

FACTORS AFFECTING NIGHT-TIME VISIBILITY OF RETROREFLECTIVE ROAD TRAFFIC SIGNS: A REVIEW

Roxan Saleh¹, Hasan Fleyeh²

¹ Swedish Transport Administration, Röda vägen 1, SE-781 89 Borlänge, Sweden

^{1,2} School of Technology and Business Studies, Dalarna University, Borlänge, Sweden

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Abstract: Road traffic signs define a visual language that can be interpreted by drivers. They represent the current traffic situation on the road, show danger and difficulties around the drivers, give them warnings, and help them with their navigation by providing useful information that makes driving safe and convenient. The main part of the road traffic sign is the retroreflective material which reflects the light from the vehicle headlights to the driver. Driving during night-time is a challenge, and the retroreflective material on the sign board helps the drivers to perceive and interpret the information on the road traffic sign properly. The aim of this paper is to study the factors affecting the performance of driving during night-time and the role the retroreflective material that plays in this regard. The vehicle headlights, ambient conditions, and the type of retroreflection material affect the light reflected from the road traffic signs. It is also found that the retroreflectivity depends on vehicle factors such as headlights colour and angle of illumination. Other factors such as environmental factors and sign factors can also affect the retroreflectivity.

Keywords: road traffic sign, retroreflective material, night-time visibility.

1. Introduction

Road traffic signs (European Committee for Standardization, 2007) represent one of the most important elements of road safety (Berces *et al.*, 2012). The purpose of road traffic signs can vary from warning the drivers, to giving them information about the road, and guiding them. They simply provide visible rules about the road to the drivers to keep them safe. Good visibility of the road traffic signs makes drivers able to react in a proper way at a proper time and distance while the low visibility increase the rate of accidents and cause a relatively higher risk of material damage, injuries and

even death (Šarić *et al.*, 2018). It is therefore important that the road traffic signs must be visible to the drivers.

To increase the visibility of the road traffic signs we must be aware of the factors that affect visibility and control these factors to get the optimal visibility. The visibility of a road traffic sign defines as the ability of the drivers to detect and read the sign and then understand its meaning. The visibility is a measure of the distance at which an object or light can be clearly discerned. The visibility distance is the distance that the driver needs to locate, read, understand, and react according to the information that

² Corresponding author: hfl@du.se

the road traffic sign gives, as illustrated in Figure 1. The visibility distance is divided into detectability distance, which begins

when a sign has been detected and legibility distance, which begins when a driver begins to read its content.

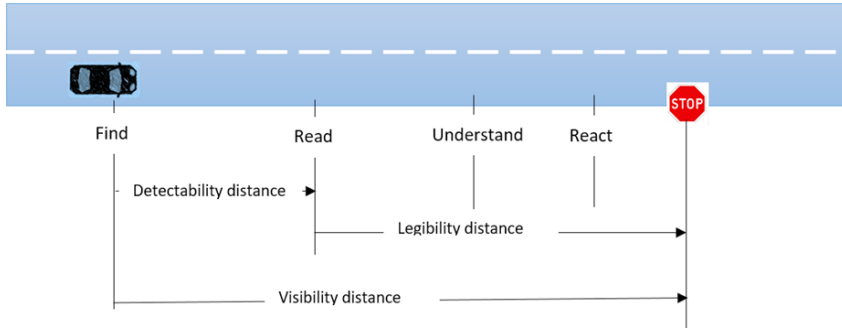


Fig. 1.

Visibility Sequences

Source: Generated by the authors

The visibility of the road traffic sign can be improved by strengthening the interaction between the road traffic sign and the driver. However, this interaction cannot be easily predicted (Garvey *et al.*, 2011) because the ability of a driver to detect and read a road traffic sign is a function of numerous factors such as human, environmental, and design factors which are characterized with complex interrelationships. Furthermore, the design and placement of a road traffic sign has a big effect on the sign visibility. The design of a detectable, legible, and understandable road traffic signs is a big challenge to ensure a safely driving in the road.

