Headlight Test and Rating Protocol (Version II)

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HEADLIGHT TEST AND RATING PROTOCOL (VERSION II)

This document describes the Insurance Institute for Highway Safety (IIHS) headlight test and rating protocol and is available from the technical protocols section of the IIHS website (http://www.iihs.org/iihs/ratings/technical-information/technical-protocols). A companion document titled *Rationale and Supporting Work for Headlight Test and Rating Protocol* also can be accessed from the IIHS website.

DOCUMENT REVISION HISTORY

A history of revisions to this document is provided in Appendix A.

SUMMARY

This protocol describes a test procedure for measuring and rating the on-road illumination provided by passenger vehicle headlight systems. The procedure is based on illumination measurements on road sections with various horizontal curvature (straightaway, 150 m radius left and right curves, and 250 m radius left and right curves). Visibility illumination distances are assessed for low and high beams, with additional credit given for systems that automatically switch between high and low beam. In the low beam tests, glare illumination for drivers of oncoming vehicles also is measured and related to thresholds developed from Federal Motor Vehicle Safety Standard (FMVSS) 108. Systems that create excessive levels of glare on specific road sections do not receive full credit for visibility readings in that scenario.

The overall headlight rating is assigned based on a combination of the low and high beam performance in the five curvature scenarios. The 10 total test conditions are weighted differently to more closely reflect their representation of real-world scenarios.

AMBIENT CONDITIONS

Tests are conducted on a dry asphalt surface (no visible moisture). Tests are not conducted when the environmental extinction coefficient is greater than 0.3 km^{-1} (this is equivalent to a daytime visibility of 10 km, or an attenuation of 5 percent at 175 m). The extinction coefficient is measured on the test track with a forward-scatter visibility sensor (Envirotech Part # SVS1). The ambient air temperature must be between 20 and 100 degrees Fahrenheit during testing. Testing occurs at least 30 minutes after sunset, when the illumination recorded by the photometers is at or below 0.3 lux.

TEST VEHICLE PREPARATION

General

Tests shall be undertaken using a new vehicle in the “as received” condition. Prior to commencing testing, ensure that:

1. The vehicle’s odometer reading is less than 1,000 km. (The vehicle may exceed this level during the process of testing.)
2. Tires are inflated to the manufacturer’s recommended cold inflation pressure. If more than one recommendation is provided, the tires are inflated to the lightly loaded condition.
3. The fuel tank is filled to 100 percent of capacity with the appropriate fuel and maintained to at least 75 percent capacity throughout the testing.
4. Instrumentation is installed in the vehicle. With the driver and all required equipment, the vehicle test weight should not exceed the vehicle curb weight by more than 125 kg.

5. Headlamps with an LED light source will be activated with the engine running for a minimum of 15 minutes prior to testing.
6. Vehicles with headlamps with a halogen light source will be placed on a battery charger for at least 2 hours prior to testing, or until the charger indicates that the battery is fully charged.

Instrumentation

The test vehicle will be equipped with an Oxford Technical Solutions (OxTS) RT2002 Inertial and GPS Navigation System to measure and record speed, longitudinal and lateral position, distance traveled, and vehicle pitch angle (Table 1). These data will be sampled and recorded at a frequency of 100 Hz. If sufficient space exists, the RT2002 will be mounted on a vertical strut positioned between the floor and roof on the lateral centerline of the vehicle just behind the front seating row. The measurement of position and distance will be adjusted to reflect the center of the vehicle's leading edge. An OxTS base station is used to provide differential GPS corrections to the vehicle to improve the accuracy of the position measurements.

Table 1
Oxford Technical Solutions RT2002 Accuracy

Measurement	Accuracy
Speed	0.1 km/h
Longitudinal and lateral position	0.02 m
Pitch angle	0.05 degrees

Headlamp Aim

The vehicle will be tested as received with the factory headlamp aim. Prior to testing, the vertical factory aim of the headlamps will be measured and recorded. The aim measurement will be made with the tire pressure and fuel level specified above, as well as with a driver or driver ballast weight (77 kg) in the vehicle. However, the aim measurement may not always be made with the instrumentation in the vehicle. Vehicles with manual leveling systems will be set at the level specified on the selection switch/dial or in the vehicle owner's manual for the unloaded/driver-only condition. If no setting is specified, the vehicle will be tested with the selection that produces the lowest aim of the headlamps.

Adaptive Headlamp Functions

Vehicles with adaptive headlamp functions such as "adaptive front-lighting systems" (AFS) will be tested with the systems enabled. It is not anticipated that vehicles with dynamic or static automatic headlamp leveling systems will need to be tested differently. All vehicles will be started on a level surface at the final loading condition for the test, and the ignition will remain on during testing. Because the illuminance measurements are taken at a steady speed, there should be minimal compensation by dynamic leveling systems for acceleration changes.

Suspension Settings

Vehicle models that are available with multiple suspension options will be tested with the standard suspension type. Vehicles with adjustable suspensions will be tested in the default condition after an ignition cycle. If the prior suspension setting is retained after cycling the ignition, the vehicle will be tested in the "normal" or "neutral" condition. If no such setting exists, the vehicle will be tested with the selection that produces the lowest headlamp height.

