Project No. 5-19

ANALYSIS OF VISUAL PERFORMANCE BENEFITS FROM ROADWAY LIGHTING

FINAL REPORT

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
of
The National Academies

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Troy, NY

June 2009

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The basis for visibility analyses summarized in this report is the Relative Visual Performance (RVP) model developed by Rea and Ouellette. The RVP model was evaluated in the outdoor environment using legibility of simulated traffic signs in a static condition in which the observer is presented with known and recognizable stimuli under static conditions. Additional validation of the RPV model for dynamic, nighttime roadway conditions should be conducted before these results are used to make decisions on appropriate roadway lighting.

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ABSTRACT

As part of National Cooperative Highway Research Program (NCHRP) Project 5-19, several analyses of the visual performance of drivers under different roadway lighting conditions were conducted using simulations based on photometrically accurate lighting software. The analyses assessed the role of different lighting characteristics as they affect visibility for drivers of different age groups. Analyses were conducted using the relative visual performance model, a model of suprathreshold visibility based on the luminance contrast, background luminance, and size of a visual target. In general, the analyses were consistent with the notion that lighting generally improves visibility and by inference, safety, when it provides illumination where potential hazards are likely to be located.

EXECUTIVE SUMMARY

A major purpose of lighting is to increase visibility for drivers and other roadway users. The present report summarizes a series of analyses conducted to systematically assess the role of roadway lighting on visual performance along intersections, interchanges, and highways, where lighting might be shown to be related to improvements in safety.

The analyses in the present report use the suprathreshold relative visual performance model to characterize visual performance under a variety of lighting conditions and roadway scenarios. The analyses address the role of light level, the role of the extent of lighting (e.g., point or localized lighting versus continuous or extended lighting) for different driving speeds, the role of light from the ambient environment (e.g., low levels in rural areas, versus high levels in urban areas), the role of different types of vehicle headlighting, and the role of different types of roadway luminaire lateral distributions on visibility for drivers of different age groups.

In general, the analyses were consistent with the notion that lighting generally improves visibility and by inference, safety, when it provides illumination where potential hazards are likely to be located. At rural roads with relatively high (>40 mph) speed limits, for example, potential hazards are unlikely to be located at the immediate junction of an intersection when they need to be detected, and therefore, point or localized lighting in these situations is not very advantageous to visibility. Along roadways with signalized intersections where driving speeds are lower and pedestrians more likely to be present, point or localized lighting has a greater beneficial impact on visibility. In urban areas with very high levels of ambient illumination, roadway lighting adds relatively little to visibility.

CHAPTER 1
BACKGROUND

INTRODUCTION

A major purpose of lighting is to increase visibility for drivers and other roadway users. The present report summarizes a series of analyses conducted to systematically assess the role of roadway lighting on visual performance along intersections, interchanges, and highways, where lighting might be shown to be related to improvements in safety.

Most studies of the effects of roadway lighting on safety have used the presence (or lack thereof) as the only independent variable associated with lighting (as summarized in the accompanying report "Review of the Safety Benefits and Other Effects of Roadway Lighting"). It could be argued that poor lighting is as effective, or even worse than, no lighting at all. Without controlling for the type of lighting, it can often be difficult to interpret findings about the impact of lighting in reducing nighttime crashes.

There have been attempts in the literature to study different characteristics of lighting using measures such as the illuminance on, or the luminance of, the roadway surface (e.g., *1, 2*), for example. Box (*1*) found that nighttime crashes decreased as light levels increased up to a point, and that they increased for even higher light levels. In contrast, Scott (*2*) found that nighttime crashes decreased as a function of increasing roadway luminance with no optimum luminance level. In both studies, the data were highly variable, so that the relationships found could not be interpreted as definitive.

While a general relationship between light levels and visibility seems reasonable, with higher levels (usually) providing improved visibility that consequently should be related to improved nighttime safety, visibility and light levels are not always correlated. A low light level could result in greater visibility than a relatively higher level if the resulting illumination provides higher luminance contrast between an object and its background, for example. For this reason, a number of studies have been performed to investigate whether certain visibility metrics might be related to nighttime crashes. Many of these studies have used metrics based on visual threshold data, such as visibility index (VI), visibility level (VL) and small target visibility (STV). Such metrics have generally been found not to be robust predictors of nighttime safety (*3-5*). One possible reason is that measures of visibility based on threshold performance (e.g., detection thresholds for visual targets) have been shown to be poor predictors of *suprathreshold* visual performance (*6*).

Another possible reason is that when driving at night, lighting can be provided not only by fixed roadway lighting, but also by vehicle lighting. If, as evidence suggests (*5, 7*), visibility under a combination of vehicle lighting and roadway lighting is different than under roadway lighting alone, visibility measures derived from roadway lighting photometric data alone should not be expected to characterize safety benefits associated with roadway lighting.

The analyses in the present report use the suprathreshold relative visual performance (RVP, *8*) model to characterize visual performance under a variety of lighting conditions and roadway scenarios. The analyses address the following issues:

- The role of light level

- The role of the extent of lighting (e.g., "point" or localized lighting versus continuous or extended lighting) for different driving speeds

- The role of light from the ambient environment (e.g., low levels in rural areas, versus high levels in urban areas)

- The role of different types of vehicle headlighting

- The role of different types of roadway luminaire lateral distributions

The analyses cover two primary roadway locations: intersections and interchanges. However, the results of these analyses can be applied to other scenarios and situations, including highway segments and other roadway facility types, when the geometric relationships between the observer (driver) and the relevant objects of interest are similar to the modeled scenarios.

RELATIVE VISUAL PERFORMANCE

Most recommendations for the illumination of roadways are given in terms of illuminance on the roadway, or the luminance of the roadway surface. Although the Illuminating Engineering Society of North America (*9*) includes roadway lighting recommendations based on STV as well as illuminance or luminance, a survey of state transportation agencies (as summarized in the accompanying report "Review of the Safety Benefits and Other Effects of Roadway Lighting") confirmed that no states were currently using STV in the design of lighting for highways. Qualitatively, the important role of light level in visibility makes sense. Generally, higher light levels are likely to produce greater visibility than lower levels. For this reason, the IESNA (*9*) recommendations for illuminance and luminance require higher light levels for roadway locations having greater visual demands, based primarily on experience and consensus within the illuminating engineering community.

The illuminance on, or luminance of, an object is not the only indicator of its visibility. As described above, the basis for visibility analyses summarized in this report is the RVP model developed by Rea and Ouellette (*8*). This model provides a method for determining the speed and accuracy with which suprathreshold (i.e., above the minimum level for detection) visual information can be processed, given several relevant parameters:

- The size of the target

- The luminance of the background surrounding the target

- The luminance contrast between the target and its background

- The age of the observer

The RVP model (*8*) was developed from the results of two experiments - one (*10*) which measured response times to flashed targets varying in size and luminance contrast against surrounding backgrounds varying in luminance, and one (*11*) which measured the speed and accuracy with which people could perform a numerical verification task. This task consisted of reading pages printed with two columns, each containing twenty five-digit numbers. All of the five-digit numbers on each page matched, except there was a single mismatched digit in zero to six of the five-digit numbers. Subjects in the experiment were asked to locate these mismatch errors on each page. The numerical verification task was performed under a range of lighting and luminance contrast conditions. Importantly, the results of each experiment were nearly identical, despite the very different methods they used, when the results were converted to the speed and accuracy of visual processing. These studies were conducted using a range of background luminances between 0.17 cd/m^2 and 255 cd/m^2.

The RVP value is compared to the speed and accuracy of a reference condition corresponding to high light levels (such as those found in offices), high luminance contrast (such as that found on white laser-printed paper using black ink) and large size (such as 10- or 12-point type). This reference condition is defined to have an RVP value of one. RVP values close to one are expected to result in similar speeds and accuracy rates as the reference visual task would produce. RVP values of zero correspond to the legibility threshold (in other words, the point at which an object can be identified), and negative RVP values correspond to visual targets that can be detected but not identified (such as a shape in the road that could be an animal or a blowing item of trash but is not visible enough for someone to make the distinction).

RVP differs from another metric that is sometimes used to quantify visual performance, the visibility level (VL). VL is defined as the ratio between the luminance contrast of a given visual task, and the minimum (threshold) luminance contrast the task could have while remaining visible. When VL is less than one, an object is invisible; when VL is greater than one, the object is visible, and in general, as VL increases, so does the visibility of the object. Ross (*6*) demonstrated that VL does not serve as more than a relatively crude predictor of visual performance; one visual task may have a lower VL than another, but performance of the former task can be demonstrably higher than that of the latter. Interpretation of VL can be difficult. For example, a VL of one indicates threshold visibility, and a VL of 10 indicates an object whose contrast is well above the visual threshold and therefore will be quite visible. A VL of 20, however, will not be twice as visible as a VL of 10, and in fact, visibility of an object with a VL of 20 in many cases will be only negligibly better than of an object with a VL of 10 (*6*).

Figure 1 shows a three-dimensional surface plot of RVP values for 10-point typewritten characters (averaging 4.8 microsteradians in solid angular size) varying in luminance contrast (i.e., having different ink lightnesses) and against a background varying in luminance (i.e., under different light levels). When both luminance and luminance contrast are low (i.e., reading light gray print on white paper under low light levels), visual performance drops precipitously. Once both luminance and luminance contrast have reached nearly asymptotic values (resulting in RVP values close to one), further increases in either luminance or luminance contrast will not substantially increase visual performance. This "plateau and escarpment" characteristic of visual performance has been illustrated in many other experiments as well. An RVP value of 0.9 is one that would result in excellent visibility, along the "plateau" of visual performance. Unlike VL, which represents the ratio of an object's luminance contrast to the minimum luminance contrast it would need to be just detectable, RVP values are proportional to the speed and accuracy of visual processing. Once the RVP value exceeds a value of about 0.9, visual processing will not increase substantially in terms of speed and accuracy with increases in luminance, luminance contrast or size.

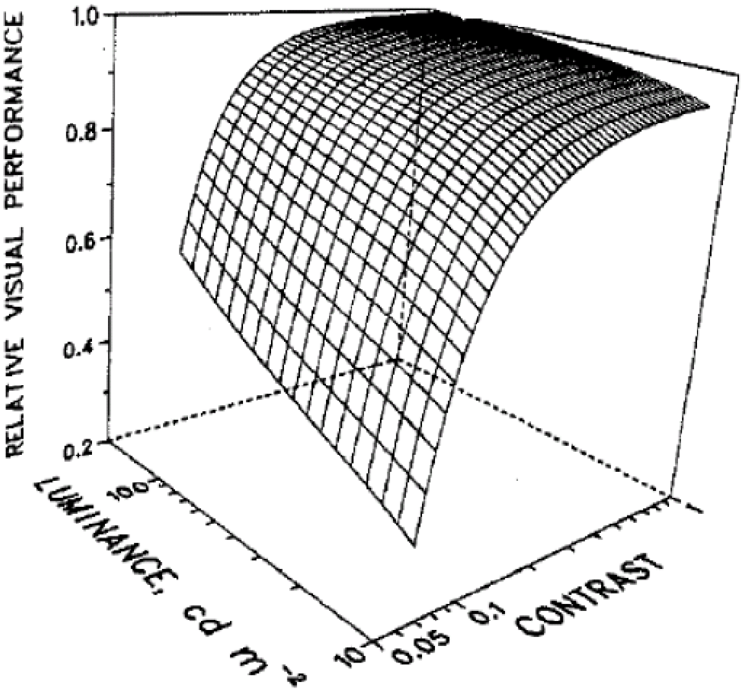


Figure 1. RVP values (8) as a function of luminance (left abscissa) and contrast (right abscissa) for 10-point typewritten characters.

As described above, the size, background luminance, and luminance contrast of an object determine its visibility, but so does the age of the person viewing the object. Until a person reaches about 70 years in age, the eye undergoes gradual changes, mainly with respect to the transmission of light through the eye's lens (*12*), and with respect to the pupil size of the iris (this the aperture through which light travels when entering the eye). As one gets older, the lens increases in thickness and becomes more yellow in color, and the pupil size of the iris tends to get smaller (*13*). These effects taken together, result in an approximately linear reduction in the amount of light reaching the retina as one gets older. Figure 2 (*14*) illustrates this reduction in light as a function of age for individuals aged 20 years through 60 years. Until the age of about 70 years, these optical changes almost exclusively explain reductions in visibility exhibited by older adults, compared to younger adults. (After this age, effects such neurological and physiological deterioration contribute to reductions in visibility also.)

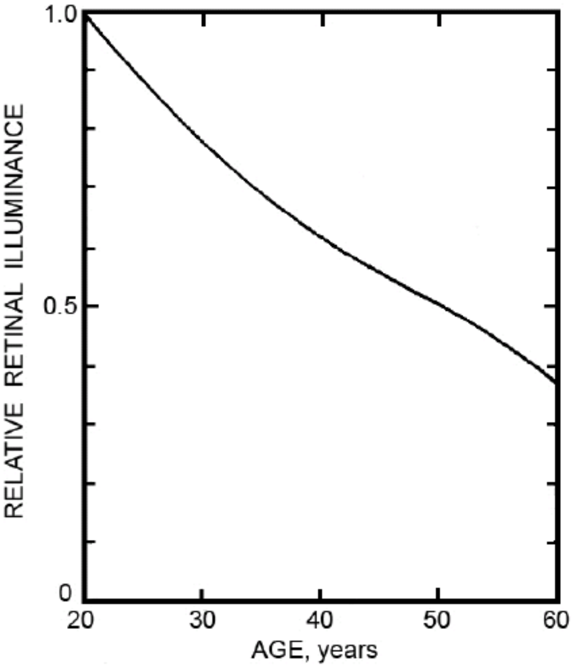


Figure 2. Age-related reduction in retinal illuminance caused by lens thickening and yellowing and by pupil size reductions (8).

The RVP model is referenced by the IESNA *Lighting Handbook* (*14*) as one of the methods used for assessing the impact of light levels for different lighting applications. An important consideration in the use of any model of visibility is the degree to which the model has been validated using independent data. Eklund et al. (*15*) performed an experiment in which subjects were requested to identify alphanumeric codes of varying sizes (printed in 6 through 16 point text, and viewed from about 40 cm) printed in varying luminance contrasts (between 0.10 and 0.93) and background luminances (between 8 cd/m² and 2400 cd/m²). The performance obtained from subjects in this experiment (Figure 3) was highly correlated with the calculated values of RVP (*8*).

Bailey et al. (*16*) measured the speed at which individuals could read text (consisting of a sequence of unrelated words averaging seven letters in length) varying in luminance contrast and size, with background luminances between approximately 10 and 5500 cd/m². The data from Bailey et al. (*16*), when converted to the number of words per second that could be read, were found to be well correlated with predictions of response times using the RVP model (*8*).

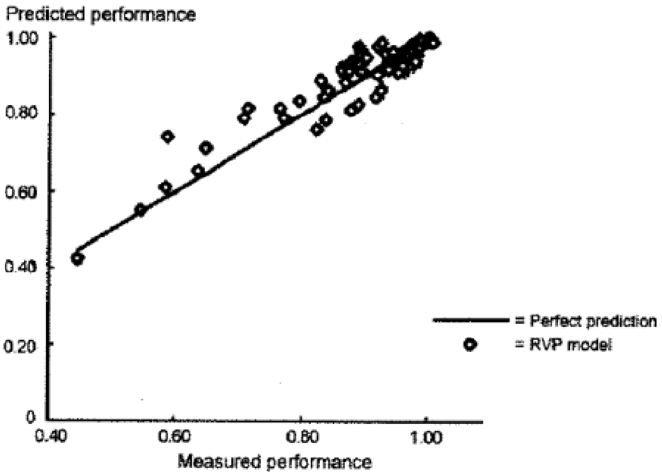


Figure 3. Comparison of predicted visual performance (Rea and Ouellette, 1991) and measured performance for an office data entry task (15).

In a study related to highway sign visibility, Goodspeed and Rea (*17*) evaluated the effects of luminance contrast and background luminance on the ability of individuals to accurately identify the orientation of Landolt "C" ring symbols. For simulated highway sign displays, subjects were asked to identify the direction of the gap in the symbol (for a properly oriented "C" the gap is to the right). Subjects viewed conditions under several different levels of surround complexity in addition to different background luminance and luminance contrast conditions. Goodspeed and Rea (*17*) compared their data to predictions of response time generated using the RVP model, and the RVP model closely predicted the measured response times (Figure 4) measured by Goodspeed and Rea (*17*), except at the lowest luminance contrast level. Such differences at low luminance and luminance contrast levels might be caused by small individual differences among people in terms of threshold contrast, which make assessments of visual performance near threshold conditions (i.e., with a luminance contrast of 0.2) less reliable. The otherwise close correspondence reinforces the ability of the RVP model to develop meaningful predictions of suprathreshold visual responses in a variety of contexts.

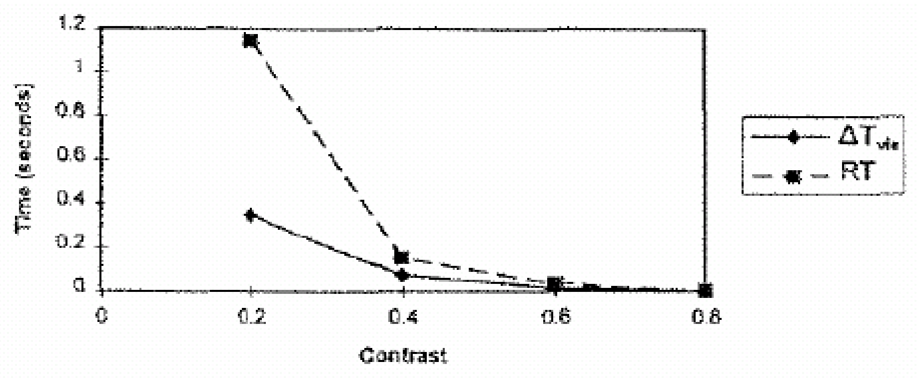


Figure 4. Measured visual response times for simulated highway sign stimuli (17) and predictions based on RVP (8).

In a subsequent study of the luminance, luminance contrast and character size needed for reliable visual acquisition of information on highway signs, Schnell et al. (*18*) measured the time necessary to correctly identify the exit number for a particular destination, while viewing a sign containing several different destinations and exit numbers. Background luminances in this study were between 3 and 80 cd/m². The time required for this visual task was strongly correlated with the response times predicted using the RVP model (*8*) for each combination of luminance, contrast and size.

Zhang (*19*) performed a nighttime field experiment in which several different lighting systems were used to illuminate a simulated mid-block crosswalk in an unlighted parking lot. Subjects were required to identify the orientation of child- and adult-sized pedestrian targets consisting of black-painted plywood silhouettes walking toward either the left or the right. During each trial, targets were placed in one of several locations within the crosswalk in a random location and with a random orientation. The time taken by each subject to identify the walking direction was measured, and these times were reliably correlated with visual response times calculated using the RVP model (*8*).

In summary, the RVP model (*8*) is a comprehensive and broadly applicable model of visual performance that has been validated in a number of diverse contexts, and can be taken as a reasonable measure of foveal visibility for luminances ranging from the mesopic range (0.17 cd/m²) to the photopic range (several thousand cd/m²). The RVP model is used in the present analyses to assess the impact of roadway lighting on visual performance for a number of different scenarios described in subsequent sections of this report.

The analyses focus on roadway intersections and highway interchanges, and as described above, several of the scenarios can be applied to highway segments and other roadway facility types as well.

CHAPTER 2
INTERSECTION ANALYSES

A series of visibility calculations were made for a driver approaching a roadway intersection, focusing on targets located in the intersection as well as ones along the roadways and in the surrounding area. The investigations were performed using photometrically accurate lighting software (AGI32, Lighting Analysts) and visibility estimates were based on relative visual performance (*8*). The photometric analysis software chosen has been validated using mock-up installations whereby calculated photometric values for several lighting installations using different luminaires were determined and compared against the corresponding physical measured values obtained under real-world mock-up installations (*20*). The simulated and measured values were highly correlated and consistent in magnitude with each other.

All simulations incorporated vehicle headlights in the modeling because these are significant (and often the only) sources of illumination in any nighttime driving situation, and because sometimes the interaction between vehicle lighting and fixed roadway lighting contributes to reduced visibility relative to either system alone (*7, 21*).

Among the factors that were varied in the simulation studies were:

- Presence of lighting
- Location type (urban or rural)
- Luminaire photometric distribution (e.g., Type II or Type III)
- Target/hazard location and type (e.g., vehicles or pedestrians)
- Target/hazard reflectance
- Light level
- Distance between the observer and the potential target/hazard

Some scenarios were designed to investigate visibility from the perspective of a driver beginning to approach an area such as an intersection, and needing to see potential hazards in and around the intersections, while other scenarios were developed to investigate visibility for a driver in or adjacent to an intersection and needing to see other vehicles or other potentially hazardous objects that might be approaching the intersection.

The data, in general, were consistent with the notion that more continuous types of lighting would be beneficial in terms of visibility in many urban intersections, but that "point" lighting in rural intersections, while likely to improve visibility of pedestrians or other hazards located close to the intersection, will not improve visibility of objects approaching the intersection from further away and would therefore not be expected to have a large safety impact.

As described above, visibility is not synonymous with safety. Nevertheless, the analyses presented here make it possible to refine and validate many assumptions about the impact of fixed lighting on visibility and therefore, improve the decision making process with regard to installation of fixed lighting on roadways as it might affect traffic safety.

The analytical approach taken for intersections can be conveniently divided into two phases. Phase I was focused on characterizing visual performance at a prototypical intersection, with and without lighting of different light levels and different spatial extents. In Phase I, only vehicle-to-object (including vehicle-to-vehicle) collisions were considered. Phase II was conducted to provide refined insights into the visual effectiveness of different types of fixed lighting systems that might be used on roadways. In Phase II, an analysis of vehicle-to-pedestrian incidents, in addition to the vehicle-to-object collisions, was performed using the analytical approach based upon RVP.

PHASE I

The overarching goal of the Phase I analysis was to determine the impacts of roadway lighting FOR different light levels and with different spatial extents on relative visual performance (RVP) values (*8*) for representative intersections modeled using photometrically-correct simulation software. To meet the goal, several scenarios were modeled. A template intersection was constructed using photometrically accurate lighting simulation software (AGI32, Lighting Analysts) to represent the various scenarios tested.

Scenario Development

A *cross* intersection was chosen for all analyses (Figure 5) because any other type of intersection: skew, tee, or wye, as well as public or private intersections, as well as many interchanges, would have similar visual requirements for drivers. Namely, a potential hazard must be seen against its background to determine its position and, if it is moving, its direction and speed.