At night, the visibility of the signs improves by using retroreflective sheeting materials on the face of the road traffic signs. Almost all the road traffic signs in use today are supplied with retroreflective materials with some level of retroreflectivity. The retroreflective sheeting material on the road traffic signs helps in increasing visibility by reflecting the incident light (from headlights

of the vehicle) back towards the drivers' eyes. The reflected light makes the road traffic sign more visible depending on the amount of light falling onto the surface of the road traffic sign.

The development of retroreflective sheeting materials dates back to the 1930s (Berces *et al.*, 2012) and since 1956 the visibility of the road traffic signs at night has been studied (Allen *et al.*, 1956). The retroreflective sheeting was improved and was in use since 1970. Almost all the road traffic signs that in use today are retroreflective and the task of choosing between different types of retroreflective sheeting to get a detectable and legible road traffic signs is a challenge for the designers.

To be able to choose the adequate retroreflective sheeting material one must be aware about what factors that can affect the performance of the retroreflective sheeting materials. Many researchers have investigated the effects of different factors,

such as retroreflectivity, human factors or weather conditions, on the visibility. The environmental conditions around road traffic signs have a big influence on the sign's visibility. Therefore, the effects of ambient conditions (day- and night-time lighting conditions) on the visibility have been investigated in so many fields and laboratory studies. The results of an eye tracking study that was carried out under good light conditions (during the day) and low light conditions (at night) showed that there is a significant reduction in the visibility of road traffic signs during driving at night (Madleňák *et al.*, 2018).

Sign visibility research studies focused on two main areas: sign detection and sign legibility and therefore this review focused on detectability and legibility. Those two areas are interdependent because a sign must be found before reading it and there is no need to detect a sign that cannot be read from the road (Garvey *et al.*, 2011).

The first aim of this paper is to test the hypotheses that night-time visibility of the road traffic signs depends on the retroreflectivity and the luminance of the retroreflective road traffic signs. The results from this paper allow us to prove the importance of using the retroreflective sign sheeting to improve night-time visibility and allow the drivers to detect and read the road signs in a minimum distance. Moreover, this paper also contributes by gathering the existing knowledge from reports and articles about the effect of using retroreflective material sheeting in increase night-time visibility of the road traffic signs.

The second aim was to increase the understanding of the role of different factors in affecting the visibility and retroreflectivity

of the road traffic signs. This paper gives an overview about the factors affecting the night-time visibility of retroreflective road traffic signs and investigates the connection between those factors and the retroreflectivity. In the main while, attempts to illustrate the gap in the literatures about the factors affecting the retroreflectivity and the luminance of the retroreflective road traffic signs.

This review is important for researchers studying the retroreflectivity because it is printing a map for the recent papers on the factors affecting the visibility of the road traffic signs and in the same time gives a description of the lack in the present studies. An important contribution of this paper is in demonstrating what factors affect visibility and retroreflectivity and in the other hand, what factors not covered by research and at the same time gives recommendations for future studies.

Overall, the present paper makes significant contributions in understanding interaction between night-time visibility and retroreflectivity of the road traffic signs. The results can provide support for road authorities when it comes to the importance of using retroreflective sheeting materials to improve the visibility of the road traffic signs.

This paper includes three main parts:

- The first part of the study (Section 3) summarizes the published research studies related to the factors affecting night-time visibility of the retroreflected road traffic signs;
- Because this study is directed towards the retroreflective road traffic signs, a separate section (Section 4) about the relationship between retroreflectivity,

luminance and other factors were included in the study;

- The third part includes a discussion (Section 5). In the discussion, factors affecting visibility categorized into groups according to several different topics;
- Finally, in the conclusion, research gap and the contribution of this study is presented.

2. Method

The retroreflective sheeting materials were used in the road traffic signs since 1947 and have been in focus of studies since 1960s. A big development achieved in the visibility performance of these materials in the latest years because of the developing in manufacturing procedures and using new technologies. There are huge amount of papers studying retroreflectivity of road traffic signs using different types of retroreflective sheeting material but this paper reviews only on the materials that in use and manufacture today, thus this paper focuses on the studies that were achieved since 2010. In some parts, references were made to the reviews done before 2010 to get some overview about the previous works associated to the road traffic signs and visibility at general.

The published research studies related to the factors affecting night time visibility of the retroreflected road traffic signs included in this paper but the degree of effect (increasing or decreasing) of each factor on the visibility, which resulted from the literature, was not included in this study. Only the factors affecting the night-time visibility are mentioned in this study.

