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Adaptive Driving Beam Headlighting System Glare Assessment

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Executive Summary

NHTSA evaluated existing European Adaptive Driving Beam (ADB) headlighting systems, a type of front-lighting system that lets upper beam headlamps adapt their beam patterns to create shaded areas around oncoming and preceding vehicles to improve long-range visibility for the driver without causing discomfort, distraction, or glare to other road users. Europe and Japan have begun to allow ADB headlighting systems as optional equipment. Using European test procedures adapted for performance on test track courses, the amount of glare cast on other vehicles by ADB systems was measured. The work summarized here together provides a basis for the development of performance criteria and an objective test procedure for ADB headlighting systems.

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16. Abstract

This report summarizes NHTSA's evaluation of existing European adaptive driving beam headlighting systems. "Adaptive Driving Beam" (ADB) is a type of adaptive front-lighting system that automatically enables upper beam headlamps and adapts their beam patterns to create a shaded area around oncoming and preceding vehicles to improve long-range visibility for the driver without causing discomfort, distraction, or glare to other road users. In recent years, Europe and Japan have begun to allow adaptive beam headlighting systems as optional equipment. Using Economic Commission for Europe (ECE) test procedure maneuver scenarios for ADB and glare limit values derived from current static beam pattern information in FMVSS No. 108, the amount of glare cast on other vehicles by ADB systems was assessed. Overall in these tests, ADB was shown to have the ability to dynamically adapt the headlamp beams to shade oncoming and preceding vehicles. However, in many cases, ADB illuminance levels exceeded that of lower beam mode in the location of other vehicles. In particular, tested ADB systems exceeded derived lower beam glare limit values in curve scenarios involving both the ADB-equipped vehicle and other vehicle moving, and in intersection scenarios. Some ADB systems were also unable to control glare to lower beam levels in scenarios involving a motorcycle.

This effort was successful in objectively assessing the performance of European ADB headlighting systems. A comprehensive objective test procedure was achieved. The test procedure was developed based on driving scenarios from the ECE R48 test procedure and incorporated use of the glare limit values derived from existing static beam pattern requirements of FMVSS No. 108. Existing FMVSS No. 108 requirements and the work summarized here together can provide a basis for performance criteria and an objective test procedure for ADB headlighting systems. Existing FMVSS No. 108 requirements and the work summarized here together can provide a basis for objective performance criteria and an objective test procedure for assessing ADB headlighting system performance.

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EXECUTIVE SUMMARY

According to the Society of Automotive Engineers (SAE)[1], “Adaptive Driving Beam" is a “long-range forward visibility beam that adapts to the presence of opposing and preceding vehicles by modifying portions of its beam pattern to avoid glare above lower beam photometry levels to the drivers of opposing and preceding vehicles.” The goal of the system is to improve long-range visibility for the driver without causing discomfort, distraction, or glare to other road users.

In recent years, both Europe and Japan have begun to allow adaptive beam headlighting systems as optional equipment. However, Federal Motor Vehicle Safety Standard (FMVSS) No. 108, which regulates automotive lighting, signaling, and reflective devices in the United States, currently does not address this type of adaptive front-lighting system that does not switch between upper and lower beams. Recently, Toyota submitted a petition to NHTSA to initiate rulemaking to amend FMVSS No. 108, to permit the use of an advanced forward lighting design called “adaptive high-beam system (AHS)” on motor vehicles.

NHTSA conducted research that sought to learn about adaptive driving beam systems and the existing European test procedures that address the technology. The specific objectives of this test program were to:

- Assess the performance of light vehicle ADB headlighting systems using existing ECE (R48) test procedures modified for performance on proving ground test courses.
- Assess whether existing ECE R48 test procedures may be modified to achieve an objective and repeatable objective test procedure that assesses an ADB system’s ability to meet glare limit values derived from existing static beam pattern requirements of FMVSS No. 108.
- Conduct additional ADB performance testing using modified test procedures to gather objective data on ADB performance in a variety of vehicle traffic geometries.
- Gather information needed to develop a comprehensive objective test procedure consisting of a modified version of the ECE R48-based test procedure and incorporating use of the glare limit values derived from existing static beam pattern requirements of FMVSS No. 108.

Given that ADB is supposed to limit glare on other vehicles to associated level comparable to lower beam illumination, applying derived lower beam glare specifications from FMVSS No. 108 to illuminance data measured at points on the other/stimulus vehicle can provide information as to whether ADB succeeds in achieving its goal. Lower beam glare limit values were derived based on the current static test requirements in FMVSS No. 108 by Flannigan and Sullivan [10] in a 2011 UMTRI research effort. From the current static beam patterns, it was determined how much light is appropriate for road illumination, other drivers’ eyes, and sign illumination. For instance, based on the current requirements in Table XIX of FMVSS No. 108 [9], Flannigan and Sullivan [10] determined that approximately 3.109 lux (based on a test point with a maximum specified intensity of 700 cd) is the maximum illumination an oncoming driver should experience at locations near the approaching vehicle (around 15 m away), while at a distance of 60 m the maximum illumination is 0.634 lux. These derived range-based values for maximum allowable glare limits provide a basis for assessing how ADB illuminance levels compare to current FMVSS No. 108 standards.

The first phase of testing consisted of subjecting production European-specification ADB-equipped light vehicles to a proving grounds implementation of the existing ECE R48 test procedures called “Test Drive Specifications for Adaptive Main-Beam Headlamps.” The ECE approach involves observation of ADB performance in a variety of traffic scenarios. and the ECE approach was augmented by using instrumentation to measure the illuminance emitted by the ADB headlighting systems tested. Illuminance data were then compared to lower beam glare limit criteria derived from existing FMVSS No. 111 requirements to permit an objective evaluation of ADB performance.

To determine the set of test trials to run, the ECE Annex 12 test drive procedure conditions of "test sections" and "road types" were crossed to get a matrix of scenarios. Combinations considered impractical or not advisable, such as changing lanes in an intersection and passing on a winding road, were excluded from the trial set. Test courses used were all proving ground facilities located at the Transportation Research Center Inc. (TRC) in East Liberty, Ohio.

Results of the first phase of testing demonstrate the technical feasibility of headlamp illuminance measurement using a whole-vehicle test, as opposed to a component-level test. Assessment of ADB performance using scripted, dynamic maneuver scenarios based on ECE road test procedures was accomplished. Maneuver scenarios were identified that would likely elicit ADB response were identified. Illuminance measurements made outdoors in variable ambient illumination conditions were valid since ambient and extraneous illumination could be measured and subtracted from recorded headlighting system illuminance data. Phase 1 testing allowed for a preliminary assessment of the repeatability of test outcomes. Based on the Phase 1 testing results, other revisions to the Phase 2 test procedure were made to allow further examination of test repeatability in the second phase of testing.

The second phase of testing subjected ADB-equipped vehicles to a modified test procedure based on the ECE R48 protocol. Test procedure modifications investigated were focused on better engaging ADB functionality and improving test efficiency. Specific changes that were investigated included:

- Excluding illuminated roadway scenarios;
- Excluding scenarios with more than two vehicles;
- Excluding most low-speed scenarios in which ADB is not designed to operate; and
- Replacing the winding road scenario with a more mildly winding scenario that could be performed at a higher speed.

Since testing involved maneuver scenarios being performed on closed courses instead of public roadways, the maneuver scenarios were categorized by maneuver geometry rather than by traffic environment. The two main categories were:

- Oncoming, including angled intersection approaches; and
- Same-direction maneuver scenarios.

For comparison purposes, each maneuver was conducted twice, once with the headlighting system in lower beam mode and once in ADB mode for each set of test trials.

Examination of the repeatability of test results was also a main focus of the second phase of testing. Each maneuver was repeated two to three times so that individual repetitions could be compared in terms of consistency of both test outcome (i.e., glare limit exceedance) and measured illuminance values. Starting or stationary positions specific to each trial or maneuver scenario were used for both vehicles to promote consistency in how individual test trials were conducted. In addition, instrumentation used to measure the distance between vehicles was also used during setup of test trials to promote consistency of inter-vehicle range during measurements.