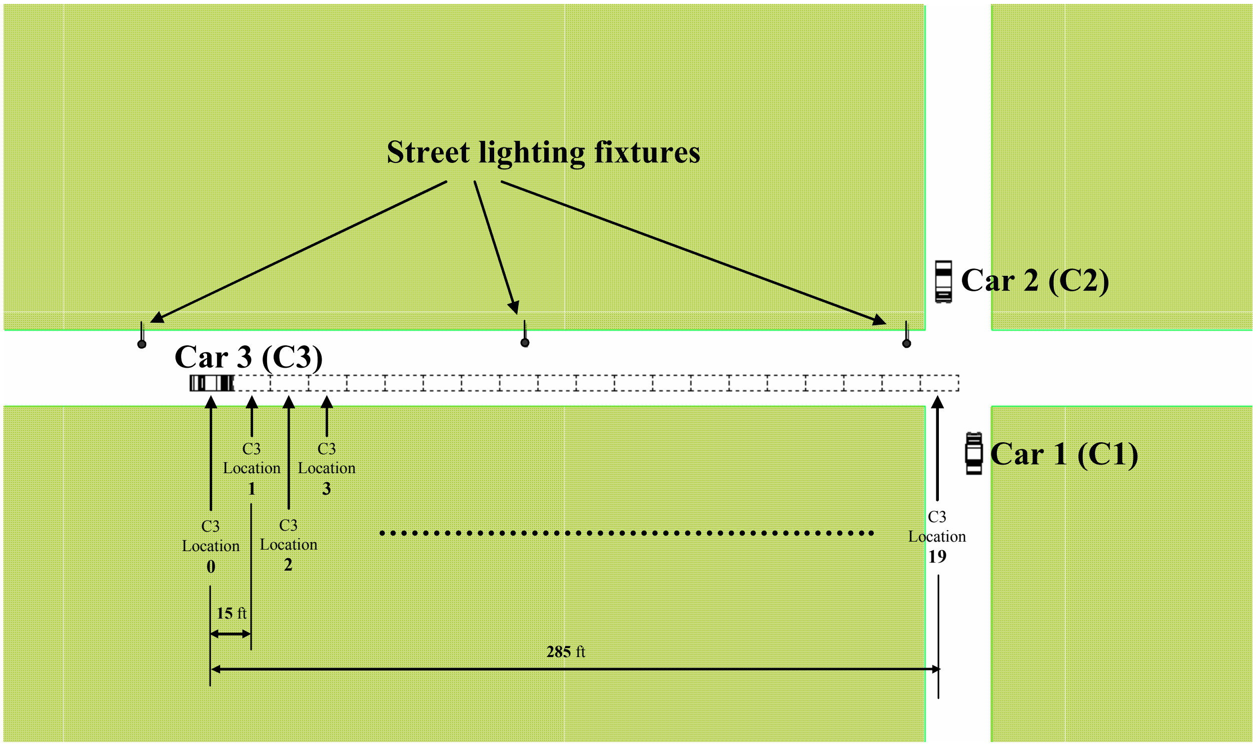


Figure 5. Cross intersection scenario used in analytical modeling.

Three passenger cars, two stopped and facing each other at the intersection (C1 and C2) and one approaching the intersection (C3) were selected for vehicle-to-object analyses (Figure 5); these three passenger car positions cover the possible variations in hazard locations.

To account for differences in the ambient light level such as would be expected between urban and rural locations, four levels of ambient illumination provided to the roadway from private or public electric lighting off the roadway were selected for analyses. These four levels represent the range of ambient illumination levels, simulating high-urban to rural lighting levels, specifically 20, 2, 0.2 and 0.02 lx, corresponding to published measurements made in highly commercially developed, urban, suburban and rural locations, respectively (*22*, see Figure 6).

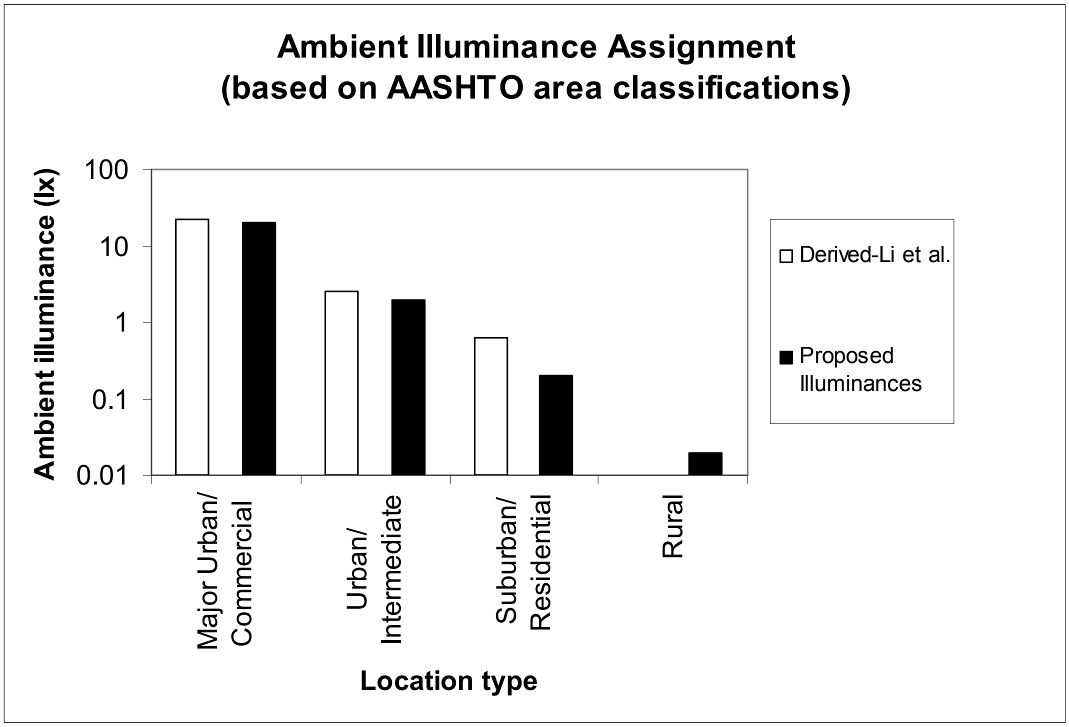


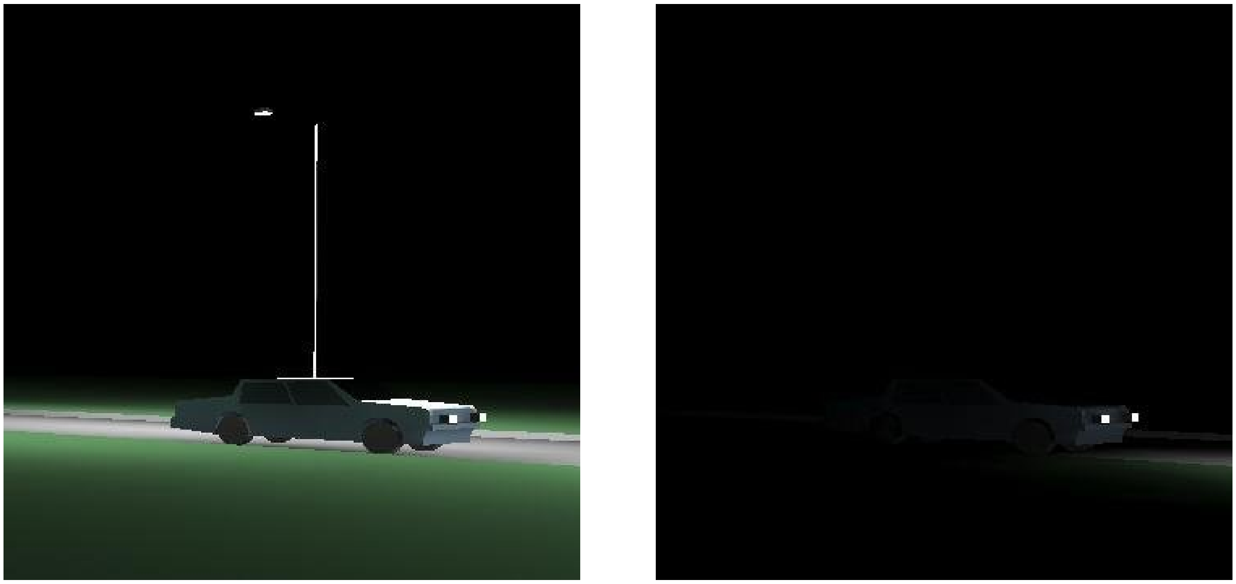
Figure 6. Estimated ambient illumination levels in commercial, intermediate, residential and rural areas, based on measurements by Li et al. (22).

Visual Performance Calculations

Three types of fixed roadway lighting, extended, localized and none, were chosen. Extended lighting refers to an illumination system that might be found if a road leading to the intersection were fitted with continuous lighting. Localized lighting refers to an illumination system consisting of a single pole located close to the intersection. Lighting layouts in the simulation software always followed conventional roadway lighting recommendations (*9, 23*).

The RVP model (*8*) was used to assess visibility. As described previously, RVP provides a valid continuous measure of visibility from response threshold to response saturation.

A key assumption was made for these analyses. It was assumed that passenger car headlights were always on, but the luminances of the headlamps themselves were never part of the RVP calculations except as a glare source (*14, 24*) for another driver. This assumption is predicated on the belief that the car's *context* is important for another driver to see in order to determine that car's relative speed and direction. Logically, if a car's headlamps were the only luminous objects important for assessing driving hazards, then there would never be any vehicle-to-vehicle accidents due to poor visibility, because headlamps would always be highly visible, and fixed lighting would simply be superfluous. It was assumed that the roadway features surrounding a potential hazard, either a vehicle or a fixed object, are essential for visually assessing its position and, if moving, its speed and direction. Headlamps alone, particularly low-beam headlamps (which are used in the majority of driving situations [*25*], even when high beam headlamps would be appropriate), simply cannot provide drivers of other vehicles with this contextual information (although they can make it more difficult to acquire information by creating disability glare [*26-28*]). Again, headlights are highly visible, but alone, they do not provide unambiguous information about a hazard's position and context (*29*). Figure 7 illustrates, through a computer rendering developed using photometrically-accurate lighting simulation software, how a fixed roadway luminaire can illuminate the area surrounding a potential hazard to improve acquisition of important visual information about its position, speed and direction.



a. **b.**

Figure 7. a: Visual information about an approaching vehicle's context is provided by roadway lighting. b: Although vehicle headlamps are inherently highly visible, without roadway lighting, little contextual information is available.

To perform the analyses, a visual target (18 x 18 cm in size, with 50% reflectance, as used in IESNA [*9*] small target visibility calculations) was used in the scenarios. Targets were located adjacent to one of the cars in Figure 5 (C1, C2 or C3) and viewed by a simulated driver of 60, 45 or 30 years of age in one of the other cars. So, as an example of one set of analyses, the visual target adjacent to car C3 might be viewed by a 60-year-old driver in car C1 at a prescribed distance of 45 feet.

Results

Each of the Tables 1 through 3 shows the results of the analyses. Each table corresponds to a different design illuminance range (“low” is defined as 6 lx on the roadway and 10 lx in the intersection; “medium” is defined as 9 lx on the roadway and 15 lx in the intersection; and “high” is defined as 18 lx on the roadway and 30 lx in the intersection). The low, medium and high illuminance ranges correspond to the lowest 33%, the middle 33% and the highest 33% of the illuminances specified by IESNA (*9*) and AASHTO (*23*) in their recommendations for roadway lighting. The lighting installations used high pressure sodium, semi-cutoff luminaires with Type II distributions, and met IESNA (*9*) and AASHTO (*23*) photometric requirements.

Table 1. Results of visual performance modeling (for low roadway illuminances).

