Road users' preferences regarding innovative road lighting along Dutch highways

Road Users' Preferences regarding Innovative Road Lighting along Dutch Highways: A Stated Choice Experiment

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Abstract

This paper presents the results of a study concerning road users' preferences regarding innovative road lighting along highways. Special attention is paid to the new concept of Glowing Lines. A stated choice experiment is setup using three lighting related attributes: type, placement, and uniformity. The attributes are used to specify different lighting alternatives that are randomly placed in choice tasks of three alternatives each. Three background attributes are added to the choice task: road conditions, weather conditions, and driving assistance. Respondents were asked to evaluate each alternative of the choice task on four different aspects: safety, detection, guidance, and comfort. In addition, respondents were invited to make a choice of the most preferred lighting alternative.

The experiment was included in an extensive online questionnaire. In total, 280 respondents completed the questionnaire. In regard to the evaluation of the four aspects, the study shows that lighting type, lighting placement, lighting uniformity, and weather conditions significantly influence the evaluation of all aspects. No influence was found for the lighting type Glowing Lines. With respect to the choices, it appears that Glowing Lines plays a more significant role. Glowing lines are preferred by the road users in the case of bends and straight courses, under foggy weather conditions, and in the case when there is no driver assistance.

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Introduction

The Dutch ministry of Infrastructure and Ecology is reconsidering its policy regarding the lighting of the Dutch highways. The main reasons for this reconsideration are the increasing costs of construction and maintenance, the energy use, and light pollution of the streetlights (I&M, 2015). To cope with the disadvantages of road lighting, the ministry is looking for possibilities to dim or turn off streetlights along highways. The considered solutions have to keep the comfort and safety level as high as possible (Figure 1). In reaction to this development, private companies in the road construction and lighting industry are looking for new kinds of lighting which fulfill the requirements of the ministry and the preferences of road users (e.g, Ping Lau et al., 2015). Insights into the preferences of the latter group are still limited.

Figure 1: Advertisement of Heijmans Technique & Mobility (leaflet)

Together with Heijmans Infrastructure, The Dutch designer Daan Roosegaarde introduced some new designs and technologies for interactive and sustainable roads of the future (Smart Highways, Figure 2). The new designs include concepts as Glowing Lines, Dynamic Paint, and Electric Priority Lane (see www.studioroosegaarde.net). An exploratory orientation of several journals and reports (see also the next section) showed that the focus is on the technical possibilities of new designs in relation to safety. Little attention has been paid to car drivers' preferences regarding new designs. The study described in this paper focuses on the car drivers' preferences regarding Glowing Lines. The goal of the study is to provide more insight into car drivers' preferences regarding new lighting concepts such as Glowing Lines and the circumstances that might influence these preferences. The study presented here is an extension of the master thesis of Van Kampen (2015).

