschrijving bestaat uit een drietal kenmerken:

Verlichtingstype - *welke soort verlichting is toegepast, schijnend of gloeiend, en de bijbehorende kleur*

Verlichtingswijze - *waar de lichtbron geplaatst is, van onder of boven*

Gelijkmatigheid - *hoe gelijk de verlichting verdeeld is over het oppervlak, van hoog naar laag*

In elke situatie vragen we u een fictieve rol in te nemen, te weten:

Passagier - *u bent niet verantwoordelijk voor het besturen van de auto*

Bestuurder - *u bent verantwoordelijk voor het besturen van de auto*

Bij alle vragen gaat het om **uw eerste indruk** van het gepresenteerde verlichtingsalternatief, foute antwoorden zijn niet mogelijk.
U wordt verzocht met aandacht de alternatieven te bekijken en zorgvuldig antwoord te geven op de vragen.

Er volgt nu een voorbeeldvraag om het principe duidelijk te maken.

Vorige | **Start deel 2**

Berg Enquête System © 2007 Design Systems

VERLICHTING
Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

VOORBEELDVRAAG

Hieronder volgt een verkeerssituatie op een snelweg in Nederland. Beoordeel elk van de alternatieven door de stellingen in te vullen en geef daarna uw voorkeur aan.

SITUATIE	ALTERNATIEF A	ALTERNATIEF B	ALTERNATIEF C
U bent **bestuurder** op een 2-baans snelweg in een **bocht** met 130 km/uur. Het is **helder weer** en er is ander verkeer aanwezig.			
Verlichtingstype	Schijnend, helder oranje	Schijnend, helder oranje	Geen verlichting
Verlichtingswijze	Van onder (in wegdek)	Van boven (via lantaarnpalen)	
Gelijkmatigheid	Gemiddeld	Hoog	

STELLING	oneens -..- neutraal -..- eens	oneens -..- neutraal -..- eens	oneens -..- neutraal -..- eens
Ik voel me hier veilig	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik kan objecten goed zien	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik kan de weg goed volgen	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik voel me hier prettig	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Voorkeur	○ Alternatief A	○ Alternatief B	○ Alternatief C

Vorige | **Volgende**

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VERLICHTING
Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

START KEUZE-EXPERIMENT

We presenteren nu drie situaties waarin we u vragen de verschillende alternatieven te beoordelen.
Daarnaast verwachten we dat u een voorkeur uitspreekt voor een van de alternatieven. Kijk hierbij eerst zorgvuldig naar de situatie waarin u zich bevindt.
Voor een vergroting van de alternatieven kunt u op de te vergroten afbeelding klikken.

Wanneer u vergeten bent iets in te vullen, dan is dit met rode vierkantjes aangegeven.

Succes!

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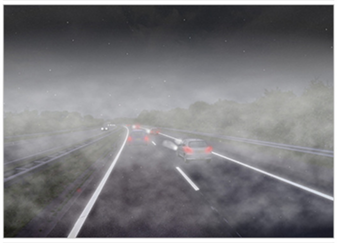
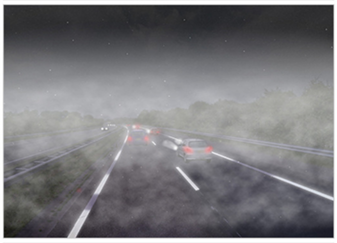
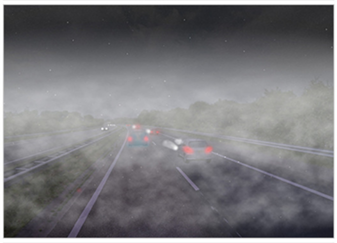
VERLICHTING

Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

SITUATIE 1

Hieronder volgt een verkeerssituatie op een snelweg in Nederland. Beoordeel elk van de alternatieven door de stellingen in te vullen en geef daarna uw voorkeur aan.

