Lane recognition for automated vehicles

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by

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Preface

This thesis was written in partial fulfillment of the bachelor's degree of Civil Engineering at Delft University of Technology.

My special thanks go out to my supervisors from the department of Transport & Planning, Dr. ir. Yufei Yuan and Ir. Rolf Koster for guiding me through the process of writing this thesis. I would also very much like to thank Dr. ir. Haneen Farah and Yongqi Dong for meeting with me regularly to advise me on the topic and to share their contacts with me. In addition, I would like to thank my fellow students who have helped me during the process of writing this thesis by performing weekly peer reviews.

Finally, I would like to thank the interviewees André Kleis and Alex van Loon, both from Rijkswaterstaat, for taking the time to answer my questions, informing me on road marking in the Netherlands and the relevant developments in the field.

S. Toonen
Delft, June 2020

Summary

In an era in which the penetration of partially automated vehicles in traffic will only increase, but human driven vehicles continue to be road users, lane marking requirements will need to be revised in order to support detection by both types of traffic. Lane marking is not only important for detection by the human eye, but up until the moment that automated vehicles do not require a human driver anymore under any circumstances, physical lane markings are needed for detection for machine vision in automated vehicles.

The quality of lane marking depends on four factors being visibility, skid resistance, wear resistance and durability. For the visibility, a set of requirements is formulated which includes requirements for day-time and night-time and under dry and wet conditions. The requirements for these quality determinants are based on the European requirements described in the standard EN1436. In these requirements for lane marking quality, the presence of (partially) automated vehicles is not taken into account. Further research shows that the visibility of the marking and its width are the determining factors in detection by machine vision systems in automated vehicles. In addition to that, the width of lane marking is also important for its detectability.

Detection systems in vehicles nowadays are designed to detect based on the lane marking that is currently present. However, in order to be able to detect the lane marking, the visibility needs to be sufficiently high. Literature shows that lane marking visibility in the Netherlands is good enough under most conditions. Only for the retro-reflective luminance under dry conditions at night, the requirement should be increased. In addition to that, a high contrast ratio should be aimed for and lane marking must be widened on roads where its width is smaller than 12 cm.

Despite road authorities having to apply and design their lane marking according to the same requirement guidelines, it occurs that roads of one authority do not necessarily have lane marking with the same characteristics as that of a same type of road managed by another authority. This leads to a lack of uniformity in applied lane marking. Even though this may not be an issue for human detection, it creates detection problems for detection systems in automated vehicles. For this reason, uniformity in lane marking is going to be an important aspect for facilitating automated vehicles.

Finally, recommendations for future research include comparative research on system and human detection, use of the skid resistance of lane marking material as detectable characteristic and optimization of wear resistance of lane marking and its durability. Recommendations for practitioners such as road authorities include further uniforming of lane marking application, as well as lane marking quality. In addition, quality inspections and maintenance should be performed to ensure the lane marking quality throughout its lifespan.

Contents

1 Introduction

"Self-driving cars: from 2020 you will become a permanent backseat driver" [2]

This was the heading of an article published on the website of The Guardian in September 2015. It now is 2020, but the majority of vehicles we see on the roads is still not fully automated. In fact, we currently only see mixed traffic up to level two automation [27] and in Q2 of 2019, only 8% of new cars sold were of level two automation [8]. The degree of vehicle automation can be defined in terms of levels, as described in figure 1.1. Before having only automated vehicles on the roads, there will be a period of time where automated and human-driven vehicles share the roads. A crucial element of supporting this mixed traffic is lane marking, an area of ongoing research. In an era of autonomous and human driven vehicles sharing road infrastructure, lane marking requirements will need to be revised in order to support detection by both types of traffic. Lane marking is not only important for detection by the human eye, as described in chapter 2, but up to and including level four automated vehicles [3], physical lane markings are needed for detection for machine vision by systems such as advanced driver assistance systems (ADAS) [1].

The **SAMEN** project is a research project at the faculty of Civil Engineering at the TU Delft, under supervision of dr. ir. Haneen Farah. The project focuses on interactions between human-driven and automated vehicles as part of its research into **S**afe and efficient oper**A**tion of auto**M**ated and human drive**EN** vehicles in mixed traffic [32]. In the SAMEN project, vehicles with automation level two, three and four are considered. These vehicles can not yet drive autonomously completely, but require human control on smaller road, in unexpected situations or when the system requests its.

As supporting work for the SAMEN project, this report focuses on the identification of lane marking quality requirements for the safe operation of vehicles equipped with lane keeping systems. This report will provide the SAMEN project with a better understanding of necessary requirements for lane marking to ensure the correct functioning and safe operation of automated vehicles, in conjunction with human driven vehicles.

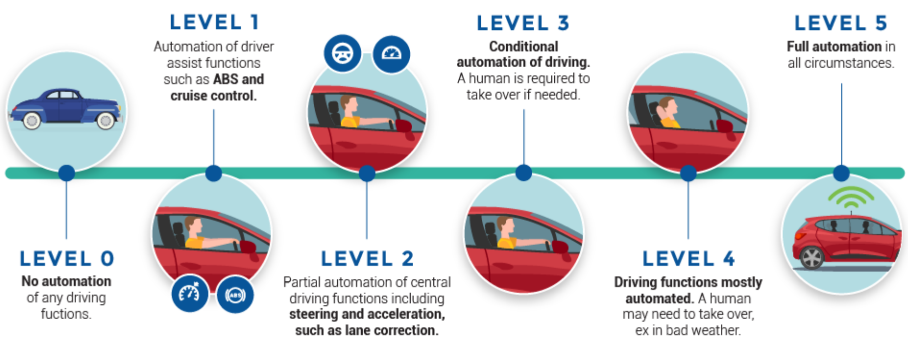


Figure 1.1: Levels of autonomous driving technology [7]

1.1. Research question

Lane marking is an important element of the road infrastructure contributing to safe driving. It has to be detectable by the human eye, as well as by automated lane keeping systems on different types of road and in different driving conditions. It is crucial that automated systems can always identify lane markings.

Given this important role of lane marking in traffic safety and its required detectability for humans and lane detection systems, the research question is:

"How do the lane marking requirements for lane detection in automated vehicles differ from the requirements for detection by human drivers in different driving conditions?"

In order to learn about the different requirements for lane marking and to eventually formulate an answer to the main research question, the following sub-questions are researched:

1. What determines the quality of lane marking?
2. What are the current requirements for lane marking?
3. How is human driver performance influenced by lane marking?
4. What are the lane marking requirements for lane detection in automated vehicles?

1.2. Problem scope

In accordance with the SAMEN research project, the geographical focus is on the Netherlands. (Minimum) Requirements that are mentioned are therefore the ones valid for lane marking in the Netherlands specifically. Furthermore, when talking about lane marking in this report, this refers to the longitudinal centre and edge lines of roads. In addition, only the permanent white marking is discussed and the temporary, yellow marking is therefore disregarded. Finally, in accordance with the SAMEN project, when referred to automated vehicles, levels two, three and four of autonomous driving technology are considered.

1.3. Method and methodology

The research was conducted in multiple steps by means of a literature study, supported by interviews with experts in the field. The first step was to identify the factors that determine the quality of lane marking and to identify the currently set requirements for lane marking on Dutch roads (sub-questions 1 and 2). In addition to literature review for which research papers, guidelines and standards were studied, an interview with André Kleis (Rijkswaterstaat; project manager monitoring test sites and road marking materials) was conducted.