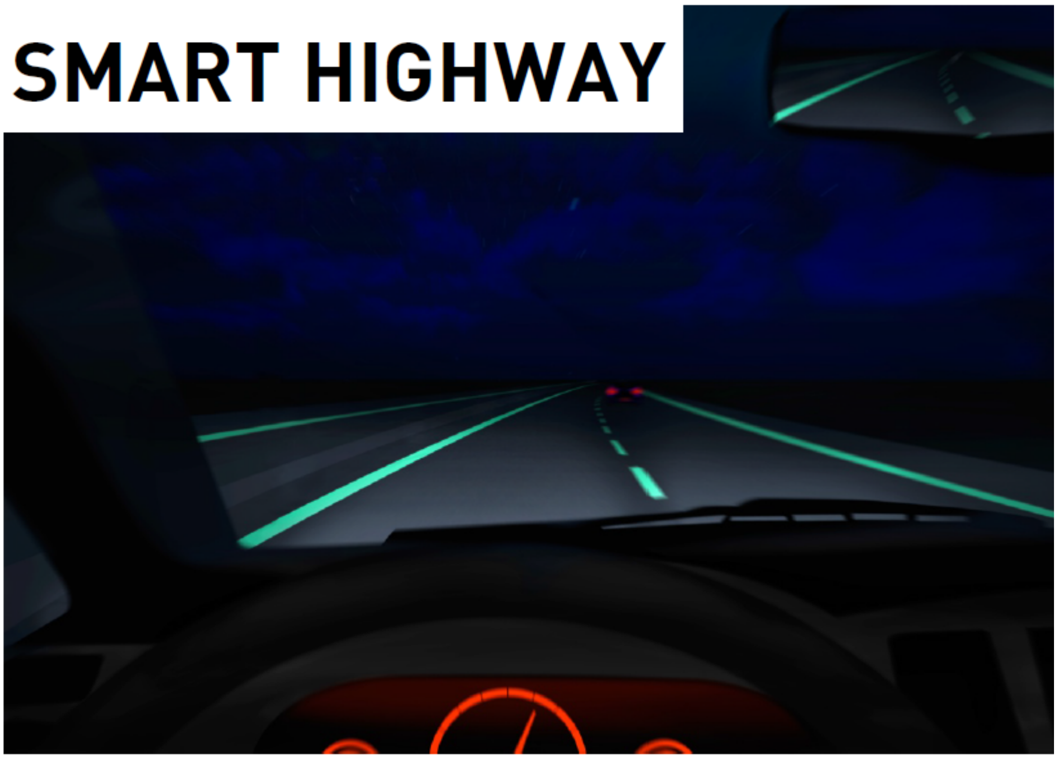

Figure 2: Glowing lines (Studio Roosegaarde & Heijmans BV)

The remainder of the paper is organized as follows. First, some insights into road lighting are presented. This section is followed by a brief description of the research approach and the data collection. The analyses consisted of two parts: analysis of evaluation scores and analysis of the choices. The paper ends with the conclusions and recommendations for implementation of road lighting plans and future research.

Road Lighting

Road lighting is developed to support road users in situations where 'natural sources are not sufficient' (SWOV, 2011). Road light is a form of public lighting which is considered as 'all artificial lighting on roads and streets, intersections and crossings, specifically altered to enhance the visibility on roads' (Elvik et al, 2009). 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 space'. Road lighting supports detection of objects on and around the road by lighting the road surface and objects on the road. In addition, road lighting guides the road users along the course of the road.

In the Netherlands, most roads are lighted using three types of road lighting (Boyce, 2009; RWS, 2010): high-pressure sodium lighting (SON), metal-halide lighting (HID), and light emitting diodes (LED). The first two types use gas-discharged lamps in which sodium and metal-halide are used to generate light. SON is the most common road lighting in the Netherlands (including highways), while HID is mainly used in urban areas. A more recent development concerns LED lighting that uses a semiconductor that emits light when an electric current is passed through it. It is expected that LED is most likely to substitute SON lighting as the next standard lighting type.

The main goal of road lighting is to aid the visual perception of road users which is mainly formed by the visibility of the road ahead and its environment. Several aspects influence this perception such as intensity and color of light, the way of integrating lighting along the road, and the reflection of the road surface (e.g., Boyce, 2009). Insights into the road users' perception are limited and mainly based on existing situations with a focus on traffic safety (e.g., Wanvik, 2009; Haans & De Kort, 2012; Jackett & Frith, 2013; Jafari Anarkooli & Hadji Hosseinlou, 2016). In addition, some attention is paid to lighting in the context of public health (e.g., Green et al., 2015). Insights regarding the effect of existing street lighting on perceptions and behavior are not consistent (e.g., SWOV, 2011). New or other ways of lighting are considered to a limited extent (e.g., RWS, 2010; Ping Lau et al., 2015).

The literature review described in Van Kampen (2015) resulted in an extensive list of thirty attributes that could be grouped into three groups: lighting attributes (e.g. lighting type, intensity, color, and luminance), situational attributes (e.g., road type, road condition, traffic intensity, and speed limit) and road user attributes (e.g., age, mentality, familiarity, and driving experience). When looking at the influence of these attributes, six different viewpoints could be distinguished. These viewpoints cover the ways road users might consider when evaluating the road lighting conditions: traffic safety, social safety; comfort, guidance, detection, and aesthetics (see table 1).