SITUATIE	ALTERNATIEF A	ALTERNATIEF B	ALTERNATIEF C
U bent **passagier** en rijdt op een 2-baans snelweg met 130 km/uur. Het is **mistig** en er is ander verkeer aanwezig.			
Verlichtingstype	Schijnend, helder wit	Schijnend, helder wit	
Verlichtingswijze	Van onder (in wegdek)	Van onder (in wegdek)	Geen verlichting
Gelijkmatigheid	Hoog	Gemiddeld	

STELLING	oneens -..- neutraal -..- eens	oneens -..- neutraal -..- eens	oneens -..- neutraal -..- eens
Ik voel me hier veilig	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik kan objecten goed zien	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik kan de weg goed volgen	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik voel me hier prettig	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Voorkeur	○ Alternatief A	○ Alternatief B	○ Alternatief C

Vorige | **Volgende**

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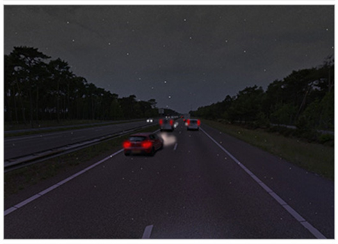
VERLICHTING

Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

SITUATIE 2

Hieronder volgt een verkeerssituatie op een snelweg in Nederland. Beoordeel elk van de alternatieven door de stellingen in te vullen en geef daarna uw voorkeur aan.

SITUATIE	ALTERNATIEF A	ALTERNATIEF B	ALTERNATIEF C
U bent **bestuurder** en rijdt op een 2-baans snelweg met 130 km/uur. Het is **helder weer** en er is ander verkeer aanwezig.			
Verlichtingstype	Schijnend, helder oranje	Schijnend, helder wit	
Verlichtingswijze	Van onder (in wegdek)	Van boven (via lantaarnpalen)	Geen verlichting
Gelijkmatigheid	Laag	Gemiddeld	

STELLING	oneens -..- neutraal -..- eens	oneens -..- neutraal -..- eens	oneens -..- neutraal -..- eens
Ik voel me hier veilig	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik kan objecten goed zien	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik kan de weg goed volgen	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik voel me hier prettig	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Voorkeur	○ Alternatief A	○ Alternatief B	○ Alternatief C

Vorige | **Volgende**

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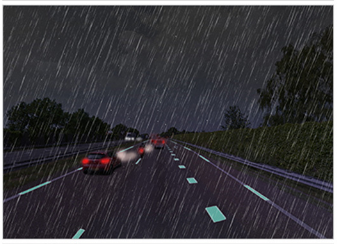
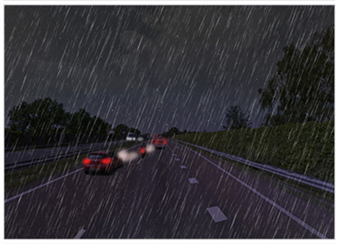
VERLICHTING

Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

SITUATIE 3

Hieronder volgt een verkeerssituatie op een snelweg in Nederland. Beoordeel elk van de alternatieven door de stellingen in te vullen en geef daarna uw voorkeur aan.

SITUATIE	ALTERNATIEF A	ALTERNATIEF B	ALTERNATIEF C
U bent **bestuurder** en rijdt op een 2-baans snelweg ter hoogte van een **afrit** met 130 km/uur. Het is **helder weer** en er is ander verkeer aanwezig.			
Verlichtingstype/td>	Gloeiend, helder groen	Schijnend, helder wit	
Verlichtingswijze	Van onder (in wegdek)	Van onder (in wegdek)	Geen verlichting
Gelijkmatigheid	Gemiddeld	Gemiddeld	

STELLING	oneens -..- neutraal -..- eens	oneens -..- neutraal -..- eens	oneens -..- neutraal -..- eens
Ik voel me hier veilig	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik kan objecten goed zien	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik kan de weg goed volgen	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Ik voel me hier prettig	○ ○ ○ ○ ○	○ ○ ○ ○ ○	○ ○ ○ ○ ○
Voorkeur	○ Alternatief A	○ Alternatief B	○ Alternatief C

Vorige | **Volgende**

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VERLICHTING

Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

DEEL 3: PERSOONLIJKE VRAGEN

Nu volgen enkele persoonlijke vragen. Deze hebben betrekking op uw achtergrond en motivatie.