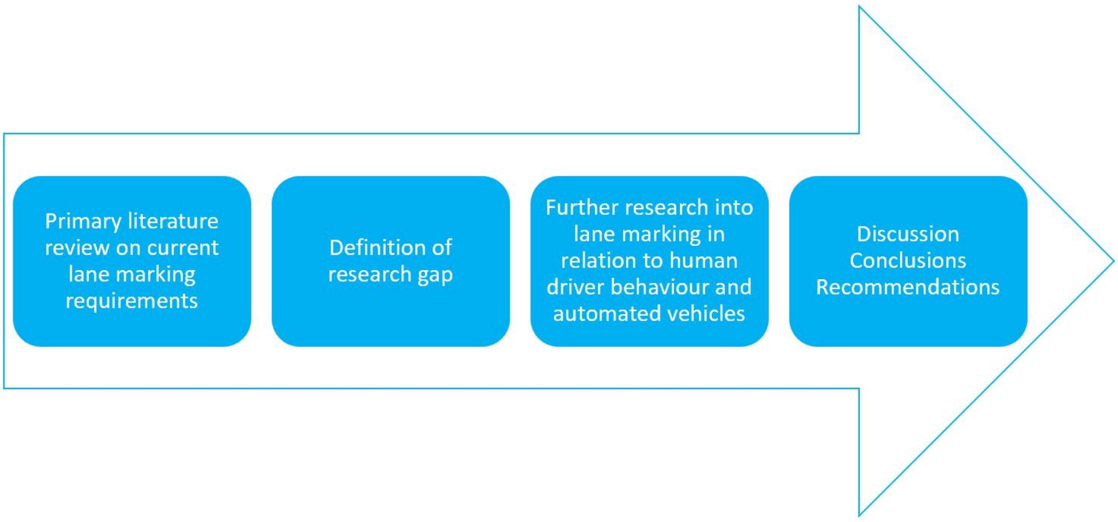
After this first step the conclusion was drawn that the currently set requirements for lane marking are based on human detectability and do not take the future large-scale introduction of automated vehicles into account. This led to the conclusion that in order to find an answer to the research question, further research was needed into the influence of lane marking on human driver performance and into the lane marking requirements for lane detection in automated vehicles. This was necessary to make a comparison possible between lane marking requirements for lane detection in automated vehicles and lane marking requirements for detection by human drivers. This led to the formulation of two additional sub-questions (sub-questions 3 and 4).

In order to answer the additional sub-questions, research papers and scientific studies were reviewed and Alex van Loon (Rijkswaterstaat; member of a work group on smart mobility) was interviewed.

Finally the comparison was made between the two sets of requirements in order to draw conclusions on how the requirements differ in values and also what additional requirements might have to be set to facilitate good detection by systems in automated vehicles.

1.4. Report structure

In chapter 2, the quality determinants and the currently set lane marking requirements are described, providing answers to sub-questions one and two. Chapter 3 describes the influence of the presence of lane marking, as well as lane marking with improved visibility on human driver behaviour. In this chapter sub-question three is discussed. Subsequently, in chapter 4, lane marking in relation to automated vehicles is studied. In the final chapter, the main findings are presented and a comparison between the requirements for automated and human-driven vehicles is made. A discussion follows and the study will finish with recommendations for future research and for practitioners working with lane marking.



2 Quality of lane marking

In this chapter, results of the initial literature review on lane marking are presented. After a brief introduction on the different types of lane marking and a description on how the quality is assured, the subsequent four sections discuss the different quality determinants. The corresponding requirements are presented in these sections as well. At the end of this chapter, in section 2.5, the key takeaways from this literature review will be summarized and the research gap for this thesis is defined.

The quality requirements set for lane marking can be best described on the basis of design guidelines and (Dutch) standards. Lane marking quality depends on the following four factors which are discussed in this chapter [34]:

- Visibility
- Skid resistance
- Wear resistance
- Durability

In the Netherlands, two types of lane marking are applied on the roads; type I and type II [21]. Type I is the original, regular marking which you would recognise as being filled lines. Marking of this type reflects light in the wrong direction under wet circumstances and therefore jeopardizes driving safety. Type II marking was developed, aiming to improve visibility during (heavy) rainfall at nighttime. The two types can be distinguished based on the coarseness of the lane marking on the pavement. Even though type II can now also be found in a filled form like type I, it is more commonly applied as 'splash' or 'multi-dot' marking [21] with a surface coverage between 50 and 70% [9]. Examples of different type II markings can be found in figure 2.1. For specific types of lane marking used in the Netherlands, appendix A can be consulted.

(a) Type II filled (visually identical to type I) [6]

(b) Type II: Splash marking [33]

(c) Type II: Multi-dot marking [5]

Figure 2.1: Different types of type II lane marking

The requirements and design guidelines for lane marking in the Netherlands are set by the different road authorities and are based on the European standard EN1436 [22]. This means that nationally, the requirements for lane marking quality can diverge. In addition to possible differences in quality requirements, differences are also found in the presence and/or appearance on lower ranked roads. However, in order to guarantee a certain quality level, road marking materials need to be KOMO or CE certified in order to be applied on Dutch roads. Most suppliers use materials that are certified previous to application. In case non certified materials are used for the marking of roads, within ten days of application, several factors need to be measured to guarantee the quality of the lane marking materials. After application, the contractor is responsible for maintenance by having to periodically perform measurements to show their lane marking still meets the requirements [23]. However, it has been concluded that the lifespan of lane marking exceeds that of pavement [22] [35], and therefore lane marking quality is no longer monitored and no maintenance is performed. As a result of this conclusion, the quality of the lane marking can not be guaranteed over its lifespan.

2.1. Visibility

The visibility requirements are set to guarantee sufficient visibility during the day, during the night and under both dry and wet conditions. In order to ensure the desired safety level at all times, different requirements are set within the spectrum of different weather conditions. All lane markings, whether it is type I or type II, contain glass pearls. These are either mixed with the lane marking material or sprinkled over after the application. By creating retro-reflection, these pearls improve the visibility of the lane marking. Retro-reflection is different from regular reflection. With regular reflection the light moves in all different directions. Retro-reflection, reflection back towards the light source, improves the visibility of the lane marking, which is especially important under bad weather conditions and at night. The difference between the two types of reflection is shown in figure 2.2.

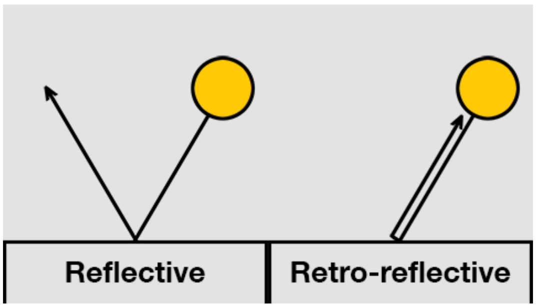
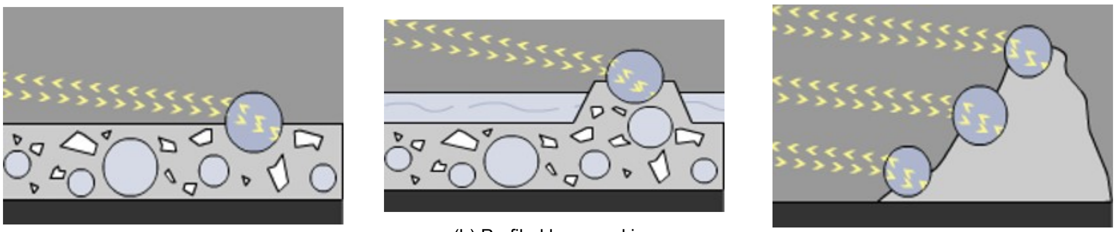


Figure 2.2: The difference between reflection and retro-reflection [28]

The degree of retro-reflection of lane marking depends on the following factors [17]:

- The quality of the lane marking material
- The amount of glass pearls at the surface of the marking
- The size of glass pearls relative to the thickness of the marking material
- The roundness of the glass pearls
- The type of glass used and the corresponding reflective index
- The way the glass pearls are applied to the material
- The wear resistance of both the lane marking material, as well as the road surface

Type II lane marking has a better visibility attained by an improved exposure of the glass beads. Improved exposure is obtained through increased size of the glass beads, preventing them from getting covered with water, or by applying the marking with a coarser structure (e.g. profiled or agglomerate). All three options are illustrated in figure 2.3. An adverse side effect caused by these measures is a decrease in skid resistance, making it dangerous for motorcyclists. In addition, the coarser structure increases traffic noise.



