MASTER

An exploration of the potential of light emitting road marking

van Mierlo, M.F.A.M.

Award date:
2017

Eindhoven University of Technology

An exploration of the potential of light emitting road marking

By M.F.A.M. v. Mierlo
(0752333)

In partial fulfilment of the requirements for the degree of

**Master of Science
in Human Technology Interaction**

Faculty of industrial engineering & innovation science

Supervisors:

Dr. ir. A. Haans	- TU/e – Industrial Engineering and Innovation science
Dr. ir. R. H. Cuijpers	- TU/e – Industrial Engineering and Innovation science
Ir. A. Krug	- Heijmans N.V.
Dr. ir. J. S. Caerteling	- Heijmans Infra B.V.

Key words: Road lighting, smart lighting, road marking, human factors in traffic, outdoor lighting, light design, driving speed, driving behaviour.

Preface

This report is the final document in fulfilment of the requirements of the Human-Technology Interaction master program.

During the enrolment in this master program my interest was always drawn by the human factors in various technical domains, but is was until in my semester abroad in Trondheim, Norway that this interest was directed towards the field of the traffic and transport engineering. In the end it led me to this graduation project which was performed in cooperation with Heijmans N.V.. It holds the exploration of the potential of light emitting road marking, an innovative light technology which was installed on one of the Dutch regional roads.

The project emerged as a great opportunity to study the field of research of traffic psychology, traffic engineering and lighting technology, a process in which I took great pleasure. The knowledge I gained and the lessons I learned I consider very valuable and I will take this with me to my next upcoming and future adventures. I am above all very grateful for the warm and positive environment which Heijmans provided.

Of course, I would like to thank the supervisor which have supported me during the course of this project. First, Alma Krug (Heijmans), thank you for your broad perspective, which made me look beyond my own frame of reference, and the input for personal development. Antal Haans (TU/e) thank you for sharing your enthusiasm for this project with me from the beginning to the end, for the support during the last couple weeks and for the insights and feedback. Jasper Caerteling (Heijmans), thank you for your professional attitude and knowledge which have been of great help in the success of the experiment. I would also like to thank you for insights, feedback and kind support that helped by in the process of my research. Bart Elbers, I would like to thank you for your critical opinion, professional input and great known-how of traffic engineering. Sander Peltenburg, thank you for your always cheerful mood and interesting conversations.

Lastly, I would like to thank my friends and family, and of course Stef, that always had confidence in me and were especially of great support during the last two weeks.

I hope you enjoy the read,

Milou van Mierlo,
Eindhoven & Rosmalen, february, 2017

Summary

Mobility describes the movement of people from one place to another by different types of mode. The demand for mobility is growing which raises challenges for urban planning of cities and the road network. Smart solutions and advanced technology are considered to provide an answer to these complex challenges. The development in the light science and technology industry presents the opportunities to deploy light as an instrument for such smart solutions in the traffic and transport sector. The light industry has refined itself into a full solution and service providing sector. In order to create successful smart light applications the knowledge of how to utilize the possibilities of light in the mobility related matters is needed. Within this field of research still a lot can be learned, especially about the opportunities of light that go beyond providing visibility.

Light emitting road marking is a technology that finds itself on the joint of the themes smart mobility and smart lighting. Its potential should be explored based on the knowledge from both the field of traffic and transport as well as that of light technology and light science. Thorough understanding of the human and technological factors in a traffic environment in combination with a comprehension of the advancements made in the field of light science and light technology results into well-found scenarios for the application of the light emitting road marking. Additionally empirical evidence is collected to confirm if the light technology indeed has the potential to improve a traffic situation and to define the details of the utilization of light.

Studying the literature of traffic and transport engineering, driving speed revealed to be an important factor regarding to traffic safety. Driving speed determines the time a driver has to perceive, interpret and anticipate on all information in the traffic environment. At the same times speed influences the size of errors and correction of those. Lastly, If errors cannot be corrected and a failure occurs, speed determines the impact of the failure and the damage that is caused. Reducing driving speed is therefore an advantage in case of traffic safety. But this cannot be seen as the sole solution. The aspects risk homeostasis, darkness, workload, driving tasks, decision making, road environment and design consistency are important concepts to take into account as well. In particular when implementing an innovative light technology in a traffic environment.

Risk homeostasis theory suggests that road users constantly evaluate the level of risk to which they are exposed to and adapt their driving behaviour in such a way that they are susceptible to a certain preferred or target level of risk. This should be taken into account when designing new road elements as it can result into the counter effect of the desired or surmised results. The risk homeostasis theory suggests a large influence from the direct environment of the road user. This is supported by the theories concerning workload, driving task and design consistency. High workloads are dangerous as drivers only have a limited capacity to perceive information and act upon this. It is therefore that one drives slower when the difficulty of a driving task increases (i.e. this way the level of accepted risk is balanced). In order to handle the workload of the complex effort of driving, not all task are performed at our highest cognitive level. Road users often apply stored rules, which are basically shortcuts in our thinking, to process information quickly. Furthermore drivers learn to operate vehicles automatically, or in other words develop skills for operational driving tasks. The link between cognition and driving tasks has been made by combining the hierarchical control model of Michon (1989) and the performance model of Rasmussen (1983).

Another aspect that diminishes driving workload and aids driving are well designed roads. This is defined by the concept of road design consistency. Matching the drivers expectancy with the geometry of the road increases the use of stored rules and learned skills and decreases the need for higher level information processing. Improving the coherence and uniformity of road designs increases consistency over the total road network.

All information so far discussed becomes even more relevant during the night time hours. Almost all information received while driving is visual. Darkness reduces our visual perception which leads to later and less accurate observation of dangerous situations. It thereby decreases safety and the feeling of being safe. Increasing the visibility of the road, other road users and objects by road lighting has been proven a good countermeasure that decreases the amount of accidents. This, increasing visibility, is also where part of the potential lies for the light emitting road marking.

Other applications of the light emitting road marking are related to the subjects of perceived speed, associations with familiar road elements and active communication using colour coding. For example, speed perception is an

important cue when considering the theory of risk homeostasis. If a drivers perception of speed increases driving speed will be adjusted, in this case lowered, so to remain at the target level of risk. Associations, for instance induced by colour, are like stored rules that provide quick information for which no deep level thinking is needed and so workload does not increase. These rules can solely evoke a reaction but can also be deployed to communicate.

A last subject that need to be discussed before composing light scenarios is the advancement of light technology, which was the inducement of this research. LED technology has broaden and extended the opportunities for light applications and thereby amplified the opportunities for the use of lighting in traffic situations. LED lights come in different intensities, colour temperatures and different colour hues which broadens the light design possibilities. Additionally LED has low energy consumption, a long life expectancy and are recyclable. The properties of LED are highly suitable for these smart lighting applications as these lighting sources can be integrated in connected networks from which the output can be changed. Depending on the system architecture this means that colour, colour temperature and intensity of each light source in a light network could be controlled either remotely or sensor based.

As a conclusion of the literature study five light scenarios were composed in which the light emitting road marking are considered to provide added value to the traditional road situations. I. Increased Visibility, in this scenario increased visibility of the course of road is ought to improve the traffic situation and provide a more comfortable drive. II. Adaptive perceived speed, describes a scenario where the pattern of the road marking can be adjusted and thereby influence perceived driving speed. This could be beneficial for the traffic flow on a road and thereby the traffic safety. III. Warning Mechanism, a scenario where alertness is induced based on associations. These applications try to warn drivers for errors and evoke a response so to reduce driving failures. IV. Communication with colours and dynamic patterns, a scenario that also makes use of built up rules, in this case using it as an active communication tool. It is considered especially beneficial in changing environments. Last, scenario V. Adaptive lanes and traffic distribution, which envisions an even greater utilization of communication by light for changing environments.

Although, from an engineering perspective the light technology is at hand little scientific studies with such innovative smart technologies have been carried out in the field. As a result, little is known about the effects and impact of the wide design space lighting systems now provide. This puts emphasis on the collection of empirical evidence. To adhere to this need, in a small way, a field experiment was set up that investigated some of the use cases proposed in the light scenarios.

Within the field experiment the light emitting road marking showed improvement of the road situation by increased visibility of the course of the road. However this led to undesired increased average speeds. Though following the theory of risk homeostasis this indicated an improvement of the road it was argued that the risk level on the road was evaluated lower. Adding a dynamic pattern that inducing a higher perception of speed could eliminate this negative effect while the positive effect of increased visibility remained. Testing the effect of colour association did not result into a straight forward answer.

In the end it was concluded that in order to utilize the full potential of smart lighting technology in the road marking it is necessary to create well designed light plans which are accustomed to the road environment and the traffic situation in which they are placed. Hence this report provides the theoretical background, summarized in a list of opportunities and limitations (Part II, Ch.4.2), needed to construct thoroughly designed light plans. Finally, concrete recommendations for the installation of light in the road marking are given and opportunities for further research are stated.

Table of content

IV. APPENDICES .

List of figures

List of tables

I. General Introduction

1. Introducing Traffic and Light

We are finding ourselves in a rapid changing environment where technological innovations aim to improve our quality of life. In various domains the technological development is taking place, including that of mobility and light science and technology. Two industries which seem to come together as lighting technology is getting a more prominent place in mobility related matters. Light increases visibility and provides a general (sense of) safety and security at night. Thereby it is known that light affect our behaviour intuitively. Add to this the possibility to control colour, temperature and intensity of light and opportunities arise in the traffic environment. This research is a contribution to obtain the knowledge of how to utilize the possibilities of light in relation to traffic.

1.1 The current traffic situation: Mobility and Safety

The ability to move ourselves from place to place via the mode we prefer gives us freedom and independence. Being mobile allows us to meet and connect, to work, to enjoy our free time, to discover and to explore. Access to means such as infrastructure, vehicles, public transport, maps and route-planning technologies facilitate these movements and determine our mobility.

High mobility for everyone seems desirable but it can have it downfalls. Increased mobility for individuals can lead to decreased collective mobility. In practice the results are congestion, delays and accidents. Unfortunately these are nowadays daily happenings when travelling by car or with public transport, especially in a dense country such as the Netherlands. Here almost 11 million people have a drivers licence and drove 133 billion km in 2015 (CBS, 2016) on almost 139,000 km road (Rijksoverheid, 2015). This situation has not only led to inconvenience or increased travel times. The intense occupation of the transport network also results into high extra costs, reduced quality of life and hundreds of the deadly accidents—621 in 2015 (CBS,2106).

TNO, a Dutch research institute, claims that congestion on Dutch roads has cost the business market between 613 and 797 million euro in 2013 (NU.nl, 2016). Calculations of SWOV, the Dutch institute for traffic safety, came to a result of 12.5 billion euro expenses caused by traffic accidents in 2009 (SWOV, 2014). In that year there were 720 traffic deaths, 18 600 severe accidents and 108 000 light injuries caused by accidents. The emotional damage that is caused might be considered even higher. Also the Dutch association of insurers—members represent more than 95% of the Dutch insurance market— raised the alarm concerning decreased traffic safety. In a press release (Verbond van verzekeraars, 2016) they state increased numbers of claims after collisions.

Internationally the Netherlands seems to do quite well considering traffic safety. Compared to other European countries only Malta and Sweden had less road fatalities by population[1] in 2014 (European commission, 2016). Though it must be noted that the numbers of this list are corrected for population and vehicle-km, meaning they do not indicate the absolute number of road fatalities of a country. And without the correction the absolute number of Dutch road fatalities is not one of the lowest rates from Europe. Thereby an increase of 9% in road fatalities is measured between 2014 and 2015 in the Netherlands. This year the number raised from 570 to 621 deaths in traffic (CBS,2016). And so it cannot be stated that the Netherlands maintains one of the safest traffic environments.

Conclusively all this means that improving the traffic situation is still a matter of course. It is important to keep striving for less congestion and a safer environment. Not only to reduce costs but to improve the quality of life and more importantly to save lives. The Dutch government therefor works in cooperation with local governments, interest groups, several research institutes and enforcement to reduce the road fatalities to under 500 in 2020 (Rijksoverheid, 2008).

1.2 Smart mobility for the future

The demand for mobility is expected to keep growing in the next few years. KiM, The Dutch Institute for Transport Policy Analysis, has estimated a 9 percent increase of traffic from 2014 to 2020 (KIM,2015). In order to provide

[1] Road fatalities by population indicates an annual number of road fatalities per capita per year and per vehicle-km.

and preserve high and safe mobility for everyone in the Netherlands it is important keep developing and creating means that we use or can use for travel and transportation. This is recognized by the Dutch authorities, research institutes, and the business sector.

The Dutch ministry of Transport, Public works and Water Management in collaboration with the platform Connecting Mobility composed six routes for development concerning mobility (Connekt, 2013):

1. Development in Intelligent Traffic Systems (ITS) should focus on more individual services.

2. Road side technology should become more cooperative.

3. Information and traffic management needs a shift towards a countrywide organization.

4. Data should be transparent as much as possible

5. There should a mix of business to government and business to business collaboration and lastly

6. A shift towards public-private collaboration and alliances is desired

Figure 1 Six routes for development in the mobility sector in Dutch. Translation of the steps are given next to the figure.

The platform Connecting Mobility functions as a catalyst to create the smart mobility environment in the Netherlands. It has resulted in numerous projects, services and facilities that are under development or already in operation (http://itsoverzicht.connectingmobility.nl/). Functions of these projects are spread from navigation and route planning technologies to safety warnings to implementing social changes.

Several other platforms such as Rotterdam mobility lab, SPARK, Connecting Mobility and SigularityU serve as kick-starters to boosts the tempo of innovative development. Contests are organised and starts-ups release new ideas concerning smart delivery, smart parking systems, autonomous boats in Amsterdam (Tien innovaties, 2016; Hack mee, n.d.; Amsterdam werkt aan, 2016). On a larger scale the automotive sector is evolving massively. In-car technology, the Internet of Things and self-driving cars will determine the way we are using our roads in the future. At the same time, developments in big data analytics provides huge opportunities for tackling current and future mobility issues.

Real time data, in-car technology and cooperative systems create opportunities to improve traffic flows and traffic safety (Mocanu, Nitsche, & Malone, 2014). Monacu et al., (2014) describe the opportunities for 1) *Travel information and dynamic route guidance.* 2) *In-vehicle speed adaption and signage.* and 3) *Local dynamic event warnings.* The possibilities of technology and data analytics provide opportunities to direct and distribute all traffic over the total transport network in the most optimal way.

Connecting cars with cars and cars with the traffic environment can smoothen intersecting routes. This means that unnecessary waits for red lights are history. It could even mean that your car adapts speed in such a way that the traffic light is always green when you are approaching the intersection. Furthermore it can give information about hazardous situations further down the road, or, for example warn the driver for that bicycle around the corner. This might seem as a visionary idea but the technologies that can create such an environment are already being designed (example: http://www.safespot-eu.org/).

Knowledge and new ideas are of great importance to create the smart environments. TNO, The Dutch Organisation for Applied Scientific Research, has a whole department that focusses on smart mobility. They see, as does the Dutch government, the Netherlands as the ideal field lab for innovative concepts to improve mobility in densely populated areas by using smart solutions (TNO, 2016). Also the three technical universities of the Netherlands acknowledged the relevance of smart mobility. Eindhoven University of Technology has even assigned smart mobility as one of the universities strategic areas (https://www.tue.nl/en/research/). TU Delft and University of Twente both offer civil engineering masters focussing on the development of infrastructure and mobility.

With all this development and acquired knowledge, roads and roadside technology should not lag behind. On the contrary it can be the binding factor of all these technologies as car-to- infrastructure communication plays a big role in cooperative systems. Emphasized on the Innovation Expo 2016 in Amsterdam was the need for collaboration (NLengineers, 2016). Road builders, engineering firms, industrial design companies, and authorities should develop a common language and agenda so the Netherlands can be one of the leading countries in developing the next generation of infrastructure. Smart roads should become an export product of the Netherlands (NLengineers, 2016). It is emphasized for all players to take a certain responsibility towards smart mobility and make sure to be part of the change in the industry.

1.3 Smart Lighting Technology

Parallel to these changes in the traffic and transport sector are the developments concerning light technologies and light science that are becoming more prominent in our society. Global awareness is sought to highlight the potential of light applications in the domains of energy, education, agriculture and health (Unesco, n.d.). The UN even proclaimed 2015 as the international Year of Light and Light-based Technologies, IYL 2015 (Unesco, n.d.). The large amount of attention to light is also seen by the seen by the forming and vision of light communities and institutes, such as ILI, CIE and LUCI[2]. These amplify the field of lighting research, accelerate the technological development and enlarge the commitment of cities to diminish the negative aspects of light.

Looking at the priority given to research topics by ILI and CIE (ILI, n.d.; CIE, 2016) the field of research can roughly be divided into four categories that are given importance. Vision and perception (topics such as: glare, colour quality of a light source, visual appearances and simulating vision), Health and Well-being (describes the Non-visual effects of light, Light therapy, induced alertness, vitality and performance by light exposure, creating a sense of safety and security with light (Loewen, Steel, & Suedfeld, 1993; Nasar, Fisher, & Grannis, 1993; Nasar & Jones, 1997), Physics of light (focusses on photometry, radiometry and measurements), and Architecture of intelligent lighting systems (network systems, autonomous dynamic lighting and tailored lighting).

Research can be restricted to one of these categories so that detailed information is gathered. For example the studies by Ling and Heynderickx (2014) that aim to simulate aged vision. Or the research by Smolders and de Kort (2014) which confirmed that different levels of intensity and temperatures have a different effect on people, mainly on people's feelings of vitality. On the other hand it is seen that research combines the topics of different categories. These studies often combine proven theory and apply them in real environments. In Eindhoven this has resulted in several living labs. For example the de-escalation project by Haans and de Kort (2014), in which a smart dynamic system is used that emits different colours of light to influence people via the non-visual pathway. The aim of this living-lab project is reduce social aggression and avoid escalation in public. Another example is the influx project of ILI in collaborations with students (http://www.gloweindhoven.nl/nl/glow-projecten/glow-next/influx). This project investigates the influence of light on the behavior of crowds. This project combines the topics of perception of light, non-visual effects of light as well as the topic of network systems and software architecture. And again another living lab was set-up to test dynamic road lighting in relation to feelings of safety and security (Haans & de Kort, 2012).

What these three project have in common and make them relevant is the utilization of the technological opportunities of LED lights which are connected to system networks. Either programmed, controlled or sensor based the LED lights give the opportunity to change colour, temperature and intensity. This makes systems adaptive and dynamic and provides opportunities in the creation of smart cities (van der Klauw, n.d.).

The livings labs are important to make the transition from theoretical research to practical applications for daily life situations. At selected test area's new light applications can be given a try out without being constrained by strict rules and regulations. The same is achieved with light art festivals. These are big accelerators for exploring the field of light technology (Smets, 2015). They provide the testing grounds needed for experimenting with new technologies. Light designers can go to the extreme with colours, patterns, and interactive or adaptive solutions.

[2] Intelligent Light institute (ILI), International Commission on Illumination (CIE), Lighting Urban Community International (LUCI)

These events also familiarize large groups of people with the possibilities of light. On a smaller scale several light art projects have already improved tunnels, roads and public areas such as parks by increasing comfort and feelings of safety in these areas (Smets, 2015).

Once more information is known light can be deployed better and smarter in city planning and road engineering as there are now opportunities that go beyond providing visibility. Though the large emphasis on light technologies and light solutions might also cause a negative effect. It will induce an increase in the use light. As Smets (2015) mentions in his new article, light expert Norman Bardsley calculated that the need for artificial light will increase by tenfold. An expansion that might be good for the lighting industry but not necessarily healthy for nature, animals and other humans.

Intrusion of artificial light alters the natural light levels and the consequences are getting discovered more and more and are discussed more elaborate further in this paper. As the negative effects on both nature and humans become clear light pollutions has gained awareness. Associations such as the International Dark-Sky Association (http://darksky.org/) try to expand this awareness and reduce sky illumination.

Despite the kick-start smart lighting might give to the lighting industry increase use of light it might also provide smart solutions so light will only emits if needed limited to certain locations. Also this is recognized. Earlier mentioned commission LUCI has the committed 48 signatory cities around the world, from which three are Dutch, to a public lighting strategy (Lighting Urban Community International, 2015). A strategy that aims to support the urban, social and economic development of cities, to reduce energy consumption and to take into account the social and environmental impacts linked to the production, exploitation and maintenance of lighting installation. Committing to this strategy might seem a challenge for but luckily the prospect of the possibilities and opportunities of smart lighting seem to be numerous, especially when applied in a smart grid and combined with the large amount of IT possibilities.

1.4 Light emitting road marking

In current research the domains of smart mobility and smart lighting merge together as it suggest smart light emitting road marking as a measure to improve the traffic environment.

On one hand road marking is generally known to reduce the amount of crashes (Noordzij, 1996) as they are in particular important for lane keeping and anticipation of the course of the road (Martens, et al., 1997). On the other research has confirmed that light on roads at night-time hours decrease the accidents rate on roads (Bullough, Donnell, & Rea, 2013; Elvik, 1995; Wanvik 2009) and increases feeling of safety (Loewen, Steel, & Suedfeld, 1993; Nasar, Fisher, & Grannis, 1993; Nasar & Jones, 1997)

A previous, and unpublished study tested the support for the use of light emitting road marking compared to traditional light posts (Van Kampen, 2016). For his study Van Kampen used visualisations in a stated choice experiment. Participants rated lines of lights placed in sides of the road higher in terms of perception of safety, perception of comfort, guidance and detection compared to normal road lighting. Although his visualisations did not use the same colour of light for both the scenarios (more yellow for the new situations and white for the traditional situation), which might have influenced the results, the outcome of his research showed the potential of new light designs and colours on the road.

Light technology as road marking has been applied and tested before. By using light studs, the concept of dynamic road marking was introduced to increase road capacities by varying the function of a lane to the capacity needs; opening, for example, extra lanes during peak hours (Tertoolen et al., 2012). These lights however emitted always the same colour of light and they were either on or off, no dimming was possible. Although this might have been sufficient for this application it is unfortunate since the design space of light is a lot bigger. Also a missed opportunity is that, to the authors knowledge, no documented tests are performed on the effects and possibilities of the dynamic road markings.

Other tests or research of in/on-road light technology that do take into account the full design space of light have not been found either. This means that little is known about the possible effects on road users neither is there concrete information about the possibilities and constrains for light emitting road marking. Gaining more knowledge of and insight in these possibilities and constrains is crucial in order to reach the full potential of the use of novel (smart) lighting technology.

2. Aim of the research

In current research it is investigated if and how light emitting road marking could stir towards correct driving behaviour and therefor it could create a better traffic environment. This research aims to find knowledge concerning the effects and possibilities of in-road light technology. With the light emitting road marking it is expected that operational and tactical driving tasks (§3.1.4) can be influenced unconsciously. Controlling strategic driving tasks such as navigation and route selection are more difficult. Thereby since light is best visible in the dark it has the potential to improve traffic safety during night-time hours. For these reasons focus has been directed towards nudging driving behaviour to improve traffic safety at mesopic and scotopic light levels. Opportunities to decrease congestion are kept in mind but are not the main point of attention.

A focus on the problem of traffic safety and a possible solution provided by in road light technology result into the following question:

How could light emitted road marking be a solution for problems concerning traffic safety?

Current study aims to understand the process of shaping safe driving behaviour unconsciously by exposing road users to light emitted road marking. With these demarcations to the scope of present research the main research question is stated as:

> ***MQ: What light scenarios for light emitting road marking have the potential to nudge people towards safer driving behaviour?***

In order to find the answer the following needs to be determined:

- *SQ1: What driving behaviour results into a safe traffic environment?*
- *SQ2: What human and technological aspects play a role in affecting driving behaviour?*
- *SQ3: What would, based on the answer to the first two questions, be potentially valuable light scenarios for light emitting road markings?*
- *SQ4: Do the light scenarios based on theory have the aimed results in the field?*

3. Structure of the report

Before starting to read the report the structure should be clarified so one does not get lost while reading. Roughly this report consists of four parts:

I. *The General Introduction*
II. *The Theoretical Background*
III. *The Field Experiment*
IV. *The General Discussion & Recommendations*

Reaching this point you have already past part I: The general introduction. Both the domain of mobility and lighting science and technology are introduced as well as the aim of the study and the research questions.

II. The theoretical background is a literature study consisting out of three chapters. Chapter 1. Safety in traffic. This chapter shortly addresses a few topics of traffic safety which are considered relevant for this research and aims to find the answer to *SQ1*. The second chapter is more elaborate. Chapter 2. Human factors in traffic and Chapter 3. Lighting gives the theoretical information needed to get an understanding of how road users can be influenced by light in a traffic environment and so makes it possible to answer *SQ2*. The human and technological aspects stated in this sub question are defined as *capabilities and limitations of road users* –Chapter 2.1 the Road User– *, the impact of geometrical road design* –Chapter 2.2 the Road– *,* and *the effect of lighting, taking into account opportunities of new light technologies* –Chapter 3 Lighting–. Part II ends with Chapter 4. Light scenario's which combines what is learned in the previous chapters order to find potentially valuable light scenarios for light emitting road markings and so answer *SQ3.*

Part III. The field experiment is a logical succession to the last chapter of the theoretical background. It holds the implementation of some of the use cases proposed in the light scenarios in a field test. This part describes a case study from the preparation, to the carrying out of the experiment, to the data collection and analysis. The experiment includes both a qualitative as well as a quantitative studies which provided data regarding the effects of the light emitting road marking.

Lastly Part IV. The general discussion evaluates the results -obtained in Part III-and discusses these in relation to the theory –given in Part II- taken into account the relevant social topics stated in the introduction – P I-. In this section the answer to the main research question will be given.

II. Theoretical Background

1. Safety in traffic

Traffic safety is generally expressed in the number of road fatalities, either as an absolute number or corrected for the number of drivers, vehicles and kilometres driven. The number of road fatalities in Europe (European commision,2016) has dropped since the seventies, thus following this measure safety on the road has improved. Though, it can always be better. As mentioned the decline of road fatalities in the Netherlands is not stable since the number increased in 2015. Thereby the aim for the Dutch government is less than 500 fatalities in 2020 (Rijksoverheid, 2008) and so focus of safety is maintained. In improve traffic safety and achieve the set goals it is important to understand different causes of reduced traffic safety. Three topics concerning traffic safety have been considered relevant for this research:

1. *Time and Speed*
2. *Risk homeostasis*
3. *Darkness*

1.1 Time and Speed

According to Wickens, Lee and Becker (1998) nearly all accidents that result into serious injury or death result from one of two sources: *a failure of lateral tracking* or *a failure of longitudinal tracking.* Errors in lateral tracking concern loss of control due to various reasons (slippery road, to narrow roads, fatigue, lapse in attention) or road way departure at high speed. Longitudinal accidents result from failure to detect a hazard, such as pedestrian or a turning vehicle. But also due to inappropriately judging the time to contact a road obstacle or intersection.

Time and thereby speed are an important parameters concerning traffic safety. Failures of lateral or longitudinal tracking in traffic do not always result into accidents. Correction of one's error can prevent any consequences. Speed determines the success of correcting errors caused by one of the two sources. Loss of control -lateral source- is often a result of overcorrection due to high speed. Travelling faster is less forgiving as it ask for a more rapid correction which easily leads to overcorrection. Concerning longitudinal errors one's speed determines the time to react in case of hazards. The faster one drives, the less time one has to react. In a literature review, Martens, Compte & Kaptein (1997) describe the clear relationship between speed and the number and severity of accidents. Additionally, in relation to the number of accidents, speed difference between vehicles are also an important factor to consider. Large speed variance is related with higher accidents rates (Aarts and Schagen 2006).

This relation between speed and safety is generally acknowledged and is the reason for a large focus on measures for speed reduction and traffic calming. Examples are increasing cognitive load, enhancing perceived risk, introducing cues for speed perception, increasing driver stress, fear of enforcement and better signing of speed limits and feedback of driving speed (Elliott, McColl, & Kennedy, 2003). Although these strategies result in a reduction of speed they do not necessarily improve safety. On the contrary it can even diminish safety. Speed, for example, can be reduced by narrowing roads. Yagar and Van Aerde (1983) studied this relation and found a reduction in speed of 5.7 km/h for every metre of reduction in lane width beyond 4 m. The reverse effect is also demonstrated (Vey & Ferreri, 1968). The explanation is that people tend to slow down on more narrow roads, as lane positioning and steering cost more effort and becomes more demanding (Marten, et al., 1997). But at the same time a narrower road gives less space for errors and correction and so the road itself becomes less tolerant. Following these terms the road itself is more dangerous when narrowed.

Harms (1986) also highlighted this conflicting relationship. In her research she found that more complex driving environments caused by variations in driving environment (highway/village) were associated with increased amount of cognitive load, which in turn were accompanied with lower speed. But in the same areas were cognitive load was high (and speed was low) there were significantly higher accident rates (Harms; 1996 in: Elliot et al., 2003). In a later study Harms (1991) also found that driver's error rates and reaction times where poorer in the case of higher cognitive load compared to lower cognitive load. So performance dropped even though the driving speed was low.

1.2 Risk Homeostasis

The conflicting effect can be elucidated by what Wilde (1988) calls risk homeostasis. He outlines his theory regarding traffic as follows: Road users constantly evaluate the level of risk they are exposed to when participating in traffic and compare this with the level of risk they are willing to accept. Everyone has a preferred, or as Wilde names it, target level of risk and this is dependent on road user's perception of the outcome of the amount and manner of mobility.

Risk homeostasis suggests that people adapt their behaviour to maintain their target level of accident risk. Wilde states accepted danger can be expressed in the number of accidents to be experienced per vehicle kilometre or time unit (Schreuder, 1986). In a publication for the SWOV, Institute for Road Safety Research in the Netherlands (Schreuder, 1986) the theory is considered too extreme since it assumes that people willingly end up in a certain number of traffic accidents. Though the underlying concept is acknowledged as it explains why some safety measure work and others not, and why some traffic safety measures show conflicting outcomes (Assum, Bjørnskau, Fosser, & Sagberg, 1999).

Risk homeostasis can, for example, explain that a safer road design does not always result into a safer traffic environment. Strictly applied the theory describes that drivers will perceive less risk when a road is well designed (i.e., wide enough lanes, and with clear markings for course indication). This, in turn, facilitates faster driving as road users adopt more risky behaviour to reach the target level of risk. This is the reverse of the statement in the previous paragraph. Where it was described that more dangerous environments result in careful and safer driving.

As people adopt behaviour to a set level of risk, the effects of new innovations concerning safety can be overestimated. When introducing new technologies in the road environment risk homeostasis should be kept in mind since it can diminish the suspected or desired effects.

1.3 Darkness

Darkness and safety are usually not two concepts that go hand in hand as darkness reduces visibility and decreases safety and the feeling of being safe. The negative relation between darkness and safety is also reflected in the road environment. Day-to-night accidents ratios show that more accidents occur despite the fact that less people drive at night, and that this ratios declines by the intervention of artificial light shows improvement of traffic safety (Bullough et al. , 2013; Wanvik, 2009). This can be explained by the fact that 90% of the information that is perceived by road users is visual (Hills,1980). Darkness reduces the amount of information that can be perceived and the distance from which objects can be detected. Therefor it is generally acknowledged in a lot of studies that road lighting increases safety (Bullough et al., 2013; Elvik, 1995).

In a meta-analysis by Elvik (1995), 37 studies that researched the safety effect of public lighting were evaluated and it was found that road lighting decreased the amount and severity of accidents. The meta-analysis resulted in an estimation of 65 percent reduction in night-time fatal accidents, a 30 percent reduction of night-time injury accidents and a 15 percent decrease of night-time property-damage-only accidents (Elvik, 1995).

In a more recent study, Monsere and Fischer (2008) analysed the safety effects of reducing freeway illumination for energy conservation. A decade later Monsere and Fischer found results comparable to the results of the meta-analysis summarized in the handbook of Road safety measures from Elvik and Vaa in 2004 (Monsere, & Fischer, 2008). In the handbook of safety (Elvik, Vaa, Erke & Sorensen, 2009) the authors explain that accidents are reduced by road lighting because it is easier to see the road, to see other road users and to detect objects on the road. This is not surprisingly since we as humans are nocturnal animal and thus perform better under lighted conditions. The study of Wanvik (2009) confirms the effects of road lighting specifically for the Dutch roads.

Based on abovementioned studies it can be concluded that road lighting is a measure that successfully improves traffic safety, which suggests that it is a measure not prone to risk homeostasis as described in the previous paragraph. This is tested by Assum et al. (1999), who evaluated whether car drivers compensate for the presence of the road lighting by adjusting their driving behaviour. Their hypothesis, which suggested that drivers would compensate driving behaviour due to lighting, was based on Wilde's theory of risk homeostasis. The results showed that drivers do compensate their behaviour in terms of increased speed and lower concentration but that it was not sufficient to make road lighting ineffective as a road accident countermeasure. In other words this research stated that road lighting creates a safer road environment even when risk homeostasis is taken into account. Additionally it suggested that the benefits of road lighting can be even greater if compensation could be avoided.

Conducting studies concerning the effect and impact of road lighting, like the ones just discussed, are very important to maintain road safety in the dark hours. Road lighting has high operational costs due to its energy demand and maintenance and this is reason for municipalities and the government to decide to not install or shut down road lighting. The Dutch government decided in 2013 to turn off road lighting on selected highways between 9pm and 5 am, on busy nodes only from 11pm. On hazardous sections light remained on during the whole night (ANWB, 2013). One year later the timing was already revised to 11pm for all sections (Rijkswaterstaat, 2013). Although the target savings have not been met due to costs of manual work to shut down sections of light (AD, 2016), the intervention reduces energy use and light pollution (Rijkswaterstaat, 2013).

The decision of the Dutch authorities to turn of road lighting along highways had gotten support from the ANWB -a Dutch travellers' association that support all modes of travel- (ANWB, n.d.). However they released a document in which they explicate their point of view (ANWB, 2012). In this document ANWB does not only point out the positive effects but also mentioned decreased driving comfort and the estimation of extra accidents by SWOV – 1 fatal accident extra in three years, and 2 more sever traffic victim per year-. The media, showed criticism from the beginning. Several newspapers or news sites in the Netherlands showed their concern towards decreased traffic safety (Nrc, 2013, nu.nl; 2014 , Ad.nl; 2016). To the authors knowledge there is no data regarding higher accidents rates on the Dutch roads which are lighted limited. Though the agitation expressed in the media shows that at least the feeling of safety is (until accustomed) reduced.

In Chapter 3.3 Lighting, the characteristics, possibilities, opportunities and negative consequences of light in the traffic environment are addressed more elaborately.

1.4 Conclusions

The problem analysis shows some important aspects that need to be taken into account when introducing new safety improving measures.

Speed is the key parameter for traffic safety since it determines **the time the driver has to anticipate on errors and the success of the correction**. Errors can be made either due to failure in lateral tracking or longitudinal tracking and depends on the environment and the driver. The environment can be designed and thus can be provide a higher tolerance of errors. However **risk homeostasis** shows that some speed reducing measures do not always result into safer driving situations. The environment might be safer but drivers adapt their behaviour to the new situation in such a way that **the risk level remains the same**, for example by using higher speeds. Additionally, **the speed variance on a road is an indicator for traffic safety.**

During night-time hours **visibility is lower** which results into more accidents. Dangerous situations are observed later and less accurate, therefore there is less time for correction and it is harder to select the appropriate reaction. **Road lighting has proven to be a good countermeasure**, even taken into account risk homeostasis. It increases visibility so that hazards are detected better and sooner. Anticipation then is better.

The problem analysis addressed four topics which are relevant to answer the first sub question: *What driving behaviour results into a safe traffic environment?* First, we now know that reducing speed is effective. Second, we learned that due to risk homeostasis not all speed reducing measures may in fact increase safety. Third, it is important to reduce darkness.

The relevant topics for traffic safety identified here is not considered complete and ask also for critical evaluation. For this a better understanding is needed regarding the human and technological aspects that play a role in affecting driving behaviour. Only then effective light scenarios can be constructed for the light emitting road markings.

1.6 Opportunities and limitations

Table 1: Opportunities for the light emitting road marking technology in relation to traffic safety.

Light emitting road marking		Traffic safety
OPPORTUNITIES	**Stimulus**	A stimulus to reduce speed can improve traffic safety. Reducing speed variance in a traffic flow also leads to safer driving environments.
	Information	Timely visible information improves traffic safety
LIMITATIONS	**Stimulus**	Measures for improvement of traffic safety can have to opposite effect by increased speed. (Risk homeostasis).
	Information	-

2. Human factors in traffic

The Netherlands has a dense traffic environment and this can lead to complex traffic situations. Road users constantly have to evaluate their position within their direct traffic environment and make timely and correct decisions. Continuous tracking and manual control, thus, are a critical part of human-vehicle interaction (Wickens, et al., 1998). In their book, *Human factors engineering,* Wickens et al. emphasize the role of human factors in technical environments, among which the traffic environment. And they are not the only with a focus on this topic. There is a substantial amount of publications regarding human factors in traffic. Thereby, the Netherlands has several institutes that conduct research in the field of traffic and transportation, including the SWOV (Wetenschappelijk onderzoek voor veiliger verkeer), the Dutch Institute for Road Safety Research, and TrafficQuest (centre for expertise on traffic management).

The large focus on human factors in traffic and transportation is not surprising, as it is generally claimed that up to 90% of the traffic accidents can be traced back to human factors (Evans, 1996; Wickens et al., 1998; SWOV, 2013). In order to create a better and safer traffic environment with the use of light emitting road marking human factors thus should be considered.

The following section discusses the human factors related to the Road User (social psychological influences, vision, attention, driving tasks, information processing and decision making; Ch. 2.1), the Road (which determines the drivers context and thereby the quality and quantity of information provided to the users; Ch. 2.2).

2.1 The Road User

he road user cannot be defined by particular set of characteristics, that should be clear. Roads are used by the most diverse population. People vary in sex, age and experience. They might participate in traffic on a bike, in a vehicle, as a pedestrian or by using public transport. Also their direct traffic environment is different and might changes along the route. Furthermore people have different intentions, capabilities and a different state of mind. All in all this results in a large variation between and even within road users over time.

Despite this large variation it is important to understand how road users behave while participating in traffic. In order to influence driving behaviour it is important to understand the different incentives behind the behaviour of road users. This chapter addresses the intrinsic human factors by the following topics:

1. *Social psychological factors*
2. *Vision*
3. *Attention and Inattentional blindness*
4. *Task analysis and information*
5. *Decision making and acting*

2.1.1 Social psychological factors

TNO, often uses a model for driving behaviour by Van der Horst (1998). In his model, van der Horst starts with the social psychological factors based on Azjen's (1985) behavioural model, the theory of planned behaviour. This model implies that drivers intentions are based on attitudes, subjective norms, and perceived behavioural control. In turn the intentions of a person influence the way they perceive and process information and the way they then decide and act. All together this then results in a certain driving behaviour.

Let's state two examples to explain the social psychological factors a bit more. Usually the driver can control how fast one travels and therefore adheres the speed limit or not. Speed selection then depends on a driver's attitudes and the subjective norm. A driver might have a rather flexible attitude towards rules/traffic advices and does not follow these very strict. Thereby this driver might value a reduction of travel time. These are attitudes that motivates for speeding. Attitudes that direct towards adhering the speed limit are a believe that the most comfortable drive is at the given design speed. Or a desire to avoid speeding tickets. The drivers intentions are not yet set, as mentioned the subjective norm also play a role . and thus influences the actual speed selection. The driver pushed by attitudes to increase speed might be controlled by road signs or by vehicles surrounding him that drive the correct speed. A driver with an attitude following the speed limit might feel pressure to drive faster by passing vehicles or by encouragement of a car passenger.

The attitudes of drivers are generally known to differ among people. Furthermore it is generally known to deviate over age groups. Young drivers tend to take more risk while driving (de Goede et al., 2013). According to Zhang, Fraser, Lindsay, Clarke, & Mao (1998) this is specifically in the case of alcohol and drug use, speeding, non-use of seat belts, fatigue and falling asleep, and inexperience. This might explain that younger drivers are listed as a risk group (Goede, Van der Horst, Wilmink, & Taale, 2013).

Social psychological factors for traffic improvement

Changing social psychological factor takes some time but can be quite effective. A program "beter benutten" – *translated as optimising use*- launched by the Dutch government stimulates people to use different modes, travel on different times of the day or work at home and not travel at all (Beter benutten, n.d.). The program has been improving the traffic situation since 2011, a 19% reduction of congestion was measured in 2015 (Ministerie van Infrastructuur en Milieu, 2015).

Altering attitudes and social norms usually takes a long period of time. Though social psychological factors can also be deployed for direct result. This is done in the case of installing Dick Bruna traffic signs. Miffy -*Nijntje in Dutch*- is one of Dick Bruna's characters for children. A study using the children's character as a traffic sign resulted in a significant drop in preferred speed of 4 km/h (Goldenbeld & Rijsdijk, 2016). This study showed it is possible to successfully nudged peoples driving behaviour by using the social norms and attitudes towards children in a traffic situation.

2.1.2 Vision

Besides social psychological capabilities, physiological aspects are important to consider. In particular the capabilities of human vision, as 90% of the information input that is necessary for driving performance is visual (Hills, 1980). Vision is constructed by the optical properties of the eye which exist of the cornea and lens, the pupil, photoreceptors and the resolution and sensitivity (Mather, 2009). These properties make sure a scene or object can be observed sharply, in colour for a certain distance under different light levels.