Wat is uw geslacht?

- ☒ Man
- ○ Vrouw

Wat is uw geboortejaar?
Noteer uw geboortejaar in 4 cijfers (YYYY).

Wat is uw gezinssamenstelling?

- ○ Eenpersoonshuishouden
- ○ Meerpersoonshuishouden zonder kinderen
- ○ Meerpersoonshuishouden met kind(eren)
- ○ Anders

Wat is uw hoogst afgeronde opleiding?

- ○ Lager- of basisonderwijs
- ○ Voortgezet onderwijs
- ○ Middelbaar beroepsonderwijs
- ○ Hoger beroepsonderwijs
- ○ Universitair onderwijs
- ○ Geen

Vorige | **Volgende**

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VERLICHTING

Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

DEEL 3: PERSOONLIJKE VRAGEN

Nu volgt een vraag over hoe u in het leven staat. Deze heeft betrekking op uw motivatie.

In welk van de volgende stelling herkent u zich het meest?

- ○ Ik houd vast aan tradities en materieel bezit.
- ○ Ik zoek evenwicht tussen traditie en moderne waarden als consumeren en genieten.
- ○ Ik streef naar een onbezorgd, plezierig en comfortabel leven.
- ○ Ik ben gefascineerd door sociale status, nieuwe technologie, risico en spanning.
- ○ Ik wil mezelf ontplooien, kom in actie voor sociaal onrecht en het milieu.
- ○ Ik breek met morele en sociale conventies, ik leef mijn eigen leven.
- ○ Ik geef ruimte aan technologische ontwikkeling, maar verzet me tegen sociale en culturele vernieuwing.
- ○ Ik hecht waarde aan succes, materialisme en genieten maar ik ben ook bezig met ontplooing.
- ○ Weet ik niet

Vorige | **Volgende**

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VERLICHTING
Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

Heeft u naar aanleiding van deze enquête nog vragen, opmerkingen of suggesties?

Als u op de hoogte gehouden wilt worden van het verdere verloop van dit onderzoek, dan kunt u hieronder uw e-mailadres achterlaten.

Vorige **Volgende**

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VERLICHTING
Onderzoek naar de voorkeur van verlichting op de snelweg in Nederland

Dit is het einde van de enquête.

Bedankt voor uw deelname!

Vorige **Volgende**

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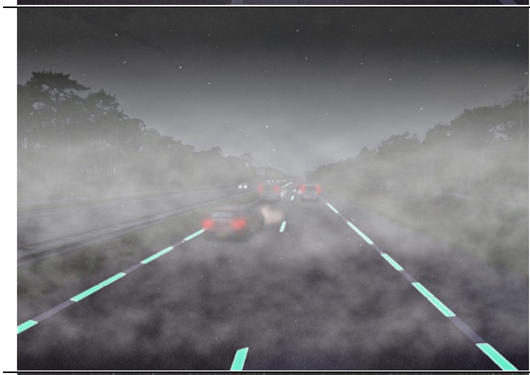
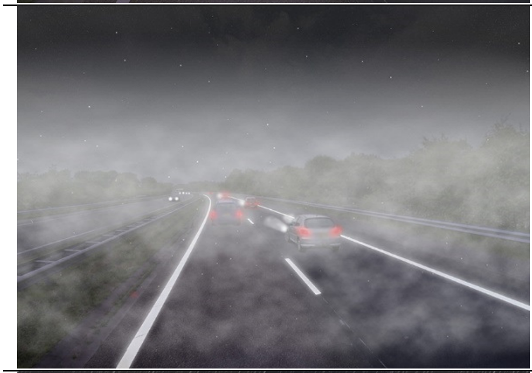
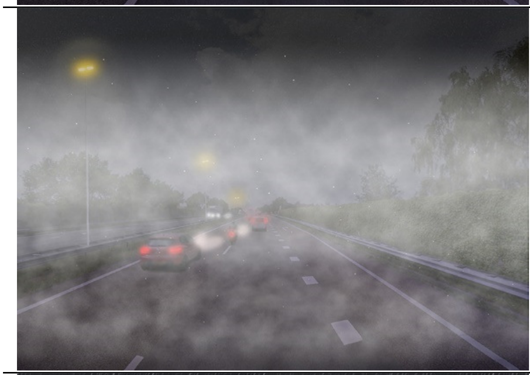
B VISUALS