The literature was searched using Google Scholar that includes journal and conference papers, theses and dissertations, academic books, pre-prints, abstracts, technical reports, and other scholarly literature from all broad areas of research.

3. Night-time Visibility

The visibility of the road traffic signs at night has been studied since 1956 (Allen *et al.*, 1956) and the factors affecting visibility was investigated since that time. Most of the studies focused on the font and colour, age and type of retroreflective sheeting as changeable factors in these studies. Since 1977 many studies pointed that the visibility of the road traffic signs can be affected by the age of the drivers (Sivak *et al.*, 1979).

Most of the studies on the retroreflective sheeting were designed to improve the visibility in a local road and investigate the effect of only one or two factors together. For example, in the USA, the choice of a proper font (type and size) was studied and the effect of font type and size in improving the visibility investigated (Carlson, 2001), (Chrysler *et al.*, 2002).

Sign visibility is an imprecise term in that it encompasses both sign detectability and sign legibility (Garvey *et al.*, 2011). Results from several studies, which describe how different factors can affect visibility in terms of conspicuity and legibility, are summarized in the following subsections.

3.1. Detectability

Detectability, which is defined as the ability to read and process the information on the

sign, is directly related to the ability to detect and find the sign (Garvey *et al.*, 2011). In general, the existing literature were not studied the detectability as much as the legibility.

The location of the sign relative to the rest of the road equipment can enhance the detectability of that sign and make it compete with other signs and objects on the road (Lundkvist, 2012), (Garvey *et al.*, 2011). The degree of visual complexity where a sign is located has also impact on how easily it can be detected (Carlson *et al.*, 2017), (Garvey *et al.*, 2011), (Bullough, 2017). Furthermore, adding a border around the sign, often enhances its detectability (Bullough, 2017).

Other factors that enhance the detectability include size, colour, and shape of the sign (Bullough, 2017), (Lundkvist, 2012), (Garvey *et al.*, 2011), (Carlson *et al.*, 2017). For example, increasing the sign's size can enhance the detectability (Garvey *et al.*, 2011).

Furthermore, the effect of ambient illumination level (night or daylight) and street lighting have a big effect on the detectability (Garvey *et al.*, 2011), (Bullough, 2017). In nighttime and on roads without public lighting, the retroreflective sheeting is important for improving detectability (Lundkvist, 2012). Among the photometric properties of the sign most related to detectability is the sign luminance and retroreflectivity (Bullough, 2017), (Lundkvist, 2012), (Owens *et al.*, 2007), (Carlson *et al.*, 2017), (Garvey *et al.*, 2011).

Another factor that has negative effect on the detectability of road traffic signs and may lead to fatal nighttime crashes is the aging of the drivers (Carlson *et al.*, 2017), (Owens *et al.*, 2007). For older driver when the illumination reduces the average speed and detectability of road traffic signs reduce. This low detectability is found to be related to the reduction in driver's vision with aging (Owens *et al.*, 2007). Table 1 summarizes the literature studying the factors affecting detectability.

Table 1
Factors Affecting Detectability

Factor	Study
Location of the sign	(Lundkvist, 2012), (Garvey <i>et al.</i> , 2011)
Adding border around the sign	(Bullough, 2017)
Sign luminance and retroreflectivity	(Bullough, 2017), (Lundkvist, 2012), (Owens <i>et al.</i> , 2007), (Carlson <i>et al.</i> , 2017), (Garvey <i>et al.</i> , 2011)
Size of the sign	(Bullough, 2017), (Lundkvist, 2012), (Garvey <i>et al.</i> , 2011)
Shape of the sign	(Garvey <i>et al.</i> , 2011), (Carlson <i>et al.</i> , 2017)
Colours of the sign	(Bullough, 2017), (Garvey <i>et al.</i> , 2011)
Visual Complexity levels	(Carlson <i>et al.</i> , 2017), (Garvey <i>et al.</i> , 2011), (Bullough, 2017)
Age of the driver	(Carlson <i>et al.</i> , 2017), (Owens <i>et al.</i> , 2007)
Ambient illumination level and street lighting	(Garvey <i>et al.</i> , 2011), (Bullough, 2017)

3.2. Legibility

Legibility is defined as the ability to read and process the information. Road traffic sign legibility depends on how easy the driver can read the text or symbols on the sign. In the literature, there were many studies have studied the legibility of road traffic signs and the factors that influence the reader's ability to process the information.