The points below summarize the main findings of this work:

- **General ADB Headlighting System Performance**:
  - In many cases ADB illuminance levels exceeded that of lower beam mode in the location of other vehicles. In most cases, the ADB systems tested consistently produced the same or greater glare than the lower beam of that vehicle.
  - ADB adaptation times measured in response to a suddenly appearing oncoming vehicle were less than 1.0 second for 3 of 4 tested vehicles. However, adaptation times in some other dynamic maneuver scenarios seemed subjectively long.
- **Maneuver scenario-specific findings for ADB performance**:
  - ADB in Straight Road Scenarios: The ADB systems produced similar glare as compared to that of lower beam on flat, straight roads when encountering oncoming and preceding passenger cars.
  - ADB in Intersection (Straight) Scenarios: All of the ADB systems produced considerably more glare in intersection scenarios than was seen with lower beam mode.
  - ADB in Curve Maneuver Scenarios: While all but one vehicle-maneuver scenario combination exceeded the derived glare limit values for ADB in oncoming curve maneuver scenarios, same direction curve maneuver scenarios proved less problematic. Only left curve same-direction maneuver scenarios where the preceding stimulus vehicle was stationary were associated with high glare values for ADB. This was true for both Small and SUV stimulus vehicles. Some systems limited glare better than others. There were no derived glare limit values exceeded for same direction, right curve maneuvers. It should be noted that no curve maneuver scenarios were run with the motorcycle.
  - ADB in Passing Maneuver Scenarios: The Lexus and Mercedes-Benz ADB systems exhibited glare levels similar to that seen with lower beam and within derived lower beam glare limits in all passing maneuver scenarios. High levels of glare with the BMW ADB system were only seen for the straight road passing maneuver with the Small DAS vehicle. The Audi ADB system produced high levels of glare in straight and right curve passing maneuvers with both sizes of DAS vehicle.
  - Maneuver Scenario Approach Direction: In terms of data variability related to test procedure effects, oncoming maneuvers tended to have smaller standard deviation values than did same-direction scenarios, particularly for trials in which the DAS vehicle was stationary.
  - ADB in Motorcycle Scenarios: One ADB system exceeded derived lower beam glare limit values in a scenario involving an oncoming motorcycle (Audi). All the ADB systems produced excessive glare in scenarios involving a preceding motorcycle.
  - ADB Performance in Encountering Stationary Versus Moving Vehicles: In some scenarios, ADB systems cast more glare on the moving DAS vehicle trial than on the stationary DAS vehicle. In scenarios involving both the ADB-equipped vehicle

and other vehicle moving, illuminance measured for tested ADB systems exceeded the derived lower beam glare limit values.

- **ADB System Response to Camera Obstruction**: When the ADB camera was fully obstructed, systems usually reverted to lower beam illumination, but not all systems responded quickly in reverting to lower beam. No ADB system's performance was affected by camera obstruction by a perforated windshield decal.

- **Development of ADB Test Procedures**:
  - This research shows that achieving a valid and repeatable, whole-vehicle objective test procedure for assessing ADB headlighting system performance with respect to relevant performance criteria is technically feasible.
  - ADB headlighting system performance showed differences in oncoming and same-direction scenarios, as well as straight, curved, and intersection roadway geometries.
  - Multiple test trials per scenario would serve to compensate for variability in dynamic maneuver scenario performance as well as ADB performance variability. More than three trials per scenario are recommended.
  - Use of a "conformance region" in a glare evaluation test procedure could serve to evaluate whether glare will be limited in driver locations for vehicle sizes spanning typical widths and statures.

- **Summary**:
  - This effort was successful in objectively assessing the performance of European ADB headlighting systems.
  - A comprehensive objective test procedure was achieved. The test procedure was developed based on driving scenarios from the ECE R48 test procedure and incorporated use of the glare limit values derived from existing static beam pattern requirements of FMVSS No. 108.
  - Overall in these tests, ADB was shown to have the ability to dynamically adapt the headlamp beams to shade oncoming and preceding vehicles. However:
    - In some cases, tested ADB systems did not succeed in shading other vehicles to lower beam illuminance levels derived from the current static test requirements in FMVSS No. 108.
  - Existing FMVSS No. 108 requirements and the work summarized here together can provide a basis for performance criteria and an objective test procedure for ADB headlighting systems.

1.0 INTRODUCTION

1.1 Background: Drivers’ Infrequent Use of Upper Beam Headlamps

Research spanning decades has documented drivers’ tendency toward infrequent use of upper beam headlamps.

- A 1968 survey by Hare and Hemion [1] found that only 25 percent of drivers in "open road" situations (neither following nor meeting another vehicle) switched their vehicles’ headlights to upper beam mode. The survey covered several regions across the United States and found that some degree of underuse was present in all regions.
- A 2004 study summarized in a paper by Sullivan et al. [2] found that little had changed with regard to drivers’ upper beam headlamp use in over 34 years. Drivers observed on unlit local roadways in the Ann Arbor, Michigan, area used upper beam headlamps only about 50 percent of the time in situations where their use would be reasonable and advisable.
- A 2006 UMTRI study by Mefford et al. [3] gathered information regarding drivers’ headlamp usage tendencies in conjunction with a crash warning system field operational test. Participants drove instrumented vehicles in their normal daily driving for periods of 7 to 27 days while their headlight use behavior was unknowingly observed. Drivers activated upper beams only 25.4 percent of the nighttime distance driven in situations where their use would be reasonable and advisable. Overall upper beam headlamp use was low, amounting to only 3.1 percent of the distance driven at night.
- A 2012 study examining “real-world use of high-beam headlamps” by Flannagan et al. [4] found that the large majority of 107 drivers who participated made very little use of upper beam headlamps. On average, these drivers used upper beam headlamps 33.2 hours per year. For example, 65 of the 108 drivers (60%) had annual rates of upper beam use less than 25 hours. The authors concluded that “…it is clear that for the great majority of drivers’ upper beam headlamp use is low, and, in fact, is substantially below what would be desirable for the best balance of seeing and glare protection.”

These studies highlight a clear trend of infrequent upper beam headlamp use by drivers. Citing this trend, Mefford et al. [3] concluded that “(1) increased high-beam use should be encouraged and (2) the use of automatic switching between high and low beams is likely to be beneficial.”

1.2 Adaptive Driving Beam

Automatic adjustment of the headlamp beam pattern can be accomplished through advanced front lighting systems, including “Adaptive Driving Beam," or ADB. According to the Society of Automotive Engineers, ADB is a “long-range forward visibility beam that adapts to the presence of opposing and preceding vehicles by modifying portions of its beam pattern to avoid glare above lower beam photometry levels to the drivers of opposing and preceding vehicles” [1]. The goal of the system is to improve long-range visibility for the driver without causing discomfort, distraction, or glare to other road users. The automatic adaptation of the beam pattern may not only serve as a convenience feature for drivers, but could result in increased, safety-beneficial upper beam use.

Improvements in motor vehicle safety may be realized by using technology to improve drivers’ view of the roadway at times when they might not take action to do so on their own (by switching the vehicle’s headlighting system to upper beam mode). A 2011 UMTRI report [6] summarizing an assessment of hypothetical ADB systems described potential benefits as follows:

> "…simulations of the effects of ADB systems on driver vision indicate that these systems can be expected to provide large improvements in pedestrian visibility over current low-beam headlighting. Although specific safety benefits cannot be inferred directly from studies of visibility, ADB systems therefore may offer substantial improvements in safety. The potential safety benefits of ADB systems can be expected to apply primarily to pedestrian crashes."

Toyota, in its March 2013 petition [7] to NHTSA submitted that its "Adaptive High-beam System" headlighting system design "offers potentially significant safety benefits in avoiding collisions with pedestrians, pedal cyclists and objects on the side of the road in unlit or low lit environments."