Lighting configuration	C3 location	Low street lighting level (6 lux on road, 10 lux at intersection)																																													
		Driver Age=30																Driver Age=45																Driver Age=60															
		Ambient Illuminance = 20 lux				Ambient Illuminance = 2 lux				Ambient Illuminance = 0.2 lux				Ambient Illuminance = 0.02 lux				Ambient Illuminance = 20 lux				Ambient Illuminance = 2 lux				Ambient Illuminance = 0.2 lux				Ambient Illuminance = 0.02 lux				Ambient Illuminance = 20 lux				Ambient Illuminance = 2 lux				Ambient Illuminance = 0.2 lux				Ambient Illuminance = 0.02 lux			
		C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2
Extended	0	0.90	0.91	0.91	0.92	0.37	0.62	0.79	0.80	####	####	0.66	0.67	####	####	0.62	0.64	0.89	0.89	0.90	0.90	0.08	0.49	0.73	0.74	####	####	0.52	0.54	####	####	0.45	0.49	0.84	0.85	0.86	0.87	####	0.07	0.56	0.58	####	####	####	####	####	####	####	####
	1	0.91	0.91	0.92	0.92	0.56	0.64	0.81	0.81	####	####	0.68	0.69	####	####	0.65	0.67	0.89	0.90	0.90	0.91	0.39	0.52	0.75	0.76	####	####	0.56	0.58	####	####	0.50	0.53	0.85	0.86	0.87	0.87	####	0.12	0.60	0.62	####	####	####	0.08	####	####	####	####
	2	0.92	0.92	0.92	0.93	0.72	0.74	0.82	0.82	0.39	0.49	0.71	0.72	0.30	0.42	0.68	0.69	0.90	0.90	0.91	0.91	0.63	0.66	0.77	0.78	0.07	0.24	0.60	0.61	####	0.12	0.55	0.57	0.86	0.87	0.88	0.88	0.36	0.43	0.63	0.65	####	####	0.10	0.20	####	####	####	0.00
	3	0.92	0.93	0.93	0.93	0.81	0.82	0.83	0.83	0.71	0.72	0.73	0.74	0.69	0.71	0.70	0.71	0.91	0.91	0.91	0.92	0.76	0.77	0.78	0.79	0.61	0.63	0.63	0.64	0.58	0.60	0.59	0.61	0.88	0.88	0.88	0.89	0.62	0.64	0.66	0.67	0.24	0.30	0.22	0.30	0.13	0.20	####	0.14
	4	0.93	0.93	0.93	0.93	0.83	0.84	0.84	0.84	0.75	0.77	0.75	0.76	0.74	0.75	0.73	0.73	0.91	0.92	0.92	0.92	0.79	0.80	0.80	0.80	0.67	0.69	0.66	0.67	0.65	0.67	0.62	0.64	0.88	0.89	0.89	0.89	0.67	0.69	0.69	0.70	0.40	0.45	0.32	0.38	0.33	0.38	0.15	0.25
	5	0.93	0.94	0.93	0.94	0.84	0.85	0.85	0.85	0.78	0.79	0.77	0.77	0.76	0.78	0.75	0.75	0.92	0.92	0.92	0.92	0.80	0.82	0.81	0.82	0.71	0.73	0.69	0.70	0.69	0.72	0.66	0.67	0.89	0.90	0.89	0.90	0.70	0.73	0.71	0.72	0.50	0.55	0.40	0.45	0.44	0.51	0.27	0.34
	6	0.94	0.94	0.94	0.94	0.86	0.87	0.86	0.86	0.81	0.83	0.78	0.79	0.80	0.83	0.77	0.77	0.92	0.93	0.93	0.93	0.82	0.84	0.82	0.83	0.76	0.79	0.71	0.72	0.74	0.78	0.69	0.70	0.90	0.90	0.90	0.90	0.74	0.77	0.73	0.74	0.61	0.67	0.47	0.50	0.58	0.65	0.37	0.42
	7	0.94	0.94	0.94	0.94	0.85	0.88	0.87	0.87	0.77	0.85	0.80	0.80	0.75	0.85	0.78	0.79	0.93	0.93	0.93	0.93	0.81	0.86	0.84	0.84	0.70	0.82	0.74	0.74	0.68	0.81	0.71	0.72	0.90	0.91	0.91	0.91	0.71	0.80	0.75	0.76	0.51	0.73	0.53	0.55	0.47	0.72	0.45	0.48
	8	0.94	0.95	0.94	0.95	0.66	0.89	0.88	0.88	0.39	0.85	0.81	0.82	0.57	0.84	0.80	0.80	0.93	0.94	0.93	0.94	0.56	0.86	0.85	0.85	0.13	0.81	0.76	0.76	0.41	0.81	0.74	0.74	0.91	0.92	0.91	0.91	0.26	0.81	0.77	0.78	####	0.72	0.58	0.60	####	0.71	0.52	0.54
	9	0.94	0.95	0.95	0.95	0.72	0.90	0.88	0.89	0.29	0.87	0.83	0.83	0.53	0.86	0.81	0.82	0.93	0.94	0.94	0.94	0.64	0.88	0.86	0.86	####	0.84	0.78	0.78	0.35	0.83	0.76	0.76	0.91	0.92	0.92	0.92	0.41	0.83	0.79	0.80	####	0.76	0.63	0.64	####	0.75	0.58	0.59
	10	0.95	0.95	0.95	0.95	0.79	0.90	0.89	0.89	####	0.86	0.84	0.84	####	0.86	0.83	0.83	0.94	0.94	0.94	0.94	0.74	0.88	0.87	0.87	####	0.83	0.80	0.80	####	0.82	0.78	0.78	0.92	0.92	0.92	0.92	0.59	0.83	0.81	0.81	####	0.75	0.67	0.67	####	0.73	0.62	0.63
	11	0.95	0.95	0.95	0.95	0.84	0.90	0.90	0.90	0.31	0.86	0.85	0.85	####	0.85	0.84	0.84	0.94	0.95	0.94	0.95	0.80	0.88	0.88	0.88	####	0.82	0.81	0.81	####	0.81	0.80	0.80	0.92	0.93	0.93	0.93	0.70	0.83	0.82	0.83	####	0.73	0.70	0.70	####	0.70	0.67	0.67
	12	0.95	0.96	0.96	0.96	0.88	0.91	0.90	0.91	0.82	0.88	0.86	0.86	0.80	0.87	0.85	0.85	0.94	0.95	0.95	0.95	0.86	0.89	0.88	0.89	0.77	0.85	0.83	0.83	0.75	0.84	0.82	0.82	0.93	0.93	0.93	0.93	0.80	0.85	0.84	0.84	0.63	0.78	0.73	0.73	0.58	0.76	0.71	0.71
	13	0.96	0.96	0.96	0.96	0.91	0.92	0.91	0.91	0.89	0.90	0.87	0.87	0.88	0.90	0.87	0.86	0.95	0.95	0.95	0.95	0.89	0.91	0.89	0.89	0.86	0.88	0.84	0.84	0.85	0.88	0.83	0.83	0.93	0.94	0.93	0.94	0.85	0.87	0.85	0.85	0.80	0.83	0.76	0.76	0.78	0.82	0.74	0.74
	14	0.96	0.96	0.96	0.96	0.92	0.93	0.92	0.92	0.90	0.91	0.89	0.88	0.90	0.91	0.88	0.87	0.95	0.96	0.95	0.95	0.91	0.92	0.90	0.90	0.88	0.89	0.86	0.85	0.88	0.89	0.85	0.84	0.94	0.94	0.94	0.94	0.87	0.89	0.86	0.86	0.83	0.85	0.79	0.78	0.83	0.85	0.78	0.76
	15	0.96	0.97	0.96	0.96	0.93	0.93	0.92	0.92	0.91	0.92	0.90	0.89	0.91	0.92	0.89	0.88	0.96	0.96	0.96	0.96	0.92	0.92	0.91	0.91	0.90	0.91	0.87	0.86	0.89	0.90	0.87	0.85	0.94	0.94	0.94	0.94	0.89	0.90	0.88	0.87	0.86	0.87	0.82	0.80	0.85	0.87	0.81	0.78
	16	0.97	0.97	0.97	0.97	0.94	0.94	0.93	0.93	0.93	0.93	0.91	0.90	0.92	0.93	0.90	0.89	0.96	0.96	0.96	0.96	0.93	0.93	0.92	0.91	0.91	0.92	0.89	0.87	0.91	0.92	0.88	0.87	0.95	0.95	0.95	0.95	0.90	0.91	0.89	0.88	0.88	0.89	0.84	0.82	0.88	0.89	0.83	0.80
	17	0.97	0.97	0.97	0.97	0.94	0.95	0.93	0.93	0.91	0.94	0.91	0.90	0.91	0.94	0.91	0.90	0.96	0.96	0.96	0.96	0.93	0.94	0.92	0.92	0.90	0.93	0.90	0.88	0.89	0.93	0.89	0.87	0.95	0.95	0.95	0.95	0.90	0.92	0.90	0.89	0.86	0.91	0.86	0.83	0.84	0.91	0.85	0.82
	18	0.97	0.97	0.97	0.97	0.89	0.96	0.93	0.93	0.94	0.95	0.91	0.91	0.94	0.95	0.91	0.90	0.96	0.97	0.96	0.96	0.86	0.95	0.92	0.92	0.93	0.94	0.90	0.89	0.93	0.94	0.89	0.88	0.95	0.95	0.95	0.95	0.81	0.93	0.90	0.89	0.90	0.93	0.86	0.84	0.91	0.93	0.85	0.83
	19	0.97	0.97	0.97	0.97	0.95	0.96	0.93	0.93	0.94	0.95	0.91	0.91	0.94	0.95	0.91	0.91	0.96	0.97	0.96	0.96	0.94	0.95	0.92	0.92	0.93	0.95	0.90	0.89	0.93	0.95	0.89	0.89	0.95	0.96	0.95	0.95	0.92	0.94	0.90	0.90	0.91	0.93	0.86	0.85	0.91	0.93	0.85	0.84
Localized	0	0.90	0.90	0.91	0.92	0.18	####	0.79	0.80	####	####	0.65	0.67	####	####	0.61	0.64	0.88	0.88	0.90	0.90	####	####	0.73	0.74	####	####	0.50	0.54	####	####	0.42	0.48	0.84	0.84	0.86	0.87	####	####	0.55	0.58	####	####	####	####	####	####	####	####
	1	0.91	0.91	0.92	0.92	0.26	0.19	0.80	0.81	####	####	0.67	0.69	####	####	0.64	0.66	0.89	0.89	0.90	0.91	####	####	0.75	0.76	####	####	0.54	0.57	####	####	0.48	0.52	0.85	0.85	0.87	0.87	####	####	0.59	0.61	####	####	####	0.06	####	####	####	####
	2	0.91	0.91	0.92	0.93	0.34	0.33	0.82	0.82	####	####	0.70	0.71	####	####	0.67	0.69	0.89	0.90	0.91	0.91	####	####	0.76	0.77	####	####	0.58	0.61	####	####	0.53	0.57	0.86	0.86	0.87	0.88	####	####	0.62	0.64	####	####	0.01	0.18	####	####	####	####
	3	0.92	0.92	0.93	0.93	0.41	0.45	0.83	0.83	####	####	0.72	0.73	####	####	0.69	0.71	0.90	0.90	0.91	0.92	0.10	0.18	0.78	0.79	####	####	0.62	0.64	####	####	0.57	0.60	0.86	0.87	0.88	0.89	####	####	0.65	0.67	####	####	0.16	0.28	####	####	####	0.11
	4	0.92	0.93	0.93	0.93	0.48	0.53	0.84	0.84	####	####	0.74	0.75	####	####	0.72	0.73	0.91	0.91	0.92	0.92	0.23	0.32	0.79	0.80	####	####	0.65	0.67	####	####	0.61	0.64	0.87	0.88	0.89	0.89	####	####	0.68	0.70	####	####	0.27	0.37	####	####	0.04	0.23
	5	0.93	0.93	0.94	0.94	0.54	0.61	0.87	0.87	####	####	0.84	0.83	####	####	0.83	0.82	0.91	0.92	0.92	0.93	0.34	0.46	0.84	0.84	####	####	0.80	0.78	####	####	0.79	0.77	0.88	0.89	0.90	0.90	####	####	0.77	0.77	####	####	0.68	0.66	####	####	0.67	0.64
	6	0.93	0.93	0.94	0.94	0.60	0.69	0.86	0.86	####	####	0.78	0.79	####	####	0.76	0.77	0.92	0.92	0.93	0.93	0.44	0.57	0.82	0.83	####	####	0.70	0.72	####	####	0.67	0.69	0.89	0.90	0.90	0.90	####	0.15	0.73	0.74	####	####	0.44	0.50	####	####	0.31	0.41
	7	0.93	0.94	0.94	0.94	0.65	0.76	0.87	0.87	####	####	0.79	0.80	####	####	0.78	0.78	0.92	0.93	0.93	0.93	0.52	0.68	0.83	0.84	####	####	0.73	0.74	####	####	0.70	0.72	0.90	0.90	0.91	0.91	0.01	0.43	0.75	0.76	####	####	0.51	0.55	####	####	0.41	0.47
	8	0.94	0.94	0.94	0.95	0.70	0.81	0.87	0.88	####	####	0.81	0.81	####	####	0.79	0.80	0.93	0.93	0.93	0.94	0.59	0.75	0.84	0.85	####	####	0.75	0.76	####	####	0.73	0.74	0.90	0.91	0.91	0.91	0.20	0.58	0.77	0.78	####	####	0.56	0.59	####	####	0.48	0.53
	9	0.94	0.95	0.95	0.95	0.73	0.83	0.88	0.89	####	####	0.82	0.83	####	####	0.81	0.81	0.93	0.94	0.94	0.94	0.64	0.79	0.86	0.86	####	####	0.77	0.78	####	####	0.75	0.76	0.91	0.92	0.92	0.92	0.34	0.66	0.79	0.80	####	####	0.61	0.63	####	####	0.55	0.58
	10	0.95	0.95	0.95	0.95	0.77	0.85	0.89	0.89	####	####	0.84	0.84	####	####	0.82	0.83	0.94	0.94	0.94	0.94	0.70	0.81	0.87	0.87	####	####	0.79	0.79	####	####	0.77	0.78	0.91	0.92	0.92	0.92	0.47	0.71	0.81	0.81	####	####	0.65	0.67	####	####	0.60	0.62
	11	0.95	0.95	0.95	0.95	0.81	0.87	0.90	0.90	####	0.30	0.85	0.85	####	####	0.84	0.84	0.94	0.94	0.94	0.95	0.76	0.84	0.87	0.88	####	####	0.81	0.81	####	####	0.79	0.80	0.92	0.93	0.93	0.93	0.60	0.75	0.82	0.83	####	####	0.69	0.70	####	####	0.65	0.66
	12	0.95	0.96	0.96	0.96	0.87	0.89	0.90	0.91	0.68	0.78	0.86	0.86	0.58	0.73	0.85	0.85	0.94	0.95	0.95	0.95	0.83	0.87	0.88	0.89	0.52	0.70	0.82	0.83	0.16	0.58	0.81	0.81	0.93	0.93	0.93	0.93	0.75	0.81	0.84	0.84	####	####	0.72	0.73	####	####	0.69	0.70
	13	0.96	0.96	0.96	0.96	0.90	0.91	0.91	0.91	0.85	0.88	0.87	0.87	0.84	0.87	0.86	0.86	0.95	0.95	0.95	0.95	0.88	0.90	0.89	0.89	0.82	0.85	0.84	0.84	0.80	0.83	0.83	0.83	0.93	0.94	0.93	0.94	0.83	0.86	0.85	0.85	0.70	0.76	0.76	0.76	0.66	0.74	0.73	0.73
	14	0.96	0.96	0.96	0.96	0.92	0.93	0.92	0.92	0.89	0.90	0.88	0.88	0.89	0.90	0.88	0.87	0.95	0.96	0.95	0.95	0.90	0.91	0.90	0.90	0.87	0.88	0.86	0.85	0.86	0.88	0.85	0.84	0.94	0.94	0.94	0.94	0.87	0.88	0.86	0.86	0.81	0.84	0.79	0.78	0.80	0.83	0.77	0.75
	15	0.96	0.97	0.96	0.96	0.93	0.93	0.92	0.92	0.91	0.92	0.90	0.89	0.91	0.92	0.89	0.88	0.96	0.96	0.96	0.96	0.92	0.92	0.91	0.91	0.89	0.90	0.87	0.86	0.89	0.90	0.87	0.85	0.94	0.94	0.94	0.94	0.89	0.90	0.88	0.87	0.85	0.87	0.82	0.80	0.85	0.86	0.80	0.78
	16	0.97	0.97	0.97	0.97	0.94	0.94	0.93	0.93	0.93	0.93	0.91	0.90	0.92	0.93	0.90	0.89	0.96	0.96	0.96	0.96	0.93	0.93	0.92	0.91	0.91	0.92	0.89	0.87	0.91	0.92	0.88	0.86	0.95	0.95	0.95	0.95	0.90	0.91	0.89	0.88	0.88	0.89	0.84	0.82	0.88	0.89	0.83	0.80
	17	0.97	0.97	0.97	0.97	0.94	0.95	0.93	0.93	0.91	0.94	0.91	0.90	0.90	0.94	0.91	0.90	0.96	0.96	0.96	0.96	0.93	0.94	0.92	0.92	0.89	0.93	0.90	0.88	0.89	0.93	0.89	0.87	0.95	0.95	0.95	0.95	0.90	0.92	0.90	0.89	0.85	0.91	0.86	0.83	0.84	0.91	0.85	0.82
	18	0.97	0.97	0.97	0.97	0.88	0.96	0.93	0.93	0.94	0.95	0.91	0.91	0.94	0.95	0.91	0.90	0.96	0.97	0.96	0.96	0.86	0.95	0.92	0.92	0.93	0.94	0.90	0.89	0.93	0.94	0.89	0.88	0.95	0.95	0.95	0.95	0.80	0.93	0.90	0.89	0.90	0.93	0.86	0.84	0.91	0.93	0.85	0.83
	19	0.97	0.97	0.97	0.97	0.95	0.96	0.93	0.93	0.94	0.95	0.91	0.91	0.94	0.95	0.91	0.91	0.96	0.97	0.96	0.96	0.94	0.95	0.92	0.92	0.93	0.95	0.89	0.89	0.93	0.95	0.89	0.89	0.95	0.96	0.95	0.95	0.92	0.94	0.90	0.90	0.91	0.93	0.85	0.85	0.91	0.93	0.84	0.84
No light	0	0.90	0.90	0.91	0.92	0.17	####	0.73	0.74	####	####	####	####	####	####	####	####	0.88	0.88	0.90	0.90	####	####	0.64	0.65	####	####	####	####	####	####	####	####	0.84	0.84	0.86	0.86	####	####	0.30	0.35	####	####	####	####	####	####	####	####
	1	0.91	0.91	0.92	0.92	0.25	0.18	0.75	0.76	####	####	####	####	####	####	####	####	0.89	0.89	0.90	0.90	####	####	0.66	0.68	####	####	####	####	####	####	####	####	0.85	0.85	0.86	0.87	####	####	0.37	0.41	####	####	####	####	####	####	####	####
	2	0.91	0.91	0.92	0.92	0.33	0.32	0.76	0.77	####	####	####	####	####	####	####	####	0.89	0.90	0.91	0.91	####	####	0.69	0.70	####	####	####	####	####	####	####	####	0.86	0.86	0.87	0.88	####	####	0.44	0.47	####	####	####	####	####	####	####	####
	3	0.92	0.92	0.93	0.93	0.39	0.44	0.78	0.79	####	####	####	####	####	####	####	####	0.90	0.90	0.91	0.91	0.07	0.16	0.71	0.72	####	####	####	####	####	####	####	####	0.86	0.87	0.88	0.88	####	####	0.49	0.52	####	####	####	####	####	####	####	####
	4	0.92	0.93	0.93	0.93	0.46	0.52	0.79	0.80	####	####	####	####	####	####	####	####	0.91	0.91	0.92	0.92	0.20	0.30	0.73	0.74	####	####	####	####	####	####	####	####	0.87	0.88	0.89	0.89	####	####	0.54	0.56	####	####	####	####	####	####	####	####
	5	0.93	0.93	0.93	0.94	0.53	0.61	0.81	0.81	####	####	####	####	####	####	####	####	0.91	0.92	0.92	0.92	0.32	0.45	0.75	0.76	####	####	####	####	####	####	####	####	0.88	0.89	0.89	0.90	####	####	0.58	0.60	####	####	####	####	####	####	####	####
	6	0.93	0.93	0.94	0.94	0.59	0.68	0.82	0.83	####	####	####	####	####	####	####	####	0.92	0.92	0.92	0.93	0.42	0.56	0.77	0.78	####	####	####	####	####	####	####	####	0.89	0.90	0.90	0.90	####	0.12	0.62	0.64	####	####	####	####	####	####	####	####
	7	0.93	0.94	0.94	0.94	0.64	0.75	0.83	0.84	####	####	####	####	####	####	####	####	0.92	0.93	0.93	0.93	0.50	0.67	0.79	0.79	####	####	####	####	####	####	####	####	0.90	0.90	0.90	0.91	####	0.41	0.66	0.67	####	####	####	####	####	####	####	####
	8	0.94	0.94	0.94	0.95	0.68	0.80	0.84	0.85	####	####	####	####	####	####	####	####	0.93	0.93	0.93	0.93	0.57	0.74	0.80	0.81	####	####	####	####	####	####	####	####	0.90	0.91	0.91	0.91	0.13	0.57	0.69	0.70	####	####	####	####	####	####	####	####
	9	0.94	0.95	0.95	0.95	0.71	0.83	0.86	0.86	####	####	####	####	####	####	####	####	0.93	0.94	0.94	0.94	0.61	0.78	0.82	0.82	####	####	####	####	####	####	####	####	0.91	0.92	0.91	0.92	0.26	0.64	0.72	0.72	####	####	####	####	####	####	####	####
	10	0.95	0.95	0.95	0.95	0.74	0.84	0.86	0.87	####	####	####	0.01	####	####	####	0.13	0.94	0.94	0.94	0.94	0.66	0.80	0.83	0.83	####	####	####	####	####	####	####	####	0.91	0.92	0.92	0.92	0.38	0.69	0.74	0.75	####	####	####	####	####	####	####	####
	11	0.95	0.95	0.95	0.95	0.77	0.86	0.87	0.88	####	####	0.18	0.27	####	####	0.22	0.34	0.94	0.94	0.94	0.94	0.69	0.82	0.84	0.85	####	####	####	####	####	####	####	####	0.92	0.93	0.92	0.93	0.47	0.72	0.77	0.77	####	####	####	####	####	####	####	####
	12	0.95	0.96	0.95	0.96	0.79	0.87	0.88	0.88	####	####	0.37	0.43	####	####	0.40	0.48	0.94	0.95	0.95	0.95	0.73	0.83	0.86	0.86	####	####	####	####	####	####	####	####	0.92	0.93	0.93	0.93	0.55	0.75	0.79	0.79	####	####	####	####	####	####	####	####
	13	0.96	0.96	0.96	0.96	0.82	0.89	0.89	0.89	####	####	0.50	0.54	####	####	0.51	0.57	0.95	0.95	0.95	0.95	0.77	0.86	0.87	0.87	####	####	####	####	####	####	####	####	0.93	0.93	0.93	0.93	0.62	0.79	0.81	0.81	####	####	####	####	####	####	####	####
	14	0.96	0.96	0.96	0.96	0.85	0.90	0.90	0.90	####	0.21	0.65	0.60	####	####	0.60	0.64	0.95	0.95	0.95	0.95	0.81	0.87	0.88	0.88	####	####	####	####	####	####	####	####	0.93	0.94	0.94	0.94	0.71	0.82	0.83	0.82	####	####	####	####	####	####	####	####
	15	0.96	0.96	0.96	0.96	0.88	0.90	0.91	0.90	####	0.55	0.77	0.64	####	####	0.66	0.68	0.95	0.96	0.95	0.96	0.85	0.88	0.89	0.89	####	####	####	####	####	####	####	####	0.94	0.94	0.94	0.94	0.77	0.84	0.85	0.84	####	####	####	####	####	####	####	####
	16	0.96	0.96	0.96	0.96	0.89	0.91	0.92	0.91	####	0.57	0.83	0.69	####	0.28	0.75	0.72	0.96	0.96	0.96	0.96	0.87	0.89	0.90	0.89	####	####	0.76	####	####	####	####	####	0.94	0.94	0.94	0.94	0.81	0.85	0.86	0.85	####	####	####	####	####	####	####	####
	17	0.97	0.97	0.97	0.97	0.91	0.92	0.92	0.91	####	0.81	0.86	0.71	####	0.71	0.83	0.73	0.96	0.96	0.96	0.96	0.89	0.90	0.91	0.90	####	####	0.82	####	####	####	0.72	####	0.95	0.95	0.95	0.95	0.85	0.87	0.87	0.86	####	####	####	####	####	####	####	####
	18	0.97	0.97	0.97	0.97	0.92	0.94	0.92	0.92	0.69	0.92	0.84	0.72	0.62	0.92	0.79	0.74	0.96	0.96	0.96	0.96	0.90	0.93	0.91	0.90	####	0.91	0.79	####	####	0.90	####	####	0.95	0.95	0.95	0.95	0.87	0.90	0.88	0.86	####	0.87	####	####	####	0.87	####	####
	19	0.97	0.97	0.97	0.97	0.94	0.94	0.92	0.92	0.92	0.93	0.74	0.73	0.91	0.92	####	0.74	0.96	0.96	0.96	0.96	0.93	0.93	0.91	0.90	0.90	0.91	####	####	0.90	0.91	####	####	0.95	0.95	0.95	0.95	0.90	0.91	0.87	0.87	0.86	0.89	####	####	0.86	0.88	####	####

Legend
☐ >= 0.90 (RVP score = 3)
🟨 >= 0.80 and < 0.90 (RVP score = 2)
🟧 >= 0.70 and < 0.80 (RVP score = 1)
🟥 < 0.70 (RVP score = 0)

Table 2. Results of visual performance modeling (for medium roadway illuminances).

