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The Contribution of Vehicle Headlights to Visibility of Targets in Road Lighting Environments

A. Ekrias, M. Eloholma, L. Halonen

Abstract – *In this paper road lighting measurements were made to study the impacts of vehicle headlights on luminance contrasts of targets located on the road. Experimental measurements were made on a highway to investigate the contribution of halogen and high-intensity discharge headlights to road lighting. The measurement results indicate that in general, the use of vehicle headlights, in the presence of road lighting, does not improve the luminance contrasts of targets located on the road. The impacts of vehicle headlights are highly dependent on the vehicle, headlights type, target reflection factor, position of the target, position of the vehicle and road lighting installation. The effects of HID headlights on targets luminance contrasts were more significant compared to the ones of halogen headlights.* ***Copyright © 2008 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords: *road lighting, vehicle headlights, luminance measurement, luminance contrast, target visibility*

I. Introduction

The purpose of road lighting is to increase the safety, efficiency and comfort of road traffic. Road lighting should provide good visibility conditions and reduce potential hazards. The function of fixed road lighting is to illuminate the road surface, targets on the road and surrounding areas. It is estimated that the implementation of road lighting reduces night-time accidents by 20…40% [1]. The impact of road lighting in reducing night-time fatal accidents is even higher [2].

In Finland, according to the road traffic legislation, motorized vehicles have to use full headlights or dipped headlights at night-time. The use of full headlights is forbidden when the road is lit with road lighting, when oncoming traffic is present and full headlights can cause glare or when the vehicle is located behind others in traffic flow. The main reason for using vehicle headlights is to improve the driving safety and visibility conditions of the driver, other traffic users and pedestrians [3]. Lately, several research papers and studies related to vehicle headlights and visibility conditions of the driver have been published [4]-[7].

Several studies on visibility measures of realistic roadway tasks indicate that in road lighting conditions targets located on the road have mainly lower luminances than the background [8]-[10]. Thus, increasing the luminance of the background against which a target is viewed increases the target contrast and chances of the target to be detected. It has been shown that under fixed road lighting conditions, visual performance improves with increase in road surface luminance and with decrease in vertical illuminance [11]-[12].

In night-time driving conditions the purpose of road lighting is mainly to illuminate the road surface, while the headlights provide illumination to vertical surfaces, i.e. targets on the road. When the impact of dipped headlights is added to the effects of road lighting, both the road surface and the target are illuminated. In case the target is seen darker than the road surface, the vehicle headlights may result in decreasing the visibility of the target and may have a negative effect on driving safety.

Development of vehicle headlights has led to the increase of luminous fluxes of the headlights. High-intensity discharge (HID) headlamps with much greater intensity than halogen headlamps are becoming more and more common. Unlike halogen headlamps, HID headlamps do not use a filament. Instead, they contain an inert gas (Xenon), which emits light when it comes in contact with a high-voltage electrical arc. It is argued, mostly by manufacturers, that HID headlights improve driver's visibility and that HID headlights do not cause any additional glare or discomfort to other road users if they are properly aligned. However, despite the regulatory constraints concerning beam patterns, there is a potential conflict between the need to increase the intensity of vehicle headlights in order to improve driver's visibility and the use of dipped headlights in road lighting environments.

This paper sets out to investigate the use of road lighting and dipped headlights at the same time and whether this may have a conflicting effect on luminance contrasts of targets located on the road. Also, a

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comparison between contrasts under high-intensity discharge headlights and halogen headlights is made.

II. Measurements and Equipment

II.1. Experimental Set-Up

Luminance contrast measurements were made on Ring Road III which is an important highway in the southern Finland. It is the outermost of the three beltways in the Helsinki region. On Ring Road III the measurements were made on a recently built extension section. The section consists of two carriageways separated by central reservation. Each carriageway has two traffic lanes. In this section the road lighting installation is new and consists of HPS lamps (250 W). The pole spacing is 55 m and the mounting height is 12 m. In this section of Ring Road III the measured average road luminance is 1.85 cd/m^2, overall luminance uniformity 0.58 and longitudinal luminance uniformity 0.49 [13]. Fig. 1 shows the pilot location and luminance distributions of the measuring area. Luminances are shown in gray scale presentation. The road pavement type was asphalt concrete AB 22/150.

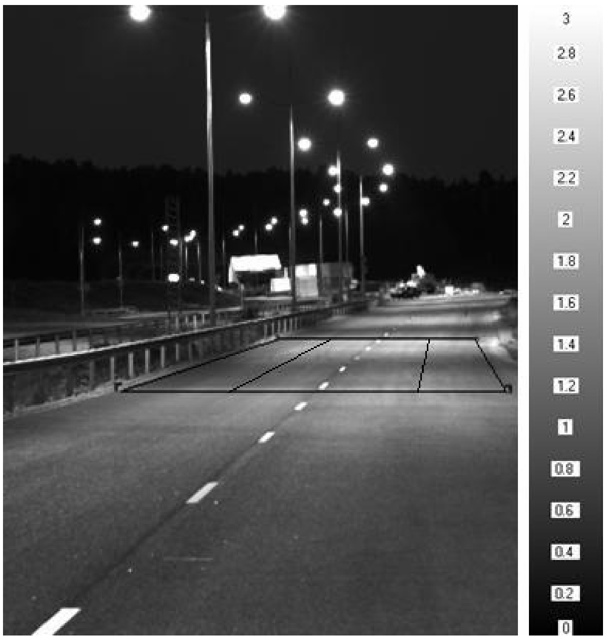

Fig. 1. The pilot location on Ring Road III and luminance distributions of the measuring area. Luminances are shown in gray scale presentation and different gray scale levels represent different luminance values. The unit of the palette values is cd/m^2

The vehicles used were a Renault Laguna 2003 and Audi A6 Avant 2006 whose headlights had been verified according to the UNECE (United Nations Economic Commission for Europe) regulations 112 and 98 [14]-[15]. The headlights of the Renault Laguna are halogen H1/H7 (55 W) and the headlights of Audi are high-intensity discharge Xenon Plus D2S (35 W).