ILLUMINANCE MEASUREMENTS

Summary

Photometers are placed at fixed locations on the test track to record the visibility and glare illumination of the test vehicle on each approach. To correct for changes in illumination that are due to changes in vehicle pitch, multiple photometers are used at each measurement location to capture illuminance readings at different heights. The illuminance readings are synchronized to the vehicle position and pitch using a common GPS time signal. The synchronized data are used to produce pitch-corrected illuminance versus distance curves that are used for the headlight rating. All data are processed using the DIAdem software package distributed by National Instruments. The processing scripts are available at https://github.com/iihs-hldi.

Instrumentation

Illuminance data are collected with Gamma Scientific photometers (Part # U68401). The photometric sensors provide a very close match to the spectral response of the human eye. They are fitted with diffusers to reduce the illuminance measurements for off-axis incidence angles in accordance with Lambert's cosine law. The sensors match the targeted cosine response to within 3 percent at angles up to 25 degrees, which is the maximum angle between the test vehicle and sensors on the sharpest curve (at distances greater than 10 m). The sensor signals are passed through a low-pass filter with a cutoff frequency of 35 Hz to allow for accurate measurements of pulse width modulated light sources such as LEDs. Each sensor is connected to its own transimpedance amplifier board that has fixed gains to yield a fast response while still minimizing linearity errors in the range of illuminance values for which the headlight ratings are assigned. Table 2 displays the photometer specifications.

Table 2
Gamma Scientific U68401 Photometer Specifications

Measurement	
Deviation of relative spectral response (f1')	<3%
Cosine correction error for incidence angles <25°	<3%
Cutoff frequency	35 Hz

The photometric data are collected with a National Instruments cRIO data acquisition system (Part # cRIO-9030). The system is fitted with 16-bit A/D conversion modules (Part # NI-9205) and a GPS time sync module (Part # NI-9467). Illuminance and GPS time data are sampled at 200 Hz. Any offset in the illuminance measurements made by each sensor is removed for each vehicle approach using the minimum ambient illumination from 1-5 seconds after the vehicle has passed the measurement location.

Pitch Correction

Visibility and glare illuminance values are assessed at heights of 25 and 110 cm, respectively. However, dynamic changes in vehicle pitch angle as the vehicle approaches the measurement location can produce relatively large changes in illuminance measured by the photometers at these specific heights. To produce results that are independent of vehicle suspension differences, as well as measurements that are repeatable at different locations on the IIHS test track and at other facilities, the data are processed to correct for the effects due to vehicle pitch. This process is outlined below.

1. Elevation profiles of the test track are measured for all of the approaches. An electronic self-leveling horizontal rotary laser system is used to take these measurements (Johnson model 40-6536, specified accuracy ±1.5 mm / 30 m). Measurements are taken approximately every 5 m

and used to calculate the height profile of the center of the approach lane relative to the center of the lane at the measurement location.

2. The vehicle pitch angle is collected during testing using the OxTS RT2002.
3. Any offset due to the installation angle of the OxTS RT2002 in the vehicle is calculated by averaging the pitch measurement while driving the vehicle over one portion of track in both directions at a fixed speed. This offset is removed from all of the pitch data collected during testing.
4. Photometers placed at different heights provide illuminance data at each measurement location.
5. After conducting a test, the pitch-corrected illuminance E_c is calculated using the following formula (see also Figure 1):

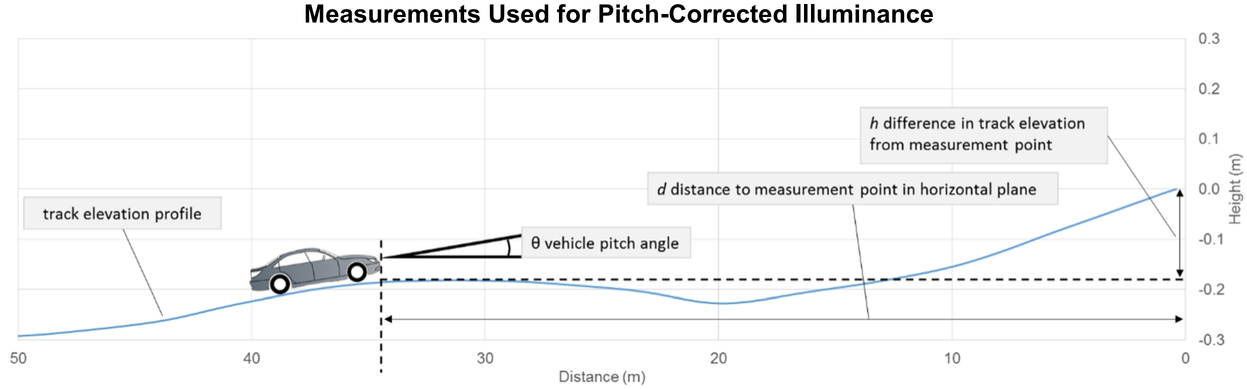
$$E_c = [(d \times \tan\theta) + h + z_t - z_1] \times \frac{(E_1 - E_2)}{(z_1 - z_2)} + E_1 \tag{1}$$

where d is the distance from the front of the vehicle to the measurement point in the horizontal plane, θ is the pitch angle of the vehicle (positive is up), h is the difference in track elevation from the measurement point to the front of the vehicle (positive when the track elevation at the vehicle is higher than at the measurement point), z_t is the target height for the measurement (25 cm for visibility and 110 cm for glare), z_1 and z_2 are the mounting heights of the two photometers used for a specific data point, and E_1 and E_2 are the illuminance values recorded by the two photometers.