The concept of ADB technology presents a promising means of improving roadway environment illumination for drivers without glaring other road users. The following section describes actual, current ADB technology implementations.

1.3 ADB Technology

Per an ECE working document titled "Proposal for Amendments to Regulations 48 and 123" (Informal Document No. GRE-64-0; 64th GRE, 4-7 October 2010 agenda item 5(d)) [8]:

> "The Adaptive Main (Driving) Beam system is based upon a sensor that identifies the positions of other vehicles and an image processor and electronic control unit (ECU) sending signals to the headlamp that automatically adapts the light distribution of the main beam to provide optimised (sic) glare controlled illumination of the road scene ahead. The sensor, ECU and lighting electronics are similar to that used for the Adaptive Dipped Beam Cut-off Line system but the light technique and the headlamp construction differ to provide more flexibility in the way that the light distribution can be adapted both vertically and horizontally."

Current ADB systems require the driver to manually select ADB mode and are designed to activate at speeds above typical city driving speeds. Activation speeds of the test vehicles used in this research ranged from 19 to 43 mph (30.6 to 69.2 kph). When driving below these speeds, the vehicle reverts to lower beam headlamps.

An ADB system uses the existing front headlamps and either implements a mechanical shade that rotates in front of the headlamp beam to block part of the beam, or turns off individual bulbs of multi-light source systems (e.g., LED matrix systems). Other system components include:

- Sensor (camera and image processing unit)
- ECU
- Control on column stalk
- Instrument panel telltale (used to indicate that the system is activated; blue upper beam telltale also illuminates when any portion of the upper beam headlamp is on)

The figure below shows photographs of three headlighting system automatic mode telltales used to indicate ADB activation.

Figure 1. Headlighting System Automatic Mode Telltales Used to Indicate ADB Activation

1.4 Current State of ADB Availability

In recent years, both Europe and Japan have begun to allow adaptive beam headlighting system as optional equipment. Toyota's recent petition [7] asked NHTSA to initiate rulemaking to amend FMVSS No. 108 [9] to "explicitly allow" advanced forward lighting system technology, such as its "adaptive high-beam system (AHS). "

2.0 STUDY OBJECTIVES AND APPROACH

2.1 Objectives

This research sought to learn about existing European adaptive driving beam systems and the test procedures that address the technology. The specific objectives of this test program were to:

- Assess the performance of European light vehicle ADB headlamp systems using existing ECE test procedures modified for performance on proving ground test courses.
- Assess whether existing ECE test procedures may be modified to achieve an objective and repeatable objective test procedure that assesses an ADB system's ability to meet FMVSS No. 108-derived glare limit values.
- Conduct additional ADB performance testing using modified test procedures to gather objective data on ADB performance in a variety of vehicle traffic geometries.
- Gather information needed to develop a comprehensive objective test procedure consisting of a modified version of the ECE test procedure and incorporating use of the FMVSS No. 108-derivedglare limit values.

2.2 Approach

The goal of ADB is to aid the driver in seeing the roadway environment by providing upper beam illumination in some parts of the roadway, while shading the area in which another vehicle is located such as to not expose them to more glare than would be seen with lower beam headlamps. Given that ADB is supposed to limit glare on other vehicles to levels that would normally be associated with lower beam illumination, applying derived lower beam glare limit values to illuminance data measured at points on the other/stimulus vehicle can provide information as to whether ADB succeeds in achieving its goal. In this effort, the basic ECE approach of observing ADB performance in a variety of traffic scenarios was used but with modifcations. The ECE approach was augmented by using instrumentation to measure the illuminance emitted by the ADB headlighting systems tested. Illuminance data were then compared to lower beam glare limit criteria derived from existing FMVSS No. 111 requirements to permit an objective evaluation of ADB performance.

Derived lower beam glare limit values were based on the current static test requirements in FMVSS No. 108 by Flannigan and Sullivan [10] in a 2011 UMTRI research effort. The derived numbers are reasonable for use in dynamic objective testing of ADB systems because the values were obtained by translating the values from stationary, fixed-distance tests to values at a set of various distances that can be used in dynamic tests. From the current static beam patterns, it was determined how much light is appropriate for road illumination, other drivers' eyes, and sign illumination. For instance, based on the current requirements in Table XIX of FMVSS No. 108 [9], Flannigan and Sullivan [10] determined that approximately 3.109 lux (based on a test point with a maximum specified intensity of 700 cd) is the maximum illumination an oncoming driver should experience at locations near the approaching vehicle (around 15 m away), while at a distance of 60 m the maximum illumination is 0.634 lux. These range-based requirements for maximum allowable glare limits provide a basis for assessing how ADB illuminance levels compare to current FMVSS No. 108 standards. Tables 1 and 2 summarize the derived glare limit values.

Table 1. Glare Limits Derived From FMVSS No. 108, Oncoming Maneuvers

Range (m)	Illuminance (lux)
15.0 – 29.9 (49.2 – 98.1 ft)	3.109
30.0 – 59.9 (98.4 – 196.5 ft)	1.776
60.0 – 119.9 (196.9 – 393.4 ft)	0.634
120.0 – 239.9 (393.7 – (787.1 ft)	0.281

Table 2. Glare Limits Derived From FMVSS No. 108, Preceding Maneuvers

Range (m)	Illuminance (lux)
15.0 – 29.9 (49.2 – 98.1 ft)	18.854
30.0 – 59.9 (98.4 – 196.5 ft)	18.854
60.0 – 119.9 (196.9 – 393.4 ft)	4.041
120.0 – 239.9 (393.7 – (787.1 ft)	4.041

As existing lower beam headlamp static performance criteria cannot be applied to ADB systems, likewise the systems also cannot be tested using existing methods prescribed by FMVSS No. 108. Since ADB is a system that activates above a minimum driving speed and reacts dynamically to the environment, primarily to other vehicles on the roadway, a traditional, passive and stationary goniometer-based laboratory test procedure will not suffice for measurement of ADB performance. To develop an objective test procedure for evaluating ADB system performance, the following methodological aspects may need to be specified:

1. Dynamic, quantitative test procedure
    - Vehicle maneuver scenarios that effectively exercise ADB.
    - Minimum characteristics of a stimulus headlighting system that elicits ADB response, as needed.
    - Illuminance measurement location points that represent other-vehicle regions where glare should be controlled.
2. ADB performance criteria
    - E.g., glare illuminance measured within a specified region should not exceed the FMVSS No. 108-derived limits for maximum allowable glare. .

With the second point above covered at least in part by existing FMVSS No. 108 requirements, a series of tests were planned to address test procedure questions and whether any additional performance criteria for ADB systems may be warranted.

Two phases of testing were conducted: a first phase that implemented existing ECE road test procedures in a proving ground environment, and a second phase in which European ADB-equipped vehicles were subjected to a revised test procedure involving whole-vehicle, dynamic objective testing. The next section provides a brief summary of the ECE road test procedures for ADB systems.

3.0 DESCRIPTION OF ADB RELATED EUROPEAN REGULATIONS

The latest versions of ECE R48 [11] and R123 [12] together provide the basis for type approval of ADB headlighting systems in Europe. The tests conducted for approval include both a vehicle-level driving test, in which the ADB-equipped vehicle is exposed to specific driving situations and generally evaluated based on the headlighting system's functionality, as well as a laboratory test that evaluates the specific intensity emitted from the lamp.

The following table is from Annex 12 of ECE R48 [11], and shows the various test conditions ADB-equipped vehicles are subjected to during an on-road subjective evaluation. The test conditions include a range of traffic scenarios and densities and span three road types. Table cells marked with an 'X' indicate which scenarios are pursued in which road type environment. A person reviewing the system submitted for type approval would operate the vehicle in the noted conditions, observe the ADB system performance, and evaluate the performance with respect to the system performance description provided by the manufacturer.