		Medium street lighting level (9 lux on road, 15 lux at intersection)																																													
		Driver Age=30																Driver Age=45																Driver Age=60															
		Ambient Illuminance = 20 lux				Ambient Illuminance = 2 lux				Ambient Illuminance = 0.2 lux				Ambient Illuminance = 0.02 lux				Ambient Illuminance = 20 lux				Ambient Illuminance = 2 lux				Ambient Illuminance = 0.2 lux				Ambient Illuminance = 0.02 lux				Ambient Illuminance = 20 lux				Ambient Illuminance = 2 lux				Ambient Illuminance = 0.2 lux				Ambient Illuminance = 0.02 lux			
Lighting configuration	C3 location	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2
Extended	0	0.91	0.91	0.92	0.92	0.32	0.70	0.81	0.82	####	0.39	0.73	0.74	####	0.30	0.72	0.73	0.89	0.89	0.90	0.90	0.00	0.61	0.76	0.77	####	0.11	0.64	0.66	####	-0.04	0.62	0.63	0.85	0.85	0.86	0.87	-1.54	0.34	0.62	0.64	####	-1.21	0.33	0.38	####	-2.03	0.25	0.31
	1	0.91	0.91	0.92	0.92	0.61	0.71	0.82	0.83	####	0.38	0.75	0.76	####	0.28	0.74	0.75	0.89	0.90	0.90	0.91	0.48	0.62	0.78	0.78	####	0.08	0.67	0.68	####	-0.10	0.65	0.66	0.85	0.86	0.87	0.87	0.03	0.36	0.65	0.67	####	-1.55	0.40	0.44	####	-2.89	0.33	0.38
	2	0.92	0.92	0.92	0.93	0.77	0.79	0.83	0.84	0.63	0.68	0.77	0.78	0.61	0.66	0.76	0.76	0.90	0.90	0.91	0.91	0.71	0.73	0.79	0.80	0.50	0.57	0.69	0.71	0.45	0.54	0.67	0.69	0.87	0.87	0.88	0.88	0.52	0.57	0.68	0.69	0.01	0.19	0.46	0.49	-0.14	0.10	0.40	0.45
	3	0.93	0.93	0.93	0.93	0.84	0.85	0.84	0.85	0.79	0.80	0.78	0.79	0.78	0.79	0.77	0.78	0.91	0.91	0.91	0.92	0.80	0.81	0.80	0.81	0.73	0.74	0.72	0.73	0.72	0.73	0.70	0.71	0.88	0.88	0.88	0.89	0.70	0.71	0.70	0.71	0.55	0.58	0.51	0.54	0.53	0.55	0.47	0.50
	4	0.93	0.93	0.93	0.93	0.86	0.86	0.85	0.86	0.81	0.82	0.80	0.80	0.81	0.82	0.79	0.79	0.92	0.92	0.92	0.92	0.82	0.83	0.82	0.82	0.76	0.77	0.74	0.75	0.75	0.77	0.72	0.73	0.89	0.89	0.89	0.89	0.73	0.75	0.72	0.73	0.62	0.64	0.56	0.58	0.60	0.62	0.52	0.55
	5	0.93	0.94	0.94	0.94	0.87	0.87	0.86	0.87	0.83	0.84	0.81	0.82	0.83	0.84	0.80	0.81	0.92	0.93	0.92	0.93	0.84	0.85	0.83	0.83	0.79	0.80	0.76	0.76	0.78	0.79	0.74	0.75	0.89	0.90	0.90	0.90	0.76	0.77	0.74	0.75	0.67	0.69	0.60	0.62	0.65	0.68	0.57	0.59
	6	0.94	0.94	0.94	0.94	0.88	0.89	0.87	0.87	0.85	0.87	0.82	0.83	0.85	0.87	0.82	0.82	0.93	0.93	0.93	0.93	0.85	0.87	0.84	0.84	0.82	0.84	0.78	0.78	0.81	0.83	0.76	0.77	0.90	0.91	0.90	0.91	0.79	0.81	0.76	0.77	0.73	0.76	0.64	0.65	0.72	0.75	0.61	0.62
	7	0.94	0.95	0.94	0.94	0.87	0.90	0.88	0.88	0.83	0.88	0.84	0.84	0.83	0.88	0.83	0.83	0.93	0.93	0.93	0.93	0.84	0.88	0.85	0.85	0.79	0.86	0.79	0.80	0.78	0.86	0.78	0.78	0.90	0.91	0.91	0.91	0.77	0.83	0.78	0.79	0.69	0.80	0.67	0.68	0.67	0.79	0.65	0.66
	8	0.94	0.95	0.95	0.95	0.43	0.90	0.89	0.89	0.70	0.88	0.85	0.85	0.75	0.88	0.84	0.84	0.93	0.94	0.93	0.94	0.21	0.88	0.86	0.86	0.61	0.85	0.81	0.81	0.68	0.85	0.80	0.80	0.91	0.92	0.91	0.92	-0.58	0.83	0.80	0.80	0.37	0.79	0.70	0.71	0.49	0.79	0.68	0.68
	9	0.94	0.95	0.95	0.95	0.61	0.91	0.89	0.89	0.67	0.89	0.86	0.86	0.73	0.89	0.85	0.85	0.93	0.94	0.94	0.94	0.48	0.89	0.87	0.87	0.57	0.87	0.82	0.82	0.66	0.87	0.81	0.81	0.91	0.92	0.92	0.92	0.11	0.85	0.81	0.82	0.29	0.82	0.73	0.73	0.45	0.81	0.71	0.71
	10	0.95	0.95	0.95	0.95	0.79	0.91	0.90	0.90	-2.79	0.89	0.87	0.87	0.19	0.89	0.86	0.86	0.94	0.94	0.94	0.94	0.73	0.89	0.88	0.88	####	0.86	0.84	0.84	-0.24	0.86	0.83	0.83	0.92	0.93	0.92	0.92	0.59	0.85	0.83	0.83	####	0.81	0.75	0.75	-3.15	0.80	0.74	0.74
	11	0.95	0.96	0.95	0.96	0.85	0.91	0.91	0.91	0.57	0.88	0.88	0.88	0.40	0.88	0.87	0.87	0.94	0.95	0.94	0.95	0.82	0.89	0.89	0.89	0.42	0.86	0.85	0.85	0.13	0.85	0.84	0.84	0.92	0.93	0.93	0.93	0.74	0.85	0.84	0.84	-0.15	0.79	0.77	0.77	-1.23	0.78	0.76	0.76
	12	0.95	0.96	0.96	0.96	0.90	0.92	0.91	0.91	0.87	0.90	0.89	0.89	0.86	0.90	0.88	0.88	0.95	0.95	0.95	0.95	0.88	0.90	0.89	0.90	0.83	0.88	0.86	0.86	0.83	0.87	0.85	0.85	0.93	0.93	0.93	0.93	0.83	0.87	0.85	0.86	0.75	0.83	0.79	0.79	0.74	0.82	0.78	0.78
	13	0.96	0.96	0.96	0.96	0.92	0.93	0.92	0.92	0.91	0.92	0.89	0.89	0.91	0.91	0.89	0.89	0.95	0.95	0.95	0.95	0.91	0.92	0.90	0.90	0.89	0.90	0.87	0.87	0.89	0.90	0.87	0.86	0.94	0.94	0.94	0.94	0.87	0.89	0.87	0.87	0.84	0.86	0.82	0.81	0.84	0.86	0.81	0.80
	14	0.96	0.96	0.96	0.96	0.93	0.94	0.92	0.92	0.92	0.92	0.90	0.90	0.92	0.92	0.90	0.89	0.95	0.96	0.95	0.95	0.92	0.92	0.91	0.91	0.90	0.91	0.88	0.88	0.90	0.91	0.88	0.87	0.94	0.94	0.94	0.94	0.89	0.90	0.88	0.88	0.87	0.88	0.84	0.83	0.86	0.88	0.83	0.82
	15	0.96	0.97	0.96	0.96	0.94	0.94	0.93	0.93	0.93	0.93	0.91	0.91	0.93	0.93	0.91	0.90	0.96	0.96	0.96	0.96	0.93	0.93	0.92	0.91	0.91	0.92	0.89	0.89	0.91	0.92	0.89	0.88	0.94	0.95	0.94	0.94	0.90	0.91	0.89	0.88	0.89	0.89	0.85	0.84	0.88	0.89	0.85	0.83
	16	0.97	0.97	0.97	0.97	0.94	0.95	0.93	0.93	0.94	0.94	0.92	0.91	0.94	0.94	0.92	0.91	0.96	0.96	0.96	0.96	0.93	0.94	0.92	0.92	0.93	0.93	0.90	0.89	0.92	0.93	0.90	0.89	0.95	0.95	0.95	0.95	0.91	0.92	0.90	0.89	0.90	0.91	0.87	0.85	0.90	0.91	0.87	0.85
	17	0.97	0.97	0.97	0.97	0.94	0.95	0.94	0.93	0.93	0.95	0.93	0.92	0.92	0.95	0.92	0.91	0.96	0.96	0.96	0.96	0.93	0.95	0.93	0.92	0.91	0.94	0.91	0.90	0.91	0.94	0.91	0.90	0.95	0.95	0.95	0.95	0.91	0.93	0.90	0.90	0.88	0.92	0.88	0.86	0.87	0.92	0.88	0.86
	18	0.97	0.97	0.97	0.97	####	0.96	0.94	0.94	0.95	0.96	0.93	0.92	0.95	0.96	0.92	0.92	0.96	0.97	0.96	0.96	####	0.95	0.93	0.92	0.94	0.95	0.91	0.90	0.94	0.95	0.91	0.90	0.95	0.96	0.95	0.95	####	0.94	0.91	0.90	0.92	0.94	0.88	0.87	0.92	0.94	0.88	0.86
	19	0.97	0.97	0.97	0.97	0.96	0.96	0.94	0.94	0.95	0.96	0.92	0.92	0.95	0.96	0.92	0.92	0.97	0.97	0.96	0.96	0.95	0.96	0.93	0.93	0.94	0.95	0.91	0.91	0.94	0.95	0.91	0.91	0.96	0.96	0.95	0.95	0.93	0.94	0.91	0.90	0.92	0.94	0.88	0.88	0.92	0.94	0.88	0.87
Localized	0	0.90	0.90	0.92	0.92	0.19	-0.02	0.81	0.82	####	####	0.73	0.74	####	####	0.71	0.72	0.88	0.88	0.90	0.90	-0.37	-0.86	0.76	0.77	####	####	0.63	0.65	####	####	0.60	0.63	0.84	0.84	0.86	0.87	####	####	0.61	0.64	####	####	0.29	0.37	####	####	0.19	0.30
	1	0.91	0.91	0.92	0.92	0.27	0.20	0.82	0.83	####	####	0.74	0.76	####	####	0.73	0.74	0.89	0.89	0.90	0.91	-0.18	-0.33	0.77	0.78	####	####	0.66	0.68	####	####	0.63	0.66	0.85	0.85	0.87	0.87	####	####	0.64	0.66	####	####	0.36	0.43	####	####	0.29	0.37
	2	0.91	0.91	0.92	0.93	0.35	0.34	0.83	0.84	####	####	0.76	0.77	####	####	0.75	0.76	0.89	0.90	0.91	0.91	-0.02	-0.03	0.79	0.80	####	####	0.68	0.70	####	####	0.66	0.68	0.86	0.86	0.88	0.88	-4.30	-4.43	0.67	0.69	####	####	0.43	0.48	####	####	0.37	0.44
	3	0.92	0.92	0.93	0.93	0.42	0.45	0.84	0.85	####	####	0.78	0.79	####	####	0.77	0.78	0.90	0.90	0.91	0.92	0.11	0.19	0.80	0.81	####	####	0.71	0.72	####	####	0.69	0.71	0.86	0.87	0.88	0.89	-2.34	-1.66	0.70	0.71	####	####	0.49	0.53	####	####	0.43	0.49
	4	0.92	0.93	0.93	0.93	0.48	0.54	0.85	0.86	####	####	0.79	0.80	####	####	0.78	0.79	0.91	0.91	0.92	0.92	0.24	0.33	0.81	0.82	####	####	0.73	0.74	####	####	0.71	0.73	0.87	0.88	0.89	0.89	-1.29	-0.77	0.72	0.73	####	####	0.54	0.57	####	####	0.49	0.54
	5	0.93	0.93	0.94	0.94	0.55	0.62	0.89	0.88	####	####	0.87	0.86	####	####	0.86	0.85	0.91	0.92	0.93	0.93	0.35	0.47	0.86	0.86	####	####	0.83	0.82	####	####	0.83	0.82	0.88	0.89	0.90	0.90	-0.66	-0.18	0.80	0.80	####	####	0.76	0.74	####	####	0.75	0.73
	6	0.93	0.93	0.94	0.94	0.61	0.69	0.87	0.87	####	####	0.82	0.83	####	####	0.81	0.82	0.92	0.92	0.93	0.93	0.45	0.58	0.84	0.84	####	####	0.77	0.78	####	####	0.76	0.77	0.89	0.90	0.90	0.91	-0.24	0.17	0.76	0.77	####	####	0.62	0.64	####	####	0.59	0.62
	7	0.93	0.94	0.94	0.94	0.66	0.76	0.88	0.88	####	####	0.83	0.84	####	####	0.82	0.83	0.92	0.93	0.93	0.93	0.53	0.68	0.85	0.85	####	####	0.79	0.79	####	####	0.77	0.78	0.90	0.90	0.91	0.91	0.04	0.44	0.78	0.79	####	####	0.66	0.67	####	####	0.63	0.65
	8	0.94	0.94	0.95	0.95	0.70	0.81	0.88	0.89	####	####	0.84	0.85	####	####	0.84	0.84	0.93	0.93	0.93	0.94	0.60	0.75	0.86	0.86	####	####	0.80	0.81	####	####	0.79	0.80	0.90	0.91	0.91	0.92	0.23	0.59	0.80	0.80	####	####	0.69	0.70	####	####	0.67	0.68
	9	0.94	0.95	0.95	0.95	0.74	0.83	0.89	0.89	####	####	0.85	0.86	####	####	0.85	0.85	0.93	0.94	0.94	0.94	0.65	0.79	0.87	0.87	####	####	0.82	0.82	####	####	0.81	0.81	0.91	0.92	0.92	0.92	0.37	0.66	0.81	0.82	####	####	0.72	0.73	####	####	0.70	0.71
	10	0.95	0.95	0.95	0.95	0.78	0.85	0.90	0.90	####	####	0.86	0.87	####	####	0.86	0.86	0.94	0.94	0.94	0.94	0.71	0.82	0.88	0.88	####	####	0.83	0.83	####	####	0.82	0.83	0.91	0.92	0.92	0.92	0.50	0.71	0.83	0.83	####	####	0.74	0.75	####	####	0.73	0.73
	11	0.95	0.95	0.95	0.96	0.82	0.87	0.90	0.91	-0.27	0.58	0.87	0.88	####	-2.62	0.87	0.87	0.94	0.94	0.94	0.95	0.78	0.84	0.88	0.89	####	-6.21	0.84	0.85	####	####	0.84	0.84	0.92	0.93	0.93	0.93	0.64	0.77	0.84	0.84	####	####	0.77	0.77	####	####	0.75	0.76
	12	0.95	0.96	0.96	0.96	0.88	0.90	0.91	0.91	0.77	0.83	0.88	0.88	0.74	0.81	0.88	0.88	0.94	0.95	0.95	0.95	0.85	0.88	0.89	0.89	0.70	0.78	0.86	0.86	0.64	0.74	0.85	0.85	0.93	0.93	0.93	0.93	0.78	0.82	0.85	0.85	0.23	0.56	0.79	0.79	####	####	0.78	0.78
	13	0.96	0.96	0.96	0.96	0.91	0.92	0.92	0.92	0.88	0.90	0.89	0.89	0.88	0.89	0.89	0.89	0.95	0.95	0.95	0.95	0.89	0.91	0.90	0.90	0.86	0.87	0.87	0.87	0.85	0.87	0.86	0.86	0.93	0.94	0.94	0.94	0.85	0.87	0.86	0.87	0.79	0.82	0.81	0.81	0.77	0.81	0.80	0.80
	14	0.96	0.96	0.96	0.96	0.93	0.93	0.92	0.92	0.91	0.92	0.90	0.90	0.91	0.92	0.90	0.89	0.95	0.96	0.95	0.95	0.91	0.92	0.91	0.91	0.89	0.90	0.88	0.88	0.89	0.90	0.88	0.87	0.94	0.94	0.94	0.94	0.88	0.89	0.88	0.87	0.85	0.87	0.83	0.82	0.85	0.86	0.82	0.81
	15	0.96	0.97	0.96	0.96	0.94	0.94	0.93	0.93	0.93	0.93	0.91	0.90	0.93	0.93	0.91	0.90	0.96	0.96	0.96	0.96	0.92	0.93	0.92	0.91	0.91	0.92	0.89	0.88	0.91	0.92	0.89	0.88	0.94	0.95	0.94	0.94	0.90	0.91	0.89	0.88	0.88	0.89	0.85	0.84	0.88	0.89	0.85	0.83
	16	0.97	0.97	0.97	0.97	0.94	0.95	0.93	0.93	0.94	0.94	0.92	0.91	0.94	0.94	0.92	0.91	0.96	0.96	0.96	0.96	0.93	0.94	0.92	0.92	0.93	0.93	0.90	0.89	0.92	0.93	0.90	0.89	0.95	0.95	0.95	0.95	0.91	0.92	0.90	0.89	0.90	0.91	0.87	0.85	0.90	0.91	0.86	0.84
	17	0.97	0.97	0.97	0.97	0.94	0.95	0.94	0.93	0.92	0.95	0.92	0.92	0.92	0.95	0.92	0.91	0.96	0.96	0.96	0.96	0.93	0.95	0.93	0.92	0.91	0.94	0.91	0.90	0.91	0.94	0.91	0.89	0.95	0.95	0.95	0.95	0.91	0.93	0.90	0.90	0.88	0.92	0.88	0.86	0.87	0.92	0.88	0.85
	18	0.97	0.97	0.97	0.97	-0.50	0.96	0.94	0.94	0.95	0.96	0.92	0.92	0.95	0.96	0.92	0.92	0.96	0.97	0.96	0.96	-3.01	0.95	0.93	0.92	0.94	0.95	0.91	0.90	0.94	0.95	0.91	0.90	0.95	0.96	0.95	0.95	####	0.94	0.91	0.90	0.92	0.94	0.88	0.87	0.92	0.94	0.88	0.86
	19	0.97	0.97	0.97	0.97	0.96	0.96	0.94	0.94	0.95	0.96	0.92	0.92	0.95	0.96	0.92	0.92	0.97	0.97	0.96	0.96	0.95	0.96	0.93	0.93	0.94	0.95	0.91	0.91	0.94	0.95	0.91	0.90	0.96	0.96	0.95	0.95	0.93	0.94	0.91	0.90	0.92	0.94	0.88	0.88	0.92	0.94	0.87	0.87
No light	0	0.90	0.90	0.91	0.92	0.17	-0.04	0.73	0.74	####	####	####	####	####	####	####	####	0.88	0.88	0.90	0.90	-0.41	-0.93	0.64	0.66	####	####	####	####	####	####	####	####	0.84	0.84	0.86	0.86	####	####	0.31	0.36	####	####	####	####	####	####	####	####
	1	0.91	0.91	0.92	0.92	0.25	0.18	0.75	0.76	####	####	####	####	####	####	####	####	0.89	0.89	0.90	0.90	-0.22	-0.38	0.67	0.68	####	####	####	####	####	####	####	####	0.85	0.85	0.86	0.87	####	####	0.38	0.42	####	####	####	####	####	####	####	####
	2	0.91	0.91	0.92	0.92	0.33	0.32	0.77	0.78	####	####	####	####	####	####	####	####	0.89	0.90	0.91	0.91	-0.06	-0.07	0.69	0.71	####	####	####	####	####	####	####	####	0.86	0.86	0.87	0.88	-5.30	-5.39	0.45	0.48	####	####	####	####	####	####	####	####
	3	0.92	0.92	0.93	0.93	0.39	0.44	0.78	0.79	####	####	####	####	####	####	####	####	0.90	0.90	0.91	0.91	0.07	0.16	0.72	0.73	####	####	####	####	####	####	####	####	0.86	0.87	0.88	0.88	-2.81	-1.93	0.50	0.53	####	####	####	####	####	####	####	####
	4	0.92	0.93	0.93	0.93	0.46	0.52	0.80	0.80	####	####	####	####	####	####	####	####	0.91	0.91	0.92	0.92	0.20	0.30	0.74	0.75	####	####	####	####	####	####	####	####	0.87	0.88	0.89	0.89	-1.54	-0.91	0.55	0.57	####	####	####	####	####	####	####	####
	5	0.93	0.93	0.93	0.94	0.53	0.61	0.81	0.82	####	####	####	####	####	####	####	####	0.91	0.92	0.92	0.92	0.32	0.45	0.76	0.76	####	####	####	####	####	####	####	####	0.88	0.89	0.89	0.90	-0.83	-0.27	0.59	0.61	####	####	####	####	####	####	####	####
	6	0.93	0.93	0.94	0.94	0.59	0.68	0.82	0.83	####	####	####	####	####	####	####	####	0.92	0.92	0.92	0.93	0.42	0.56	0.77	0.78	####	####	####	####	####	####	####	####	0.89	0.90	0.90	0.90	-0.36	0.12	0.63	0.64	####	####	####	####	####	####	####	####
	7	0.93	0.94	0.94	0.94	0.64	0.75	0.84	0.84	####	####	####	####	####	####	####	-5.61	0.92	0.93	0.93	0.93	0.50	0.67	0.79	0.80	####	####	####	####	####	####	####	####	0.90	0.90	0.90	0.91	-0.07	0.41	0.66	0.67	####	####	####	####	####	####	####	####
	8	0.94	0.94	0.94	0.95	0.68	0.80	0.85	0.85	####	####	-3.66	-1.54	####	####	-3.01	-1.13	0.93	0.93	0.93	0.93	0.57	0.74	0.81	0.81	####	####	####	####	####	####	####	####	0.90	0.91	0.91	0.91	0.13	0.57	0.69	0.70	####	####	####	####	####	####	####	####
	9	0.94	0.95	0.95	0.95	0.71	0.83	0.86	0.86	####	####	-0.85	-0.40	####	####	-0.74	-0.25	0.93	0.94	0.94	0.94	0.61	0.78	0.82	0.82	####	####	####	####	####	####	####	####	0.91	0.92	0.91	0.92	0.26	0.64	0.72	0.73	####	####	####	####	####	####	####	####
	10	0.95	0.95	0.95	0.95	0.74	0.84	0.87	0.87	####	####	-0.13	0.05	####	####	-0.09	0.13	0.94	0.94	0.94	0.94	0.66	0.80	0.83	0.84	####	####	####	####	####	####	####	####	0.91	0.92	0.92	0.92	0.38	0.69	0.75	0.75	####	####	####	####	####	####	####	####
	11	0.95	0.95	0.95	0.95	0.77	0.86	0.88	0.88	####	####	0.19	0.30	####	####	0.22	0.35	0.94	0.94	0.94	0.94	0.69	0.82	0.85	0.85	####	####	####	####	####	####	####	####	0.92	0.93	0.92	0.93	0.47	0.72	0.77	0.77	####	####	####	####	####	####	####	####
	12	0.95	0.96	0.95	0.96	0.79	0.87	0.88	0.89	####	####	0.38	0.45	####	####	0.40	0.48	0.94	0.95	0.95	0.95	0.73	0.83	0.86	0.86	####	####	####	####	####	####	####	####	0.92	0.93	0.93	0.93	0.55	0.75	0.79	0.79	####	####	####	####	####	####	####	####
	13	0.96	0.96	0.96	0.96	0.82	0.89	0.89	0.89	####	####	0.62	0.55	####	####	0.52	0.58	0.95	0.95	0.95	0.95	0.77	0.86	0.87	0.87	####	####	####	####	####	####	####	####	0.93	0.93	0.93	0.93	0.62	0.79	0.81	0.81	####	####	####	####	####	####	####	####
	14	0.96	0.96	0.96	0.96	0.85	0.90	0.90	0.90	####	0.21	0.74	0.61	####	####	0.60	0.64	0.95	0.95	0.95	0.95	0.81	0.87	0.88	0.88	####	####	####	####	####	####	####	####	0.93	0.94	0.94	0.94	0.71	0.82	0.83	0.83	####	####	####	####	####	####	####	####
	15	0.96	0.96	0.96	0.96	0.88	0.90	0.91	0.90	####	0.55	0.81	0.65	####	-0.88	0.66	0.68	0.95	0.96	0.96	0.96	0.85	0.88	0.89	0.89	####	####	0.70	####	####	####	####	####	0.94	0.94	0.94	0.94	0.77	0.84	0.85	0.84	####	####	####	####	####	####	####	####
	16	0.96	0.96	0.96	0.96	0.89	0.91	0.92	0.91	####	0.59	0.85	0.70	####	0.46	0.82	0.72	0.96	0.96	0.96	0.96	0.87	0.89	0.90	0.89	####	####	0.81	####	####	####	0.74	####	0.94	0.94	0.94	0.94	0.81	0.85	0.87	0.85	####	####	####	####	####	####	####	####
	17	0.97	0.97	0.97	0.97	0.91	0.92	0.92	0.91	-0.93	0.84	0.88	0.71	####	0.76	0.86	0.73	0.96	0.96	0.96	0.96	0.89	0.90	0.91	0.90	####	0.77	0.85	####	####	####	0.83	####	0.95	0.95	0.95	0.95	0.85	0.87	0.88	0.86	####	####	0.69	####	####	####	####	####
	18	0.97	0.97	0.97	0.97	0.92	0.94	0.92	0.92	0.69	0.93	0.87	0.72	0.66	0.93	0.84	0.74	0.96	0.96	0.96	0.96	0.90	0.93	0.91	0.90	####	0.92	0.83	####	####	0.92	0.78	####	0.95	0.95	0.95	0.95	0.87	0.91	0.88	0.86	####	0.89	####	####	####	0.89	####	####
	19	0.97	0.97	0.97	0.97	0.94	0.95	0.92	0.92	0.93	0.94	0.76	0.73	0.93	0.94	-2.40	0.75	0.96	0.96	0.96	0.96	0.93	0.94	0.91	0.90	0.91	0.93	0.00	####	0.91	0.92	####	####	0.95	0.95	0.95	0.95	0.91	0.92	0.87	0.87	0.89	0.90	####	####	0.88	0.90	####	####

Legend

⬜	>= 0.90	(RVP score = 3)
🟨	>= 0.80 and < 0.90	(RVP score = 2)
🟧	>= 0.70 and < 0.80	(RVP score = 1)
🟥	< 0.70	(RVP score = 0)

Table 3. Results of visual performance modeling (for high roadway illuminances).