Table 1: Viewpoints when evaluating road lighting (Van Kampen, 2015)

Viewpoint	Description
Traffic safety	The perception of being safe on the road and closely related to the aspects seeing and being seen.
Social safety	The perception of being safe from criminal activities on the road, such as gatherings at gas stations.
Comfort	The level of comfort as derived from the kind of road lighting used, such as the brightness and placement of lighting.
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.
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.
Aesthetics	The overall appreciation of the armatures and lighting based on beauty.

Changes in road users' viewpoints due to improved road lighting might trigger them to change driving and/or travel behavior. For example, when road users feel safer due to improved lighting, they increase the driving speed and/or the level of risk acceptance (Assum et al., 1999). Another example concerns the positive effect of road improvements on work travel in Iceland (Bjarnason, 2014).

Research approach

To get more insight into the road users' preferences regarding the lighting of roads, a stated choice experiment is set up. In several previous studies an experiment is set up in a real world context (e.g., Mayeur et al., 2010; Haans & De Kort, 2012; Gibbons et al., 2016). Setting up an experiment in a real world situation is time and money intensive, and the possibilities to investigate strongly depend on the availability of an acceptable location. The approach adopted for this study is less time and money consuming, and provides the opportunity to control included attributes as much as possible (e.g., Abele & Møller, 2011; Bella; 2013). Because it is a first attempt to investigate these types of preferences, the experiment focuses on highways in the Netherlands. For the experiment several hypothetical lighting alternatives are generated. The alternatives are described using three lighting attributes (Table 2): lighting type, lighting placement, and lighting uniformity. The selection is based on an extensive literature review (see Van Kampen, 2015). In the experiment three different types of lighting are included: high pressure sodium lighting (SON), light emitting diodes (LED), and glowing lighting (GL). The second attribute concerns the placement of the lighting with levels from below and above. The final attribute concerns the uniformity of lighting along the road. Three levels are distinguished: low (less than 40 percent uniformity), medium (between 40 and 70 percent), and high (more than 70 percent).

The valuation of road lighting might be influenced by situational attributes like traffic intensity, darkness conditions, and course of the road (e.g., NSVV, 2011). In this study, three attributes that represent the situational aspects are investigated in more detail: road conditions, weather conditions, and driver assistance. Different road conditions exist on highways: bends, straight lanes, junctions, bridges, tunnels, and exit lanes. Based on appearance and generality, the following road conditions are included: straight lanes, bends, and exit lanes. Based on the most common weather conditions in the Netherlands, the following conditions are distinguished: fine, rainy and foggy weather. The final situational aspect concerns the presence of driver assistance: full assistance or no assistance.

Table 2: Overview of attributes and attribute levels

Groups	Attributes	Abbreviation	Levels
Lighting related	Light type	LT	GL LED SON
	Lighting placement	LP	Below Above
	Light uniformity	LU	High Medium Low
Situational	Road conditions	RC	Bend Exit lane Straight lane
	Weather conditions	WC	Rainy weather Foggy weather Fine weather
	Drivers assistance	DA	Full assistance No assistance

The planned choice situations were set up as follows. First, a general context is presented to the respondent. This context consisted of four aspects which were set in advance.

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

In addition, each choice situation included a specific context description consisting of three situational attributes, and two choice alternatives each consisting of three light related attributes. This set up results into 5832 different choice situations (3^6x2^3). From this full factorial design a fraction of 27 choice sets was retrieved following the principles of Addelman (1962). To each choice situation an alternative indicating 'no lighting' was added as base alternative. The attributes were transformed into graphical representations using Photoshop (see Figures 1a and 1b). To stress the exact situation presented in the pictures also a description of the attributes was included.