(a) Larger glass pearls

(b) Profiled lane marking

(c) Agglomerate lane marking

Figure 2.3: Improved exposure of glass beads in type II lane marking [34]

2.1.1. Daytime visibility

Rijkswaterstaat defines daytime visibility as being the visibility of markings in a) normal daylight circumstances or b) public lighting as seen by the driver of a passenger car [34]. The following applies to daytime visibility [21]:

Type I markings	Class B3	$\beta \geq 0.40[-]$
Type II markings	Class Q3	$Q_d \geq 130\,[mcd/m^2/lx]$

β : Luminance factor
Q_d : Luminance coefficient
$mcd/m^2/lx$: Millicandelas per square metre per lux

As can be seen, the type I and type II daytime visibility requirement are measured with a different parameters, namely luminance factor (β) and luminance coefficient (Q_d). They both measure the brightness of lane marking, but differ in measuring method. Q_d is measured over a longer viewing distance whereas β is measured from close to the material [14]. The reason for applying two different parameters is that Q_d is more suitable for type II lane markings.

The classes mentioned in the second column follow from class divisions defined by the European Union. The corresponding standard is EN 1436 in which it is also described how the daytime visibility is measured.

The luminance factor is determined using a spectrophotometer. It is placed on a small area (of at least 5cm^2) of the marking material and measures at an angle of (0±10)° the daylight illumination at an angle of (45±5)°. From this measurement follows a luminance-index Y from which β follows by dividing Y by 100 [17][14].

The luminance coefficient is the ratio between the luminance of the marking material and the illuminance of the pavement [14]. In order to determine a realistically correct Q_d value, the measurements are done at a distance of thirty meters from the driver, at an angle of 2.29°.

2.1.2. Night-time visibility

Visibility of lane marking at night is defined as the visibility under the illumination of headlamps as seen from the driver seat of a passenger car. A distinction is made between dry and wet conditions. The term used for the reflected light is retro-reflection. Just as for daytime visibility, NEN EN 1436 is also the valid standard including all the relevant requirements and measuring details.

Retro-reflection is measured similarly to the Q_d. The same ratio is calculated, but now the amount of reflected light measured is the light being reflected into the direction from which the light is emitted from the source (in this case the headlamps of the vehicle) [17].

Dry conditions

In dry conditions, the following requirements must be complied with [21]:

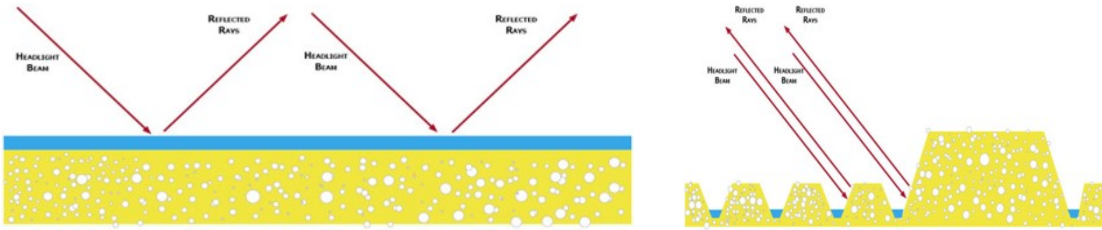
Class R2 $\quad R_L \geq 100\,[mcd/m^2/lx]$

R_L : Retro-reflected luminance
$mcd/m^2/lx$: Millicandelas per square metre per lux

When it's dry, the visibility requirements for type I and type II are the same. The visibility enhancing characteristics of the type II marking don't have any impact in dry circumstances since the functioning of the smaller glass pearls in the type I marking is not hindered.

Wet conditions

During heavy rainfall, the glass pearls in type I markings are covered with too much water which causes the light to be reflected in the wrong direction. The larger size of the pearls, or the improved exposure due to the material structure in type II markings lead to the water sliding off, maintaining their functionality of providing sufficient retro-reflection of light . In figure 2.4, the two situations are depicted.



(a) Type I marking (b) Type II marking

Figure 2.4: Retro-reflection under wet circumstances [34]

Under wet circumstances at night, the only way of meeting the visibility requirements is to apply type II marking [19]. The following requirement is in place:

$$\text{Class RW2} \quad R_L \geq 35\,[mcd/m^2/lx]$$

R_L : Retro-reflected luminance
$mcd/m^2/lx$: Millicandelas per square metre per lux

In wet circumstances a distinction is made between wetness and rain. Under rainy conditions the R_L measurement can be done after five minutes of continuous rain. For wetness, for example when the road surface is flooded, the measurement can be done after one minute already [14].

2.2. Skid resistance

Determining the minimum requirements for skid resistance is done under wet conditions and at low speeds. The requirements do not only depend on the type of marking, but also on the thickness of the marking product.

Type I	S2	layer thickness ≤ 0.5 mm	$SRT \geq 50[-]$
	S3	layer thickness > 0.5 - 3 mm	$SRT \geq 55[-]$
Type II	S3	filled	$SRT \geq 55[-]$
	S1	multi-dot / splash	$SRT \geq 45[-]$

SRT : Skid resistance tester

The skid resistance is measured by letting a rubber slider with set dimensions slide over the specified length of road surface. The measured loss of energy resulting from the friction that arises is the skid resistance tester value [14].

2.3. Wear resistance

The wear resistance of lane marking indicates simply how susceptible the marking material is to wearing off as a result of vehicles driving over it. In the Netherlands, a minimum of 80% of the lane marking material is required to stay in place for the duration of its lifespan [34]. It is measured by taking a picture of the most worn part of the surface after which it is analyzed with image editing software to calculate the ratio between light and dark, indicating sufficient lane marking and worn lane marking (underlying pavements is visible) respectively.

2.4. Durability

The durability of lane marking influences its expected lifespan. The expected lifespan needs to be determined when the lane marking material is tested for the issuing of certificates (KOMO and/or CE). The durability is defined as the wear resistance per x number tire rolls. In the Netherlands, Rijkswaterstaat advises a durability of two million tire rolls, belonging to level P6 [23]. The wear resistance also influences the expected lifespan. The corresponding lifespans per marking material are as follows:

Road paint	1 - 2 years
Spray plastics (1.5 mm)	4 - 5 years
Thermoplastics (3 mm)	7 - 10 years

2.5. Key takeaways and research gap

The main findings of this study into current requirements showed that, first of all, the quality is determined by the factors visibility, skid resistance, wear resistance and durability. Throughout its lifespan, no quality inspections are done anymore due to the once drawn conclusion that generally, the lane markings lifespan is longer than that of the underlying pavement. Because of this observation, the renewal of lane marking when pavement maintenance takes place was deemed sufficient.

Secondly, not once, automated vehicles were mentioned which leaves room for concluding that the current requirements are solely developed focusing on the detectability by human drivers. This means that further literature study into lane marking for automated vehicles is required to provide enough information for answering the research question. The research gap includes the effect on human driver behaviour and the importance of lane marking for system detection in automated vehicles.

3 Lane marking and human driver behaviour

In this chapter, the influence of lane marking visibility on the human driver behaviour will be explained. This information is relevant for helping to understand what driving behaviour is influenced by in relation to lane marking.