Lighting configuration	C3 location	High street lighting level (18 lux on road, 30 lux at intersection)															
		Driver Age=30															
		Ambient Illuminance = 20 lux				Ambient Illuminance = 2 lux				Ambient Illuminance = 0.2 lux				Ambient Illuminance = 0.02 lux			
		C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2
Extended	0	0.91	0.91	0.92	0.92	####	0.80	0.85	0.85	####	0.72	0.82	0.82	0.08	0.71	0.81	0.82
	1	0.91	0.92	0.92	0.93	0.69	0.80	0.86	0.86	####	0.72	0.83	0.83	####	0.71	0.82	0.83
	2	0.92	0.92	0.93	0.93	0.84	0.85	0.87	0.87	0.80	0.82	0.84	0.84	0.80	0.82	0.84	0.84
	3	0.93	0.93	0.93	0.93	0.88	0.89	0.87	0.88	0.86	0.87	0.85	0.85	0.86	0.87	0.85	0.85
	4	0.94	0.94	0.93	0.94	0.89	0.90	0.88	0.88	0.88	0.88	0.86	0.86	0.87	0.88	0.85	0.86
	5	0.94	0.94	0.94	0.94	0.90	0.90	0.89	0.89	0.89	0.89	0.87	0.87	0.88	0.89	0.86	0.87
	6	0.94	0.95	0.94	0.94	0.91	0.92	0.89	0.90	0.90	0.91	0.87	0.88	0.90	0.91	0.87	0.87
	7	0.94	0.95	0.94	0.95	0.90	0.92	0.90	0.90	0.89	0.92	0.88	0.88	0.89	0.92	0.88	0.88
	8	0.94	0.95	0.95	0.95	####	0.92	0.91	0.91	0.86	0.92	0.89	0.89	0.87	0.91	0.89	0.89
	9	0.95	0.95	0.95	0.95	####	0.93	0.91	0.91	0.85	0.92	0.90	0.90	0.86	0.92	0.89	0.89
	10	0.95	0.96	0.95	0.95	0.70	0.93	0.92	0.92	0.61	0.92	0.90	0.90	0.71	0.92	0.90	0.90
	11	0.95	0.96	0.96	0.96	0.88	0.93	0.92	0.92	0.78	0.92	0.91	0.91	0.74	0.91	0.91	0.91
	12	0.96	0.96	0.96	0.96	0.92	0.93	0.93	0.93	0.91	0.93	0.91	0.91	0.91	0.93	0.91	0.91
	13	0.96	0.96	0.96	0.96	0.94	0.94	0.93	0.93	0.93	0.94	0.92	0.92	0.93	0.94	0.92	0.92
	14	0.97	0.97	0.96	0.96	0.94	0.95	0.94	0.93	0.94	0.94	0.93	0.92	0.94	0.94	0.93	0.92
	15	0.97	0.97	0.97	0.97	0.95	0.95	0.94	0.94	0.95	0.95	0.93	0.93	0.95	0.95	0.93	0.93
	16	0.97	0.97	0.97	0.97	0.96	0.96	0.95	0.94	0.95	0.96	0.94	0.93	0.95	0.95	0.94	0.93
	17	0.97	0.97	0.97	0.97	0.95	0.96	0.95	0.94	0.94	0.96	0.94	0.93	0.94	0.96	0.94	0.93
	18	0.97	0.98	0.97	0.97	0.95	0.97	0.95	0.95	0.96	0.97	0.94	0.94	0.96	0.97	0.94	0.94
	19	0.98	0.98	0.97	0.97	0.96	0.97	0.95	0.95	0.96	0.97	0.94	0.94	0.96	0.97	0.94	0.94
Localized	0	0.90	0.90	0.92	0.92	0.20	0.01	0.85	0.85	####	####	0.81	0.82	####	####	0.81	0.82
	1	0.91	0.91	0.92	0.93	0.29	0.22	0.85	0.86	####	####	0.82	0.83	####	####	0.82	0.83
	2	0.91	0.92	0.93	0.93	0.37	0.36	0.86	0.87	####	####	0.83	0.84	####	####	0.83	0.84
	3	0.92	0.92	0.93	0.93	0.44	0.47	0.87	0.87	####	####	0.84	0.85	####	####	0.84	0.85
	4	0.92	0.93	0.93	0.94	0.50	0.55	0.88	0.88	####	####	0.85	0.86	####	####	0.85	0.86
	5	0.93	0.93	0.94	0.94	0.57	0.63	0.91	0.91	####	####	0.90	0.90	####	####	0.90	0.89
	6	0.93	0.93	0.94	0.94	0.63	0.70	0.89	0.89	####	####	0.87	0.88	####	####	0.87	0.87
	7	0.93	0.94	0.94	0.95	0.68	0.77	0.90	0.90	####	####	0.88	0.88	####	####	0.88	0.88
	8	0.94	0.94	0.95	0.95	0.72	0.81	0.90	0.91	####	####	0.89	0.89	####	####	0.88	0.89
	9	0.94	0.95	0.95	0.95	0.76	0.84	0.91	0.91	####	####	0.89	0.90	####	####	0.89	0.89
	10	0.95	0.95	0.95	0.95	0.80	0.86	0.92	0.92	####	0.28	0.90	0.90	####	####	0.90	0.90
	11	0.95	0.95	0.96	0.96	0.85	0.88	0.92	0.92	0.60	0.75	0.91	0.91	0.44	0.69	0.91	0.91
	12	0.95	0.96	0.96	0.96	0.90	0.91	0.93	0.93	0.86	0.88	0.91	0.91	0.85	0.87	0.91	0.91
	13	0.96	0.96	0.96	0.96	0.93	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.91	0.92	0.92	0.92
	14	0.96	0.97	0.96	0.96	0.94	0.94	0.94	0.93	0.93	0.94	0.93	0.92	0.93	0.94	0.92	0.92
	15	0.97	0.97	0.97	0.97	0.95	0.95	0.94	0.94	0.94	0.95	0.93	0.93	0.94	0.95	0.93	0.93
	16	0.97	0.97	0.97	0.97	0.96	0.96	0.94	0.94	0.95	0.95	0.94	0.93	0.95	0.95	0.94	0.93
	17	0.97	0.97	0.97	0.97	0.95	0.96	0.95	0.94	0.94	0.96	0.94	0.93	0.94	0.96	0.94	0.93
	18	0.97	0.98	0.97	0.97	0.95	0.97	0.95	0.95	0.96	0.97	0.94	0.94	0.96	0.97	0.94	0.94
	19	0.98	0.98	0.97	0.97	0.96	0.97	0.95	0.95	0.96	0.97	0.94	0.94	0.96	0.97	0.94	0.94
No light	0	0.90	0.90	0.91	0.92	0.17	####	0.74	0.75	####	####	####	####	####	####	####	####
	1	0.91	0.91	0.92	0.92	0.25	0.18	0.76	0.77	####	####	####	####	####	####	####	####
	2	0.91	0.91	0.92	0.92	0.33	0.32	0.77	0.78	####	####	####	####	####	####	####	####
	3	0.92	0.92	0.93	0.93	0.39	0.44	0.79	0.80	####	####	####	####	####	####	####	####
	4	0.92	0.93	0.93	0.93	0.46	0.52	0.80	0.81	####	####	####	####	####	####	####	####
	5	0.93	0.93	0.93	0.94	0.53	0.61	0.82	0.82	####	####	####	####	####	####	####	####
	6	0.93	0.93	0.94	0.94	0.59	0.68	0.83	0.83	####	####	####	####	####	####	####	####
	7	0.93	0.94	0.94	0.94	0.64	0.75	0.84	0.84	####	####	####	####	####	####	####	####
	8	0.94	0.94	0.94	0.95	0.68	0.80	0.85	0.85	####	####	####	####	####	####	####	####
	9	0.94	0.95	0.95	0.95	0.71	0.83	0.86	0.86	####	####	####	####	####	####	####	####
	10	0.95	0.95	0.95	0.95	0.74	0.84	0.87	0.87	####	####	####	0.09	####	####	####	0.14
	11	0.95	0.95	0.95	0.95	0.77	0.86	0.88	0.88	####	####	0.54	0.32	####	####	0.22	0.35
	12	0.95	0.96	0.96	0.96	0.79	0.87	0.89	0.89	####	####	0.67	0.46	####	####	0.40	0.48
	13	0.96	0.96	0.96	0.96	0.82	0.89	0.90	0.89	####	####	0.75	0.56	####	####	0.52	0.58
	14	0.96	0.96	0.96	0.96	0.85	0.90	0.91	0.90	####	0.24	0.81	0.62	####	####	0.74	0.64
	15	0.96	0.96	0.96	0.96	0.88	0.90	0.92	0.91	####	0.56	0.86	0.66	####	0.05	0.83	0.68
	16	0.96	0.96	0.97	0.96	0.89	0.91	0.92	0.91	####	0.63	0.89	0.70	####	0.60	0.88	0.72
	17	0.97	0.97	0.97	0.97	0.91	0.92	0.93	0.91	####	0.88	0.91	0.71	####	0.86	0.90	0.74
	18	0.97	0.97	0.97	0.97	0.92	0.95	0.93	0.92	0.76	0.95	0.90	0.73	0.70	0.95	0.89	0.75
	19	0.97	0.97	0.97	0.97	0.95	0.96	0.92	0.92	0.94	0.95	0.71	0.73	0.94	0.95	0.79	0.75

Lighting configuration	C3 location	High street lighting level (18 lux on road, 30 lux at intersection)															
		Driver Age=45															
		Ambient Illuminance = 20 lux				Ambient Illuminance = 2 lux				Ambient Illuminance = 0.2 lux				Ambient Illuminance = 0.02 lux			
		C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2
Extended	0	0.89	0.90	0.90	0.91	####	0.75	0.81	0.82	####	0.65	0.77	0.77	####	0.63	0.76	0.77
	1	0.90	0.90	0.91	0.91	0.60	0.75	0.82	0.83	####	0.64	0.78	0.79	####	0.62	0.78	0.78
	2	0.91	0.91	0.91	0.92	0.80	0.82	0.83	0.84	0.75	0.78	0.80	0.80	0.74	0.77	0.79	0.80
	3	0.92	0.92	0.92	0.92	0.85	0.86	0.84	0.85	0.83	0.84	0.81	0.82	0.83	0.84	0.81	0.81
	4	0.92	0.93	0.92	0.92	0.87	0.87	0.85	0.86	0.85	0.85	0.82	0.83	0.85	0.85	0.82	0.82
	5	0.93	0.93	0.93	0.93	0.88	0.88	0.86	0.86	0.86	0.87	0.83	0.84	0.86	0.87	0.83	0.83
	6	0.93	0.94	0.93	0.93	0.89	0.90	0.87	0.87	0.88	0.89	0.85	0.85	0.88	0.89	0.84	0.84
	7	0.93	0.94	0.93	0.94	0.89	0.91	0.88	0.88	0.87	0.90	0.86	0.86	0.87	0.90	0.85	0.85
	8	0.93	0.94	0.94	0.94	####	0.91	0.89	0.89	0.83	0.90	0.86	0.87	0.84	0.90	0.86	0.86
	9	0.94	0.95	0.94	0.94	####	0.91	0.89	0.89	0.82	0.91	0.87	0.87	0.83	0.91	0.87	0.87
	10	0.94	0.95	0.94	0.95	0.62	0.91	0.90	0.90	0.49	0.90	0.88	0.88	0.63	0.90	0.88	0.88
	11	0.94	0.95	0.95	0.95	0.85	0.91	0.91	0.91	0.72	0.90	0.89	0.89	0.68	0.90	0.89	0.89
	12	0.95	0.95	0.95	0.95	0.91	0.92	0.91	0.91	0.89	0.91	0.90	0.90	0.89	0.91	0.90	0.89
	13	0.95	0.96	0.95	0.95	0.93	0.93	0.92	0.92	0.92	0.93	0.90	0.90	0.92	0.92	0.90	0.90
	14	0.96	0.96	0.96	0.96	0.93	0.94	0.92	0.92	0.93	0.93	0.91	0.91	0.93	0.93	0.91	0.91
	15	0.96	0.96	0.96	0.96	0.94	0.94	0.93	0.93	0.94	0.94	0.92	0.91	0.94	0.94	0.92	0.91
	16	0.96	0.96	0.96	0.96	0.95	0.95	0.94	0.93	0.94	0.95	0.93	0.92	0.94	0.95	0.93	0.92
	17	0.97	0.97	0.96	0.96	0.94	0.96	0.94	0.93	0.93	0.95	0.93	0.92	0.93	0.95	0.93	0.92
	18	0.97	0.97	0.96	0.96	0.94	0.96	0.94	0.94	0.95	0.96	0.93	0.93	0.95	0.96	0.93	0.93
	19	0.97	0.97	0.96	0.96	0.96	0.97	0.94	0.94	0.96	0.96	0.93	0.93	0.95	0.96	0.93	0.93
Localized	0	0.88	0.88	0.90	0.91	####	####	0.81	0.81	####	####	0.76	0.77	####	####	0.75	0.77
	1	0.89	0.89	0.91	0.91	####	####	0.82	0.83	####	####	0.78	0.79	####	####	0.77	0.78
	2	0.90	0.90	0.91	0.91	0.02	0.00	0.83	0.84	####	####	0.79	0.80	####	####	0.79	0.80
	3	0.90	0.90	0.92	0.92	0.15	0.22	0.84	0.85	####	####	0.81	0.81	####	####	0.80	0.81
	4	0.91	0.91	0.92	0.92	0.27	0.35	0.85	0.86	####	####	0.82	0.82	####	####	0.81	0.82
	5	0.91	0.92	0.93	0.93	0.38	0.49	0.89	0.89	####	####	0.88	0.87	####	####	0.88	0.87
	6	0.92	0.92	0.93	0.93	0.48	0.59	0.87	0.87	####	####	0.84	0.85	####	####	0.84	0.84
	7	0.92	0.93	0.93	0.94	0.56	0.70	0.88	0.88	####	####	0.85	0.86	####	####	0.85	0.85
	8	0.93	0.93	0.94	0.94	0.63	0.76	0.88	0.89	####	####	0.86	0.86	####	####	0.86	0.86
	9	0.93	0.94	0.94	0.94	0.68	0.80	0.89	0.89	####	####	0.87	0.87	####	####	0.87	0.87
	10	0.94	0.94	0.94	0.95	0.74	0.82	0.90	0.90	####	####	0.88	0.88	####	####	0.88	0.88
	11	0.94	0.94	0.95	0.95	0.81	0.86	0.90	0.91	0.36	0.65	0.89	0.89	####	0.45	0.88	0.89
	12	0.95	0.95	0.95	0.95	0.88	0.89	0.91	0.91	0.82	0.85	0.90	0.90	0.81	0.84	0.89	0.89
	13	0.95	0.95	0.95	0.95	0.91	0.92	0.92	0.92	0.90	0.91	0.90	0.90	0.90	0.90	0.90	0.90
	14	0.96	0.96	0.96	0.96	0.93	0.93	0.92	0.92	0.92	0.93	0.91	0.91	0.92	0.92	0.91	0.91
	15	0.96	0.96	0.96	0.96	0.94	0.94	0.93	0.93	0.93	0.94	0.92	0.91	0.93	0.94	0.92	0.91
	16	0.96	0.96	0.96	0.96	0.95	0.95	0.93	0.93	0.94	0.95	0.93	0.92	0.94	0.95	0.93	0.92
	17	0.97	0.97	0.96	0.96	0.94	0.96	0.94	0.93	0.93	0.95	0.93	0.92	0.93	0.95	0.93	0.92
	18	0.97	0.97	0.96	0.96	0.94	0.96	0.94	0.94	0.95	0.96	0.93	0.93	0.96	0.96	0.93	0.92
	19	0.97	0.97	0.96	0.96	0.96	0.97	0.94	0.94	0.95	0.96	0.93	0.93	0.95	0.96	0.93	0.93
No light	0	0.88	0.88	0.90	0.90	####	####	0.65	0.67	####	####	####	####	####	####	####	####
	1	0.89	0.89	0.90	0.91	####	####	0.68	0.69	####	####	####	####	####	####	####	####
	2	0.89	0.90	0.91	0.91	####	####	0.70	0.71	####	####	####	####	####	####	####	####
	3	0.90	0.90	0.91	0.91	0.07	0.16	0.72	0.73	####	####	####	####	####	####	####	####
	4	0.91	0.91	0.92	0.92	0.20	0.30	0.74	0.75	####	####	####	####	####	####	####	####
	5	0.91	0.92	0.92	0.92	0.32	0.45	0.76	0.77	####	####	####	####	####	####	####	####
	6	0.92	0.92	0.92	0.93	0.42	0.56	0.78	0.79	####	####	####	####	####	####	####	####
	7	0.92	0.93	0.93	0.93	0.50	0.67	0.80	0.80	####	####	####	####	####	####	####	####
	8	0.93	0.93	0.93	0.93	0.57	0.74	0.81	0.81	####	####	####	####	####	####	####	####
	9	0.93	0.94	0.94	0.94	0.61	0.78	0.83	0.83	####	####	####	####	####	####	####	####
	10	0.94	0.94	0.94	0.94	0.66	0.80	0.84	0.84	####	####	####	####	####	####	####	####
	11	0.94	0.94	0.94	0.94	0.69	0.82	0.85	0.85	####	####	####	####	####	####	####	####
	12	0.94	0.95	0.95	0.95	0.73	0.83	0.86	0.86	####	####	####	####	####	####	####	####
	13	0.95	0.95	0.95	0.95	0.77	0.86	0.88	0.87	####	####	0.51	####	####	####	####	####
	14	0.95	0.95	0.95	0.95	0.81	0.87	0.89	0.88	####	####	0.73	####	####	####	####	####
	15	0.95	0.96	0.96	0.96	0.85	0.88	0.90	0.89	####	####	0.82	####	####	####	0.78	####
	16	0.96	0.96	0.96	0.96	0.87	0.89	0.91	0.89	####	####	0.86	####	####	####	0.85	####
	17	0.96	0.96	0.96	0.96	0.89	0.91	0.92	0.90	####	0.84	0.89	####	####	0.82	0.88	####
	18	0.96	0.96	0.96	0.96	0.90	0.94	0.92	0.90	####	0.94	0.87	####	####	0.94	0.86	####
	19	0.96	0.97	0.96	0.96	0.94	0.95	0.91	0.90	0.93	0.94	0.53	####	0.93	0.94	0.64	####

Lighting configuration	C3 location	High street lighting level (18 lux on road, 30 lux at intersection)															
		Driver Age=60															
		Ambient Illuminance = 20 lux				Ambient Illuminance = 2 lux				Ambient Illuminance = 0.2 lux				Ambient Illuminance = 0.02 lux			
		C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2	C1 look at C3	C2 look at C3	C3 look at C1	C3 look at C2
Extended	0	0.85	0.86	0.87	0.87	####	0.62	0.72	0.73	####	0.43	0.63	0.65	####	0.40	0.62	0.64
	1	0.86	0.87	0.87	0.88	0.35	0.62	0.74	0.74	####	0.42	0.66	0.68	####	0.38	0.65	0.67
	2	0.87	0.88	0.88	0.89	0.70	0.73	0.75	0.76	0.61	0.66	0.69	0.70	0.60	0.65	0.68	0.69
	3	0.89	0.89	0.89	0.89	0.79	0.80	0.77	0.78	0.75	0.76	0.71	0.72	0.75	0.76	0.70	0.71
	4	0.90	0.90	0.89	0.90	0.81	0.82	0.79	0.79	0.78	0.79	0.73	0.74	0.77	0.79	0.73	0.73
	5	0.90	0.91	0.90	0.90	0.83	0.84	0.80	0.81	0.80	0.81	0.75	0.76	0.80	0.81	0.75	0.75
	6	0.91	0.91	0.91	0.91	0.85	0.86	0.82	0.82	0.83	0.84	0.77	0.78	0.83	0.84	0.77	0.77
	7	0.91	0.92	0.91	0.91	0.84	0.88	0.83	0.83	0.82	0.87	0.79	0.79	0.82	0.86	0.78	0.79
	8	0.91	0.92	0.92	0.92	####	0.88	0.84	0.84	0.76	0.86	0.81	0.81	0.77	0.86	0.80	0.80
	9	0.91	0.93	0.92	0.92	####	0.89	0.85	0.85	0.75	0.87	0.82	0.82	0.77	0.87	0.82	0.82
	10	0.92	0.93	0.93	0.93	0.42	0.88	0.86	0.86	0.15	0.87	0.83	0.83	0.41	0.87	0.83	0.83
	11	0.93	0.93	0.93	0.93	0.80	0.88	0.87	0.87	0.57	0.86	0.85	0.85	0.49	0.86	0.84	0.84
	12	0.93	0.94	0.93	0.94	0.88	0.89	0.88	0.88	0.85	0.88	0.86	0.86	0.85	0.88	0.86	0.85
	13	0.94	0.94	0.94	0.94	0.90	0.91	0.89	0.89	0.89	0.90	0.87	0.87	0.89	0.90	0.87	0.86
	14	0.94	0.95	0.94	0.94	0.91	0.92	0.90	0.90	0.91	0.91	0.88	0.88	0.90	0.91	0.88	0.87
	15	0.95	0.95	0.95	0.95	0.92	0.93	0.91	0.90	0.92	0.92	0.89	0.88	0.92	0.92	0.89	0.88
	16	0.95	0.95	0.95	0.95	0.93	0.93	0.92	0.91	0.93	0.93	0.90	0.89	0.93	0.93	0.90	0.89
	17	0.95	0.96	0.95	0.95	0.92	0.94	0.92	0.91	0.91	0.94	0.91	0.90	0.91	0.94	0.91	0.90
	18	0.95	0.96	0.95	0.95	0.92	0.95	0.92	0.92	0.94	0.95	0.91	0.90	0.94	0.95	0.91	0.90
	19	0.96	0.96	0.95	0.95	0.94	0.95	0.92	0.92	0.94	0.95	0.91	0.91	0.94	0.95	0.91	0.91
Localized	0	0.84	0.84	0.87	0.87	####	####	0.71	0.72	####	####	0.62	0.65	####	####	0.61	0.63
	1	0.85	0.85	0.87	0.88	####	####	0.73	0.74	####	####	0.65	0.67	####	####	0.64	0.66
	2	0.86	0.86	0.88	0.89	####	####	0.75	0.76	####	####	0.68	0.70	####	####	0.67	0.69
	3	0.87	0.87	0.89	0.89	####	####	0.77	0.78	####	####	0.70	0.72	####	####	0.69	0.71
	4	0.87	0.88	0.89	0.90	####	####	0.78	0.79	####	####	0.73	0.74	####	####	0.72	0.73
	5	0.88	0.89	0.91	0.91	####	####	0.85	0.84	####	####	0.83	0.82	####	####	0.83	0.82
	6	0.89	0.90	0.91	0.91	####	0.21	0.81	0.82	####	####	0.77	0.78	####	####	0.76	0.77
	7	0.90	0.90	0.91	0.91	0.12	0.47	0.83	0.83	####	####	0.78	0.79	####	####	0.78	0.78
	8	0.90	0.91	0.92	0.92	0.31	0.60	0.84	0.84	####	####	0.80	0.81	####	####	0.79	0.80
	9	0.91	0.92	0.92	0.92	0.44	0.68	0.85	0.85	####	####	0.82	0.82	####	####	0.81	0.81
	10	0.91	0.92	0.93	0.93	0.58	0.73	0.86	0.86	####	####	0.83	0.83	####	####	0.83	0.83
	11	0.92	0.93	0.93	0.93	0.71	0.79	0.87	0.87	####	####	0.84	0.84	####	####	0.84	0.84
	12	0.93	0.93	0.93	0.94	0.83	0.85	0.88	0.88	0.73	0.78	0.86	0.86	0.71	0.76	0.85	0.85
	13	0.94	0.94	0.94	0.94	0.89	0.89	0.89	0.89	0.86	0.87	0.87	0.87	0.86	0.87	0.86	0.86
	14	0.94	0.95	0.94	0.94	0.91	0.91	0.90	0.90	0.90	0.90	0.88	0.88	0.89	0.90	0.88	0.87
	15	0.95	0.95	0.95	0.95	0.92	0.92	0.91	0.90	0.91	0.92	0.89	0.88	0.91	0.92	0.89	0.88
	16	0.95	0.95	0.95	0.95	0.93	0.93	0.91	0.91	0.93	0.93	0.90	0.89	0.93	0.93	0.90	0.89
	17	0.95	0.96	0.95	0.95	0.92	0.94	0.92	0.91	0.91	0.94	0.91	0.90	0.91	0.94	0.91	0.90
	18	0.95	0.96	0.95	0.95	0.92	0.95	0.92	0.92	0.94	0.95	0.91	0.90	0.94	0.95	0.91	0.90
	19	0.96	0.96	0.95	0.95	0.94	0.95	0.92	0.92	0.94	0.95	0.91	0.91	0.94	0.95	0.91	0.91
No light	0	0.84	0.84	0.86	0.86	####	####	0.34	0.38	####	####	####	####	####	####	####	####
	1	0.85	0.85	0.87	0.87	####	####	0.41	0.44	####	####	####	####	####	####	####	####
	2	0.86	0.86	0.87	0.88	####	####	0.47	0.50	####	####	####	####	####	####	####	####
	3	0.86	0.87	0.88	0.88	####	####	0.52	0.54	####	####	####	####	####	####	####	####
	4	0.87	0.88	0.89	0.89	####	####	0.57	0.58	####	####	####	####	####	####	####	####
	5	0.88	0.89	0.89	0.90	####	####	0.61	0.62	####	####	####	####	####	####	####	####
	6	0.89	0.90	0.90	0.90	####	0.12	0.64	0.65	####	####	####	####	####	####	####	####
	7	0.90	0.90	0.90	0.91	####	0.41	0.68	0.68	####	####	####	####	####	####	####	####
	8	0.90	0.91	0.91	0.91	0.13	0.57	0.71	0.71	####	####	####	####	####	####	####	####
	9	0.91	0.92	0.92	0.92	0.26	0.64	0.73	0.73	####	####	####	####	####	####	####	####
	10	0.91	0.92	0.92	0.92	0.38	0.69	0.76	0.76	####	####	####	####	####	####	####	####
	11	0.92	0.93	0.92	0.93	0.47	0.72	0.78	0.78	####	####	####	####	####	####	####	####
	12	0.92	0.93	0.93	0.93	0.55	0.75	0.80	0.80	####	####	####	####	####	####	####	####
	13	0.93	0.93	0.93	0.94	0.62	0.79	0.82	0.81	####	####	####	####	####	####	####	####
	14	0.93	0.94	0.94	0.94	0.71	0.82	0.84	0.83	####	####	####	####	####	####	####	####
	15	0.94	0.94	0.94	0.94	0.77	0.84	0.86	0.84	####	####	####	####	####	####	####	####
	16	0.94	0.94	0.95	0.94	0.81	0.85	0.88	0.85	####	####	0.79	####	####	####	0.75	####
	17	0.95	0.95	0.95	0.95	0.85	0.88	0.89	0.86	####	0.58	0.84	####	####	####	0.83	####
	18	0.95	0.95	0.95	0.95	0.87	0.93	0.89	0.86	####	0.92	0.81	####	####	0.92	0.78	####
	19	0.95	0.96	0.95	0.95	0.92	0.93	0.88	0.87	0.91	0.93	####	####	0.91	0.93	####	####

Legend		
☐	>= 0.90	(RVP score = 3)
🟨	>= 0.80 and < 0.90	(RVP score = 2)
🟧	>= 0.70 and < 0.80	(RVP score = 1)
🟥	< 0.70	(RVP score = 0)

Tables 1 through 3 are each composed of a matrix of twelve, 4 x 20 tables. Each table row is the 15-ft incremental distance of car C3 from a point 300 ft from the intersection (C3 location "0") to a point in the intersection (C3 location "19") where cars C1 and C2 are stopped (Figure 5). Each table column defines the viewing relationship between two cars; the first car in the column designation is the position of the viewer and the second designation is the car adjacent to the object being viewed. For example, the designation "C1 > C3" corresponds to the driver in car C1 viewing the visual target next to car C3. For the two conditions "C1 > C3" and "C2 > C3," low beam headlamps (halogen headlamps from a common import passenger car) on car C3 are assumed to produce contrast-reducing disability glare to the observers at locations C1 and C2 (*14, 24*).