Impairment

Reduced abilities of one or more optical properties can lead to visual impairment or blindness. Some impairment can be corrected, for example by lenses or glasses. Other visual impairment is dependent on age and gender. When aging, vision is reduced is several ways in particular acuity, and contrast declines but elderly also have problems with vision by night and suffer more from glare (Ling & Heynderickx, 2014). One of the causes of reduced elderly vision is the yellowing of the lens (Okajima & Takase, 2001) and the increased density of the lens (Porkorny, Smith & Lutze 1987). Hereby the sensitivity to light decreases and light gets scatters more in the elderly eye.

Problems concerning colour vision are known to be more common for men. Where 1 out of 12 men suffer from colour blindness this is the case for only 1 out of 200 women (colour blind awareness, n.d.). Since visual impairment is quite common limited vision should be taken into account when designing light scenarios.

Visual fields

Also important for the perception of the light emitting road marking is the distinction between our visual fields. In order to understand and perceive the world around us, people use three different visual fields (figure 2). These are the *focus, central* and *peripheral visual field* and each has its capabilities. Focus vision is, for car drivers, related to object detection, targeting and perceiving displayed information. This vision is dependent on the focal point of the eye. The central vision concerns position on the road and direction of the road. The peripheral vision detects motion and colour changes. In respect to the in-road light technology central and peripheral vision are targeted. Further ahead the light emitting road marking indicates the course of the road; this information is received from the central vision. Closer by the light provides the road user information via the peripheral vision.

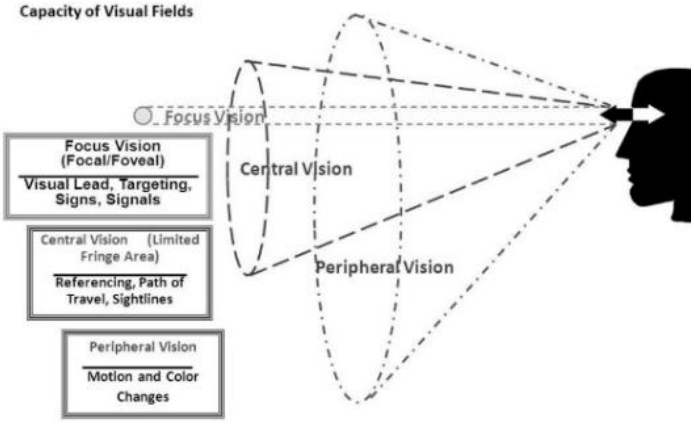


Figure 2: capacity of visual fields (Source:Holland, n.d.)

Cones and rods

Within the retina of our eye lie our photoreceptors. Two types of photoreceptors are responsible for converting light into neural signals: cones and rods (Mather, 2009). There are three types of cones: the short (S), Middle (M) and Long (L) wavelength cones which register colour and function under high light levels. Rods, containing light sensitive pigment, more sensitive for low light levels (Mather, 2009) and are incapable to register colour (Fairchild, 2005). This means, as most of us can relate, that colour vision is better under high light levels. Due to the capabilities of cones and rods colour is perceived differently under photopic or scotopic light levels. The effect, where the spectral sensitivity model moves towards the blue side of the spectrum, is known as the Purkinje shift (Fairchild 2013). It does not mean we see everything in blue at night but that we tend to perceive light with short wave length brighter than light long wave length in very low luminance levels.

A side from the different characteristics of cones and rods there are also differences in quantities and retinal distribution (Mather, 2009). Humans have far more rods than cones and the relative population between L, M, and S cones is 40 : 20 :1 (Fairchild 2005). In the fovea of the eye only cones are located and no rods. The red cones are widely spread over the whole fovea and Blue sensitive cones distributed sparely over the fovea but absent in the central fovea (Fairchild, 2015). This results in to a better vision of blue in the sight at the periphery of the focus area (Wesselink, 2016).

2.1.3 Attention and blindness

Salience

It is not possible to see everything that lies in our field of vision, since this would simply result into processing to much information. It is also therefore that one sees differently among the three visual fields. Hence what a person sees or where one directs its focus vision has a relation to attention. Attention can be drawn or directed and usually this is an unconscious process (Taylor & Fiske, 1978).

Salience or conspicuity are characteristics that can grab our attention. For example salient coloured and shaped traffic signs grab our attention maybe in our peripheral vision and subsequently we direct our focus vision on the sign to perceive the information it provides. Another example is the introduction of the red breaking lights on the back of a car. The motion and colour are characteristics that differ from it direct environment and draw attention selectively to the object, thus making it salient in the immediate context. This is also known as “comparative distinctiveness". Salience is important because it activates knowledge and determines which information will become accessible (Higgins, 1996). How this is important in a traffic situations is elaborated further in relation to cognitive information processing (§3.4.2. performance model).

Inattentional blindness

So our attention can be captured and directed but the opposite effect cab also occur and is named inattentional blindness. When there are too much stimuli in an environment to attend to an individual fails to detect stimulus, despite being salient and in plain sight. (Mack and Rock, 1998). A psychological lack of attention toward a certain stimuli, not associated with any vision defects, leads to temporary functional blindness effect. It can also be described by the experience of looking without seeing. The impact of inattentional blindness concerning a road environment will be discussed deeper in relation with traffic signs (§4.2.2)

2.1.4 Task analysis and information processing.

Task levels

Driving tasks are generally divided into three hierarchical levels of activities, *Strategic, tactical* or *operational*, (Michon, 1989). Strategic tasks include activities that focus on the purpose of the trip and the drivers overall goals. Navigation and trip planning are such tasks. The tactical level concerns choice of manoeuvring, obstacle avoidance, speed selection and lane choice. Last, the third operational level, tabs into the control of the vehicle. Tasks like maintaining a desired speed, keeping a desired distance and lane keeping are covered in this level. Except for novices these task are largely automatic action patterns (Ranney, 1994).

Performance model

Besides the three tasks there is also a categorization of human-behaviour concerning performance in complex situations. Rasmussen (1983) differentiated again three levels. *Skill-based, rule-based* and *knowledge-based* behaviour. Skill-based behaviour is the lowest level which asks for low cognitive processing, it concerns automated schemata. Rule-based behaviour involves the activation of rules or productions and therefore the cognitive load is somewhat higher. Knowledge based behaviour relates to conscious problem solving. This level asks for higher information processing and is generally used in novel situations for which no existing rules apply. The levels by Rasmussen can be linked to the different tasks levels concerning cognitive control of driving by Michon (1989) as can be seen in Table 2. The coloured block indicate how the models are connected for experienced drivers under normal driving conditions.

Table 2; Classification of selected driving tasks by Michon's control hierarchy and Rasmussen's skill-based framework. (adapted from T. A. Ranney , 1994)

	Strategic	*Tactical*	*Operational*
Knowledge	Navigating in unfamiliar area	Controlling skid	Novice on first lesson
Rule	Choices between familiar routes	Passing other vehicles	Driving unfamiliar vehicle
Skill	Route used for daily commute	Negotiating familiar intersection	Vehicle handling on curves

= the cross level for experienced drivers.

Cross levels

In regard to the innovative in-road-technology at question the cross levels (blue blocks in table 2) based on the *tactical* and *control* tasks that involve the *rule* and *skill* levels of performance behaviour are relevant. In this research it is not aimed to address the strategic task level and the knowledge behavioural level since information can only be transmitted by colours and patterns. No symbols nor text to inform car drivers can be displayed with this application. Although the technology might be introduced in a new environment were the knowledge-based level is used, the light technology is aimed to ease/simplify a situation by activating the lower two behavioural levels. This way the demanding knowledge-based level is less needed and cognitive load will be decreased. According to Harms (1986) this result into a safer driving environment.

In theory the rule- and skill-based levels are both depended on feed forward control, but whereby rule-based behaviour is goal orientated and controlled by a stored rule, the skill-based behaviour takes place without conscious control (Rasmussen, 1983). The boundary between skill-based and rule-based performance, as Rasmussen (1983) points out, is not quite distinct. It largely depends on intra en inter personal variations, like level of training and attention.

Classical cognitive system

Another approach of categorizing the way we think and act is by the two classical cognitive systems (Thaler & Sustein, 2008). By psychologists also referred to as system I, the automatic system, and system II, the reflective system. The first system is rapid and, like the name suggest, automatic. It acts upon associations, is effortless and depends on skills. The reflective system is, as Thaler and Sustein (2008) mention, more deliberate and self-conscious. Actions/reactions based on this system are slower as they cost effort and problem solving is needed. Comparing this to the framework of Rasmussen it can be said that skilled- and rule-based behaviour acts upon the automatic system and knowledge-based behaviour falls under the reflective system.

Though it must be said that Thaler and Sustein (2008) categorize rule-following to the reflective system. Arguing in the interest of traffic situations the rule-based level follows stored rules and applies these instantly. For example a red light at a traffic system activates the stored rule of stopping, a speed limit sign activates the behaviour of checking current speed and if necessary act upon this perceived information. In these cases the rule evokes automatic behaviour and rule-based behaviour can be categorised within system I.

Thus when developing the different light scenarios it should be kept in mind that the focus should lie on the automatic cognitive system. This means that the road marking with integrated LED light should directly influence *tactical* driving decisions or indirectly control driving behaviour at the *operational* task level. In this case the in road technology is ought to nudge people towards the correct behaviour. The light scenarios should be designed based on common associations, salient cues and known heuristics.

2.1.5 Decision making and acting

After all information is perceived and processed a decision is made in order to act. At this moment all input is turned into output or driving behaviour. In the field of travel and traffic decisions can globally divided into two categories. Decision made before a trip, e.g. choice for destinations, time, mode and route, and decisions made during the trip, e.g. choice speed up, slow down, take over, deviate from chosen route etc.. For current research it is important to focus on the choices made during a travel. This is when the light emitting road marking can have an influence on the decisions making process. But first the influencing factors of decision making are quickly discussed.

According to Godthelp et al. (2012) a lot of travel choices that are made are the result of a habitual behaviour. Once a choice for mode or route is made and acted out repeatedly this behaviour becomes inflexible even when conditions change. Habitual behaviour can be deconditioned as they say by intervening with an alternative or by providing up-to-date personal information. Furthermore, in their background document Godthelp et al. emphasize the costs of time and money as main drivers for making a choice. Additionally comfort and safety are also determining factors (Klöckner & Matthies, 2004).

Other literature points out that decision making is often linked to personal characteristics. The research of French, West, Elander & Wildling, (1993) confirms that a person's general decision making style is also used in driving situations. In their research they show that peoples abilities concerning control, thoroughness, instinctiveness, social resistance, hesitancy, perfectionism, and idealism affect driving speed, calmness, social resistance, focus and planning. Furthermore it is found that age and sex have an influence on driving behaviour (Reason, Manstead, Stradling & Campbel, 1990). Their research also hints that errors and violations, which are unconscious and conscious decisions, are mediated by different psychological mechanisms. However, Little influence can be exerted to these individual characteristics with the technology in question, so this is not further deliberated. Instead, the light emitting road marking should be deployed to provide contextual cues that can be understood by the majority and in this way influence driving behaviour.

From previous paragraph (§3.1.4) it is known that information is processed either consciously or unconsciously. And that the technology in question is best suited for providing information that addresses skill- and rule-based behaviour. The same can be said regarding decisions making. One can deliberately make a choice to take a certain route. And one can make an automatic, rule-based decision to stop for a red light or skill based decision to switch gear. This means that decisions can also be influenced consciously or unconsciously, so with or without the road user noticing an intervention. The latter is called nudging.

When nudging people's behaviour an environment is created that shapes people's decisions in a desired or positive way. Thaler and Sustein (2008) excessively address this mechanism in there book Nudge. They have defined a nudge as "*any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid.*" Important is to realise that a nudging does not result in obligations. People should still be able to make their own choices. It merely illustrates that the way an environment is designed can have influence on the outcome of an decision and so it is possible to guide people to either making bad or good decisions. Desired is of course to stir people in making good decisions. Chapter 3.2 and 3.3 will show how the traffic environment with in particular its roads, sign and lights effect choices and behaviour.

2.1.6 Conclusions

Driving behaviour is dependent on **social psychological factors, physiological factors and cognitive abilities.** Social psychological factors cover the attitudes of road users, the perceived control they have and the subjective norms to which people adhere. These construct the drivers intentions which in turn lead to accepting or rejecting road measures that aim to control traffic behaviour.

The most important physiological factors deal with **vision** as most information is perceived visually by road users. How and which information is perceived depends on its **position in the visual field** and its salient characteristics. Conspicuous colours and shapes can **grab and direct ones attention**. So based on the **Comparative distinctiveness** between objects and their environment **someone's focus and central vision is shifted to important elements** first noticed in the peripheral visual field. If no attention is given to an element it can be missed, this results into inattentional blindness.

The information that is captivated can be processed via three different cognitive levels according to Rasmussen's (1983) performance model: **Knowledge-based, rule-based and skill-based. Rule- and skill based behaviour are considered to be automatic cognitive processes** for experienced drivers. Higher level information processing demands more attention and cognitive capacity. A second model introduced by Michon (1989) divides driving tasks in also three levels: **Strategic, Tactical and Operational**. The two models are often linked as the different task levels that ask for a different level of information processing. Under normal driving conditions the following cross levels apply for experience drivers: Knowledge-based level is used for strategically tasks, the Rule-based level is used for tactical tasks and the Skill-based level is used for operational tasks. Under different conditions it is seen that **driving experience and familiarity in the environment both plays big roles in the cognitive demand needed** to perform these tasks.

Once information is processed a decision-making step is made which lead to a certain driving behaviour. These can also be made conscious and unconscious. **The decision process and therefor driving behaviour can be influenced without diminishing freedom of choice**. This is called **nudging** and aims to stimulate correct behaviour.

2.1.7 Opportunities and limitations

Light emitting road marking		Human factors: The road user
OPPORTUNITIES	**Stimulus**	Stimulus in the central (the lights further ahead) and peripheral visual field (the lights next to the car).
	Information	The possible to unconsciously influence driving behaviour for tasks related to tactical and operational tasks by using adjusting the information related to the skill-and rule-based levels of cognitive processing.
LIMITATIONS	**Stimulus**	Stimulus should not be conspicuous, this grabs someone's aimed focus and asks for higher cognitive processing. Thereby will it distract driver from their core driving task. Colour blindness occurs relatively often which can be a problem when using colour coding.
	Information	Not possible to affect strategic driving tasks as it is not desired to activate the knowledge based level information processing and due to the lack of generalizable skill- and rule-based constructs related to this tasks.

2.2 The Road

In previous chapter the capabilities and limitations of people in relation to road use and traffic safety are discussed. This chapter addresses the relevant road engineering aspects that are related to human factors. It will not discuss all technical features concerning road building, design of structural elements nor provide technical specifications or formulas. Instead it will predominantly addresses the influence of road design on the road users behaviour, bearing in mind its relevance to the potential of the light emitting road marking. The following topics will be discussed:

1. *Geometrical road design*
2. *Road markings*
3. *Road environment*

2.2.1 Geometrical road design

Geometrical road engineering includes the structural features of a road as well as the markings, traffic signs, Intelligent Traffic Systems (ITS) elements, organization of the roadside, and the speed limit or advice assigned to a road. Integrating all elements in a way that they complement and not counteract each other is very important. The total of road elements should be comprehensible for the users, passing by with a certain speed. For example, it is important to separate information based on the task levels of Michon (1989) and provide this information in the hierarchical order. A new speed limit, for instance, should not be displayed on the same sign as the directions of a route (Goede et al., 2013). A better way is to provide the navigational information first, followed by the cues for speed.

Like the example shows, road engineers are shaping the environment in which people need to perceive and process information, and in which they need to make decisions and have to act quickly. How the road and its direct environment is organized has thus a direct effect on driving workload and driving anticipation (Gibreel, Easa, Hassan & El-Dimeery, 1999). This asks for a road environment which is designed with great consideration. The importance of geometrical road design is highlighted by Evans (1996), who reports that road design has, of all engineering factors, the most impact on driving behaviour; even more than automotive engineering.

Hence, the impact on driving workload is also the reason why road design has an influence on traffic flow and traffic safety. In previous chapter the relation between high workload and traffic safety was broadly addressed. Regarding to safety, geometrical road design focuses on eliminating or at least reducing the errors that concern lack of visibility, deficiencies in information display, stability of vehicle, operating speed and alignment indices – i.e. the course of the road including the length of straight section, radius of curves and the slopes of gradients. – (Kanellaidis, 1996; Ng & Sayed, 2004).

Road design consistency

Before evaluating the different road design elements, the importance of design consistency needs to be brought to attention. The concept of road design consistency (the conformance of the geometry of a road with the drivers expectancy) made an entrance in the eighties and since the concept is not only emphasized greatly in literature regarding to road safety but also became a rule in road design (Lamm, Guenther & Choueri; 1995; Kanellaides, 1996; Gibreel et al., 1999; N.g. & Sayet, 2004). Within the literature concerning road design consistency speed again appeared to be the key parameter for measurement. (Lamm, Guenther & Choueri; 1995; Kanellaides, 1996; Gibreel et al, 1999; N.g. & Sayet, 2004). For example, high speed variance or an average speed level much higher than the speed advice suggest an ambiguous road design and/or a speed advice that does not match the road design and thus not match the drivers expectancy.

Consistent road design for the road network results into comprehensive situations. Inconsistent design on the other hand is said to increase a driver's workload (Kanellaidis, 1996; Ng & Sayed 2004), which is in line with the theory of Rasmussen (1983). When encountering situations on the road for which no stored rules can be used, drivers need to consciously and quickly process all the relevant information before they react. This means that people need to use the knowledge-based behaviour level, the highest level of the performance model that asks for the most demanding cognitive processing (discussed in § 2.1.4). A consistent design is related to more automatic driving behaviour as the driving situation is comprehensible and familiar. Hence, it can be argued that design consistency also describes the coherence and uniformity of road design over the total road network. Coherence and uniformity align the expected behaviour for certain types of road as ambiguity decreases.

The aspects of road design consistency are in particularly important in transitioning areas, for example at intersections or when the road changes from a highway to a rural or urban road. The fact is that transition means a discrepancy in the road environment which changes drivers expectancies and increases the workload. A clear changeover from one comprehensive environment to another is therefore important. The transition environment itself should be designed recognizable and familiar to similar transition environment so that the driver knows what driving behaviour is expected.

Thinking about smart mobility or innovation within the infrastructure industry it is important revise new elements to the expectancies of road users. The appearances of innovation in, on and next to the road should match the driving behaviour on that particular road. For example, a shocking effect should be avoided at all costs and new information given should ask for only a minimal increases in the level of cognitive processing. It is better when new elements look somewhat familiar and information it signals is congruent with stored rules. This way workload is maintained to a reasonable level as a driver can depend more on his skill- and rule- based performance levels.

Throughout this chapter design consistency remains an important topic. When discussing the different design elements and how they impact driving behaviour, various examples will be given that relate to consistency.

2.2.3 Road markings

Once the structural road is built, road markings are applied to clarify the aimed use of the road. They classify a road type, provide guidance, influence perception of speed, or indicate concrete information. Road markings show users which behaviour is expected on a road like which speed to select or when to merge or changes lanes.

Centre and Edge lines

The majority of markings are edge or centre lines which to provide guidance to road users. Known from research these road markings are in particular important for lane keeping and anticipation of the course of the road, which improves safety (Martens, et al., 1997; Schreuder, 1986). Centre and edge lines reduces the amount of crashes by improving the lateral position of cars (Noordzij, 1996) and by increasing the visibility of the course of the road (Davidse, van Driel, & Goldenbeld, 2004). Davidse et al. reported that this visibility is, logically, the best for continuous lines. They also state that increased visibility of the course of the road reduce mental load and the attention required to follow the road. This can, however, result into higher diving speeds – as predicted by the theory of risk homeostasis-.

Broken lines, on the other hand, can cause a decrease in driving speed as they give driver's a more accurate perception of their driving speed (Davidse et al., 2004). When one drives along the broken road lining, the marking flashes by in the driver's peripheral vision giving the driver feedback of how fast one travels. Though the pattern design plays an important role. A denser pattern (i.e. short lines that are closer to each other) constructs a higher perception of speed. Conversely, when the lines are longer and further apart, a lower speed is perceived (Martens et al., 1997). Thinking about design consistency it is better to apply the denser pattern on a road where traffic drives slower or needs to slow down and the wider pattern on roads with high speed limits, such as highways. The down side of broken lining lies within the fact that the patterns provide less visual guidance, especially at night, due to less retro reflective material being present on the road (Davidse etal., 2004).

So both continuous and broken lines have advantages and disadvantages in guiding people toward desired driving behaviour. Therefore a combination of continuous and broken lines is often used. For example edge lines that are continuous to provide people better visibility of the direction of the road combined with broken centre lines that give people a correct or overcorrected perception of speed. Both these effects are based on the skill-based behaviour level as they do not require any deep information processing or stored rules and associations. The sensory system provides the information needed and people use this more or less automatically to adapt their driving.

Other road marking applications do activate rule-based behaviour. A broken lines for example means that one is allowed to change lanes, whereas a continuous line holds the rule 'do not cross'. The introduction of rush hour lanes in the Netherlands has shown how robust this rule-based behaviour in traffic can be. During rush hours or with peak traffic (1350 veh/h) emergency lanes are allowed to be used as a normal lane (Rijksoverheid, n.d.). This means that road users need to cross the continuous edge line which causes confusion (Rijkswaterstaat, 2013). The inconsistency between road marking design and driver's expectations has restrained the optimal use of this measure. Big campaigns (see Figure 3) were needed to convince and explain the driver how to use the rush hour lane.

Figure 3: Campaign crossing the continuous line. Source: Rijkswaterstaat (2013) veiligheid spitsstroken

The rule-based behaviour linked to centre and edge lines is also used to improve road design. In 2008 the Dutch road authority introduced new road marking designs (figure 4) for roads in rural areas. The road marking designs are matched to a speed limit and indicate if road users are allowed to overtake other traffic (nieuwe strepen, 2008). When exposed to these road designs regularly over a longer period of time the correct driving behaviour will be induced unconsciously. For example double centre lining signals that higher speeds can be adopted. 80 km/h for only double centre lining and 100 km/h for double centre lining within green lining in the middle. No centre line means 60km/h. The speed limit of these designs are consistent with driver expectancies, which makes it easier to adopt the new rules in our automatic driving behaviour. The double lining provides higher tolerance for errors as the distance between oncoming directions is bigger and it thus safer to drive faster. On smaller rural roads should result into more careful and alert driving and thus drivers should adopt lower speeds. Uniformity of the roads throughout the whole country makes the designs more comprehensive and reduces driving workload and contribute to safer driver environments (nieuwe strepen,2008).

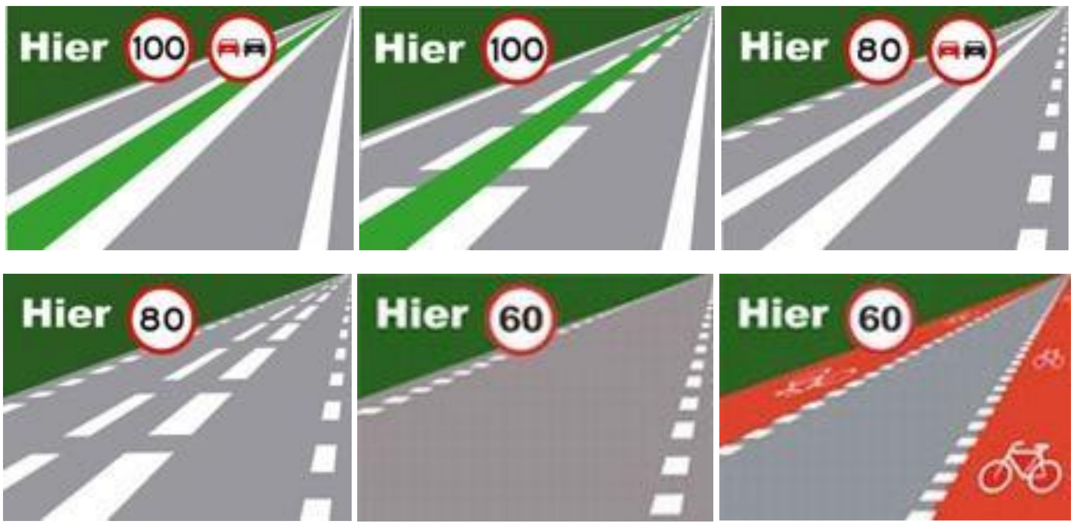


Figure 4: Design of road markings with their matching speed limit for different road types. Verkeer - Nederlandse wegen - Belijning en maximumsnelheid, 2008.

Road markings for hazardous situations

Besides the edge and centre lines other road marking designs are adopted to slow traffic down or to warn road users for hazardous situations. Think about the zigzag patterns, oblique and horizontal markings, rumbles trips and painted gores (Appendix A). These markings usually do not provide guidance of the longitudinal path of the road, and are mostly applied in transition areas.

Transverse road marking such as, zigzag patterns, oblique and horizontal marking, and lane wide rumple strips are applied to slow down traffic. As people drive at a certain speed for a longer period of time they get accustomed to this speed. When approaching a different traffic environment people can have problems to adopt the a safe driving speed (Elliot et al., 2003). Design patterns were distance between the markings decreases or a funnel illusion is created over a certain longitudinal section which influence the perception of speed more effectively compared to normal broken lines.

Lastly, a special type of road marking can actively warn drivers. Small rumble marking as part or next to normal road marking alert the road user as they drift off toward the edge of the road. Lane wide rumble strips provide discomforting vibrating and auditory feedback along with the visual feedback.

Providing information

Lastly road markings can activate the knowledge-based behaviour and transfer information concerning the speed limit, the route (road number), the type of road and directions. Think, for example, of arrows or speed limits painted on the road (for more examples see Appendix A). An advantage of this measure is that the road markings are applied in people's central vision which makes it easy to perceive. Since this research does not aim to activate knowledge-based behaviour this topic is not further discussed.

2.2.4 Road environment

The direct road environment includes the roadside and the space above the road. Within the road environment the applicable rules and regulations are displayed. Hence, the organization of the road side is very important as it has a big impact on the drivers information processes and thus determines the driving workload.

In the following sections, focus lies mostly on how information is displayed in relation with the performance model of Rasmussen (1983) and the task levels of Michon (1989). From this it is expected to get more in sight in how information on the road is perceived and influences driving behaviour. Despite the fact that the light emitting road marking are applied on the road and thus not part of the road environment the information is considered important for the design of the light scenarios.

Vertical alignment and amount of elements.

The alignment of vertical elements in the road side heavily influences people's speed perception, way more than for example broken road lining. Vertical alignment includes the density, height and overhang of the elements on the road side, combined with the distance to the road which provide more and bigger stimuli than marking on the road. Thereby, vertical alignment falls in the peripheral visual field and road lining in the our frontal vision. According to Salvatore (1968), peripheral visual stimulation leads to a more accurate assessment of velocity than frontal visual stimulation as the angular velocity is much greater in the peripheral than in the frontal vision. So vertical alignment of elements in the road environment is more effective than broken road lining, though the principles of affecting speed perception are the same. More elements, closer together result into a higher speed perception, and the other way around less elements further apart result into lower speed perception.

So when designing the road consistently surrounding packed with elements and information should be created for slow driving traffic or for traffic that needs to slow down. Think for example on the trees alongside a road in rural areas, often these are placed closer together when one approaches a village. Conversely, open surroundings are suitable for the organization of fast driving road environments. Research of Antonson, Mårdh, Wiklund, and Blomqvist (2009) confirmed open surroundings facilitate higher driving speeds and a lateral position that is farther from the road centre. Antonson et al. (2009) found that open spaces are considered relaxing and create a sense of security as the driver can oversee all possible dangers.

The relation of the vertical alignment in the road environment and driving speed can also easily be explained by the drivers workload. An open road environment provides the driver less information that needs to be perceived and processed. A dense road environment asks for lower speed in order to see and understand all relevant information. The rule of thumb states that a minimum of two seconds is needed for the perception of information plus the reaction time (Hills, 1980). And of course, when one drives faster one passes a larger distance and information should be placed further apart.

So for a consistent road design the space between the elements should be congruent to the travelling speed. Since drivers typically adjust their speed to the information provided, this can also be used the other way around: Increasing workload by introducing more, sometimes duplicate signing is can be used to increased workload to slow down traffic (Elliot, 2003).

Signs and nudging

Road signs provide the driver with symbolic information concerning hazards, priority, directives and prohibitions. It is important to know how the displayed information is processed by road users, especially when in motion. As said one's speed affects how much information can be processed, but there are more determinative factors, like the placement of road signs. Route information signs and variable message signs (*in dutch: matrixborden*) above the road that are perceived in the central visual field. Traffic signs next to the road are detected in our central vision as well but only from a distance. When the driver is closer they are only visible in the peripheral visual field. As pointed in chapter 2.1, the peripheral vision detects motion, salient colours and changes. Therefor signs next to the road cannot provide symbolic information, such as a warning for a dangerous intersection, without drivers shifting their visual focus.

As briefly mentioned in Chapter 3.1, the concepts salience (or conspicuity) and attention (or inattention) are factors that influence sign recognition and information processing. Reflectivity, size, and placement of traffic sign are found to affect the ability to attract attention (Itti, Koch & Niebur, 1998). Furthermore it has been confirmed that colour and forms that are distinct from their surroundings plays an important role in providing information to the road user (Fleyeh, 2004). But what needs to be questioned is whether providing information that needs to be processed on a higher level should be provided next to the road.

Several papers confirm that traffic signs are not an optimal way to provide higher level -*knowledge-based*- information (Crundall, & Underwood, 2001; Charlton, 2004; Charlton, 2006; Oei & Papendrecht 2014). Studies that applied a *roadblock paradigm* –stopping cars and interviewing road user about traffic signs they just passed- showed poor recall of signs. Crundall and Underwood (2001) state that research of Sprenger, Schneider & Derkum (1999) confirmed that drivers fixate less frequently on traffic signs than always expected. These findings, however, have not led to a belief that traffic signs are ineffective. On the contrary, other studies have showed how drivers slow down, or change position due to conspicuous signs (Charlton, 2006).

Taken together these findings have led to the belief that implicit cues, processed unconsciously, influence driving behaviour (Fisher, 1992; Crundal & Underwood 2001; Charlton 2006;). As Charlton (2004) explains, information that is processed unconsciously affects driver's behaviour automatically. This is called the priming function of road signs (Crundall and Underwood, 2001) and explains why colour and form are such important factors. Certain colour, mostly blue (§2.1.2), and shapes are well perceived in the peripheral visual field and suggested to be processed on based our stored rules.

The priming characteristics of road signs are an important finding for innovation in the road sector. Exposure to cues that are unconsciously processed can shape driving behaviour. This shows that conscious information processing is not a necessity when one desires to alter behaviour to improve safety. And as we know conscious information processing increases workload which decreases the time to anticipate. Slowing drivers down without increasing workload is suggested to be highly beneficial for traffic safety. As mentioned earlier (CH 3.1), influencing people by shaping their environment without limiting the freedom of choice is called *nudging* (Thaler and Sustein, 2008). By shaping the traffic environment with good designed light scenarios emitted by the light emitting road marking driving behaviour could be influenced. Therefore it could be said that the light cues provide a nudge towards correct driving behaviour.

Colours, shapes and associations

In order to correctly prime road users and to nudge them toward the desired driving behaviour it is import to find the right cues for certain behaviour. As mentioned before, there is no one average type of road user. The diversity is huge, meaning that road users think differently, create different associations, and do not construct their road behaviour the same way. But still some more or less universal cues will be developed over time, and which result into specific driving behaviour.

Few studies have addressed the topic of colours, patterns and associations in traffic. Sometimes a publications briefly mentions the, apparently accepted, associations red=stop, green=go and yellow=danger (Fleyeh, 2004). Despite the lack of studies concerning the symbol and colours associations in traffic there are strict standardized rules and regulations for the shapes and colours of elements in traffic. Often these are constructed nationwide. Within Europe most countries adhere to the 1968 Vienna convention on Road Signs and Signals. This collaboration underlines the recognition for importance of consistency in traffic internationally.

So, apparently the design of signs and signals –the colours and shapes- are meticulously selected. And even though countries have different rules and regulations signs do show a lot of similarity. Also, somehow a traffic light in Europe has the same characteristics as the ones on other continents and these characteristics have been like this since 1928. It suggests that over time a consensus has emerged over the colour and shape of road elements and the information it provides. Since the colour pattern has not changed since its introduction and the meaning of the red –*stop*–, yellow –*cautions/change*– and green –*go*– light remained the same ever since, the associations with a traffic light have become robust rules which induces automatic behaviour (i.e, rule-based behaviour).

The classical Stroop task (Stroop, 1935) supports how robust colour and its meaning can be. The classical tasks is a proven method that shows how workload is reduced if visual information –like colour– is congruent with its meaning and how information processing becomes more demanding when visual information is incongruent with its meaning. A conflicting coding combination like displaying the letters STOP in green results into a Stroop interference (Lidwell, Holden & Butler, 2010). The incongruent information therefore leads into higher reaction times compared to displaying these letters in red.

A new connection between a colour or a shape and a specific meaning can be established over time. In their study, Crundall and Underwood (2001) explain the role of experience regarding traffic sign recognition. Automatic responses to road signs are built op by experienced road users for many years. Novice drivers have less stable or slower responses. This indicates that associations that come along with colours, patterns and shapes in traffic are based on the elements and cues to which road users have been exposed to for several years. In order to embed the light emitting road marking effectively in a traffic situation, it is valuable for the current research to analyse these elements and cues.

Within most countries, including the Netherlands, triangular signs with red borders indicate hazards and priority, round signs with red border show what is prohibited. Blue round signs are commands such as a driving direction. Squared blue signs only provide information, for example about route numbers, distances or directions Yellow/amber coloured signs and signals alert road users for changes and temporary situations, like in the case of road works or when a lower speeds limit should be adopted in rush hour. As mentioned the colours of a traffic signals are proposed to have a strong priming effect on people. The order green-orange-red with it meaning of *go-caution-stop* is also in the Netherlands a strong communicational construct which is even used in sectors outside the traffic industry (Chapman, 2012; Communicating color efficiently, n.d.)

Then there are the (emergency) services that act in traffic and use distinct cues. The police in the Netherlands is connected to the colour blue, the fire department to the colour red, the ambulance to the colour yellow and road works to orange. These colours, together with the matching equipment (sound alarms, flashing lights, signs, the vehicles, and such), should be implicit cues for these agencies to road users. Blue flickering light on a police car, for example, might send a warning signal that means “watch out” while orange flickering light at road works might be less compelling and hold the message “caution”. Lastly, white could have a meaning to road users as well. As road markings are, in normal situations, white as well as traditional road lighting it is proposed that white has built up a neutral construct of the guidance of traffic.

2.2.5 Conclusions

Consistency is one of the most important aspects in road design concerning traffic safety. Consistent design (conformance of the geometry of a road with the driver's expectancy) **diminishes the workload** of the driver as it does not ask for extra attention nor for processing new information asks for a knowledge-based cognitive performance level. A contribution to consistency is **coherence and uniformity of road design over the total road network**. Coherence and uniformity increases familiarity of a certain type of road and its environment which aligns the expected behaviour for certain types of road as ambiguity decreases. **New technologies violate these rules of consistency.** Firstly it are elements for which no expectancies or stored rules are built up meaning that the drivers expectations cannot confirm with the road design. Secondly new elements disrupt the coherence and uniformity of road design.

The layout of the pavement, with the applied road markings have shown to improve safety. Road markings increase visibility of the course of the road, provide drivers with feedback of their driving speed, and can guide and warn road users as well as signal information. **The application of road markings have shown to reduce traffic accidents despite the effect of risk homeostasis**.

Edge and centre lines lead to a lower workload as lane positioning and following the course of the road becomes easier and driving comfort increases. This is especially the case when continuous lines are applied. Patterned road markings, such as broken lines and transverse lining can control the perception of speed. The same is found for the organization of the road environment. Open environments facilitate lower perception of speed. **More elements in the road environment**, or **broken lines with smaller markings and denser spacing**, result into **higher perceptions of speed.** Road marking in the middle of lane can provide information about route direction or the speed limit. An advantage of road marking is that it lies in central vision.

This section of the theoretical background also shows how rule-based concepts are built up and used in traffic situations. Information in the traffic environment has been organised with **consistent colours and shapes over a long time**. This results into stable associations with colour and patterns. The theory of Rasmussen (1983) explains, by the rule-based level of the performance model, how these **stable associations can be deployed to prime driving behaviour,** even when the road user cannot recall passing the information. This is called nudging and aims **to direct people toward correct behaviour without diminishing their freedom of choice.**

2.2.6 Opportunities and limitations

Table 3: Opportunities for the light emitting road marking technology in relation to the road user.

Light emitting road marking		Human factors: The Road
OPPORTUNITIES	Stimulus	• The road environment, road marking can alter a drivers speed perception. • No need for extra salience ques as stimulus lies within the visual field. • If the light scenarios adhere to the design of design consistency it can decrease driving workload.
	Information	• The association with the colours pattern of a traffic have become robust rules: –*stop*–, yellow/orange –*cautions/change*– and green –*go*–. • Blue flickering light is a familiar cue to signal "*Watch out"* and Amber flickering light "Caution". • New rules can be made and learned. In time these will be adopted in our automatic information processing.
LIMITATIO	Stimulus	New technologies inherently violate the rules of consistency.
	Information	Too much signals in the road environment results into to high workloads and neglect (like with signs).

3. Lighting

The third chapter of the theoretical background addresses the different aspects of light in the road environment. Here, the topic of outdoor light is considered specifically in relation to human factors and traffic safety, but the chapter will also discuss light in a broader perspective including the social impact, the development in light technologies and some physics theory. The chapter is divided into the following sections:

1. *Introduction of outdoor lighting*
2. *Human factors of lighting*
3. *New technologies and coloured light*

3.1 Introduction of outdoor lighting

In the second half of the 20th century technological development changed our cities and the way we live. As Schreuder (2008) puts it: "*the curse of darkness was banned*". Since then, outdoor lighting has been facilitating travel, activity and recreation by night simply because people are able to see (better) in the dark. The primary functions of outdoor light are improving task performance and reducing accidents and crimes.

The importance of road lighting in relation to traffic safety has already been discussed in the first chapter of the theoretical background (Ch.1 Safety in traffic). Here it was explained how light increases visibility of the road, other road users and objects on the road which lead to less and less severe accidents. Several studies confirm the positive effect of road lighting on traffic safety during night-time hours. Measured in several ways; before and after studies, studies of similar roads with and without lighting, day-night accidents ratios and odds ratios[3] (Monsere & Fischer 2008; Assum et al., 1999, Bullough 2013, Wanvik, 2009) the statistics show a reduction of accidents for traffic situations under higher light levels. Beside light's primary functions of improving task performance, increasing safety and security it can also positively affect the feeling of well-being or enliven a scene (i.e., decorative lighting).

LED lights

The introduction of LED light has broaden and extended the opportunities for light applications and thus amplified the opportunities for the use of lighting in traffic situations. LED lights come in different intensities, colour temperatures and different colour hues which broadens the light design possibilities. Additionally LED has low energy consumption, an increased life expectancy compared to other type of light sources, and they are recyclable. Properties which make LED lights a more sustainable choice. It is no surprise that these properties have caused a revolution in the light industry which not only led to a massive increase in the amount of light used (Fouquet & Pearson, 2011) but also transformed the lighting industry from a hardware into a full solution and service industry (den Ouden,Valkenburg, Aarts (2014)

LED lighting is also transforming our road lighting network. Replacing traditional road lighting with LED reduces operational costs–both maintenance as energy costs–and is therefore beneficial. Especially a reduction of energy costs can have a big impact as road lighting can take up to 70% of the energy bill of municipalities (Taskforce Verlichting, 2008). Additionally, the street poles along our roads are also changing towards full solution and service networks. These changes are further elaborated in § 3.3.

Light pollution

The improvement of our lighting sources not only associated to positive developments. Fouquet and Pearson (2011) critically evaluate the rebound effect of the new generation of cheap, energy efficient lighting. They explain that our increased use of light is likely to have major and possibly complex implications for energy consumption associated with lighting, both in the short and long term. Expected is that the consumption of light keeps growing (i.e. tenfold increase) and could increase energy use instead of decreasing it (in Fouquet & Pearson 2011). This inevitably also results into light pollution as sky glow is unavoidable when light usage increases.

[3] Odds ratio : $\frac{\text{Number of accidents in darkness on lit roads/number of accidents in daylight on lit roads}}{\text{Number of accidents in darkness on unlit roads/number of accidents in daylight on unlit roads}}$

A growing concern has emerged about the negative effects of the ubiquitous installation of utilitarian, amenity and decorative lights. Light during the night time hours has brought us more flexibility, the freedom to do things at any desired time, and has started the 24/7 economy. Though, the intrusion of artificial light alters the natural light levels in our environment and this has its consequences. The amount of research with a particular focus on the problems of light pollution are increasing (Schreuder 2008, Falchi, Cinzano, Elvidge, Keith & Haim, 2011, Cinzano, Falchi, & Elvidge, 2001; International Dark-Sky Association: light pollution, n.d.). There is even international dark-sky association (http://darksky.org/) formed. Clearly light pollution is taken more and more seriousness and efforts to uncover its consequences have increased correspondently.