Fig. 2. LMK Mobile Advanced

The targets used were 20 cm x 20 cm flat square surfaces positioned perpendicular to the road surface. The size of the targets corresponds roughly to the least clearance between the road surface and the body structure of normal cars. This so called small target represents a critical object which is the most difficult to perceive but still dangerous for a normal-sized vehicle [8, 16]. The targets had reflection factors 0.09, 0.20 and 0.50 and could be considered as being Lambertian.

In the American National Standard Practice for Roadway Lighting similar 18 cm x 18 cm square targets with reflection factor 0.50 are used for Small Target Visibility calculations [17]. Similar flat surface targets with different reflection factors were also used as the basis of present road lighting recommendations [11].

The measurements and analysis were made using imaging luminance photometer LMK Mobile Advanced (Fig. 2) and computer programs LMK 2000 and Road LumiMeter v2.0. The LMK Mobile Advanced is based on the digital camera Canon EOS 350D and a CMOS Canon ASP-C is used as a sensor. Softwares LMK 2000 and Road Lumimeter v2.0 were used to analyze the measured data.

II.2. Luminance Contrast

A surface and target are made visible by virtue of light being reflected from it and entering the eye of the observer. The greater the amount of light entering the eye, the stronger will be the visual sensation experienced. Thus, the illuminance on a road surface, which refers only to amount of light reaching that surface per unit of area, can give no indication of how strong the visual sensation will be and how bright the road surface will appear to the driver [12]. The brightness depends on the amount of light radiated by the surface per unit of bright area and per unit of solid angle in the direction of the observer. This is the luminance (L) of the surface, which is given by:

$$L = Eq \tag{1}$$

where E is the illuminance on the surface and q is its luminance coefficient, which is a measure of the amount of light reflected by the surface in the direction of the observer. Since brightness is finally determined not by illuminance but by luminance, the visual performance and visual comfort of a driver are directly influenced by the complex pattern of luminances existing in driver's view of the road ahead.

The ability to see small differences in brightness is usually considered to be the most fundamental function of the visual system. The ability to do this is usually indicated by contrast sensitivity. A target may be seen because it differs from its background either in luminance or in colour: that is, there may be either a luminance contrast or a chromatic contrast. Both types of contrast depend on the reflectance properties of the scene and of the incident illumination. This work concentrates merely on the luminance contrasts. Luminance contrast between a target and its adjacent background is usually defined as follows:

$$C = \frac{L_t - L_b}{L_b} \qquad (2)$$

where, C is contrast, L_t is luminance of the target and L_b is luminance of the background. If the target is darker than the background it will be seen in silhouette and its contrast is negative. On the other hand, if the target is seen brighter than the background, its luminance contrast is positive [12].

In this work road surface luminance and luminance contrast measurements were carried out to investigate the contribution of headlights to target visibility in road lighting conditions. Luminance contrasts of the targets were measured in different locations and at different measurement distances. The contrasts of the targets were calculated using the measured target luminance (L_t) and background luminance (L_b) [18]:

$$C = \frac{L_b - L_t}{L_b} \qquad (3)$$

when $L_b > L_t$ and:

$$C = \frac{L_t - L_b}{L_t} \qquad (4)$$

when $L_b < L_t$.

By using this definition of the luminance contrast, the calculation of contrast for $L_b > L_t$ is similar to the commonly used contrast definition (Equation (2)), except for the "sign" which changes to positive. The range is from 0 to +1. In the case of $L_b < L_t$, the original denominator L_b is replaced by L_t, and the range also becomes from 0 to +1. Thus the negative and positive contrast test conditions can be combined to derive one luminance contrast scale for the analysis of vehicle headlights effects. Following the above definitions for luminance contrast the same absolute contrast values are taken to lead to equal visual performance for targets both darker and lighter than the background [18]. A contrast of zero corresponds with a situation in which L_t = L_b; the target being invisible.

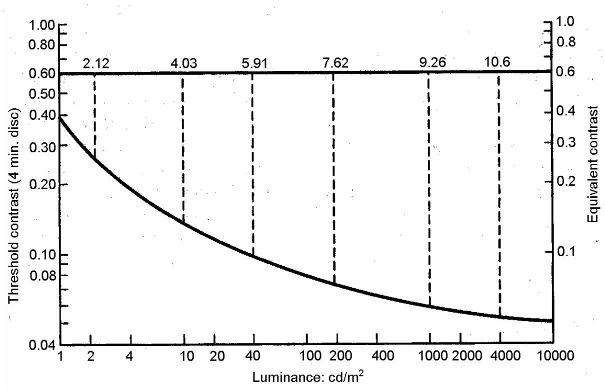

Fig. 3. The relation between sensitivity to contrast and adaptation luminance (the average luminance of the range of vision) for a 4' disc [19]

The sensitivity to contrast is the measure for the smallest luminance difference, which can still be perceived. The threshold value for the contrast which can just be seen depends on a number of factors; the most important is the general brightness (adaptation level). CIE has established a curve for threshold contrast, shown in Fig. 3, which is based on the measurements by Blackwell (1946), combined with other measurements [19].