The two photometers that are used at each point in the measurement are chosen based on the value of the total height offset represented by $(d \times \tan\theta) + h$. Adding this offset to z_t produces the ideal height at which a photometer would be placed to capture the desired measurement at a given point in time. The two sensors that have mounting heights closest to this ideal height are selected for use in Equation 1 (when one of the sensors is at exactly the ideal height, Equation 1 reduces to $E_c = E_1$). The number of photometers and the vertical spacing between them can be chosen based on the anticipated magnitude of the correction that will be needed and the headlamp mounting height.

It should be noted that on the curved approaches, the horizontal distance d in Equation 1 (and Figure 1) is the length of the tangent from the front center of the vehicle to the center of the lane at the measurement point (the origin 'x' in Figure 2), in contrast to the travel distance around the arc of the curve, which is used for the evaluation of illuminance distances described below.

Figure 1
Measurements Used for Pitch-Corrected Illuminance



TEST CONDITIONS

The test track is configured for the five different vehicle approaches listed in Table 3. For the curved approaches, the radius describes the center of the test vehicle's travel lane. The length of the curved approaches is 120 m measured along the arc of the curve, while the straightaway approach is 250 m long. At the end of each of the five approaches, illuminance measurements are recorded at specific locations shown in Figure 2. For the curved approaches, the visibility illuminance is measured at points 1 and 2, which correspond to the right and left edges of a 3.3 m wide travel lane. For the straightaway approach, visibility illuminance is measured at points 1 and 3, which correspond to the right and left edges of a 6.6 m wide road. For all five approaches, glare illuminance is measured at point 4, which corresponds to a point in the oncoming travel lane 3 m to the left of the center of the test vehicle's lane. All visibility illuminance measurements are made 25 cm from the ground, and the glare illuminance measurement is made 110 cm from the ground, with the readings at these heights corrected for changes in vehicle pitch as described above. The distance measurements are referenced to an origin that is laterally located in the center of the vehicle's travel lane at the same longitudinal position as the illuminance sensors. All illumination measurements are made in a vertical plane perpendicular to the road at this origin.

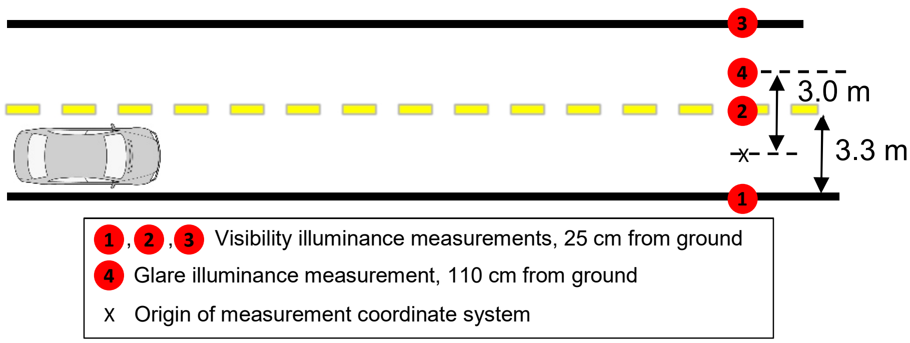
Table 3
Test Conditions

Approach	Length	Test speed	Location of visibility measurements (Fig. 2)
150 m radius right curve	120 m	65 km/h*	Points 1, 2
150 m radius left curve	120 m	65 km/h*	Points 1, 2
250 m radius right curve	120 m	80 km/h*	Points 1, 2
250 m radius left curve	120 m	80 km/h*	Points 1, 2
Straightaway	250 m	Any	Points 1, 3

*Applies to vehicles with active lighting systems only. Vehicles with static lighting systems are tested at any constant speed.

For a test to be considered valid, speed and lane keeping criteria must be met continuously for the entire test length (120 m for the curved approaches, and 250 m for the straightaway). The test speed must be maintained within ±3 km/h from nominal test speed. This nominal speed can be any speed for the straightaway condition and for vehicles without adaptive lighting functions. For vehicles with adaptive lighting functions, the nominal speed is 65 km/h on the 150 m radius curves and 80 km/h on the 250 m radius curves. For lane keeping, the front center of the vehicle must remain within ±30 cm from the lateral center of the approach lane.

Figure 2
Measurement Locations



VISIBILITY AND GLARE METRICS

After completion of a test, vehicle data are processed to determine whether the speed and lane keeping criteria were satisfied. If the test is valid, the vehicle position and illuminance measurements recorded on the test track are synced using the common GPS time signal. The visibility and glare illuminance measurements are corrected for vehicle pitch changes as described above and are then filtered by taking a moving average with 0.05 sec of data on both sides of each data point. The illuminance versus distance measurements are used to assess visibility and low beam glare performance.