That millions of people will not be able to see the Milky-way at least once in their lives may not sound too shocking, but some have argued that it diminish the effect of the reflect on humanity and our place in the universe (International Dark-Sky Association: night sky heritage, n.d). More concrete consequence such as disruption of human and animal sleep cycles and the photosynthesis process of our nature (Cinzano et al., 2001) might be more alarming to the majority.

Light at night alters the production of several hormones, the most important being melatonin which is related to sleep (Navara & Nelson, 2007). Light acts as one of our time keepers and unnatural high levels of light during the night affect our sleeps patterns (Boyce & Barriball, 2010). A shift in the sleep-wake cycle can cause disruption to our circadian rhythm (Boyce & Barriball, 2010). The impact of light at night has been connected with health issues such as reduced performance, alertness, alteration of metabolism, oxidative stress, increased obesity or diabetes and it can even result into forms of cancer (Haus & Smolensky 2006; Navarro & Nelson, 2007; Pauley 2004; Rajaratnam, & Arendt, 2001). Not only human individuals suffer from Light at night, the ecological consequences are just as high. Light at night has consequences for predator/prey interactions, orientation and migration of animals, navigational activities and timing of breeding (Navarro & Nelson, 2007).

Though reducing the use of light in total is the best way to reduce light pollution, some other measures can be adopted if outdoor light is needed. Full shielding, limiting the area of lighting, eliminating over-lighting, shutting of lights when not in use, and limiting growth of installed lighting are suggested and verified methods (Falchi et al., 2011). All these measures focus on preventing light to be “wasted” by deploying light more efficiently and / or directing it towards where it is required. Additionally light with the short wavelengths are considered to cause most harm and pollute the dark environment the most and therefor use of bluish light should be avoided (Falchi, 2011).

The negative effects of light pollution and the possible way to diminish these should be eminent directives when designing new light feature for the outdoor environment. The light emitting road markings, which are investigated in this research, could provide some benefits over traditional road lighting in this respect. Where the source of light of traditional light poles are mounted a few meter above the pavement they, in order enlighten a sufficient part of the road, need to emit a rather high light intensity compared to the source of light road markings are placed in the pavement. In the latter case light source falls automatically in the driver’s visual field and therefor intensity levels can be lower. Requirement then, however is that the design of the road marking should include some sort of shielding of the light in the direction no light is necessary. Also it should be noted that the function of the light emitting road markings differs from that of light poles as they do not enlighten the pavement.

3.2 Human factors of lighting

Light is registered via a visual and non-visual pathway (Boyce, 2014; Smolders, 2013). The image forming pathway enables us to convert light into visual images of our surrounding. The non-image forming pathway signals information to brain areas that are involved in the regulation of behaviour, mood and physiology (for an overview of studies see Smolders, 2013). Human factors of light deal with both the visual as the non-visual effects of light.

Visual effects: visual performance

As described in §2.1.1 light enables us to see as photoreceptors in the human eye convert light into a signal which is sent to our brain’s visual cortex (Mather, 2009). Under high light levels the human vision works the best (see §2.1.1) and therefore artificial light sources are used in order to increase our visibility when natural light is absent or of too little intensity. But light sources can also reduce our visibility. In this regard, and within the scope of traffic safety, the human factors related to glare and uniformity of light need to be pointed out.

Glare is the difficulty to see, or the blinding experience, caused by a light source in relation to the task angle and the surrounding light level. Two types are generally distinguished: discomfort and disability glare (Theeuwes & Alferdinck, 2002). Discomfort glare describes the sensation of discomfort caused by a light source which creates the urge to look away from that source. Disability glare causes reduced contrast sensitivity and diminishes visual capabilities. It should be understood that discomfort does not necessarily result into disability glare nor does disability glare always causes visual discomfort (Boyce, 2014).

Within the traffic environment, glare caused by a rising/setting sun, headlights, or road lighting may cause failure to witness other road users, objects or road elements, which of course can lead to very unsafe situations. Theeuwes and Alferdinck (2002) showed for example that lane keeping became much more difficult in the presence of discomfort glare. Furthermore it has been confirmed that the effects of disability and discomfort glare are more severe for elderly people, since these people's eyes scatter incoming light more (Klein, 1991; Theeuwes & Alferdinck, 2002; Boyce, 2014). This is important to mention since elderly drivers are the main risk group in the Netherland when discussing traffic safety (Verbond van verzekeraars, 2016; CBS, 2016).

Glare is a result of too high contrast levels between the source and its background or the occurrence of a light stimulus that rises above the upper limit of sensitivity of the visual system (Schreuder, 1998). When engineering balanced road lighting scenes uniformity is an important factor to consider. It determines the amount of contrast between light levels and thus adaption that its needed of our eyes. In the Netherland, the design process follows the directive for public lighting (NSVV, 2015). For a uniform light scene the heights of light poles and the distances between the poles are to be considered. For light poles placed further apart a wide distribution of light is needed which asks for either a light source with a wider distribution (leading to glare) or a light source with higher intensity at a high position (more light pollution, especially when not shielded). If the not well engineered an uncomfortable flickering zebra effect arises. Also when designing the in light scenarios for the light emitting road marking the aspects of glare, uniformity and comfort should be taken into account. Though it should be noted that the directives for traditional road lighting cannot be one-on-one applied for this this technology.

Visual effects: experience

Beside the better visual performance under higher light levels, light also has an visual effect on experience. Light can create certain atmospheres with shared impressions, for example light with a lower correlated colour temperature (CCT) is often experience warmer, more relaxing and less tense (for an overview see Smolders, 2013). A study by Hidayetogly, Yildirm and Akaling (2012) explored how the visual experience of light affects people's navigation and orientation in indoor spaces. They tested way finding in indoor environments by using different brightness levels and with either warm, neutral or cold light temperature. With their study they concluded that warm coloured enlightened spaces were considered more attractive and remembrance of these spaces was higher, therefore they claimed that warm coloured light is best suitable as a landmark for way finding. Cool-coloured spaces were seen as more navigable. Furthermore Hidayetogly et al. (2012) concluded that low brightness levels are perceived more negative.

In the scope of this research more attention should be focused on the experience of outdoor enlightened scenes and traffic safety. Higher visibility at night could increase, besides task performance and thus traffic safety (§1.1.3), a driver's feeling of safety and security. The presence of light is considered one of the important contributors to perceived personal safety, at least for pedestrians (Loewen, Steel, & Suedfeld, 1993; Nasar, Fisher, & Grannis, 1993; Nasar & Jones, 1997). Uniformity, intensity and quality of light are variables affecting this feeling of safety.

Another study suggests the use of subjective attitudes towards different types of lighting, like in the study of Hidayetogly et al. (2012), to influence peoples travel patterns in outdoor environments (Sieβ et al. 2015). In their experiment they propose that outdoor light scenes which differ in colour temperature can influence peoples route choice and thereby it would be possible to distribute pedestrian crowds over the city. Routes with warm white light should attract people on foot and paths that are lighted with less preferred blue light discourage use. Unfortunately Sieβ et al. (2015) only evaluated their strategy with experts and did not conduct a real test.

Another study that tests the potential of outdoor light to subconsciously affect people and influence behaviour focusses on social aggression. With the de-escalation project, Haans & De Kort (2014) also aim to influence human behaviour in a public outdoor space by the use of light. They study the potential of light to reduce social aggression and avoid escalation of social behaviour in public spaces. Reasons for this project are the effects of light tested in laboratory studies (most of them are already discussed but for an overview see Haans & De Kort, 2014) and the role of surrounding triggers for aggression (Carlsmith & Anderson, 1979). This project has also been started only recently, results are therefore not yet published. However the researchers are confident that they will learn more about the effect of light on aggression in apublic space.

Non-visual aspects: Health and comfort

The effects of light go beyond the aspect of visibility, as light is also processed via a non-visual pathway. Light that falls on the retina of the eye is also converted by photosensitive receptors that project a signal to diverse brain areas which are involved into the regulation of sleep, wakefulness, alertness and mood (Smolders, 2013). Light processed via these neural paths is found to affect timing of internal processes, and states of alertness, mood, arousal and cognitive processing.

For example bright light can induce alertness and vitality (Smolder & de Kort, 2014; Smolders, De Kort & Van den Berg, 2013) and these effects are found larger for cold/bluish white light (Viola, James, Schlangen, & Dijk, 2008; Glickman, Byrne, Pineda, Hauck, & Brainard, 2006). The results of Smolders and de Kort (2014) were based on daylight light exposure and they emphasize that these results cannot be directly translated to night time situations due to the complex picture of the results. There are, however, several other studies that confirm enhanced performance when exposed to bright light during night times. (Badia, Myers, Boecker, Culpepper & Harsh, 1991; Campbell, & Dawson, 1990; Dawson, Encel & Lushington, 1995). This increased performance however comes with price, as bright light at night disrupts the sleep cycle and thereby timing of our internal processes. Several reviews regarding night-shift work show these negative effects (Costa, 1996; Rajaratnam & Arendt, 2001) related to increased numbers of accidents and errors, problems with social relations, and deterioration of health by disturbance of sleeping patterns, and eating habits.

Generally studies show increased level of alertness and vitality under light with shortwave length. This is also confirmed by the study of Figueiro, Bierman, Plitnick, & Rea (2009). But their study also provided preliminary evidence that red light can also induce higher levels of alertness at night. Findings of Figueiro et al. (2009) are important because, as they state, it is well accepted that the circadian system is maximally sensitive to shortwave length light and quite insensitive to long-wavelength light and thus not to red light. They suggest that increased alertness caused by red light is an effect processed via the visual pathway. Meaning that where blue light effects our melatonin production and disrupts our sleep patterns red light does only shortly increases alertness.

3.3 New technologies and coloured light

In order to keep the benefits of outdoor lighting but eliminate or at least diminish the negative effects of outdoor lighting new (smart) light technologies are proposed as a solution. The properties of LED are highly suitable for these applications as these lighting sources can be integrated in connected networks from which the output can be changed. Depending on the system architecture this means that colour hue, colour temperature and intensity of each light source in a light network could be controlled either remotely or sensor based.

This development has provided numerous options for dynamic, adaptive, and interactive light systems for both indoor as outdoor spaces. Though at the moment, to the author's knowledge, little scientific studies with these new light technologies have been carried out in the field. As a result, little is known about the effects and impact of the wide design space lighting systems now provides, especially concerning outdoor environments. In the following sections gathered, and will discuss, relevant findings regarding to the possibilities and limitations of dynamic light and those of coloured light.

Dynamic lighting

Dynamic lighting (i.e., light that is not constantly emitting the same intensity or quality of light) offers some advantages regarding to energy use, glare and light pollution. The primary idea is that light poles are only activated when needed. So if no one makes use of a street or road, then the lights are switched of. Though the details of these systems still need to be first set and then adjusted in order to create good systems. As mentioned, the development of system architectures for light networks is one of the important topics in the field of light science and technology. Alongside this research, municipalities have already anticipated on these technologies. Eindhoven, the Dutch city of light, has for example set up a road map for implementing smart light systems, because they see the benefits for sustainability and experience of the city (den Ouden & Valkenburg, 2012).

Tests and studies are very important in the innovation process to finding find the relevant parameters for the systems that are needed to be successful. Atıcı and colleagues (2011) have made one of these first steps and documented the development and testing of a system architecture for an intelligent road lighting design. Haans en De Kort (2012) adopted a different focus, and concentrated on the user needs. In their study they found that it is more important that dynamic street lighting lit a person's immediate surrounding and it is not per definition necessary that the environment further ahead is enlightened. It can be argued that this could be different for drivers as they might feel less vulnerable within their vehicles, the direct environment in the moving direction is lit by the headlight and that seeing the course of the road is more important because travelling speed is higher.

It is important that research also makes steps in defining the parameters of dynamic lighting systems for faster traffic. From an engineering perspective it is probably already possible to create the intelligent lighting system. However the details that result into comfortable and effective light system need to be further explored before the technology can be successful. Thereby it is also necessary to replace many still good luminaires by LEDs, which could be considered a waste.

Colour hues

Even more possibilities arise with RGB LEDs which give the opportunity to create different hues. The possibilities and the pros and cons of the different hues of light are starting to get discovered more and more. Red coloured light, for instance is, suggested as a light colour that is to be way less disturbing for nocturnal animals, like bats(Wesselink, 2016; Philips, n.d.). Green light does not disturb the natural cycle for green plants since they reflect this colour (otherwise they would not look green). And green light reduces disturbance of the navigation process of birds. Additionally it is confirmed that the energy consumption of green light is lower compared to other colours that enlighten a scene (Steg, De Waard, Lindenberg, & Brookhuis, 2010). Less light is needed because in dimmed lighting situations humans are most sensitive to greenish light.

More relevant for the current study are effects of coloured light in a road situations. As emphasized, visibility is one of the main factors of increased safety by night, so Helmholtz-Kohlrausch effect should be introduced (Nayatani, 1997). This effect describes the perceived increase of brightness by an increase of saturation. In case of light this means that coloured light is perceived brighter compared to white light with the same luminance level (Wood, 2012). Understanding this effect is important because it results in overestimation of the range of visibility by road users under coloured light conditions. This effect of overestimation appears to be largest for blue colours (Wood, 2012; Nayatani, 1997). So people are perceiving brighter light when it is coloured blue compared to white or another colour while actual visible performance is lower.

Research of Wesselink (2016) tested the visibility of small targets under different colours of light. In his test set up he used reaction time for object detection as well as subjective responses under different coloured light settings. In his research Wesselink found differences in visibility but only in adaption between transitioning from one colour settings to another. Subjective ratings indicated confirmed *green, white, red* and sometimes *amber* light to be the better in terms of visibility. *Blue* was rated considerable worse.

The objective results indicated that after white light *Red* is the best option for coloured road light in terms of focal visibility. Amber coloured light also indicated good visual performance with results close to the scores observed in white light transitions. Wesselink (2016) does argue that this might be due to familiarity to amber coloured light which, as he states, is the most encountered light colour in traffic lighting worldwide. This can be supported by the fact that recommendations for different lighting classes are only tested for white and amber coloured lighting (NSVV, 2011; CIE, 2010). When designing the light scenarios this is interesting because familiarity is an important factor concerning road design consistency (§ 2.2.1). Finally, Wesselink (2016) stated that *blue* to be least effective colour for object detection and advised to not use blue light regarding to safety.

Reflecting on the information above one should not only focus on the visibility on the road but also consider that light has the potential to decrease cognitive processes while driving at night based on associations to different colours. The aim of the light emitting road marketing is not to lighten the pavement of a road and, but meant to improve the visibility of the course of the road and to create a tool that can induce certain behaviour on a subconscious level.

3.4 Conclusions

It cannot be mentioned enough that light in traffic situations **increases road safety.** Light enhances our visibility of the road, other road users, objects, and hazardous situations. With good quality lighting visual detection is better and earlier so a driver can respond in the right way and on time. However, lights is not always of good quality. **Glare can either lead to discomfort or limited visibility**; both of which can be dangerous. Other negative aspects of abundant use of light are the **high operational cost due to maintenance and energy consumption** and the consequences of **light pollution such as disruption of human and animal sleep cycles and the photosynthesis process of our nature.** Emphasis on light pollution has grown and research continues to reveal the effects of high unnatural light levels at night.

Literature also learns us that light **influences the perception and experience of a space** and this can affect human (travel) behaviour. Furthermore light does not only affects us via the visual pathway as light is also processed via **a non-visual pathway.** The latter neural process is related to our timing of internal processes and states of alertness, mood, arousal and cognitive processing. The visual experience of enlightened scenes and the non-visual effect of light can been seen as opportunities to create the environment that can **nudge drivers toward better travelling behaviour.** Using smart technology provides the **opportunities to use light as a tool for this.**

The technology is there and from an engineering perspective the possibilities with intensities, colours and dynamics are numerous. But little scientific studies with these technologies have been carried out in the field. As a result, little is known about the effects and impact of the wide design space lighting systems now provide. Most research is related to white light with variations in brightness and temperature. **Studies involving coloured light are scarce and so far only information concerning visibility is measured.**

3.5 Opportunities and limitations.

Table 4: Opportunities for the light emitting road marking technology in relation to the road

Light emitting road marking		Human factors: The Road
OPPORTUNITIES	Stimulus	• Humans can be directed and guided unconsciously by light on pedestrian speed which suggest this also possible when people are travelling faster. • With smart light technology colour hue, colour temperature and intensity of each light source in a light network could be controlled. (Dynamic light)
	Information	• Light can provide information in the dark.
LIMITATIONS	Stimulus	• Light pollution causes disruption of human and animal sleep cycles and the photosynthesis process of our nature. • Glare causes difficulty to see or a blinding experience
	Information	

4. Light scenarios

This chapter combines the knowledge from the previous chapters and translate the findings into light scenarios which can be applied on the light emitting road marking, and so answering sub questions 1-3.

4.1 Combining what is learned

So what is learned? Speed is one of the main parameters in traffic safety. Too high speeds result into more and more severe accidents. Though the first sub question can however not solely be answered by inducing lower driving speeds.

SQ 1: What driving behaviour results into a safe traffic environment?

In some cases it was even seen that in safer environments road users drove faster. Selection of speed is a process that works on rule-based behaviour and falls under the tactical driving tasks. These are operational driving tasks and for these handlings drivers use learned skills. In the decision making process the automatic behaviour levels are important for reducing decision time in traffic. It leads to more time and mental capacity for anticipation on unexpected situations and correction of errors.

The way the road is designed determines the tolerance that is given for errors and the amount of information that a driver needs to process. Design consistency has emerged to be one of the most important parameters for safe road environments. Inconsistency results into higher workloads and although this might lead to speed reduction it also leads to unsafe situations. Characteristics of new innovations should therefor only differ when it directly leads to improvement in traffic situations.

Both road markings and road lighting have shown to be road design elements that increases safety despite the phenomenon of risk homeostasis. Road markings improve safety by increased visibility of the course of the road and because less effort is needed for lane keeping. Road lighting improves safety because it is easier to see the road, to see other road users and to detect objects on the road

Light emitting road marking is suggested to improve safety during night time hours by increasing visibility of the course of the road. The benefits of road marking (provide information in the driver's central vision for which no extra effort is needed) are with light also effective during the dark hours. Additionally the technology also presents a stimulus in the peripheral visual field, so patterns and colours could unconsciously nudge driving behaviour. If light emitting road marking is to be used for this purpose, then it is important to take into account the colour and pattern associations that trigger skill- and rule-based behaviour. Associations towards light, shapes and colours in traffic are estimated based on familiar stimuli in the Dutch traffic environment.

When using white and coloured light also the experience of the enlightened scene can be evaluated. Spaces which are lit with warm white light are evaluated more attractive. Also remembrance of such enlightened spaces is higher and can therefore act as landmarks. Cold, bright white light has found to be more beneficial when navigating. Furthermore it is known that such light has an positive effect on peoples alertness and vitality. But light with short wavelengths also disturbs the sleep cycle of humans, animals and nature.

Lastly, the technology at is at hand, but the possibilities with and effects of new lighting systems are not yet fully discovered. In total there is little conclusive knowledge about the effects of coloured and dynamic light within the traffic environment.

4.2 Combined opportunities and limitations.

In total all what was learned had been combined to answer the second sub question.

SQ 2: What human and technological aspects play a role in affecting driving behaviour?

Table 5: Opportunities for the light emitting road marking technology categorized per chapter.

LER		Traffic safety	HF: Road User	HF: The Road	Lighting
OPPORTUNITIES	**Stimulus**	• Reduce speed • Reduce speed variance	Stimulus in the central and peripheral visual field	• Speed perception. • Stimulus lies within the visual field. • Design consistency it can decrease driving workload.	• Humans can be directed and guided unconsciously by light on pedestrian speed which suggest this also possible when people are travelling faster. • With smart light technology colour hue, colour temperature and intensity (Dynamic light)
	Information	Timely visible information	Unconsciously influence driving behaviour for tasks related to tactical and operational tasks by using adjusting the information related to the skill-and rule-based levels of cognitive processing.	• The association with the colours pattern of a traffic signal • Blue flickering light is a familiar cue to signal *"Watch out"* and Amber flickering light "Caution". • New rules can be adopted in our automatic information processing.	• Light can provide information in the dark.
LIMITATIONS	**Stimulus**	Measures for improvement of traffic safety can have to opposite effect by increased speed. (Risk homeostasis).	• Conspicuous • Colour blindness problem when using colour coding.	New technologies inherently violate the rules of consistency.	• Light pollution causes disruption of human and animal sleep cycles and the photosynthesis process of our nature. • Glare causes difficulty to see or a blinding experience
	Information	-	Not possible to affect strategic driving tasks	Too much signals in the road environment results into to high workloads and neglect (like with signs).	-

4.3 Light scenarios for the light emitting road markings

The theory from the literature study provided the knowledge to compose varies scenarios in which the light emitting road marking are considered to provide added value to the traditional road situations. Or in other words:

SQ3: What would, based on the answer to the first two questions, be potentially valuable light scenarios for light emitting road markings?

I. Increased visibility

In essence the light technology can enhance the visibility of all types of road marking in the dark. An improvement is above all made for visibility at a further distance. With lights integrated in in centre and edge lines visibility of the course of the road is increased. This aids the road user to drive safer as it eases lane keeping and facilitates timely anticipation on the course of the road, for example selecting the appropriate speed before a curve roads, during the night. The road situation is especially improved compared to a road with no road lighting on which people normally gaze into the dark. Compared to roads with road lighting the light emitting road marking can offer an improvement in regard to energy use and light pollution. Thereby it suggested the light emitting road marking provide calm an clear scene, without glare of an overload of light, and this should lead to more comfortable and therefore safer driving situation.

II. Adaptive perceived Speed

With the light emitting road marking technology it is possible to change driver's speed perception on a road or road section. As it is learned speed perception can be altered by the pattern of road marking and by the (vertical) alignment of cues in our peripheral visual field. If the patterns of the centre and edge lines can be altered the perception of speed can be altered as well. Imagine continuous lines that guides faster driving traffic if there are only a few vehicle on the road, but the lines change into broken a broken pattern when the number of vehicles increases and again change to an even denser pattern when the road capacity (highest traffic flow possible) is met. Compared to traditional road marking an advantages is not only achieved by making the lines adaptive, the lights in the road marking can also provide a stimulus in the peripheral visual field.

In this scenario the road marking influences the speed perception and as a consequence the appropriate speed will be adopted. So the continuous line does not provide feedback of speed but helps drivers to follow the road as they drive faster. The broken line should does give feedback and as the patterns gets denser speed perception get higher which would result into lower driving speeds. With this light scenario the speed can be regulated according to the occupation of the road which could be beneficial for the total traffic flow. That is if the road marking pattern is timely adjusted it can prevent congestion as it can reduce drivers to the speed that is related the road maximum capacity. The other way around if traffic density is low drivers can be encourage to drive faster so more vehicles can pass a road section.

The adaptive road marking can also be an advantage in merging situations. Within a running pattern that gets denser towards the point of merging and gets wider when traffic disperses. This way the traffic is guided to more efficient merging process, something which is safer and also beneficial for the traffic flow.

III. Warning mechanism

This scenario describes the potential it has in regard to warning drivers for dangerous situations. With the light emitting road marking it is possible to literally highlight and mark dangerous sections of the road. A sharp turn (think about highway exits or mountain roads) can for example be equipped with road marking emitting orange light. This might be a better solution compared to rumble strips because the lights provide cues in advance and rumbles strips provide feedback when an error is already made. One can also think about a more profound warning for ghost drivers by emitting bright white light similar to headlights of another vehicle when one is about to take the wrong exit/entry.

These are just two examples, but it is believed that light cues emitted by road marking can be a service beneficial in all kind of dangerous situations, also in urban areas. Furthermore it is believed that a great enhancement can be made if the light system works interactive or in other words if the lights are activated in case a road user approaches the dangerous situation.

IV. Communication with colours and dynamic patterns

The light emitting road markings can also be used as an active communication tool which is in particular beneficial in changing situations. In comparison to road signs the benefit lie in the fact that the information will be provided in our central visual field. So there is no need to shift one's visual focus nor does it ask for unnecessary salient stimuli to grab the ones attention. These salient cues are better to be appointed to the message itself.

With the intrinsic message that a colour holds stored rules can be activated. As we learned the constructs go – caution – stop related to the colours of a traffic signal, green, yellow/ amber, and red respectively are very familiar and robust. Though one should be careful by emitting red light by road marking. This because it might also activate the association with tail lights of other vehicles. In tunnels for example red light studs on the road are sometimes used to indicate drivers are using the correct lane. The colour green is less ambiguous and could be employed for visualizing a green wave between traffic signals in an urban area. A green colour emitted by the road marking will enhance the efficiency of the green wave and this might even be increased if the road marking shows a moving pattern with the appropriate speed.

As also proposed in the previous scenario amber coloured light can be used for warnings. The effect of such warnings can even be increased by signalling a (soft) flicker that is activated based on vehicle detection. This would enhance people's attention. An appropriate implementation of amber coloured flickering light would be in the case of congestion. The road marking can communicate to drivers that they are approaching a traffic jam and so decrease the number of read end collisions.

Another possibility to communicate with colours applies to emergency situations. Imagine that the road marking lights up in a blue colour pattern that will be activated when a police car with sirens is approaching. The message from the road marking is received more apparent and more in advance compared to the signals from the emergency vehicle itself. This results into more time to clear the road for the emergency vehicles. Prerequisite is then that the technology acts immediately and only on a short section, also when the emergency services have past the road marking should signals that normal driving can be continued.

Of course more light plans can be composed. Most important in this scenario is that the light cues are congruent to a certain message. In case of the last example the road marking could maybe also emit a white flashing light instead of a blue pattern the point is that the drivers know what the message is. These rules can be set and integrated in our automatic driving behaviour the same way as we learn the meaning of traffic signs. Though when the light output us intuitively congruent with is meaning this is easier and the result is more effective.

V. Adaptive lanes and traffic distribution

This scenario focusses on possibility to create adaptive lanes. First, and most obvious solution for the problems with the rush hour lanes (§ 2.2.3, p. 27). If the edge lines of the emergency lanes are equipped with light emitting road marking the lines can adapt from continuous to broken when a higher road capacity is needed. This not only uses the stored rules that say a continuous line means "do not cross" and broken lines "allowed to switch lanes" it also does not interfere with them, which is the case at the moment. Note that this measure also includes the effect of higher perceived speed

If it is possible to allow or deny drivers the use of a lane at certain times it could also be possible to assign a lane a dual function. A lane can then be assigned with different driving direction, for example one way in the morning and the other way in the evening. The visionary idea is based on the idea of too little capacity on a route but not enough pavement. A road accessing the city is often crowded in the morning, when people are heading to work and in the evening congestion occurs while exiting. If a four lane road can be transfer from a two by two lane road into a three by one lane road in the direction with more traffic no additional pavement is needed. This however asks for a thoroughly designed roads and good communication to drivers before it can be implemented. The lights in the road marking can be used to signal the direction by using continuous and broken lanes in merging situations and/or by indicating the direction with the use of colours.

III. The Field Experiment

1. Method

The literature study (part II.) ended with five possible scenarios in which the light emitted road marking are suggested to be effective. This part discusses a field experiment were some of the use cases described in the scenarios are tested.

1.1 Design

The aim of the field experiment was to investigate if the light emitting road marking could indeed affect driving behaviour (*SQ4*). Within the last chapter of previous section (part II., 4.2, page 41) several use cases were proposed for the application of the light emitting road marking. These applications however ought to be effective for a certain corresponding road situation and thus the test environment was a directive for the design of the experiment. The test section that was selected lies in one direction on the N329. This is one of the Dutch regional roads (speed limit is 80 km/h) without road lighting (Figure 6). To test if driving behaviour was influenced by light in the road marking four light plans were constructed with the aim to affect driving speed. This resulted into a five condition between-subject experiment with speed as the dependent variable under the following conditions: a baseline test and four different light plans *1. White static light, 2. White dynamic light, 3. Amber coloured static light,* and *Amber coloured dynamic light*.

The total testing period lasted five weeks. Since traffic varies over the hours of a day and over the days of a week each condition was run for a period of one week. One week was considered to have reliable measurements over time and day and could reveal all but minimal and thus practically irrelevant effects of the lighting plans. A testing week started on Monday at 17:00 and ended Monday on 08:00.

Both quantitative and qualitative data was obtained. The quantitative measurement gave numeric traffic data about the differences in driving behaviour between the different light conditions, taken into account some confounding factors. The traffic data was collected by sensors placed on five positions in the road pavement. The qualitative measurement collected data regarding to driver's experience and attitudes towards the light technology by using online questionnaires.

1.1.1 Testing environment

As mentioned the test environment determined the possibilities and limitations for the application of the light emitting road marking that were expected to be effective and therefor the environment was defined before the light plans (conditions) were created. Here the important details of the test environment are explained, for a better understanding on the test section a sequence of photos of the test section can be found in Appendix B.

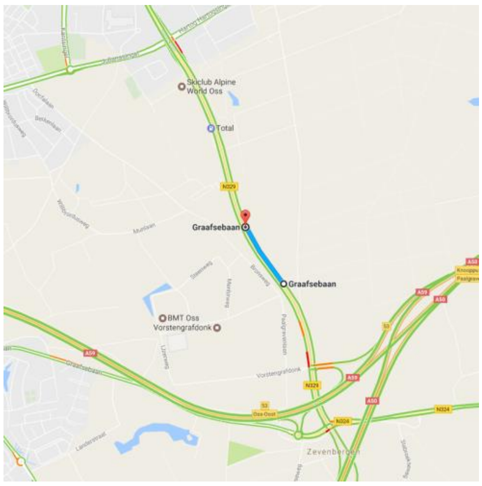


Figure 5: Location of the N329. Source: Google Maps
Figure 6: Road section, 500m, where the light emitting road marking is applied. Source: Google maps

In one direction on the N329 a section of 500m was selected as the testing ground for the light emitting road marking. The N329 is a urban road in the middle of the Netherlands with a speed limit of 80km/h and separated directions. Each direction has two lanes with a total width of 7m. The centre contains medium high vegetation alongside the testing ground, blocking the light of headlights of the other direction.

Before approaching the test section, drivers would first pass a big intersection controlled by traffic signals (TRI). This causes a fluctuating traffic flow that is accelerating (free flow) during the first part of the N329. From the East, the lane that is turning right onto the N329 is part of the intersection, but not controlled with by the traffic signal. At this point two types of road signs were placed (Appendix B). After the intersection drivers head Northbound and within and after the test section the road curved first to the North-West and then back in Northern direction (Figure 6).

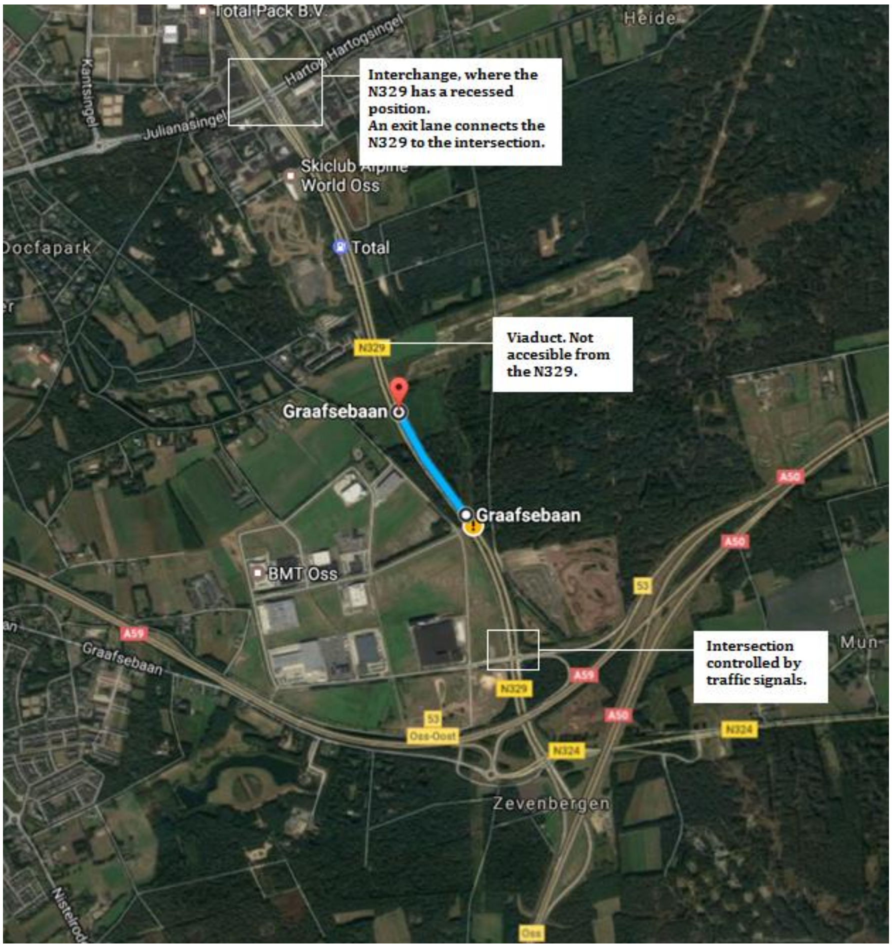


Figure 6: Situation of the test section. Source: Google maps.

The light emitting road marking was only applied in the direction South-North, which founds itself on the inner side of the curve. The test section started 600m after the signal controlled intersection which was considered long enough for drivers to reach their average speed after a red signal. After the test section, approximately 300m there was a viaduct with light which could not be accessed from the N329 and 1.5km after the last light in the road marking there was an exit and an overpass. This could have influenced a driver's lane selection and driving speed.

Figure 7: Test section, direction South- North, N329: View by daylight Source: Google maps.

Along the test section there are no light poles, but at the intersection before road lighting was installed. The last light pole was placed 300m before the test site. After the test section the first light pole was situated next to the exit (1.5 km past the test section). Before the first light in the road marking a temporary orange sign was placed with the message *"test section alternative road marking".* Last the road marking design by day looked like traditional road marking with the following design. A continuous line on the left edge, a broken line on the right edge – three meter lining by three space- and a centre line – three meter lining by six meter space – (see figure 7). Figure 8 shows how the situation looks when light sources are integrated in the road marking and are activated with a green pattern. This pattern show one meter light activated every six meter..

Figure 8: Light sources integrated in the road marking, activated with a green colour.

1.1.2 Testing conditions

Based on the road situation above four light plans where designed based on three concepts described in the light scenarios (part II., §4.2, page 41): *Increased visibility of the course of the road*, *influencing perceived speed* and *association with amber coloured light*. Prior to the weeks testing the light plan a baseline test was conducted.

Testing condition	Colour	Pattern	Theory
0. Baseline	-	-	-
1. White static light (Figure 9)	White	1m light on 12 road[4]	Increased visibility of the course of the road.
2. White dynamic light	White	1m light on 12 road, a block of 48m with a denser pattern (i.e. one meter of light every six meters) will run on a loop in opposite driving direction.	The denser patter and the direction is expected to increase speed perception which would result into lower speeds.
3. Amber coloured static light	Amber	1m light on 12 road	The amber coloured light should activate the association caution or danger and should direct people to slow down.
4. Amber coloured dynamic light	Amber	1m light on 12 road, the lights will illuminate more intense (double) and then be dimmed. The lights are not dimmed fully to avoid a shocking effect which would be dangerous.	The flashing amber colour pattern is expected to enhance a drivers alertness which would amplify the effect of light plan.

Figure 9: Visualization light plan 1.

[4] *With a speed of 80 km/h or 22.2 m/s a driver passes a light every 0.54*

1.1.3 Model

Driving speed (Dependent variable)

Four each light plan the effect on driving speed[5] was investigated (Figure 10). For this driving speed was defined by average speed and speed variance (Part II. §1.1). As explained throughout all chapters in the theoretical background the driving speed is as key parameter in traffic safety. Thereby can it be accurately measured. The conditions are designed in such a way that they aim to reduce driving speed and speed variance. But speed is dependent on a lot more variables and which it is important to control for these variables.

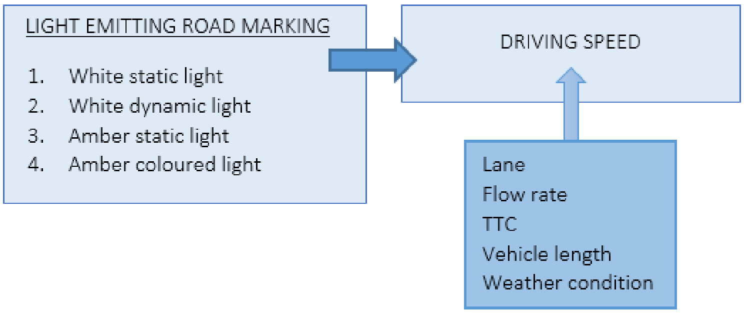


Figure 10: Visualization of the design of the testing model

The road

The road on which a road user is driving influences driving speed. The test-road as described above had two lanes, with width of 7m and a speed limit of 80 km/h. The road marking pattern was different on the left lane (continuous) compared to the right lane (broken) which could have an influence on driving speed (Part II. §2.2.3). Furthermore the road environment was calm (i.e. only vegetation along the test section and no signs) which facilitate fast driving. But most the important road factor to consider is the traffic signal controlled intersection which has an impact on the traffic flow, this explained in the next paragraph.

With this road situation it was expected that the average speed would lie around the speed limit of 80 km/h for the right lane. For the left it was expected that this would higher, however the absolute difference could not be estimated. Since the road environment was the same under all conditions and a baseline was included only the confounding variable "lane" needed to be included in the model.

Other traffic

Not only the road but also the traffic flow influences driving speed. Traffic flow is often described by the relation of Speed (*u,* [distance per time]), traffic density (*k*, [veh. per distance]) and flow rate [*q*, veh. per time]) (Gazis, 2006). The simplest relation can be expressed by equation 1. The TRI causes a traffic flow with an interval pattern, i.e. the green light signal causes a chain of vehicles over the road section followed by a lapse with few or no traffic due to a red signal. According to the traffic flow theory this effects driving speed.

$$q = u \cdot k \qquad \text{Eq. 1}$$

After green light at the TRI traffic is in a state of free flow where the traffic situation is not stable. Most importantly this means vehicles are accelerating and this obviously has an impact on driving speed. The test section starts approximately 600m after the TRI, it is therefore important to test if drivers already reached a levelled speed.

The interval traffic flow pattern also has an effect on the gaps between vehicles. Firstly within the chain of vehicles drivers adopts smaller gaps and between the chains of vehicle large gaps arise. Secondly the flee flow state impacts the gap acceptance of drivers. Generally, drivers allow greater gaps between cars during acceleration then during deceleration (Gazis, 2006). This because drivers are ok driving to the minimum distance for safe driver during

[5] Originally it was planned to also measure the lateral position on a lane, so to describe if driver would drive more to the middle of the road or not. However due to complications with the data storage of the camera files no camera images could be retrieved. Hence no data was available that could give information regarding driver's lateral position.

deceleration but when accelerating the they let gaps increase (Gazis,2006). Very large gaps are not considered to have an effect on driving speed as a driver's speed selection is not influenced by other traffic. Smaller gaps on the other hand do affect driving speed. With the visual feedback of the distance to a previous vehicle a driver determines the time to contact or time to collision (TTC) and makes a decision if slowing down is needed. As TTC is expected to describes part of the variance of driving speed gaps up to 6 seconds (REF) needed to be included in the testing model.

Lastly the length of vehicle was taken into account. Vehicle length is an indicator for vehicle size. The bigger the vehicle the longer it is –this can be said for both passenger cars, transport vans and trucks. Longer and bigger vehicle affect the traffic situations in several ways. Firstly acceleration is lower and so these vehicles need a longer road section to reached a levelled speed. Additionally, they block the view on the road for the driver in the following vehicle this motivates to larger gap distances resulting in lower speeds. Or this can be reason for following vehicles to change lanes and over take other traffic leading to higher speeds. Furthermore, heavy vehicles cannot adopt very high speeds and are often limited to a maximum speed.

Weather

Other variables which is suggested to influence driving behaviour are related to the weather. Weather conditions can cause decreased visibility (fog, heavy rain) or can create more dangerous road situations (slippery roads due to ice forming) to which people adapt their driving behaviour. Therefor the it is important to control for the occurring weather conditions.

1.1.4 Hypotheses

The field test aims to find the answer to sub question 4: *Do the light scenarios based on theory have the aimed results in the field?* and thereby find the evidence that can answer the main research question. Based on the theory and the conditions in the testing model null hypothesis and two alternative hypothesis were set up.

H0. There is no difference in driving behaviour due to the activation of lights in the road marking

H1. There is a difference in driving speed due to the activation of lights in the road marking.

The alternative hypothesis can be further defined into the following expectations per condition:

- H1.1 Speed will be higher under the light plan 1 as visibility on the course of the road increases.
- H1.2 Speed will be lower under light plan 2 because perceived speed increases.
- H1.3 Speed will be lower under light plan 3 due to associations with colour amber.
- H1.4 Speed will be lower under light plan 4 due to associations with colour amber and the effect will be bigger compared to light plan 4.

H2. There is a difference in driving experience due to activation of lights in the road marking.

The second alternative hypothesis can also be further defined into the following expectations:

- H2.1 Average driving comfort under the condition of light plan 1 will increase as visibility on the course of the road increases.
- H2.2 Average driving comfort under the condition of light plan 2 will decrease as more and moving stimuli are provided in the driving environment.
- H2.3 Alertness under the condition of light plan 3 will increase due to the association with colour amber.
- H2.4 Alertness under the condition of light plan 4 will increase due to the association with flashing coloured amber lights.