Among these factors is the amount of information on the sign and the size of the sign itself which have a big influences on the legibility (Bullough, 2017). For example the legibility can be improved by using graphical symbols and using alphanumeric characters has lower effect on the legibility (Bullough, 2017).

Other factors affecting the legibility are the design of the sign, such as sign shape and colour, and message design factors. Message design factors, such as font type, text size, letter height and letter spacing, are important to maximize the potential for a driver to read the sign within the road environment and increase the legibility of the sign (Funkhouser *et al.*, 2008), (Bullough, 2017), (Garvey *et al.*, 2011), (Lundkvist, 2012).

Moreover, sign luminance and retroreflectivity has a big impact on the legibility (Owens *et al.*, 2007), (Schieber *et al.*, 2004), (Bullough, 2017), (Lundkvist, 2012), (Garvey *et al.*, 2011), (Kosmas *et al.*, 2018). Generally speaking, increasing the

luminance or brightness of a sign would increase its detectability but excessive brightness can lead to irradiation of the characters and symbols on the sign, reducing the legibility (Bullough, 2017).

Several factors found to systematically influence sign legibility distance were driving environment, ambient illumination level, street lighting and complex background visual clutter (Schieber *et al.*, 2004), (Carlson *et al.*, 2017), (Garvey *et al.*, 2011), (Bullough, 2017).

The driver's skill and familiarity with road traffic signs in general, and in some cases, their knowledge of the selected road names have a significant effect on legibility distance (Funkhouser *et al.*, 2008).

Another important factor is viewing geometry and location of a sign have also an influence on the degree to where it can be easily read (Garvey *et al.*, 2011), (Kosmas *et al.*, 2018), (Bullough, 2017).

Finally, it is important to mention that some studies failed to find a significant effect of certain factors on the legibility of the road traffic sign such as certain sign colour (Funkhouser *et al.*, 2008) and driver's age (Schieber *et al.*, 2004). For example, in one study the green and purple colours performed equivalently in terms of legibility distances during daytime and nighttime (Funkhouser *et al.*, 2008). Table 2 summarizes the factors affecting the detectability.

Table 2
Factors Affecting the Legibility

Factor	Study
Shape of the sign	(Bullough, 2017)
Size of the sign	(Bullough, 2017)
Sign luminance and retroreflectivity	(Owens <i>et al.</i> , 2007), (Schieber <i>et al.</i> , 2004), (Bullough, 2017), (Lundkvist, 2012), (Garvey <i>et al.</i> , 2011), (Kosmas <i>et al.</i> , 2018)
Driving environment High speed rural road/low speed suburban	(Schieber <i>et al.</i> , 2004)
Ambient illumination level and street lighting	(Schieber <i>et al.</i> , 2004), (Carlson <i>et al.</i> , 2017), (Garvey <i>et al.</i> , 2011), (Bullough, 2017)
Complex background visual clutter	(Schieber <i>et al.</i> , 2004), (Bullough, 2017)
Font type, text size, letter height, letter spacing	(Funkhouser <i>et al.</i> , 2008), (Bullough, 2017), (Garvey <i>et al.</i> , 2011)
Colours of the sign	(Bullough, 2017), (Lundkvist, 2012), (Garvey <i>et al.</i> , 2011)
Driver's skill	(Funkhouser <i>et al.</i> , 2008)
Use of graphical symbols	(Bullough, 2017)
Location of the sign	(Garvey <i>et al.</i> , 2011), (Kosmas <i>et al.</i> , 2018), (Bullough, 2017)
Viewing geometry	(Bullough, 2017)

4. Retroreflectivity

Among the important ways to improve nighttime visibility is using the retroreflective sheeting for the road traffic signs. Retroreflective sheeting materials are used to support nighttime legibility of road traffic signs. The purpose of retroreflective sheeting is to reflect the light of the vehicles headlights towards the driver.

