Headlight Test and Rating Protocol (Version I)

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HEADLIGHT TEST AND RATING PROTOCOL (VERSION I)

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, three photometers are used at each measurement location. One photometer is located at the height of the target measurement, with the other two placed vertically above and below the target height. 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.

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 average obtained from 1 second of data 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. Additional photometers placed above and below the target measurement height provide illuminance data in all of the tests.
5. After conducting a test, the pitch-corrected illuminance E_c is calculated using the following formula (see also Figure 1):

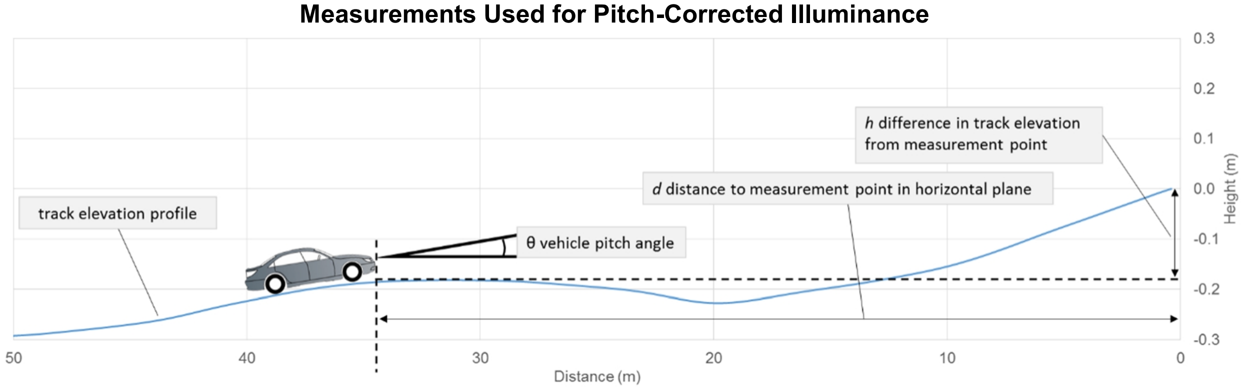
$$E_c = \frac{(d \times \tan\theta) + h}{v} \times (E_s - E_t) + E_t \tag{1}$$

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), v is the distance between the mounting heights of the photometers, E_t is the illuminance recorded by the photometer at the target measurement height, and E_s is the illuminance of the secondary photometer.

The secondary photometer is chosen based on the sign of the total height offset represented by $(d \times \tan\theta) + h$. When this value is positive, the illuminance from the top photometer is used; when this value is negative, the illuminance from the bottom photometer is used. In other words, the illuminance reading from the middle photometer (placed at the target measurement height) is always adjusted with the reading from only one of the other photometers. The vertical spacing v between the photometer mounting heights can be chosen based on the anticipated magnitude of the correction that will be needed and the headlamp mounting height. Typical values of v are 15 cm for the visibility measurements and 25 cm for the glare measurements (i.e., 15 and 25 cm above and below the target 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.

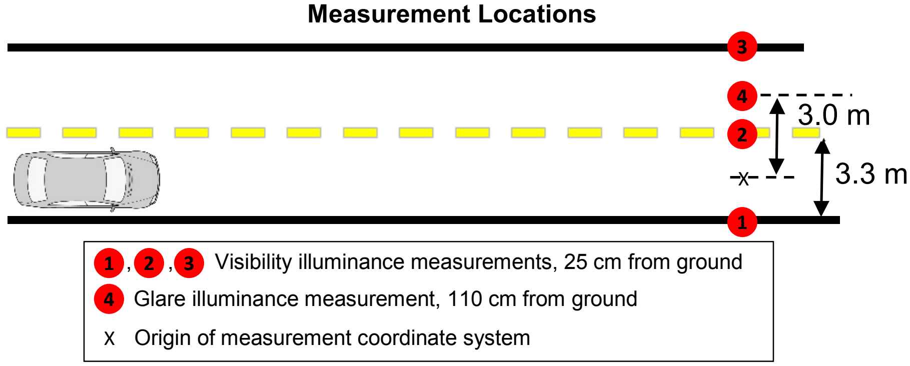
Table 3
Test Conditions

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 performance and low beam glare acceptability.