Within each of Tables 1 through 3, each row of 4 x 20 tables corresponds to a different type of lighting: either *extended* lighting with luminaires located along the roadway approaching the intersection out to 300 ft from the intersection, *localized* lighting in which a single luminaire illuminates only the intersection conflict area, or *no* roadway lighting in which all illumination is assumed to come from vehicle headlamps (and the specified ambient illumination level between 0.02 and 20 lx associated with the type of location from rural to very urban).

Entries in the cells of every table are the RVP values determined for a specific driver age (30, 45 or 60 years) viewing the specified visual target adjacent to the car being viewed (when RVP calculations indicate that an object is below the detection threshold, the cells contain the characters "###"). As described previously, visual performance, or the speed and accuracy of processing visual information, exhibits a "plateau and escarpment" characteristic (*8*). That is, above threshold (the break-point between seeing and not seeing an object), there is a rapid rise in visual performance (escarpment) to a level that is relatively constant (plateau). Practically speaking then, RVP values on or near the escarpment should be avoided whereas those on the plateau ensure high levels of visual performance. To help illustrate the "plateau and escarpment" nature of RVP, cells in Tables 1 through 3 are color coded. Cells highlighted in red correspond to RVP values on the "escarpment" (with values less than 0.70), including objects below threshold; orange cells correspond to RVP values between 0.70 and 0.799; yellow cells correspond to values from 0.80 to 0.899; and cells not highlighted correspond to values on the "plateau" with RVP values above 0.90.

As can be seen in Table 2, for example, there are no red cells and very few orange cells at the highest ambient illumination levels (20 and 2 lx); only at lower ambient levels do RVP values drop to levels of concern. This suggests that ambient illumination from urban and suburban environments help considerably with visual performance. Extended lighting from fixed roadway lighting also improves visual performance, particularly some distance away from the intersection (C3 locations 0 through 9), whereas localized lighting provides little benefit except near the intersection itself (C3 locations 10 through 19).

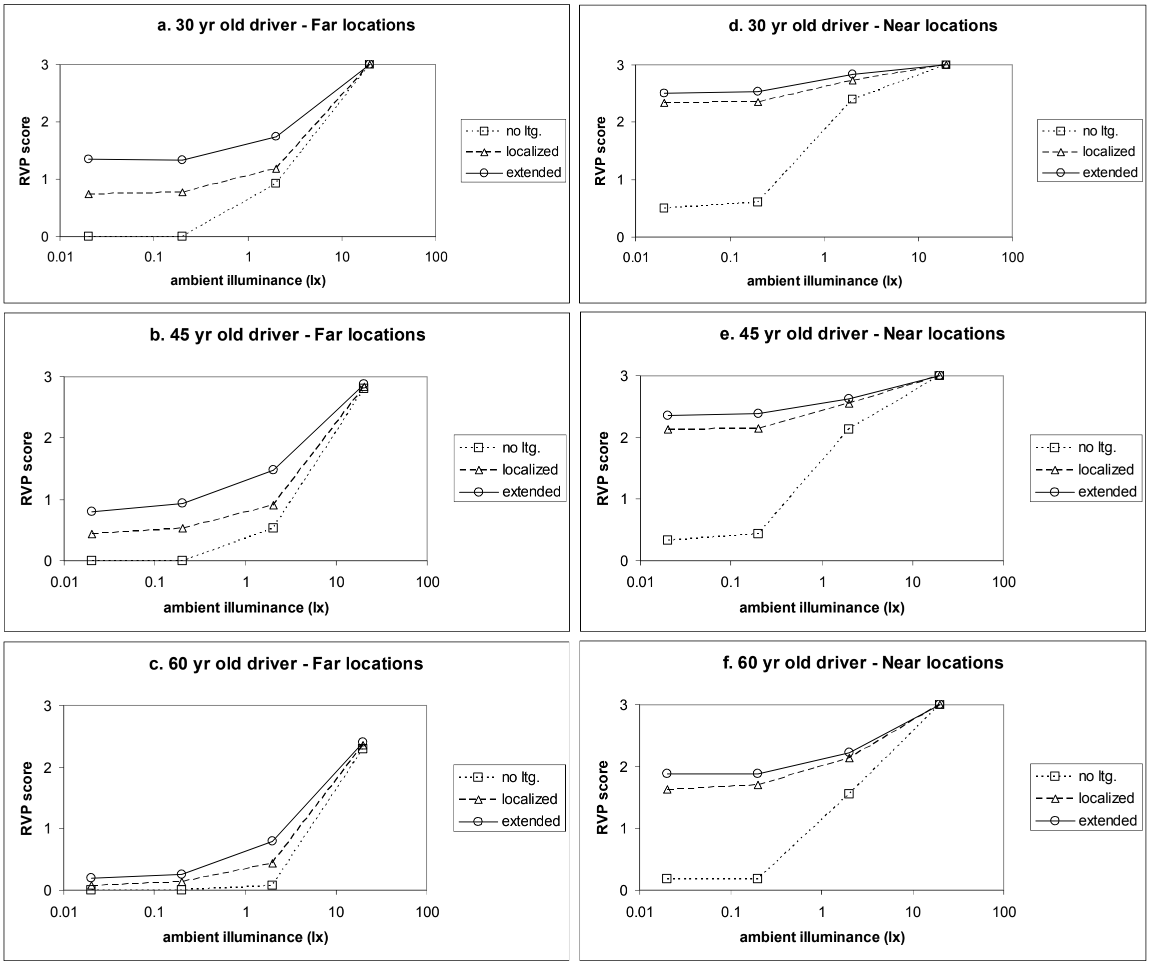
To simplify the visual performance analysis, RVP values were converted into a four-point score (denoted *RVP score*); a score of 0 was assigned to all RVP values less than 0.7 because the rate of decline to threshold is very fast below that value (these are the cells colored red in Tables 1 through 3). A score of 3 was given to all RVP values greater than 0.9 because above this value RVP is essentially flat (these are the cells colored white in Tables 1 through 3). Visual performance changes more gradually between 0.7 and 0.9, so a score of 1 was given to

RVP values from 0.7 to 0.8 (cells colored orange) and a score of 2 was given to all RVP values between 0.8 and 0.9 (cells colored yellow).

For the evaluation of visual performance associated with relatively high speeds (e.g., based on high speed limits, or unsignalized intersections), the standard target should be placed some distance from the intersection where there would be potential conflict. Figures 8a through 8c illustrate the visual performance levels associated with the standard target placed at several locations further from the intersection (C3 locations 0 through 9 in Figure 5, referred to as the *far* targets). The light levels for roadway illumination represented in Figure 8 correspond to the *medium* range (i.e., 9 lx on the roadway and 15 lx in the conflict area of the intersection).

For example, Figure 8a shows, for the far targets (corresponding to C3 locations 0 through 9), with the lowest ambient illuminance (0.02 lx) and for the 30-year-old drivers, an RVP score of zero with no lighting. In other words, all 40 cells in Table 2 corresponding to a 30-year-old driver, to an ambient illuminance of 0.02 lx, to no lighting (the bottom third of the table), and to target locations 0 through 9 are shaded red, meaning they have RVP values less than 0.7, which is defined as an RVP score of zero. In the same figure, extended lighting is shown to have an RVP score with a value of 1.35. Looking at the 40 cells in Table 2 corresponding to a 30-year-old driver, an ambient illuminance of 0.02 lx, target locations 0 through 9, and for extended lighting (the upper third of the table), there are six red cells with RVP < 0.7 (score = 0), 14 orange cells with 0.7 ≤ RVP < 0.8 (score = 1), 20 yellow cells with 0.8 ≤ RVP < 0.9 (score = 2), and no white cells with RVP ≥ 0.9. The resulting average RVP score is 1.35. This means that for this situation, extended lighting was found to increase the average RVP score for the far targets by 1.35. In comparison, localized lighting (a luminaire near the intersection's junction) only increased the average RVP score for the far targets relative to no lighting by about half as much.

The breakpoint between the far targets (locations 0 through 9) and near targets (locations 10 through 19) in Figure 5 reflects the AASHTO (*30*) highway design guidance that 2.5 seconds is assumed for detecting and perceiving targets on the roadway as potential hazards (*31*). A number of organizations use 40 mph as a cutoff between high- and low-speed roadway facilities (*32-40*). Thus, for high speeds (> 40 mph) the standard target would be between 150 and 300 ft away. RVP score is plotted in Figures 8a through 8c as a function of ambient light level for extended, localized and no roadway lighting. Each of these three figures is for a different age group. Three age groups, 30, 45 and 60 years of age, were modeled. Similarly, Figures 8d through 8f relate to placing that same target near the intersection (between 0 and 150 feet, at C3 locations 10 through 19 in Figure 5, referred to as the *near* targets), and these three figures show how RVP score varies as a function of ambient light level for the three different age groups in situations corresponding to low driving speeds or signalized intersections.



Medium illuminances for the far targets

Medium illuminances for the near targets

Figure 8. RVP score values for the medium design illuminances.

As can be seen from Figures 8a through 8f, the RVP score always increases with the ambient light level, and for an ambient light level of 20 lx, fixed lighting is superfluous to visual performance. These six figures clearly show how important ambient light levels are to visibility. A closer examination of these six figures also shows, as expected, that for comparable lighting conditions, RVP score is ordered by the age of the observer; RVP score increases as age decreases. It should also be noted, however, that as ambient light level increases, RVP score is differentially affected for the different age groups. In fact, RVP score values are highly dependent upon interactions among the modeled variables. For example, for extended lighting, Figure 8a shows that roadway lighting makes a large difference in the RVP score at the lowest ambient light levels (0.02 and 0.2 lx) for 30-year-olds, Figure 8c shows that it makes little difference for 60-year-olds, because RVP scores are low for the older group. The differences in RVP scores for different roadway lighting conditions actually increase with ambient illumination (up to 2 lx) in the 60-year-olds as visibility improves, but these differences decrease with ambient illumination for 30-year-olds.

PHASE II

Additional analyses were conducted to assess the relationship between visibility under the scenarios described above and other factors associated with the lighting and visual environment (such as the influence of different vehicle headlamp types, and the lateral distribution of roadway luminaires). It was found (described below) that high beam headlamps and possibly, the use of high-performance headlamps using high-intensity discharge lamps could improve visibility when the potential hazard was relatively close to the vehicle. With respect to lateral distributions, the use of Type II or Type III luminaires had very little influence on visual performance for specific light levels. In both of these types of analyses, emphasis is placed on the visibility of pedestrians in addition to targets that are more likely to be associated with vehicle-to-vehicle crashes, which was the focus of the Phase I evaluations.

Rationale for Investigating Different Vehicle Headlamps

As described by the Illuminating Engineering Society of North America (IESNA), a major purpose of fixed roadway lighting systems is to serve "as a supplement to vehicular headlights" (*14*). Vehicle headlamps in the U.S. consist of two beam pattern distributions, low beams and high beams. In practice, most drivers spend most of their nighttime driving hours using their low beams (*25*), even at times when usage of their high beams would be appropriate (*41*). This is the primary reason that the investigations in the previous section have assumed vehicle lighting consisting of low beam, halogen headlamps.

Nonetheless, new headlamp technologies are emerging on vehicles in the United States. For example, HID headlamps have been demonstrated in several studies to provide improved visibility relative to that from the prevailing technology, halogen headlamps (*42-44*). In addition, efforts are underway to develop automated high-beam systems that would enable drivers to utilize their high beam headlamps for a much larger proportion of their nighttime driving hours (*45-54*). If such efforts are successful, the role of roadway lighting as a supplement to vehicular lighting could change dramatically.

Rationale for Investigating Different Roadway Lateral Distributions

All of the investigations in the Phase I analyses used roadway luminaires with lateral light distributions denoted as Type II. In essence, the lateral light distribution classification system of the IESNA (*14*) uses five Roman numeral types with the lowest Roman numerals (Types I and II) corresponding to distributions that distribute light along the road in a relatively narrow manner, with little light along sidewalks and other adjacent areas, typically with a purpose of maximizing the spacing of roadway luminaires and providing illumination only on the roadway surface (and typically for roads with a small number of lanes). Lateral distribution types with higher Roman numerals distribute greater amounts of light in directions across the roadway rather than along the roadway, and these luminaire types are more commonly used in locations where illumination of sidewalks, roadway shoulders and adjacent areas is desirable (e.g., for facilitating detection of pedestrians), or where roadways contain a large number of lanes. Because they are not optimized to distribute light along a relatively narrow, elongated path, the spacing between luminaires of the higher Roman numeral types can be shorter than those of the lower Roman numeral types.

For example, the Minnesota Department of Transportation (*55*) specifies the use of either Type II or Type III luminaires for roadway lighting. Type III luminaires are more commonly used than Type II luminaires when the pedestrian population is high, or when the number of roadway lanes is large. These two luminaire types appear to be the most common in most functional roadway lighting installations based on information about commercially available luminaires published by the National Lighting Product Information Program (*56*). Since Type III luminaires might be specified for use in some roadway lighting situations, it is worthwhile to investigate the differential change in visibility associated with lighting systems between these two types of luminaires.

Vehicle Headlamp Analyses

Method

In order to compare the visibility conditions provided by different headlamps and fixed roadway lighting conditions, the same types of scenarios that were used to assess the role of lighting for visibility at intersections were developed. An observer (corresponding to car C3 in Figure 5) in a vehicle driving toward a cross intersection was located 150 ft from the center of the intersection. The visibility of the two other vehicles in the scenario (cars C1 and C2), located along the cross road near the intersection was calculated as in the previous analyses, and the visibility of two pedestrians located along the passenger side of the road upon which car C3 traveled was calculated. Pedestrian locations for these targets were 75 and 150 ft ahead of the driver in car C3.

The pedestrian was modeled by calculating the average illuminance on a vertical plane 6 ft high by 1 ft wide, and facing the observer, at each of the two locations. Assuming a reflectance of 0.5, the resulting luminance was used as the luminance of a small target at the observer eye height (assumed to be 4 ft [*57*]) with the luminances of the surfaces behind the target used as the background luminance. RVP (*8*) calculations were performed for an assumed driver age of 30 years. RVP values were converted to RVP scores using the same transformation as in the Phase I analyses (RVP values of 0.9 or higher corresponded to an RVP score of 3, RVP values less than 0.9 but greater than or equal to 0.8 corresponded to an RVP score of 2, RVP values less than 0.8 but greater than or equal to 0.7 corresponded to an RVP score of 1, and RVP values less than 0.7 corresponded to an RVP score of 0). RVP scores were determined for the four ambient illuminances (0.02 lx, 0.2 lx, 2 lx and 20 lx) and for the three different lighting conditions (no fixed roadway lighting, localized lighting at the intersection, and extended lighting consisting of continuous lighting along the road containing car C3). All fixed lighting conditions corresponded to the medium level (9 lx on the roadway and 15 lx in the intersection conflict area).

Five different headlamp systems were used for each of the lighting/target scenarios described above: the same halogen headlamp used as the vehicle lighting in the analyses summarized in Phase I (corresponding to a common imported vehicle manufacturer); a halogen headlamp representing a market-weighted average of halogen headlamps in the United States (*58*), a specific HID headlamp corresponding to a different imported vehicle manufacturer, a market-weighted average HID headlamp (*58*), and a market-weighted halogen high-beam headlamp (*58*).

Results

Despite some differences among the headlamp systems (e.g., for the closer pedestrian target, located furthest off-axis, one of the HID headlamps and one of the halogen headlamps resulted in slightly higher RVP score values than the other headlamps, but for the further pedestrian target, the high beam headlamp resulted in greater RVP score values), all five of the headlamp systems yielded RVP scores that were highly correlated with each other. The coefficients of determination (r^2) between the RVP scores using the original halogen headlamp in Phase I and each of the other four headlamps were all greater than 0.92 for the vehicle targets, and greater than 0.82 for the pedestrian targets. Because of this close agreement, the RVP scores for all five headlamp systems were combined. The mean RVP scores for each fixed lighting/ambient lighting condition are plotted in Figures 9 (for the vehicle targets), 10 (for the near pedestrian target) and 11 (for the further pedestrian target).

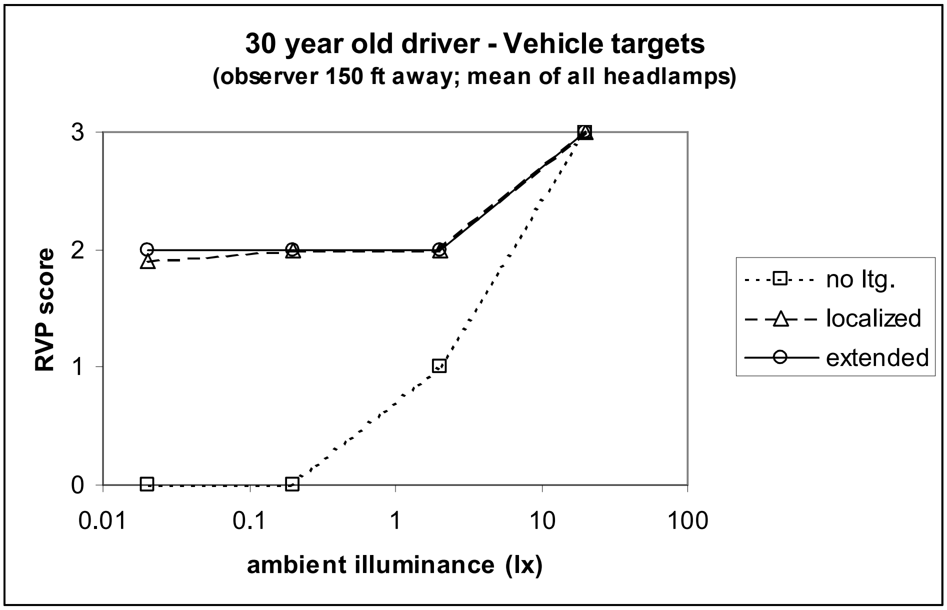


Figure 9. RVP scores for the vehicle targets (combined for all headlamp conditions) for each combination of roadway lighting and ambient lighting.

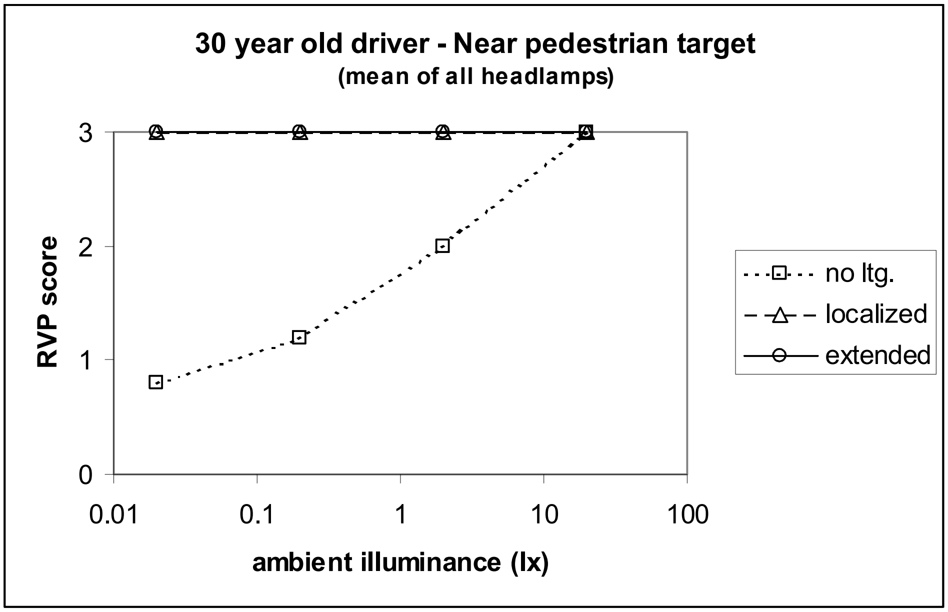


Figure 10. RVP scores for the near pedestrian target (combined for all headlamp conditions) for each combination of roadway lighting and ambient lighting.