Retroreflecting sheeting is a material that has a thin continuous layer of small retroreflective elements that reflects light to its source (Pościk *et al.*, 2019). It has been used for road traffic signs for more than 80 years and is still a key part of the road safety infrastructure on the roads nowadays (Berces *et al.*, 2012). Different types of retroreflective sheeting reflect the light in different ways and in a different intensity depending on the material, they made of. There are many types of retroreflective sheeting materials available in the market today; therefore, choosing the

suitable and effective type to be used for the road traffic signs is a challenge.

Retroreflectivity is the ability of a surface or material to reflect the light back to its source. Regarding road traffic signs, retroreflection represented by the coefficient of retroreflection, known as R_A (its unit is candle/lux /m²) which can be given by Eq. 1.

$$R_A = \frac{L}{E} \dots \quad (1)$$

Where:

R_A - coefficient of retroreflection, cd/lux/m²;
 L - Luminous intensity, cd/m²;
 E - Illuminance, lux.

The luminance can easily be defined as the amount of light returned from the sign's surface to the human eyes that makes the sign appear bright. While the illuminance is the amount of light, subjected and spread on the road traffic sign, as shown in Figure 2.

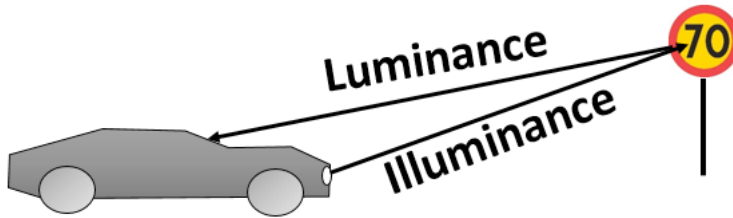


Fig. 2.
Illustration of the Retroreflectivity
 Source: Generated by the authors

From Eq. 1, the amount of retroreflected light (luminance) of the road traffic sign depends on the illuminated light and the type of retroreflective sheeting materials. The luminance can be increased by using a material with high reflectivity. However, a very high retroreflectivity can cause negative effect by glaring the drivers’ eyes. Choosing a retroreflective sheeting material with a

proper reflective level for the road traffic sign can reduce such effect.

The luminance of the retroreflective sheeting materials depends on the type of material, the technology used in the production, ambient conditions, observation and illumination angles and the properties of the incident light (Junior *et al.*, 2018), see Table 3.

Table 3
Factors Affecting the Luminance

Factor	Study
Type of retroreflective sheeting material (reflective layer technology, substrate type, and colour)	(Junior <i>et al.</i> , 2018)
Ambient illumination level and street lighting	(Junior <i>et al.</i> , 2018)
The angle of illumination by vehicle headlights	(Junior <i>et al.</i> , 2018)

Since the first retroreflective sheeting was used for road traffic signs in 1937, the researchers began to study and develop these retroreflective sheeting materials (Khrapova, 2019). A summary of the factors affecting retroreflectivity is presented in Table 4.

Many researchers explored the impact of different factors on retroreflective properties of signs, see Table 4. Certain

factors such as weather conditions attracted more attention (Khrapova, 2019), (Junior *et al.*, 2018), (Carlson *et al.*, 2017), (Kirk *et al.*, 2001) while only few researchers studied the impact of dew and frost on the retroreflectivity. Furthermore, factors such as the temperature during measuring the retroreflectivity of in-service signs were ignored (Khrapova, 2019).

There are other factors affect the retroreflectivity such as the ambient conditions, the angle of illumination by vehicle headlights, and the type of reflective sheeting material (reflective layer technology) (Junior *et al.*, 2018). The type and colour of the retroreflective sheeting have a significant influence on the degree

of degradation of the retroreflective values under dew and frost conditions (Khrapova, 2019). The colour of the light and the sign is also of the essence because it affects the photometric properties (Junior *et al.*, 2018). In addition, the reflection coefficient depends on the surface of the retroreflective sheeting (Junior *et al.*, 2018).