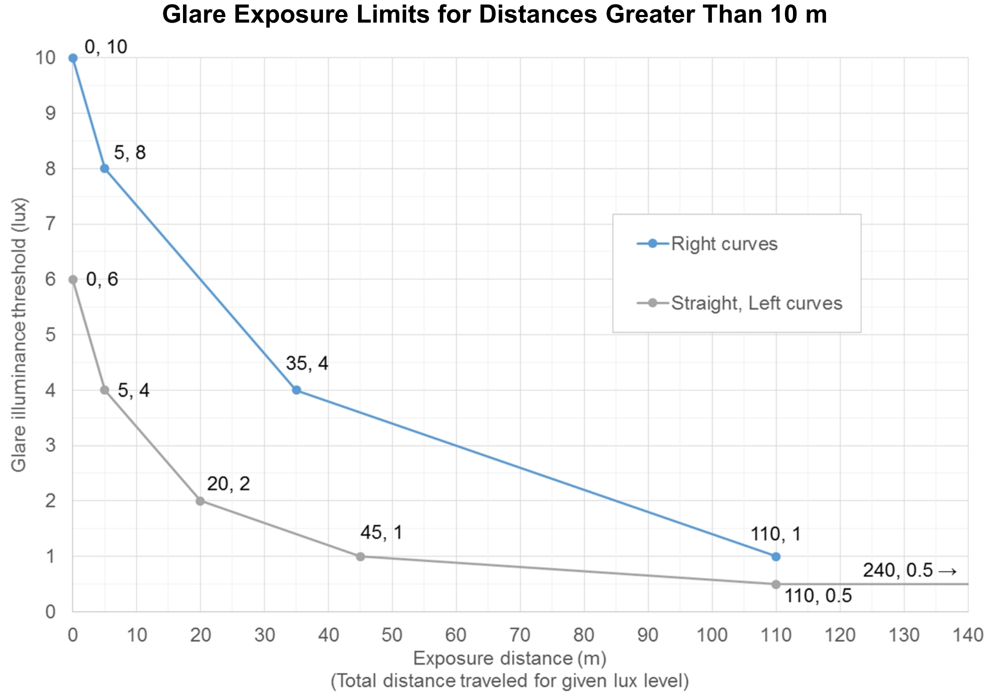
Visibility Metric

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 will be considered acceptable if it meets two criteria. First, the maximum glare from 5-10 m must 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) must 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 from 5-10 m also are averaged. For high beam tests, and for low beam tests where the average glare exposure does not exceed the threshold for the given condition, the average 5 lux visibility distance is used to calculate the 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