1.2 Materials & Setting

1.2.1 Materials

Light emitting road marking

The light emitting road marking on the N329 was developed by of Heijmans-a contractor company specified in, among other things, road construction. The technology consists out of a light source which is integrated in the traditional road marking (Figure 8). The robustness and specification of the technology have been tested in the lab but this was the first application of the technology in a real traffic environment.

In September 2016 Heijmans installed 172 light emitting road markings on the test section of the N239. Technical details of light sources and installation of the light emitting road marking can be found in appendix C.

Speed radars:

On five locations on each lanes of the test section speed radars were installed in the road pavement by the company Active Roads (http://www.traffic-tube.nl/.) The Traffic Tube technology consist out of four detection points which mounted in the road over a distance of 20m. It logs Time, measures speed and vehicle length.

One week before the tests started the speed radars were applied. The sensors were replaced by new ones after three weeks. At this moment the data could also be retrieved. After again three weeks the radars were removed and replaced by dummies.

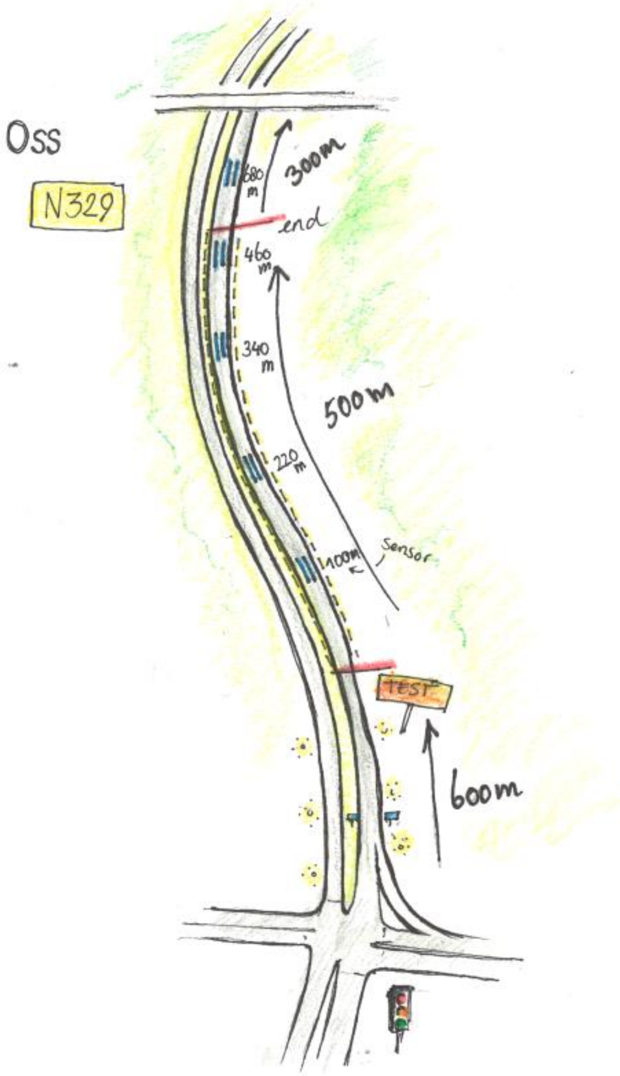


Figure 11: Schematic drawing of the test situation and its environment. Important elements:Intersection controlled by traffic signals, light poles and sign before the test section, placement of the road sensors (blue), viaduct.

Table 6 Exact positioning of the light emitting road marking and radars.

Element	Position on the road
First light source:	0 m
Lights:	0-482.5m (1 every 6m)
Speed radars location 1:	100-120m
Speed radar 2:	220 -240m.
Speed radar 3:	340-360m
Speed radar 4:	460-480m
Speed radar 5:	680-700m

'

Other materials:

For the traffic measurement the database of the Dutch meteorological institute was used to obtain relevant weather data during the test period (http://projects.knmi.nl/klimatologie/uurgegevens/selectie.cgi).

For the Qualitative measurement the online survey tool Survio was used to create and distribute a questionnaire and to gather and report the answers (http://www.survio.com/nl/).

1.2 Participants

Speed radar data was obtained from all vehicles passing (N = 594 863) the test section on the N329 during all hours of the five weeks testing period (i.e., drivers of all vehicles on both lanes in the direction South-North). The data obtained from these vehicles was completely anonymous and no data regarding the driver's identity were recorded.

The participants (n = 26) who completed the survey were sampled from the road users of the N329 that passed by the installed technology in the road during the testing weeks, regularly. For recruiting these participants, the companies of the nearby industrial areas (Vorstengrafdonk, Elzenburg, Landweer, and Danenhoef) were approached for their support in distributing the surveys among their employees. Fifteen companies (26%) gave approval for participation upon which they received an informative email with further information about the test and the procedure was provided by email (Appendix F).

1.3 Procedure

The testing period started in November 2016. Heijmans was responsible for the (de)activation of the different light scenarios. The light sources were activated one hour before sunset and one hour after sunrise. Light settings scheduled to be changed, according to the experimental condition, on Mondays during working hours. However light plan 2 (in week 3) and plan 3 (in week 4) were activated later than planned (at 19:00 pm and Tuesday during working hours, respectively). Therefor these hours should be excluded from the data.

The first week started with the baseline test for which the light sources were deactivated. In the second testing week the first light plan was activated. I . The light colour of Scenario 3 (in week 4) turned out to be soft yellow instead of amber coloured. After consideration the colour setting were not change for this week, but for Scenario 4 (in Week 5) the light colour was set to a proper amber colour. As a result and against what was planned, the colour of the lighting differed between Scenarios 3 and 4. This has an impact on the analysis since now it is not possible to compare the data of these two weeks in order to find the effect of the dynamic pattern.

The data collected for the traffic measurement did not require any effort other than replacing the sensors as described previously. For collection of the qualitative data, two emails (Appendix F) were sent each week. All companies chose to distribute the mails for participating in the survey among personnel themselves due to privacy regulations. On Tuesdays an email, containing the link to the survey, which was updated each week, was sent to the contact e-mail address of the companies. The e-mail described that it was necessary to first pass the road and fill out the survey afterwards. On Thursdays an e-mail containing a reminder was sent.

The link in the e-mails would redirect participants to an online questionnaire. The first page of the survey displayed the information concerning informed consent. Participants needed to check a box which states: I have read the informed consent and I agree with the terms. Only after checking this box participants could continue to the questions (Appendix F). When filling out the questionnaire the participants were informed about their progress by displaying the number of questions answered and unanswered. They also had the option to go back and forth between the questions. In the questionnaire of the final week participants could leave there email-address if they wanted to be informed on the outcome of the study.

After the fifth and final week of the testing period, data were retrieved from the speed radars by ActiveRoads, the supplier of the Traffic Tubes.

Participants who completed the surveys were thanked for their effort by one last e-mail. In the email, it was once more stressed that the results were anonymous and would be stored confidentially. Participants that indicated to be interested in the results were given a summary of the finding after analysis. The email also included contact information in the case of any further questions.

1.4 Measures

1.4.1 Traffic measurement

The data from the road sensors were retrieved by the supplier of the technology (Active Roads) and was provided as CVS-files separated for each lane and position (Figure 12). The road sensors measured the variables speed and length which were logged based on a timestamp with a accuracy of 0.01 seconds. In the data file however the time stamp was rounded to one second. The data points were also given a corresponding reliability score between 0 and 1.

Tijdstip	Snelheid	Lengte	Betrouwbaarheid	Gap	Seconds in day	Headway
28-11-2016 09:16:26	31,1	02,729	0,0	-0,32	33386,01	0,00
28-11-2016 09:56:47	-18,9	08,687	1,0	2422,88	35807,23	2421,22
28-11-2016 09:56:54	72,1	05,717	0,9	6,63	35814,15	6,92
28-11-2016 09:57:04	65,9	03,498	0,4	10,15	35824,49	10,34
28-11-2016 09:57:08	76,5	05,276	0,9	3,64	35828,38	3,89
28-11-2016 09:57:14	68,6	03,780	0,4	5,97	35834,55	6,17
28-11-2016 09:57:23	60,9	17,505	1,0	8,35	35843,93	9,38
28-11-2016 09:57:27	63,6	03,953	1,0	3,14	35847,30	3,37
28-11-2016 09:57:32	63,6	09,413	1,0	4,49	35852,32	5,02
28-11-2016 09:57:37	68,2	07,844	1,0	4,60	35857,33	5,02
28-11-2016 09:57:49	67,2	03,682	1,0	11,56	35869,09	11,76
28-11-2016 09:57:53	76,4	04,079	1,0	4,45	35873,74	4,65
28-11-2016 09:57:55	70,5	05,504	1,0	1,67	35875,69	1,95
28-11-2016 09:57:58	75,1	04,798	1,0	2,23	35878,15	2,46
28-11-2016 09:58:05	63,7	16,670	1,0	6,66	35885,75	7,60
28-11-2016 09:58:12	64,8	17,649	1,0	5,28	35892,00	6,26
28-11-2016 09:58:14	64,2	03,859	1,0	1,91	35894,13	2,12
28-11-2016 09:58:44	81,0	04,774	1,0	30,61	35924,95	30,82

Figure 12: Example of the data provided by ActiveRoads. Source: data file Sensor position 1, Right lane.

Based on the data measured by the road sensor the variable flow rate and gap time could be derived. Active Roads calculated gap_{time} based on the unrounded timestamp and then corrected for speed and Vehicle length (Equation 2). From this the variable TTC[6] was selected. The flow rate was constructed when the data was aggregated to hour computing the sum of the measurement for each hour.

$$Gap_{time} = Headway_{time} - \left(\frac{Vehicle\ length}{Vehicle\ speed}\right) \qquad \text{Eq.2}$$

For weather conditions the data of the weather station closest to the test road was obtained from the KNMI data base. This was weather station ‘Volkel’ and was located on a distance of approximately 16 km to the test road. Data regarding to visibility, rainfall, mist and ice were selected. Visibility[7] was an ordinal variable were each number corresponded to a certain distance of sight per hour, Rainfall was measured by the amount of mm that fell in an hour. Mist and Ice were categorical variables with 0 = no occurrence of mist or ice for a measured hour and 1 = occurrence of mist or ice for a measured hour.

[6] *TTC* includes the gap smaller than 6 seconds. This criteria is chosen based on the McLeod and Ross, H. E. (1983).

[7] *Visibility code: 0=minder dan 100m, 1=100-200m, 2=200-300m,..., 49=4900-5000m, 50=5-6km, 56=6-7km, 57=7-8km, ..., 79=29-30km, 80=30-35km, 81=35-40km,..., 89=meer".*

1.4.2 Questionnaire

In order to collect qualitative feedback of the driving experience passing light technology, short online questionnaires constructed in Dutch (Appendix F). The description of the information given and questions asked below are translated to English by the author.

A small pilot was conducted to test whether the questions in the survey would be understood by participant, and to detect any organizational problems in completing the survey. Friends and family members of the author were asked to drive over the N329 in the dark when the light emitting road marking was activated. Afterwards they received the link to the online questionnaire by e-mail. A small feedback session, either face-to-face or by phone indicated that the questions were understood correctly. Based on this feedback only minor adjustments to the questions and the instructions were made.

The qualitative data collection would always start by asking the participant for their informed consent, also when the participant was filling out the questionnaire for a second time. This because the participation was anonymous and because participation was possible even when the questions of the previous week were not filled out. The first page of the online questionnaire contained the information to which participants gave their consent (Appendix F). Participants needed to check a box which stated: *"I have read the informed consent and I agree with the terms"* in order to continue to the questions.

The questionnaire started by asking for a username, age and gender. A username was important as it indicated if a participant filled the questionnaires every week or not. The following questions asked about the date and time participants passed the light technology, whether they were the driver, and what kind of vehicle they were in. After completing out these general question a short text was displayed to induce better recall. Asking participants about the details of an event would result into more accurate recall of the situation and improves the content of the response (Dillman, 2000).

> "*Try to replace yourself into the moment where find yourself in your vehicle on the N329 passing Oss. To the moment just before you passed the light emitting road marking. From which direction did you come? Did you need to wait before the traffic light or could you drive along straight away? Think for yourself where you where before driving here and to where you were heading. Was there something different than the last time? For example, the weather? Maybe you were driving with a passenger or not. Lastly think about whether you were participating in other activities like navigating, having a hands free call, or having a conversation with a fellow passenger."*

After indicating to have read the above seven open questions were given one by one. These questions asked the participants first about what they saw, what they experienced and whether this was different than the week before (the latter was not stated in the first week). Then participants were asked whether they though the light emitting road marking influenced their driving behaviour. The following two questions asked to evaluate the visibility respectively, the traffic safety compared to traditional road marking. After these open questions two matrix questions asked participants to rate in total eight constructs regarding to their experience of driving passed the lights (Figure 13). Above the questions the following was stated: "*try to fill out the intuitively. So do not think too long and choose the option that first comes in mind"*. Finally the questionnaire ended with the open question: "*Do you think the current situation, with the light emitting road marking is better or worse than a traditional situation? Please explain your answer"*. The first and last questionnaire ended different than the others. For the first week participants were asked to rate the extent to which they would like to see the light emitting road marking technology on other roads (Figure 14). The final week included the question whether participants wanted to be informed about the outcome, and if so they could give their email address.

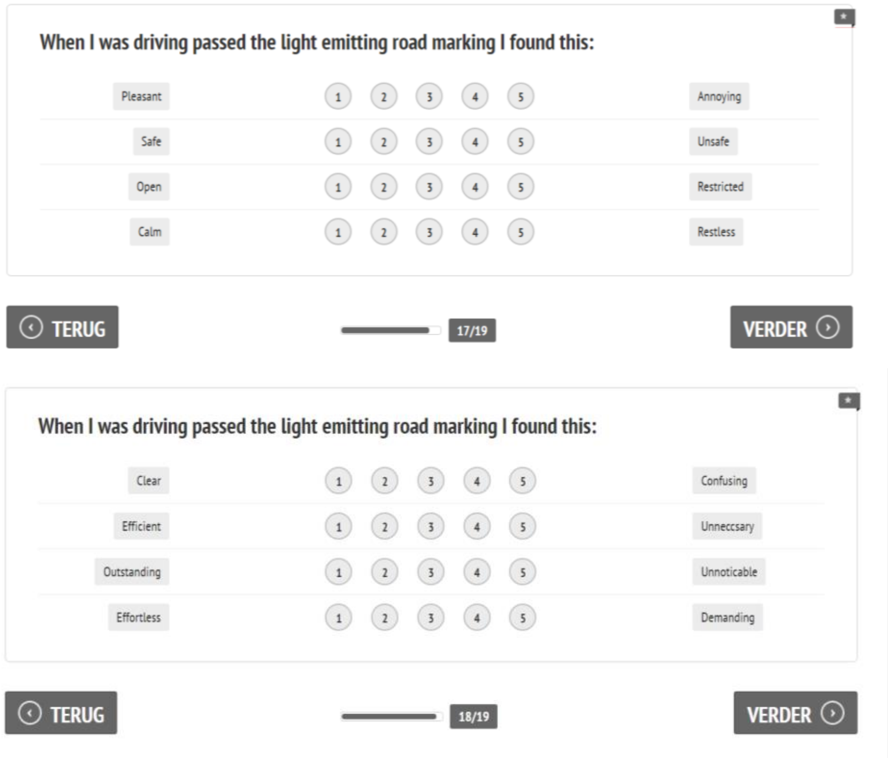


Figure 13: Lay-out of the matrix questions. The concepts are translate from Dutch to English.

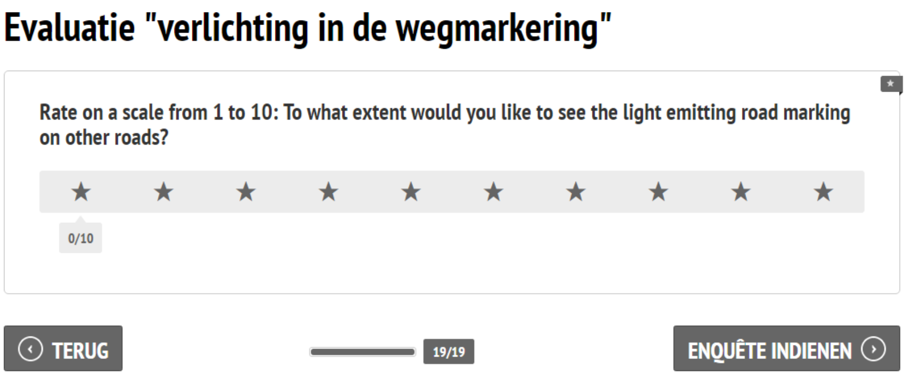


Figure 14: Extra question Week 1 The question is translate from Dutch to English.

2. Analysis and results

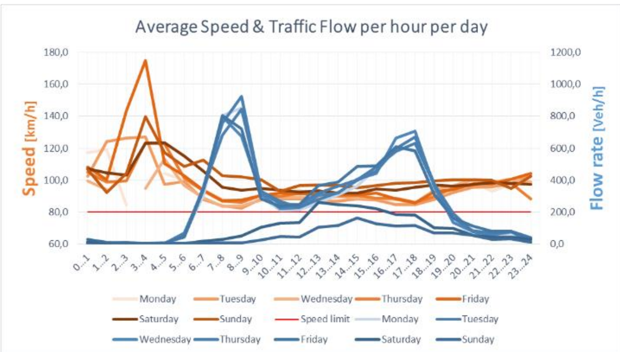
2.1 Quantitative Study

Once the experiment was completed the traffic data was collected and analysed with a regression analysis. This chapter describes the steps that were made to structure the data in preparation of a regression analysis. Also, the choices made for the analysis are elaborated. Hence the results are stated and interpreted and finally a conclusion made.

2.1.2 Data

The raw data retrieved from the sensors in the road was very detailed and considered a rich source of information. At the same the data was not structured and was separated over different files. In order to cope with this big data a better understanding was needed of the characteristics of the traffic situation on the N329. For this hourly data of the baseline week was studied. Additionally the weather conditions during the five week testing period were mapped. The initial exploration of the data was solely conducted to get familiar with traffic data, a summary of this process is described in Appendix D. The most important conclusion made was differences between traffic on the left and the right lane. A difference in the average driving speed and traffic flow is illustrated in figure 15 and 16. Studying the data of the other positions and testing weeks these differences remained. Hence it was decided to separate the data of the two lanes and to test the hypothesis for each lane independently.

Lane 1: Left



Lane 2 : Right

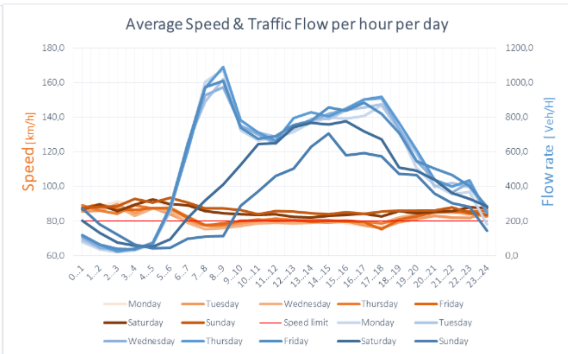


Figure 15 & Figure 16: Average Speed and traffic flow per hour per day on the left and right lane based on data from the measurement position 1. Orange represents the average speed and is plotted on the left Y-axis. Blue represents the traffic flow and should be read from the right Y-axis. (enlargements are found in appendix D)

Preparing the datasets in SPSS

After exploring the characteristics of the data and the testing conditions two datasets were created in SPSS: One for the left lane and one for the right lane. At this moment the data sets contained variables: *date, hour, speed, length, reliability* and Gap_{time}.

The separate data points were examined for false results and outliers. Measurements which indicated negative values for *Length, Speed* and Gap_{time} were removed from the data as they were considered false measurements, since this cannot be possible. Additionally all the measurements with an assigned reliability score lower than 0.8 (on a scale from 0 to 1) were removed. In order to find and eliminate outliers in the data the standardized values of *Speed* and *Length* were saved as new variables. Zscores lower than -3 and higher than 3 for both variables were also excluded from the data et. Before and after the elimination of the outliers the distribution of the speed and length data was examined based on boxplots and histograms. The speed data generally showed a distribution with a high positive kurtosis for the right lane data and a small negative skew for the for left lane data. The length data generally showed positive skewed data, which was especially high for the right lane.

After exploration of the relevant variables the following variables were created: *NVeh*[8]*, Lane , Sensor* and *TTC.* The following step aggregated the data per hour computing the mean and standard deviation variables of *Speed,*

[8] To create *Nveh* a value 1 was given to each data point.

Length, and TTC and the sum for *NVeh,* which was then renamed into *Flow rate*. Within the new dataset the variables *light_plan* and *Day* were created for which data was put in manually and the weather variables were added. Lastly, the day-time hours (08:00-17:00h), and the Monday data where removed since during daytime the lighted road markings were deactivated. This process has been followed for the data sets of all the sensor positions (five on each lane).

The next step examined the speed data over the five sensors (Tables, see Appendix E). On the right lane the traffic showed increasing speed over the first three sensors, there was no significant difference between the third and fourth sensor or between the fourth and fifth sensor. This indicates that the traffic was still accelerating due to a green signal at the TRI. On the left lane there was only a small difference between the second and third sensor, , which can be explained by the fact acceleration is faster on the left lane –probably because slow accelerating traffic uses the right lane. These findings gave reason to merge the data into sensor variable with three levels. Data of the first two sensors and data of the third and fourth were aggregated. The data of the fifth sensor was kept separate because the sensor was not placed in the test section as it functioned as a reference point and where the differences between the fifth and the first two sensor statistically significant.

After all data aggregation steps were conducted once more was that data examined for outliers. On the right lane there were two possible outliers, one on the lower side of the speed data and one on the upper side of the length data. For the left lane two cases on the lower side of the speed data and three on the upper side of the length data could be considered possible outliers. Hence analysis should be run with and without the outliers to test it the result is affected.

Step five examined the mutual correlation of the controlling and dependent variables were examined (Appendix E). This is important as it gives insights in possible unintended differences between the conditions that mask the effect of the manipulation on the dependent variable speed. A major difference between the left and right lane was found between the correlation of the two dependent variables speed, speed variance and the two predictors flow rate and TTC. Speed and Speed variance showed low correlation on the left ($r(1166)= .06$, $p < .05$) and high on the right ($r(1260)= .65$, $p < .001$). A similar effect was seen between flow rate and TTC. This indicates that on the left lane drivers were not influenced by other traffic in their choice of speed. Additionally, as expected there where high correlation between the weather data. The variables visibility, mist and rainfall showed significant correlation of 0.5 or higher (See appendix E) and should not be put in a regression model together. Lastly the data was examined to see if the predictor variables average length, flow rate and TTC differed over the five test conditions (weeks). A significant difference was only found for the average length, but this difference was very low < 0.1m for the right lane and <.2m for the left. It was thereby expected that these predictors would not show a confounding effect.

2.1.2 Regression Analysis

Approach 1

A hierarchical regression analysis is conducted to predict the average speed and speed variance under the four manipulated light conditions [*light plan 1,2,3,4*] including the other independent and confounding variables. With the two separated datasets this resulted into four regression models (§ 2.1.3.).

A manual stepwise approach was adopted during which the other independent and confounding variables were added in three blocks: conditions, traffic characteristics, weather conditions. For the **right lane** following variables were included in the regression: condition *[Light_plan_0,1,2,3,4, as dummy variables],* location *[sensor],* number of vehicles per hour *[Flow rate]*, Length *[length_mean],* TTC *[TTC_mean],* Rain *[Rainfall],* and Mist *[Mist]*. Ice and Visibility were excluded from the model. For the **left lane** following variables were included in the regression: condition *[Light_plan_0,1,2,3,4, as dummy variables],* location *[sensor],* number of vehicles per hour *[Flow rate]*, TTC *[TTC_mean].* Length was not

As regression analysis assumes normal distributions of the residuals and heteroscedasticity. So for the final model the regression analysis was asked to save the unstandardized residuals on which a normality test of the residuals was performed. If violated the regression model was run again but this time it was preceded by bootstrapping of the included variables.

If heteroscedasticity was expected based the scatterplot of standardized predictor versus residuals a macro was to estimate the regression model with heteroscedasticity-consistent standard errors using the HC3 procedures (http://afhayes.com/spss-sas-and-mplus-macros-and-code.html).

Finally the analysis was run with and without outliers but the results did not show any differences so the outliers were kept in the model.

Approach 2

A second approach was adopted to test if the effects of the light plans can explain the variance in speed above and beyond the effect of the other predictors. For this first the regression models was calculated to predict either average speed or speed variance (both for the **left** and **right** lane) based on the same predictors as the models used for the first approach with one difference: the conditions were kept out of the model. The unstandardized residuals were asked to be saved.

A One-way ANOVA test was conducted to compare the effect of the light plans on the unexplained variance of average speed. The same done for the residuals of the regression model predicting speed variance. Thus, this approach test if the light plans can explain the variance in driving speed when the variance explained by all other factors is already excluded. Hence a post hoc analysis using Fisher's least significant difference technique was performed to compare the means for each condition. Since the amber colour in the third and fourth week was not the same it is only relevant to compare the results of light plan 1-4 with the baseline, to compare light plan 2-4 with light plan 1.

Finally the analysis was run with and without outliers but the results did not show any differences so the outliers were kept in the model.

2.1.3 Results

In this section the relevant results are given of the final regression models. A complete overview of the analysis can be found in Appendix F Approach 1:

Left Lane, dependent variable : Speed

Both bootstrapping and the HC 3 method was used to control for normality of the residuals and heteroscedasticity. The result of the HC 3 method did not show large differences compared to the bootstrapped model.

Table 7: Model summery regression analysis predicting average speed, approach 1, left lane

Model Summary [d]				
Model	R	R Square	Adjusted R Square	SE of the Estimate
3	,709[c]	,503	,499	3,695

d. Predictors: (Constant), Light_plan_4, Light_plan_1, Light_plan_3, Light_plan_2, Sensor, Flow rate, TTC mean

Table 8: Coefficients regression analysis predicting average speed, approach 1, left lane

Bootstrap for Coefficients [a]							
Model		B	Bootstrap [a]				
			Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
						Lower	Upper
3	*(Constant)*	98,928	,008	,721	,001	97,485	100,296
	Light_plan_1	1,303	-,002	,327	,001	,619	1,925
	Light_plan_2	,148	-,029	,393	,705	-,674	,905
	Light_plan_3	,869	,008	,360	,019	,115	1,536
	Light_plan_4	1,937	-,010	,391	,001	1,154	2,671
	Sensor	1,077	,007	,155	,001	,779	1,396
	Flow rate	-,018	-3,844E-5	,001	,001	-,019	-,017
	TTC	-,342	-,003	,248	,175	-,795	,173

a. Dependent Variable: Average Speed

Approach 1:**Left Lane**, dependent variable : Speed variance

Table 9: Model summery regression analysis predicting speed variance, approach 1, left lane

Model Summary [d]				
Model	R	R Square	Adjusted R Square	SE of the Estimate
3	,394[c]	,156	,148	1,918

d. Predictors: (Constant), Light_plan_4, Light_plan_1, Light_plan_3, Light_plan_2, Sensor, Flow rate, TTC mean

Table 10: Coefficients regression analysis predicting speed variance, approach 1, left lane

Bootstrap for Coefficients [a]							
Model		B	Bootstrap [a]				
			Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
						Lower	Upper
3	*(Constant)*	10,327	,003	,388	,001	9,547	11,092
	Light_plan_1	-,078	,006	,158	,630	-,405	,233
	Light_plan_2	,031	,008	,193	,881	-,339	,419
	Light_plan_3	-,056	,012	,206	,800	-,437	,346
	Light_plan_4	,243	,004	,213	,253	-,160	,675
	Sensor	,125	-,001	,086	,147	-,057	,295
	Flow rate	-,004	-1,236E-5	,000	,001	-,004	-,003
	TTC	,049	-,002	,130	,702	-,183	,299

a. Dependent Variable: Speed Variance

*Approach 2: **Left Lane,** dependent variable : Speed*

Table 11: ANOVA: The effect of the light plans on the unexplained variance of average speed Approach 2:, left lane

Tests of Between-Subjects Effects					
Dependent Variable: Unstandardized Residual					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	450,226[a]	4	112,556	8,272	,000
Intercept	,019	1	,019	,001	,971
Light plan	450,226	4	112,556	8,272	,000
Error	11579,860	851	13,607		
Total	12030,086	856			
Corrected Total	12030,086	855			

Table 12: Post hoc (LSD): Comparing the effect of the different light plans on the unexplained variance of average speed Approach 2:, left lane

Multiple Comparisons						
Dependent Variable: Unstandardized Residual						
(I) Light_plan	(J) Light_plan	Mean Difference (I-J)	SE	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	1	-1,307*	,408	,001	-2,107	-,506
	2	-,157	,398	,693	-,938	,624
	3	-,873*	,404	,031	-1,667	-,079
	4	-1,935*	,399	,000	-2,718	-1,152
1	2	1,150*	,398	,004	,3681	1,931
	3	,434	,405	,284	-,361	1,229
	4	-,628	,399	,116	-1,412	,156

*. The mean difference is significant at the ,05 level.

Approach 2: **Left Lane,** dependent variable : Speed variance

Table 13: ANOVA. The effect of the light plans on the unexplained variance of speed variance. Approach 2:, left lane

Tests of Between-Subjects Effects					
Dependent Variable: Unstandardized Residual					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	11,270[a]	4	2,817	,769	,546
Intercept	,009	1	,009	,003	,960
Light plan	11,270	4	2,817	,769	,546
Error	3089,173	843	3,664		
Total	3100,443	848			
Corrected Total	3100,443	847			

Table 14: Post hoc (LSD): Comparing the effect of the different light plans on the unexplained variance of speed variance. Approach 2:, left lane

Multiple Comparisons						
Dependent Variable: Unstandardized Residual						
(I) Light plan	(J) Light plan	Mean Difference (I-J)	SE	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	1	,0767	,212	,717	-,339	,492
	2	-,0325	,208	,876	-,441	,376
	3	,0557	,210	,791	-,357	,468
	4	-,242	,207	,242	-,649	,164
1	2	-,109	,208	,600	-,518	,300
	3	-,021	,210	,921	-,434	,392
	4	-,319	,208	,125	-,726	,088

*. The mean difference is significant at the ,05 level.

Left Lane *Interpretation of the results*

The results show that the light plans can only explain the variation of average speed and does not seem to have an effect on the speed variance. The low correlation between speed and speed variance already indicated that the drivers were not influenced by other traffic in their choice of speed. This could also explain why the effect of TTC became insignificant after bootstrapping was performed. The left lane was generally not saturated (see also Figure 15).

That the light plans do not significantly influence speed variance but do influence average speed suggest that the light plans are most effective when gaps are large and a drivers speed selection is not influenced by other road traffic. A logic explanation for this is that the light emitting road marking increases the visibility of road markings further ahead, closer by the retro reflective material makes road marking visible. When there are less vehicles on the road and gaps are bigger the light emitting road markings can provide information from a further distance.

Based on the coefficient table of the regression analysis (Table 8) it can be seen that the first, fourth light plans increased the average driving speed. This was also the case for light plan 3, but that effect was very small. Tight plan during week 2 did not show a significant different with the baseline week. The small effect of light plan 3 can be explained by the fact that the light was barely visible as the settings were not good. Table 12 shows this effect as well, naturally the results of light plans to the baseline are almost identical to the B coefficients of the regression. Comparing the light plan 2-4 to light plan 1 it can been seen that the light plan of condition two significantly decreased the average speed.

*Approach 1: **Right Lane**, dependent variable : Speed*

The residuals were normally distributed W = .976, $p < .001$. There was a motivation to test for heteroscedasticity Calculating the regression model with heteroscedasticity-consistent standard errors using the HC3 procedures all predictors remained significant and the coefficients showed similar values (appendix E).

Table 15: Model summery regression analysis predicting average speed, approach 1, right lane

Model Fit [e]				
Model	R	R Square	Adjusted R Square	SE of the Estimate
4	,856[d]	,733	,732	1,55948

e. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1, Sensor, Flow rate, TTC, average, Length, Mist, Rainfall.

Table 16: Coefficients regression analysis predicting average speed, approach 1, right lane

Coefficients [a]								
Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
4	*(Constant)*	85,890	,360		238,820	,000		
	Light_plan_1	1,339	,152	,178	8,834	,000	,531	1,882
	Light_plan_2	,557	,153	,074	3,644	,000	,522	1,917
	Light_plan_3	,973	,149	,129	6,546	,000	,552	1,811
	Light_plan_4	1,659	,152	,221	10,928	,000	,525	1,906
	Sensor	1,020	,055	,277	18,612	,000	,971	1,029
	Flow rate	-,009	,000	-,762	-44,055	,000	,720	1,390
	TTC	,349	,087	,071	4,028	,000	,690	1,449
	Mist	-,523	,131	-,061	-3,988	,000	,918	1,089
	Rainfall	-,482	,126	-,062	-3,818	,000	,818	1,222

a. Dependent Variable: Average Speed

Approach 1: **Right Lane**, dependent variable : Speed variance

The residuals were normally distributed W = .945, $p < .001$.

Table 17: Model summery regression analysis predicting speed variance, approach 1, right lane

Model Summary [e]				
Model	R	R Square	Adjusted R Square	SE of the Estimate
4	,743[d]	,552	,549	,78952

e. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1, Sensor, Flow rate, TTC, average, Length, Mist, Rainfall.

Table 18: Coefficients regression analysis predicting speed variance, approach 1, right lane

Coefficients [a]								
Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
4	*(Constant)*	7,497	,349		21,470	,000		
	Light_plan_1	,283	,077	,096	3,693	,000	,531	1,884
	Light_plan_2	,262	,077	,089	3,383	,001	,521	1,919
	Light_plan_3	,524	,075	,178	6,956	,000	,551	1,814
	Light_plan_4	,386	,077	,132	5,011	,000	,523	1,910
	Sensor	,166	,028	,116	5,978	,000	,968	1,033
	Flow rate	-,003	,000	-,647	-27,242	,000	,641	1,560
	TTC	-,021	,045	-,011	-,470	,638	,671	1,491
	Mist	,505	,052	,198	9,688	,000	,864	1,157
	Rainfall	-,030	,066	-,009	-,458	,647	,918	1,089

a. Dependent Variable: Average Speed

*Approach 2: **Right Lane**, dependent variable : Speed*

Table 19: ANOVA: The effect of the light plans on the unexplained variance of average speed. Approach 2:, Right lane

Tests of Between-Subjects Effects					
Dependent Variable: Unstandardized Residual					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	309,082[a]	4	77,271	33,084	,000
Intercept	,003	1	,003	,001	,970
Light plan	309,082	4	77,271	33,084	,000
Error	2903,137	1243	2,336		
Total	3212,219	1248			
Corrected Total	3212,219	1247			

a. R Squared = ,096 (Adjusted R Squared = ,093)

Table 20: Post hoc (LSD): Comparing the effect of the different light plans on the unexplained variance of average speed. Approach 2:, Right lane

Multiple Comparisons						
Dependent Variable: Unstandardized Residual						
LSD						
(I) Light plan	(J) Light plan	Mean Difference (I-J)	SE	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	1	-1,063*	,137	,000	-1,338	-,794
	2	-,283*	,137	,039	-,552	-,015
	3	-,727*	,137	,000	-,996	-,458
	4	-1,364*	,137	,000	-1,632	-1,096
1	2	,780*	,137	,000	,511	1,048
	3	,336*	,137	,014	,068	,6051
	4	-,301*	,137	,028	-,568	-,033

*. The mean difference is significant at the ,05 level.

Approach 2: **Right Lane**, dependent variable : Speed variance

Table 21: ANOVA: The effect of the light plans on the unexplained variance of speed variance. Approach 2:, Right lane

Tests of Between-Subjects Effects					
Dependent Variable: Unstandardized Residual					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	28,644[a]	4	7,161	11,488	,000
Intercept	4,288E-5	1	4,288E-5	,000	,993
Light plan	28,644	4	7,161	11,488	,000
Error	774,780	1243	,623		
Total	803,423	1248			
Corrected Total	803,423	1247			

a. R Squared = ,036 (Adjusted R Squared = ,033

Table 22: Post hoc (LSD): Comparing the effect of the different light plans on the unexplained variance of average speed. Approach 2:, Right lane

Multiple Comparisons						
Dependent Variable: Unstandardized Residual						
LSD						
(I) Light plan	(J) Light plan	Mean Difference (I-J)	SE	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	1	-,215*	,071	,002	-,354	-,077
	2	-,187*	,071	,008	-,325	-,048
	3	-,461*	,071	,000	-,600	-,322
	4	-,312*	,071	,000	-,451	-,174
1	2	,029	,071	,683	-,110	,168
	3	-,245*	,071	,001	-,384	-,107
	4	-,096	,071	,171	-,235	,042

*. The mean difference is significant at the ,05 level.

Right Lane *Interpretation of the results*

The results of the data on the right lane show two important differences with result on the right lane. Firstly the light plans increase speed variance. The effect is very small during the first two testing weeks, increases to almost 0.5 km/h in the second week and then decline during the last week. No good explanation can be given but the following is suggested. The light yellow colour (instead of amber, but similar) did provoke an association which might led so small confusion and caused a higher differences in driving speed. During the last week the effect was less either because drivers were already a bit used to the colour or the message was less ambiguous. But it is more likely that between these two weeks speed variance was lower because the average speed was higher (Aarts & Van Schagen, 2006). Note that the light plans show different effect between the other weeks for average speed and speed variance suggesting that implementing colour caused the difference in speed variance.

Secondly the results on the right lane regarding to average speed show similar but a bit more modest effects compared to the right lane. Though, on the right lane the positive effect of the light plan was significant but very small. This can be explained by the fact that speed selection of right lane drivers is more affected by other traffic. As and also the weather.

2.2 Qualitative Study

During the testing period qualitative data regarding peoples' experiences with and opinions to the light emitting road marking were collected via online questionnaires. This chapter describes the approach of analysing the qualitative data as well as the results that emerged from this. It ends with a conclusion based on the outcomes of this study.

2.2.1 Analysis

The survey tool from Survio used to develop the questionnaire and to collect the data also provided options to document the answers. Weekly reports are found in appendix G. The reports quantified all closed-end questions. Answers to the open-end questions were stated in order of reply without connection to any characteristic of the participant. Using the online tool individual responses could be accessed and answers could be linked to a user name. In addition usernames showed if the different questionnaires were filled out by the same participants or not.

Before the data was analysed the questionnaires were counted and checked for missing answers. Analysis started with data of the general questions, such as age and gender. Additionally the date and time of passing the test section were examined as well as the type of vehicle. Secondly the data of the open ended questions was analysed using a cluster analysis (Figure 17). After reading all statements four clusters or categories were set up: *Visibility [yellow], Safety [purple], Experience & comfort [pink],* and *Other [light blue].* All responses were assigned to a cluster by given them a colour (Yellow, orange, pink and blue). The next step was to assign a positive, negative or neutral value to the responses within a category (+ ,- or ,+/-).

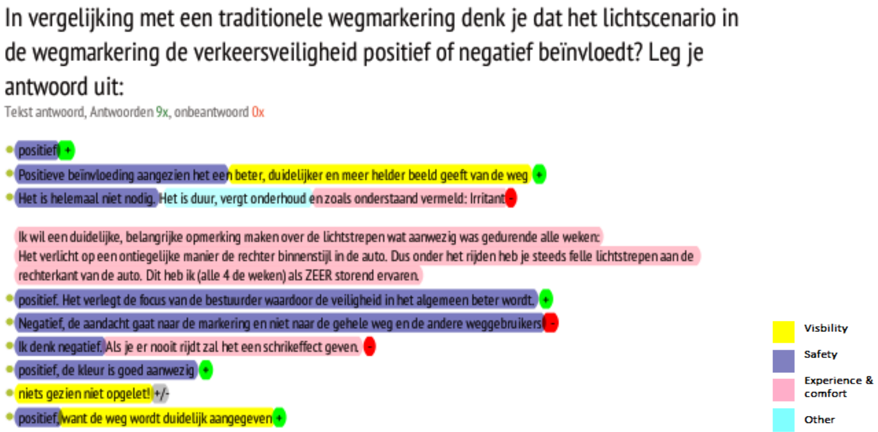


Figure 17: Example of the colour and value coding of the cluster analysis. Source: laatste week Evaluatie "verlichting in de weg markering".

Once the qualitative data was coded all statements were collected per category per condition (light plan) and summarized (Appendix G). Finally the summarized result of the matrix questions are stated. These results were generated by the Survio but stripped from any quantitative value. The response rate is too low to assign any quantitative value to the different answers though the graphs do show the common qualitative attitude towards the light technology.

2.2.2 Results

Overall the general response of the participants was positive with judgements concerning clear visibility of the road and a better demarcation of the width and course of the road. This assessment was given throughout all the weeks. Both open-end as well as the matrix questions support this conclusion. None of the results indicate a situation that was worse than before in terms of visibility.

Concerning safety the responses were more divided. Were several participants considered a positive influence on traffic safety others determined the light affected traffic safety negatively. Positive reactions were related to better visibility, alertness, easier to stay on the road and a comfortable feeling of security. In Part II. the theory shows that traffic safety improves with these aspects –visibility, attention, demarcation of the road. Negative reactions discussed topics such as distraction from traffic and a shocking effect. These reactions were mostly given in the first testing weeks suggesting that habitation towards the lights has occurred.