Lane marking is an important element of the infrastructure contributing to safe driving. For human drivers, this means that its purpose is to guide road users and to inform them of their location on the road [20]. In order to do that, lane marking needs to be present and clearly detectable. Through the correct use of lane marking, driver behaviour can be influenced. Importantly, the difference between lane keeping detection and lane keeping performance should be briefly clarified. Lane detecting is the act of perceiving lane marking on the road surface. In order to perceive, the factors influencing visibility play a very important role. Lane keeping performance is what comes after the perception of the markings. Among other things, it includes the (adjustments in) driving speed and the lateral position of the vehicle on the road in response to the degree of observability of the road markings.

3.1. The presence of marking applied as an influence factor

Even though the influence of road design on human driving behaviour has been studied in many different ways, studies with lane marking as the influence factor have not been performed as elaborately. In a meta-analysis performed by SWOV, a Dutch research institute for traffic safety, the lane keeping performance in terms of speed and lateral position on the road was studied after a change in markings. Different types of changes were made to the centre and/or edge lines after which the speed and lateral position were monitored [10]. The results of this analysis can be found in appendix B and show that different combinations of alterations led to different driver behaviour in terms of both driving speed and lateral position on the road. For example, the adding of an edge or centre line on a road surface that was unmarked before leads to an increase in the driving speed and shifts the position of the vehicle towards the edge of the road. On the other hand, by adding an edge line to a road that already contained a centre line, the driving speed actually decreased.

3.2. The influence of type II lane marking on driver behaviour

The key in lane detection is to be able to do so under any given circumstances. Wet conditions during the night generally create the toughest condition to properly detect [29]. As described earlier, type II lane marking was developed to facilitate better visibility under such conditions and therefore (positively) influencing the driver behaviour.

The RAINVISION project studied the driving behaviour of people from different age groups, influenced by the visibility and retro-reflectivity of road markings [12]. The study was performed in dry, wet and rainy conditions. The difference between wet and rainy conditions was previously explained under the 'wet conditions' section on page 8. Three trials were done; a simulation, a track test and on-road. Results from the simulation showed a number of errors 70% higher with type I marking, compared to type II [12]. The results from the track clearly showed that driver performance with the type II markings was a lot better than in the traditional situation. Speeds were generally highest with type II lane marking applied, without causing dangerous situations as a result of it. The risk of an increase in driving speed (different per type of alteration) was compensated in this trial by the improved visibility and hence ensured the safety of the driver. The final trial, on several roads in the United Kingdom monitored speeds of passing cars for a full year, under any kind of weather conditions. In one location, type I marking was applied, in another type II was used. Even though the results of this trial showed a small decrease in driving speed, the overall conclusion drawn by the RAINVISION research team described the influence of type II marking on driving behaviour as ”ensuring clear trajectories of the driving path, taking a substantial workload off the driver” [12].

3.3. Key takeaways

The presence of lane marking and the application of lane marking with improved visibility have a positive effect on human driver performance. Adding marking generally increases the driver speed with several kilometers per hour. The effect on lateral road position of the vehicle depends on which line (centre or edge) is marked. With the application of one of two, the vehicles moved away from the line added. With both lines added, the vehicles were positioned more towards the middle of the lane.

The application of type II marking, which is coupled with improved visibility, shows an increase in driving speed as well. More importantly, however, is the significant decrease in observed errors during driving as a result from improved visibility.

These findings provide an understanding of the significance of lane marking on human driver behaviour. In relation to the research question, this information is needed to learn about the limits in which the lane marking requirements for automated vehicles can be changed without negatively influencing the human driver performance.

4

Lane detection in automated vehicles

”Lane keeping systems for keeping a vehicle in the desired lane is key to advanced driving assistance system in autonomous vehicles.” It is needed for the generation of a reference path, which in its turn is needed for lane keeping by gaining information on the position of the vehicle on the road, relative to the detected markings [24].

Lane detection is a type of computer vision [18] and is a very important element of the lane keeping systems in automated vehicles. In ADAS, lane detection plays an essential role by supporting functions such as lane departure warning and lane keeping assistance [24].

This chapter explains the way lane keeping systems detect the lane marking on the road. By studying the way systems detect, as well as their sensitivity to visibility characteristics, essential knowledge is laid out for drawing conclusions on lane marking requirements for detection by automated vehicles. The intention of looking into these two topics is to find out what lane detection systems need for proper detection. Current developments in the field of automated vehicles in relation to lane marking are discussed in section 4.4. At the end of this chapter, the main findings are summarized in the section key takeaways.

4.1. Detection of lane marking

The detection of physical, visible lane markings by vision based detection systems is commonly done in three steps [24][16][36] which are listed below and displayed in figure 4.1:

1. Image pre-processing
2. Lane detection by feature extraction and model fitting
3. Tracking of detected lane

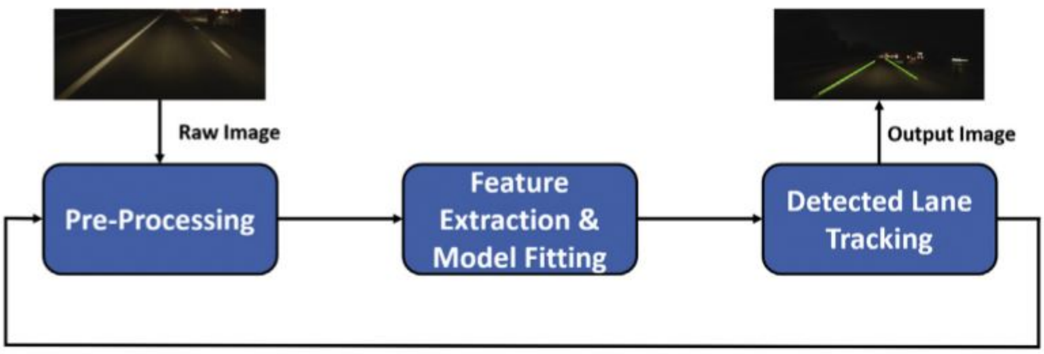


Figure 4.1: Lane detection system [36]

In the pre-processing stage, camera input is adapted to enable clear detection. Among other things, this includes changing colour picture to a specified colour format (often grayscale) and the selecting of a so-called region of interest [16]. In the detection process, features such as marking edges can be extracted from the pre-processed image. In case of curved lines instead of straight, model fitting of extracted features is required. The final stage of tracking the detected lane implies the positioning of the vehicle in between the detected lane markings.

The detection can be subdivided into two categories : feature-based and model-based [36]. Feature-based detection requires elements like colour and clear edges of lane marking to properly detect and in model-based detection, by means of model fitting, lane marking lines are assumed to be straight lines or parabolic curves [25]. The difference between the two is that in model-based detection, model fitting techniques are applied to take out irrelevant features of the input picture. Feature-based detection more accurately detects markings when the lanes are clearly visible. However, [36] states that ”too many constraints are assumed, such as lane colours and shape”, meaning model-based detection is better in poorer visibility conditions.

4.2. The effect of visibility factors on the performance of lane detection systems

In this section, the results of a study by Potters Industries, an American producer of glass beads, are discussed. The choice for this study specifically is based on its relevance to this thesis. The company performed a study in which they raised the question of how the factors retro-reflectivity, contrast ratio and marking width affect the performance of machine vision [11]. These measurements were done with a test vehicle, equiped with a machine vision system. Further details on the test methods can be found in appendix C.

For the retro-reflectivity, the measurements were performed at night. Tests showed that the influence of retro-reflectivity during the day had minimal effect on machine vision performance [11]. The effect of three types of lane marking (40 mcd, 240 mcd and 900 mcd), each with a different luminous intensity ([mcd]), was tested on two different types of pavement (8 mcd and 25 mcd). The higher the luminous intensity, the brighter the surface is. The results can be seen in figure 4.2 and are explained on the next page.