The threshold contrast at low adaptation level is quite high. For example adaptation levels 1.0 cd/m^2 and 2.0 cd/m^2 are equivalent to threshold contrast values of C = 0.38 and C = 0.28. Road surface luminances lie in the area where the threshold value of the contrast is reduced clearly with increased luminance. This is the reason that relatively high luminance levels are recommended for use in road lighting, where perception is critical [10]-[11].

In this work the background luminances of the targets were calculated separately for every target using the average luminance of the areas around the target close to the target boundaries. This definition of the background luminance value is similar to the one used in Small Target Visibility calculations, but includes more measuring points for contrast calculation [17].

II.3. Studies

In this work the luminance contrast measurements were divided into three different studies. Study I focused on the influence of dipped halogen headlights on contrasts of small targets (20 cm x 20 cm) having varying reflection factors. Luminances of the targets and target backgrounds were measured with and without the effect of dipped headlights (Renault Laguna 2003). The targets were located on the central axis of the lane in front of the vehicle and the measuring distances were 40 m, 60 m, 80 m and 100 m. Fig. 4 represents the measurement area and the target positioning. The targets were positioned between the luminaire spacing at intervals of 10 m.

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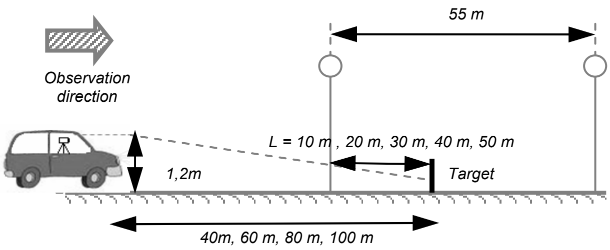

Fig. 4. Measurement set-up. Measuring distance varied from 40 m to 100 m and the targets were located between the two luminaires at intervals of 10 m. Measuring height was 1.2 m. Luminaire spacing was 55 m

The vehicle and the luminance meter always moved parallel to the central axis of both lanes.

The luminance photometer was placed 1.2 m above the road surface corresponding to the average height of the eyes of the driver. The measurements were made from both inside and outside the vehicle (Renault Laguna 2003) to study the effect of vehicle windshield.

Study II focused on investigating the effects of high-intensity discharge headlights on luminance contrasts of small targets (20 cm x 20 cm) located on the road with installed road lighting. The positions of the vehicle and the targets were consistent to Study I (Fig. 4).

Study III compared the effects of dipped halogen headlights and dipped high-intensity discharge headlights on target contrasts.

III. Results

III.1. Study I

A first series of contrast measurements were carried out for different target locations (10 m, 20 m, 30 m, 40 m and 50 m from the first luminaire; Fig. 4), first without road lighting and with full halogen headlights on, and then with the road lighting on and with or without dipped halogen headlights. For distances greater than 80 m, the dipped halogen headlights had little effect on target contrasts. For example at a distance of 100 m, the effect of dipped halogen headlights was below plus - minus few per cents, depending on the target position and target reflectance. At a distance of 60 m the effects of headlights became more significant and at a distance of 40 m the effects of dipped headlights were quite dominant. Fig. 5 shows measured luminance contrasts of a small target with reflectance of 0.20 located in front of the vehicle on the central axis of the left lane.

Fig. 5 shows how luminance contrast of the target is highly dependent on the target longitudinal position between the luminaires. When the target was located 10 m from the first luminaire, the luminance contrast of the target was 0.1 with only road lighting on. The target was seen lighter than the background.

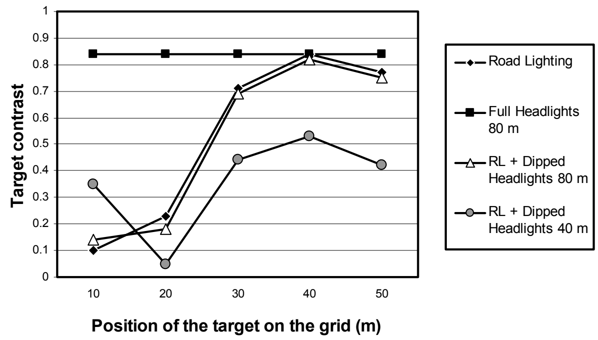

Fig. 5. Study I. Luminance contrasts of small target with reflectance of 0.20 located in front of the vehicle Renault Laguna with halogen headlights. Target is illuminated with road lighting (RL; measured from 80 m), full headlights (distance 80 m) and with dipped headlights and road lighting (distances 80 m, 40 m)

At the same time the contrast of the target located 40 m from the first luminaire was 0.85 and the target was seen darker than the background.