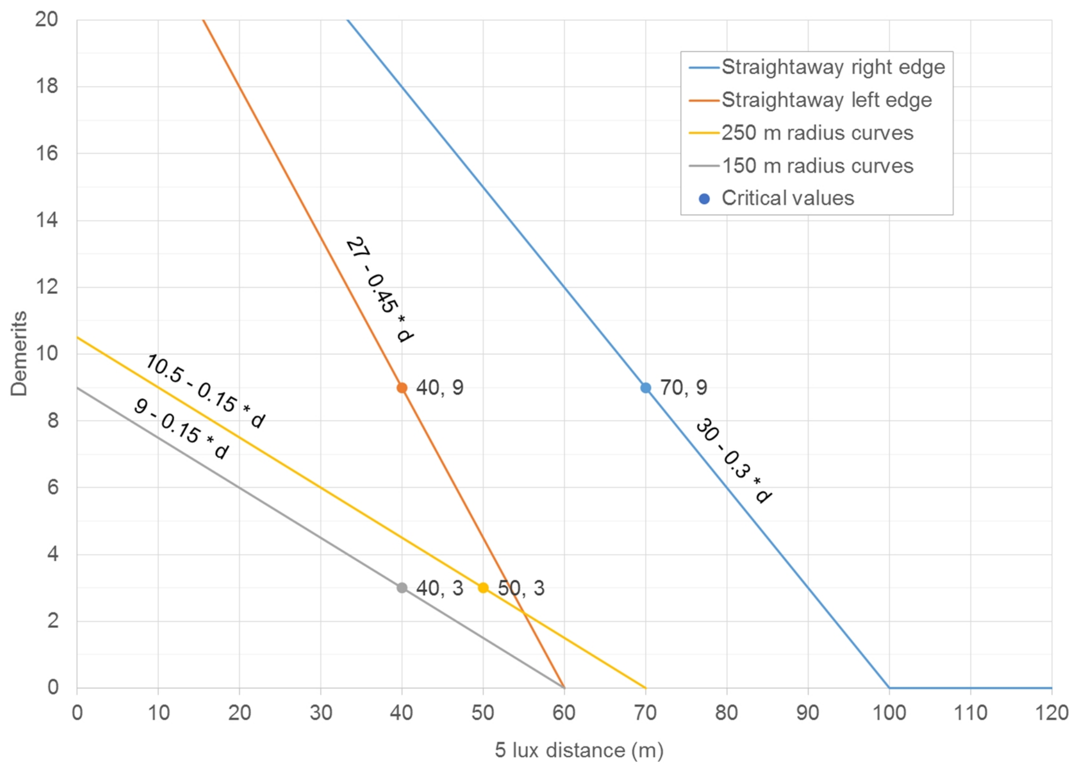
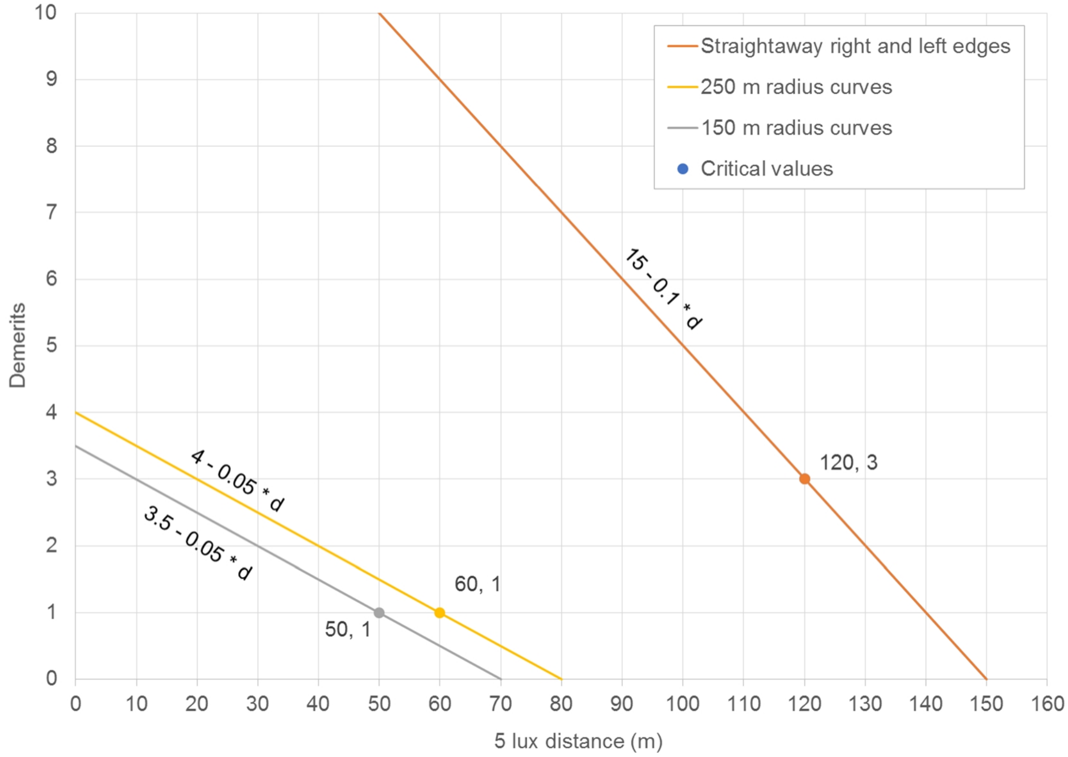


Figure 5
High Beam Demerits



If the glare threshold was crossed for a specific low beam condition, the vehicle is assigned either the demerits in the “Critical value” column in Table 4 for that condition or the demerits calculated using the average 5 lux visibility distance, whichever is greater.