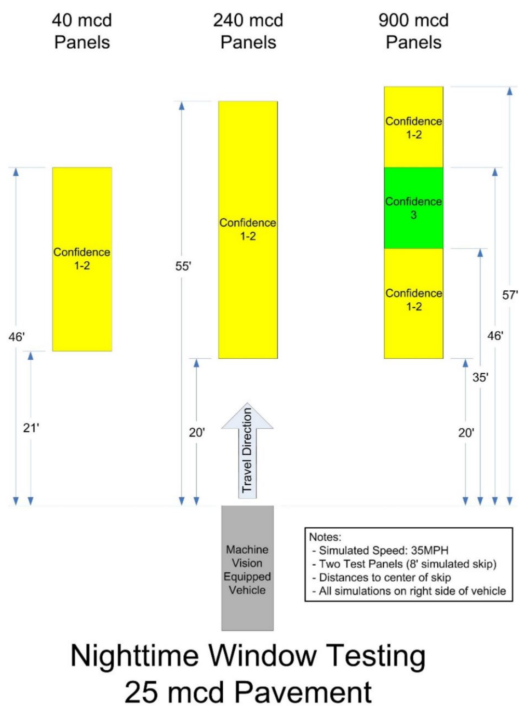
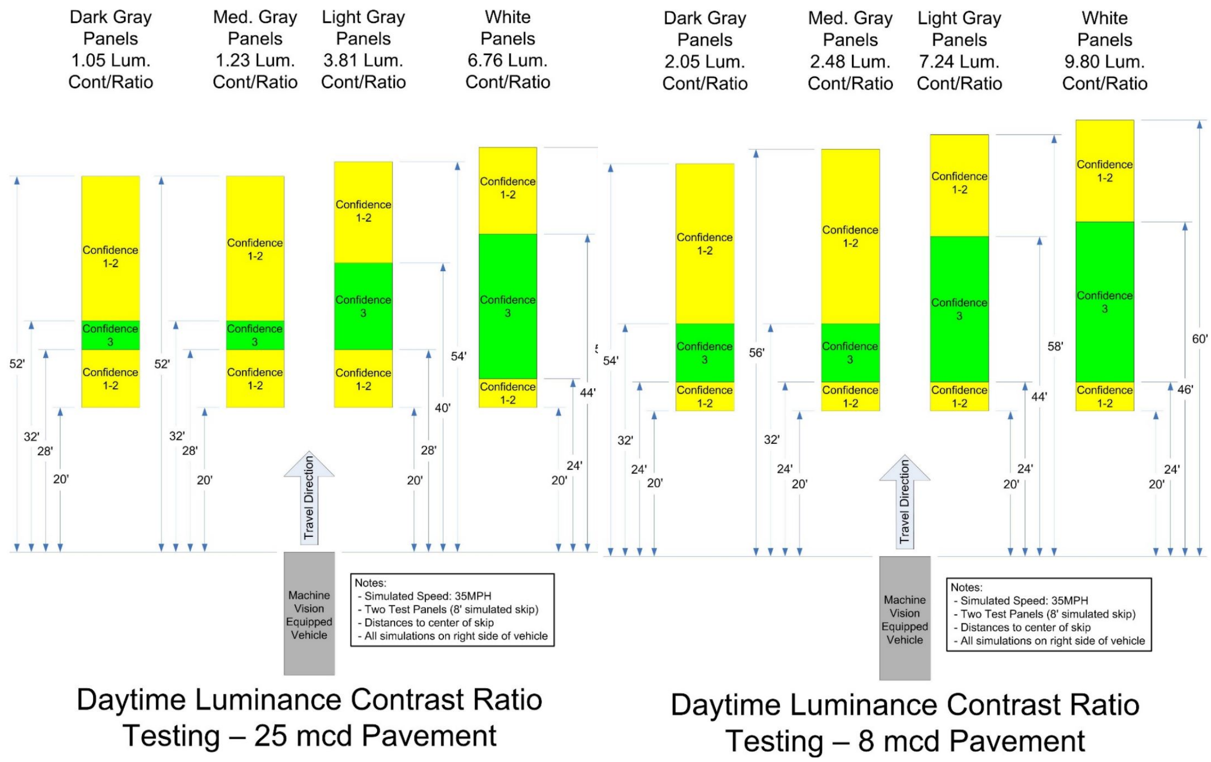


Figure 4.2: Results retro-reflectivity on 25 mcd pavement [11]

The retro-reflectivity, measured on a pavement of 8 mcd and 25 mcd showed to be nearly identical, not giving preference over one of the pavement types. Besides that, the confidence level showed to be highest at a distance between 46 and 57 feet (≈14 - 17.4 meters) meaning that at this location, with the 900 mcd marking, the retro-reflection was strongest.

At daytime, the luminance contrast is the most important factor to influence detectability. For the measurements, the luminance contrast ratio between marking material and pavement is taken into account. The results are shown in figure 4.3. These results clearly show that the darker pavement with 8 mcd obtains higher lane confidence over larger distances (46-60 feet compared to 44-54 feet) as compared to the pavement with 25 mcd. Especially the combination of bright marking on dark pavement shows to have the largest lane marking detectable range (right-most confidence 3 part of figure 4.3b



(a) 25 mcd pavement

(b) 8 mcd pavement

Figure 4.3: Luminance contrast ratio on two different pavements [11]

Finally, the testing of lane confidence in relation to lane marking width demonstrated that a 6 inch (≈15 cm) wide mark with lower retro-reflectivity leads to similar, or slightly better lane confidence than a 4 inch (≈10 cm) wide mark with higher retro-reflectivity [11].

4.3. Requirements for lane marking for automated vehicles

The quality standard of lane marking on Dutch roads is among the best in Europe [22] and in order to prevent having to do the same work twice, Rijkswaterstaat currently awaits recommendations from the European Union for the uniforming of road design, to accommodate smart traffic in all of Europe. The use of uniform lane marking would make it feasible for automated vehicles to drive without the support of their human driver. An additional advantage is that the software-engineers who program the systems responsible for detecting and keeping lanes do not have to take into account all the potential exceptions [27], making the systems more reliable in different conditions.

In recent years, the American Traffic Safety Services Association (ATSSA), the Auto Alliance (who represents 70% of all car and light sale trucks in the United States [26]) and global camera sensor market leader Mobileye, published a report on their preferred road design characteristics for detection by automated vehicles. Below are mentioned the lane marking preferable characteristics.

ATTSA [4]:

- More uniformity on the width of marking, preferably 12-15 cm
- Minimum retro-reflectivity
- Pre-set lengths of interrupted lines
- A minimum required contrast between marking and road surface on roads with design speeds > 65 km/h

Auto Alliance [26]:

- Lane markings should be consistent in width, color and length
- New markings should not be adjusted inadvertently (e.g. leaving behind marks by driving over wet paint)
- Do not leave remains behind after removing lane markings

Mobileye [4]:

- Apply only filled lines
- Higher retro-reflectivity requirements
- Completely remove old markings

In Europe, the European Automobile Manufacturers' Association, ACEA, has defined three sorts of factors in which things of negative impact on lane keeping systems are organized [13].

- **High factors:** Road surface condition and worn markings
- **Medium factors:** Road gradient, curvature and boundaries between lanes
- **Low factors:** Lane width and visibility

Of these factors that ACEA distinguishes, only the visibility factor is quantified by the European Union Road Federation. The retro-reflectivity of lane markings should equal 150 and 35 mcd/m^2/lx in dry and wet conditions respectively [13].