When the target was illuminated with the dipped headlights from a distance of 80 m, the luminance contrasts of the target decreased slightly except for the first position (10 m). This was due the fact that in this position target was seen lighter than the background (had higher luminance than the road surface). When the vehicle distance decreased to 40 m, the effects of headlights on target contrast became significant. The dipped headlights had a positive effect on target visibility in first position improving the target contrast from 0.10 to 0.35. However, in the other four positions the dipped headlights reduced the contrasts of the target. For example, when the target was located 50 m from the first luminaire, the dipped headlights lowered the luminance contrast of the target from 0.77 to 0.42.

The luminance contrast of the target (ρ = 0.20) illuminated with just full headlights was 0.85 in every location and resulted in better visibility compared to the situation with only road lighting on. However, in case of full headlights the target was seen substantially lighter than the background and the contrast was positive while in case of road lighting the contrast of the target was mostly negative and the target was seen darker than the road surface.

Figs. 6-7 indicate the variation of contrasts of dark (reflectance 0.09) and light (reflectance 0.50) targets according to the position of the target between the luminaire spacing. The targets were positioned in front of the vehicle on the central axis of the left lane. Luminance contrasts of the small target with reflection factor 0.09 were between 0.35….0.88 when road lighting was on and the vehicle headlights were off. The target was seen darker than the background in every target position. Contrasts of the light target were between 0.38…0.68 and in the first two positions (10 m, 20 m) the target was seen lighter that the background. Dipped headlights had a negative effect on luminance contrasts of the dark target (ρ = 0.09) in every target position.

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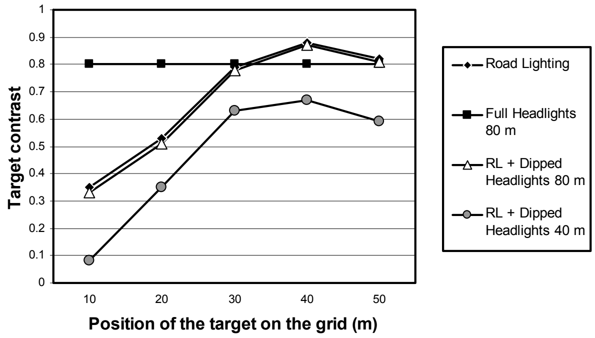

Fig. 6. Study I. Luminance contrasts of small target with reflectance of 0.09. Target is illuminated with road lighting (RL), full headlights and with dipped headlights and road lighting (distances 80 m, 40 m)

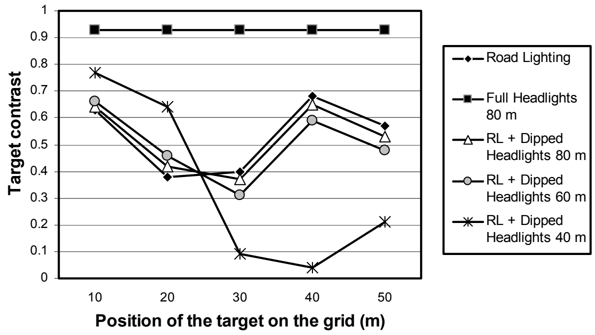

Fig. 7. Study I. Luminance contrasts of small target with reflectance of 0.50. The vehicle is positioned at distances of 80 m, 60 m, and 40 m from the target

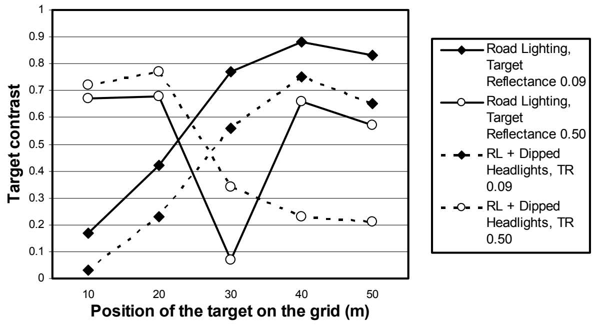

Fig. 8. Study I. Luminance contrasts of small targets with reflectance of 0.09 and 0.50 with and without the effects of the vehicle headlights. The vehicle was positioned at a distance of 40 m from the targets. The targets and the vehicle were positioned on the central axis of the right lane

In case of vehicle distance of 40 m, the target located at 10 m from the first luminaire merged almost completely into the background (Fig. 6).

When the light target (ρ = 0.50) was placed on the road in the first two positions (10 m and 20 m), the vehicle headlights had a positive effect on target visibility improving the target contrasts (Fig. 7). In other three cases the dipped headlights reduced the contrasts of the target. Critical occasions were observed when the vehicle was located at a distance of 40 m from the target and the target was positioned 30 m and 40 m from the first luminaire.

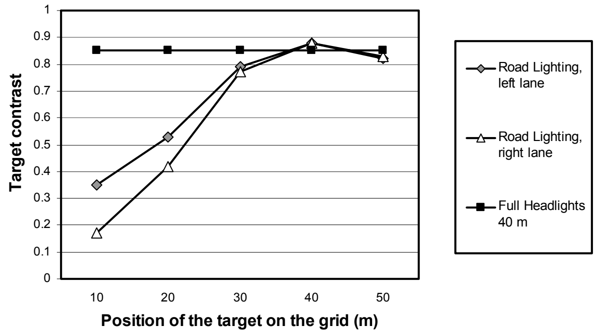

Fig. 9. Study I. Luminance contrast variation of small target with reflectance of 0.09 in relation to the target position on the road (measured from 40 m). The target was positioned on central axis of both lanes. The target was also illuminated with full halogen headlights (distance 40 m)

Fig. 7 shows an example of the increasing effect of dipped halogen headlights on target contrasts with the decrease of the distance. In series of measurements with the light target (ρ = 0.50), having only full headlights on resulted in highest luminance contrasts.