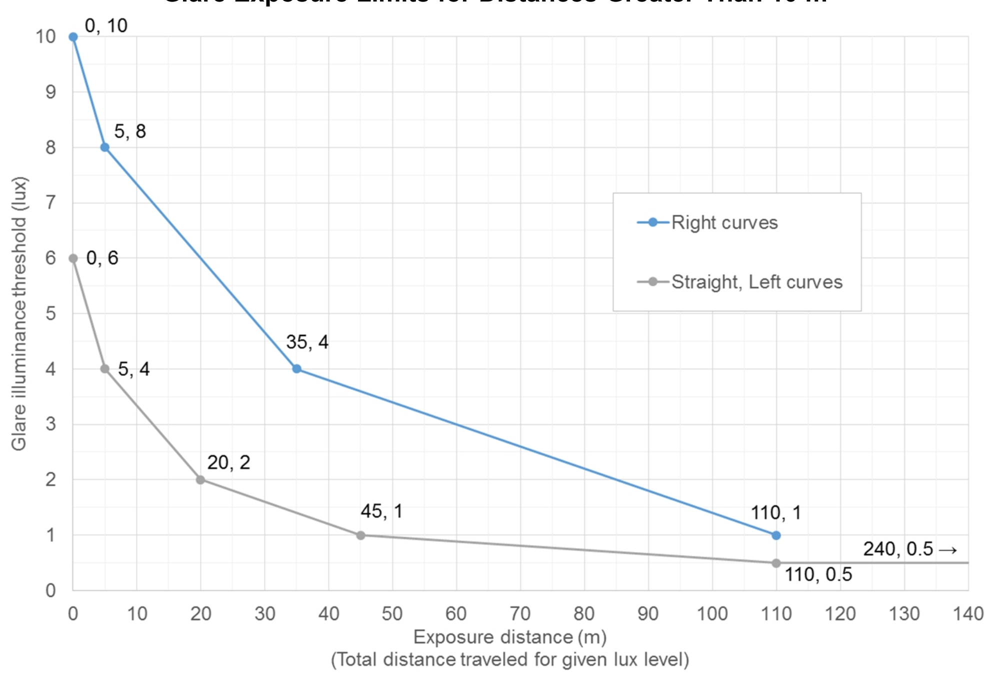
Visibility Metric

Visibility performance is assessed as the distance at which 5 lux is reached and continuously maintained until the vehicle is at most 10 m away, or 15 m for the left edge of the straightaway. The distance is defined as the travel distance of the vehicle along the center of the travel lane (the arc of the curve for curved tests) to the origin ('x' in Figure 2). For each visibility illuminance measurement point listed in Table 3, the overall 5 lux distance is obtained by averaging the results from three valid tests. Example visibility illuminance data are shown in Figure B1 in Appendix B.

Glare Metric

The glare illuminance produced by the low beams on a given approach is judged against two criteria. First, the maximum glare for 5-10 m should not exceed 10 lux. Second, the glare illuminance for the remainder of the approach (i.e., 10-120 m for curves and 10-250 m for the straightaway) should not exceed the cumulative exposure distance limits shown in Figure 3. The distance value for the glare limit reflects the maximum cumulative distance traveled during the approach for which the glare illuminance may exceed a given threshold lux level. The cumulative distance can include multiple illuminance peaks and is independent of the distance from the measurement point at which the glare illuminance occurred. Example glare illuminance data are shown in Appendix B. Glare illuminance at distances below 5 m is ignored due to sensor inaccuracies associated with greater light incidence angles.

Figure 3
Glare Exposure Limits for Distances Greater Than 10 m



OVERALL ASSESSMENT

The visibility and glare illuminance measurements are combined using a system of demerits to produce an overall assessment of a vehicle's headlight system. After completing three valid tests for a specific test condition and measurement location (e.g., right edge of travel lane), the 5 lux visibility distances from the three tests are averaged. For low beam tests, the full glare exposure curves and the peak glare illuminance values for 5-10 m also are averaged. Using these averages, visibility and glare demerits are calculated separately and then summed to determine the overall rating for the headlight system.

For each low and high beam test, the average 5 lux distance is used to calculate the visibility demerits, if any, for that test condition. For all of the curved approaches, 5 lux distances are calculated independently for the left and right edges of the travel lane (Figure 2, points 1 and 2) and the edge with the shortest visibility distance (left or right) is used to calculate and assign demerits for each condition. For the straightaway approach, demerits are calculated and assigned separately for the left and right edges of the road (Figure 2, points 1 and 3).

Table 4 and Figures 4 and 5 show the demerit scheme for all of the specific visibility measurements. Each demerit equation was defined using the range of 5 lux distances measured during research testing, with the "critical values" representing typical distances on the low end of this range and the "no demerit" distances on the high end. The demerits assigned to the critical value distances reflect the different weighting for each condition. Additional details are given in the companion document *Rationale and Supporting Work for Headlight Test and Rating Protocol*.