4.4. Current developments of lane marking in relation to automated vehicles

Developments on lane marking in relation to automated vehicles are mostly taking place from a technical point of view and not organizational wise by governments and lawmakers. Nevertheless, also from the organizational perspective, preparations must be made for the introduction of automated vehicles to their roads. In the Netherlands, Rijkswaterstaat is mostly monitoring the developments around lane keeping systems and awaits the EU recommendations. However, to facilitate a smooth transition towards mixed traffic and to develop good conditions for automated vehicles, a work group has been composed to monitor technical developments and to work on smart mobility and its introduction and transition to Dutch roads [30]. Their goal is to enable a quick and smooth transition of mixed traffic including higher level automated vehicles.

Many parties who are not obligated to take into account human drivers in their research are working on developments around lane marking that would facilitate higher level automated vehicles. These developments however often entail a type of lane marking that is not visible (enough) for human drivers. As the scope of this project is defined as including mixed traffic, and therefore human drivers, detailed research into developments in which physical lane marking is replaced by virtual lane marking, is not required. Instead, only brief descriptions are provided:

- **Digital marking:** Instead of detecting the markings with a built-in system, the vehicle would receive detailed information on the location of the markings and would, based on that, know where to position itself on the road. ”Currently, the online data on lane marking positions is not detailed enough to perform trials with this”, Alex van Loon, member of the Rijkswaterstaat work group ’Smart Mobility’ explains [35].
- **Radar detection:** Lane marking detection based on radar is also an ongoing development. Once again, this is a method that would not be able to be used by human drivers. Radar reflectors would have to be integrated in the pavement [15]. This is however a detection method that could be used alongside the traditional, physical lane marking. Currently, radar detection is only used in adaptive cruise control.

4.5. Key takeaways

On the visibility requirements for detection by vision-based detection systems in automated vehicles, the following was found. For retro-reflection, the European Union Road Federation deems a minimum retro-reflection of 150 and 35 mcd/m^2/lx for dry and wet nighttime conditions respectively, to be sufficient for detection by lane detection systems. Concerning the contrast ratio between lane marking and pavement, research showed that the higher the ratio, the more capable the system was to detect the lane marking. However, literature review showed no optimum factor. Lastly, the width is an important factor in the detectability of lane marking by automated vehicles. The American Traffic Safety Services Association states that a lane marking width between 12 and 15 cm is preferred. The study by Potters Industries supports this in showing that 15 cm wide lane marking with lower retro-reflectivity is better detectable than 10 cm wide marking with higher retro-reflectivity. Lastly, removal of old lane marking should not leave behind any remains as lane detection systems are prone to wrongly detect these remains as being lane marking.

5

Discussion and conclusion

The goal of this thesis is to find an answer to the question "How do the lane marking requirements for lane-detection in automated vehicles differ from the requirements for detection by human drivers in different driving conditions?". At the start, sub-questions were defined to approach the research problem.

Using these sub-questions as a guideline, in the previous chapters, information on the current lane marking requirements, the influence of lane marking on human driver behaviour and detection systems in automated vehicles was collected. In this chapter, a short recap of the findings is provided, followed by a discussion. Afterwards, in section 5.2, the current lane marking requirements (based on human driven cars) and the lane marking requirements for detection systems in automated vehicles are compared and conclusions on the research question are formulated. At the end of this chapter recommendations are provided for academic research and practitioners.

5.1. Discussion

Key criteria on the basis of which the requirements for the detection of lane marking in automated vehicles and by human drivers are compared are visibility and lane marking width. Literature review shows that these factors are most important for the detectability of lane marking by both the human eye and lane detection systems in automated vehicles. The findings of said literature review are discussed in this section.

Lane marking visibility depends on the luminance factor, representing the brightness, and the amount of retro-reflection created by glass beads in the marking material. Since lane marking must be visible under all driving conditions, the set of visibility requirements is made up of minimum required values during day and night-time. During the night, a further distinction is made between dry and wet conditions.

As mentioned in the beginning of chapter 4, the quality requirements in the Netherlands are based on the requirements described in the European standard EN 1436 in which different quality classes are defined. In order to conclude whether the requirements set in the Netherlands are on the higher end of the range of requirements for the European Union, it is best to compare these to the classes defined in EN 1436. This information is displayed in the following overview:

Quality determinant	Range EN1436 classes	Minimum required class NL	High/Med/Low
Visibility (daytime)	B1-B5	B3 (type I marking)	Med
Visibility (daytime)	Q1-Q5	Q3 (type II marking)	Med
Visibility (night-time)	R2-R5	R2 (dry conditions)	Low
Visibility (night-time)	RW1-RW6	RW2 (wet conditions)	Low
Skid resistance	S1-S5	S1-S3	Low-Med

The above clearly shows that none of the Dutch requirements fall under the high end of EN1436 classes. This means that within this range of requirements, the quality of Dutch lane marking can still be improved a lot. Since the conclusion was drawn earlier that the same factors play a role in lane marking detectability by humans and lane detection systems, increasing the requirement class would be beneficial for both detection types. For this thesis, no research was done into lane marking requirements in other European countries. This means that based on the overview, one can only say that the absolute requirements are not necessarily set to be very high, but the quality standards relative to other European countries can not be commented on. In other words, the Dutch lane marking may be of a high standard compared to other countries, with only mediocre requirements.

Tests with lane detection systems on national highways have shown that the systems are capable of detecting the currently applied lane markings [35]. This indicates that the quality requirements for the conditions in which the tests took place were of a high enough standard. Despite not being discussed at length in this report, it can still be said that the test result would highly depend on the state of lane marking. Due to the current absence of monitoring and maintenance, the quality requirements that are met at the time of application can not be guaranteed for the full lifespan of lane marking. In relation to detection, this issue is not necessarily a problem for human detection. Humans are capable of 'filling the gaps', of course to a certain extent, to still sufficiently detect the markings. Systems on the other hand are not necessarily capable of doing the same and would require model-based detection systems to fit input data in such a way that worn lane marking can still be detected. However, if the quality is too low, model fitting might also not be able to fill those gaps.

If monitoring of lane marking quality would be reintroduced in the future (which is recommended in the following section), the following might be a solution: Drive the roads with vehicles equipped with vision detection systems on a regular basis, analyse these data and go back to locations where lane marking was not detected for closer monitoring.

5.2. Conclusion

In the development of the currently applied lane marking requirements, detectability for automated vehicles is not taken into account and therefore merely focuses on detection by the human driver. This means that lane detection systems at the moment are developed to detect the currently applied lane marking. Research has shown that the detectability of lane marking by lane detection systems in automated vehicles depends on retro-reflectivity, contrast and marking width. Comparing these requirements for the detection of lane marking by automated vehicles with the currently set requirements, based on human detection, the conclusion can be drawn that for retro-reflection under wet conditions at night, the current requirement for lane marking, with a retro-reflective luminance of 35 mcd/m^2/lx, is in accordance with the requirements for detection by automated vehicles under identical circumstances. However, for dry conditions at night, lane detection systems in automated vehicles require a higher retro-reflective luminance than the current requirement. For sufficient detectability by automated vehicles, the retro-reflective luminance should be at least 150 mcd/m^2/lx.

Concerning the required contrast ratio of lane markings, the conclusion has to be drawn that a meaningful comparison between the luminance factor (as defined in the current visibility requirements for human detection) and the luminance contrast ratio (that was studied in relation to lane detection in automated vehicles by Potters Industries), cannot be made. Whereas the luminance factor is the ratio between (lane marking) surface luminance and the luminance of a specified diffuser [31], the luminance contrast ratio is the ratio between the luminance of marking material and that of the underlying pavement. However, what can be concluded is that the higher the contrast ratio of the lane marking, the better the detectability by detection systems. A high contrast ratio is also beneficial for human detection.

For the final factor, lane marking width, the literature review shows that the width of lane marking on motorways in the Netherlands complies with the required width by lane detection systems in automated vehicles. However, on lower ranked roads such as access roads inside the built-up area and distributor roads outside the built-up area, where a lane marking width of 10 cm is applied, the required width should be increased to 12 cm at least. On access roads inside the built-up area, lane marking is not required at all [9].