Table 3. Conditions Used in Phase 1 ADB Testing, from ECE R48

		Road type		
	Traffic conditions	Urban areas	Multi-lane road, e.g. motorway	Country road
	Speed	50 ± 10kph (31 ± 6 mph)	100 ± 20kph (62 ± 12 mph)	80 ± 20kph (50 ± 12 mph)
Test Section	**Average percentage of the full test course length**	10 %	20 %	70 %
A	Single oncoming vehicle or single preceding vehicle in a frequency so that the adaptive main beam will react to demonstrate the adaptation process.		X	X
B	Combined oncoming and preceding traffic situations in a frequency so that the adaptive main beam will react to demonstrate the adaptation process.		X	X
C	Active and passive overtaking maneuvers, in a frequency so that the adaptive main beam will react to demonstrate the adaptation process.		X	X
D	Oncoming bicycle, as described in paragraph 6.22.9.3.1.2 (of ECE R48).			X
E	Combined oncoming and preceding traffic situations.	X		

ECE R48 [11] contains the following additional descriptions of the specified road types:

> "2.3. Urban areas shall comprise roads with and without illumination.
>
> 2.4. Country roads shall comprise sections having two lanes and sections having four or more lanes and shall include junctions, hills and/or slopes, dips and winding roads.
>
> 2.5. Multi lane (sic) roads (e.g. motorways) and country roads shall comprise sections having straight level parts with a length of more than 600 m. Additionally they shall comprise of sections having curves to the left and to the right."

ECE R48 [11] also contains the following additional description of an oncoming bicycle (test section D):

> “An oncoming bicycle at a distance extending to at least 75 m, its illumination represented by a white lamp with a luminous intensity of 150 cd with a light emitting area of 10cm² +/- 3cm² and a height above a ground of 0.8 m.”

Based on this ECE test procedure description, a set of specific test scenarios was developed that could be implemented in a controlled, proving ground environment. This development is described in Section 4.

4.0 PHASE 1 TEST METHOD: ECE-BASED TEST PROCEDURE

The first phase of testing consisted of subjecting production European-specification ADB-equipped light vehicles to a proving grounds implementation of the existing ECE R48 test procedures called "Test Drive Specifications for Adaptive Main-Beam Headlamps."

4.1 Implementation of ECE-Based Test Procedure

To determine the set of test trials to run, the ECE Annex 12 test drive procedure conditions of "test sections" and "road types" were crossed to get a matrix of scenarios. Combinations considered impractical or not advisable, such as changing lanes in an intersection and passing on a winding road, were excluded from the trial set.

Test courses used were all proving ground facilities located at the Transportation Research Center Inc. (TRC) in East Liberty, OH. Straight, level road sections all had lengths greater than 600 m (1969 ft). Left and right curve scenarios were conducted on the TRC's Vehicle Dynamics Area in the "South Loop," which had a radius of curvature of 764 ft (231 m). It should be noted that while many of the ECE scenarios are described as encountering other vehicles "in a frequency so that ADB will react to demonstrate adaptation," as implemented here, each trial included only a single instance of the described traffic interaction.

Tables 4 through 6 detail the dynamic maneuver scenario trial set used in the first phase of testing. Features of each trial are listed including ADB and other/stimulus vehicle speed, and vehicle positional relationships in terms of lane position.

Table 4. Phase 1 Dynamic Maneuver Scenarios, Part 1

SCENARIO DESCRIPTION	CONDITIONS (from *ADB vehicle perspective*)	LANE POSITION (i.e., stimulus vehicle is ___ as/from ADB vehicle)	SPEED Stimulus Vehicle (mph)	SPEED ADB Vehicle (mph)	HEADLIGHTING SYSTEM SETTINGS	TEST COURSE USED
Single oncoming vehicle (A)	Straight, level	In adjacent lane (1 lane over)	62 ± 12	62 ± 12	Lower, ADB, Upper	Skid pad
		2 lanes over	62 ± 12	62 ± 12	ADB	Skid pad
		3 lanes over	62 ± 12	62 ± 12	ADB	Skid pad
		4 lanes over	62 ± 12	62 ± 12	ADB	Skid pad
	Curve left	In adjacent lane	62 ± 12	62 ± 12	ADB	VDA S Loop
	Curve right		62 ± 12	62 ± 12	ADB	VDA S Loop
	2-lane, junction		0	40	Lower, ADB, Upper	WRC intersection
	2-lane junction		40	40	Lower, ADB, Upper	WRC intersection
	2-lane dip		50 ± 12	50 ± 12	ADB	PHRC
	2-lane dip		0	50 ± 12	Lower, ADB, Upper	PHRC
	2-lane hill		50 ± 12	50 ± 12	ADB	PHRC
	2-lane slope		50 ± 12	50 ± 12	ADB	PHRC
	2-lane winding		50 ± 12	50 ± 12	ADB	WRC F-H
Single preceding vehicle (A)	Straight, level	In same lane	62 ± 12	62 ± 12	ADB	Skid pad
		In adj. lane	62 ± 12	62 ± 12	Lower, ADB, Upper	
	Curve left	In same lane	62 ± 12	62 ± 12	ADB	VDA S Loop
	Curve right	In same lane	62 ± 12	62 ± 12	ADB	VDA S Loop
	Curve left	In adj. lane	62 ± 12	62 ± 12	ADB	VDA S Loop
	Curve right	In adj. lane	62 ± 12	62 ± 12	ADB	VDA S Loop
	2-lane junction	In same lane	40	40	ADB	WRC intersection
	2-lane dip	In same lane	50 ± 12	50 ± 12	ADB	PHRC
	2-lane hill	In same lane	50 ± 12	50 ± 12	Lower, ADB	PHRC
	2-lane slope	In same lane	50 ± 12	50 ± 12	Lower, ADB	PHRC
	2-lane winding	In same lane	50 ± 12	50 ± 12	ADB	WRC F-H

NOTE: "VDA" refers to TRC's Vehicle Dynamics Area.
"WRC" refers to TRC's Winding Road Course.
"PHRC" refers to TRC's Paved Hilly Road Course.

Table 5. Phase 1 Dynamic Maneuver Scenarios, Part 2

SCENARIO DESCRIPTION	CONDITIONS (from *ADB vehicle perspective*)	LANE POSITION (i.e., stimulus vehicle is ___ as/from ADB vehicle)	SPEED Stimulus Vehicle (mph)	SPEED ADB Vehicle (mph)	HEADLIGHTING SYSTEM SETTINGS	TEST COURSE USED
Combined oncoming and preceding traffic situations (B)	Straight, level	In same lane; other traffic oncoming in adj. lane	62 ± 12	62 ± 12	ADB	Skid pad
	Curve left		62 ± 12	62 ± 12	ADB	VDA S Loop CCW
	Curve right		62 ± 12	62 ± 12	ADB	VDA S Loop CW
	2-lane junction		50 ± 12	50 ± 12	ADB	WRC intersection
	2-lane dip		50 ± 12	50 ± 12	ADB	PHRC
	2-lane hill		50 ± 12	50 ± 12	ADB	PHRC
	2-lane slope		50 ± 12	50 ± 12	ADB	PHRC
	2-lane winding		25	25	ADB	WRC F-H
	2-lane winding	In same lane; 3rd vehicle oncoming in adj. lane at 0 mph	25	25	ADB	WRC F-H
Active overtaking (C)	Straight, level	In same lane	0	62 ± 12	ADB	Skid pad
			50	62 ± 12	Lower, ADB, Upper	
	Curve left		50	62 ± 12	ADB	VDA S Loop CCW
	Curve right		50	62 ± 12	ADB	VDA S Loop CW
	2-lane hill		50	62 ± 12	ADB	PHRC
	2-lane slope		50	62 ± 12	ADB	PHRC
Passive overtaking (C)	Straight, level	In same lane	62 ± 12	50	Lower, ADB, Upper	Skid pad
	Curve left		62 ± 12	50	ADB	VDA S Loop CCW
	Curve right		62 ± 12	50	ADB	VDA S Loop CW
	2-lane hill		62 ± 12	50	ADB	PHRC
	2-lane slope		62 ± 12	50	ADB	PHRC
Oncoming bicycle (D)	2-lane junction	In adj. lane	0	38	Lower, ADB, Upper	Skid pad
			15	38	Lower, ADB, Upper	
			15	50	Lower, ADB	