The third category – experience & comfort- showed the most diversity among its answers. There were respondents that evaluated the light "*pretty", "pleasant", "comfortable", "an improvement for roads in the dark"* and people would like to see a such light for a longer stretch and on more roads. One person was curious when passing the light and one other had the feeling of a narrower road. Though the result of the matrix question was always open and never oppressively. The rest of the results of the matrix questions also showed positive scores in general. But there are also several negative experiences, all describing the flickering and reflecting effect of the lights. One comment made was: *"tuning the intensity settings should be well considered".* And as answers showed either an increase or decrease of the flicker effect between the different plans, which should be taken into account in further development of the technology. It must be noted that this concerns not only the intensity as well as the colour of the light. The amber coloured light settings were evaluated more comfortable by both the people which already had a positive attitude and the persons which hold a negative attitude towards the implementation of the light. The latter was considered surprising since the colour amber is often used for warnings in traffic (Part II. CH2.1). On the other hand, we also learned that people have preference for warm coloured light (Part II. CH3.2).

Lastly, people were not good in the detection of the different light patterns. Only one person noticed one of the dynamic patterns. A difference was noticed when the colour changed however not all that noticed a difference described the change correctly. Thereby it must also be said that these people were probably more attentive to any change by the fact that they participated in this study. This means that it can be suggested that, if minor, changes in light plans for the light emitting road marking are not consciously detected and processed. This would contribute to the theory of nudging provided that there is a change in driving behaviour.

3. Conclusion

This chapter includes the conclusions of both the quantitative and qualitative measurement. Together sub questions four can be answered.

3.1 Quantitative analysis

Based on the results of the traffic analysis it can be concluded that light integrated in the road marking increases driving speed. This means that the null hypothesis can be rejected and the first alternative hypothesis is accepted.

~~H0. There is no difference in driving behaviour due to the activation of lights in the road marking~~

H1. There is a difference in driving speed due to the activation of lights in the road marking.

The alternative hypothesis was further defined into four expectations. From which the first hypothesis can be accepted.

- H1.1 Speed will be higher under the light plan 1 as visibility on the course of the road increases.

Taking into account the theory of risk homeostasis it can be argued that the this not necessarily decreases traffic safety. Based on the difference between the left and the right lane it can be concluded that visibility of the light emitting road marking is higher when there are less vehicles on the road and gap times are bigger. If the visibility of the course of the road increases it can facilitate faster driving speed because it is easier to anticipate on the road, which in this case is almost straight. In other words the light emitting road marking decreases the perceived risk on the road in the dark whereby people can adopt higher speeds in order to reach their preferred level of risk.

The second expectation is both accepted as well as rejected

- H1.2 Speed will be lower under light plan 2 because perceived speed increases.

The second light plan barely resulted into a difference in average speed compared to a situation with traditional road marking (baseline). But there was a significant decrease in driving speed when the results of light plan 2 were compared to light plan 1. Since this was the only parameter that was changed the pattern is responsible for the slower average driving speed. This indicates that a denser the pattern in the broken road marking, moving in opposite direction of the traffic stabilizes the effect of risk homeostasis. So visibility of the course of the road declines perceived risk, however drivers do act upon this effect by increasing their speeds.

The last two hypothesis need to be rejected.

- ~~H1.3 Speed will be lower under light plan 3 due to associations with colour amber.~~
- ~~H1.4 Speed will be lower under light plan 4 due to associations with colour amber and the effect will be bigger compared to light plan 4.~~

During the weeks in which light plan 3 and 4 were activated speeds significantly increased. This effect was very small for the third light plan, explained by the effect that visibility was low compared to light plan 1 and 4. The effect of light plan four was very big, almost two kilometre per hour more. One could argue that light plan 4 amplified the effects of light plan 3 and H1.4 is partially true. However since the colour settings were not exactly the same this cannot be said with certainty and therefor this last hypothesis is fully rejected. Discussing the results of these light plans it can be said that the expectations were not only not met but the opposite effect was even detected. Hence it can be concluded that it is not possible to just estimate the reactions of drivers based on familiar cues in the road environment.

3.2 Qualitative analysis

Based on the qualitative feedback of drivers on the test road it can be concluded that there is a difference in driving experience on a road with light emitting road marking and therefore the second alternative hypothesis can be accepted.

H2. There is a difference in driving experience due to activation of lights in the road marking.

Conclusions regarding hypothesis 2.1-2.4 are a bit more ambiguous. The first expectation proposed the relation between increased visibility and driving comfort.

- H2.1 Average driving comfort under the condition of light plan 1 will increase as visibility on the course of the road increases.

This was true for most drivers so the hypothesis is expected however notion must be made that there was a minority which described uncomfortable flashing of light in the peripheral visual field.

The second expectation was rejected.

- ~~H2.2 Average driving comfort under the condition of light plan 2 will decrease as more and moving stimuli are provided in the driving environment.~~

Only one person made notion of the dynamic patter in the second testing week. Other responses reported nog change or change that mentioned a calmer situation. So it cannot be concluded that light plan 2 provided the road user more stimuli, at least they did process this consciously.

Light plan three and four were rejected as well as drivers did not seem associate the light colour hue (light yellow or amber) with the an association which made them more alert.

- ~~H2.3 Alertness under the condition of light plan 3 will increase due to the association with colour amber.~~
- ~~H2.4 Alertness under the condition of light plan 4 will increase due to the association with flashing coloured amber lights.~~

During the last two testing weeks drivers did not seem to have created an association with the amber coloured dynamic pattern that induced a higher level of alertness. Conversely drivers described a calmer, more dimmed and more comfortable light setting. This was even pointed out by the drivers which mentioned the disturbing effect from the light. A more comfortable light setting could explain the increased average speeds which were measured.

3.3 Combined conclusion

In the end the conclusions of both measurement an answer can be given to the fourth sub question that was set up.

SQ4: Do the light scenarios based on theory have the aimed results in the field?

Not unexpected this question cannot be answered by a simple yes or no, merely because the light scenarios were based on different theories. The light emitting road marking do improve visibility on the road, and although it was not desired the increased average speeds indicated an improvement of the road according to the theory of risk homeostasis. Thereby it must be mentioned that the test section was an almost straight road with a calm organization of the road side. The results should therefore be seen from a driver perspective. The light emitting road marking provided visual information about the road of the in the dark which was: the road in the distance is straight (there is no need for slower speeds). The negative effect of increased visibility could however be fully eliminated by a dynamic denser road marking pattern while the positive effect remained. This confirms the theory that increasing the perception of speed with light emitting road marking induces speed reduction. And while the information of the course of the road was also provided this situation is suggested to be safer than the dark road environment.

The last two light plans showed a reverse effect compared what was expected. Amber coloured light resulted in higher speeds. This refutes the theory that amber coloured light could evoke the association to be cautions and result into lower driving speed. This effect was even found when the effect of increased visibility was removed (by comparing it to light plan 1). The responses of the road user suggest that the estimated association was incorrect, rather than a different reaction to the estimated association. Feedback of the road users described the light setting wad perceived as more comfortable. This could explain the higher driving speeds.

III. General Discussion & Recommendations

1. General Discussion

Within this report two fields of research were brought together in order to explore the potential of light emitting road marking, that of mobility and light science and technology. The light industry is moving towards a full solution and service industry which gives light not only a more prominent place in our urban environment but also provides opportunities in the traffic and transport sector. This research has been a search to obtain the knowledge of how to utilize the possibilities of light in mobility related matters. More precise, a literature study was combined with a field experiment to investigate the potential of light emitting road marking and so to improve traffic safety on the Dutch roads. Here, a reflection is made on the conclusions to provide the answer to the main research question.

Based on the empirical data from the field experiment it can be concluded that light in the road marking improves the road situation but as people aim to always drive at a preferred level of risk this leads to increased speed, which is considered less safe driving behaviour. Though, the test setting should be taken into account when a general conclusion is constructed. On the test road the light emitting road marking did not signal drivers to slow down as they provided the message that the road was (almost) straight, it signals: “there is no need to anticipate on the course of road” and so higher speeds can be adopted. In this case it should be argued that lower speed might not be the best measurement for safer driving behaviour.

The contrary can be said about inducing a perception of higher speeds. No significant difference in average driving speed was found between the traditional situation and the condition which aimed to raise the perceived speed. Analysing the effect on a deeper level resulted in the conclusion that this means safety in this situation was improved. It is explained as follows, a dynamic denser pattern that causes a higher perception of speed eliminates the negative consequence of light in the road marking (i.e. speeding to reach a preferred level of risk) while at the same time the positive effect of increased visibility on the road is preserved. These findings show light scenarios that increased speed perception nudges drivers towards safer driving. Furthermore, the visual cues that induce the perception of higher speed are processed on the lowest cognitive level, skill-based performance. Hence it can be suggested that light emitting road marking is effective for scenarios that influence the operational driving tasks, in this case influencing the control of driving speed.

Concerning the influence of tactical driving tasks, acted out based on rule-based performance matters are less straight forward. The field experiment did not provide results supporting the theory that light emitting road marking could activate stored rules which would then result into safer driving behaviour neither did the results disprove this theory. The outcome of the field experiment could only explain that on the test road amber coloured light did result into an association with the estimated meaning “caution”. Feedback of the road user indicated the light settings were found comfortable. As the lighting theory makes notion of the preference for warm coloured white light (low colour temperature) it can only be concluded that the association drivers have cannot be bluntly estimated from familiar traffic situation. Again the test road situation needs to be evaluated for making such conclusions. It needs to be taken into account that the test road did not provide any other cue indicating a hazardous situation in which a driver needs to be cautious. This might be a precondition for the activation of stored rules. In terms of road design consistency, the context needs to be congruent to a drivers expectancy. For this test case the clear road design and calm road side organization could direct the interpretation of the colour settings of the light emitting road marking. For this extended research is needed.

In conclusion, what does this imply and how can the main research question be answered?

MQ: What light scenarios for light emitting road marking have the potential to nudge people towards safer driving behaviour?

Most importantly potential of the light scenarios that nudge people towards safer driving behaviour is highly dependent on the road environment and the traffic situation. This research suggests that scenarios which increase visibility of the course road create a safer road environment however this might not lead to lower driving speed due to the theory of risk homeostasis. Light scenarios that influence the skill-based performance have the potential to correct for this negative effect and can nudge people towards safer driving behaviour. This has been confirmed by inducing higher perception of speed by the means of activating a denser dynamic light pattern. The potential of the light emitting road marking to act as a warning or communication tool cannot be confirmed nor denied. For this further research concerning the associations and meanings of different colour hues, colour temperatures and intensities in different traffic environments is needed.

2. Recommendations

The light emitting road marking is an innovative technology that can be used to improve and enliven the road. Most importantly the technology provides information in the driver's central visual field about the course of the road in the dark. By this it is easier for road users to anticipate their driving behaviour on the situation, this is suggested to decrease the perceived risk. At the same time it can result into higher driving speeds. This given the application of this technology in its most basic form, i.e. a light source in the road marking, is considered most suitable on roads that facilitate fast traffic.

To utilize the full potential of smart lighting technology in the road marking it is considered necessary to create well designed light plans which are accustomed to the road environment and the traffic situation in which they are placed. As road design consistency describes, a safe road should meet the expectations of the road user. When light plans are constructed the light settings, colour hue, colour temperature and intensity are found to be very important and should be specified in detail. Light intensity should not be too high as it can cause glare and causes a discomfort which leads to a negative attitude towards the technology. This research cannot provide recommendations for the colour settings other than the fact that a choice of colour cannot bluntly be based on the characteristics of other road or traffic elements. These topics ask for more research.

Although the light technology is context dependent this research provides a list of the opportunities and limitations based on literature (Table 5, p.35 which can be used in creating a light plan. Additionally in this research a translation was made of the opportunities and limitations into five scenarios (Part II, Ch.4.2, p.36) in which several use cases are proposed for the application of the light emitting. *I. Increased visibility II. Adaptive speed perception, III. Warning mechanism, IV. Communication by colours and dynamic patterns, V. Adaptive lanes and traffic distribution.* The field test could confirm effective application of the first two scenarios. For the other applications further research is needed before it can safely be implemented on the road.

So besides increasing visibility the light technology is suggested to be functional as technology that can change a driver's perceived speed. A denser broken light pattern which moves in opposite direction compared to the driver was tested in this research and it was found that it diminished the negative speeding effect due to increased visibility. An advantage of this application is that perceived speed is constructed automatically by our skill-based performance level. Thereby the light plan does not increase the workload needed and cognitive capacity can be used for other driving tasks.

A last recommendation can be made concerning the use of light in an outdoor environment. The development of the light industry has resulted in abundant use of light thereby polluting our night sky and consuming high amounts of energy. Light at night for traffic situations is proven to prevent accidents and so it remains important to install lights on our roads. However not without considering the quantity of light that is needed and quality of the light that should be used. Smart light networks in the road marking can deactivate the light source when there is no need for light, i.e. the moments when there are no cars on the road. Compared to traditional light poles, the light emitting road marking needs lower light intensities. Furthermore light should be shielded in the direction in which light is not needed (in the case of the road lighting to the outer sides of the road) and short wave length, bluish light should be avoided. For coloured hues some research indicates certain colours are more beneficial than others. However, as this field of research is only recently expanding a critical point of view is needed towards these findings.

3. Further research

The explorative character of this research have raised several questions regarding light in our traffic environment, in particular concerning light integrated in the road marking. To some of these questions an answer could be given but others left a need or an opportunity for further research. Here topics are listed that invite both the lighting and the mobility industry to conduct further research.

Extended research on perceived speed.
The light scenario that described altering a driver's perception of speed was considered to have the most potential in nudging drivers towards safer driving behaviour. Extended research should test different light patterns and so define the most optimal light plans. Thereby tests are also needed on other types of roads.

The other light scenarios.
The field experiment tested only four light plans. To discover the full potential of the light emitting road marking tests of the other use cases should be carried out. For some scenarios this means a test section with different characteristics needs to be selected. Concrete uses case for which tests can be conducted are:

- Increased visibility of the course of the road by demarcation of sharp turns.
- Adaptive road marking in merging situations.
- Warning mechanism based on interactive light in possible hazardous situation: like, amber coloured flickering light in the case of congestion.
- Visualizing a green wave between traffic signals in an urban area
- Adaptive rush hour lanes road marking.
- Adaptive lanes changing the direction of traffic dependent on the time of the day.

Stored rules.
More research is needed to discover the perceived meaning of light colour hues and temperatures and dynamic patterns in a traffic environment. Studies should on one hand focus on the possible associations road users have with different types of light. More smart lighting technology are installed in our urban environment. This research has clearly shown that without knowing the effect of the colours and dynamic patterns can result into opposite effects. The field experiment demonstrates that theories described in literature of different field of research cannot simply be combined. The developments in the light industry ask for tests with a specific focus on the traffic environment.

On the other hand a focus is needed on how stored rules in relation to light in a traffic environment are constructed and how new rules can be constructed for the total population of road users. This might seem to describe big interventions however the program "beter benutten" or standardardization of road design by the Dutch authority of road networks show such developments are not impossible.

Other types of road marking
This research focus on light integrated into the edge lines that demarcated the road. But as all road users known there are various types of road marking design (appendix A). An advantage of road design is the fact that it provides a driver information his or her central visual field. So to obtain information no shift of attention is needed and so also no unnecessary conspicuous cues are needed to capture a driver's attention. The light technology provide the opportunity to make all the information road markings provide visible in the dark. Research regarding this topic should focus on the various types of road marking and investigate if integrated light in the road marking has an advantages over traditional road lighting. The economic and social effects of lighting technology should be taken into account.

Envision the future
In the scope of all technological development that is causing rapid change of our environment a look on the can be adopted. Smart mobility will increase the use of smart solution in the car and on the road. The in-car technology takes over more and more tasks of the driver. So driver perception becomes of less importance in the next decades. Still opportunities remain for smart road marking. As autonomous vehicles will be controlling the drive the communication with the drivers becomes obsolete but then communication between the road and the

autonomous vehicle will be given precedence. In this case the output of a light cue should be adapted into a wireless communicative signal.

Another scenario could be envisioned as well. Autonomous vehicles are not far from the point to take over the vehicles used today and question remains if they will ever fully do (think about all the car lover). But its integration is not a question of if the technology will enter the world of traffic but more of when and how. A transition period is needed and here opportunities lie for the light emitting road marking. Smart road (marking) technology can make our road more flexibles to the development of car technology. Think for example on separate lanes for platooning trucks. And then separate lanes for autonomous vehicles. With rapid development one lane might be turned in to two.

Other opportunities seen in the transition towards autonomous vehicles are related to the human factors. There will be a time that technology is so far developed that it can take over most of our driving tasks (especially the boring ones such as driving in traffic jams) but not all as humans are excellent in thinking out of the box and sometimes it might be better to not adhere to the rules and regulations. As drivers will perform less and less driving tasks relinquishing them to technology which causes a us to unlearn our skills and stored rules, meaning more task rely on our active information processing. The question raises what is road environment is needed to provide drivers necessary information without a creating cognitive overload.

References

Aarts, L., & Van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. *Accident Analysis & Prevention, 38(*2), 215-224.

Antonson, H., Mårdh, S., Wiklund, M., & Blomqvist, G. (2009). Effect of surrounding landscape on driving behaviour: A driving simulator study. *Journal of Environmental Psychology*, *29*(4), 493-502.

ANWB (n.d.) Verlichting snelwegen uit, retreived from http://www.anwb.nl/belangenbehartiging/verkeer/verkeersveiligheid/verlichting-snelwegen-uit

ANWB (2012) Standpunt over bezuinigen op verlichting langs autosnelwegen. Retrieved from: https://www.anwb.nl/binaries/content/assets/anwb/pdf/verkeer/alb/verlichting-anwb-standpunt.pdf

Amsterdam werkt aan vloot van zelfvarende boten. (2016, September 19) .Retrieved from http://www.verkeersnet.nl/category/smart-mobility/

Assum, T., Bjørnskau, T., Fosser, S., & Sagberg, F. (1999). Risk compensation—the case of road lighting. *Accident Analysis & Prevention*, *31*(5), 545-553.

Badia, P., Myers, B., Boecker, M., Culpepper, J., & Harsh, J. R. (1991). Bright light effects on body temperature, alertness, EEG and behavior. *Physiology & behavior*, *50*(3), 583-588.

Beter Benutten (n.d.) Ambitie en Doel Beter Benutten. Retrieved from http://beterbenutten.nl/overons

Boyce, P. R. (2014). *Human factors in lighting*. Crc Press.

Boyce, P., & Barriball, E. (2010). Circadian rhythms and depression. *Australian family physician, 39*(5), 307.

Bullough, J. D., Donnell, E. T., & Rea, M. S. (2013). To illuminate or not to illuminate: Roadway lighting as it affects traffic safety at intersections. *Accident Analysis & Prevention*, *53*, 65-77.

Campbell, S. S., & Dawson, D. (1990). Enhancement of nighttime alertness and performance with bright ambient light. *Physiology & Behavior*, *48*(2), 317-320.

Carlsmith & Anderson 1979J.M. Carlsmith & C.A. Anderson, 'Ambient temperature and the occurrence of collective violence: A new analysis', Journal of Personality and Social Psychology (37) 1979, p. 337-344.

CBS, Centraal bureau voor statistiek (2016) Aantal verkeersdoden stijgt naar 621 in 2015.

CBS, Centraal bureau voor statistiek (2016) Factsheet verkeer in Nederland in cijfers.

Chapman, S. G. (2012). The Five Keys to Mindful Communication Using Deep Listening and Mindful Speech to Strengthen Relationships, Heal Conflicts, and Accomplish Your Goals. Shambhala Publications.

Charlton, S. G. (2004). Perceptual and attentional effects on drivers' speed selection at curves. *Accident Analysis & Prevention, 36(5),* 877-884.

Charlton, S. G. (2006). Conspicuity, memorability, comprehension, and priming in road hazard warning signs. Accident Analysis & Prevention, 38(3), 496-506.

CIE (2010). Lighting of roads for motor and pedestrian traffic (2nd ed.). Vienna: Commission Internationale de l'éclairage, CIE.

CIE (2016, August) CIE research strategy. Retrieved from: http://www.cie.co.at/index.php/Research+Strategy

Cinzano, P., Falchi, F., & Elvidge, C. D. (2001). The first world atlas of the artificial night sky brightness. *Monthly Notices of the Royal Astronomical Society*, *328*(3), 689-707.

Communicating color efficiently – red & green (n.d.) retrieved from https://blog.kissmetrics.com/communicating-color-efficiently/

Connekt (2013, October) Beter geïnformeerd op weg. Routekaart 2013- 2023.

Colour blind awareness (n.d.) Colour blindness. Retrieved from : http://www.colourblindawareness.org/colour-blindness/

Costa, G. (1996). The impact of shift and night work on health. *Applied ergonomics*, *27*(1), 9-16.

Crundall, D., & Underwood, G. (2001). The priming function of road signs. *Transportation research part F: traffic psychology and behaviour*, *4*(3), 187-200.

Davidse, R., van Driel, C., & Goldenbeld, C. (2004). The effect of altered road markings on speed and lateral position. *SWOV Institute for Road Safety Research, The Netherlands*.

Davidse, R. (2007). *Assisting the older driver: Intersection design and in-car devices to improve the safety of the older driver.*

Dawson, D., Encel, N., & Lushington, K. (1995). Improving adaptation to simulated night shift: timed exposure to bright light versus daytime melatonin administration. *Sleep: Journal of Sleep Research & Sleep Medicine*.

den Ouden, E. & Valkenburg, R. (2012) Vision and roadmap urban lighting Eindhoven 2030.

den Ouden, E., Valkenburg, R., Aarts, E. (2014). Service design based on smart urban lighting. In: Open *Innovation 2.0 Yearbook 2014* (pp.120-124). Luxemburg Publication Office of the European Union.

Dillman, D. A. (2000). Mail and internet surveys: The tailored design method (Vol. 2). New York: Wiley.

Elliott, M. A., McColl, V. A., & Kennedy, J. V. (2003). ROAD DESIGN MEASURES TO REDUCE DRIVERS'SPEED VIA'PSYCHOLOGICAL'PROCESSES: A LITERATURE REVIEW.

Elvik, R. (1995). Meta-analysis of evaluations of public lighting as accident countermeasure. *Transportation Research Record*, *1485*(1), 12-24.

Elvik, R., Vaa, T., Erke, A., & Sorensen, M. (Eds.). (2009). *The handbook of road safety measures*. Emerald Group Publishing.

European commission (2016, September 14) Road Safety evolution in the EU by population. Retrieved from http://ec.europa.eu/transport/road_safety/specialist/statistics/index_en.htm

European commission (2016, September 14) Road Safety evolution in the EU. Retrieved from http://ec.europa.eu/transport/road_safety/specialist/statistics/index_en.htm

Evans, L. (1996). The dominant role of driver behavior in traffic safety. *American Journal of Public Health, 86*(6), 784-786.

Falchi, F., Cinzano, P., Elvidge, C. D., Keith, D. M., & Haim, A. (2011). Limiting the impact of light pollution on human health, environment and stellar visibility. *Journal of environmental management*, *92*(10), 2714-2722.

Fairchild, M. D. (2013). *Color appearance models*. John Wiley & Sons.

Figueiro, M. G., Bierman, A., Plitnick, B., & Rea, M. S. (2009). Preliminary evidence that both blue and red light can induce alertness at night. *BMC neuroscience*, *10*(1), 1.

Fisher, J. (1992). Testing the Effect of Road Traffic Signs' Informational Value on Driver Behavior. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *34*(2), 231-237.

Fleyeh, H. (2004). Color detection and segmentation for road and traffic signs. In *Cybernetics and Intelligent Systems, 2004 IEEE Conference on* (Vol. 2, pp. 809-814). IEEE.

Fouquet, R., & Pearson, P. J. (2011). The long run demand for lighting: elasticities and rebound effects in different phases of economic development.

French, D. J., West, R. J., Elander, J., & Wilding, J. M. (1993). Decision-making style, driving style, and self-reported involvement in road traffic accidents. *Ergonomics*, *36*(6), 627-644.

Gazis, D. C. (2006). Traffic theory (Vol. 50). Springer Science & Business Media.

Gibreel, G. M., Easa, S. M., Hassan, Y., & El-Dimeery, I. A. (1999). State of the art of highway geometric design consistency. *Journal of transportation engineering*, *125*(4), 305-313.

Glickman, G., Byrne, B., Pineda, C., Hauck, W. W., & Brainard, G. C. (2006). Light therapy for seasonal affective disorder with blue narrow-band light-emitting diodes (LEDs). *Biological psychiatry*, *59*(6), 502-507.

Godthelp, H., Goede, M. D., Hogema, J. H., van der Horst, A. R. A., Martens, M. H., & Rasker, P. C. (2012). Human factors in Traffic Management. State-of-the-Art Background Document.

Goede, M. D., van der Horst, A. R. A., Wilmink, I. R., & Taale, H. (2013). De ontwerpweggebruiker. Kenmerken van de weggebruiker en relatie met verkeersmanagement.

Goldenbeld, C., & J de & Rijsdijk, H. A. (2016). Beïnvloeding van snelheidsgedrag door nudging: vragenlijstonderzoek naar het effect van Dick Bruna-borden op geschatte rijsnelheid binnen de bebouwde kom.

Haans, A., & de Kort, Y. A. (2012). Light distribution in dynamic street lighting: Two experimental studies on its effects on perceived safety, prospect, concealment, and escape. *Journal of Environmental Psychology*, *32*(4), 342-352.

Haans, A., & de Kort, Y. A. W. (2014). Reducing social aggression with dynamic lighting: The De-escalate project in Eindhoven. *Justitiele Verkenningen*, *40*(4), 54.

Hack mee voor slimmer & duurzamer vervoer in Brabant (n.d.) retrieved from http://nextmobilityhack.nl/hackathon/.

Harms, L. (1986) Drivers' attentional responses to environmental variations: a dual task real traffic study. In: Elliott, M. A., McColl, V. A., & Kennedy, J. V. (2003). ROAD DESIGN MEASURES TO REDUCE DRIVERS'SPEED VIA'PSYCHOLOGICAL'PROCESSES: A LITERATURE REVIEW

Harms, L. (1991). Variation in drivers' cognitive load. Effects of driving through village areas and rural junctions. *Ergonomics*, *34*(2), 151-160.

Haus, E. L., & Smolensky, M. H. (2013). Shift work and cancer risk: potential mechanistic roles of circadian disruption, light at night, and sleep deprivation. *Sleep medicine reviews*, *17*(4), 273-284.

Hidayetoglu, M. L., Yildirim, K., & Akalin, A. (2012). The effects of color and light on indoor wayfinding and the evaluation of the perceived environment. *Journal of Environmental Psychology*, *32*(1), 50-58.

Higgins, E. T. (1996). Knowledge activation: Accessibility, applicability, and salience.

Hills, B. L. (1980). Vision, visibility, and perception in driving. *Perception*, *9*(2), 183-216.

Holland, J. (n.d.) Gaining Visual Information. Retrieved from http://slideplayer.com/slide/7758191/

ILI (n.d.) Research. Retrieved from: https://www.tue.nl/onderzoek/instituten-groepen-scholen/toponderzoeksgroepen/intelligent-lighting-institute/research/

International Dark-Sky Association: Light Pollution. (n.d.). Retrieved from http://darksky.org/light-pollution/

International Dark-Sky Association: Night sky heritage. (n.d.). Retrieved from http://darksky.org/light-pollution/night-sky-heritage/

Itti, L., Koch, C., & Niebur, E. (1998). A model of saliency-based visual attention for rapid scene analysis. IEEE Transactions on pattern analysis and machine intelligence, 20(11), 1254-1259.

Kanellaidis, G. (1996). Human factors in highway geometric design. Journal of Transportation Engineering, 122(1), 59-66.

Kennisinstituut voor mobiliteitsbeleid KiM (2015) Mobiliteitsbeeld 2015.

Klein, R. (1991). Age-related eye disease, visual impairment, and driving in the elderly. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *33*(5), 521-525.

Klöckner, C. A., & Matthies, E. (2004). How habits interfere with norm-directed behaviour: A normative decision-making model for travel mode choice. *Journal of Environmental Psychology*, *24*(3), 319-327.

Lamm, R., Guenther, A. K., & Choueiri, E. M. (1995). Safety module for highway geometric design. *Transportation Research Record*, *1512*(9), 7-15.

Leonard, T. C. (2008). Richard H. Thaler, Cass R. Sunstein, Nudge: Improving decisions about health, wealth, and happiness. *Constitutional Political Economy*, *19*(4), 356-360.

Lidwell, W., Holden, K., & Butler, J. (2010). *Universal principles of design, revised and updated: 125 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design*. Rockport Pub.

Lighting Urban Community International (2015, 07) LUCI Charter. Retrieved from: http://www.luciassociation.org/about-luci/charter-on-urban-lighting/

Ling, Y., & Heynderickx, I. (2014). Simulating aged vision for real environments. In *International conference on the Effects of Light on Well-being* (Vol. 36, p. 39).

Loewen, L. J., Steel, G. D., & Suedfeld, P. (1993). Perceived safety from crime in the urban environment. *Journal of environmental psychology*, *13*(4), 323-331.

Mack, A., & Rock, I. (1999). Inattentional blindness. *Psyche*, *5*(3).

Martens, M. H., Compte, S., & Kaptein, N. A. (1997). The effects of road design on speed behaviour: a literature review.

Mather, G. (2009). *Foundations of sensation and perception* (Vol. 10). Psychology Press.

Michon, J. A. (1989). Explanatory pitfalls and rule-based driver models. *Accident Analysis & Prevention, 21*(4), 341-353.

Ministerie van Infrastructuur en Milieu (2015, November) De resultatenkrant. Retrieved from : http://beterbenutten.nl/assets/upload/files/Resultatenkrant_def_13112015.pdf

Mocanu, I., Nitsche, P., & Malone, K. (2014, April). The impacts of cooperative traffic systems on safety, environment and travel times: A literature survey. In *Transport Research Arena (TRA) 5th Conference: Transport Solutions from Research to Deployment*.

Monsere, C. M., & Fischer, E. L. (2008). Safety effects of reducing freeway illumination for energy conservation. *Accident Analysis & Prevention*, *40*(5), 1773-1780.

Nasar, J. L., & Jones, K. M. (1997). Landscapes of fear and stress. *Environment and behavior*, *29*(3), 291-323.

Nasar, J. L., Fisher, B., & Grannis, M. (1993). Proximate physical cues to fear of crime. *Landscape and urban planning*, *26*(1-4), 161-178.

Navara, K. J., & Nelson, R. J. (2007). The dark side of light at night: physiological, epidemiological, and ecological consequences. *Journal of pineal research*, *43*(3), 215-224.

Nayatani, Y. (1997). Simple estimation methods for the Helmholtz—Kohlrausch effect. *Color Research & Application*, *22*(6), 385-401.).

Nederlandse stichting voor verlichtingskunde NSVV. (2015). Nieuwe Praktijkrichtlijn NPR 13201-1.

Ng, J. C., & Sayed, T. (2004). Effect of geometric design consistency on road safety. *Canadian Journal of Civil Engineering*, *31*(2), 218-227.

NLengineers (2016, April 9) Smart Roads: Bring in the Dutch! Retrieved from http://www.nlingenieurs.nl/smart-roads-nieuw-export-product/#.V-KKq_4Qapp.

Nrc, (2013, September 1st) Vanaf vandaag gaat stapsgewijs het licht uit op veel snelwegen. Retrieved from: https://www.nrc.nl/nieuws/2013/09/01/vanaf-vandaag-gaat-stapsgewijs-het-licht-uit-op-veel-snelwegen-a1431961

Nu.nl (2014, April, 22) Schultz houdt verlichting langs snelweg uit. Retrieved from http://www.nu.nl/politiek/3757756/schultz-houdt-verlichting-langs-snelweg.html

Oei, H. L., & Papendrecht, J. H. (2014). Hebben snelheidsborden effect op de verkeersveiligheid?

Okajima, K., & Takase, M. (2001). Computerized simulation and chromatic adaptation experiments based on a model of aged human lens. *Optical review*, *8*(1), 64-70.

Philips (n.d.) ClearField en ClearSky – licht voor de biodiversiteit. Retrieved from http://images.philips.com/is/content/PhilipsConsumer/PDFDownloads/Netherlands/ODLI20160301_001-UPD-nl_NL-11046-PH-Clearfield-Clearsky-A4.pdf

Planbureau voor de leefomgeving (PBL)/ Centraal bureau voor statistiek (CBS), (2016) Regionale bevolkings- en huishoudensprognose 2016-2040: sterke regionale verschillen.

Platform beter benutten (n.d.) Ambitie en doel Beter Benutten. Retrieved October 2016 from http://beterbenutten.nl/overons

Rajaratnam, S. M., & Arendt, J. (2001). Health in a 24-h society. *The Lancet*, *358*(9286), 999-1005.

Ranney, T. A. (1994). Models of driving behavior: a review of their evolution. *Accident Analysis & Prevention, 26(6), 733-750.*

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE transactions on systems, man, and cybernetics*, (3), 257-266.

Rijksoverheid (n.d.) Zelfrijdende auto's en vrachtwagens. Retrieved from https://www.rijksoverheid.nl/onderwerpen/mobiliteit-nu-en-in-de-toekomst/inhoud/zelfrijdende-autos

Rijksoverheid (2008, July, 10) Eurlings: niet 580 maar 500 verkeersdoden in 2020.

Rijkswaterstaat (n.d.) spitsstroken. Retrieved October 2016 from https://www.rijkswaterstaat.nl/wegen/wegbeheer/spitsstroken

Rijkswaterstaat (2013, August, 26) Minder verlichting op de snelwegen. Retrieved from http://www.rijkswaterstaat.nl/over-ons/nieuws/nieuwsarchief/p2013/08/Minder-verlichting-op-de-snelwegen.aspx

Rijkswaterstaat (2013) Veiligheid spitsstroken. Retrieved from https://www.rijksoverheid.nl/documenten/rapporten/2013/04/08/veiligheid-spitsstroken

Salvatore, S. (1968). The estimation of vehicular velocity as a function of visual stimulation. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *10*(1), 27-31.

Schreuder, D. A. (1986). The function of road markings in relation to driver's visual needs (Vol. 86, No. 29). Leidschendam: SWOV.

Schreuder, D. A. (1998). Road lighting for safety. Thomas Telford.

Schreuder, D. (2008). Outdoor lighting: physics, vision and perception (pp. 286-311). New York, NY: Springer.

Sieß, A., Hübel, K., Hepperle, D., Dronov, A., Hufnagel, C., Aktun, J., & Wölfel, M. (2015) Incentive Guidance of Crowds by Smart City Lights. *Mensch und Computer 2015–Proceedings*.

Smets, S (2015, November 5) Slim licht is de toekomst. Retrieved from https://www.nrc.nl/nieuws/2015/11/05/slim-licht-is-de-toekomst-1553037-a441969.

Smolders, K. C. H. J. (2013). Daytime light exposure: effects and preferences.

Smolders, K. C., & de Kort, Y. A. (2014). Bright light and mental fatigue: Effects on alertness, vitality, performance and physiological arousal. *Journal of environmental psychology*, *39*, 77-91.

Smolders, K. C. H. J., De Kort, Y. A. W., & Van den Berg, S. M. (2013). Daytime light exposure and feelings of vitality: Results of a field study during regular weekdays. *Journal of environmental psychology*, *36*, 270-279.

Steg, L., De Waard, D., Lindenberg, S. M., & Brookhuis, K. A. (2010). Acceptatie en gevolgen van groene straatverlichting: Eindrapportage (In opdracht van Gemeente Assen).

Strepen op de weg (2008, January, 01) retrieved from https://www.rijksoverheid.nl/onderwerpen/verkeersregels/documenten/brochures/2008/01/01/nieuwe-strepen-op-de-weg-makkelijker-en-veiliger

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology*, *18*(6), 643.

SWOV, Wetenschappelijk Onderzoek Verkeersveiligheid. (2013, Juli) SWOV-Factsheet: Noodzaak, inhoud en evaluatie van verkeerseducatie.

Taylor, S. E., & Fiske, S. T. (1978). Salience, attention, and attribution: Top of the head phenomena. *Advances in experimental social psychology*, *11*, 249-288.

Theeuwes, J., Alferdinck, J. W., & Perel, M. (2002). Relation between glare and driving performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *44*(1), 95-107.

Tien innovatieve start-ups aan de slag in Rotterdam. (2016, September 15). Retrieved from http://www.verkeersnet.nl/category/smart-mobility/

TNO, Netherlands Organisation for Applied Scientific Research (n.d.) Smart mobility. Retrieved from https://www.tno.nl/en/collaboration/expertise/earth-life-and-social-sciences/smart-mobility/.

Unesco (n.d.). About the Year of Light. retrieved from http://www.light2015.org/Home/About.html.

Van der Klauw, K. (n.d.) Lighting, beyond illumination. Retrieved from: http://www.smart-circle.org/lighting/smart-city-lighting/lighting-beyond-illumination/

Van Kampen (2016) Enlighting the roads of tomorrow. Exploring road users' preferences of road lighting along highways in the Netherlands. Unpublished Master thesis). University of technology, Eindhoven, the Netherlands.

Verlichting, T. (2008). Groen licht voor energiebesparing—eindrapport van de taskforce verlichting. *Report, SenterNovem*.

Viola, A. U., James, L. M., Schlangen, L. J., & Dijk, D. J. (2008). Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality. *Scandinavian journal of work, environment & health*, 297-306.

Wanvik, P. O. (2009). Effects of road lighting: an analysis based on Dutch accident statistics 1987–2006. *Accident Analysis & Prevention*, *41*(1), 123-128.

Wesselink, R.P. (2016) The influence of temporal transitions in coloured road lighting on the visual performance of drivers in mesopic lighting conditions. (Unpublished Master thesis). University of technology, Eindhoven, the Netherlands

Wickens, C. D., Gordon, S. E., Liu, Y., & Lee, J. (1998). An introduction to human factors engineering.

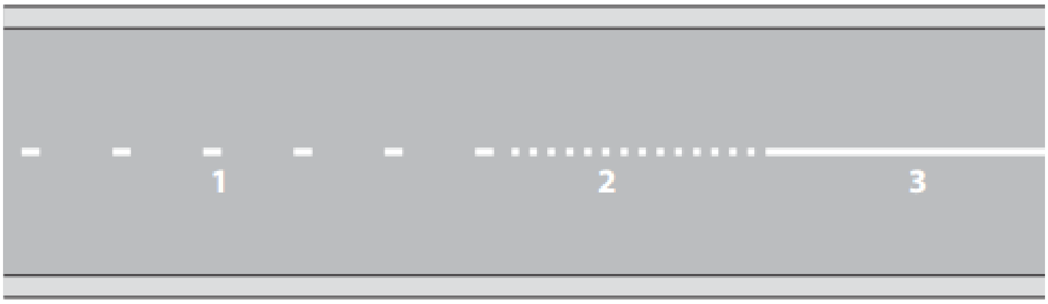
Wood, M. (2012). Article: Lightness - The Helmholtz-Kohlrausch effect. Retrieved from: http://www.mikewoodconsulting.com/articles/Protocol%20Summer%202012%20-%20HK%20Effect.pdf

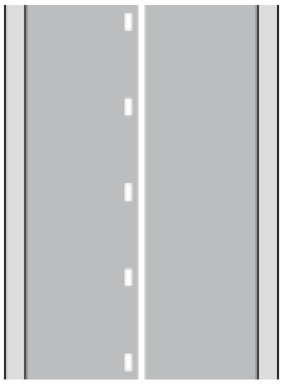
Zhang, J., Fraser, S., Lindsay, J., Clarke, K., & Mao, Y. (1998). Age-specific patterns of factors related to fatal motor vehicle traffic crashes: focus on young and elderly drivers. *Public health*, *112*(5), 289-295.