Concluding, and in answer to the research question, tests show that the current requirements based on detection by human drivers provide sufficiently high quality of lane marking for detection in automated vehicles. However, requirements formulated by the industry do require an increase in nighttime visibility, under dry conditions. It is possible that these tests only took place in daylight and therefore did not show any (potential) detection difficulties during nighttime. Therefore, in addition to the current requirements the following adjustments should be made to facilitate reliable conditions for detection by higher level automated vehicles:

- The retro-reflective luminance under dry conditions during the night should be increased from 100 mcd/m^2/lx to 150 mcd/m^2/lx
- A high contrast ratio should be aimed for
- Lane marking width should be equal to, or exceed 12 cm on all roads where lane marking is required

In addition, the quality of lane marking should be ensured for its entire lifespan in order to fulfill the requirements for lane detection by automated vehicles .

For as long as humans are needed to take over driving tasks if requested by the automated systems, lane marking requirements can only be changed in favor of automated vehicles if it is beneficial, or at least does not influence, human detection and human driver performance.

5.3. Recommendations

This bachelor thesis provides a collection of reviewed literature on the topic of lane marking requirements for both automated and human-driven vehicles. Based on performed literature review, several recommendations can be made for both future research and for practitioners.

5.3.1. Recommendations for scientific research

While performing literature research for finding an answer to the main research question, many scientific papers were studied. In relation to lane marking requirements for the detection in automated vehicles, the following recommendations can be made for future research, which would be helpful for further defining these requirements.

Since traffic will be made up of different levels of automation for a long time, more comparative research should be performed on lane keeping performance of automated vehicles and the human driver. This must be done to come to optimum lane marking requirements for both the human driver, as well as the lane detection system in automated vehicles. This can be done for all the comparison criteria discussed in section 5.1.

As explained in chapter 4, in addition to visibility, wear resistance and durability of lane marking, skid resistance is also a quality determinant. It influences the detection by human drivers, as well as by detection systems in automated vehicles [36]. Further research into the potential influence of lane marking texture on the detection should be performed.

Finally, research into ways of increasing durability and wear resistance of the lane marking would be desirable. Improved wear resistance and durability would contribute to keeping lane marking quality high throughout its lifespan by improving its visibility.

5.3.2. Recommendations for practice

Resulting from the performed literature review, for practitioners such as contractors and road authorities, the following recommendations can be formulated.

Despite the fact that uniformity in lane marking is already being pursued for years, it is still commonplace that a road of a certain type in province A has different lane marking than a road of similar type in province B. In order to move towards complete uniformity, requirements on lane marking application and lane marking quality should be set nationally. This way, road authorities in province A would apply the same type of lane marking in the same location on the road surface as road authorities in province B.

In addition to uniformity, inspection and maintenance of lane marking by road authorities should be reintroduced. The performance of detection systems depends on high quality and premature wear of the lane marking would cause problems. Therefore, the recommendation for road authorities, such as Rijkswaterstaat, to perform inspection on a regular basis and carry out the necessary maintenance. In addition to that, it would be recommended to continuously collect and store data on the lane marking quality on all roads in the Netherlands.

A
Lane marking in the Netherlands

As described in chapter 2, two types of lane markings can be found on Dutch roads. The geographical location of the relevant road is often a decisive factor in the choice between type I and type II. In places without any lighting, or where lighting is dimmed in the absence of road users, type II lane marking is applied. Type I may be applied when there are no additional visibility requirements and the standard marking suffices. Another reason for applying type I marking is when noise disturbance needs to be minimized because of the road being located in a quiet area [22].

Within type I and II, a variety of materials can be used for the markings. The choice of material in case of permanent application, on for example a new road deck, depends on four factors. Firstly, the type of road surface plays an important role. Not all materials can be applied on permeable concrete (ZOAB) for example. The second factor is the (residual) lifespan of the pavement and lastly, the lifespan of the marking itself. Finally, the intensity of traffic is must be taken into account as one material wears off quicker than another. The marking materials used for lane marking in the Netherlands are [34][9]:

- Road paint
  - Type I: Traditional
  - Type II: Improved reflective properties
- Thermoplastic material
  - Type I: Traditional
  - Type II: Improved reflective properties
- Thermoplastic spray
- Cold plastic material
  - Type I: Traditional
  - Type II: Improved reflective properties
- Preformed materials, e.g. tape
  - Type I: Traditional
  - Type II: Improved reflective properties

Rijkswaterstaat uses road paint generally on roads on which the improved retro-reflection is not required. It is also applied when temporary road marking needs to be applied as a result of road work for example. In this case, the paint is yellow instead of white. In case that replacement of the road surface is required within two to three years, paint might also be used to cover up worn markings to recreate sufficient visibility for the remaining years. Thermoplastics are used on new asphalt or cement concrete road pavements. When it is applied after road surface repairs, it is only applied if the road surface needs to last at least another three years. For cold plastic materials the minimum number of years the road has to last after application is five. In addition to that, due to the cold plastics being prone to wear, it is applied in places in which it is not driven over very often; for example for the markings on the left side of the leftmost lane. Finally, preformed materials are often used in situations of road work and for reparation of existing markings. In section two of this appendix, in Dutch, an overview of the characteristics of each above mentioned type of lane marking material can be found.

A.1. Design

The design of lane marking is also required to meet specific requirements. These requirements are described in a CROW publication containing guidelines for the beaconing and marking of roads. The following guidelines are defined in terms of the composition of the lane markings [19]:

- The marking should be clearly outlined
- The width of the marking should not deviate more than 5 mm from the prescribed width (which varies between 10 and 20 cm, depending on the type of road)
- In case of an interrupted line, the length of a single part should not be shorter than 50 mm or longer than 100 mm than the prescribed length

In general, the thickness of the lane marking is set to be 3 mm, with an allowable margin of 10%. In case of a agglomerate type II marking, the maximum thickness is 5 mm and the same margin is valid.

A.2. Lane marking materials and their characteristics

The top row of the table shows the material type. From left to right:

- (Reflective) road paint
- Thermoplastics
- Sprayable thermoplastics
- Cold plastics
- Preformed materials
- Type II markings (thermoplastics, cold plastics and tapes)

The first column shows different material characteristics. From the top down it says:

- Layer thickness (mm)
- Daytime visibility: dry and wet pavement
- Night visibility: dry and wet pavement
- Skid resistance: dry and wet pavement
- Colour fastness
- Lifespan
- Suitability for the kind of marking: longitudinal, transverse, symbol, text.

Materiaalsoort	(Reflecterende) wegenverf	Thermoplastisch materiaal	Verspuitbaar thermoplastisch materiaal	Meercomponentenmateriaal (koud-plastisch)	Voorgevormde markerings-materialen (thermoplasten of tapes voor tijdelijke en permanente toepassing)	Type-II-markeringen (thermo-, koudplast en tapes)
Laagdikte (mm)	< 0,5	≤ 3	ca. 1,5	≤ 3	2 -3	0 - 5
Dagzichtbaarheid: droog wegdek nat wegdek	 goed matig	 goed redelijk/goed	 goed matig/redelijk	 goed matig	 goed matig	 goed matig
Nachtzichtbaarheid: droog wegdek nat wegdek	 goed matig	 goed matig	 goed matig	 goed matig	 goed matig/goed	 goed redelijk/goed
Stroefheid: droog wegdek nat wegdek	 goed redelijk	 goed redelijk	 goed redelijk	 matig matig	 redelijk/goed matig/redelijk	 matig/goed matig/goed
Kleurvastheid	witheid loopt sterk tot lang-zaam terug	witheid loopt langzaam terug	witheid loopt langzaam terug	witheid loopt eerst sterk op en daarna vrij snel terug	witheid loopt langzaam terug	witheid loopt langzaam terug
Levensduur	1 tot 2 jaar	7 tot 10 jaar	3 tot 5 jaar	5 tot 10 jaar	6 maanden tot 10 jaar	3 tot 7 jaar
Geschiktheid voor type markering: lengte dwars symbool tekst vlak, puntstuk	 + + + + +	 + + + + +	 + – – – +/–	 +/– + + + +/–	 + + +/– +/– +/–	 + – – – –