Table 6. Phase 1 Dynamic Maneuver Scenarios, Part 3

SCENARIO DESCRIPTION (all straight, level)	CONDITIONS (from *ADB vehicle perspective*)	Speed Stimulus Vehicle	Speed ADB Vehicle	Headlighting System Settings	Roadway Illumination
Combined oncoming and preceding traffic situations	ADB follows stimulus vehicle and encounters oncoming 3rd vehicle	20 mph	20 mph	ADB	Yes, No
Multi-vehicle preceding situations	ADB follows stimulus vehicle which is behind a 3rd vehicle, DAS turns left exiting platoon	20 mph	20 mph	ADB	Yes, No
Combined oncoming and preceding traffic situations	ADB follows stimulus vehicle; 3rd vehicle turns left across path between them	20 mph	20 mph	ADB	Yes, No
Multi-vehicle preceding situations	ADB follows stimulus vehicle; 3rd vehicle turns right between them joining their path	20 mph	20 mph	ADB	Yes, No

4.1.1 Multi-lane Road Maneuver Scenarios

Multi-lane road maneuver scenarios used both straight and curved roads with same and opposite direction travel (i.e., preceding (same direction) and oncoming other/stimulus vehicle). Active and passive passing maneuvers were conducted, as well as multi-vehicle (adding a third, oncoming vehicle) scenarios. Straight, multi-lane road type trials were conducted on TRC's Skid Pad facility. The facility has five paved lanes, each 12 feet in width and 3,600 feet long.

4.1.2 Country Road Maneuver Scenarios

Country maneuver scenarios used straight roads, as well as left and right curves. When possible, trial speeds were conducted at 50 mph (80.5 kph). Country road maneuver scenarios also included winding, uphill, down slope, and dip conditions.

For curved maneuvers, the South loop of TRC's Vehicle Dynamics Area was used. The curve has a radius of 764 feet (231 m) and the two lanes are each 12 feet in width. The loop has a length of 0.9 miles.

Country road junction (i.e., intersection) and winding road scenarios were conducted on TRC's Winding Road Course. This is generally a two-lane wide course in a rural setting in which the overall width is between 24 and 25 feet in most areas, with some curves having significantly wider widths. Two sections of the course were used for testing. The junction is approximately centered on a 1,550 feet straight section of the course, while the winding section is approximately 1,700 feet long and consists of four curves. Each curve was short in length with a fairly tight radius, which necessitated slow driving speeds on this section of the course.

Country road type scenarios involving a hill, slope, and dip were conducted on TRC's Paved and Gravel Hilly Road Course. The straight section containing several dips is approximately 2,100 feet long with two lanes that are approximately 9 feet wide. The hill and slope section is approximately 1,500 feet long with two lanes that are approximately 10.5 feet wide.

Bicycle scenario trials were conducted on TRC's Skid Pad facility. The scenario mimicked an oncoming bicycle located on the road berm approaching an ADB-equipped vehicle. The approaching bicycle was simulated by mounting a small, adjustable output light to the passenger-side of the other/stimulus vehicle, which was driven with its headlighting system off. The light, a Switronix TorchLED TL-50, was affixed to the front, passenger-side window of the other/stimulus vehicle with a suction cup and a Manfrotto Variable Friction Arm, model 2929QR. The mounting arm allowed the height of the bicycle headlamp to be adjusted to the ECE-specified 0.8m above the ground, and also allowed it to be quickly detached for conducting non-bicycle trials. To achieve the specifications for a bicycle lamp noted in ECE R48, a cover was fitted to the end of the light to reduce the light emitting area to 10 cm^2 +/- 3 cm^2. The light's output was also adjusted to meet the specification of 150 cd. During the test trials, the light was connected to a power inverter in the stimulus vehicle in order to maintain a consistent voltage level and lux output for the duration of the testing.

4.1.3 Urban Road Maneuver Scenarios

Urban road maneuver scenarios used straight road sections under both illuminated and unilluminated conditions. No specifications for urban scenario geometry are provided in the ECE ADB road test procedure, so scenarios were constructed involving different interactions and approaches amongst three vehicles. Three of four urban scenarios involved one of the three vehicles turning. Urban, illuminated intersection scenarios were designed to simulate various approach paths and geometries. Unilluminated urban scenarios were conducted on TRC's Skid Pad facility. The figure below illustrates these scenarios.

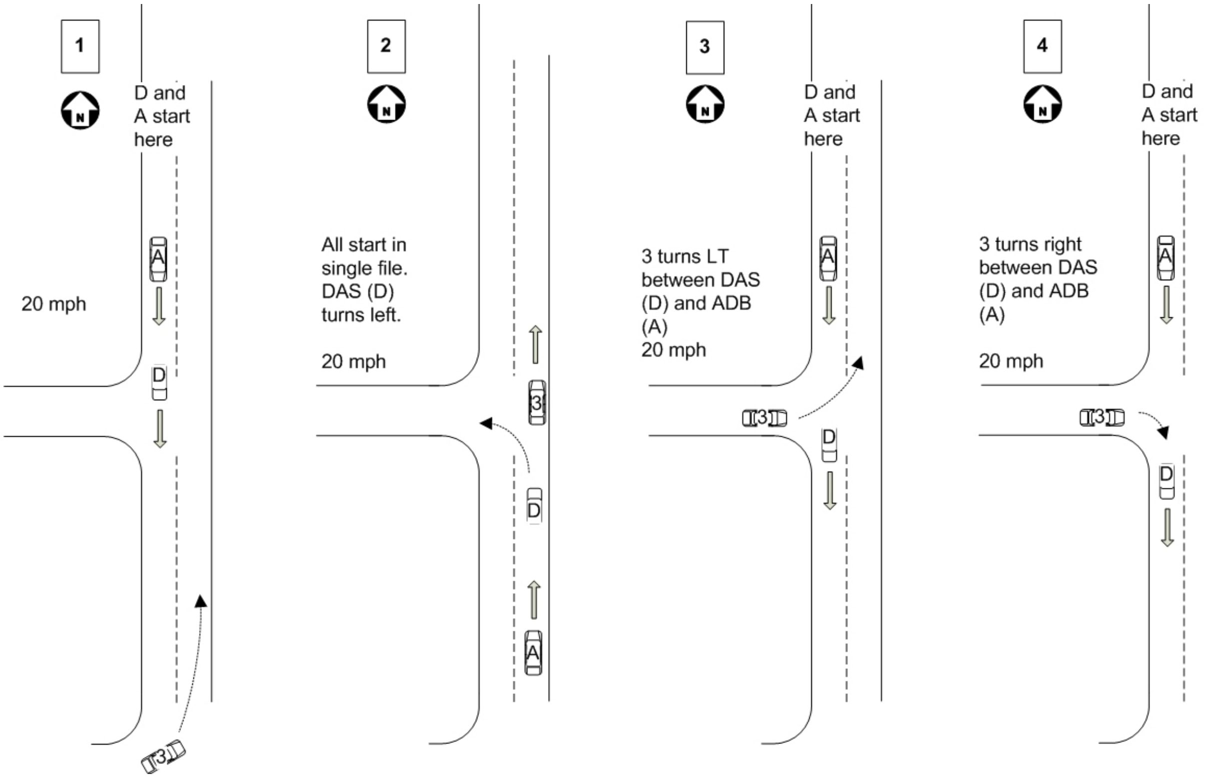

Figure 2. Illustrations of Urban Maneuver Scenarios (Where A = ADB Vehicle and D = DAS (stimulus) Vehicle)

4.2 Phase 1 Test Vehicles

Test vehicles used in both phases included four commercially-available European-specification ADB-equipped light vehicles. Two of the four vehicles were modified by the manufacturer to have beam patterns that conform to U.S. performance criteria as noted below.