Vehicles equipped with automatic high beam assist systems can obtain a reduction in demerits for specific test conditions. The demerit for the low beam test condition is reduced when the following conditions are met:

1. The low beam does not exceed the glare illuminance thresholds for the given test.
2. The 5 lux visibility distance for the high beam exceeds the 5 lux visibility distance for the low beam in the same measurement.

When these conditions are met, the demerit reduction for the specific test condition is determined by calculating the low beam demerits that would result using both the low beam and high beam 5 lux distances for the given curve. 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:

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

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

Table 4
Demerit Values

Visibility measurement	Minimum 5 lux distance for no demerits	Critical value	Demerit calculation (d=5 lux distance)
Low beams			
Straightaway right edge	100 m	70 m = 9 points	30-0.3*d
Straightaway left edge	60 m	40 m = 9 points	27-0.45*d
250 m radius right curve, right or left edge (min)	70 m	50 m = 3 points	10.5-0.15*d
250 m radius left curve, right or left edge (min)	70 m	50 m = 3 points	10.5-0.15*d
150 m radius right curve, right or left edge (min)	60 m	40 m = 3 points	9-0.15*d
150 m radius left curve, right or left edge (min)	60 m	40 m = 3 points	9-0.15*d
High beams			
Straightaway right edge	150 m	120 m = 3 points	15-0.1*d
Straightaway left edge	150 m	120 m = 3 points	15-0.1*d
250 m radius right curve, right or left edge (min)	80 m	60 m = 1 point	4-0.05*d
250 m radius left curve, right or left edge (min)	80 m	60 m = 1 point	4-0.05*d
150 m radius right curve, right or left edge (min)	70 m	50 m = 1 point	3.5-0.05*d
150 m radius left curve, right or left edge (min)	70 m	50 m = 1 point	3.5-0.05*d

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.