Fig. 8 shows contrasts of the dark (ρ = 0.09) and light (ρ = 0.50) target located on the central axis of the right lane 40 m in front of the vehicle. The targets were illuminated with road lighting and dipped halogen headlights were switched on/off in turn. In case of the dark target, the dipped headlights had a negative effect on target visibility resulting in significantly decreased luminance contrast values in every position. In case of the light target, the headlights had a negative effect on target contrasts located at 40 m and 50 m from the first luminaire, but positive effect on target contrasts located at 10 m, 20 m and 30 m from the first luminaire.

Fig. 8 shows an example of the variation of target contrast for two targets with different reflection factors. The results indicate that contrasts of targets and the degree of headlights effects depend highly on target reflectance.

Fig. 9 shows the contrast variation of the target with reflection factor 0.09 in relation to the target position on the road. The luminance contrasts of the target located on the central axis of the left lane varied less compared to the contrasts of the target located on the central axis of the right lane in relation to the target longitudinal position on the grid. The results indicate that the target contrasts are not only dependent on their longitudinal position between the luminaires but also on the position in the transverse direction. This results from the geometry of the road lighting installation and the light distribution of the luminaires.

According to the Study I, the effects of halogen headlights on target contrasts are highly dependent on the distance between the vehicle and the target. The effects of dipped headlights are more significant when the distance between the target and the vehicle is reduced, and also when the target has higher reflectance. According to the results, the contrasts of the

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targets and the degree of the headlights effects also depend on the target longitudinal and transverse position on the road.

When full headlights illuminate the target without fixed road lighting, there is high contrast between the target, which appears light and the road surface, which appears black. In the opposite case, with only road lighting on, the target is apparently darker than the illuminated road surface. When the impact of dipped headlights is added to the effects of road lighting, both the road surface and the target are illuminated. This usually results in lower contrasts compared to the situation when only road lighting is on.

In reality, very few targets, which usually occur on the road have higher reflection factor than 0.50. Previous studies indicate that targets with reflectance of 0.20 and lower are prevailing in night time driving conditions [20]-[21]. Such targets are usually seen darker than the background, and when dipped headlights illuminate the target the luminance contrast is reduced. Hence the measurement results of this paper indicate that, in general, dipped headlights have an undesirable and ambiguous effect on target contrasts in road lighting conditions.

In study I the luminance contrast measurements were made both from a driving seat of the car and from outside the car to study the effects of vehicle windshield. Comparable measurements were made also with clean and dirty windshields. The measured windshield transmittance coefficient varied between 0.63…0.83 depending on the cleanliness of the windshield and the position of the vehicle in relation to the luminaires. The average transmittance coefficient for the clean windshield (Renault Laguna 2003) was 0.75. Although the windshield transmittance coefficient measurements presented in this work do not represent any specified standard conditions, they do, however, indicate that vehicle windshields have a significant effect on the visibility of the driver. Thus the effect of vehicle windshield and possible variation of windshield transmittance coefficient value should be considered in evaluating the visibility conditions of drivers.

III.2. Study II

In Study II the same measurements were made with high-intensity discharge headlights (Audi A6 Avant 2006). The effects of HID headlights on small target contrasts were very significant and even at a distance of 80 m the contrasts of the targets were reduced or increased due to headlights. In general, dipped HID headlights reduced contrasts of small targets with reflection factors 0.09 and 0.20 and increased contrasts of the light target ($\rho = 0.50$).

Fig. 10 shows measured luminance contrasts of a small target with reflectance of 0.20, located in front of the vehicle on the central axis of the left lane.

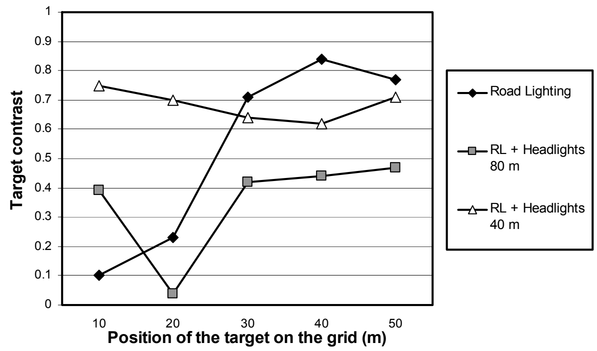

Fig. 10. Study II. The effects of HID headlights on luminance contrast of a small target with reflectance of 0.20. The vehicle (Audi A6 Avant) is positioned at distances of 80 m and 40 m from the target on the central axis of the left lane

At a distance of 80 m the HID headlights had distinct effect on target luminance contrast, resulting in lower luminance contrasts in all except the first target position. Especially in case when the target had much lower luminance than the background (high negative contrast; 30 m, 40 m, 50 m) the HID headlights resulted in reducing target visibility to a large extent.