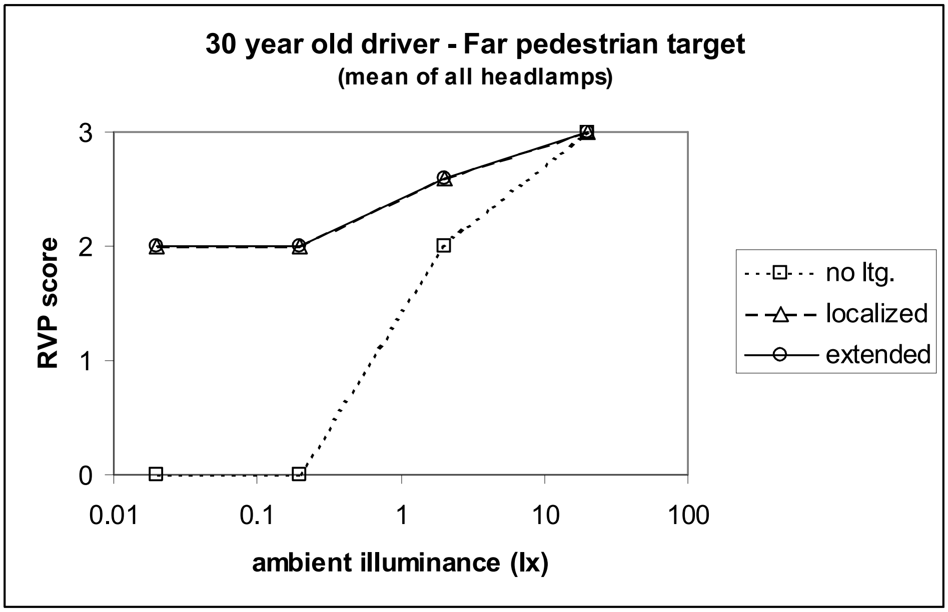


Figure 11. RVP scores for the far pedestrian target (combined for all headlamp conditions) for each combination of roadway lighting and ambient lighting.

Consistent with the results from Phase I, the ambient illuminance has a large influence on the visibility of both types of targets; RVP scores with the highest ambient illuminance (20 lx) always had a value of 3. The influence of fixed lighting is greater when the target is furthest away from the vehicle, as might be expected. The difference in visibility for all of the targets between the localized and extended lighting is hardly evident. This probably is because of the relative proximity of all of the targets to the center of the intersection (even the near pedestrian [to the observer in car C3] is only 75 feet from the intersection's center).

Lateral Distribution Analyses

Vehicle-to-Vehicle Targets

Method. A series of analyses that were fundamentally identical to those conducted for Phase I were conducted using luminaires with a Type III distribution (the previous analyses described in the main report used Type II luminaires). Observers aged 30 and 60 years were used, and the mean RVP scores were determined for the near and far locations (corresponding to targets that would need to be detected by drivers traveling at low and high speeds, respectively). As in the previous analyses, targets were small square targets (18 cm along each side, reflectance 0.5) corresponding to the small target used in the calculation of STV (*9*).

The roadway illuminances for these scenarios corresponded to the medium range used in Phase I (9 lx along the roadway and 15 lx in the intersection conflict areas).

Results. Figures 12a and 12b show the mean RVP scores for the far targets (positions 0 through 9 in Figure 5) for 30- and 60-year-old drivers. These figures are very similar in appearance to Figures 8a and 8c, illustrating the effect of lighting for these age groups when using Type II luminaires.

Figures 13a and 13b show the RVP scores for the near targets (positions 10 through 19 in Figure 5) for the same two age groups. Again, the form of the curves in these figures are very close to those in Figures 8d and 8f, despite the difference in luminaire lateral distributions.

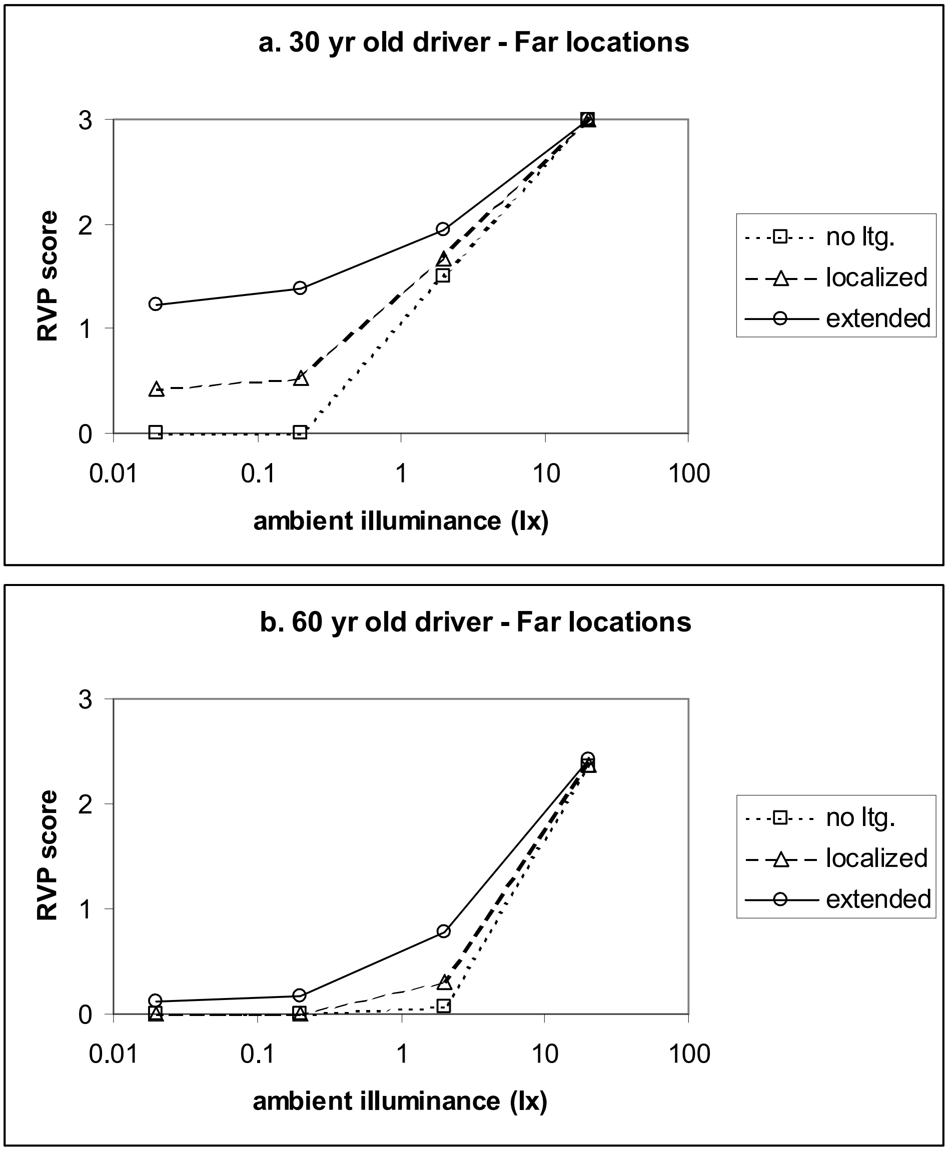


Figure 12a-b. RVP score values with Type III luminaires under medium illuminances for high-speed targets and for drivers of different ages.

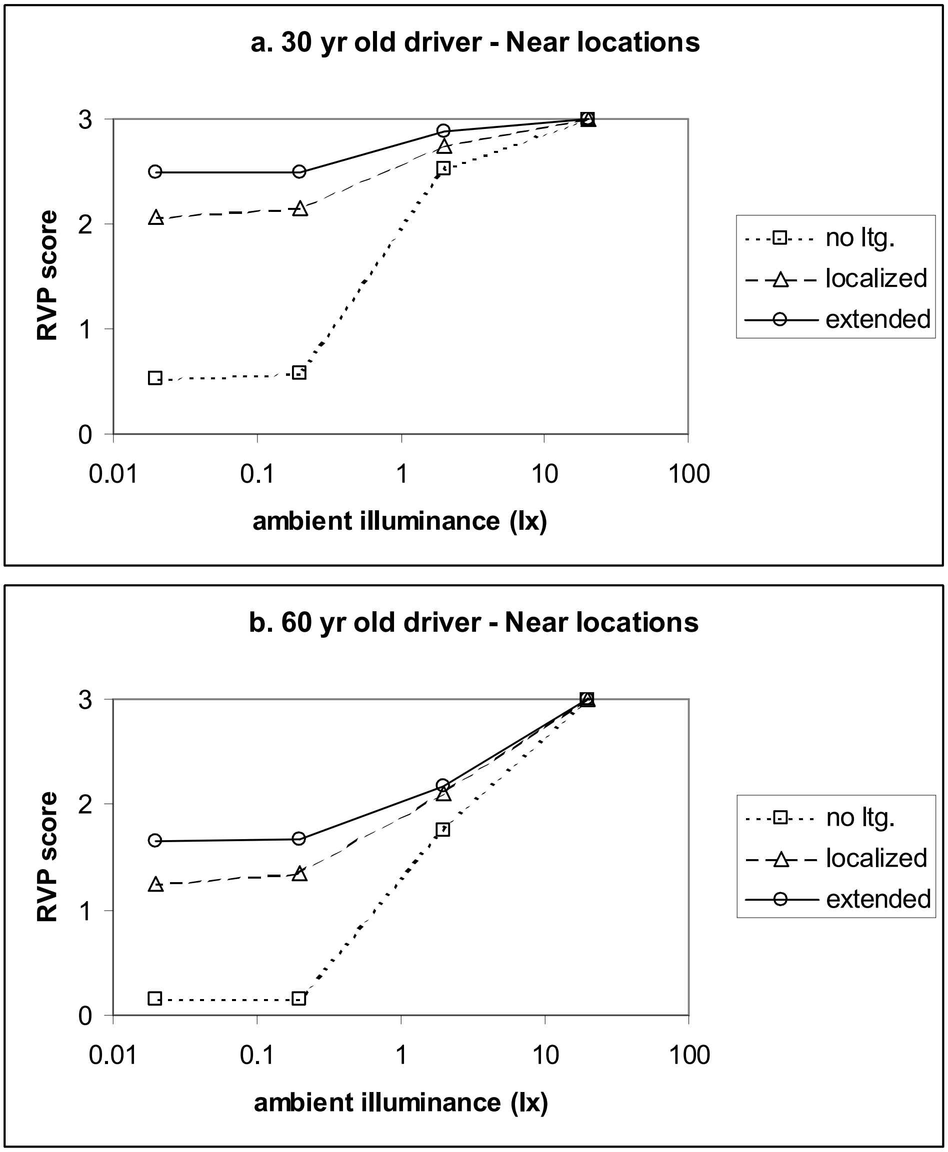
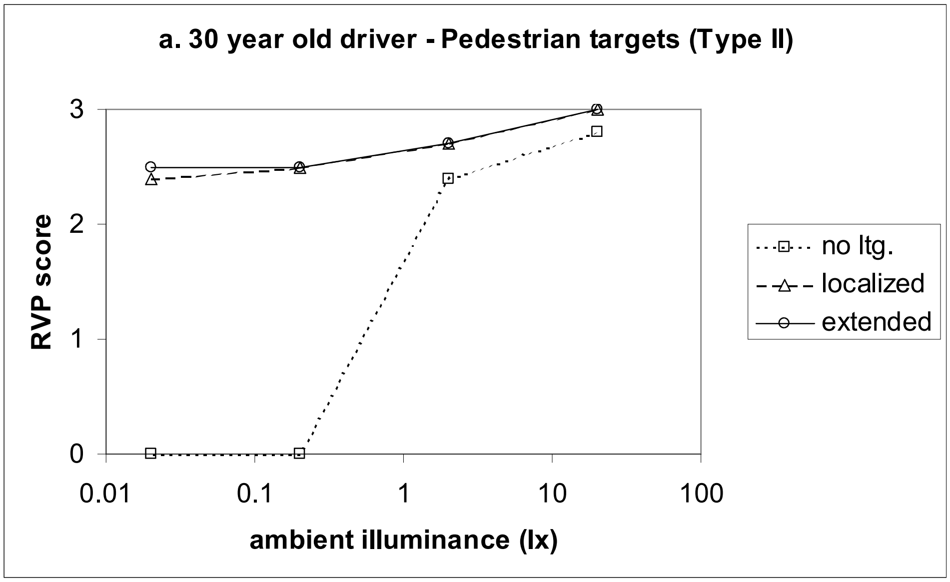


Figure 13a-b. RVP score values with Type III luminaires under medium illuminances for low-speed targets and for drivers of different ages.

Pedestrian Targets

Method. In order to compare the visibility of pedestrian targets provided by Type II and Type III luminaires, RVP score values were calculated in similar fashion as those in the previous analyses. The location of the observer (car C3 in Figure 5) was fixed at 150 ft ahead of the intersection. The pedestrian targets were 18 cm squares, 0.5 reflectance having the same average illuminance on them as a 6-foot by 1-foot rectangle positioned along the passenger side of the roadway, located every 15 ft between the observer and the center of the intersection.

Results. Figures 14a and 14b illustrate the resulting RVP scores for the pedestrian targets visible from the observer's location under Type II luminaires for 30 and 60 year old drivers, and Figures 15a and 15b show the same information for Type III luminaires.



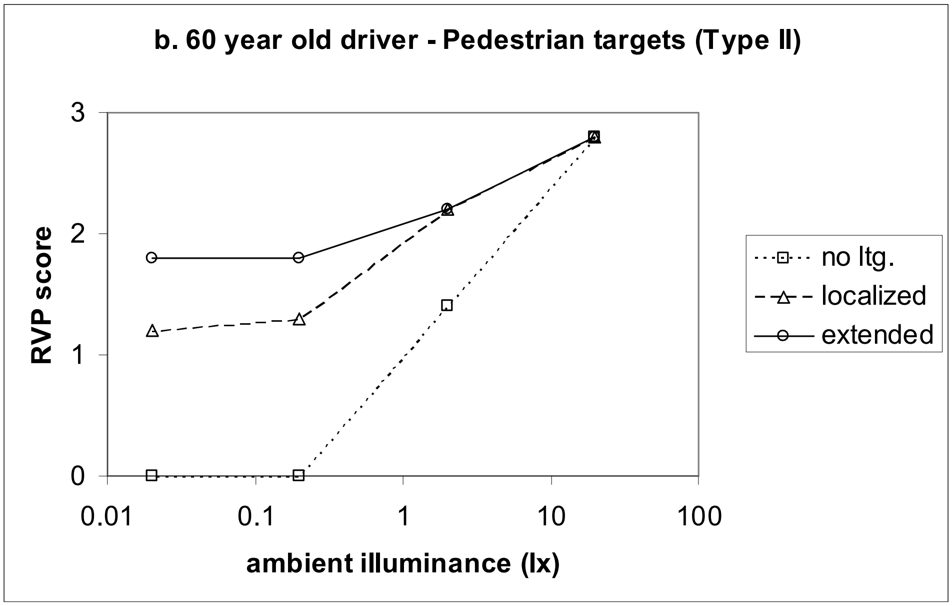


Figure 14a-b. RVP score values for pedestrian targets with Type II luminaires under medium illuminances for drivers of different ages.

The graphs in Figures 14 and 15 clearly show the differences between the two driver ages as well as the influence of ambient illuminance on visual performance for pedestrian targets under these conditions. For both types of luminaires, localized lighting configurations result in nearly equal visibility as extended lighting for the younger drivers, but the older drivers benefit visually from extended lighting.

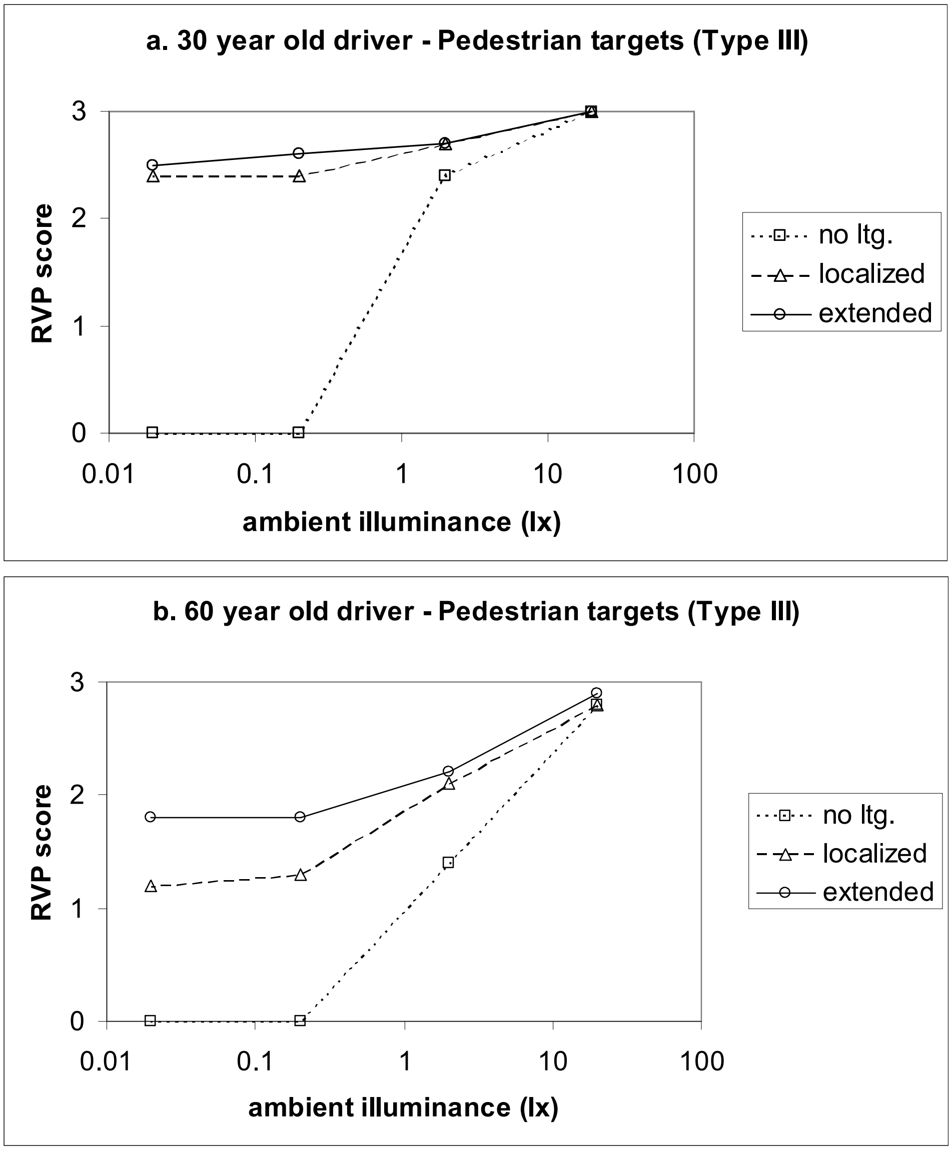


Figure 15a-b. RVP score values for pedestrian targets with Type III luminaires under medium illuminances for drivers of different ages.

Regarding the influence of the lateral distribution types on visibility, the differences between the two types of luminaires used are relatively small compared to the effects of lighting type (none, localized or extended) and ambient illuminance. There appear to be some small improvements in visibility for the pedestrian targets with the Type III luminaire but these are at best on the order of 0.1 RVP score units, certainly not a very large difference, but one that is consistent with the recommendation to use Type III luminaires in locations containing large pedestrian populations.

DISCUSSION

Regarding headlamp beam usage, the advantages of high-beam headlamps appear to be greatest for potential hazards seen from large distances. The advantages of HID headlamps appear to be greatest for targets at moderate distances located in the peripheral field of view, where these headlamps tend to have greater output than conventional low beam halogen headlamps (*43, 44*). Nonetheless, roadway lighting confers visibility improvements regardless of headlamp type. The methodology developed for assessing visibility in the present project is useful for characterizing the benefits of both vehicular and fixed roadway lighting.

Regarding the influence of lateral distribution types on visibility, the present analyses indicate that using Type III luminaires instead of Type II luminaires in locations where there are many pedestrians to be found is a reasonable practice. The visibility of hazards that are more likely to be associated with car-to-car crashes is not substantially affected, and there may be a slight improvement in pedestrian visibility, and by extension safety, with Type III luminaires.

CHAPTER 3
INTERCHANGE ANALYSES

SCENARIO DEVELOPMENT

Using a method similar to that in the analytical investigations of intersection lighting, we investigated the role of interchange lighting on visibility of relevant targets. The scenario developed for analysis simulated an interchange ramp merge/diverge area with lighting providing an average of 21 lx on the ramp (nominally, this is in the *medium* range of light levels for conflict areas in highways as specified by the IESNA [*9*]). Figure 16 shows a plan view of this area, created using photometrically accurate simulation software.