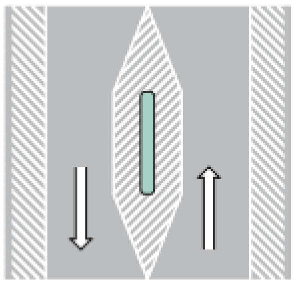
IV. APPENDICES

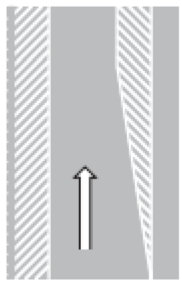
Appendix A –Road marking design

A.1 Road Marking designs that aid driving



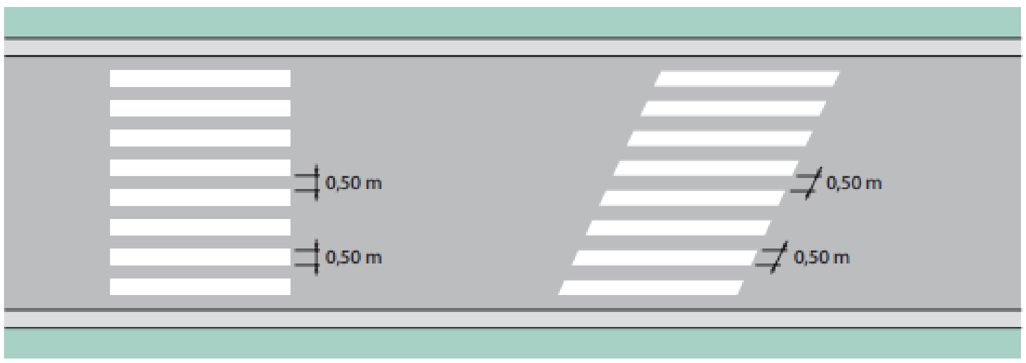


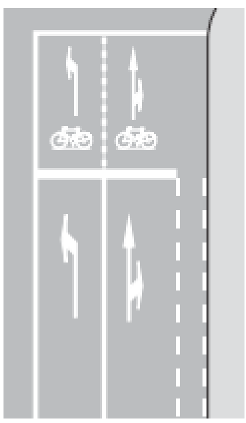


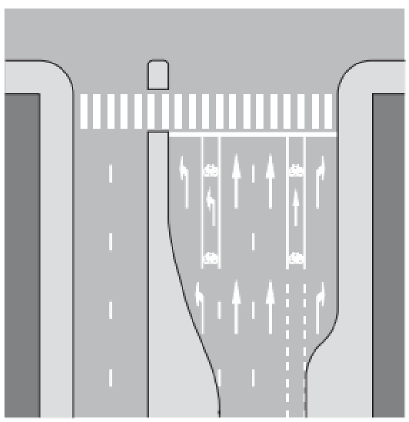


Voorbeelden van de toepassing van strepen

A.2 Road Marking designs that provide information

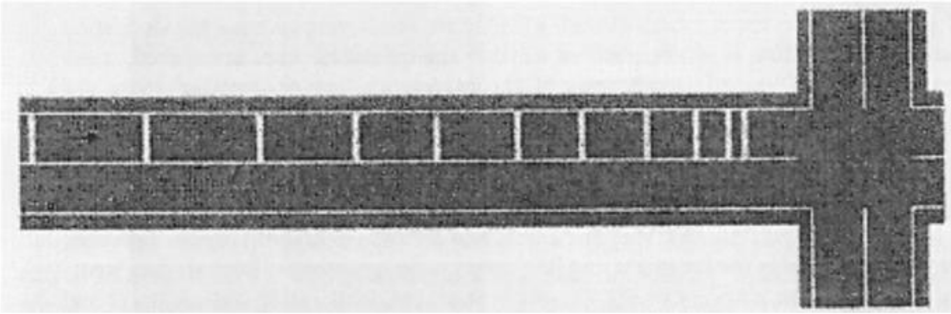




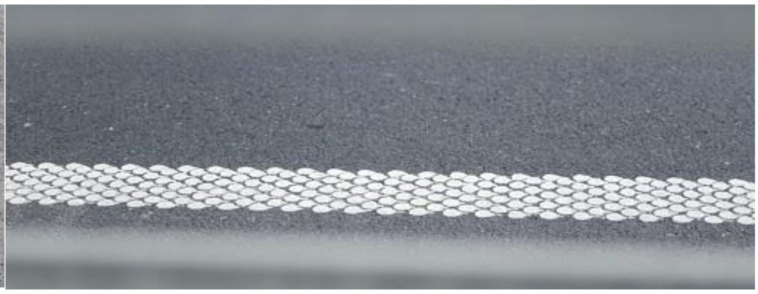


Source: Opzoekingscentrum voor de wege bouw (OCW), (2007) Handleiding voor de uitvoering van wegmarkeringen.

A.3 Road markings design to increase perceived speed



A.2 Road markings design that provide vibrating and auditory feedback



Appendix B – Test Road

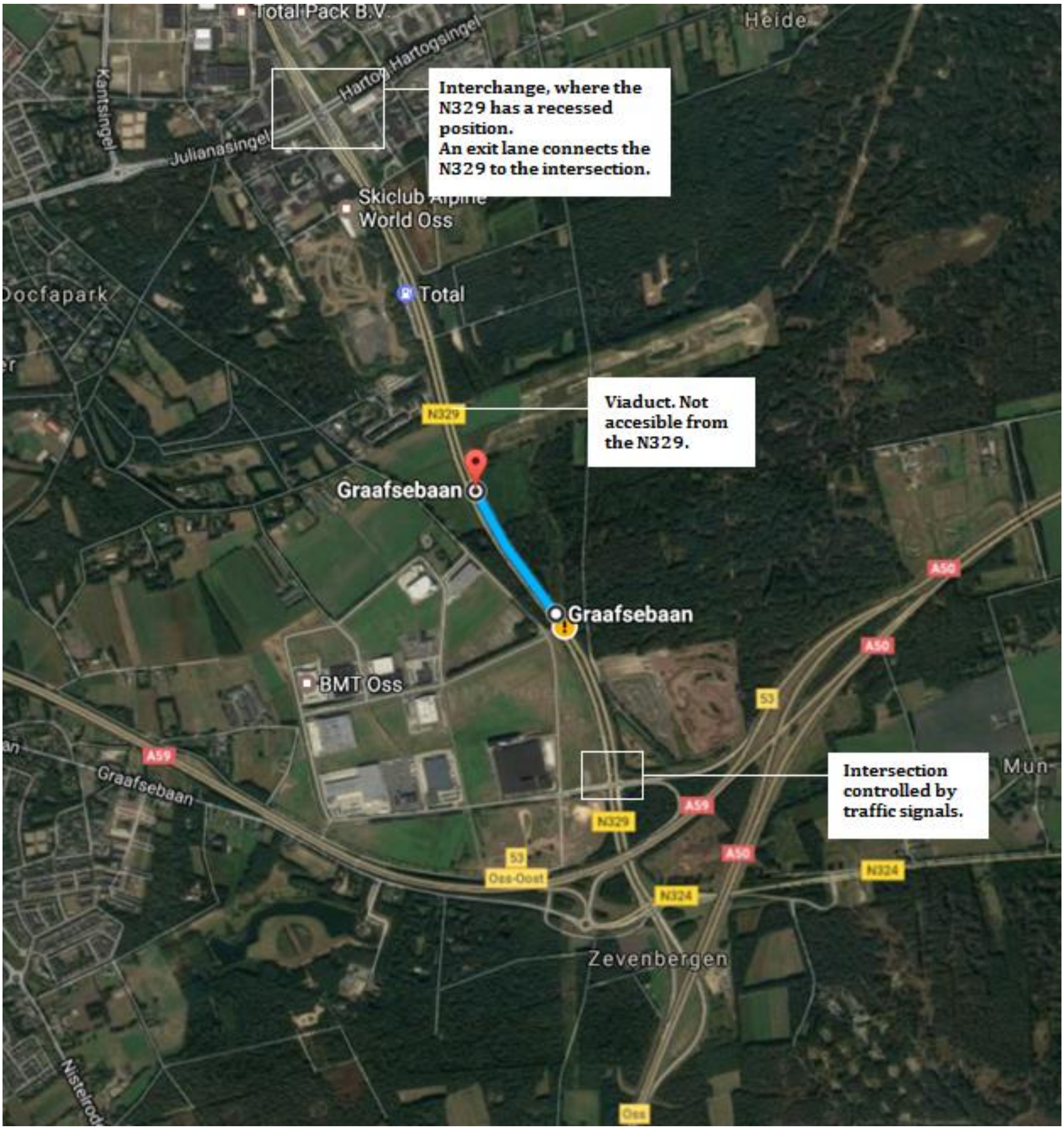


Figure 18: Situation of the N329 on which the test road lies. Source underlying map: Google Maps

Figure 2: Traffic signal controlled intersection prior to the test road. Source: Google Maps.

Figure 3: Viaduct 300m after the test section ends. Source: Google Maps.

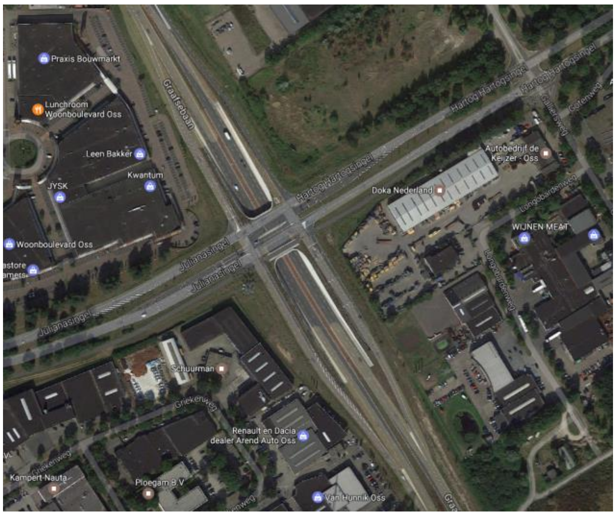


Figure 4: Intersection, where the N329 has a recessed position. Source: Google Maps.

Figure 5: Sequence of the a drivers view starting

Appendix C – Light emitting road marking

-confidential-

Appendix D -Quantitative analysis (Data)

The raw data retrieved from the sensors in the road was very detailed and considered a rich source of information. At the same the data was not structured and was separated over different files. In order to cope with this big data a better understanding was needed of the characteristics of the traffic situation on the N329 the data of the baseline week was studied. Additionally the weather conditions during the five week testing period were mapped.

Average speed and traffic flow

The traffic on the N329 is first defined based on average driving speed and number of vehicles per hour. The graphs in Figure 1 & 2 show the difference in speed and traffic flow per hour, day and lane. As can be immediately traffic flow varies over the hours of the day and between week- and workdays. During the week the rush hour peaks are very clear, in the weekend no spikes in the number of vehicles occur. Average speed, which lies above the speed limit, is rather constant except on the left lane during morning hours. A better look reveals mall drops in average speed during the rush hours on week days.

More meticulously screening of the plots show the lane differences. The left lane show a high variance of speed and traffic flow over the hours and between the different days of the week. Speed on the left lane deviates a lot between different days of the week in the morning hours. During these hours the number of vehicle is very low on both lanes but especially on the left lane. Furthermore the number of vehicle between the rush hour peaks remains quite high on weekdays for the right lane compared to the left. The plots also show most people drive right in the weekend. Lastly the average speed is higher on the left lane and the number of vehicles per hour is higher on the right lane.

Lane 1: Left

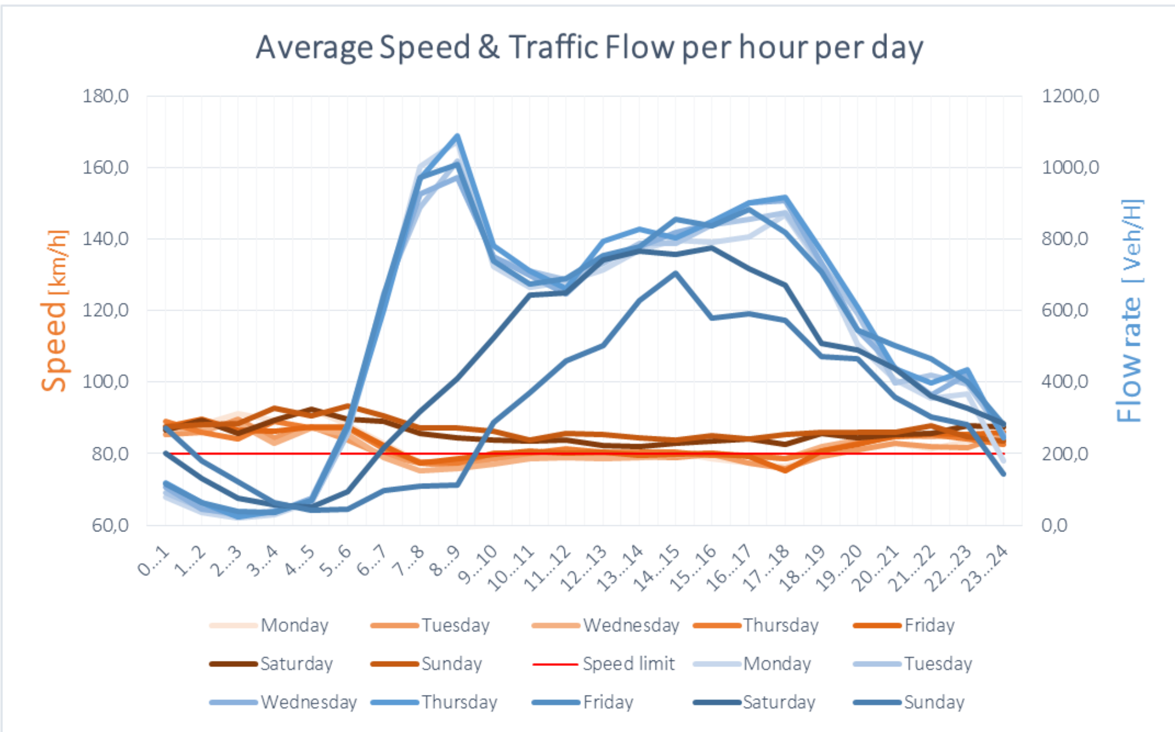


Figure 1: Average Speed and traffic flow per hour per day on the left lane based on data from the measurement position 1. Orange represents the average speed and is plotted on the left Y-axis. Blue represents the traffic flow and should be read from the right Y-axis.

Lane 2: Right

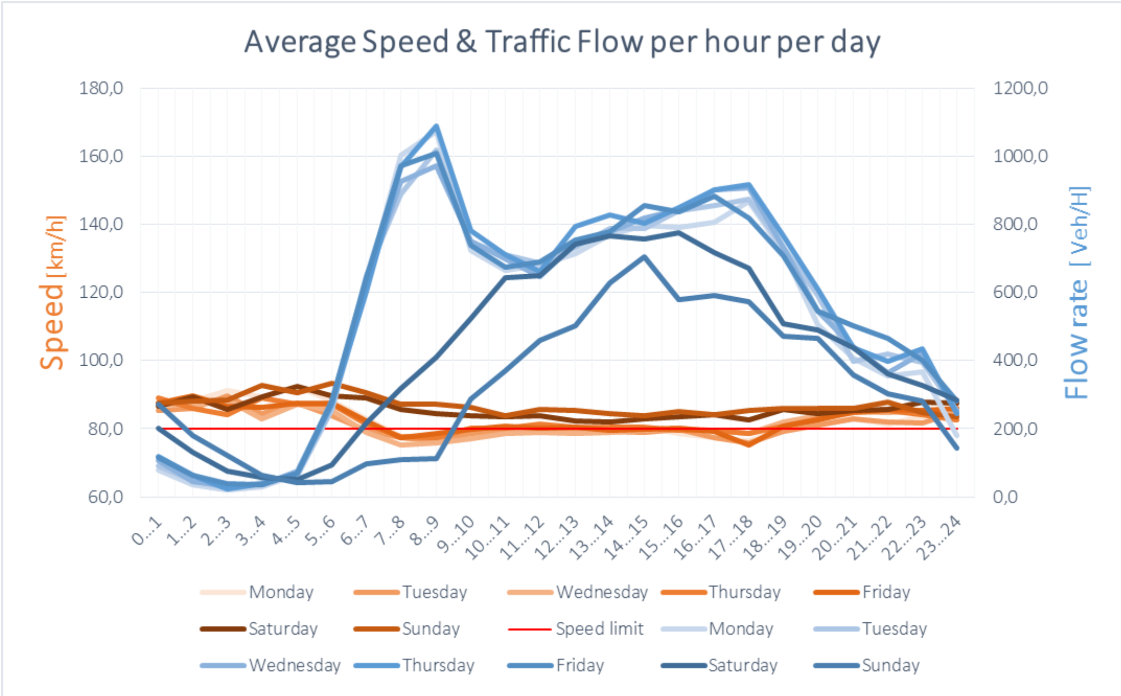


Figure 2: Average Speed and traffic flow per hour per day on the right lane based on data from the measurement position 1. Orange represents the average speed and is plotted on the left Y-axis. Blue represents the traffic flow and should be read from the right Y-axis.

Gap distributions

The plots is figure 3 and 4 show the gap_{time} distributions for both lanes again over the hours of the day, for this with the data of Monday. Based on the traffic flow plots above the Monday can be considered as a representation of a weekday. For the gap_{time} distributions traffic data is categorized using the $_{gaptime}$ critera for excluding data. Note that the total number of vehicles is not the sum of the categories as the first category already holds the total number vehicles.

As the title suggests one should examine at the distribution of the gaps and thus look the differences between the categories. Doing this it can be seen that both graphs show steep distrubtions during peak hours indicating that drivers adopt small gaps; a logical result when density increases. During the night hours the distributions are flat, meaning that from all the gaptimes adopted most of them are bigger than 5s.

Comapring the left lane to the right it can be seen that the right lane shows a more gradual distribution whereby the difference between first and the second category is small compared to the difference between other categories. This suggest drivers adopt a gap_{time} of one second relatively less often. The left lane graph show a much steeper gap_{time} ditribution for the first categories and a flatter distribution among the following cagetories. In other words, there are bigger differences between the first and second and the second and third catergory then between categories four to six, indicating that on the left lane drivers adopt smaller gaps. Note that this happens despite the lower total number of vehicles. The graphs of the weekenddays showed a different pattern between the hours of the day, which can be explained by the difference in traffic flow. Though the plots showed the same effect for the left and right lane –higher difference between the first two categories for left and a smaller difference between the first two categories for right.

Lane 1: Left

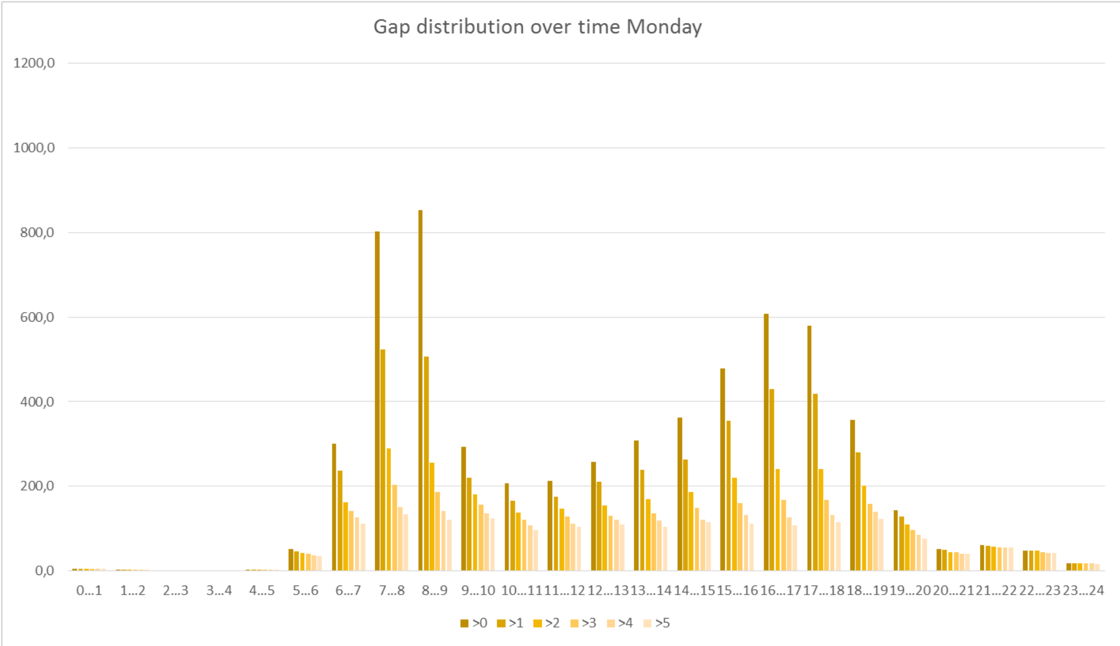


Figure 5: Gap distribution per hour for the left and the right lane on Monday based on data from the measurement position 1.

Lane 2 : Right

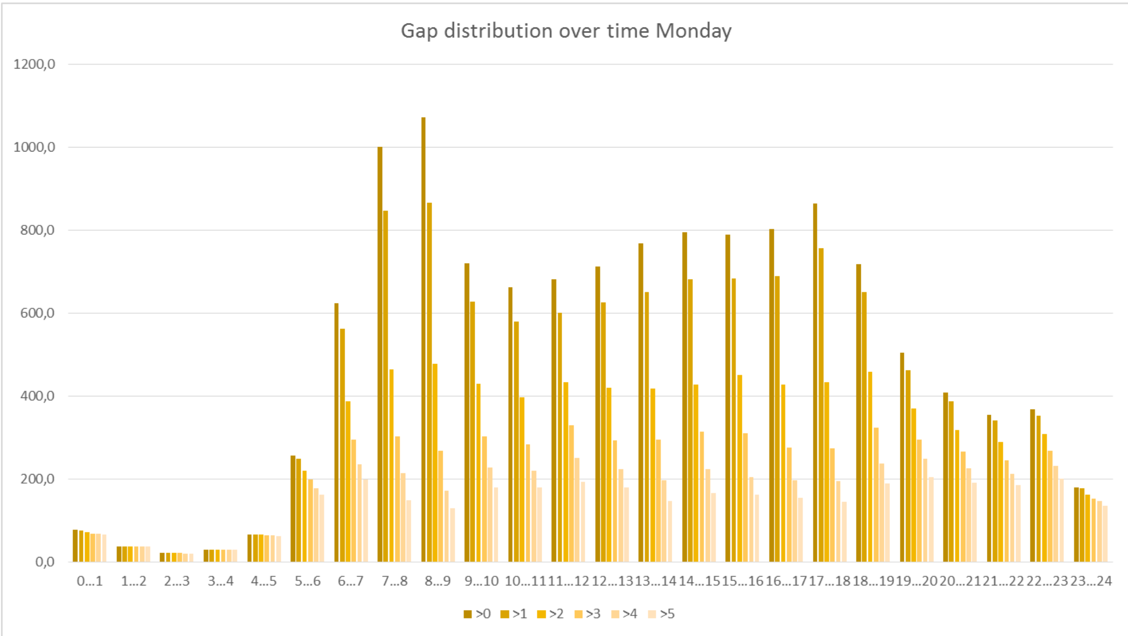


Figure 4: Gap distribution per hour for the the right lane on Monday based on data from the measurement position 1.

Lane 1: Left

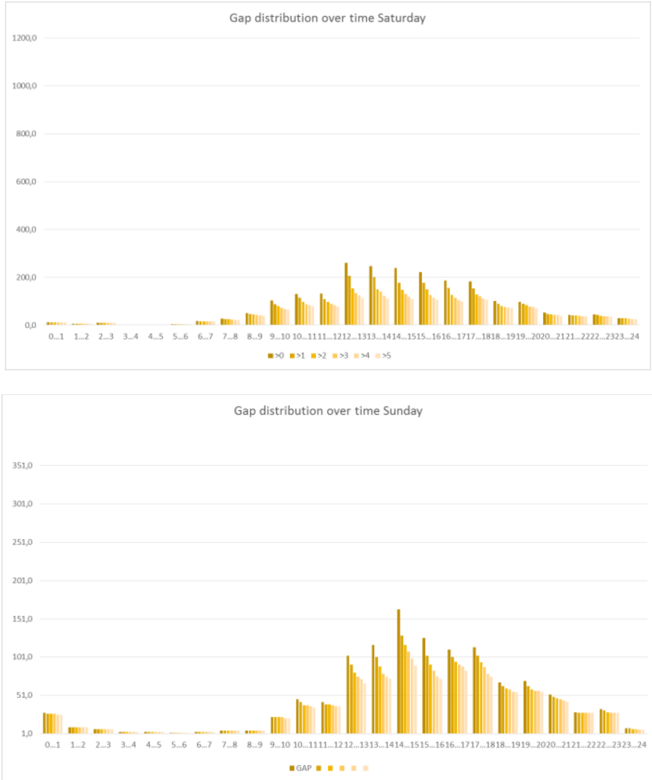


Figure 5: Gap distribution per hour for the left on Saturday and Sunday data from the measurement position 1.

Lane 2: Right

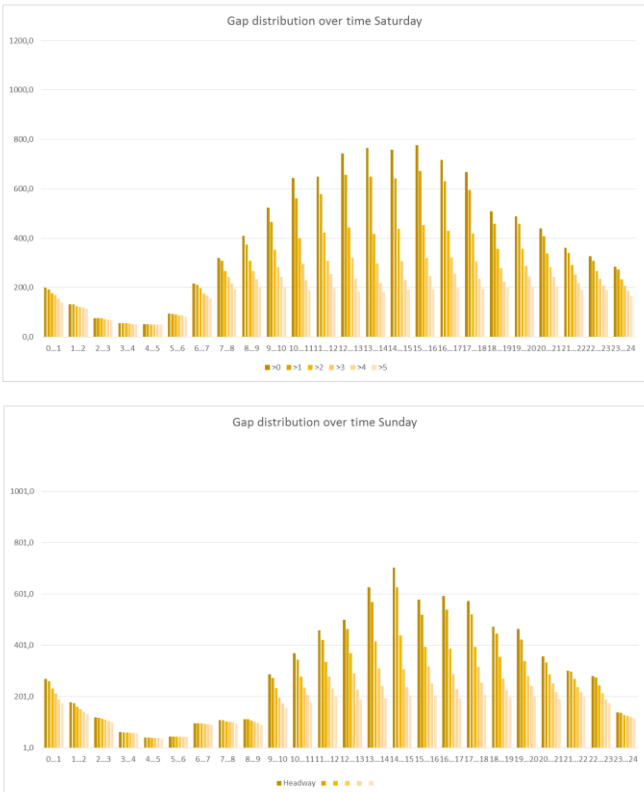


Figure 6: Gap distribution per hour right lane on Saturday and Sunday from the measurement position 1.

Vehicle length

A fourth characteristic that is explored is the Vehicle length. When the point data was converted to hours, vehicle length was separated on vehicle classification. This divided vehicle length in five categories (Statens vegvesen, 2014). Figure 5 and 6 show the vehicle distribution over the hours of the day for both lanes. First, it should be mentioned that the graphs are logarithmically scaled. Knowing this one can conclude that most vehicles that make use of the N329 are shorter than 5.6 m, which suggests that these are passenger cars. Another conclusion that can be made is that, not surprisingly, longer vehicles (>7.6 m) use the right lane. For example where during the day often between 50 – 100 vehicles longer than 16 m drive on the right, not even ten vehicles this long drive on the left.

Lane 1: Left

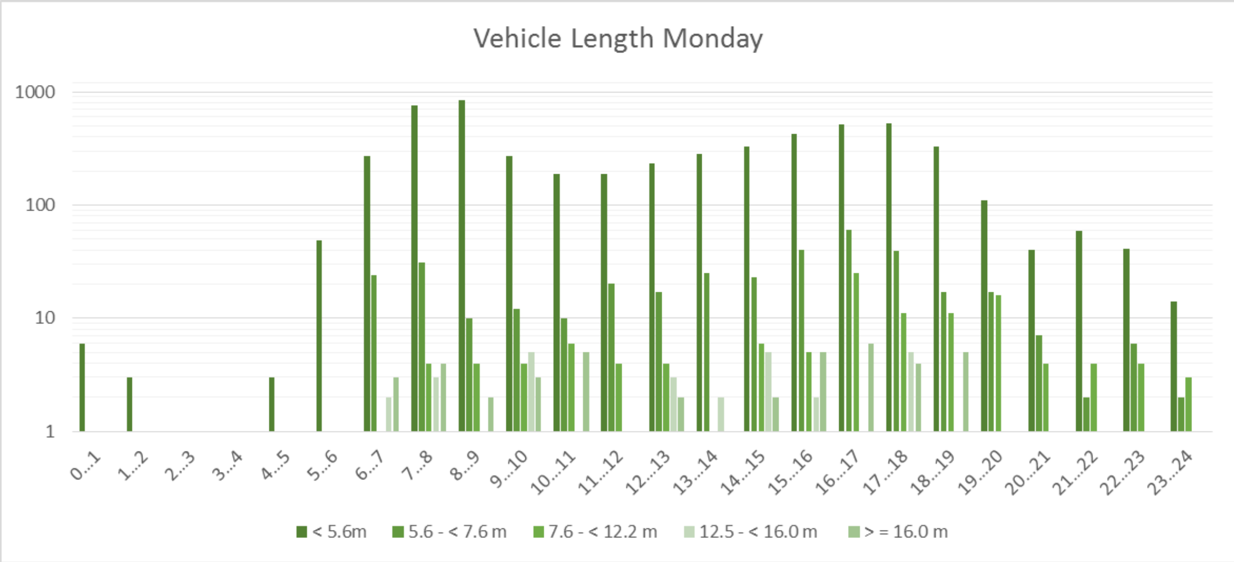


Figure 7 :Vehicle classification per hour for the left lane on Monday based on data from the measurement position 1.

Lane 2 : Right

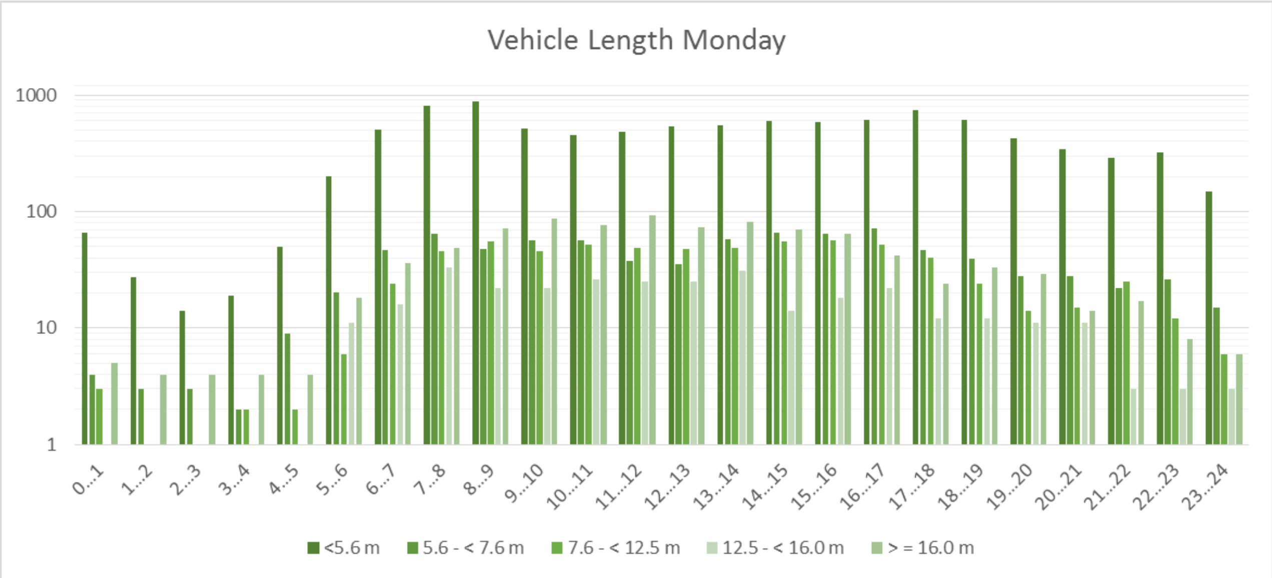
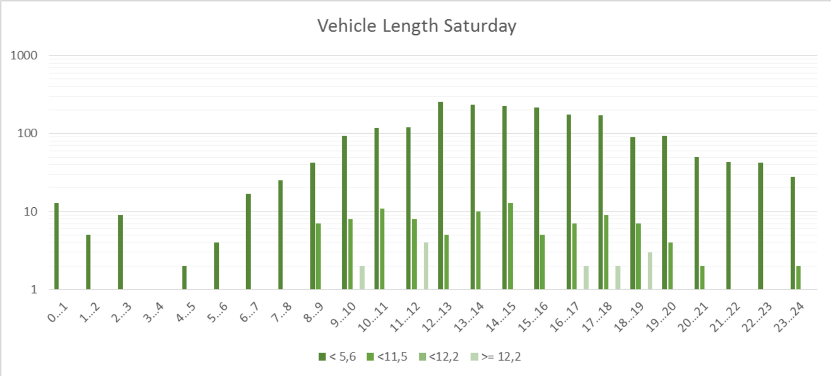


Figure 8: Vehicle classification per hour for the right lane on Monday based on data from the measurement position 1.

Lane 1: Left



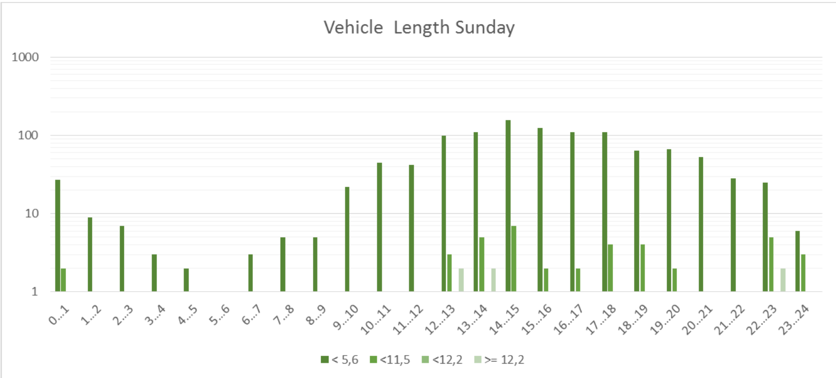
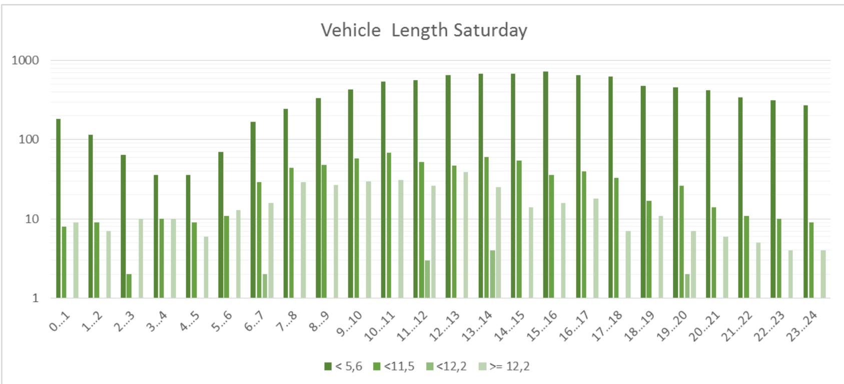


Figure 9: Vehicle classification per hour for the left lane on Saturday and sunday based on data from the measurement position 1.

Lane 2 : Right



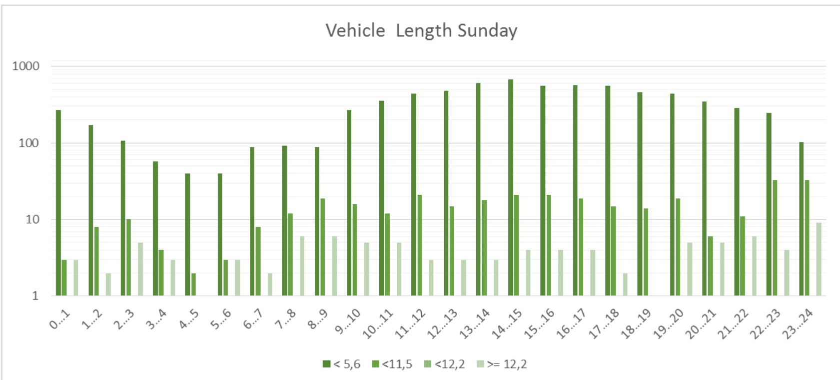


Figure10: Vehicle classification per hour for the right lane on Saturday and sunday based on data from the measurement. Position 1.

Speed profile

Lastly the data enabled plotting the speed profile for both lanes. The graphs show again the higher speed levels and a bigger variety of average speed levels on the left lane. Generally the graphs shows that within the hour the speed profile is more or less constant, especially if the night hours are not taken into account. Comparing the different days some more deviations can be seen, mainly on the left lane. Due to the amount of space all these graphs are not included within this the main report.

Lane 1: Left

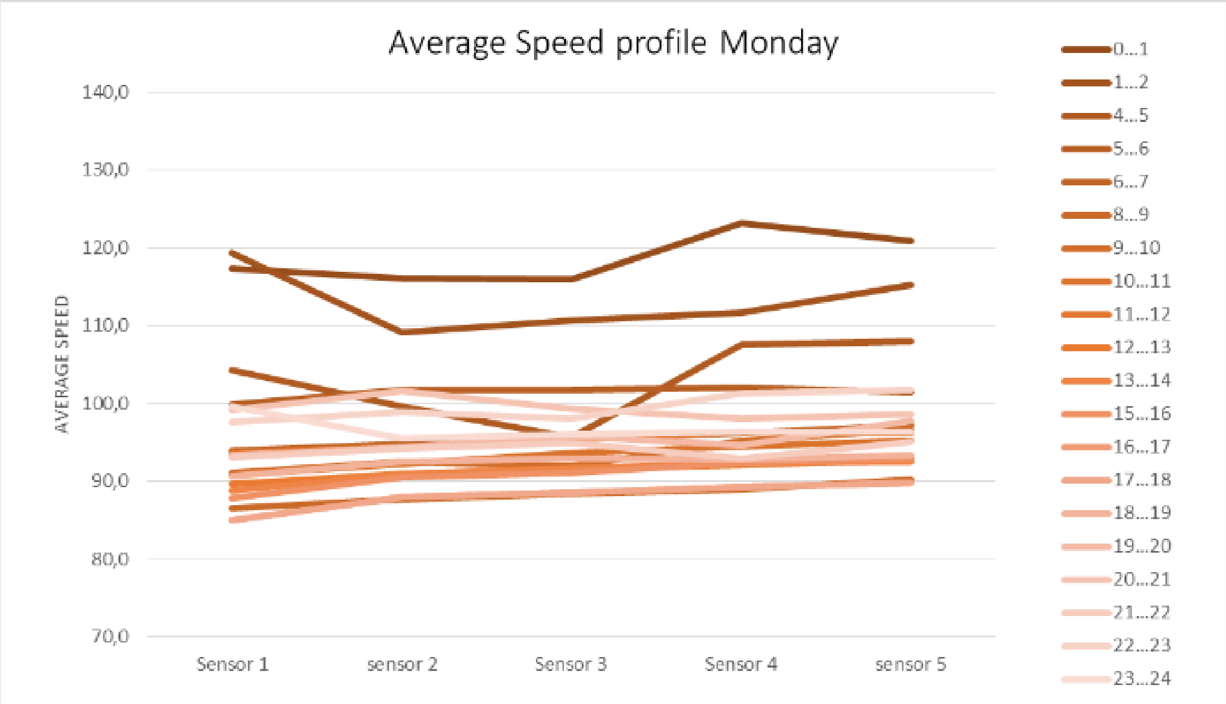


Figure 11: Speed profile per hour for the left lane on Monday

Lane 2: Right

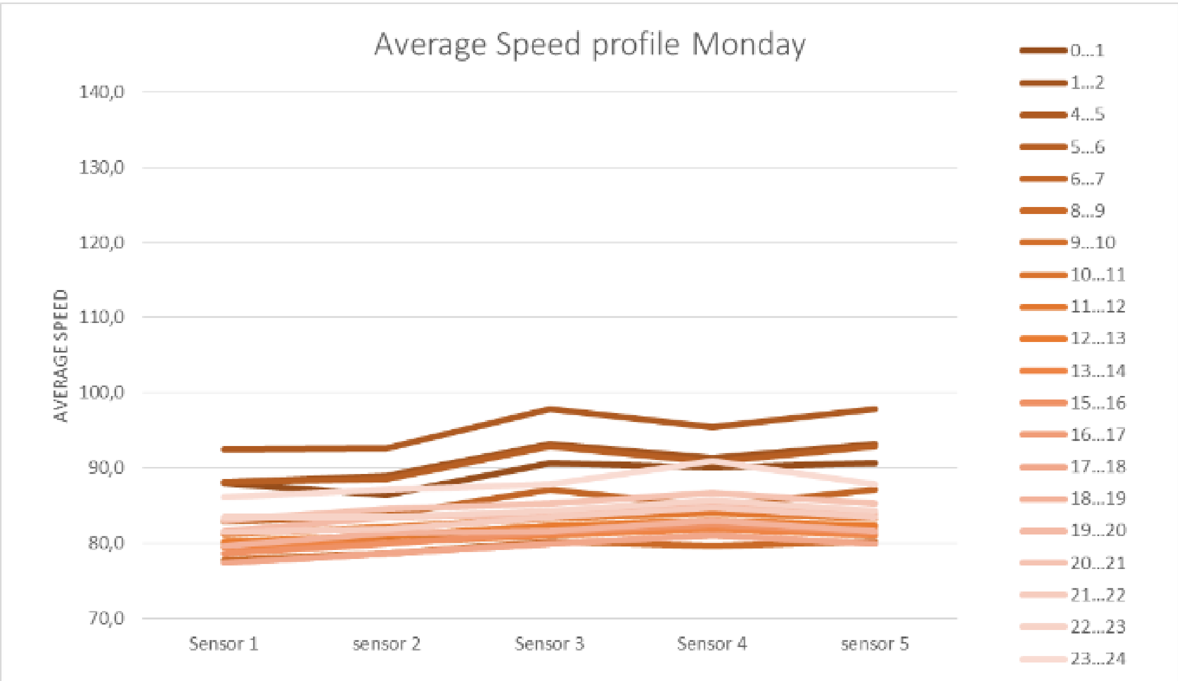


Figure12: Speed profile per hour for the right lane on Monday

Weather

The weather variables Visibility, rain fall and occurrence of mist and ice were selected from all the variables measured by the weather station (§1.4). Below the hourly data is plotted over de different testing weeks. It mostly rained during the baseline test and in the beginning of the second week. The variable rainfall should only be considered a confound variable during these weeks. Mist occurrence reduces the visibility should be taken into account in week 2 – 5, though occurrence is low and therefor it is expected that mist does not have a significant effect on the dependent variables. Additionally it is expected, screening the graphs, that mist correlates with the measured variable visibility. Visibility varies strongly over the days of the week but based on this plot no suggestions can be made. Further analysis should investigate the effect of visibility. Lastly, ice forming causes slippery roads which might make drivers more cautious. In weeks 3 and 4 the effect of ice should be tested, however as with the variable mist occurrence is low to it is likely that there will be no significant influence of ice on the dependent variables.