Figure 4
Low Beam Demerits

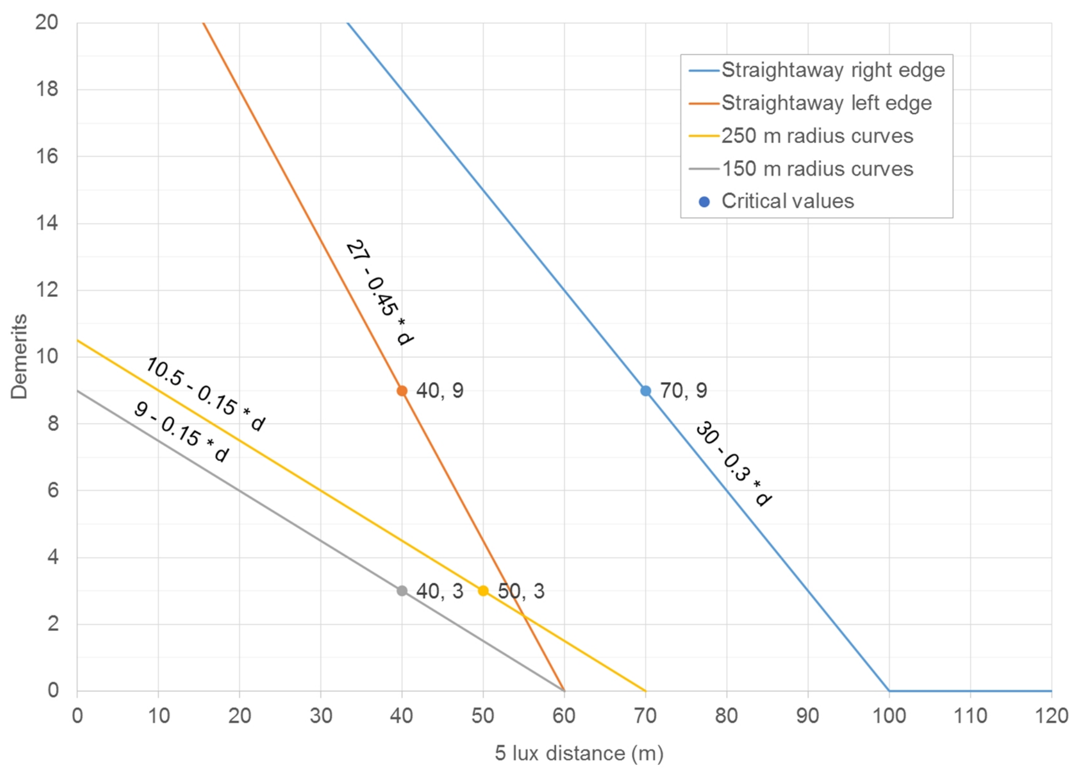
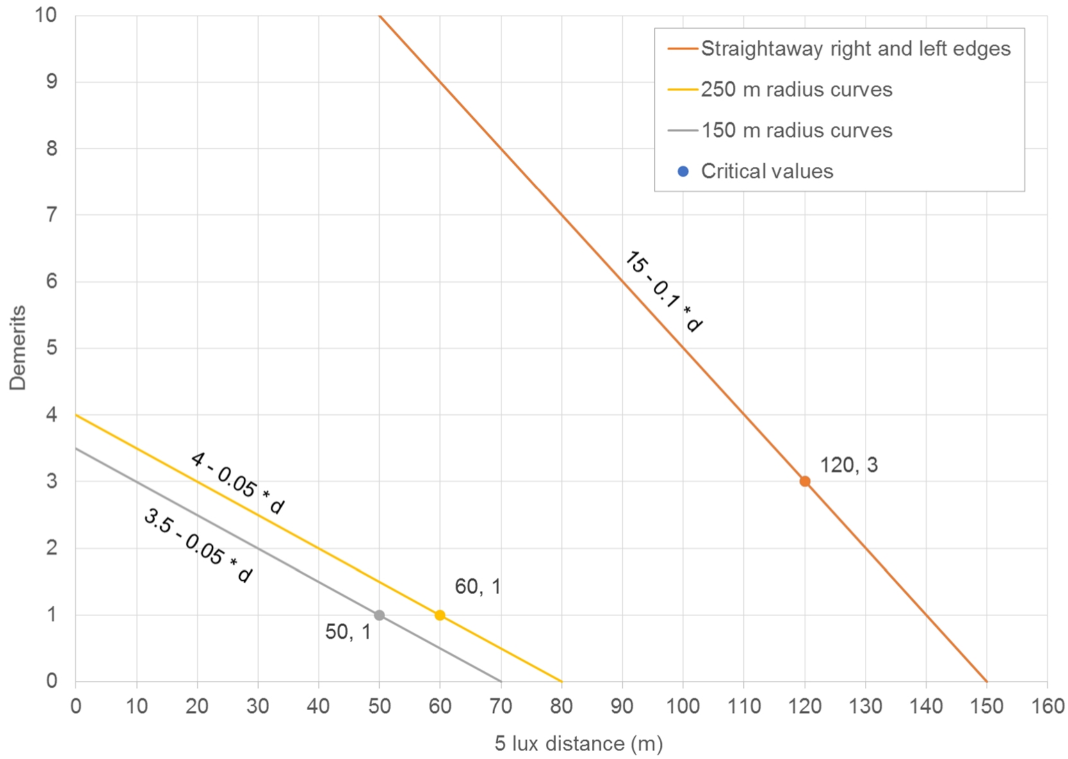


Figure 5
High Beam Demerits



Vehicles equipped with automatic high beam assist systems can obtain a reduction in visibility demerits for specific test conditions. If the 5 lux visibility distance for the high beam exceeds the 5 lux visibility distance for the low beam in the same measurement, then the demerit for the low beam test condition is reduced. The reduction for the specific test condition is determined by calculating the low beam visibility demerits that would result using both the low beam and high beam 5 lux distances for the given approach. The reduction is equivalent to one-third of the difference between these two demerit values. For example, if on the 250 m radius right curve the low beam 5 lux distance is 45 m and the high beam 5 lux distance is 55 m, the low beam demerits would be reduced by 0.5:

$$\frac{(10.5 - 0.15 \times 45) - (10.5 - 0.15 \times 55)}{3} = 0.5$$

If the high beam 5 lux distance produces 0 demerits in the low beam demerit equation, then the low beam visibility demerits are reduced by one-third.