Table 4

Factors Affecting the Retroreflectivity

Factor	Study
Weather conditions such as dirtiness precipitation, drizzle, dew and hoarfrost	(Khrapova, 2019), (Junior <i>et al.</i> , 2018), (Carlson <i>et al.</i> , 2017), (Kirk <i>et al.</i> , 2001)
Colour of light and road traffic sign	(Junior <i>et al.</i> , 2018)
Ambient conditions including surrounding light, temperature, dust and moisture	(Junior <i>et al.</i> , 2018)
Angle of illumination by vehicle headlights	(Junior <i>et al.</i> , 2018)
Type of reflective sheeting material (reflective layer technology, substrate type, and colour)	(Junior <i>et al.</i> , 2018), (Khrapova, 2019)
Surface of the retroreflective sheeting material	(Junior <i>et al.</i> , 2018)

A recent study (Khrapova, 2019), found that the majority of the studies did not provide data about temperature and air relative humidity and did not investigate the effect of weather conditions on the retroreflectivity of the road traffic signs. This study has also found that weather conditions such as rain, drizzle, fog, dew, and hoarfrost have a big effect on the visibility of the road traffic signs. Furthermore, the same study found that the presence of any type of precipitation on the surfaces of signs, such as dirtiness and frost, significantly impairs its retroreflective properties.

Many studies did not found any relationship between weather conditions and the

retroreflectivity (Khrapova, 2019), (Junior *et al.*, 2018), (Carlson *et al.*, 2017), (Kirk *et al.*, 2001). For example changing temperature or humidity has no connection with the retroreflectivity especially for sheeting with a high level of retroreflection (Khrapova, 2019). Even the relationship between the level of retroreflectivity and age of the sign could not be approved, especially with in the first twelve-years (Kirk *et al.*, 2001).

5. Discussion

The factors that identified through this review and found to influence the visibility are summarized in Table 5.

Table 5*Factors Affecting the Visibility of Road Traffic Signs*

Human Factors	Sign Factors	Vehicle Factors	Environmental Factors	Road Design Factors
Age of the Driver	Sign retroreflectivity and type of retroreflective sheeting material: <ul style="list-style-type: none"> • reflective layer • technology • substrate type • surface of the material • colour 	The angle of illumination by vehicle headlights	Ambient conditions: <ul style="list-style-type: none"> • illumination level • surrounding light • street lighting 	Driving environment High speed rural road/low speed suburban
Driver's Skill	Text: <ul style="list-style-type: none"> • Font type, • text size, • letter height, • letter spacing 	Colour of headlights	Weather conditions: <ul style="list-style-type: none"> • temperature • dust • moisture • dirtyness • precipitation • drizzle • dew • hoarfrost 	
	Sign: <ul style="list-style-type: none"> • Location • size • shape • colour 		Visual Complexity levels and complex background	
	Visual clutter			
	Adding border around the sign			
	Use of graphical symbols			
	Viewing geometry			

The factors that influence the visibility can be divided into five groups:

1. Human factors;
2. Factors concerning sign;
3. Factors concerning vehicle;
4. Environmental factors;
5. Road design factors.

The factors written in bold text in Table 5 are those that affect the retroreflection and have been included in the previous studies, while the other factors have unknown effects on the retroreflection. Human and road factors were not studied as affecting factors according to the literature review while factors concerning sign, vehicle or environmental factors were found to be effective on the retroreflection. The location, size, shape, colour of the sign,

and type of retroreflective sheeting material have an impact on both, the detectability, and the legibility. The retroreflectivity of the road traffic sign have a big effect on the visibility.

5.1. Does the Retroreflectivity Affect the Visibility of the Road Traffic Sign?

The studies included in the current review concentrated on the effect of retroreflectivity and luminance on the detectability and legibility of the road traffic signs. These studies gave clear evidence that the night-time visibility improves by using the adequate level of retroreflectivity. The reason for this is that the luminance from the retroreflective signs improves the detectability and legibility of the road traffic signs.

5.2. Factors Affecting the Visibility of the Road Traffic Sign

Most of the studies reviewed in this paper studied sign factor (shape, size, colours etc.) and found that this factor is the most related to the **visibility** compared with the other factors.

The vehicle headlights, ambient condition, and the type of retroreflection sheeting material affect the **luminance** of the road traffic signs. The vehicle factors (headlights colour and angle of illumination), environmental factors (weather and ambient conditions) and sign factors (type and colour of retroreflective sheeting material) found to be essential on the retroreflectivity.