Figure 1a: Example of the choice set: Driver, bend, clear weather

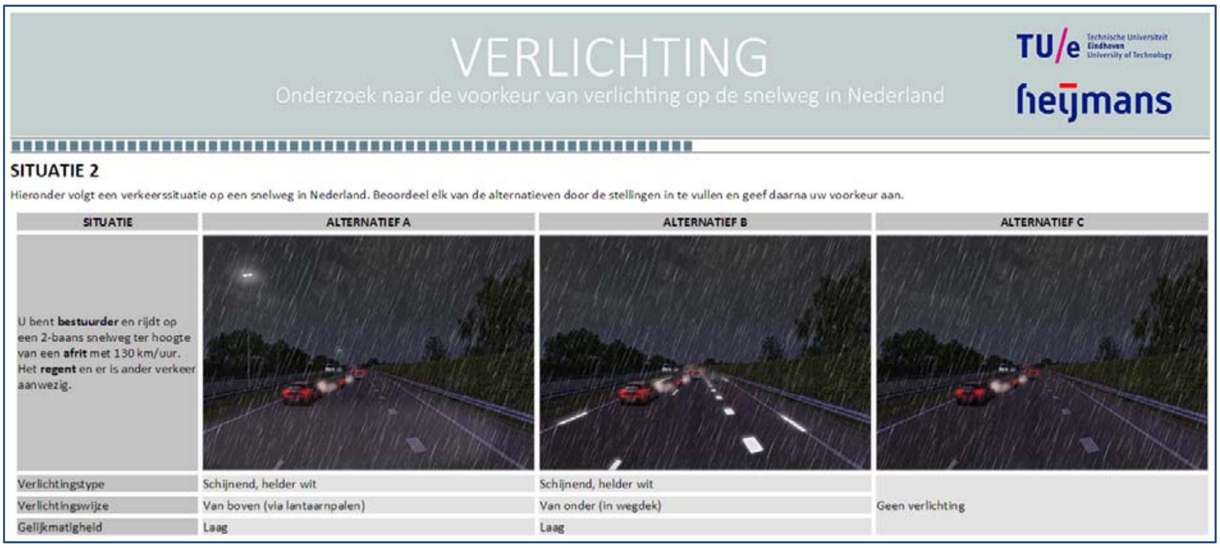

Figure 1b: Example of the choice set: Driver, exit lane, rainy weather

The evaluation of the choice situation consisted of two parts: valuation of aspects and a choice of most preferred alternative (Figure 2). The following aspects were investigated in the experiment: safety (first proposition: I feel safe), detection (second proposition: I can see objects very well), guidance (third proposition: I can follow the road), and comfort (fourth proposition: I feel pleasant). The respondents could evaluate the alternatives on a five points scale ranges from Disagree to Agree.

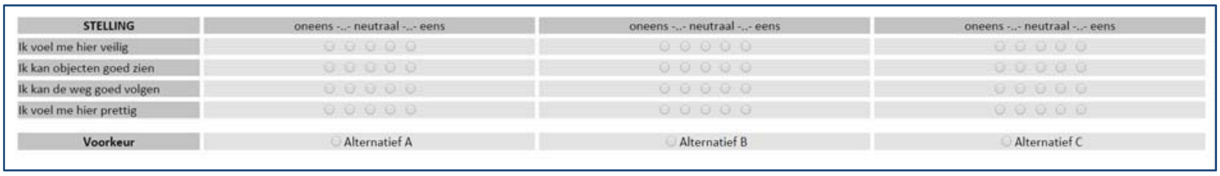

Figure 2: Evaluation task

Each respondent was asked to evaluate three different choice situations. The choice situations were randomly distributed across the respondents. The stated choice experiment was included in an online questionnaire that also included questions regarding the respondents' driving experiences and personal characteristics.

Data

The invitations for the questionnaire are distributed across a convenience sample of family, friends, and colleagues. In total 280 respondents completed the questionnaire. Based on the rule of thumb suggested by Orme (see Rose & Bliemer, 2013), the number of respondents is sufficient to analyze the stated preference data. Some details of the sample are presented in Table 2. Due to a lack of data, it is not clear if the sample represents the Dutch highway users well. Despite this fact, the distribution across the various characteristics levels is considered as sufficient to continue the analyses.