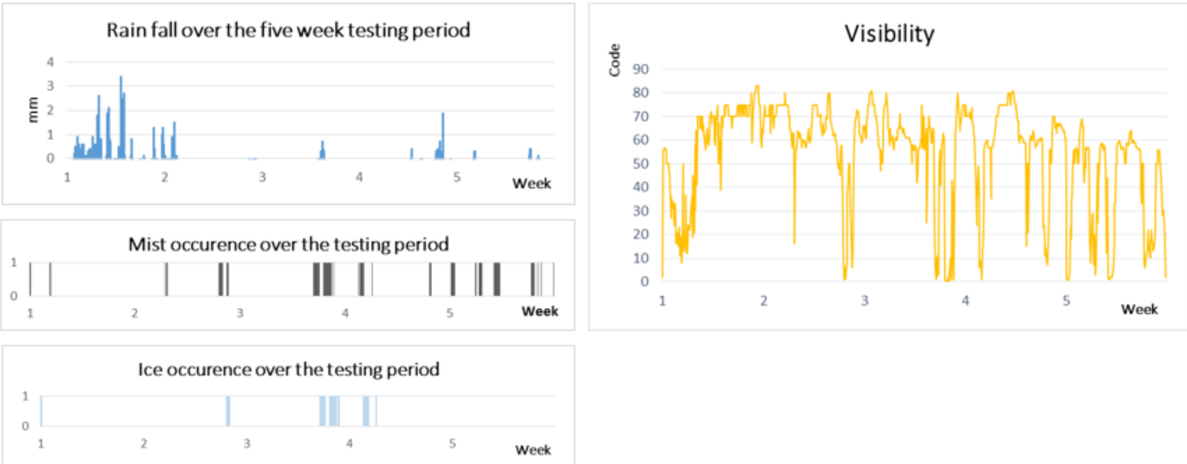


Figure 9: Weather data plotted over the five week testing period. Source: KNMI station 235 Volkel. "Visibility code: (0=minder dan 100m, 1=100-200m, 2=200-300m,..., 49=4900-5000m, 50=5-6km, 56=6-7km, 57=7-8km, ..., 79=29-30km, 80=30-35km, 81=35-40km,..., 89=meer"

Appendix E – Quantitative analysis

Sensors

Lane 1: Links

Tests of Between-Subjects Effects					
Dependent Variable: Average Speed					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2181,356[a]	4	545,339	10,362	,000
Intercept	19081172,062	1	19081172,062	362578,744	,000
Sensor	2181,356	4	545,339	10,362	,000
Error	100095,193	1902	52,626		
Total	19183729,365	1907			
Corrected Total	102276,548	1906			

a. R Squared = ,021 (Adjusted R Squared = ,019)

Multiple Comparisons						
Dependent Variable: Average Speed						
LSD						
(I) Sensor	(J) Sensor	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	-,3486	,52223	,504	-1,3728	,6756
	3,00	-1,5524*	,52257	,003	-2,5772	-,5275
	4,00	-2,3206*	,52506	,000	-3,3503	-1,2909
	5,00	-2,7241*	,52188	,000	-3,7476	-1,7006
2,00	1,00	,3486	,52223	,504	-,6756	1,3728
	3,00	-1,2038*	,52594	,022	-2,2352	-,1723
	4,00	-1,9720*	,52841	,000	-3,0083	-,9357
	5,00	-2,3755*	,52525	,000	-3,4056	-1,3454
3,00	1,00	1,5524*	,52257	,003	,5275	2,5772
	2,00	1,2038*	,52594	,022	,1723	2,2352
	4,00	-,7682	,52875	,146	-1,8052	,2688
	5,00	-1,1718*	,52560	,026	-2,2026	-,1409
4,00	1,00	2,3206*	,52506	,000	1,2909	3,3503
	2,00	1,9720*	,52841	,000	,9357	3,0083
	3,00	,7682	,52875	,146	-,2688	1,8052
	5,00	-,4035	,52807	,445	-1,4392	,6321
5,00	1,00	2,7241*	,52188	,000	1,7006	3,7476
	2,00	2,3755*	,52525	,000	1,3454	3,4056
	3,00	1,1718*	,52560	,026	,1409	2,2026
	4,00	,4035	,52807	,445	-,6321	1,4392

Lane 2: Rechts - Sensoren

Tests of Between-Subjects Effects					
Dependent Variable: Average Speed					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2324,880[a]	4	581,220	68,448	,000
Intercept	17616704,911	1	17616704,911	2074655,012	,000
Sensor	2324,880	4	581,220	68,448	,000
Error	21355,846	2515	8,491		
Total	19115334,769	2520			
Corrected Total	102276,548	1906			

Multiple Comparisons						
Dependent Variable: Average Speed						
LSD						
(I) Sensor	(J) Sensor	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	-1,0604*	,20109	,000	-1,4548	-,6661
	3,00	-2,2896*	,20109	,000	-2,6839	-1,8953
	4,00	-2,5594*	,17414	,000	-2,9009	-2,2179
	5,00	-2,3968*	,20109	,000	-2,7911	-2,0025
2,00	1,00	1,0604*	,20109	,000	-,6661	1,4548
	3,00	-1,2291*	,20109	,000	-1,6234	-,8348
	4,00	-1,4990*	,17414	,000	-1,8404	-1,1575
	5,00	-1,3363*	,20109	,000	-1,7306	-,9420
3,00	1,00	2,2896*	,20109	,000	1,8953	2,6839
	2,00	1,4990*	,20109	,000	,8348	1,6234
	4,00	-,2698	,17414	,121	-,6113	,0716
	5,00	-,1072	,20109	,594	-,5015	-,9420
4,00	1,00	2,5594*	17414	,000	2,2179	2,9009
	2,00	1,4990*	17414	,000	1,1575	1,8404
	3,00	,2698	17414	,121	-,0716	,6113
	5,00	-,1627	17414	,350	-,1788	,5041
5,00	1,00	2,3968*	, ,20109	,000	2,0025	2,7911
	2,00	1,3363*	,20109	,000	,9420	1,7306
	3,00	,1072	,20109	,594	-,2871	,5015
	4,00	-,1627	,17414	,350	-,5041	,1788

LANE 1: LINKS

Correlations

Correlations												
		Average Speed	*Speed variance*	*Sensor*	*Length mean*	*Gap_7s*	*TTC*	*Flow rate*	*Visibility*	*Mist*	*Ice*	*Rainfall*
Average Speed	Pearson Correlation	1	,062*	,134**	,038	,251**	,113**	-,505**	-,029	,059*	,014	-,070*
	Sig. (2-tailed)		,046	,000	,191	,000	,001	,000	,321	,045	,629	,016
	N	1166	1048	1166	1166	1163	856	1166	1166	1166	1166	1166
Speed variance	Pearson Correlation	,062*	1	,017	,029	-,012	,113**	-,231**	,013	-,023	,035	,056
	Sig. (2-tailed)	,046		,585	,343	,702	,001	,000	,664	,451	,255	,069
	N	1048	1048	1048	1048	1048	848	1048	1048	1048	1048	1048
Sensor	Pearson Correlation	,134**	,017	1	,009	,054	,035	-,018	-,010	,006	,000	-,010
	Sig. (2-tailed)	,000	,585		,749	,067	,300	,538	,732	,838	,994	,728
	N	1166	1048	1166	1166	1163	856	1166	1166	1166	1166	1166
Average Length	Pearson Correlation	,038	,029	,009	1	,202**	-,006	-,047	-,048	-,047	,013	,220**
	Sig. (2-tailed)	,191	,343	,749		,000	,858	,111	,103	,108	,669	,000
	N	1166	1048	1166	1166	1163	856	1166	1166	1166	1166	1166
Gap_7	Pearson Correlation	,251**	-,012	,054	,202**	1	-,023	-,258**	-,055	,082**	,017	,004
	Sig. (2-tailed)	,000	,702	,067	,000		,510	,000	,059	,005	,569	,889
	N	1163	1048	1163	1163	1163	853	1163	1163	1163	1163	1163
TTC	Pearson Correlation	,113**	,113**	,035	-,006	-,023	1	-,224**	-,059	,036	-,032	,081*
	Sig. (2-tailed)	,001	,001	,300		,510		,000	,083	,287	,343	,018
	N	856	848	856		853	856	856	856	856	856	856
Flow rate	Pearson Correlation	-,505**	-,231**	-,018		-,258**	-,224**	1	,061*	-,073*	-,061*	-,001
	Sig. (2-tailed)	,000	,000	,538		,000	,000		,036	,013	,038	,965
	N	1166	1048	1166		1163	856	1166	1166	1166	1166	1166
Visibility	Pearson Correlation	-,029	,013	-,010		-,055	-,059	,061*	1	-,718**	-,505**	-,008
	Sig. (2-tailed)	,321	,664	,732		,059	,083	,036		,000	,000	,777
	N	1166	1048	1166		1163	856	1166	1166	1166	1166	1166
Mist	Pearson Correlation	,059*	-,023	,006		,082**	,036	-,073*	-,718**	1	,699**	-,080**

	Sig. (2-tailed)	,045	,451	,838		,005	,287	,013	,000		,000	,006
	N	1166	1048	1166		1163	856	1166	1166	1166	1166	1166
Ice	Pearson Correlation	,014	,035	,000		,017	-,032	-,061*	-,505**	,699**	1	-,070*
	Sig. (2-tailed)	,629	,255	,994		,569	,343	,038	,000	,000		,017
	N	1166	1048	1166		1163	856	1166	1166	1166	1166	1166
Rainfall	Pearson Correlation	-,070*	,056	-,010		,004	,081*	-,001	-,008	-,080**	-,070*	1
	Sig. (2-tailed)	,016	,069	,728		,889	,018	,965	,777	,006		
	N	1166	1048	1166		1163	856	1166	1166	1166		1166

Regression I: SPEED

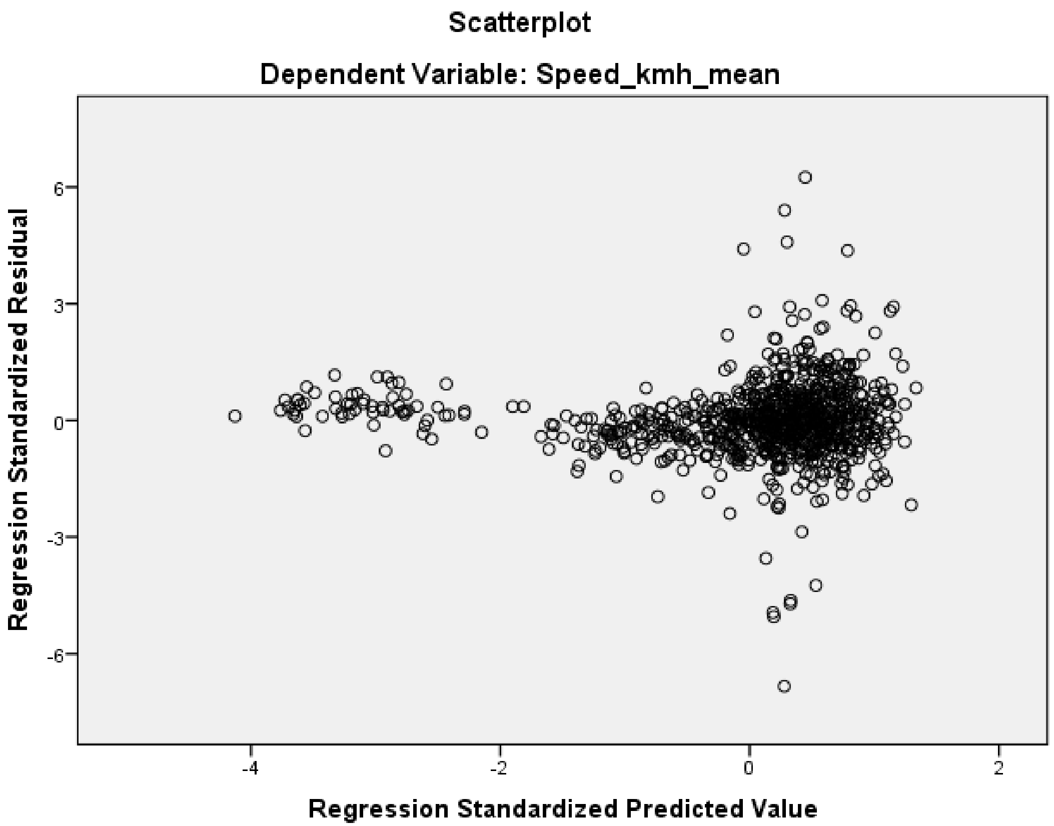
Model Summary [e]									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,133[a]	,018	,013	5,18454	,018	3,804	4	851	,005
2	,200[b]	,040	,034	5,12815	,022	19,820	1	850	,000
3	,709[c]	,503	,499	3,69515	,463	394,550	2	848	,000

ANOVA [a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	408,982	4	102,246	3,804	,005[b]
	Residual	22874,460	851	26,880		
	Total	23283,442	855			
2	Regression	930,203	5	186,041	7,074	,000[c]
	Residual	22353,239	850	26,298		
	Total	23283,442	855			
3	Regression	11704,712	7	1672,102	122,461	,000[d]
	Residual	11578,730	848	13,654		
	Total	23283,442	855			

a. Dependent Variable: Average Speed
b. Predictors: (Constant), Light_plan_4, Light_plan_1, Light_plan_3, Light_plan_2
c. Predictors: (Constant), Light_plan_4, Light_plan_1, Light_plan_3, Light_plan_2, Sensor, Flow rate, TTC_mean

Coefficients[a]								
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	*(Constant)*	97,921	,405		241,872	,000		
	Light_plan_1	1,100	,573	,083	1,918	,055	,619	1,614
	Light_plan_2	,213	,559	,017	,382	,703	,603	1,659
	Light_plan_3	,830	,568	,063	1,461	,144	,614	1,630
	Light_plan_4	1,927	,560	,150	3,438	,001	,605	1,654
2	*(Constant)*	96,038	,582		164,884	,000		
	Light_plan_1	1,088	,567	,082	1,919	,055	,619	1,614
	Light_plan_2	,322	,553	,025	,582	,561	,602	1,662
	Light_plan_3	,937	,563	,071	1,665	,096	,613	1,633
	Light_plan_4	2,000	,555	,156	3,606	,000	,604	1,656
	Sensor	,950	,213	,150	4,452	,000	,996	1,004
3	*(Constant)*	98,928	,572		172,937	,000		
	Light_plan_1	1,303	,409	,098	3,184	,002	,618	1,618
	Light_plan_2	,148	,400	,012	,370	,712	,598	1,672
	Light_plan_3	,869	,406	,066	2,142	,033	,612	1,635
	Light_plan_4	1,937	,400	,151	4,846	,000	,604	1,656
	Sensor	1,077	,154	,170	6,997	,000	,993	1,007
	Flow rate	-,018	,001	-,691	-27,773	,000	,947	1,056
	TTC	-,342	,158	-,054	-2,161	,031	,938	1,066

a. Dependent Variable: Speed_kmh_mean



Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	,093	856	,000	,887	856	,000

Bootstrap for Coefficients							
Model		B	Bootstrap[a]				
			Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
						Lower	Upper
1	*(Constant)*	97,921	,024	,398	,001	97,155	98,720
	Light_plan_1	1,100	,007	,555	,055	-,015	2,222
	Light_plan_2	,213	-,058	,598	,692	-1,028	1,316
	Light_plan_3	,830	,007	,533	,127	-,166	1,911
	Light_plan_4	1,927	-,015	,564	,001	,794	3,025
2	*(Constant)*	96,038	,007	,581	,001	94,892	97,177
	Light_plan_1	1,088	,007	,543	,050	-,037	2,141
	Light_plan_2	,322	-,056	,586	,577	-,891	1,432
	Light_plan_3	,937	,014	,528	,082	-,039	1,968
	Light_plan_4	2,000	-,013	,559	,001	,881	3,140
	Sensor	,950	,007	,212	,001	,530	1,377
3	*(Constant)*	98,928	,008	,721	,001	97,485	100,296
	Light_plan_1	1,303	-,002	,327	,001	,619	1,925
	Light_plan_2	,148	-,029	,393	,705	-,674	,905
	Light_plan_3	,869	,008	,360	,019	,115	1,536
	Light_plan_4	1,937	-,010	,391	,001	1,154	2,671
	Sensor	1,077	,007	,155	,001	,779	1,396
	Flow rate	-,018	-3,844E-5	,001	,001	-,019	-,017
	TTC	-,342	-,003	,248	,175	-,795	,173

Run MATRIX procedure: HC Method 3 **Criterion Variable**: Speed_kmh_mean

Model Fit:

R-sq	F	df1	df2	p
,4740	241,4271	6,0000	849,0000	,0000

Heteroscedasticity-Consistent Regression Results

	Coeff	SE(HC)	t	P>|t|
Constant	100,9361	,6643	151,9419	,0000
Light_1	1,3188	,3438	3,8358	,0001
Light__2	,0346	,4408	,0785	,9375
Light__3	,7530	,3862	1,9494	,0516
Light__4	1,8530	,3922	4,7246	,0000
Flow_rat	-,0178	,0005	-32,8304	,0000
TTC_mean	-,2973	,2375	-1,2517	,2110

Covariance Matrix of Parameter Estimates

	Constant	Light_1	Light__2	Light__3	Light__4	Flow_rat	TTC_mean
Constant	,4413	-,0819	-,0410	-,0912	-,0983	-,0002	-,1432
Light_1	-,0819	,1182	,0687	,0701	,0708	,0000	,0052
Light__2	-,0410	,0687	,1943	,0688	,0721	-,0001	-,0092
Light__3	-,0912	,0701	,0688	,1492	,0702	,0000	,0090
Light__4	-,0983	,0708	,0721	,0702	,1538	,0000	,0126
Flow_rat	-,0002	,0000	-,0001	,0000	,0000	,0000	,0001
TTC_mean	-,1432	,0052	-,0092	,0090	,0126	,0001	,0564

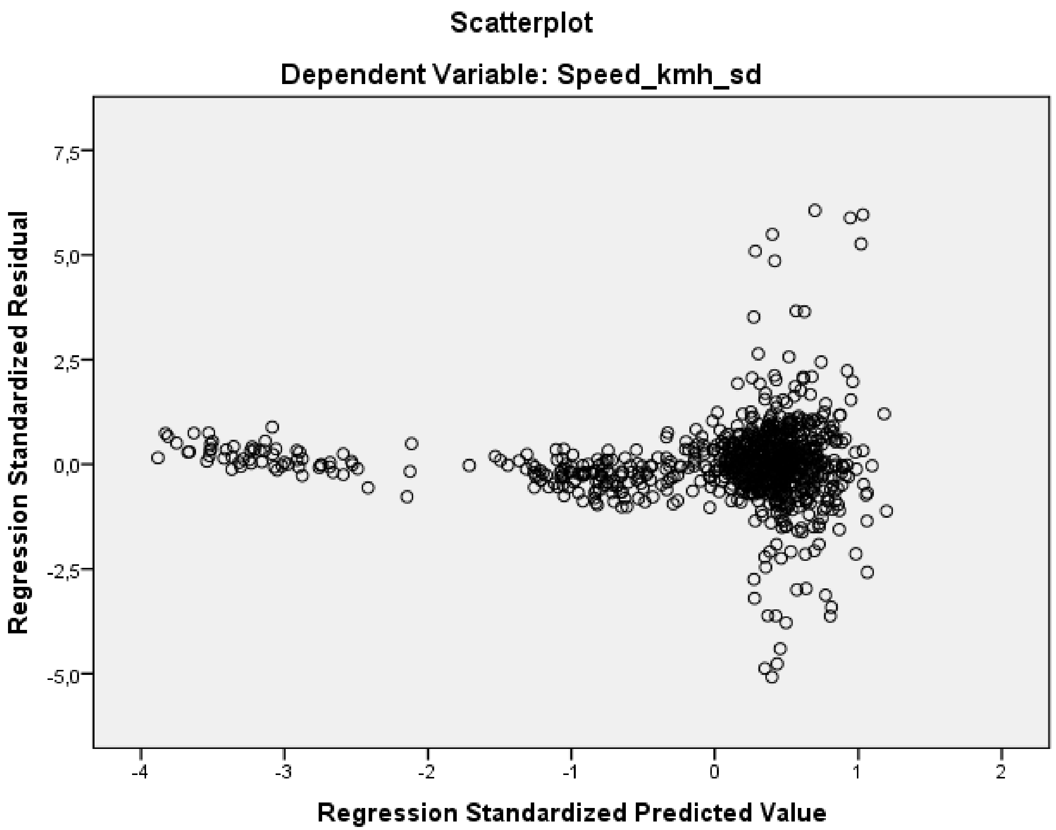
Regression I: SPEED VARIANCE

Model Summary[d]									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,064[a]	,004	-,001	2,07878	,004	,873	4	843	,480
2	,077[b]	,006	,000	2,07816	,002	1,503	1	842	,221
3	,394[c]	,156	,148	1,91769	,150	74,407	2	840	,000

ANOVA[d]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15,083	4	3,771	,873	,480[b]
	Residual	3642,875	843	4,321		
	Total	3657,958	847			
2	Regression	21,573	5	4,315	,999	,417[c]
	Residual	3636,385	842	4,319		
	Total	3657,958	847			
3	Regression	568,842	7	81,263	22,097	,000[d]
	Residual	3089,116	840	3,678		
	Total	3657,958	847			

a. Dependent Variable: Speed variance
b. Predictors: (Constant), Light_plan_4, Light_plan_1, Light_plan_3, Light_plan_2
c. Predictors: (Constant), Light_plan_4, Light_plan_1, Light_plan_3, Light_plan_2, Sensor
d. Predictors: (Constant), Light_plan_4, Light_plan_1, Light_plan_3, Light_plan_2, Sensor, Flow rate, TTC

Coefficients [a]								
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Toleranc e	VIF
1	*(Constant)*	10,178	,162		62,702	,000		
	Light_plan_1	-,139	,230	-,026	-,602	,547	,621	1,611
	Light_plan_2	,022	,226	,004	,097	,923	,610	1,640
	Light_plan_3	-,067	,228	-,013	-,292	,770	,616	1,623
	Light_plan_4	,253	,225	,050	1,124	,261	,607	1,648
2	*(Constant)*	9,967	,237		42,105	,000		
	Light_plan_1	-,140	,230	-,027	-,608	,543	,621	1,611
	Light_plan_2	,031	,226	,006	,137	,891	,609	1,642
	Light_plan_3	-,055	,228	-,011	-,242	,809	,615	1,626
	Light_plan_4	,261	,225	,051	1,158	,247	,606	1,649
	Sensor	,107	,087	,042	1,226	,221	,997	1,003
3	*(Constant)*	10,327	,300		34,389	,000		
	Light_plan_1	-,078	,212	-,015	-,367	,714	,619	1,614
	Light_plan_2	,031	,209	,006	,148	,882	,606	1,651
	Light_plan_3	-,056	,211	-,011	-,268	,789	,614	1,628
	Light_plan_4	,243	,208	,048	1,171	,242	,606	1,650
	Sensor	,125	,080	,049	1,554	,121	,995	1,005
	Flow rate	-,004	,000	-,382	-11,717	,000	,945	1,058
	TTC	,049	,083	,019	,586	,558	,935	1,069



Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	,119	848	,000	,827	848	,000

Bootstrap for Coefficients							
Model		B	Bootstrap[a]				
			Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
						Lower	Upper
1	*(Constant)*	10,178	-,006	,149	,001	9,887	10,470
	Light_plan_1	-,139	,009	,178	,449	-,476	,223
	Light_plan_2	,022	,010	,218	,913	-,404	,458
	Light_plan_3	-,067	,014	,224	,773	-,504	,377
	Light_plan_4	,253	,006	,236	,272	-,198	,744
2	*(Constant)*	9,967	-,003	,236	,001	9,521	10,430
	Light_plan_1	-,140	,009	,179	,443	-,484	,224
	Light_plan_2	,031	,010	,217	,876	-,394	,469
	Light_plan_3	-,055	,014	,224	,811	-,495	,379
	Light_plan_4	,261	,005	,236	,266	-,189	,747
	Sensor	,107	-,002	,092	,253	-,081	,281
3	*(Constant)*	10,327	,003	,388	,001	9,547	11,092
	Light_plan_1	-,078	,006	,158	,630	-,405	,233
	Light_plan_2	,031	,008	,193	,881	-,339	,419
	Light_plan_3	-,056	,012	,206	,800	-,437	,346
	Light_plan_4	,243	,004	,213	,253	-,160	,675
	Sensor	,125	-,001	,086	,147	-,057	,295
	Flow rate	-,004	-1,236E-5	,000	,001	-,004	-,003
	TTC	,049	-,002	,130	,702	-,183	,299

Run MATRIX procedure: HC Method 3 **Criterion Variable:** Speed_kmh_sd

Model Fit:

R-sq	F	df1	df2	p
,1531	62,6600	6,0000	841,0000	,0000

Heteroscedasticity-Consistent Regression Results

	Coeff	SE(HC)	t	P>|t|
Constant	10,5620	,3592	29,4074	,0000
Light_1	-,0760	,1665	-,4565	,6481
Light__2	,0213	,1909	,1115	,9113
Light__3	-,0693	,2117	-,3272	,7436
Light__4	,2340	,2187	1,0702	,2848
Flow_rat	-,0039	,0003	-15,5311	,0000
TTC_mean	,0535	,1304	,4100	,6819

Covariance Matrix of Parameter Estimates

	Constant	Light_1	Light__2	Light__3	Light__4	Flow_rat	TTC_mean
Constant	,1290	-,0198	-,0169	-,0150	-,0303	-,0001	-,0431
Light_1	-,0198	,0277	,0168	,0169	,0177	,0000	,0010
Light__2	-,0169	,0168	,0365	,0165	,0181	,0000	,0001
Light__3	-,0150	,0169	,0165	,0448	,0176	,0000	-,0005
Light__4	-,0303	,0177	,0181	,0176	,0478	,0000	,0059
Flow_rat	-,0001	,0000	,0000	,0000	,0000	,0000	,0000
TTC_mean	-,0431	,0010	,0001	-,0005	,0059	,0000	,0170

Regression II: SPEED

Variables included in the regression:

. Predictors: (Constant), Sensor, Flow rate, TTC

Tests of Between-Subjects Effects					
Dependent Variable: Unstandardized Residual					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	450,226[a]	4	112,556	8,272	,000
Intercept	,019	1	,019	,001	,971
Light_plan	450,226	4	112,556	8,272	,000
Error	11579,860	851	13,607		
Total	12030,086	856			
Corrected Total	12030,086	855			

a. R Squared = ,037 (Adjusted R Squared = ,033)

Post Hoc Tests :LSD

Multiple Comparisons						
Dependent Variable: Unstandardized Residual						
LSD						
(I) Light_plan	(J) Light_plan	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	1	-1,3069766*	,40798578	,001	-2,1077530	-,5062003
	2	-,1569958	,39768134	,693	-,9375470	,6235554
	3	-,8731097*	,40433721	,031	-1,6667248	-,0794946
	4	-1,9350716*	,39873604	,000	-2,7176929	-1,1524502

1	0	1,3069766*	,40798578	,001	,5062003	2,1077530
	2	1,1499809*	,39832082	,004	,3681745	1,9317872
	3	,4338670	,40496619	,284	-,3609826	1,2287166
	4	-,6280949	,39937384	,116	-1,4119681	,1557783
2	0	,1569958	,39768134	,693	-,6235554	,9375470
	1	-1,1499809*	,39832082	,004	-1,9317872	-,3681745
	3	-,7161139	,39458290	,070	-1,4905836	,0583559
	4	-1,7780758*	,38884124	,000	-2,5412761	-1,0148755
3	0	,8731097*	,40433721	,031	,0794946	1,6667248
	1	-,4338670	,40496619	,284	-1,2287166	,3609826
	2	,7161139	,39458290	,070	-,0583559	1,4905836
	4	-1,0619619*	,39564586	,007	-1,8385180	-,2854058

Based on observed means.
The error term is Mean Square(Error) = 13,607.

*. The mean difference is significant at the ,05 level.

Regression II: SPEED VARIANCE

Variables included in the regression:

c. Predictors: (Constant), Sensor, Flow rate, TTC

Tests of Between-Subjects Effects					
Dependent Variable: Unstandardized Residual					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	11,270[a]	4	2,817	,769	,546
Intercept	,009	1	,009	,003	,960
Light_plan	11,270	4	2,817	,769	,546
Error	3089,173	843	3,664		
Total	3100,443	848			
Corrected Total	3100,443	847			

a. R Squared = ,004 (Adjusted R Squared = -,001)

Post Hoc Tests :LSD

Multiple Comparisons						
Dependent Variable: Unstandardized Residual						
LSD						
(I) Light_plan	(J) Light_plan	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	1	,0766525	,21172176	,717	-,3389112	,4922162
	2	-,0325132	,20804930	,876	-,4408686	,3758422
	3	,0557380	,21013569	,791	-,3567125	,4681886
	4	-,2424575	,20719939	,242	-,6491447	,1642298
1	0	-,0766525	,21172176	,717	-,4922162	,3389112

	2	-,1091657	,20837848	,600	-,5181672	,2998359
	3	-,0209145	,21046162	,921	-,4340048	,3921758
	4	-,3191100	,20752993	,125	-,7264460	,0882260
2	0	,0325132	,20804930	,876	-,3758422	,4408686
	1	,1091657	,20837848	,600	-,2998359	,5181672
	3	,0882512	,20676677	,670	-,3175869	,4940893
	4	-,2099443	,20378193	,303	-,6099238	,1900352
3	0	-,0557380	,21013569	,791	-,4681886	,3567125
	1	,0209145	,21046162	,921	-,3921758	,4340048
	2	-,0882512	,20676677	,670	-,4940893	,3175869
	4	-,2981955	,20591157	,148	-,7023551	,1059640

Based on observed means.

The error term is Mean Square(Error) = 3,664.

LANE 2: RECHTS

Correlations

Correlations												
		Average Speed	*Speed Variance*	*Average Length*	*Sensor*	*Gap_7s*	*TTC*	*Flow rate*	*Visibility*	*Mist*	*Ice*	*Rainfall*
Average Speed	Pearson Correlation	1	,647**	,087**	,252**	,355**	,402**	-,780**	,019	,070*	,011	-,085**
	Sig. (2-tailed)		,000	,002	,000	,000	,000	,000	,510	,013	,709	,002
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260
Speed variance	Pearson Correlation	,647**	1	,378**	,102**	,584**	,309**	-,695**	-,012	,078**	,048	,059*
	Sig. (2-tailed)	,000		,000	,000	,000	,000	,000	,670	,006	,090	,037
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260
Average Length	Pearson Correlation	,087**	,378**	1	-,034	,548**	,013	-,300**	,010	-,008	-,055	,168**
	Sig. (2-tailed)	,002	,000		,222	,000	,638	,000	,730	,789	,050	,000
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260
Sensor	Pearson Correlation	,252**	,102**	-,034	1	-,129**	-,151**	,017	,000	,000	,000	,000
	Sig. (2-tailed)	,000	,000	,222		,000	,000	,546	1,000	1,000	1,000	1,000
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260
Gap_7s	Pearson Correlation	,355**	,584**	,548**	-,129**	1	,302**	-,603**	-,074**	,122**	,064*	,005
	Sig. (2-tailed)	,000	,000	,000	,000		,000	,000	,008	,000	,023	,866
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260
TTC	Pearson Correlation	,402**	,309**	,013	-,151**	,302**	1	-,513**	-,120**	,112**	,095**	,003

	Sig. (2-tailed)	,000	,000	,638	,000	,000		,000	,000	,000	,001	,920
	N	1248	1248	1248	1248	1248	1248	1248	1248	1248	1248	1248
Flow rate	Pearson Correlation	-,780**	-,695**	-,300**	,017	-,603**	-,513**	1	,082**	-,116**	-,069*	-,044
	Sig. (2-tailed)	,000	,000	,000	,546	,000	,000		,004	,000	,014	,116
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260
Visibility	Pearson Correlation	,019	-,012	,010	,000	-,074**	-,120**	,082**	1	-,714**	-,495**	-,010
	Sig. (2-tailed)	,510	,670	,730	1,000	,008	,000	,004		,000	,000	,715
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260
Mist	Pearson Correlation	,070*	,078**	-,008	,000	,122**	,112**	-,116**	-,714**	1	,691**	-,085**
	Sig. (2-tailed)	,013	,006	,789	1,000	,000	,000	,000	,000		,000	,002
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260
Ice	Pearson Correlation	,011	,048	-,055	,000	,064*	,095**	-,069*	-,495**	,691**	1	-,071*
	Sig. (2-tailed)	,709	,090	,050	1,000	,023	,001	,014	,000	,000		,012
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260
Rainfall	Pearson Correlation	-,085**	,059*	,168**	,000	,005	,003	-,044	-,010	-,085**	-,071*	1
	Sig. (2-tailed)	,002	,037	,000	1,000	,866	,920	,116	,715	,002	,012	
	N	1260	1260	1260	1260	1260	1248	1260	1260	1260	1260	1260

Regression I: SPEED

Model Summary [e]									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,194[a]	,037	,034	2,95776	,037	12,092	4	1243	,000
2	,319[b]	,102	,098	2,85820	,064	89,105	1	1242	,000
3	,853[c]	,727	,725	1,57730	,625	1419,130	2	1240	,000
4	,856[d]	,733	,732	1,55948	,007	15,251	2	1238	,000

ANOVA [a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	423,140	4	105,785	12,092	,000[b]
	Residual	10874,179	1243	8,748		
	Total	11297,319	1247			
2	Regression	1151,065	5	230,213	28,180	,000[c]
	Residual	10146,254	1242	8,169		
	Total	11297,319	1247			
3	Regression	8212,337	7	1173,191	471,561	,000[d]
	Residual	3084,982	1240	2,488		
	Total	11297,319	1247			
4	Regression	8286,519	9	920,724	378,589	,000[e]
	Residual	3010,800	1238	2,432		
	Total	11297,319	1247			

a. Dependent Variable: Speed_kmh_mean

b. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1

c. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1, Sensor

d. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1, Sensor, Flow_rate, TTC_mean Length_mean

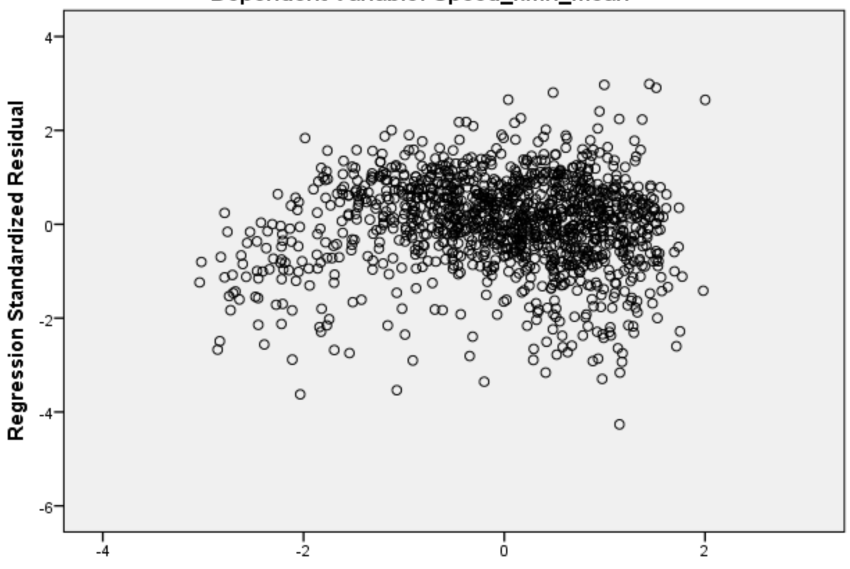
e. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1, Sensor, Flow_rate, TTC_mean,Length_mean Mist, Rainfall

Coefficients [a]								
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	*(Constant)*	86,043	,187		459,044	,000		
	Light_plan_1	1,357	,265	,180	5,119	,000	,625	1,601
	Light_plan_2	,638	,265	,085	2,406	,016	,625	1,601
	Light_plan_3	1,058	,265	,141	3,992	,000	,625	1,601
	Light_plan_4	1,668	,264	,223	6,312	,000	,623	1,606
2	*(Constant)*	84,170	,269		313,256	,000		
	Light_plan_1	1,353	,256	,180	5,283	,000	,625	1,601
	Light_plan_2	,649	,256	,086	2,533	,011	,625	1,601
	Light_plan_3	1,062	,256	,141	4,146	,000	,625	1,601
	Light_plan_4	1,672	,255	,223	6,546	,000	,623	1,606
	Sensor	,935	,099	,254	9,440	,000	1,000	1,000
3	*(Constant)*	85,682	,358		239,327	,000		
	Light_plan_1	1,478	,142	,196	10,395	,000	,617	1,620
	Light_plan_2	,635	,142	,084	4,482	,000	,622	1,608
	Light_plan_3	1,093	,141	,145	7,728	,000	,624	1,603
	Light_plan_4	1,731	,141	,231	12,278	,000	,623	1,606
	Sensor	1,018	,055	,276	18,357	,000	,972	1,029
	Flow rate	-,009	,000	-,753	-43,250	,000	,726	1,377
	TTC	,342	,088	,070	3,901	,000	,692	1,445

4	*(Constant)*	85,890	,360		238,820	,000		
	Light_plan_1	1,339	,152	,178	8,834	,000	,531	1,882
	Light_plan_2	,557	,153	,074	3,644	,000	,522	1,917
	Light_plan_3	,973	,149	,129	6,546	,000	,552	1,811
	Light_plan_4	1,659	,152	,221	10,928	,000	,525	1,906
	Sensor	1,020	,055	,277	18,612	,000	,971	1,029
	Flow rate	-,009	,000	-,762	-44,055	,000	,720	1,390
	TTC	,349	,087	,071	4,028	,000	,690	1,449
	Mist	-,523	,131	-,061	-3,988	,000	,918	1,089
	Rainfall	-,482	,126	-,062	-3,818	,000	,818	1,222

Scatterplot

Dependent Variable: Speed_kmh_mean



Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	,054	1248	,000	,976	1248	,000

Run MATRIX procedure: HC Method 3 **Criterion Variable:** Speed_kmh_mean

Model Fit:

R-sq	F	df1	df2	p
,6758	247,0321	9,0000	1238,0000	,0000

Heteroscedasticity-Consistent Regression Results

	Coeff	SE(HC)	t	P>|t|
Constant	93,9822	,8236	114,1173	,0000
Light_1	1,2523	,1732	7,2305	,0000
Light__2	,5266	,1869	2,8177	,0049
Light__3	,9277	,1663	5,5801	,0000
Light__4	1,5912	,1687	9,4339	,0000
Flow_rat	-,0100	,0003	-38,9263	,0000
TTC_mean	-,0454	,1170	-,3880	,6981
Length_m	-,9116	,1384	-6,5877	,0000
Mist	-,5058	,1453	-3,4821	,0005
Rainfall	-,3461	,1675	-2,0667	,0390

Covariance Matrix of Parameter Estimates

	Constant	Light_1	Light__2	Light__3	Light__4	Flow_rat	TTC_mean	Length_m	Mist	Rainfall
Constant	,6782	-,0193	-,0241	-,0131	-,0250	-,0001	-,0479	-,0977	,0021	,0077
Light_1	-,0193	,0300	,0195	,0182	,0193	,0000	,0013	-,0007	-,0035	,0094
Light__2	-,0241	,0195	,0349	,0189	,0198	,0000	-,0007	,0018	-,0064	,0090
Light__3	-,0131	,0182	,0189	,0276	,0183	,0000	-,0012	-,0001	-,0017	,0080
Light__4	-,0250	,0193	,0198	,0183	,0284	,0000	,0009	,0008	-,0035	,0091
Flow_rat	-,0001	,0000	,0000	,0000	,0000	,0000	,0000	,0000	,0000	,0000
TTC_mean	-,0479	,0013	-,0007	-,0012	,0009	,0000	,0137	,0003	-,0013	-,0001
Length_m	-,0977	-,0007	,0018	-,0001	,0008	,0000	,0003	,0191	,0002	-,0035
Mist	,0021	-,0035	-,0064	-,0017	-,0035	,0000	-,0013	,0002	,0211	-,0001
Rainfall	,0077	,0094	,0090	,0080	,0091	,0000	-,0001	-,0035	-,0001	,0281

Regression I: SPEED VARIANCE

Model Summary [e]									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,107[a]	,011	,008	1,17028	,011	3,572	4	/**	,007
2	,147[b]	,022	,018	1,16471	,010	12,927	1	1242	,000
3	,742[c]	,550	,547	,79087	,528	484,898	3	1239	,000
4	,743[d]	,552	,549	,78952	,002	3,122	2	1237	,044

ANOVA [a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19,567	4	4,892	3,572	,007[b]
	Residual	1702,369	1243	1,370		
	Total	1721,936	1247			
2	Regression	37,103	5	7,421	5,470	,000[c]
	Residual	1684,833	1242	1,357		
	Total	1721,936	1247			
3	Regression	946,975	8	118,372	189,252	,000[d]
	Residual	774,961	1239	,625		
	Total	1721,936	1247			
4	Regression	950,867	10	95,087	152,544	,000[e]
	Residual	771,069	1237	,623		
	Total	1721,936	1247			

a. Dependent Variable: Speed_kmh_sd

b. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1

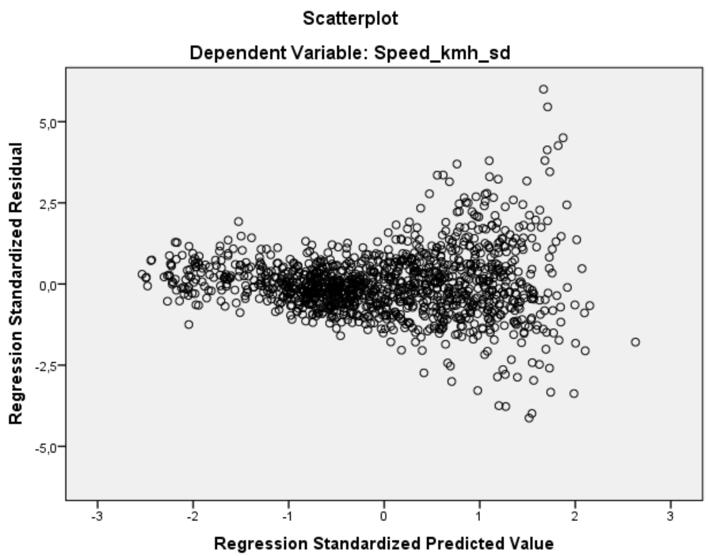
c. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1, Sensor

d. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1, Sensor, Flow_rate, Length_mean, TTC_mean

e. Predictors: (Constant), Light_plan_4, Light_plan_3, Light_plan_2, Light_plan_1, Sensor, Flow_rate, Length_mean, TTC_mean, Mist, Rainfall

Coefficients [a]								
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	*(Constant)*	9,471	,074		127,706	,000		
	Light_plan_1	,152	,105	,052	1,454	,146	,625	1,601
	Light_plan_2	,114	,105	,039	1,090	,276	,625	1,601
	Light_plan_3	,378	,105	,129	3,607	,000	,625	1,601
	Light_plan_4	,224	,105	,077	2,144	,032	,623	1,606
2	*(Constant)*	9,180	,109		83,845	,000		
	Light_plan_1	,152	,104	,052	1,455	,146	,625	1,601
	Light_plan_2	,116	,104	,040	1,112	,266	,625	1,601
	Light_plan_3	,379	,104	,129	3,630	,000	,625	1,601
	Light_plan_4	,225	,104	,077	2,159	,031	,623	1,606
	Sensor	,145	,040	,101	3,595	,000	1,000	1,000
3	*(Constant)*	7,489	,350		21,412	,000		
	Light_plan_1	,214	,072	,073	2,986	,003	,613	1,631
	Light_plan_2	,190	,071	,065	2,669	,008	,618	1,618
	Light_plan_3	,462	,071	,157	6,492	,000	,619	1,614
	Light_plan_4	,316	,071	,108	4,449	,000	,617	1,621
	Sensor	,167	,028	,116	5,982	,000	,969	1,033
	Flow rate	-,003	,000	-,647	-27,260	,000	,645	1,550
	TTC	-,022	,045	-,012	-,502	,616	,672	1,488

	Average Length	,521	,052	,204	10,038	,000	,877	1,141
4	*(Constant)*	7,497	,349		21,470	,000		
	Light_plan_1	,283	,077	,096	3,693	,000	,531	1,884
	Light_plan_2	,262	,077	,089	3,383	,001	,521	1,919
	Light_plan_3	,524	,075	,178	6,956	,000	,551	1,814
	Light_plan_4	,386	,077	,132	5,011	,000	,523	1,910
	Sensor	,166	,028	,116	5,978	,000	,968	1,033
	Flow rate	-,003	,000	-,647	-27,242	,000	,641	1,560
	TTC	-,021	,045	-,011	-,470	,638	,671	1,491
	Average Length	,505	,052	,198	9,688	,000	,864	1,157
	Mist	-,030	,066	-,009	-,458	,647	,918	1,089
	Rainfall	,158	,064	,052	2,457	,014	,807	1,240



Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	,070	1248	,000	,945	1248	,000

Run MATRIX procedure: HC Method 3 **Criterion Variable** Speed_kmh_sd

Model Fit:

R-sq	F	df1	df2	p
,5393	155,4622	9,0000	1238,0000	,0000

Heteroscedasticity-Consistent Regression Results

	Coeff	SE(HC)	t	P>|t|
Constant	8,0795	,4917	16,4327	,0000
Light_1	,2751	,0703	3,9143	,0001
Light__2	,2630	,0718	3,6617	,0003
Light__3	,5242	,0723	7,2500	,0000
Light__4	,3834	,0775	4,9469	,0000
Flow_rat	-,0031	,0001	-22,9450	,0000
TTC_mean	-,0675	,0725	-,9301	,3525
Length_m	,4875	,0726	6,7178	,0000
Mist	-,0264	,0864	-,3052	,7603
Rainfall	,1613	,0890	1,8120	,0702

Covariance Matrix of Parameter Estimates

	Constant	Light_1	Light__2	Light__3	Light__4	Flow_rat	TTC_mean	Length_m	Mist	Rainfall
Constant	,2417	-,0067	-,0009	-,0082	-,0029	,0000	-,0243	-,0305	-,0132	,0007
Light_1	-,0067	,0049	,0026	,0026	,0023	,0000	,0007	,0003	-,0004	,0020
Light__2	-,0009	,0026	,0052	,0025	,0028	,0000	-,0008	,0002	-,0016	,0021
Light__3	-,0082	,0026	,0025	,0052	,0025	,0000	,0003	,0010	,0000	,0017
Light__4	-,0029	,0023	,0028	,0025	,0060	,0000	-,0013	,0010	-,0006	,0017
Flow_rat	,0000	,0000	,0000	,0000	,0000	,0000	,0000	,0000	,0000	,0000
TTC_mean	-,0243	,0007	-,0008	,0003	-,0013	,0000	,0053	,0012	,0012	-,0003
Length_m	-,0305	,0003	,0002	,0010	,0010	,0000	,0012	,0053	,0018	-,0004
Mist	-,0132	-,0004	-,0016	,0000	-,0006	,0000	,0012	,0018	,0075	-,0005
Rainfall	,0007	,0020	,0021	,0017	,0017	,0000	-,0003	-,0004	-,0005	,0079

Regression II: SPEED

Variables included in the regression:

d. Predictors: (Constant), Sensor, Flow rate, Average Length , TTC , Mist, Rainfall

b.