This appendix shows a number of the visuals as presented in the survey. Each of the visuals has been created by combining several levels, according to the theory of stated choice experiments. The visuals are created using Adobe Photoshop 5 with road lighting experts and checked among a pilot group for understanding. The images below show the visuals and their corresponding levels.

VISUAL	LIGHTING ASPECTS	CONTEXT ASPECTS
	- no lighting	- straight lane - fine weather
	- LED lighting - From above - Medium uniformity	- straight lane - fine weather
	- EL lighting - From below - Medium uniformity	- straight lane - foggy weather
	- SON lighting - From below - Medium uniformity	- straight lane - rainy weather

VISUAL	LIGHTING ASPECTS	CONTEXT ASPECTS
	- no lighting	- bended lane - fine weather
	- SON lighting - From above - High uniformity	- bended lane - fine weather
	- LED lighting - From below - High uniformity	- bended lane - foggy weather
	- EL lighting - From below - High uniformity	- bended lane - rainy weather

VISUAL	LIGHTING ASPECTS	CONTEXT ASPECTS
	- no lighting	- exit lane - fine weather
	- EL lighting - From above - Low uniformity	- exit lane - fine weather
	- SON lighting - From above - Low uniformity	- exit lane - foggy weather
	- LED lighting - From below - Low uniformity	- exit lane - rainy weather

C SPSS OUTPUT – CORRELATION MATRIX

		Road conditions	Road conditions	Weather conditions	Weather conditions	Driver Assistance	Lighting type	Lighting type	Lighting plan	Lighting Uniformity	Lighting Uniformity
Road conditions	Pearson Correlation	1	,500**	.023	-.034	,093**	.016	-,044*	.038	.010	.007
	Sig. (2-tailed)		.000	.244	.089	.000	.424	.028	.057	.606	.716
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
Road conditions	Pearson Correlation	,500**	1	-.034	-,057**	,105**	.017	-.029	-.005	.003	.010
	Sig. (2-tailed)	.000		.089	.004	.000	.383	.140	.800	.883	.611
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
Weather conditions	Pearson Correlation	.023	-.034	1	,500**	-.006	.010	.008	-,058**	.016	-,042*
	Sig. (2-tailed)	.244	.089		.000	.756	.611	.705	.004	.418	.035
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
Weather conditions	Pearson Correlation	-.034	-,057**	,500**	1	.019	,062**	,041*	-.015	-,043*	-,058**
	Sig. (2-tailed)	.089	.004	.000		.352	.002	.037	.447	.033	.004
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
Driver Assistance	Pearson Correlation	,093**	,105**	-.006	.019	1	-.032	-.007	-.028	-.022	-.019
	Sig. (2-tailed)	.000	.000	.756	.352		.110	.710	.164	.278	.345
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
Lighting type	Pearson Correlation	.016	.017	.010	,062**	-.032	1	,463**	,048*	-.032	-.013
	Sig. (2-tailed)	.424	.383	.611	.002	.110		.000	.016	.109	.505
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
Lighting type	Pearson Correlation	-,044*	-.029	.008	,041*	-.007	,463**	1	.023	,117**	,068**
	Sig. (2-tailed)	.028	.140	.705	.037	.710	.000		.253	.000	.001
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
Lighting plan	Pearson Correlation	.038	-.005	-,058**	-.015	-.028	,048*	.023	1	.000	.000
	Sig. (2-tailed)	.057	.800	.004	.447	.164	.016	.253		.989	.992
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
Lighting Uniformity	Pearson Correlation	.010	.003	.016	-,043*	-.022	-.032	,117**	.000	1	,497**
	Sig. (2-tailed)	.606	.883	.418	.033	.278	.109	.000	.989		.000
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
Lighting Uniformity	Pearson Correlation	.007	.010	-,042*	-,058**	-.019	-.013	,068**	.000	,497**	1
	Sig. (2-tailed)	.716	.611	.035	.004	.345	.505	.001	.992	.000	
	N	2520	2520	2520	2520	2520	2520	2520	2520	2520	2520