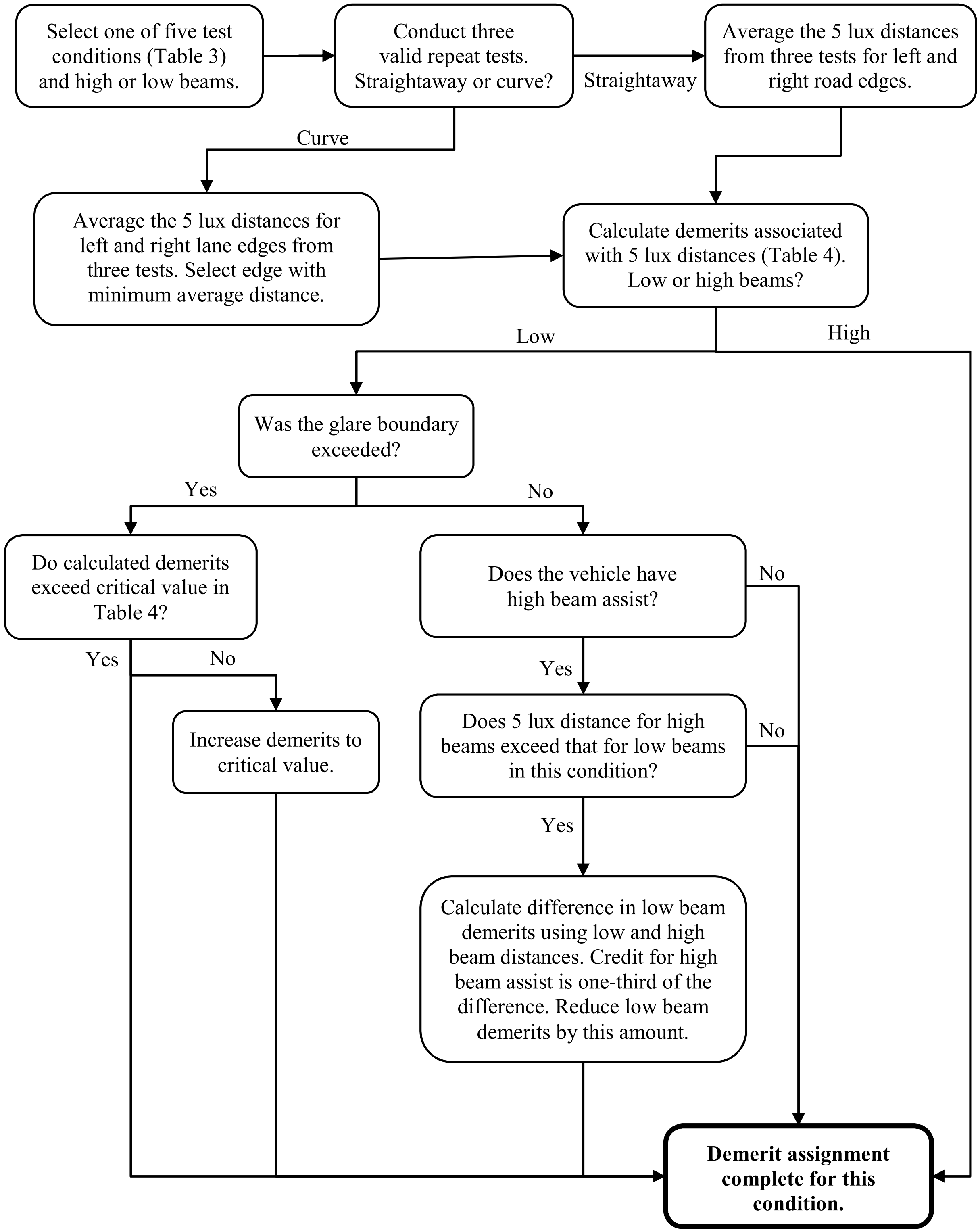
The overall assessment for a vehicle is obtained by adding the demerits from all 12 low and high beam measurements and then rounding to the nearest whole demerit. The rating is assigned using the ranges in Table 5, with the additional requirement that a vehicle receiving an overall rating of good or acceptable cannot exceed the glare threshold in any of the 5 low beam test conditions. Specifically, vehicles that have 20 or fewer demerits but exceed one or more glare boundaries will be assigned a marginal rating.

Table 5
Overall Rating Assignment

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

*Good or acceptable ratings are not assigned if any glare boundaries were exceeded

Figure 6
Flow Chart: Assigning Demerits for a Test Condition



APPENDIX A

Document Revision History

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:

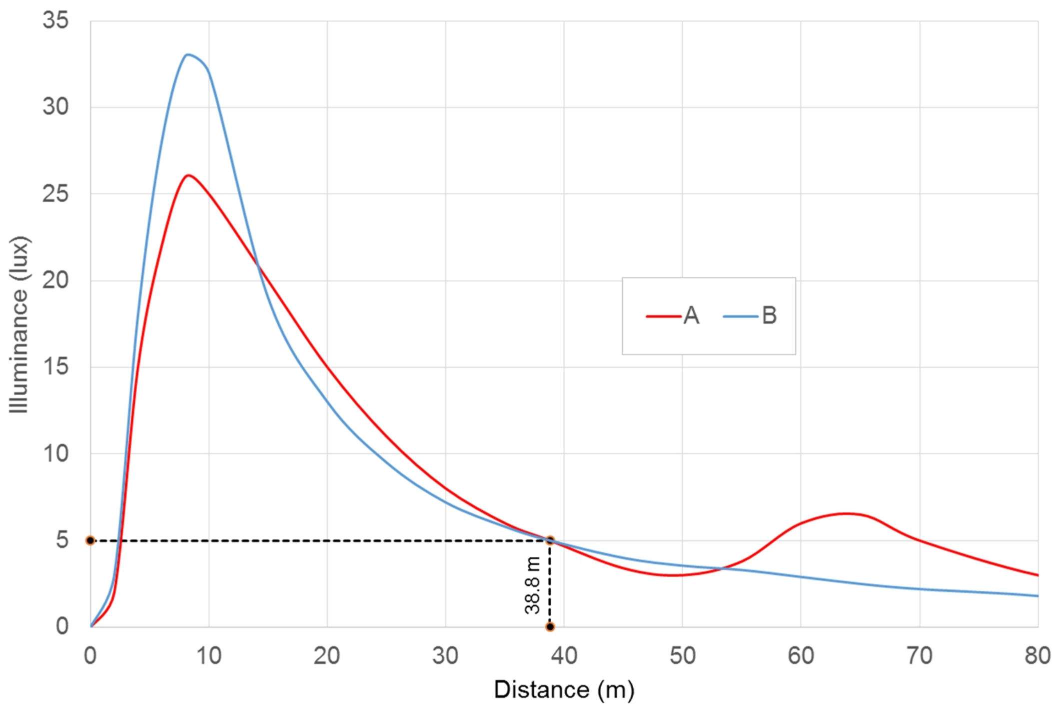
- Ambient conditions – Adds an objective criterion for environmental visibility; reduces minimum allowable ambient temperature; increases maximum allowable ambient illumination.
- Test vehicle preparation – Adds a maximum allowable mileage for a test vehicle; adds a minimum warm up time for LED headlamps; 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. While 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 of 5-10 m below 10 lux. Examples A and B also remain under the threshold illuminance values of 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 instance, the illuminance exceeds 2 lux for a total of 22 m of the approach distance, which is 2 m more than allowed.