If the glare thresholds were not crossed in any of the five low beam test conditions, then no glare demerits are assigned and the overall rating is determined from any visibility demerits. For each condition where a glare threshold was crossed, the maximum percentage by which the limit was exceeded is calculated by dividing the average glare exposure curve by the corresponding limit curve at 0.1 m increments (see Appendix B for an example). The maximum percentage also could come from the amount by which the average peak glare illuminance for 5-10 m exceeds 10 lux. To determine the number of glare demerits for each test condition, the maximum percentage that a limit is exceeded is multiplied by the corresponding glare demerit multiplier shown in Table 4. For example, if a vehicle exceeded the glare threshold on the straightaway by a maximum of 10 percent, it would receive 0.10 × 36 = 3.6 glare demerits.

Table 4
Demerit Values

Test condition	Visibility: Measurement location – edge of lane/road	Visibility: Min. 5 lux distance for no demerits	Visibility: Critical value	Visibility: Demerit calculation (d = 5 lux distance)	Glare: Demerit multiplier
Low beams					
Straightaway	Right	100 m	70 m = 9 points	30-0.3*d	36
	Left	60 m	40 m = 9 points	27-0.45*d	
250 m radius right curve	Right or left (min.)	70 m	50 m = 3 points	10.5-0.15*d	6
250 m radius left curve	Right or left (min.)	70 m	50 m = 3 points	10.5-0.15*d	6
150 m radius right curve	Right or left (min.)	60 m	40 m = 3 points	9-0.15*d	6
150 m radius left curve	Right or left (min.)	60 m	40 m = 3 points	9-0.15*d	6
High beams					
Straightaway	Right	150 m	120 m = 3 points	15-0.1*d	n/a
	Left	150 m	120 m = 3 points	15-0.1*d	
250 m radius right curve	Right or left (min.)	80 m	60 m = 1 point	4-0.05*d	n/a
250 m radius left curve	Right or left (min.)	80 m	60 m = 1 point	4-0.05*d	n/a
150 m radius right curve	Right or left (min.)	70 m	50 m = 1 point	3.5-0.05*d	n/a
150 m radius left curve	Right or left (min.)	70 m	50 m = 1 point	3.5-0.05*d	n/a

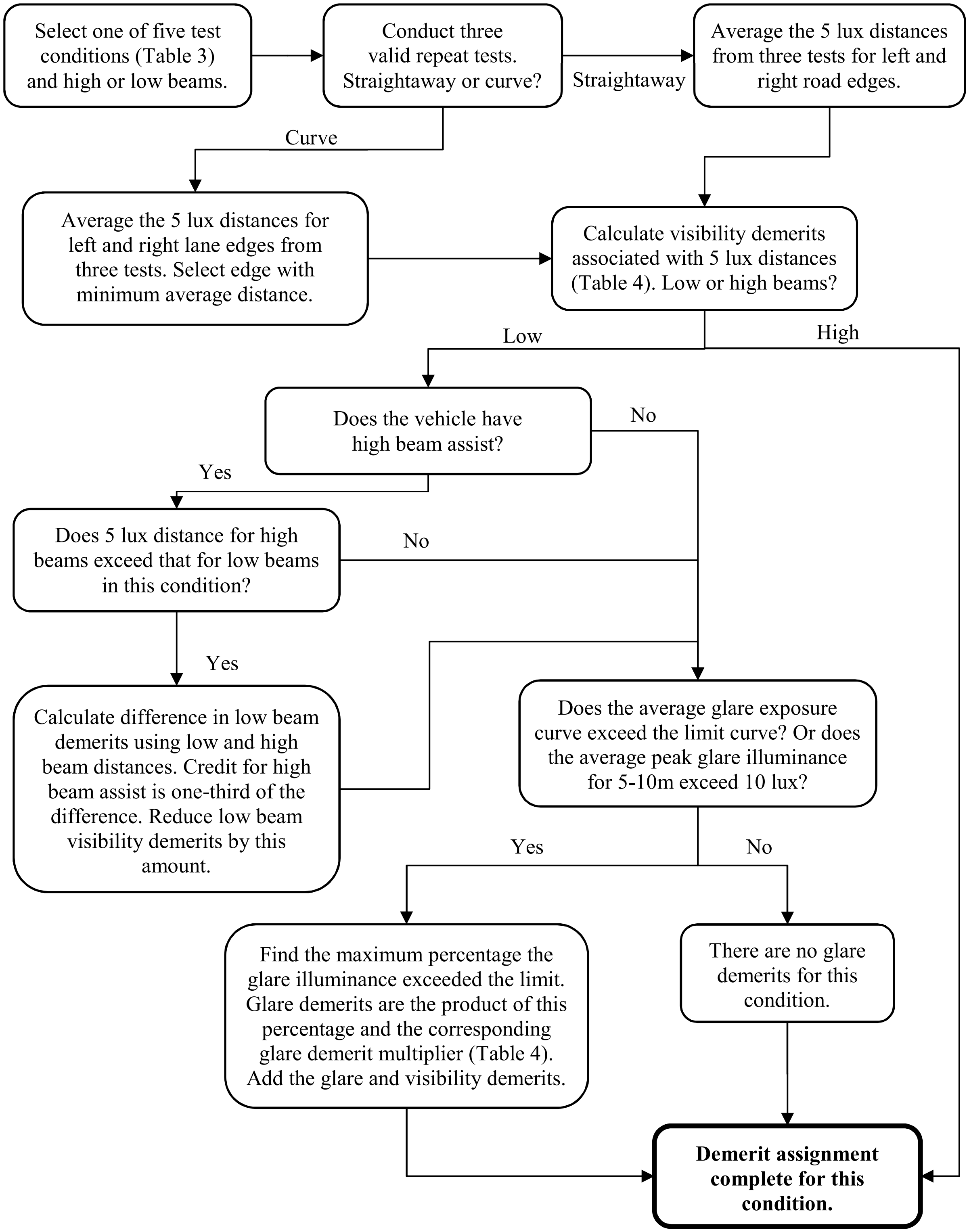
The flow chart in Figure 6 (next page) illustrates the process of combining visibility illuminance, glare illuminance, and the presence of high beam assist to assign demerits for each test condition.