At a distance of 40 m the effects of HID headlights were very predominant. At first two positions (10 m, 20 m from the first luminaire) the HID headlights increased the target contrast exceedingly when compared to road lighting, but at further positions (30 m, 40 m and 50 m from the first luminaire) the contrast value decreased (Fig. 10).

It is worth noticing that in case with only road lighting on, the target is seen darker than the background in all except the first position, but in case with road lighting and HID headlights on, the target is seen brighter than the background in all positions.

Fig. 11 presents the effects of HID headlights on contrasts of the dark target (ρ = 0.09). The luminance contrasts decreased substantially when the vehicle with dipped HID headlights was placed at a distance of 80 m. For example, a target located at 10 m from the first luminaire became barely visible (C= 0.14).

When the vehicle was placed at a distance of 40 m, the HID headlights had a negative effect on target contrasts located at 30 m, 40 m and 50 m from the first luminaire, but positive effect on target located at 10 m from the first luminaire (Fig. 11). Again in case with road lighting and HID headlights on, the target was seen brighter that the background in all positions.

Unlike the dark targets, light targets are not always seen as dark against the background due to their higher reflectance.

For example in Fig. 12, in case when only road lighting is on, the target with reflectance of 0.50 is seen brighter than the background in first two positions (10 m, 20 m). Adding the effect of vehicle headlights, the target luminance is increased resulting in higher luminance contrasts.

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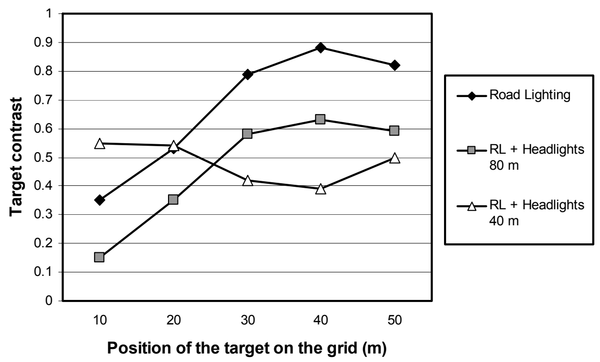

Fig. 11. Study II. The effects of HID headlights on luminance contrast of a small target with reflectance of 0.09. The vehicle (Audi A6 Avant) is positioned at distances of 80 m and 40 m from the target on the central axis of the left lane

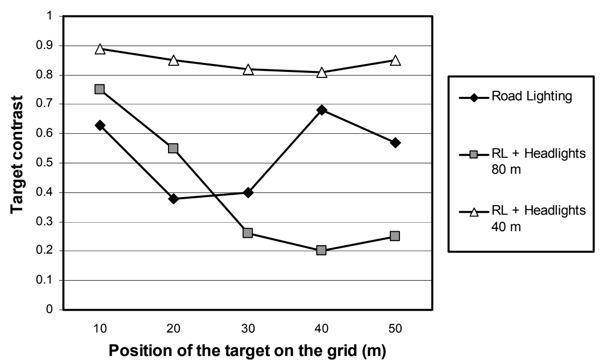

Fig. 12. The effects of HID headlights on luminance contrast of a small target with reflectance of 0.50. The vehicle (Audi A6 Avant) is positioned at distances of 80 m and 40 m from the target on the central axis of the left lane

Luminance contrasts of the target with reflection factor 0.50 decreased exceedingly at the measuring distance of 80 m, when the target was placed 30 m, 40 m and 50 m from the first luminaire, and increased when the target was positioned 10 m and 20 m from the first luminaire. The luminance contrast of the light target at a vehicle distance of 40 m increased in all occasions and the target had higher luminance than the background.

The results of Study II indicate that when the distance between the target and the vehicle is 60 m or longer, the HID headlights have mostly a negative effect on target contrasts. When the vehicle is located close to the target, the effects of HID headlights on target contrast are occasionally positive and the lighter the target the higher the effect. However, at longer distances the impact of dipped HID headlights is undesirable. For example on major roads and highways with high driving speeds, the stopping distances are long and it is very important for the driver to detect the target located on the road from the safe distance. However, according to the results especially at longer measuring distances, the effects of HID headlights in contribution to road lighting resulted in decreased luminance contrasts. This is because in road lighting conditions targets located on the road have usually lower luminances than the background [8]-[10].

The luminance contrasts of small targets varied highly depending on the target longitudinal position and the distance between the target and the vehicle. Target position on different lanes resulted either in higher or lower luminance contrasts depending on its position in the longitudinal direction and on the vehicle distance.

III.3. Study III

Study III combined the Studies I and II together comparing the effects of HID headlights to the effects of halogen headlights. Fig. 13 presents measured contrasts of the small target with reflection factor 0.09 at a distance of 80 m with HID and halogen dipped headlights. Fig. 14 shows the same results for the target with reflection factor 0.20.