- Audi A8 (2014)
    - "MatrixBeam" system
    - The vehicle's ADB activation speeds were reduced by the manufacturer from the original equipment European-specification setting to allow ADB to be engaged on shorter test courses. Activation speed was 19 mph (30.6 kph) and deactivation speed was 14 mph (22.5 kph). Original equipment settings have activation at 37 mph (59.5 kph), and deactivation below 25 mph (40.2 kph).
    - Audi indicated that the upper and lower beams of the vehicle tested were compliant with FMVSS No. 108.
- BMW X5 xDrive35i (2014)
    - "Adaptive High-Beam Assist"
    - Activation speed was 43 mph (69.2 kph) and deactivation speed was below 37 mph (59.5 kph).
- Lexus LS460 F Sport (2014)
    - "Adaptive high-beam system (AHS)" (previously referred to as "All Zone Beam" (AZB))
    - Activation speed was 37 mph (59.5 kph) and deactivation speed was below 31 mph (49.9 kph).
- Mercedes-Benz E350 (2014)
    - "Adaptive Highbeam Assist"
    - Activation speed was 19 mph (30.6 kph) and deactivation speed was below 19 mph (30.6 kph).
    - The vehicle manufacturer applied a software modification to the vehicle to produce a FMVSS No. 108-compliant upper and lower beam pattern.

For all vehicles, headlighting system automatic mode was engaged by moving the headlighting system control to the automatic mode position. To engage ADB mode, the turn signal stalk on the steering column was either moved longitudinally fore or aft, or a button on the end of the stalk was pushed.

For an headlighting system automatic mode telltale, each vehicle used a variation of the standard headlighting system symbol. Figure 1 showed photographs of three headlighting system automatic mode telltales used to indicate ADB activation. Two of the telltales were white in color, while the third was green (the center telltale in Figure 1).

A specific member of the research team drove all tested ADB-equipped vehicles in all maneuver scenario trials.

4.3 Measurements and Instrumentation

Data were continuously measured and recorded throughout each test scenario. For some trials, video footage was recorded to document the scenario. The specifics for measurement of individual data channels are described in the following section.

The ambient temperature and humidity conditions were also obtained for each test night based on proving grounds condition information maintained by the facility manager (Transportation Research Center Inc.).

4.3.1 Stimulus/DAS Vehicle

Phase 1 testing involved use of a “DAS” (Data Acquisition System) vehicle to create driving scenarios and record objective data. The DAS vehicle provided the “other/stimulus vehicle” headlighting system stimulus that elicited the ADB response. The equipment and instrumentation used to record test data were mounted to a 2011 Ford Fiesta Titanium hatchback with a standard original equipment headlighting system. The vehicle was purchased in the U.S. and was certified to FMVSS.

The Fiesta was referred to as the “DAS vehicle” (later in this report referred to as “Small DAS Vehicle”) and contained a DAS, sensors, and other equipment to collect illuminance readings and relative vehicle positioning (the distance between the test vehicles and the data collection vehicle). The vehicle was fitted with a commercially available roof rack for ease of mounting exterior equipment, such as illuminance receptor heads. The actual DAS used to collect the data from the various sources was a United Electronic Industries Cube (UEIPAC 600) data acquisition system. The components used for measuring illuminance and vehicle positioning are described in the following sections.

In all maneuver scenario trials except those involving a bicycle, the DAS vehicle’s headlighting system was set to the lower beam setting.

In all maneuver scenario trials for all tested ADB-equipped vehicles, the DAS vehicle was driven by the same person.

4.3.2 Illuminance Measurement Equipment

A Konica Minolta T-10A illuminance meter configured with multiple receptor heads was used to measure the amount of light from the tested ADB systems that reached the DAS vehicle. The unit is a multi-function digital illuminance meter with detachable receptor head. The unit was configured with multiple receptor heads connected in series to permit the measurement of separate illuminance values at various locations throughout and around the DAS vehicle. The separate illuminance data channels were recorded to the DAS at a frequency of 200 Hz. The T-10A had an operating temperature range of 14 to 104 degrees Fahrenheit (-10 to 40 degrees Celsius) and specified operating conditions of 85 percent or less (at 35°C/95°F) relative humidity with no condensation.

Eight receptor heads were installed to measure illuminance. Two forward-facing receptor heads were positioned inside the vehicle for both outer front seating positions. Two additional forward-facing receptor heads were mounted to the roof rack bar directly above the two interior ones. Two receptor heads that faced rearward were positioned adjacent to the forward facing roof-mounted receptor heads. A receptor head was positioned inside the vehicle at the driver’s eye point. Lastly, midway through testing, an eighth receptor head was added to the exterior of the vehicle at the driver’s side A-pillar (and at the proper eye point height).

Receptor heads 1 through 7 were positioned to coincide with the longitudinal coordinate of a 50th percentile male’s eye midpoint[1] when seated with the seat back at a 25-degree angle and

[1] For a description of the determination of the 50th percentile male seated driver’s eye midpoint, see Appendix A.

the seat adjusted to the midpoint of the longitudinal adjustment range and to the lowest point of all vertical adjustment ranges present. The point of view of a 50th percentile male driver was chosen as an average representation of driver eye location, as has been done in other recent NHTSA work relating to driver visibility [13, 14]. A piece of matte-finish material was affixed to the vehicle's roof to prevent light reflected from the roof affecting the measurements of the exterior, roof-mounted receptor heads. The locations of all 8 receptor heads are illustrated in the following figure.