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

D PROCEDURE NLOGIT – MULTINOMIAL LOGIT MODEL

```
*****DATA SET UP***********************************************
RESET
read ; Nobs = 2520
  ; Nvar = 15
  ; Names = id,group,set,alt,choice,rc1,rc2,wc1,wc2,da,lt1,lt2,lp1,lu1,lu2
  ; Format = (f12.0,f1.0,13f12.0)
  ; File = data.dat$

******DETERMINING ALTERNATIVE-SPECIFIC CONSTANT*****
create; if(alt=1) asc=1$
create; if(alt=2) asc=1$
create; if(alt=3) asc=0$

*****CREATING FIRST LEVEL INTERACTION ON ROAD CONDITIONS**********************
create; lt1_rc1=lt1*rc1$
create; lt1_rc2=lt1*rc2$
create; lt2_rc1=lt2*rc1$
create; lt2_rc2=lt2*rc2$
create; lu1_rc1=lu1*rc1$
create; lu1_rc2=lu1*rc2$
create; lu2_rc1=lu2*rc1$
create; lu2_rc2=lu2*rc2$
create; lp1_rc1=lp1*rc1$
create; lp1_rc2=lp1*rc2$

*****CREATING FIRST LEVEL INTERACTION ON WEATHER CONDITIONS*******************
create; lt1_wc1=lt1*wc1$
create; lt1_wc2=lt1*wc2$
create; lt2_wc1=lt2*wc1$
create; lt2_wc2=lt2*wc2$
create; lu1_wc1=lu1*wc1$
create; lu1_wc2=lu1*wc2$
create; lu2_wc1=lu2*wc1$
create; lu2_wc2=lu2*wc2$
create; lp1_wc1=lp1*wc1$
create; lp1_wc2=lp1*wc2$

*****CREATING FIRST LEVEL INTERACTION ON DRIVING ASSISTANCE*******************
create; lt1_da=lt1*da$
create; lt2_da=lt2*da$
create; lu1_da=lu1*da$
create; lu2_da=lu2*da$
create; lp1_da=lp1*da$

*****RUNNING MULTINOMIAL LOGIT MODEL*******************************************
DISCRETE CHOICE ; Lhs = choice
  ; Choices = 1,2,3
  ; Rhs  = asc,lt1,lt2,lp1,lu1,lu2,
     lt1_rc1,lt1_rc2,lt2_rc1,lt2_rc2,
     lu1_rc1,lu1_rc2,lu2_rc1,lu2_rc2,
     lp1_rc1,lp1_rc2,
     lt1_wc1,lt1_wc2,lt2_wc1,lt2_wc2,
     lu1_wc1,lu1_wc2,lu2_wc1,lu2_wc2,
     lp1_wc1,lp1_wc2,
     lt1_da,lt2_da,
     lu1_da,lu2_da,
     lp1_da
  ; Show Model
  ; Describe
  ; Crosstab
  ; Prob = pmnl$
```