+ = goed of redelijk geschikt
– = minder geschikt of ongeschikt

Figure A.1: Material characteristics for lane marking[9]

B

Human driver behaviour, SWOV

Type of alteration		N[1]	Range		Mean	Standard deviation
			min	max		
1.	no lines => centre line (cl)	14	-1.9	9.6	3.0	4.6
2.	no lines => edge line (el)	12	1.2	10.6	6.1	3.5
3.	cl => cl + edge line	56	-5.0	8.1	0.4	2.7
4.	cl => no cl + edge line	14	-4.0	1.0	-1.7	1.7
5.	cl+el => cl+'other type of el'	86	-9.3	6.5	-0.7	3.0
6.	cl+el => no cl+'other type of el'	4	0.0	1.2	0.7	0.6
7.	cl+el => 'other type of cl'+el	32	-4.4	4.4	-0.1	2.8
8.	cl+el => variation of both cl+el	4	-0.8	0.0	-0.4	0.5
9.	alterations involving RPMs	56	-4.1	5.1	0.6	2.3
10.	other alteration	42	-10.6	2.4	-2.5	3.3
[1]Since not all experiments have studied the effect on speed, the number of effect sizes can differ from the number of experiments reported in *Table 3.1*.						

Figure B.1: The effect of changes to the lane marking on the driving speed [10]

Type of alteration		N[1]	Range		Mean	Standard deviation
			min	max		
1.	no lines => centre line (cl)	30	-19	48	12	20
2.	no lines => edge line (el)	22	-15	48	10	16
3.	cl => cl + edge line	85	-27	35	-1	11
4.	cl => no cl + edge line	20	-42	21	-12	21
5.	cl+el => cl+'other type of el'	80	-117	80	-3	30
7.	cl+el => 'other type of cl'+el	38	-30	58	2	18
8.	cl+el => variation of both cl+el	4	-18	8	-5	15
9.	alterations involving RPMs	52	-41	52	4	21
10.	other alteration	38	-124	29	-10	38
[1]Since not all experiments have studied the effect on lateral position, the number of effect sizes can differ from the number of studies reported in Table 3.1.						

Figure B.2: The effect of changes to the lane-marking on the lateral position [10]

C
Study by Potters Industry

In this appendix, the test methods are **copied directly** from the source: [11], in order to provide the potentially desired background information to the results of this study that are discussed in chapter 4.2.

This study by Potters Industry was performed to answer the following questions: "How does pavement marking (1) , (2), (3) affect the performance of machine vision?" [11]

1. Retro-reflectivity
2. Contrast ratio
3. Width

Test method for part 1. and 2. of the research question mentioned at the top of this page:

- A test vehicle was equipped with a machine vision system.
- The system was modified such that it could be run in a static mode with varying simulated speeds.
- The system was tested in a static environment with consistent parameters (lighting, pavement retro-reflectivity, etc). By placing retro-reflective pavement marking panels in the view window.
- The simulated speed was kept at a constant 35MPH.
- Two different pavement surfaces (8 mcd and 25 mcd) were tested.

Test method for part 3. of the research question mentioned at the top of this page:

- A test vehicle was equipped with a machine vision system.
- The system was modified such that it could be run in a static mode with varying simulated speeds.
- The system was tested in a static environment with consistent parameters (lighting, pavement retro-reflectivity, etc). By placing retro-reflective pavement marking panels in the view window.
- The simulated speed was kept at a constant 35MPH.
- Two different pavement surfaces (8 mcd and 25 mcd) were tested.
- For the wet recovery testing, a bucket of water was poured on the markings at the start of the test.
- All testing was done at night.

D

Interviews

This appendix provides the questions and corresponding answers that are included in this report.

D.1. André Kleis, RWS *[20/02/2020]*

In the RWS 'Eisen Markeringen' document it says the reason for creating this document is to create national uniformity in lane marking. What is currently the difference at national level?

"Besides the financial aspect, the application of different types of lane marking depends on the road surface, location and even the preference of the responsible road authority. The application of type II marking might be required in places where public lighting is not sufficient for proper visibility of the markings. A reason for preferring to apply type I over type II is the noise that is produced due to the larger glass beads."

In certain countries, a large variety of marking is applied. What could be the reason for that and why do we in the Netherlands seek uniformity on our roads?

"As a result of the implementation of roads on the basis of essential recognition characteristics, we seek uniformity in the Netherlands. We believe that the road users should know on what type of road they are driving and the corresponding maximum speeds, based on the lane-marking. So even though there might be certain differences in marking on a provincial or municipal level, roads should be recognisable anywhere in the NL."

Could you describe the process of (re)developing standards and a corresponding set of requirements for lane-marking?

"The lane-marking requirements ('Eisen markeringen') are evaluated every year. When changes are in place, the document will be adjusted. The requirements are based on EU regulations. These standards are developed by CEN, an organisation established in 1961 for the standardization of, in this case, road markings. CEN consists of many committees that have their own task and work groups. Each work group is responsible for keeping one European norm up-to-date. In the Netherlands, for the national standards, the normalization institute is called the NEN."

Does RWS have any goals related to automated vehicles entering the Dutch roads?

"At the moment RWS waits for the recommendations from the EU committees to avoid work having to be done twice.

"I [André] strongly believe that our road-marking is of a really high quality (material and functionality) and belongs to the top in Europe. One used to believe that the automobile industry had to adjust their systems to the existing road characteristics. However, since several years, collaboration with manufacturers has preference. Within RWS, there are teams that are working on ADAS (advanced driver assistance systems) and MaaS (mobility as a service)."

Are there other aspects that should be considered for lane-marking in relation to automated vehicles?

"That depends on what will follow from all the different committees working on this. Once it's decided that uniformity throughout Europe is pursued, then the dimensions would have to be changed.* Marking requirements for visibility and skid resistance would possibly also have to be raised or renewed.
*In the NL, our lines on the side of the road are 20 cm wide, whereas in Germany for example it is 30 cm. This has to do with the space in the NL."

D.2. Alex van Loon, RWS *[08/06/2020]*

What is the role of Rijkswaterstaat in the development of smart mobility in the Netherlands?

"For Smart mobility, Rijkswaterstaat is important in the future facilitating of automated vehicles. Our role in this is not only in relation to our own roads, but also in the creation of coherence with other road authorities. We are also deployed by the Dutch government to advise them on different topics. One of which is being smart mobility; to monitor the developments."

Where do you, from a RWS point of view, stand on the development of lane markings and automated vehicles? Which should be adjusted to which and whose responsibility is it to adjust (RWS or AV-manufacturers)?

"As a road authority, you can't deny that the automation levels of vehicles on our roads will become higher and that we need to facilitate that. We are responsible for developing our roads to the requirements and standards that are currently set, because that is required for detection by human drivers. We know that there abnormalities can be found in the characteristics of lane marking and that marking is not sufficiently visible everywhere. As road authority you are aware of that, but also realise that for human drivers, the additional risks are minimal. However, with increasing numbers of automated vehicles, these said abnormalities become more critical due to the lack of ability to fill the gaps. Therefore, for Rijkswaterstaat on the one hand it is our responsibility to design our roads according to all the requirements. On the other hand, it is our responsibility to raise the road marking quality if it is not sufficient anymore. We don't only do this for the smart vehicles, but also for the traditional road users which, in the end, creates a beneficial situation for both types of road users."

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