

Vehicle Lighting and Modern Roundabouts: Implications for Pedestrian Safety

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ABSTRACT

Modern roundabout facilities are increasing in number throughout North America and the world. Appropriate vehicle lighting, including the application of intelligent headlighting systems, might help support safe, efficient driving behavior while navigating through these new intersection types. We present the results of a field study conducted to compare different vehicle lighting systems in terms of drivers' ability to detect and identify pedestrian activity, under different amounts of illumination from fixed outdoor lighting systems. The results are compared to analytical predictions of visibility using a validated visual performance model.

CITATION: Bullough, J. and Skinner, N., "Vehicle Lighting and Modern Roundabouts: Implications for Pedestrian Safety," *SAE Int. J. Passeng. Cars - Mech. Syst.* 5(1):2012, doi:10.4271/2012-01-0268.

INTRODUCTION

Roundabouts are being constructed increasingly throughout North America (Robinson, 2000). Among the reasons for doing so is that they can help maintain traffic flow compared to signalized intersections. Roundabouts also reduce the angles between approaching vehicles entering the roundabout and those vehicles already in the roundabout, which in turn decreases severity in the case of a crash. Presently, lighting practices (IES, 2008) for these facilities do not take into account illumination from vehicle headlamps, nor do they necessarily provide the visual guidance required by drivers unfamiliar with the layout and geometry of roundabouts in an optimal manner (Bullough et al., 2009). Typical fixed illumination practices for roundabouts involve relatively high horizontal illuminances in the roadway portion of the roundabout.

Unlike at traditional roadway intersections, where the locations of pedestrian crosswalks are usually known by drivers, crosswalks at roundabouts tend to occur along the approaching legs of the roundabout, and are not always perpendicular to roadway traffic patterns. This can result in confusion among drivers. The situation can be further compounded by findings from published studies that pedestrians tend to overestimate the ability of drivers to see and respond to their presence along the road (Whetsel et al., 2011).

Various studies have been conducted to assess the visual performance of drivers under different advanced vehicle forward lighting systems including high intensity discharge

(HID) headlamps (Van Derlofske et al., 2001, 2002) and adaptive forward-lighting systems (AFS) such as swiveling headlamps (Bullough et al., 2007; Bullough, 2009). The contexts of many of these evaluations are often rather simplistic roadway scenarios such as straight roads or single curves to the left and/or right. Navigating a roundabout can involve several reversals in steering to first enter the roundabout, then turn in the opposite direction to travel along the circular portion of the roundabout, and then to reverse steering direction again when exiting the roundabout. It would then be of use to understand the value of advanced vehicle lighting systems on drivers' ability to see pedestrians in these types of roadway facilities.

Skinner and Bullough (2011) recently performed visual performance analyses of visibility under HID and AFS systems, based on photometric simulations of headlamps including different levels of ambient illumination from fixed roadway lighting systems. They used the relative visual performance (RVP) model (Rea and Ouellette, 1991) to evaluate visibility. This model is based on the light level, contrast, and size of an object, and predicts the speed and accuracy of visual responses. Skinner and Bullough (2011) found that under conventional, static headlamps, the combination of headlamps and fixed roadway illumination could sometimes result in poorer visibility than with headlamps alone. In comparison, both HID and AFS (swiveling) headlamp systems produced luminous conditions that were relatively insensitive to the presence of fixed illumination.

Table 1. Geometric and Photometric Characteristics of the Targets in the Field Experiment.

Distance (m)	Angle (deg.)	Halogen		HID	
		Target Lum. (cd/m ²)	Pavement Lum. (cd/m ²)	Target Lum. (cd/m ²)	Pavement Lum. (cd/m ²)
20	2°	1.26	0.12	1.23	0.12
23	15°	0.11	0.01	0.51	0.04
30	0°	1.17	0.12	1.47	0.15
39	11°	0.06	0.003	0.26	0.01
40	0°	1.00	0.09	1.20	0.10
50	0°	0.38	0.02	0.41	0.02

Table 2. Mean Identification Times for Each Experimental Condition.

Distance, m	Angle, deg.	Halogen	HID
		Mean Identification Time, s (s.d.)	Mean Identification Time, s (s.d.)
20	2°	1.37 (0.43)	1.43 (0.33)
23	15°	1.87 (0.66)	1.04 (0.30)
30	0°	1.98 (0.35)	1.10 (0.16)
39	11°	5.94 (2.09)	5.22 (1.63)
40	0°	2.20 (0.43)	1.48 (0.21)
50	0	3.79 (1.19)	1.70 (0.55)

The present paper summarizes the execution and outcomes of a field experiment designed to compare different vehicle lighting configurations in the context of roundabout intersections. It also provides an opportunity to test the ability of the RVP (Rea and Ouellette, 1991) model to predict the visibility of pedestrians in a realistic, outdoor context.

**Figure 1. Target used in the field experiment.**

METHOD

In an outdoor location demarcated as a modern roundabout intersection (with asphalt pavement of 10%-15% reflectance), study participants were instructed to identify the walking direction (left or right) of a pedestrian target consisting of a black-painted (reflectance, 5%) silhouette (1 m height) of a walking child (Figure 1), as quickly as possible. Subjects ranged in age from 28 to 65 years (mean 50, s.d. 15).

Two headlamp systems were used: a halogen low-beam set, and a high-intensity discharge (HID) set equipped with swiveling functionality. The headlamp and target geometries were set to match, as closely as possible, vehicle-headlamp-

pedestrian geometries evaluated by Skinner and Bullough (2011) in their simulation analyses. During some of the experimental trials, targets were located directly in front of the test vehicle to represent the effect of swiveled headlamps in the direction of the pedestrians. The distances and angular positions of the pedestrian target (a child-sized silhouette) and measured target/pavement luminances are summarized in Table 1.

For some of the test locations, the illuminance from a nearby fixed exterior lighting system was approximately 2 lx, corresponding to the maximum ambient illumination level evaluated by Skinner and Bullough (2011). In other locations the illuminance from the fixed system was negligible.

Subjects viewed each of the six target locations under each lighting configuration in a randomized order, in two groups of five. Each subject was seated behind the headlamp system and held a laptop computer that provided instructions and recorded their response times. After the lighting and target condition was set (while subjects looked toward their laptop screens), the software indicated when subjects should look up for a pedestrian target and press the left or right arrow, corresponding to the walking direction of the pedestrian target.

RESULTS

Table 2 lists the mean identification times (and standard deviations) for each target location and lighting configuration. In general, for the targets located furthest away or in the peripheral field of view, identification times were longer. A repeated-measured analysis of variance on the identification times revealed statistically significant ($p < 0.05$) effects of lamp type and of the use of swiveling in the direction of the targets. Identification times were shorter under HID illumination and when headlamps were swiveled toward the targets.