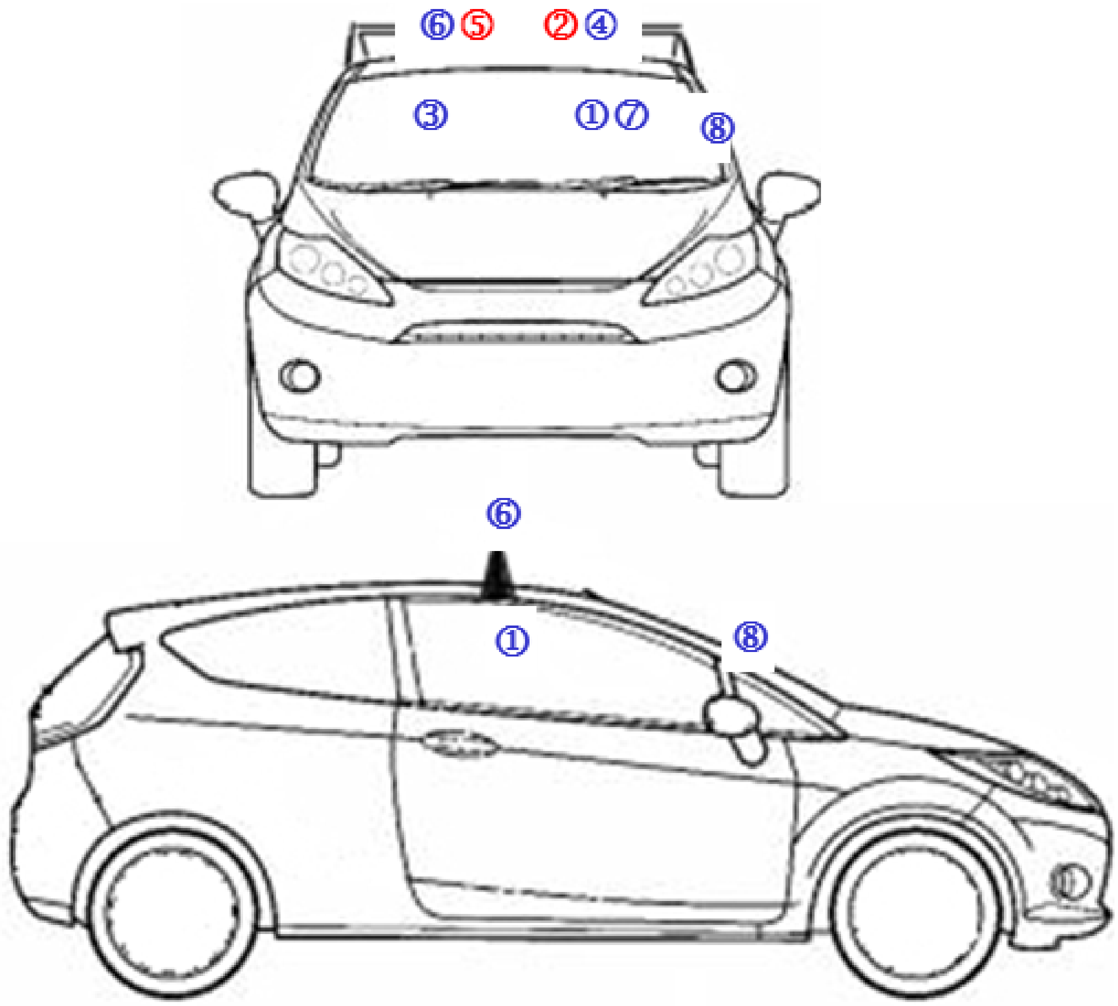

Figure 3. Illuminance Measurement, Receptor Head Positioning on DAS Vehicle, Phase 1

4.3.3 Distance Measurement Equipment

RT-range monitoring systems were installed in the ADB-equipped test vehicles and the DAS vehicle. These systems were used to detect and record the relative positions of the ADB-equipped vehicle and the DAS vehicle, which were used to determine the distance between the two vehicles in each of the test trials. This relative position and distance data were sent to the UEI Cube data acquisition system.

In the DAS vehicle, the RT-range monitoring system hardware consisted of a RT-Range Hunter (RT3000, Oxford Technical Solutions (OXTS)) differential GPS unit coupled with a RT3003 Inertial Measurement Unit (IMU) and a FreeWave (FreeWave Technologies, Inc.) wireless data transceiver. In the ADB-equipped vehicles, the hardware consisted of a RT-Range Target (RT3000) differential GPS unit coupled with a RT3002 IMU and a FreeWave wireless data transceiver.

4.3.4 Headlamp Voltage Measurement

Headlamp voltage for both the DAS vehicle and the ADB-equipped test vehicles was measured. To access headlamp voltage in the ADB vehicles, two wires were tapped in the main headlamp connector to acquire the voltage level at the headlamp. The acquired signal was run into a voltage divider to reduce the voltage to a level that allowed it to be fed into a small data acquisition system. The data acquisition system had a USB output that was connected to a laptop. The laptop ran a custom software program that read the incoming signal and multiplied it by a factor that resulted in values matching the original headlamp voltage values. The data were then recorded along with GPS time that was also collected by the laptop. Using GPS time, the voltage data were time synchronized to the DAS vehicle data.

The method for accessing headlamp voltage in the DAS vehicles was the same as for the ADB vehicles up until the point that the signal was sent to the DAS. At the DAS, custom software running on the DAS multiplied the values by a factor to correct the voltage to match the original headlamp voltage levels, before recording the voltage data.

4.4 Initial In-Laboratory Preparations

Headlamp aim for each of the ADB-equipped test vehicles was documented through photographs taken in a laboratory setting. Each vehicle was parked 20 feet from a vertical wall containing a grid. The headlighting system pattern projected on the grid was photographed and measurements were made to document the setup. No adjustment of headlamp aim was attempted for these European-specification test vehicles.

4.5 Test Procedure

Headlamp lenses, illuminance meter receptor heads, and the vehicles' windshields were cleaned before each evening of testing.

During each evening's test session, research staff performed the series of test scenarios following a test sheet, and made notes to document any noteworthy observed headlighting system behavior, such as flicker and activation conditions. Ambient temperature and humidity values were also monitored to ensure that test conditions complied with the operating conditions of the illuminance meter. Environmental conditions during testing involved no precipitation, dry or mostly dry pavement, and minimal ambient illumination.

A single set of static measurement and dynamic maneuver scenario trials was conducted for each ADB-equipped test vehicle. Completion of each ADB-equipped vehicle's single set of trials took multiple evenings as the research team familiarized themselves with procedures and scenarios.

4.5.1 Static Measurement Trials

Baseline illumination measurements were made nightly as part of each set of test trials to document environmental and DAS vehicle contributions to illuminance each test night. Baseline illuminance levels were recorded with the ADB and DAS vehicles running and positioned facing each other in adjacent lanes in a U.S. lane orientation at multiple separation distances (30 m, 60 m, and 120 m). Different headlighting system setting combinations were used for the ADB (lower, upper) and DAS (off, lower) vehicles at each distance (e.g., ADB-equipped vehicle with lower beams on, DAS vehicle headlighting system off in one trial, on in the next). Baseline headlighting system illuminance values were recorded for both NW and SE facing directions that corresponded to the approach directions used in the dynamic maneuver scenarios. Measured illuminance values documented what ambient illumination conditions the testing was conducted in as well as what output levels were associated with the different headlighting system settings.

“Headlamp warm-up trials” were conducted in which the DAS and ADB vehicles were running and positioned facing each other in adjacent lanes. The DAS vehicle’s headlighting system was off and the ADB vehicle’s headlighting system was cycled through off, lower beam, and upper beam settings. Headlighting system mode settings were held for 15 s, 30 s, and 60 seconds, respectively, while data were recorded. This trial was intended for use in examining the stability of light output from the headlighting system over time, as well as for illustrating differences in illuminance values across receptor head locations.

4.5.2 Dynamic Maneuver Scenario Trials

Dynamic maneuver scenarios were designed to exercise the ADB to allow assessment of ADB performance and measurement of glare illuminance for comparison to lower beam performance for each vehicle. The dynamic maneuvers described in Section 4.1 were performed in an order designed to allow completion of testing in the shortest time possible.

4.5.3 Subjective Glare Assessment

For dynamic maneuver scenario trials, the research staff member driving the DAS vehicle also subjectively rated perceived glare experienced during the dynamic maneuver scenario trials. Upon completion of each maneuver scenario trial, the DAS vehicle driver spoke a number corresponding to the De Boer scale. The De Boer [15] glare rating scale shown in Table 7 below was used for the subjective ratings.

Table 7. Subject Glare Rating Scale, De Boer 1967

Rating	Qualifier
1	Unbearable
2	
3	Disturbing
4	
5	Just Acceptable
6	
7	Satisfactory
8	
9	Just Noticeable

4.5.4 ADB System Response to Camera Obstruction

The ADB systems were tested to see how they would perform, and what warnings would be presented, if there was an ADB camera obstruction. ADB image failure check trials served to determine whether ADB systems failed in a safe way; i.e., that they did not default to full upper beam illumination, which would subject other drivers to a high amount of glare. The ADB camera was fully obscured by applying black tape to the vehicle’s windshield in front of the camera. Several trials were conducted in which the ADB-equipped vehicle drove toward the

DAS vehicle, which was parked in an adjacent lane with lower beam headlamps on. The behavior of the headlighting system was recorded along with any messages or warnings provided by the vehicle to the driver.

4.5.5 Repeatability Trials

A small set of additional trials were run to provide a preliminary look at test procedure repeatability. Maneuver scenarios included straight oncoming and passing maneuver scenarios, as well as oncoming curved roadway scenarios. Since the examination of repeatability was not originally planned for inclusion in the first phase of testing, only a single vehicle was examined (the Lexus LS460).

4.5.6 Data Quality Checks

Data review also involved ensuring that measured illuminance values changed appropriately in response to the detection of another vehicle's headlighting system. In addition, headlamp voltage data were examined for any voltage fluctuations that may have affected headlighting system performance or output during the test trials.

4.6 Data Analysis

The objectives of the data analyses were to assess the ability of the test procedures to exercise ADB functionality, characterize headlamp performance, and provide repeatable test outcomes. Data analysis involved summarizing and plotting measured illuminance values by scenario and distance, for comparison to a set of glare limit values derived from FMVSS No. 108.