The exciting literature cover a wide range of research related to the factors affecting **visibility** while only a few references founded on the factors affecting retroreflectivity and luminance.

5.3. Missing Evidence about Some Factors that can Affect the Visibility of the Road Traffic Sign

Many studies found that the colours of the road traffic signs affect the visibility including legibility but, in some cases, when purple is used instead of green backgrounds, the colours have no significant effect on the legibility.

According to many studies, the age of the driver affects the legibility of the road traffic signs but a surprising result from one study was the complete lack of any statistically significant differences in sign legibility based upon driver age.

The weather conditions affect the retroreflection but the retroreflection does not always depend on the changes in temperature and humidity especially for sheeting with a high level of retroreflection (Khrapova, 2019). Furthermore, the retroreflectivity of road traffic signs do not vary much due to weather conditions with age especially within the first twelve-years of the sign age (Kirk *et al.*, 2001). This can be motivated because of the twelve years span are not long enough to detect weathering effects.

5.4. Factors not Covered by the Research Studies

Based on the results of this literature review, there are some factors which have unknown effects on the visibility of the road traffic signs and need therefore further investigation. At the same time, the combinations of two or more factors was not investigated either.

Human Factors/ Detectability and Legibility

Age and skills of the drivers have effects on the detectability and legibility of the road traffic signs according to three studies. The effect of other human factors such as visual characteristics, health condition, tiredness, medicine, stress, and mental load, need to be studied.

Vehicle and Road Design Factors/ Detectability and Legibility

There is no evidence about two factors, road design and vehicle factors, which can influence the detectability and legibility of the road traffic signs.

Human and Road Factors/ Retroreflectivity

This review demonstrates the need to conduct research on the effect of human and road factors on the retroreflectivity. The hypotheses that Road factors (such as road design and alignment) have a big effect on the driving geometries and therefore can affect the retroreflectivity need to be tested.

There is even a general lack of prior studies on the factors affecting the retroreflectivity and most of the studies concentrate on the factors affecting detectability and legibility.

6. Conclusion

In the recent years, many studies have addressed the effect of the retroreflectivity and luminance on the night-time visibility of road traffic signs. This paper gathers the existing knowledge from previous work about night-time visibility of the retroreflective road traffic signs and collects the factors affecting visibility. The results from this paper allowed us to establish the importance of the retroreflectivity and luminance on improving the detectability and legibility of the road traffic signs. In addition to that, many studies gave clear evidence that the night-time visibility improves by using the adequate level of retroreflectivity.

The knowledge produced by this paper is expected to provide a guide for the road authorities when it comes to the importance of using retroreflective sheeting material to improve night-time visibility and what factors affecting the performance of this material.

An important contribution of this paper is in gathering the results from previous studies

to summaries the factors affecting night-time visibility of the retroreflective traffic road signs.

The vehicle headlights, ambient condition, and the type of retroreflection material were found to affect the luminance of the road traffic signs. The retroreflectivity depends on vehicle factors (headlights colour and angle of illumination), environmental factors (weather and ambient conditions) and sign factors (type and colour of retroreflective sheeting material). Furthermore, the results from previous work point to the fact that the weather conditions affect the retroreflection but the retroreflection does not always depend on the changes in temperature and humidity especially for sheeting with a high level of retroreflection. It was also found that the retroreflectivity do not vary much within the first twelve-year of the sign age. The sign factors (shape, size, colours etc.) were the most related to the visibility compared with the other factors.

Most of the literatures cover the factors affecting visibility (detectability and legibility) while only a few references found on the factors affecting retroreflectivity and luminance. This result gives therefore a recommendation for future studies to investigate the factors affecting retroreflectivity. The effect of human and road factors on the retroreflectivity has not been investigated and thus the hypotheses that these factors have a big effect on the retroreflectivity need to be tested.

Age and skills of the drivers have effects on the visibility of the road traffic signs but the effect of other human factors such as visual characteristics, health condition, tiredness, medicine, stress, and mental load need to be studied. Furthermore, there is no evidence

about the effect of two factors, road design and vehicle factors, which can influence the visibility of the road traffic signs. For this reason, the understandings of the effect of road design, human and vehicle factors, and the interactions between these factors on the retroreflectivity need to be increased.

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