The overall assessment for a vehicle is obtained by summing any demerits from all 12 low and high beam visibility measurements with any demerits from all 5 low beam glare measurements, and then rounding to the nearest whole demerit. The overall rating is assigned using the ranges in Table 5.

Table 5
Overall Rating Assignment

Headlight rating	Demerits
Good	0-10
Acceptable	11-20
Marginal	21-30
Poor	>30

Figure 6
Flow Chart: Assigning Demerits for a Test Condition



APPENDIX A

Document Revision History

Revisions to Version II of the protocol compared with Version I:

- Glare demerits and overall rating – Revises the procedure for including glare measurements in the rating. Instead of treating glare exposure as a "pass/fail" measurement relative to the boundaries, the percentage by which the exposure exceeds the boundaries is considered. Glare demerits are calculated separately for each curve and summed with the visibility demerits to determine the overall rating. Credit can be earned for high beam assist whether or not the glare boundary was exceeded. The overall rating is not adjusted after summing the demerits; headlight systems may have some glare demerits and still achieve a good or acceptable rating.
- Pitch correction – Equation 1 was generalized to show the pitch correction procedure independent of the number of photometers or their mounting height.

Version I is the first official version of this document following an initial draft published in August 2015. It contains the following differences from the initial draft:

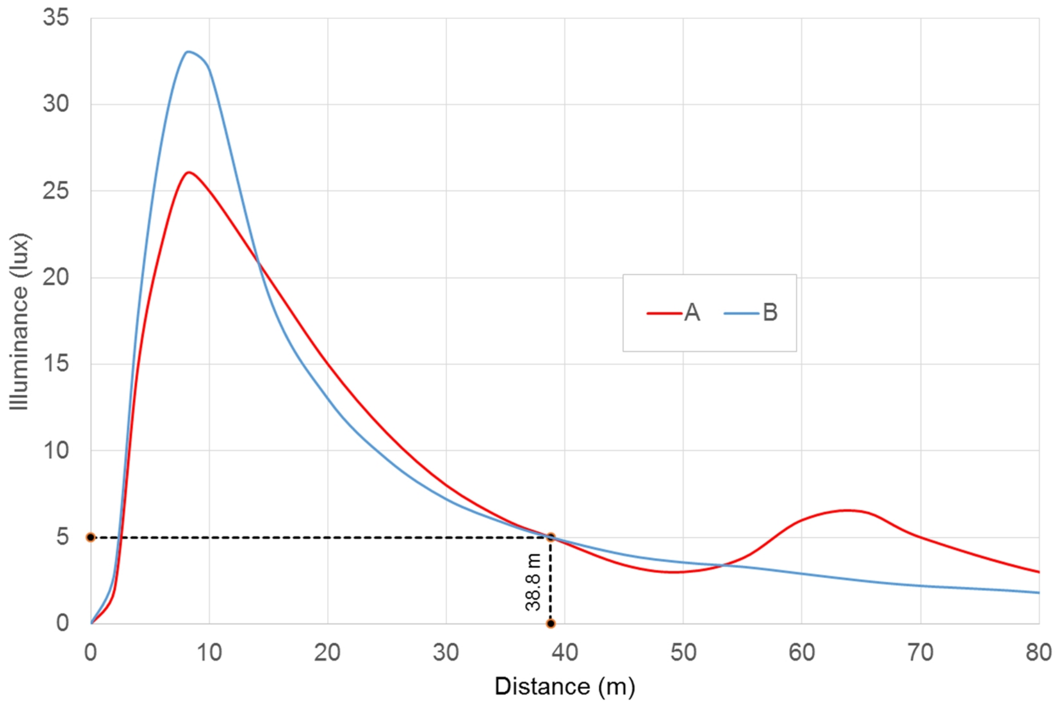
- Ambient conditions – Adds an objective criterion for environmental visibility; reduces minimum allowable ambient temperature; increases maximum allowable ambient illumination.
- Test vehicle preparation – Adds a maximum allowable mileage for a test vehicle; adds a minimum warm up time for LED headlamps; specifies a period of charging the vehicle battery prior to testing vehicles with halogen headlamps; adds procedure for selecting manual beam leveling, when equipped; adds procedure for suspension selection, when different suspensions are available for a vehicle model or when a given vehicle has driver-selectable suspension settings.
- Illuminance measurements – Specifies procedure for removing offset in illuminance measurements.
- Test conditions – Revises speed-keeping criteria for vehicles that do not have adaptive lighting functions; tightens lane-keeping criterion.
- Visibility and glare metrics – Specifies procedure for filtering pitch-corrected illuminance data; increases maximum distance from the vehicle at which the straightaway left edge visibility measurement can fall below 5 lux.
- Overall assessment – Specifies procedure for averaging glare metric from three valid runs; modifies procedure for calculating the bonus for high beam assist systems; defines overall rating boundaries.