Figure B2
Example Glare Illuminance Measurements

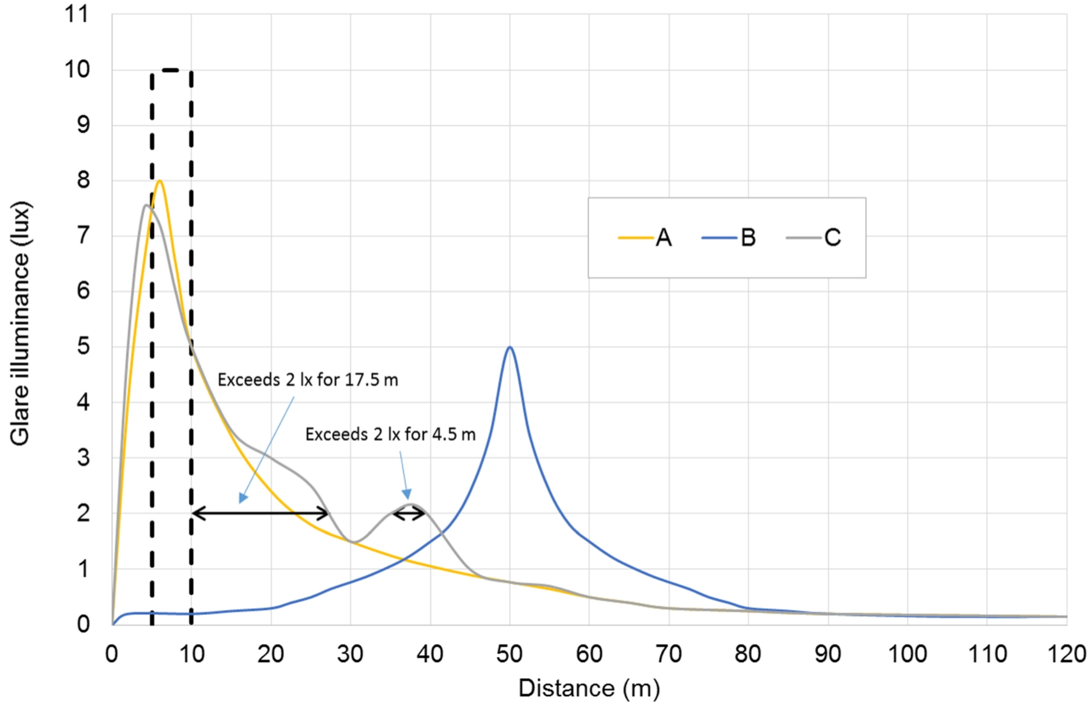


Figure B3
Example Glare Exposure Distances