Tests of Between-Subjects Effects					
Dependent Variable: Unstandardized Residual					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	309,082[a]	4	77,271	33,084	,000
Intercept	,003	1	,003	,001	,970
Light_plan	309,082	4	77,271	33,084	,000
Error	2903,137	1243	2,336		
Total	3212,219	1248			
Corrected Total	3212,219	1247			

R Squared = ,096 (Adjusted R Squared = ,093)

Post Hoc Tests: LSD

Multiple Comparisons						
Dependent Variable: Unstandardized Residual						
LSD						
(I) Light_plan	(J) Light_plan	Mean Difference (I-J)	SE	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	1	-1,0630566*	,13696624	,000	-1,3317672	-,7943461
	2	-,2832894*	,13696624	,039	-,5519999	-,0145789
	3	-,7268360*	,13696624	,000	-,9955466	-,4581255

	4	-1,3636396*	,13655799	,000	-1,6315492	-1,0957300
1	0	1,0630566*	,13696624	,000	,7943461	1,3317672
	2	,7797672*	,13696624	,000	,5110567	1,0484778
	3	,3362206*	,13696624	,014	,0675101	,6049311
	4	-,3005830*	,13655799	,028	-,5684926	-,0326734
2	0	,2832894*	,13696624	,039	,0145789	,5519999
	1	-,7797672*	,13696624	,000	-1,0484778	-,5110567
	3	-,4435466*	,13696624	,001	-,7122572	-,1748361
	4	-1,0803502*	,13655799	,000	-1,3482598	-,8124406
3	0	,7268360*	,13696624	,000	,4581255	,9955466
	1	-,3362206*	,13696624	,014	-,6049311	-,0675101
	2	,4435466*	,13696624	,001	,1748361	,7122572
	4	-,6368036*	,13655799	,000	-,9047132	-,3688940

Based on observed means.

The error term is Mean Square(Error) = 2,336.

*. The mean difference is significant at the ,05 level.

Regression II: SPEED VARIANCE

Variables included in the regression:

Predictors in the Model: (Constant), Sensor, Flow rate, Average Length, TTC

Tests of Between-Subjects Effects					
Dependent Variable: Unstandardized Residual					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	28,644[a]	4	7,161	11,488	,000
Intercept	4,288E-5	1	4,288E-5	,000	,993
Light_plan	28,644	4	7,161	11,488	,000
Error	774,780	1243	,623		
Total	803,423	1248			
Corrected Total	803,423	1247			

a. R Squared = ,036 (Adjusted R Squared = ,033)

Post Hoc Tests: LSD

Multiple Comparisons						
Dependent Variable: Unstandardized Residual						
LSD						
(I) Light_plan	(J) Light_plan	Mean Difference (I-J)	SE	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	1	-,2154982*	,07075691	,002	-,3543143	-,0766820
	2	-,1865671*	,07075691	,008	-,3253833	-,0477510

	3	-,4609670*	,07075691	,000	-,5997831	-,3221508
	4	-,3121431*	,07054601	,000	-,4505455	-,1737407
1	0	,2154982*	,07075691	,002	,0766820	,3543143
	2	,0289310	,07075691	,683	-,1098851	,1677472
	3	-,2454688*	,07075691	,001	-,3842850	-,1066526
	4	-,0966450	,07054601	,171	-,2350474	,0417574
2	0	,1865671*	,07075691	,008	,0477510	,3253833
	1	-,0289310	,07075691	,683	-,1677472	,1098851
	3	-,2743998*	,07075691	,000	-,4132160	-,1355837
	4	-,1255760	,07054601	,075	-,2639784	,0128264
3	0	,4609670*	,07075691	,000	,3221508	,5997831
	1	,2454688*	,07075691	,001	,1066526	,3842850
	2	,2743998*	,07075691	,000	,1355837	,4132160
	4	,1488238*	,07054601	,035	,0104215	,2872262
4	0	,3121431*	,07054601	,000	,1737407	,4505455
	1	,0966450	,07054601	,171	-,0417574	,2350474
	2	,1255760	,07054601	,075	-,0128264	,2639784
	3	-,1488238*	,07054601	,035	-,2872262	-,0104215

Based on observed means. The error term is Mean Square(Error) = ,623.

*. The mean difference is significant at the ,05 level.

Appendix F – Qualitative analysis (preparation)

F.1 Information E-mail

Beste Heer/mevrouw

Na aanleiding van een telefoon gesprek zojuist hierbij de informatie over de test “verlichte wegmarkering”

Voor een afstudeeronderzoek aan de Technische Universiteit in Eindhoven in samenwerking met Heijmans zal er over twee weken een test beginnen met verlichte wegmarkering op de N329, de weg van de toekomst. Het doel is zowel kwantitatieve als kwalitatieve data te verzamelen. Voor het laatste zijn we op zoek naar wegbestuurders die minimaal 1x per week in de schemer of in het donker over de N329 rijden.

Via dit e-mail adres willen 4x een korte anonieme vragenlijst 10-15 min onder het personeel van jullie bedrijf laten distribueren. Dit word verspreid over 4 weken, elke week zal er een andere lichtscenario op de weg te zien zijn. Graag zouden we twee maal per week een email sturen (direct of via jullie interne mailing). De eerste email in het begin van de week met de vragenlijst en de tweede email functioneert als herinnering.

De enquête gaat in op de ervaringen met betrekking tot en de beleving van de licht technologie. Denk hierbij aan vragen over zichtbaarheid en veiligheid. Er is hierbij ook ruimte voor open antwoorden en feedback. De technologie is op een stuk van de N329 in Noordelijke richting aangelegd (dus Zuid-Noord). De N329, loopt vanuit knooppunt Paalgraven langs Oss. In de link onder dit bericht wordt het precieze stuk weg waar de licht uitstralende wegmarkering is geïnstalleerd aangeduid.

Als er binnen [Bedrijfsnaam] potentiele deelnemers zijn horen wij dit graag. De link naar de enquête kan dan direct worden gemaild of via een contact persoon bij jullie intern worden verstuurd. De eerste mail mogen jullie dan op 22 november verwachten.

Wij hopen natuurlijk dat jullie ons kunnen helpen.

Met vriendelijke groet,

Milou van Mierlo.

Afstudeerder Human Technology Interaction TU/e & Heijmans.

https://www.google.nl/maps/dir/51.7360223,5.5709995/51.7474981,5.5626049/@51.7391697,5.5592388,14.78z/data=!4m2!4m1!3e0?hl=nl

F.2 Invitation to the Questionnaire (Dutch)

The email stated below is the invitation sent in the first week of the study. The invitations were changed a bit every week though the content remained the same.

Beste [contact persoon]

Hierbij de eerste uitnodiging naar de enquête welke doorgestuurd kunnen worden naar de werknemers.

Bedankt voor uw hulp!

Beste medewerker van [Bedrijfsnaam]

Bedankt voor je deelname aan de het onderzoek “Verlichte wegmarkering op de N329”. De evaluatie duurt vier weken, waarbij we je vragen één keer per week een vragenlijst in te vullen. We bevinden ons op dit moment in de eerste week van het onderzoek.

De volgende link zal je doorsturen naar de anonieme enquête: https://www.survio.com/survey/d/verlichting-in-de-wegmarkering. Het invullen duurt ongeveer 10-15 minuten. We willen je vragen om de enquête pas in te vullen **nadat** je langs de verlichte wegmarkering op de N329 bent gereden.

De verlichte wegmarkering is aangelegd op 500m van de N329 vanaf knooppunt Paalgraven in Noordelijke richting. https://www.google.nl/maps/dir/51.7360223,5.5709995/51.7474981,5.5626049/@51.7391697,5.5592388,14.78z/data=!4m2!4m1!3e0?hl=nl

Met jouw deelname lever je een bijdrage aan de ontwikkeling van innovaties in het verkeer.

Succes en nogmaals bedankt!

Milou van Mierlo

Afstudeerder Human Technology Interaction TU/e & Heijmans.

mmierlo@heijmans.nl
06-15060886

F.3 Reminder to the Questionnaire (Dutch)

Hallo [contactpersoon]

Hierbij de herinnering aan jullie medewerkers voor het invullen van de eerste enquête!

Bedankt voor het doorsturen!

Beste medewerker van [Bedrijfsnaam]

Vergeet niet de enquête: “evaluatie verlichting in de wegmarkering" in te vullen, we kunnen jou feedback goed gebruiken! Hierbij de link naar die je zal doorsturen naar de anonieme enquête: https://www.survio.com/survey/d/verlichting-in-de-wegmarkering.

- **De vragen zijn afgestemd op een specifiek lichtscenario dat alléén deze week (21 november – 27 november) aan staat. De vragenlijst kan worden in gevuld tot zondag 27 november.** Volgende week zal er een ander lichtscenario aan gaan en ontvangen jullie de tweede enquête.

Mocht het onduidelijk zijn waar de verlichte wegmarkering kijk dan even op het kaartje: Belangrijk om hierbij mede te delen: het gaat om 500m weg van de N329 vanaf knooppunt Paalgraven in Noordelijke richting.
https://www.google.nl/maps/dir/51.7360223,5.5709995/51.7474981,5.5626049/@51.7391697,5.5592388,14.78z/data=!4m2!4m1!3e0?hl=nl

Met jouw deelname lever je een bijdrage aan de ontwikkeling van innovaties in het verkeer.

Succes en nogmaals bedankt

Milou van Mierlo

Afstudeerder Human Technology Interaction TU/e & Heijmans.

mmierlo@heijmans.nl
06-15060886

F.4 Introduction Questionnaire (Dutch)

Geachte Heer / Mevrouw,

Bedankt dat je mee wilt werken aan de evaluatie van verlichting in de wegmarkering. De evaluatie duurt vier weken, waarbij we je vragen één keer per week een vragenlijst in te vullen. Het beantwoorden van de vragen duurt 10-15 min.

Om de resultaten te kunnen verwerken vragen wij je een gebruikersnaam op te geven. Deze mag je zelf verzinnen, maar zorgen dat je alle vier keer dezelfde gebruikersnaam gebruikt. Als tip: de eerste twee letters van je voornaam + eerste twee letters van je achternaam + eerste twee cijfers van de dag van je verjaardag. *Bijvoorbeeld: Jan de Vries, jarig op 4 november: javr04*
De vragenlijst zal altijd beginnen met het vragen om je vrijwillige toestemming. Lees daarom de informatie onder dit bericht goed door.

Met uw medewerking lever je samen met andere deelnemers een bijdrage aan het innoveren van de weg.

Vriendelijke groeten,

Milou van Mierlo

F.5 Informed Consent (Dutch)

Vrijwillige deelname

Exploratie lichtgevende wegmarkering *Voordat de vragenlijst begint is het belangrijk dat je op de hoogte bent van procedures die gevolgd worden in deze studie en dat je instemt met vrijwillige deelname. Lees dit bericht daarom zorgvuldig door.*

Doel en voordelen van de studie *Het doel van deze studie is om de ervaring en beleving van lichtgevende wegmarkering te meten. Deze informatie wordt gebruikt om te bepalen wat het effect is van licht technologie in de weg op weggebruikers. Dit onderzoek wordt uitgevoerd als onderdeel van een afstudeeronderzoek door Milou van Mierlo, een student onder toezicht van Antal Haans van de Technische universiteit Eindhoven en Jasper Caerteling van Heijmans infra.*

Procedure *Op de volgende pagina word naar een aantal algemene kenmerken van weggebruikers gevraagd. De pagina's die hierna volgen wordt je gevraagd naar je ervaringen met en je beleving van de lichtgevende wegmarkering op de weg langs Oss. De N329, vanaf knooppunt Paalgraven in Noordelijke richting. Probeer voor het beantwoorden van de vragen, je te verplaatsen naar het moment dat je langs de verlichting in wegmarkering reed. Vul dan de vragen alsjeblieft zo volledig mogelijk in.*

Risico's *Deelname aan de vragenlijst brengt <u>geen</u> enkel risico of schadelijke bijwerkingen met zich mee.*

Duur *De vragenlijst zal ongeveer **10** tot **15** minuten duren.*

Deelnemers *Je bent geselecteerd omdat je een werknemer bent op één van de bedrijven gevestigd op bedrijventerrein Vorstengrafdonk, Elzenburg, Landweer of Danenhoef gelegen aan de N329.*

Vrijwillig *Je deelname is geheel vrijwillig. Je kunt weigeren deel te nemen zonder opgaaf van redenen en je kunt je deelname stoppen op elk gewenst moment tijdens de vragenlijst. Dit alles zal geen enkele negatieve gevolgen hebben.*

Vertrouwelijkheid *Al het onderzoek uitgevoerd aan de Human-Technology Interaction Group houdt zich aan de Code of Ethics van het NIP (Nederlands Instituut voor Psychologen - Nederlands Instituut voor Psychologen).*

Persoonlijke informatie zal niet gedeeld worden buiten het onderzoeksteam. De informatie die wij verzamelen van dit onderzoek wordt gebruikt voor het schrijven van wetenschappelijke publicaties en zal alleen worden gemeld op groepsniveau. Het zal volledig anoniem zijn en het kan niet naar je terug worden getraceerd.

Verdere informatie *Als je meer informatie over dit onderzoek wilt, kan je contact opnemen met Milou van Mierlo, e-mail: mmierlo@heijmans.nl*

BEGIN ENQUÊTE

F.6 Questionnaire (Dutch)

One Question was shown per page

Evaluatie "verlichting in de wegmarkering"

Heb je de informatie betreft vrijwillige deelname gelezen en ga je hiermee akkoord?

- Ik heb de informatie betreft vrijwillige deelname gelezen en ga hiermee akkoord.
- Ik heb de informatie betreft vrijwillige deelname gelezen en ga hier niet mee akkoord.

TERUG 1/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Evaluatie "verlichting in de wegmarkering"

Gebruikersnaam:

Deze mag je zelf verzinnen, maar zorg dat je alle vier keer dezelfde gebruikersnaam gebruikt. Als tip: de eerste twee letters van je voornaam + eerste twee letters van je achternaam + eerste twee cijfers van de dag van je verjaardag. Bijvoorbeeld: Jan de Vries, jarig op 4 november: javr04

Typ één of enkele woorden

TERUG 2/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Evaluatie "verlichting in de wegmarkering"

Wat is je geslacht?

- Man
- Vrouw

TERUG 3/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Evaluatie "verlichting in de wegmarkering"

Wat is je leeftijd?

Typ een nummer

TERUG 4/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Op welke datum reed je langs de verlichting in de wegmarkering? (meerdere antwoorden mogelijk)

- 28 november 2016
- 29 november 2016
- 30 november 2016
- 1 december 2016
- 2 december 2016
- 3 december 2016
- 4 december 2016

TERUG 5/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Op welk tijdstip reed je langs de verlichting in de wegmarkering?

- Tussen 06:00-09:00
- Tussen 09:00-17:00
- Tussen 17:00-20:00
- Tussen 20:00-23:00
- Tussen 23:00-06:00

TERUG 6/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Was je een bestuurder of een passagier?

- [ ] Bestuurder
- [ ] Passagier

TERUG — 7/19 — VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

In wat voor type voertuig reed je?

- [ ] Personenauto
- [ ] Transport bus (werkbus)
- [ ] Vrachtwagen
- [ ] Landbouw voertuig
- [ ] Motor
- [ ] Anders

Typ uw antwoord

TERUG — 8/19 — VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Probeer je te verplaatsen naar het moment dat je, je in je voertuig bevindt op de N329 bij Oss. Vlak voor het moment dat je weer voorbij de verlichte wegmarkering reed. Van welke kant kwam je? Stond je eerst te wachten voor het stoplicht of mocht je meteen door rijden?

Bedenk voor jezelf waar je vandaan kwam en waar je naartoe onder weg was. Was er iets anders vergeleken met vorige keer? Bijvoorbeeld het weer dat anders was. Wellicht reisde je dit keer samen of juist niet. Bedenk als laatste of je bezig was met andere activiteiten zoals navigeren, handsfree bellen of het voeren van een gesprek.

Beantwoord nu de volgende vragen.

Heb je bovenstaande gelezen?

- Ja
- Nee, gelieve dit alsnog te doen.

TERUG 9/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

This question was not included in the first questionnaire:

Week 2 Evaluatie "verlichting in de wegmarkering"

Zag je verschil in de verlichte wegmarkering wanneer je het vergelijkt met vorige week? (Zo ja, wat was er anders?)

Typ een paragraaf

TERUG 10/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Beschrijf hier de situatie zoals je die ervaren heeft. (Wat zag je? Wat vond je ervan in vergelijking met vorige week?)

Typ een paragraaf

TERUG 11/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Wat waren de eerste gedachten die in je op kwamen op het moment dat je dit lichtscenario in de wegmarkering zag? En licht deze toe:

Typ een paragraaf

TERUG 12/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Denk je dat jij (of de bestuurder) anders bent (is) gaan rijden op het moment dat je (de bestuurder) dit lichtscenario in de wegmarkering zag? Zo ja, leg uit op welke manier je denkt dat je (de bestuurder) anders bent (is) gaan rijden.

Typ een paragraaf

TERUG 13/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Wat denk je dat het effect is dat men wil bereiken met dit specifieke lichtscenario in de wegmarkering? Leg je antwoord uit:

Typ een paragraaf

TERUG 14/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Bij de volgende vragen: Vergelijk de wegsituatie met verlichte wegmarkering met een wegsituatie met traditionele wegmarkering.

In vergelijking met een traditionele wegmarkering wat vond je van de zichtbaarheid van het verloop van de weg? Leg je antwoord uit:

Typ een paragraaf

TERUG 15/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

In vergelijking met een traditionele wegmarkering denk je dat het lichtscenario in de wegmarkering de verkeersveiligheid positief of negatief beïnvloedt? Leg je antwoord uit:

Typ een paragraaf

TERUG 16/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Je wordt nu gevraagd onderstaande matrix schalen in te vullen. Probeer dit intuïtief te doen. Denk dus niet te veel na en kies de optie die als eerste in je op komt.

Toen ik tussen de verlichting wegmarkering reed vond ik dit:

Prettig	1	2	3	4	5	Vervelend
Veilig	1	2	3	4	5	Onveilig
Open	1	2	3	4	5	Beklemmend
Kalm	1	2	3	4	5	Onrustig

TERUG 17/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Toen ik tussen de verlichting wegmarkering reed vond ik dit:

Duidelijk	1	2	3	4	5	Verwarrend
Efficient	1	2	3	4	5	Overbodig
Opvallend	1	2	3	4	5	Onopvallend
Makkelijk	1	2	3	4	5	DemandingVeeleisend

TERUG 18/19 VERDER

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

Week 2 Evaluatie "verlichting in de wegmarkering"

Vind je de huidige situatie, met dit lichtscenarios in de weg beter of slechter dan een traditionele situatie? Leg uit waarom je dit antwoord heeft gekozen

Typ een paragraaf

TERUG 19/19 ENQUÊTE INDIENEN

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

The following question was only stated in the first questionnaire

Evaluatie "verlichting in de wegmarkering"

Geef aan op een schaal van 1 tot 10. Zou je graag deze verlichting oko op andere wegen zien?

★ ★ ★ ★ ★ ★ ★ ★ ★ ★

0/10

TERUG 19/19 ENQUÊTE INDIENEN

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

The following question was only stated in the last questionnaire:

Laatste week Evaluatie "verlichting in de wegmarkering"

Zou je graag op de hoogte worden gehouden van de uitkomst van het onderzoek? Zo ja vul dan hier je e-mail adres in.

Typ een zin

TERUG 19/19 ENQUÊTE INDIENEN

Evaluatie "verlichting in de wegmarkering". Bedankt voor je deelname

F.7 Final Email

Beste [contantcperspoon] / werknemer [bedrijfsnaam]

Bij deze wil ik jou en je collega's bedanken voor jullie deelname.

Het onderzoek dat afgelopen weken gaande is geweest probeert te zoeken naar het juiste lichtscenario voor de verlichte wegmarkering.

Afgelopen weken hebben we de setting o.a. van kleur laten veranderen. Ook hebben we een aantal bewegende patronen toegepast. We hebben gemerkt dat dit pas goed zichtbaar is bij een lagere verkeersdrukte. Verder hebben we een aantal positieve als wel kritische feedback van jullie gekregen, dank hiervoor. Naast de enquêtes die door jullie zijn ingevuld hebben we een verkeersmeting uitgevoerd. Komende tijd zullen alle gegevens worden geanalyseerd.

Mocht je na deze informatie nog vragen of opmerkingen hebben dan mag je me gewoon bellen of mailen!

Alvast een hele fijne kerst en een gelukkig nieuwjaar!

Met vriendelijke groet,

Milou van Mierlo
Afstudeerder Human Technology Interaction TU/e & Heijmans

Appendix G – Qualitative analysis

Week 1: 21 until 27 November 2016 - Light scenario 1: White static light

The first week the response rate was 17 from which one participant did gave his/her informed consent and therefor didn't continue with the questions. Five other participants did not continue the questionnaire after they give informed consent. No questions were answered and so these responses are eliminated from the study. A sixth response could not be included since this participant indicated that she drove along the road section during the baseline week. when the lights were deactivated. Although she gave responses that indicate she saw the lights in working conditions there is no information about when she passed the activated lights since this could not have been during the baseline test.

The questionnaires of the remaining 12 responses were completed fully. Following documentation and analysis of the results of week 1 are based on the these 12 responses.

General Questions:

From the 12 participants 7 were man and 4 woman (63.6% resp. 36.4%) with an average age of 44.1 (std. 11.0). All were the driver of a normal passenger car (no trucks, transport vans or other). Almost all participants drove on weekdays over the test track, only one responded to have made use of the road on a Saturday. Also only one, a different respondent then the last, indicate to drive on the N329 between 20.00 and 23.00. All others drove there during peak hours either in the morning between 06:00 and 09:00 (5) or between 17:00 and 20:00 (5).

Visibility

Responses labelled in relation to visibility were most often positive. Multiple participants indicate repeatedly that the lighting created a clear and distinct view of lights which resulted into a clear and distinct demarcation of the road. Participants described the visibility light technology among other things: *"an improvement to traditional road marking".* Though three participants indicated not noticing the light in the road marking. One of the participants even questioned if the lights were working.

When asking participants what they thought the effect was that one wants to achieve with the light emitting road marking, three out of eleven made a reference that can be related to visibility of the road. *"better visibility of the road", "Clearly demarcating the road",* and *"indicating the road marking".*

Compared to traditional road marking the majority (8/11) found the visibility new situation good or better, one only stated to find it nonsense though did not made a statement regarding the visibility and few (2/11) noticed "*no difference*" and "*no difference, the coloured marking was not visible"*. The latter can be declared because white light was activated. Within the elaboration of the reactions indicating visibility was higher participants either reacted positive: *"100% better/ speaks for itself",* neutral *"the width of the road it clearly visible, as well as the direction of the road"* or negative: *"way to visible, to bright,…".*

Other responses that were labelled to the category visibility hinted towards bad weather conditions. Though participants made no statement about driving in bad weather conditions the responses of four persons described the benefits of the light in bad weather conditions such as rain or mist.

Safety

The first reactions that can be related to safety were given when asking participants why they thought the lights where installed (Question 13). More than half of the participants (6/11) gave an answer that implied improvement of safety such as: "*Of course safety*", "*safe lighting*" and "*increase safety*". A reaction further in the questionnaire stated: *"….less people that drift of the road".*

When asking explicitly about the effect on traffic safety the reactions varied from positive to negative. Again 7 out of 11 reactions said the lights would positively influence traffic safety, three reactions stated this would be negative and one did not know. A positive influence on safety was mostly related to increased visibility especially in bad weather conditions. One person did mention the comment that the intensity settings of the light should be considered. The negative reactions claim the lights distract drivers and one person stated: "*negative, this because people will drive more to the centre of the road".*

Experience & comfort

Where the first two categories focus more on the functionality of the light this category includes the responses related to the experience of passing the lights and the (dis)comfort that they provide. Positive reactions are mainly given related increased visibility and safety as discussed above. Other reactions are "*nice, pretty, convenient and safe*" or "*I think this is pleasant*", and "*I did not get blinded, and the light do shines shine that much…*".

But most responses that fall in this category were negative. Several respondents repeatedly mention the flickering effect on the sides of the car and due to the reflection in the side mirrors. Given reaction are: "a light flash in the side mirror when driving of the left lane", *"flashing light in the passenger window", "In the car flashes the reflection of the lights.*

Lastly one participant gave the following curious statement: "*The lighted section is in the first instance interesting. You try to discover if the light pieces light up due to your headlights, or if they do this permanently".*

Other

There were three answers which made a statement about sustainability. Participants mentioned energy use and disturbance of flora and fauna. This was when participants where asking about the why the lights would be installed. A small note should be given that this was a higher with the pilot test where from the 8 persons four people made a reference to this topic with their answers.

Matrix-questions

Figure 12 shows the summarized result of the responses to the matrix questions of all participants. From the figure it can be seen that in general the rating of the light was positive. The highest scores are given to open, clear and noticeable. Efficiency was given the lowest though the summarized result does not state the group of participants considered the technology unnecessary.

Figure 1: The summarized response of the matrix questions, week 1.
Source: Evaluatie "verlichting in de weg markering", see appendix E

Week2: 28 November until 4 December 2016 - Light scenario 2: White dynamic light

The second week the response rate was 8. Two questionnaires were not completed as they were stopped before answering any of the open questions. These responses were rejected and therefore the answers of only six questionnaires could be analysed. These six were completed to the end.

General Questions:

Four men and two women (66.7% reps. 33.3%) with an average age of 44.2 (std. 12.3) filled out all questions. Four of the usernames were the same as the week before, two new user names were listed. It is assumed that the latter two had not filled out the first questionnaire.

As the week before all participants drove a normal passenger car. All made use of the road on week days, two of them in the morning between 06:00-09:00, three between 17:00 and 20:00 and one participants between 20:00-23:00).

Visibility

Only one participant made mention of a moving pattern in the light system. Two other persons mentioned there were less lights activated respectively the lights were now white and last week red/green. These evaluations are both indirect as there were more light activated and the colour was in both cases white.

The remainder arguments concerning visibility again hinted towards clear demarcation of the road and respondents judged this as positive: *"better than traditional road marking", "unfortunately the testing section is so short!!", "better, very clear road marking"*. Though this week the statement were a bit more elaborate as they described that: "*the course of the road is way more clear and that there is a good overview of the road".* There was only one (1/6) statement that mentioned "*the lights are not standing out and that there is little difference compared to traditional road marking".* This person however does consider what the effect of the light might be during rainy conditions.

Safety

Respondent made more concrete statements about the contribution to safety compared to week 1. They associate the light with: "a safe and correct way of driving". When asking to evaluate the light scenario in terms of traffic safety replies are positive: *"a contribution to traffic safety, in all weather conditions it is clearly visible were the markings are"*, *"… You become more concentrated"*, *"… because it enlightens the road you also clearly sees the course of the road"* and negative: *"remains distracting"*, *"it can distract you because you want to look at it".* Compared to traditional road marking there was one reaction indicated the situation was way safer. And lastly one person indicated to driving more careful because of the light.

Experience & comfort

In this week the responses can be related more to this category; experience and comfort. When asked if participants saw any difference they answer among other things that the scenarios was "*less striking, calmer*", "*dimmed", "softer colours which is more pleasant to pass"* and *"last week the light was disturbingly present, now it is standing out less"*. However the persons that had noticed some dynamics in the light scenario's replied it was more restless and asked for more attention. Another person gave the general reaction of: *"what a fun fair"* Which is interpreted as *extravagant or overdone.* Discomforting statements again pointed out the reflecting effect in the mirror and pointed out the distracting effect.

Other

No statements regarding to sustainability. One person hinted that the light could indicate a message to the driver. This participant mentions "could indication that you drive to fast but it has little influence" and "colours that indicate that your speed is too high…".

Matrix-questions

The summarized result of the responses to the matrix questions (Figure 13) are more again in total more positive. Though the positive assessments given are more positive than last week two scales show a negative shift. The total result of judging if the situation looked calm or restless ended precisely in the middle. Furthermore this week the light was evaluated way more noticeable but at the same time also unnecessary.

When I was driving between the lights I found this:

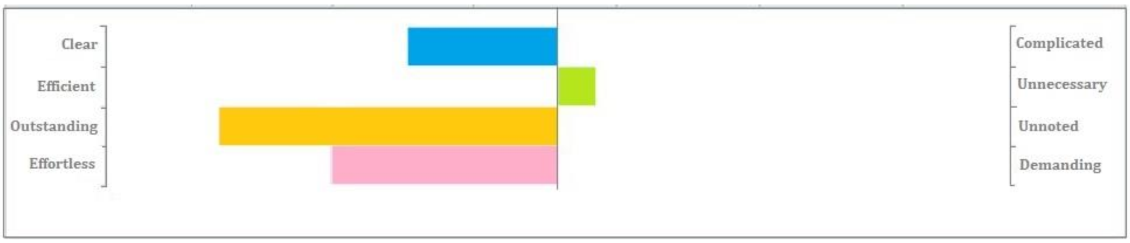


Figure 2: The summarized response of the matrix questions, week 2
Source:Week 2 Evaluatie "verlichting in de weg markering", see appendix E

Week 3: 5 until 11 December 2016 -Light scenario 3: amber coloured light

The third week the response rate was five. All five were fully completed and all were used for analysis. Although the response rate was low the answers are discussed since they still provided some new insights as well as they give some information regarding the difference to the previous week.

General Questions:

From the respondents two were men and three women (40% reps. 60%) with an average age of 45.2 (std. 12.6). Three of the user names were similar to the first and second week. One username was new and One username was used in week two as well, though in week 2 this response was rejected for analysis.

All participants drove a normal passenger car and drove past the testing section on weekdays either in the morning or evening peak (06:00-09:00 or 17:00 and 20:00).

Visibility

All participants made notice of seeing the lights. Though asking about the change in comparison to the weeks before answers differed from not seeing any difference, to seeing a moving patterns, to calmer light, to more noticeable. One person responded with: "*less bright, bit still clear visible".* Additionally, notions were made regarding to the clear demarcation of the road, a better overview and a clearer view of the course of the road. One person mentioned the light scenario beneficial since it improves clarity. Lastly the following statement was given: *"There is a gentle curve in the road; which is this way clearly marked".*

Safety

The statements related to safety maintain divided. Both positive as well as negative. Positive responses are again related to the clear appearance and visibility. Negative responses again mentioned that the light is far too present. Furthermore one answer highlighted the effect of driving more carefully.

Experience & comfort

A high amount of answers could be labelled to the category experience and comfort. Several answers describe a more calm and more relaxed view. "*It certainly gives serenity and is not striking".* Answers also describe driving with the lights as "*…pleasant*". Other reactions hint the lights cause more alertness and is invigorating. Though the opposite statements are also given: *"too conspicuously present"* , *"distracting"* and *"flickering light is not pleasant"*. One participant made the comments that the light make the roadway optically narrower. She did not make a statement if she considered this positive or negative.

Other

This week one person made a comment about the necessity and the costs of the light technology. This comments was also labelled with a negative value as he stated to find the light emitting road marking not necessary in comparison to traditional road marking. Concerning the influence on traffic one comment was made which describe the utilizations of improving traffic flow.

Matrix-questions

In week 3 the summarized results of the responses to the matrix questions gave again a moderate positive result. Noticeable remained to have the highest score. The rest of the score received a lower rating. Though it should be kept in mind that the response rate of this week was very low. This leads to the fact that the answers of one respondent have more impact on the total result compared to the other weeks.

When I was driving between the lights I found this:

Figure 3:The summarized response of the matrix questions, week 3.
Source: Week 3 Evaluatie "verlichting in de weg markering", see appendix E

Week 4: 12 until 18 December 2016 - Light scenario 4: amber coloured dynamic light

The last week the response rate picked up again and resulted in 11 responses. Two of the participants ended the questionnaire before answering any of the open questions. These responses were rejected which left 9 fully answered questionnaires.

General Questions:

55,6% of the participants was male and 44.4 % was female (5 resp. 4 participants). The average age was calculated to be 46.3 years (std. 9.5). This week three of the user names were also used in the first, second and third week of the test period. One username was used in the first but not the second nor the third time. Two usernames showed high resemblance to one used in the first week and one used in third week (mm67 to moonman67 and Sioss to Sioss004). Answer of the participants made notion of comparisons with the first/third week, though it cannot be said with certainty that these are the same person. The other four usernames were new.

From all participants one person drove past the test section during weekend days (Saturday and Sunday). All participants made use of the road during week days. The time of driving on the road was this week distributed between morning (06:00-09:00), evening (17:00-20:00), late evening (20:00-23:00) and night (23:00-06:00). The responses rate was 2 , 4, 1 resp. 2. All participants were drivers of a normal passenger car.

Visibility

None of the respondents noticed the dynamic pattern applied in this scenario, also not the person who spotted the dynamic pattern in week 2. Though most respondent described to see some difference (7/9). Five answers described more dimmed or calmer light. Two participants made notice of the a yellow/orange colour. One person made the following statement: *"this time it was a 'simple' stripe, without the fancy distraction".* Furthermore reactions concerning visibility indicated, like all previous weeks, a good and clear marking, a clear demarcation of the road (width) and a clear view from a distance.

Safety

This week one of the respondents indicated to have gotten a positive feeling of security: "*no more gazing in the dark, but the road was clearly marked on both sides and this gave a feeling of security".* Another concretely stated the colour was safe. When asking about the intended effect of this light scenario's five answers discussed the topic safety. Further reading their statement safety was brought in relation with constant speed, demarcation of the road and clarity. Less positive was the expectation that the lights lead to less attention to the road, which would make the situation less safe.

When asking explicitly about the impact on traffic safety, the same five persons answered a positive effect due to: *"better, clearer and view of the road", "shifts the focus of the driver, whereby the safety in general improves", "the colour is well present", "the road is clearly demarcated".* One person answered to not have seen anything, one that the technology is unnecessary and two persons think traffic safety is affected negatively. They stated:

"Attention is attracted to the marking and not to the road and other road users" and *"if you never drive there it will give a shock effect".*

Experience & comfort

Most participants were positive and/or described an improvement compared to the weeks before. *"The lights reflect in the metal parts of the inside of the car, a bit less that last time but still very disturbing", "more pleasant compared to last time, but still annoying", "better than the weeks before ",* and *"it looks calmer, the lights were not that bright. And the light does not comes so much at you".*

Despite this experience improved blunts statements were made regarding the experience of the flickering effect to be "VERY disturbing" (this statement was added to the answer of every question by one respondent) improvement was described. One other respondent made notice of the reflecting effect of the light.

Other positive reactions describe again a pleasant way of driving and a good and safe choice of the colour but mostly comments mention the words "calmer", "more pleasant" and "clearer". Lastly the comment of feeling safe discussed in the category 'safety' when driving past the light was also labelled to this category.

Other

This week one statements was made concerning energy savings. Another raised attention towards the cost and maintenance.

Matrix-questions

The last week showed a different distribution of the summarized results of the responses to the matrix questions compared to other weeks but still positive in general. Noticeable remained to have the highest score. The concept *Pleasant – Unpleasant* was rated positive but the result was very low. The combination *Calm- Restless* was a bit negatively rated.

When I was driving between the lights I found this:

Figure 4: The summarized response of the matrix questions, week 4.
Source: Week 3 Evaluatie "verlichting in de weg markering", see appendix E