APPENDIX B

Visibility Illuminance Examples

Figure B1 shows two example data curves, both of which result in 5 lux distances of 38.8 m. Although Example A initially reached the 5 lux level at a greater distance than this, the illumination fell below 5 lux again while the vehicle was still more than 10 m from the measurement point.

Figure B1
Example Visibility Illuminance Measurements



Glare Illuminance Examples

Figure B2 shows three example glare illuminance measurements for a left curved approach. All three fulfill the first glare criterion with maximum illuminance for 5-10 m below 10 lux. Examples A and B also remain under the threshold illuminance values for 10-120 m with identical illuminance threshold versus exposure distance curves (Figure B3). However, Example C does not remain below the allowable glare threshold. For example, the illuminance exceeds 2 lux for a total of 28.5 m of the approach distance, which is 8.5 m more than allowed. The arrows show the percentage by which Example C exceeds the limit at three different points. In this example, the maximum percentage over the limit is 33 percent. This percentage would be multiplied by the corresponding glare demerit multiplier in Table 4 to determine the number of glare demerits for this curve (0.33 × 6 = 2.0 glare demerits).

Figure B2
Example Glare Illuminance Measurements

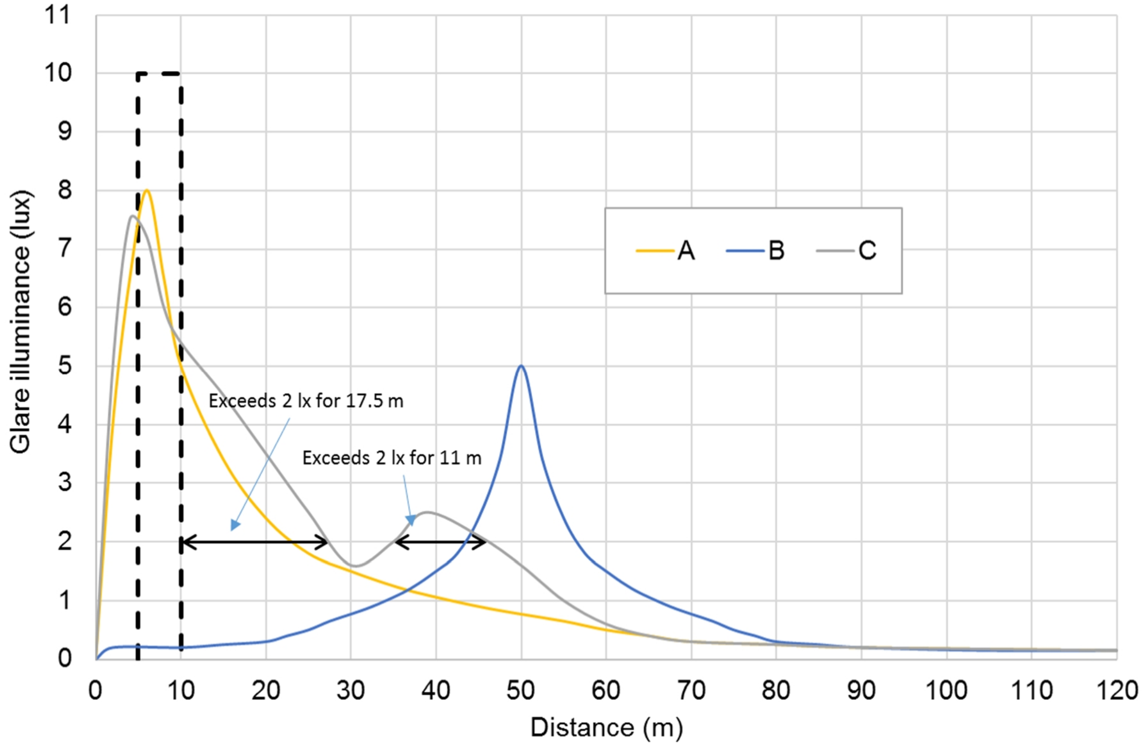


Figure B3
Example Glare Exposure Distances