Table 2: Personal characteristics

Characteristics	Levels	Frequency	Percentage
Personal			
Gender	Male	176	62.9
	Female	104	37.1
Age	Younger than 40	133	47.5
	40 years and older	147	52.5
Education	Medium level	82	29.3
	Higher level	198	70.7
Household situation	Family with children	143	51.1
	Family without children	137	48.9
Experience			
Driving experience	Less than 30,000 km/year	174	62.1
	30,000 km/year or more	106	37.9
Highway familiarity	Fairly familiar	57	20.4
	Very familiar	223	79.6
Frequency of driver	4 days or less	94	33.6
	5 days or more	186	76.4
Frequency of passenger	0 days	112	40.0
	1 day or more	168	60.0
Total		280	100.0

Analysis of evaluation scores

The data are analyzed in two stages. First, the evaluations of the propositions are analyzed using ordinal regression analysis, because the evaluations are considered as ordinal variables where the distances between the ratings are not defined as equal and the distances are in fact unknown (e.g., Long & Freese, 2003). Ordinal regression is commonly presented as a latent variable model, defining y^* as a latent variable ranging between -∞ and +∞.

Table 3: Estimation results of the ordinal regression analyses

Attributes	Aspects			
	Safety	Guidance	Detection	Comfort
Threshold 1	-1.930*	-1.780*	-1.894*	-1.823*
Threshold 2	-0.894*	-0.498*	-0.780*	-0.723*
Threshold 3	0.152*	0.540*	0.144*	0.431*
Threshold 4	1.377*	1.869*	1.413*	1.752*
Lighting type				
- GL	0.006	-0.007	0.011	0.068
- LED	0.167*	0.177*	0.152*	0.173*
*- SON***	*-0.173*	*-0.170*	*-0.163*	*-0.241*
Lighting placement				
- Below	0.591*	0.496*	0.963*	0.663*
- Above	*-0.591*	*-0.496*	*-0.963*	*-0.663*
Lighting uniformity				
- High	0.081	0.118*	0.217*	0.201
- Medium	0.080	0.061	0.021	0.012
- Low	*-0.161*	*-0.179*	*-0.238*	*-0.213*
Road conditions				
- Bend	0.032	0.027	0.017	0.008
- Exit lane	-0.023	-0.042	-0.060	-0.039
- Straight lane	*-0.009*	*0.015*	*0.042*	*0.031*
Weather conditions				
- Rainy weather	0.068	0.051	0.009	0.000
- Foggy weather	-0.579*	-0.562*	-0.441*	-0.576*
- Fine weather	*0.511*	*0.511*	*0.432*	*0.575*
Driving assistance				
- Full assistance	0.006	-0.061	0.013	-0.021
- No assistance	*-0.006*	*0.061*	*-0.013*	*0.021*
Goodness-of-fit				
Log-likelihood - base	-2,268.519	-2,706.268	-2,209.468	-2,398.031
Log-likelihood - optimal	-1,932.629	-2,171.355	-1,917.493	-1,993.012
Chi-square values	385.890	534.913	291.975	403.019
Test value (df=10)	18.31	18.31	18.31	18.31
McFadden's R^2	0.148	0.198	0.132	0.169

* Significant at 90 percent confidence level (α<0.10); ** base attribute level in *italics*

The equation of the ordinal regression model is:

$$y_i^* = \beta_i x_i + \epsilon_i$$

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*.

Effect coding is used to represent the effects of the independent attributes on the dependent evaluation scores.

Based on Chi-square values, test values, and McFadden's R^2, it can be concluded that all estimated models perform quite well (Table 3). All models outperform the base model that included the intercept only, indicating that the set of selected attributes significantly contribute to the prediction of the evaluation scores. The estimation results also show that lighting type, lighting placement, and weather conditions significantly influence the evaluation of all aspects. A positive parameter means that the attribute levels results in an increase of the evaluation score. For example, the presence of LED lighting increases the evaluation score of all aspects. Most remarkable finding concerns the positive parameter for lighting from below. Road users prefer lighting from below more than lighting from above. The highest contribution is found for the aspect 'Detection' (detection of objects) and lowest contribution for 'Guidance' (notice of road course). As expected, the presence of foggy weather decreases the evaluation scores for all aspects significantly. The effect is more or less equal across all aspects. No influence is found for the attributes road conditions and driving assistance.