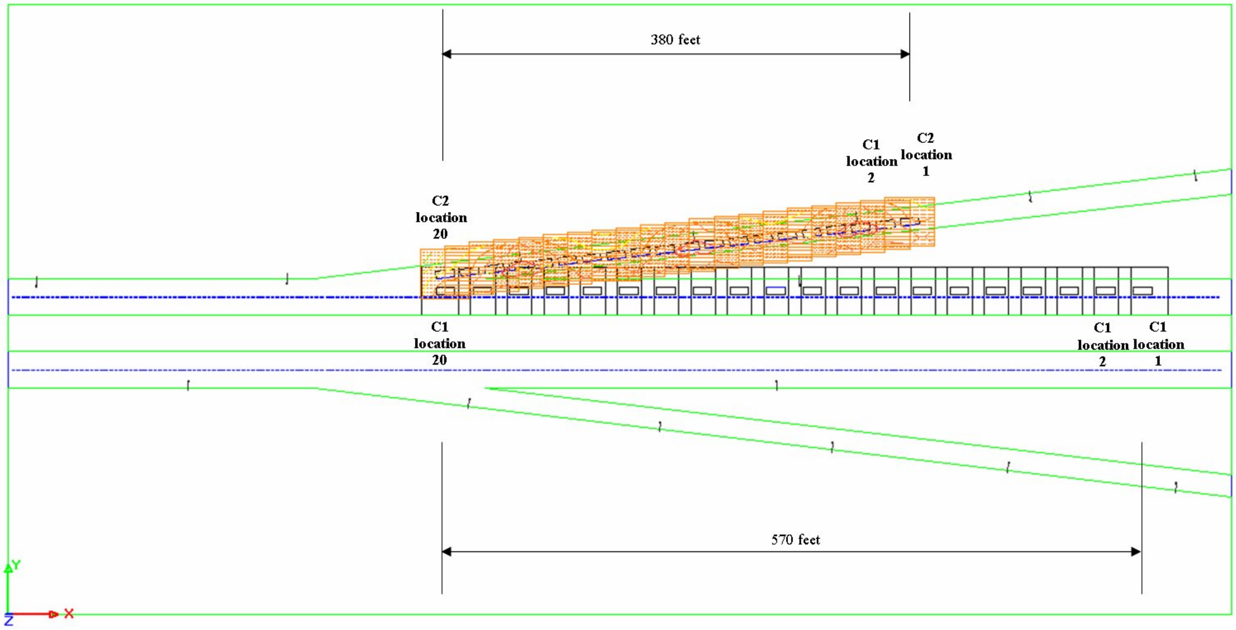
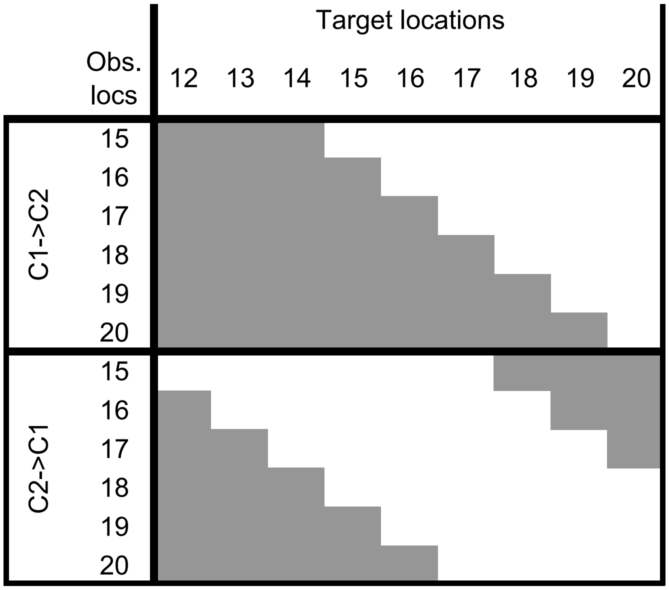


Figure 16. Plan view of interchange ramp merge area.

The investigation looked at visibility from two perspectives: that of a driver (in car C1) on a highway approaching the merge area of a ramp, and that of another driver (in car C2) on a ramp attempting to merge onto the highway. Twenty positions for each vehicle (cars C1 and C2) were investigated as shown in Figure 16. It was assumed that traffic on the ramp was two-thirds that on the highway (e.g., 60 mph on the highway and 40 mph on the ramp).

The relevant visual target for a driver in car C1 would be car C2, and the relevant visual target for a driver in car C2 would be the vehicle driven by C1. In some locations, for example, if car C1 is in location 20 and if car C2 is positioned well behind in location 1, car C2 would be a relatively unimportant visual target for the driver of car C1 (because car C1 would already be well ahead of car C2 *and* traveling faster than car C2), and car C2 would be in a position such that the tail lights of car C1 would be the primary visual cue for the driver of car C2 to detect car C1.

The critical areas in which the drivers of cars C1 and C2 would need to see one another are close to the actual merge area (near location 20 for each vehicle). Since car C1 (on the highway) is traveling faster than car C2 (on the ramp), it is more important for the driver of car C1 to see car C2 at locations adjacent to and ahead of car C1. However, the driver of car C2 would need to see car C1 at locations both slightly behind and slightly ahead of car C2, since vehicles behind can C2 can overtake car C2 as car C2 merges onto the highway. Figure 17 shows these critical areas (shown in white); the noncritical areas are shaded gray in Figure 17.



	Obs. locs	Target locations								
		12	13	14	15	16	17	18	19	20
C1->C2	15	▨	▨	▨						
	16	▨	▨	▨	▨					
	17	▨	▨	▨	▨	▨				
	18	▨	▨	▨	▨	▨	▨			
	19	▨	▨	▨	▨	▨	▨	▨		
	20	▨	▨	▨	▨	▨	▨	▨	▨	
C2->C1	15							▨	▨	▨
	16	▨							▨	▨
	17	▨	▨							▨
	18	▨	▨	▨						
	19	▨	▨	▨	▨					
	20	▨	▨	▨	▨	▨				

Figure 17. Identification of critical locations (unshaded/white cells) for observer C1 to see C2, and observer C2 to see C1.

For all of the remaining locations (those shown in Figure 17 as shaded/gray, and those corresponding to locations 1 through 15 for the drivers of cars C1 and C2), it is assumed that the role of lighting is unimportant to traffic safety. As described above, when the target vehicle is well ahead of the observer, the relevant visual target is assumed to be the tail or brake lights of the target vehicle, and the visibility of these signals would be largely unaffected by the presence of lighting (in fact, one might expect the conspicuity of tail lights to be lower in the presence of roadway lighting because the ratio of the tail light luminance to that of the roadway is lower when lighting is present than when it is not). When the target vehicle is well behind the observer, it is assumed that it is an irrelevant target. Thus, of the 800 possible observer/target scenarios (there are 20 locations for both cars C1 and C2 in Figure 16, resulting in 400 scenarios for the driver of car C1 and 400 scenarios for the driver of car C2), only the 54 shown in Figure 17 as unshaded cells (6.75% of the total) are those where lighting might be expected to influence safety.

Since in highway merging operations, it is important to detect the presence of vehicles in adjacent lanes so that merging or appropriate avoidance maneuvers can be performed, the visual target was assumed to be a vehicle with the size of a typical passenger car. Two reflectances for the target vehicle were assumed (0.1 and 0.5). Headlights for the observers' vehicles were used in the simulations (using halogen low beam headlamps for a common import passenger car), but the headlights of the target vehicle were not used as part of the relevant target since these would always be highly visible regardless of the lighting. As with the intersection analyses, ambient illuminances from 0.02 to 20 lx were incorporated in the visual performance calculations in order to account for rural, suburban, urban and very commercial locations.

Table 4. RVP values for each of the critical locations without interchange lighting.

ρ=0.5		Veiling Illuminance = 20 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.97	0.97	0.97	0.97	0.97	0.97
	16					0.97	0.97	0.97	0.97	0.97
	17						0.97	0.97	0.97	0.97
	18							0.97	0.97	0.97
	19								0.97	0.97
	20									0.97
C2->C1	15	0.97	0.97	0.97	0.97	0.97	0.97			
	16		0.97	0.97	0.97	0.97	0.97	0.97		
	17			0.97	0.97	0.97	0.97	0.97	0.97	
	18				0.97	0.97	0.97	0.97	0.97	0.97
	19					0.97	0.97	0.97	0.97	0.97
	20						0.97	0.97	0.97	0.97

ρ=0.5		Veiling Illuminance = 2 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.93	0.93	0.92	0.92	0.92	0.92
	16					0.93	0.93	0.93	0.92	0.92
	17						0.93	0.93	0.93	0.93
	18							0.93	0.94	0.93
	19								0.93	0.94
	20									0.92
C2->C1	15	0.92	0.92	0.92	0.92	0.92	0.92			
	16		0.92	0.92	0.92	0.92	0.92	0.93		
	17			0.92	0.92	0.92	0.92	0.92	0.93	
	18				0.92	0.92	0.92	0.92	0.92	0.94
	19					0.92	0.92	0.92	0.92	0.93
	20						0.92	0.92	0.92	0.92

ρ=0.5		Veiling Illuminance = 0.2 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.87	0.85	0.83	0.80	0.77	0.76
	16					0.89	0.88	0.86	0.84	0.81
	17						0.90	0.90	0.89	0.86
	18							0.90	0.92	0.91
	19								0.83	0.93
	20									0.74
C2->C1	15	0.74	0.74	0.74	0.74	0.74	0.75			
	16		0.74	0.74	0.74	0.74	0.74	0.85		
	17			0.74	0.74	0.74	0.74	0.70	0.90	
	18				0.74	0.74	0.74	0.74	0.76	0.92
	19					0.74	0.74	0.74	0.74	0.91
	20						0.74	0.74	0.74	0.70

ρ=0.5		Veiling Illuminance = 0.02 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.85	0.77	0.77	0.77	0.77	0.77
	16					0.88	0.86	0.80	0.77	0.77
	17						0.89	0.90	0.87	0.82
	18							0.89	0.92	0.90
	19								0.36	0.92
	20									0.66
C2->C1	15	0.74	0.74	0.74	0.74	0.74	####			
	16		0.74	0.74	0.74	0.74	0.74	0.78		
	17			0.74	0.74	0.74	0.74	####	0.89	
	18				0.74	0.74	0.74	0.74	0.69	0.92
	19					0.74	0.74	0.74	0.74	0.90
	20						0.74	0.74	0.74	####

ρ=0.1		Veiling Illuminance = 20 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.95	0.95	0.94	0.95	0.95	0.94
	16					0.95	0.95	0.95	0.95	0.95
	17						0.95	0.95	0.95	0.95
	18							0.94	0.95	0.95
	19								0.93	0.96
	20									0.94
C2->C1	15	0.94	0.94	0.94	0.94	0.94	0.94			
	16		0.94	0.94	0.94	0.94	0.94	0.94		
	17			0.94	0.94	0.94	0.94	0.94	0.93	
	18				0.94	0.94	0.94	0.94	0.94	0.95
	19					0.94	0.94	0.94	0.94	0.94
	20						0.94	0.94	0.94	0.94

ρ=0.1		Veiling Illuminance = 2 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.91	0.90	0.89	0.90	0.90	0.89
	16					0.92	0.91	0.90	0.91	0.90
	17						0.92	0.92	0.91	0.91
	18							0.88	0.93	0.92
	19								0.60	0.93
	20									0.65
C2->C1	15	0.85	0.85	0.85	0.85	0.85	0.78			
	16		0.85	0.85	0.85	0.85	0.85	####		
	17			0.85	0.85	0.85	0.85	0.83	####	
	18				0.85	0.85	0.85	0.85	0.42	0.90
	19					0.85	0.85	0.85	0.85	-4.15
	20						0.85	0.85	0.85	0.80

ρ=0.1		Veiling Illuminance = 0.2 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.86	0.82	0.78	0.76	0.72	0.70
	16					0.88	0.86	0.82	0.81	0.78
	17						0.88	0.89	0.86	0.85
	18							0.82	0.91	0.89
	19								0.87	0.92
	20									0.77
C2->C1	15	####	####	####	####	####	0.50			
	16		####	####	####	####	####	0.85		
	17			####	####	####	####	####	0.84	
	18				####	####	####	####	0.87	0.87
	19					####	####	####	####	0.70
	20						####	####	####	-7.62

ρ=0.1		Veiling Illuminance = 0.02 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.83	0.68	0.68	0.74	0.74	0.74
	16					0.87	0.84	0.75	0.73	0.74
	17						0.88	0.88	0.84	0.79
	18							0.81	0.91	0.88
	19								0.87	0.92
	20									0.76
C2->C1	15	####	####	####	####	####	0.73			
	16		####	####	####	####	####	0.85		
	17			####	####	####	####	0.67	0.84	
	18				####	####	####	####	0.87	0.87
	19					####	####	####	####	0.74
	20						####	####	####	0.73

Table 5. RVP values for each of the critical locations with interchange lighting.

ρ=0.5		Veiling Illuminance = 20 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.97	0.97	0.97	0.97	0.97	0.97
	16					0.97	0.97	0.97	0.97	0.97
	17						0.97	0.97	0.97	0.97
	18							0.97	0.97	0.97
	19								0.97	0.97
	20									0.97
C2->C1	15	0.97	0.97	0.97	0.97	0.97	0.97			
	16		0.97	0.97	0.97	0.97	0.97	0.97		
	17			0.97	0.97	0.97	0.97	0.97	0.97	
	18				0.97	0.97	0.97	0.97	0.97	0.97
	19					0.97	0.97	0.97	0.97	0.97
	20						0.97	0.97	0.97	0.97

ρ=0.5		Veiling Illuminance = 2 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.95	0.93	0.80	0.94	0.95	0.94
	16					0.95	0.94	0.94	0.95	0.94
	17						0.95	0.96	0.95	0.94
	18							0.94	0.96	0.95
	19								0.94	0.95
	20									0.94
C2->C1	15	0.96	0.95	0.95	0.95	0.95	0.96			
	16		0.95	0.95	0.95	0.95	0.96	0.96		
	17			0.95	0.95	0.95	0.96	0.96	0.96	
	18				0.95	0.95	0.96	0.96	0.96	0.95
	19					0.95	0.96	0.96	0.96	0.95
	20						0.96	0.96	0.96	0.95

ρ=0.5		Veiling Illuminance = 0.2 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.94	####	0.92	0.79	0.93	0.92
	16					0.95	0.81	0.86	0.94	0.93
	17						0.94	0.95	0.94	0.94
	18							0.90	0.95	0.94
	19								0.16	0.95
	20									0.89
C2->C1	15	0.95	0.95	0.94	0.95	0.95	0.95			
	16		0.95	0.94	0.95	0.95	0.95	0.96		
	17			0.94	0.95	0.95	0.95	0.96	0.96	
	18				0.95	0.95	0.95	0.96	0.96	0.95
	19					0.95	0.95	0.96	0.96	0.95
	20						0.95	0.96	0.96	0.94

ρ=0.5		Veiling Illuminance = 0.02 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.94	####	0.93	0.52	0.93	0.92
	16					0.95	0.69	0.80	0.93	0.93
	17						0.93	0.95	0.94	0.93
	18							0.88	0.95	0.94
	19								####	0.95
	20									0.86
C2->C1	15	0.95	0.95	0.94	0.95	0.95	0.95			
	16		0.95	0.94	0.95	0.95	0.95	0.96		
	17			0.94	0.95	0.95	0.95	0.96	0.96	
	18				0.95	0.95	0.95	0.96	0.96	0.95
	19					0.95	0.95	0.96	0.96	0.95
	20						0.95	0.96	0.96	0.94

ρ=0.1		Veiling Illuminance = 20 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				-4.25	0.95	0.96	0.94	####	0.90
	16					0.94	0.96	0.94	####	0.91
	17						0.95	0.92	####	0.92
	18							0.94	0.91	0.93
	19								0.84	0.95
	20									0.84
C2->C1	15	0.80	0.95	0.95	0.96	0.95	0.94			
	16		0.95	0.95	0.96	0.95	0.95	0.94		
	17			0.95	0.96	0.95	0.95	0.95	0.96	
	18				0.96	0.95	0.95	0.95	0.96	0.95
	19					0.95	0.95	0.95	0.96	0.95
	20						0.95	0.95	0.96	0.95

ρ=0.1		Veiling Illuminance = 2 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.94	0.96	0.97	0.96	0.94	0.91
	16					0.96	0.96	0.96	0.94	0.88
	17						0.96	0.95	0.94	0.72
	18							0.96	0.46	####
	19								0.95	0.94
	20									0.93
C2->C1	15	0.91	0.94	0.93	0.94	0.93	0.91			
	16		0.94	0.93	0.94	0.93	0.91	0.91		
	17			0.93	0.94	0.93	0.91	0.92	0.95	
	18				0.94	0.93	0.91	0.92	0.95	0.93
	19					0.93	0.91	0.92	0.95	0.93
	20						0.91	0.92	0.95	0.93

ρ=0.1		Veiling Illuminance = 0.2 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.94	0.96	0.96	0.96	0.94	0.92
	16					0.96	0.96	0.96	0.94	0.90
	17						0.96	0.95	0.94	0.86
	18							0.96	0.79	0.65
	19								0.95	0.93
	20									0.93
C2->C1	15	0.92	0.93	0.92	0.94	0.93	0.90			
	16		0.93	0.92	0.94	0.93	0.91	0.91		
	17			0.92	0.94	0.93	0.91	0.91	0.94	
	18				0.94	0.93	0.91	0.92	0.94	0.93
	19					0.93	0.91	0.92	0.94	0.92
	20						0.91	0.92	0.94	0.92

ρ=0.1		Veiling Illuminance = 0.02 lux Target locations								
	Obs. locs	12	13	14	15	16	17	18	19	20
C1->C2	15				0.94	0.96	0.96	0.96	0.94	0.92
	16					0.96	0.96	0.96	0.94	0.91
	17						0.96	0.95	0.94	0.86
	18							0.96	0.80	0.69
	19								0.95	0.93
	20									0.93
C2->C1	15	0.92	0.93	0.92	0.93	0.93	0.90			
	16		0.93	0.92	0.93	0.93	0.91	0.91		
	17			0.92	0.93	0.93	0.91	0.91	0.94	
	18				0.93	0.93	0.91	0.92	0.94	0.93
	19					0.93	0.91	0.92	0.94	0.92
	20						0.91	0.92	0.94	0.92

RESULTS

Table 4 illustrates the RVP values (*8*) for each of the scenarios in Figure 17 for each assumed target reflectance and ambient illuminance, when no interchange lighting was used in the simulation. Table 5 lists the RVP values when interchange lighting was present. The cells in Tables 4 and 5 are shaded white for RVP values greater than 0.9, yellow for values between 0.8 and 0.9, orange for values between 0.7 and 0.8, and red for values below 0.7. As with the intersection analyses, RVP scores for each cell were calculated as follows: white=3, yellow=2, orange=1 and red=0. Figure 18 shows the average RVP scores for the critical locations in Figure 17, combined for both target reflectances, as a function of the ambient illuminance. Two features are evident upon inspection of Figure 18; one is that ambient illuminance improves visibility when interchange lighting is not present, and the other is that the presence of roadway lighting can in some locations actually result in reduced visibility relative to no lighting, primarily because of reduced contrast between a target and its background.

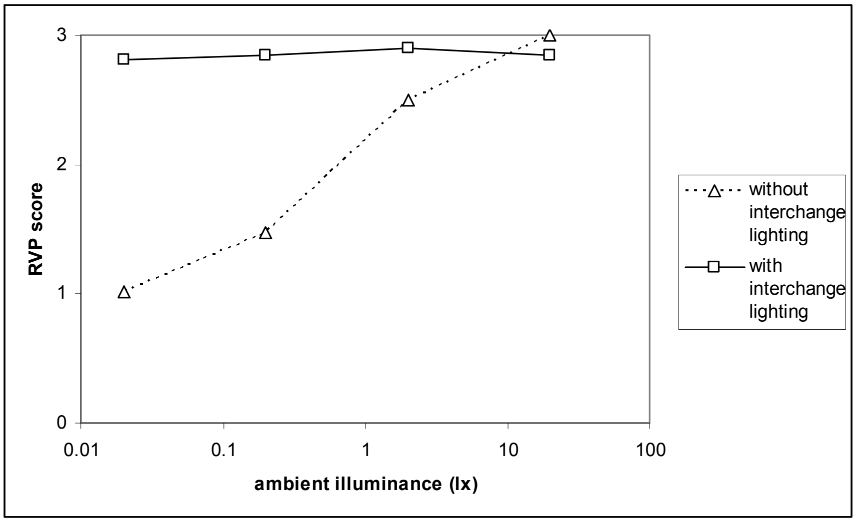


Figure 18. Mean RVP scores for different ambient illuminances with and without fixed interchange lighting present in the critical locations.

Because the directions of travel for the vehicles in Figure 16 (cars C1 and C2) are nearly parallel, the results from the analyses in this section could also be applicable to freeway segments where drivers might be attempting lane changing maneuvers and where the ability to see other vehicles could be important. In many situations, however, relevant visual targets for driving on freeways include vehicle tail lights and lane markings, which by design are highly visible regardless of fixed lighting conditions, implying that there would likely be a relatively small effect of lighting on visibility on highway segments.

CHAPTER 4
CONCLUSIONS

Taken together, these findings have several implications for lighting practice. At interchanges, they imply that lighting at locations other than the merge/conflict areas of an interchange is probably of little value because the visibility of relevant visual targets is not influenced by roadway lighting, and further, that lighting in urban or highly commercial districts is of limited value. Because relative speeds at interchanges are close to one another and because only the locations closest to the merge/conflict areas of interchanges are likely to benefit from lighting, localized lighting at these locations seems likely to provide as much or nearly as much benefit in terms of visibility improvement as extended lighting. The concept of partial interchange lighting, defined as the use of only a few luminaires at the exit/entrance locations of an interchange (*59*), therefore appears to be a viable approach to improving crash safety at interchanges. At intersections, lighting is likely to be of greater value in terms of visibility.

Based on the investigations described above, lighting consisting of one or two luminaires at an intersection, as is commonly found at rural intersections, is not likely to be of significant benefit, in terms of visibility, to a driver approaching the intersection at a relatively high speed (>40 mph). High speeds are less likely in urban locations, and what is more, urban intersections are more likely to have unexpected hazards in the form of pedestrians or entering vehicles. Naturally, the safety benefit will be strongly affected by traffic and population densities. Therefore, “partial” or “point” lighting (consisting of localized lighting from one or two luminaires near the traffic conflict) lighting might be more easily justified in urban locations where there are relatively slow driving speeds combined with high traffic and pedestrian densities.

The analyses presented in this report use a suprathreshold measure of visual performance, the RVP model (*9*) to characterize visibility under different lighting conditions, which has been shown to be strongly correlated with the speed and accuracy of visual processing in a number of contexts (*15-19*). Unlike most previous investigations of lighting as they pertain to safety and visibility (*1-4*), the present analyses included illumination and glare from vehicle headlamps.

The analyses further segregated visual targets into near and far groups, recognizing that along high speed roadways, relevant potential hazards may not be in the roadway, but could be located quite far from possible conflict points. Thus, at intersections, far targets were those located at a distance from the intersection corresponding to a 2.5-s perception-response time (*30, 31*) while driving at a speed of 40 mph or higher.

The results of the analyses demonstrate, for example, that roadway lighting located only at the intersection will provide little additional visibility of potential hazards located away from the intersection at the time they need to be seen. Using the same logic, roadway lighting would improve visibility of hazards such as deer along rural roadways, but the uncertainty of knowing where a deer that might enter the roadway is located would probably make lighting of all rural roadways not cost-effective. Thus, lighting is expected to have the strongest benefit at conflict locations such as intersections and the merge/diverge areas of interchanges. These conclusions are consistent with the findings presented in two companion reports, "Review of the Safety

Benefits and Other Effects of Roadway Lighting" (*60*) and "Analysis of Safety Effects for the Presence of Roadway Lighting" (*61*).

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