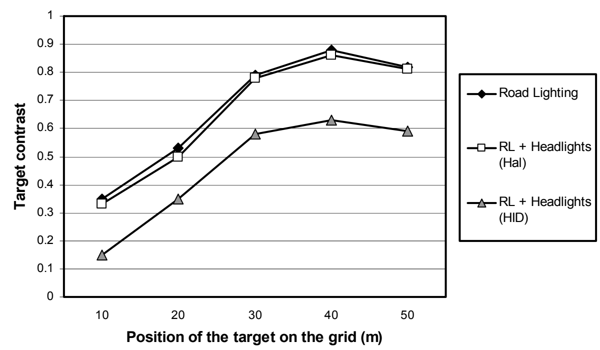

Fig. 13. Luminance contrast measurements with dipped HID headlights and dipped halogen headlights. Measuring distance is 80 m and target reflectance 0.09

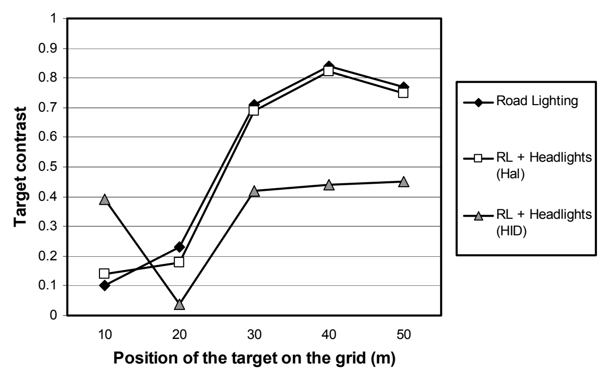

Fig. 14. Luminance contrast measurements with dipped HID headlights and dipped halogen headlights. Measuring distance is 80 m and target reflectance 0.20

As shown in Figs. 13-14, the HID headlights have much higher effect on target contrasts compared to the halogen headlights. This is mostly due to the higher luminous intensity of the HID headlights.

Due to the vehicle structure, HID headlights were situated approximately 10 cm higher from the road surface than in the case of halogen headlights. This was found to have a major role on the luminance contrasts of small targets.

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At longer distances high luminous intensity of HID headlights results in better target contrasts only with bright targets and only in few target positions. In case with targets with reflection factors 0.09 and 0.20, the HID headlights increased targets contrasts only in one position. In all other positions the contrast values decreased notably. This is contradictory to the introduction of HID headlamps in their characteristics of providing better visibility conditions by producing more light. Thus also road lighting conditions should be taken into account when considering the positive effects of HID headlights on night-time driving safety and target visibility.

As the distance between the vehicle and the target decreases, the illuminating effect of headlights becomes higher. At a distance of 40 m the effect of HID headlights is so strong that targets are seen brighter than the background regardless of the target position (Figs. 15-16). At the same time also dipped halogen headlights illuminate targets more efficiently. However, because of the lower luminous intensity, halogen headlights usually result in significantly decreased target contrasts.

Fig. 15 shows contrasts of the dark target ($\rho = 0.09$) illuminated with road lighting and with the dipped halogen headlights or dipped HID headlights. Vehicles were placed 40 m in front of the target. In case with HID headlights in first target position (10 m) contrast value increased, but in the last three positions (30 m, 40 m, 50 m) they reduced.

The dipped halogen headlights resulted in lower contrast values in all target positions comparing to the bare road lighting.

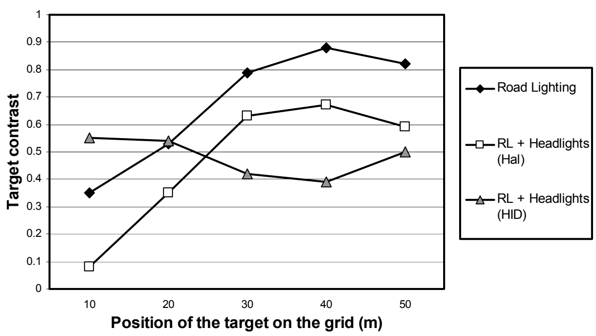

Fig. 15. Luminance contrast measurements with dipped HID headlights and dipped halogen headlights. Measuring distance is 40 m and target reflectance 0.09

Fig. 16 shows contrasts of the light target ($\rho = 0.50$) illuminated with road lighting and with the headlights. Despite the great variation in luminance contrasts in case when only road lighting is on, the contrasts are quite constant in case when both road lighting and HID headlights are on. The luminance contrasts are also rather high and target visibility is better compared to the bare road lighting and road lighting with halogen headlights.

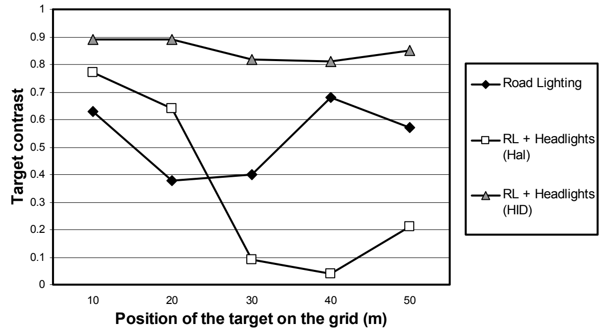

Fig. 16. Luminance contrast measurements with dipped HID headlights and dipped halogen headlights. Measuring distance is 40 m and target reflectance 0.50

The dipped headlights had quite marginal effects on road surface luminances when the distance between the vehicle and the measurement area (luminaire spacing) was above 60 m. Only HID dipped headlights at a distance of 40 m had a significant effect on road surface luminances.

IV. Discussion

The luminance contrast measurements indicate that in general, in road lighting environments, dipped headlights reduce contrasts of small vertical targets located on the road. It is, however, very difficult to determine how these effects relate to the safety of the driver in various traffic conditions. A number of field measurements and traffic accident statistics are needed to determine the overall effects of vehicle headlights on target visibility in road lighting environments.