Analysis of choices

The choices of the respondents are analyzed using a standard multinomial logit (MNL) model. The model is able to relate an individual's choice for a specific alternative to the attributes of the alternative and all other alternatives. Given the principles of the random utility theory, the comparison of the alternatives is based on the structural utility derived from the attributes of the alternatives (e.g., Train, 2009):

$$V_j = \beta_0 + \beta_i x_{ij} + \beta_i y_{ii'j}$$

Where

V_j is the structural utility of alternative *j*;

β_0 is a constant indicating the average profile rating (alternative specific constant);

β_i is the regression coefficient corresponding to attribute *i*;

x_{ij} is the value of attribute *i* and alternative *j*;

$y_{ii'j}$ is the value of the context attribute *i'* in relation to attribute *i* of alternative *j*.

The structural utilities of all alternatives are included in the MNL model with the following equation.

$$P_j = \frac{e^{V_j}}{\sum_J e^{V_{j'}}}$$

Where

P_j is the probability that alternative *j* will be chosen;

V_j is the structural utility of alternative *j*;

$V_{j'}$ is the structural utility of all alternatives *j'*;

The estimation of the model parameters is based on 840 choices. The specified MNL model included both main and context effects. The main effects are estimated for the light related attributes lighting type, lighting placement, and lighting uniformity. Context effects cover the effects of the situational attributes (road conditions, weather conditions, and driving assistance) in relation to all lighting attributes. Again, effect coding is used to represent the effect of the attributes on the choice probabilities.

The goodness-of-fit information shows that the model performs quite well (Table 4). The model outperforms a model with all parameters equal to zero indicating that the inclusion of model parameters significantly improves the model performance. Based on McFadden's R^2 value, it can be concluded that the model is also well able to describe the observed choices. Regarding the individual parameter estimates the following conclusions can be drawn. Based on the positive parameter of the constant, it can be concluded that respondents prefer alternatives with lighting more than the base alternative with no lighting. In addition, respondents prefer LED lighting and highly uniformed lighting. No influenced is found for the placement of lighting.

Regarding the context effects the model estimation shows that the background attributes influence the road users' preferences for the lighting related attributes significantly. Again, a positive sign of the parameter means that the attribute level increases the preference of road users. For road conditions the following influences are found. In bends, road users prefer GL and LED lighting, lighting from above, and lighting with medium uniformity. At exit lanes, road users prefer lighting types LED and SON, lighting from below, and high uniformity of lighting. In the case of a straight course, road users prefer EL and SON lighting, lighting from above, and medium lighting uniformity. In the case of weather conditions the following influences can be noticed. When it rains, road users prefer LED lighting and a low uniformity of lighting. In the case of foggy weather, road users prefer GL lighting and a medium lighting uniformity. If the weather is fine, road users prefer SON lighting and a high level of lighting uniformity. Looking at the influence of the presence of driver assistance, it appears that in the case of full driver assistance road users prefer LED lighting and low lighting uniformity. When there is no assistance, road users prefer GL lighting and medium lighting uniformity.

Table 4: Estimation results of the MNL model

Main effects	Levels	Parameter	Range	Rank
Constant		4.830*		
Lighting type	GL	0.077	1.275	2
	LED	0.599*		
	*SON***	*-0.676*		
Lighting placement	Below	0.185	0.371	3
	Above	-0.185		
Lighting uniformity	High	1.685*	2.589	1
	Medium	-0.904*		
	Low	-0.782		
Road conditions	Levels	Bend	Exit lane	*Straight*
Lighting type	GL	1.454*	-2.009*	*0.555*
	LED	1.123*	0.215	*-1.338*
	SON	-2.577	1.794	*0.783*
Lighting placement	Below	-0.642*	0.657*	*-0.015*
	Above	0.642	-0.657	*0.015*
Lighting uniformity	High	-0.339	1.211	*-0.871*
	Medium	0.873*	-1.672*	*0.799*
	Low	-0.534	0.462	*0.073*
Weather conditions	Levels	Rainy	Foggy	*Fine*
Lighting type	GL	-0.555*	0.492*	*0.063*
	LED	0.442*	-0.223	*-0.218*
	SON	0.114	-0.269	*0.155*
Lighting placement	Below	0.098	0.315	*-0.413*
	Above	-0.098	-0.315	*0.413*
Lighting uniformity	High	-0.447*	0.190	*0.258*
	Medium	-0.328	0.781*	*-0.453*
	Low	0.775	-0.970	*0.195*
Driving assistance	Levels	Full	*No*	
Lighting type	GL	-1.684*	*1.684*	
	LED	1.016*	*-1.016*	
	SON	0.668	*-0.668*	
Lighting placement	Below	-0.066	*0.066*	
	Above	0.066	*-0.066*	
Lighting uniformity	High	-0.169	*0.169*	
	Medium	-0.871*	*0.871*	
	Low	1.040	*-1.040*	
Goodness-of-fit				
Log-likelihood - zero		-922.834		
Log-likelihood - optimal		-519.494		
Log-likelihood ratio statistic		806.680		
Chi-square test value (degrees-of-freedom: 31)		61.098		
McFadden's R^2		0.437		

* Significant at 90 percent confidence level (α<0.10); ** base attribute level in *italics*

Conclusions

Research on road users' preferences regarding existing and new types of road lighting is still limited. The goal of this paper is to extend the existing insights into road users' preferences in general and preferences of users of highways in particular. Special attention is paid to the concept of Glowing Lines, lines that are loaded during daytime and glow during nighttime. The research is triggered by the ideas of the Dutch government to reduce or even turn off the lighting along highways. This study provides some insights into the effects of actions the government could take.

The study consisted of two parts. The first part focused on the evaluation of various hypothetical combinations of lighting type, lighting placement, lighting uniformity given a certain road condition, weather condition, and presence of driver assistance. The evaluation covered four aspects of driving: safety, detection, guidance, and comfort. It appeared that lighting type, lighting placement, lighting uniformity, and weather conditions significantly influence the evaluation of all aspects. No influence was found for the lighting type Glowing Lines (GL). The second part of the analyses consisted of a choice between three hypothetical combinations: two varying combinations and one base 'combination' (no lighting). The model estimation shows a varied of significant influences. Now, it appears that Glowing Lines (GL) plays a more significant role. Glowing Lines are preferred by the road users in the case of bends and straight courses, under foggy weather conditions, and in the case when there is no driver assistance.

Table 5: Example

Attributes	Current situation		Future situation	
	Description	Utility	Description	Utility
Constant		4.830		4.830
Lighting type	SON	-0.676	GL	0.077
Lighting placement	Above	-0.185	Below	0.185
Lighting uniformity	Medium	-0.904	Medium	-0.904
Road conditions	Straight		Straight	
- Lighting type		0.783		0.555
- Lighting placement		0.015		-0.015
- Lighting uniformity		0.799		0.799
Weather conditions	Rainy weather		Rainy weather	
- Lighting type		0.114		-0.555
- Lighting placement		-0.098		0.098
- Lighting uniformity		-0.328		-0.328
Driving assistance	No assistance		No assistance	
- Lighting type		-0.668		1.684
- Lighting placement		0.066		-0.066
- Lighting uniformity		-0.871		-0.871
Preferences		2.877		5.489

The results of this study can be used by traffic engineers and planners to see what the influence of a change in lighting characteristics is on road users' preferences. To illustrate the way the generated results can be used, a small example is worked out. First, the lighting for the current situation is specified; SON lights, lighting from above, and medium level of uniformity. Next, this lighting situation is considered for a straight lane, rainy weather, and no driving assistance. A new lighting plan is suggested consisting of Glowing Lines (GL), lighted from below, and medium uniformity. Considering the weights extracted from the choice model estimation, it appears that this change will almost double road users' preferences. In this way, all kind of variants can be evaluated.

The findings of the current study are based on several assumptions and decisions that could be explored in more detail in the future. Within the current study and its data collection, more sophisticated models could be used to describe the evaluations and choices, and the effects of the road user's personal situation could be included in the model analyses.

The following issues could be of interest when setting up a new study. The first issue concerns the effects of the visuals that are included in the study. The introduction of virtual reality could increase the road users' experiences with the different lighting and background conditions. Other, road conditions could be added to the experiment, including non-highway related situations.

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