A major problem of these kinds of target visibility measurements is that it is not known what targets are likely to appear on the road and which targets are critical for the safety of the driver. In driving, luminances of the target and the target background are changing constantly and the target cannot be expected to be stationary. In road lighting conditions visual targets may also have non-uniform luminance and colour contrasts. It is also quite obvious that the targets will not be completely diffuse and usually can not be considered as being Lambertian.

One potential extension scenario for luminance contrast measurements presented in this work would be to study how road lighting dimming, different weather conditions and different pavement types affect the impacts of vehicle headlights on target contrasts. Also, the targets located off-axis and the impacts of multiple vehicle headlights on target luminance contrasts should be included. It would also be useful to conduct similar luminance contrast measurements with different target, vehicle and headlight types. Also, if oncoming traffic is considered in the measurements, the negative effects of glare on driver's visibility conditions should be investigated.

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In this paper luminance contrast calculations were made by using somewhat distinct contrast formulas compared to the conventional definition of the contrast. This was made to simplify the comparison and the diagrammatic representation of the results. It can be argued that positive and negative contrast targets are quite different visual tasks for the driver and thus can not be directly compared with each other. However, according to Janoff, positive and negative contrast tasks are highly related and have correlation coefficient close to one [18].

Small Target Visibility design described in the American National Standard for Roadway Lighting is based on visibility of 18 cm x 18 cm small targets with reflection factor 0.50 [17]. It is obvious that small targets with such high reflection factor are susceptible to the impact of vehicle headlights. Fig. 12 shows a good example of the effects of HID headlights on target contrast (ρ = 0.50) at a distance of 80 m. The measurement set-up described in the American National Standard for the Small Target Visibility (STV) design is very similar to the one used in this example. The STV calculation described in the standard is done by using target and target background luminance values. According to this work, HID headlights have a major effect on target luminance and hence have a significant effect on the calculated STV values. Thus the effects of vehicle headlights should definitely be included in STV calculation. Of course, this means that calculations have to be settled on some design values of certain typical vehicle headlight types.

Sources of error in the measurements are estimated to be the possible differences in vehicle and target positioning when measuring different variations of the same type of measurement (halogen headlights and HID headlights). Because the measurements were done during several nights, background noises (external factors such as sky-glow, moonlight and so on) were measured but found to be negligible. The system measurement error for luminance measurement repeatability of the LMK Mobile Advanced, according to the manufacturer's certificate, is ± 1.9 %.

V. Conclusion

The luminance contrast measurements indicated that in general, the use of vehicle headlights, in the presence of road lighting, does not improve the visibility of various targets located on the road. In fact, in most cases when the targets were seen darker than the background, vehicle headlights reduced target contrasts and in some cases they made the target merge into the background.

According to the measurements, the effects of dipped headlights are highly dependent on the position of the vehicle, location of the target in relation to luminaires, target reflectance, vehicle and headlight type and road lighting installation.

Dipped halogen headlights had little effect on target contrasts when the distance between the target and the vehicle was more than 80 m. However, with decreasing distance, the effect of dipped headlights became higher. Road lighting usually resulted in lower target luminance contrasts compared to the situation when only full headlights were on. However, in case of full headlights, the target contrasts were positive and the target was seen substantially lighter than the background while in case of road lighting the target was seen darker than the road surface and the contrasts were negative. When the road lighting and dipped headlights were both on, luminance contrasts were usually lower compared to the situation with only road lighting on.

The dipped high-intensity discharge headlights had more significant effects on target contrasts than the dipped halogen headlights. At longer distances the negative impact of dipped HID headlights on target visibility increased significantly compared to the halogen headlights. This may be a problem on major roads with high driving speeds and long stopping distances. At shorter distances the effects of HID headlights were so strong that even the dark targets were usually seen lighter than the background and in most cases the HID headlights increased the luminance contrasts of the targets.

It is difficult to determine the relationship between the use of dipped headlights in addition to road lighting and the safety of the driver. It is also to be resolved how the negative effects of dipped headlights relate to the safety critical tasks that drivers have to see to avoid collisions. Further research is needed to determine these issues.

It can be argued, that there is a strong conflicting effect in the use of vehicle headlights in road lighting environments. One solution may perhaps be the use of parking lights instead of dipped headlights in the presence of road lighting. This may, however, result in other unwanted effects concerning traffic safety. The use of parking lights may reduce the visibility of other vehicles in traffic and also the illumination of road surroundings will become completely dependent on the installed road lighting. Visibility of other vehicles in traffic could be improved by using for example LEDs in cars to indicate the vehicle. Those LEDs would not illuminate the road ahead but make the vehicle visible for other drivers in road lighting conditions.

The use of parking lights in the presence of road lighting would also add one extra function for drivers to perform, which may result in confusion and distraction. The drivers would have to remember to use parking lights in road lighting environments, switch them to full headlights when there is no road lighting, and then change them to dipped headlights when oncoming traffic is present.

The luminance contrast measurements presented in this work do not represent any specified standard conditions in studying the contribution of vehicle

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headlights to road lighting. They do, however, indicate the remarkable changes that vehicle headlights can have on the luminance contrasts of various targets located on the road.

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