The following defines the derived glare limit values used for comparison to the measured illuminance values. The illumination reaching the eyes of a driver approached by an oncoming ADB-equipped vehicle was assessed with respect to the glare limit values developed by Flannigan and Sullivan [10] for distances from 120 m to 15 m (far distances require a lower maximum because the glare source is nearer the line of sight). Thus, data from oncoming test maneuvers were compared to these maximum illuminance glare limits to determine whether or not the DAS vehicle driver experienced glare from the ADB vehicle. To determine if an unacceptable degree of glare was experienced, the maximum illuminance values recorded over various distance ranges during the oncoming maneuvers were compared to these derived glare limit values: 3.109 lux at a range of 15 m to 30 m, 1.776 lux at a range of 30 m to 60 m, 0.634 lux at a range of 60 m to 120 m, and 0.281 lux beyond 120 meters. The range is defined as the longitudinal distance from the ADB vehicle's headlamps to the receptor head locations on the DAS vehicle. For same direction (preceding and lane change) maneuvers, the derived glare limit values are: 18.854 lux at a range of 15 m to 60 m, and 4.041 lux beyond 60 meters.

To simplify analysis, maneuver scenarios were categorized according to which receptor heads were directly facing the approaching ADB-equipped vehicle for that particular maneuver geometry. For example, oncoming maneuvers were analyzed based on data from forward-facing receptor heads. DAS preceding (same direction) maneuvers were analyzed based on data from rear-facing receptor heads.

4.6.1 Data Adjustments for Comparison to Glare Limit Values

Before the illuminance data was analyzed, the distance and illuminance data were both adjusted to permit a more accurate comparison to the glare limit values. Since the actual measured distance was that between GPS antennas mounted on the roofs of the DAS and ADB vehicles, the longitudinal distance had to be adjusted to obtain the distance from each receptor head's position on the DAS vehicle to the ADB-equipped vehicle's headlamp locations. In addition, illuminance was adjusted to remove the illuminance contribution from the DAS vehicle’s headlighting system and any environmental ambient illumination. These adjustments are described in more detail in Appendix A.

5.0 PHASE 1 TEST RESULTS

Analyses were conducted to assess the ability of objective test procedures based on ECE road test scenarios to characterize headlamp performance, exercise ADB functionality, and provide repeatable test outcomes. Selected data and results are presented here to address those points.

5.1 Headlighting System Illuminance Static Measurements

Baseline headlamp performance was characterized through illuminance levels recorded in an outdoor, static scenario. The ADB and DAS vehicles with their engines running were parked facing each other in adjacent lanes (U.S. lane orientation) at multiple separation distances. Table 8 summarizes average illuminance for the four vehicles' headlighting systems for both lower and upper beam modes measured at 30 m, 60 m, and 120 m distances. For each trial, illuminance was recorded over a 20-second period and then an average value was calculated. Values represent the average of all trial repetition averages (along with the corresponding standard deviation. Average ambient illumination values are also included in the table to document the conditions in which testing was conducted. Ambient illumination for the initial phase of testing was generally 0.1 lux or lower.

Table 8. Baseline Measured Illuminance Values by Headlighting System Mode and Ambient Conditions (Receptor Head 4)

DAS Vehicle Heading	Distance	Headlighting System Setting		Audi A8 (n=4)		BMW X5 (n=2)		Lexus LS460 (n=3)		Mercedes-Benz E350 (n=3)	
		ADB	DAS	Average (lux)	SD	Average (lux)	SD	Average (lux)	SD	Average (lux)	SD
NW	N/A	OFF (ambient)	OFF (ambient)	N/A	N/A	0.06	0.03	0.01	N/A	N/A	N/A
NW	30 m (98 ft)	OFF	LOW	N/A	N/A	0.32	0.22	0.40	0.01	0.36	0.02
NW	30 m (98 ft)	LOWER	LOW	1.71	0.41	1.89	0.24	1.46	0.10	1.41	0.09
NW	30 m (98 ft)	LOWER	OFF	1.31	0.41	1.62	0.40	1.08	0.09	1.07	0.10
NW	30 m (98 ft)	UPPER	OFF	N/A	N/A	N/A	N/A	27.62*	3.32*	N/A	N/A
NW	60 m (197 ft)	LOWER	LOW	0.81	0.09	0.70	0.11	0.72	0.02	0.67	0.03
NW	60 m (197 ft)	LOWER	OFF	0.40	0.10	0.43	0.08	0.32	0.00	0.34	0.02
NW	60 m (197 ft)	UPPER	OFF	N/A	N/A	N/A	N/A	29.97*	2.49*	N/A	N/A
NW	120 m (394 ft)	LOWER	LOW	0.53	0.04	0.42	0.22	0.48	0.02	0.47	0.02
NW	120 m (394 ft)	LOWER	OFF	0.14	0.01	0.14	0.00	0.10	0.02	0.11	0.01
NW	120 m (394 ft)	UPPER	OFF	N/A	N/A	N/A	N/A	15.53	0.17	N/A	N/A
SE	N/A	OFF (ambient)	OFF (ambient)	0.08	0.05	0.08	0.00	0.05	0.00	0.03	0.01
SE	30 m (98 ft)	OFF	LOW	0.49	0.02	0.37	0.26	0.43	0.01	0.41	0.05
SE	30 m (98 ft)	LOWER	LOW	1.81	0.55	2.29	0.94	1.47	0.14	1.39	0.02
SE	30 m (98 ft)	LOWER	OFF	1.39	0.56	2.02	1.18	1.08	0.15	0.99	0.01
SE	30 m (98 ft)	UPPER	OFF	N/A	N/A	N/A	N/A	27.68*	5.24*	N/A	N/A
SE	60 m (197 ft)	LOWER	LOW	0.87	0.09	0.72	0.09	0.72	0.02	0.72	0.04
SE	60 m (197 ft)	LOWER	OFF	0.45	0.12	0.46	0.12	0.34	0.00	0.36	0.02
SE	60 m (197 ft)	UPPER	OFF	N/A	N/A	N/A	N/A	30.58*	1.17*	N/A	N/A
SE	120 m (394 ft)	LOWER	LOW	0.64	0.09	0.41	0.21	0.49	0.01	0.48	0.07
SE	120 m (394 ft)	LOWER	OFF	0.23	0.08	0.15	0.01	0.12	0.01	0.14	0.01
SE	120 m (394 ft)	UPPER	OFF	N/A	N/A	N/A	N/A	16.36	1.62	N/A	N/A

*Note: Trials averaged to obtain these noted values include at least one instance of measurement clipping due to actual illuminance levels exceeding the measurement range of the illuminance meter.

Measured values for the Audi (sedan) and BMW (SUV) vehicles tended to be slightly higher than those of the Lexus and Mercedes-Benz. The largest standard deviation values were seen for upper beam measurements.

5.2 Compare Illuminance by Receptor Head Locations

"Warm-Up trials" were another type of test conducted both to characterize headlamp performance in terms of illuminance distribution and to provide information as to which receptor head locations may be most helpful for measuring illuminance for ADB performance assessment. In these trials, the DAS and ADB vehicles were stationary, running, and facing each other in adjacent lanes while the ADB vehicle's headlighting system was cycled through three modes: (1) off for an initial 15 seconds, (2) lower beam mode for 30 seconds, and (3) upper beam mode for 60 seconds. This trial was intended for use in examining the stability of light output from the headlighting system over time, as well as for illustrating differences in illuminance values across receptor head locations. Figure 4 is a graph of data from a warm-up trial recorded for the Audi A8. Figure 5 shows only the first 45 seconds of that same trial to highlight the lower beam data. As can be seen in Figure 4, the light output was fairly stable. The values in the first 15 seconds of the trial are not true ambient illumination data, since the Audi had daytime running lights that could not be turned off.

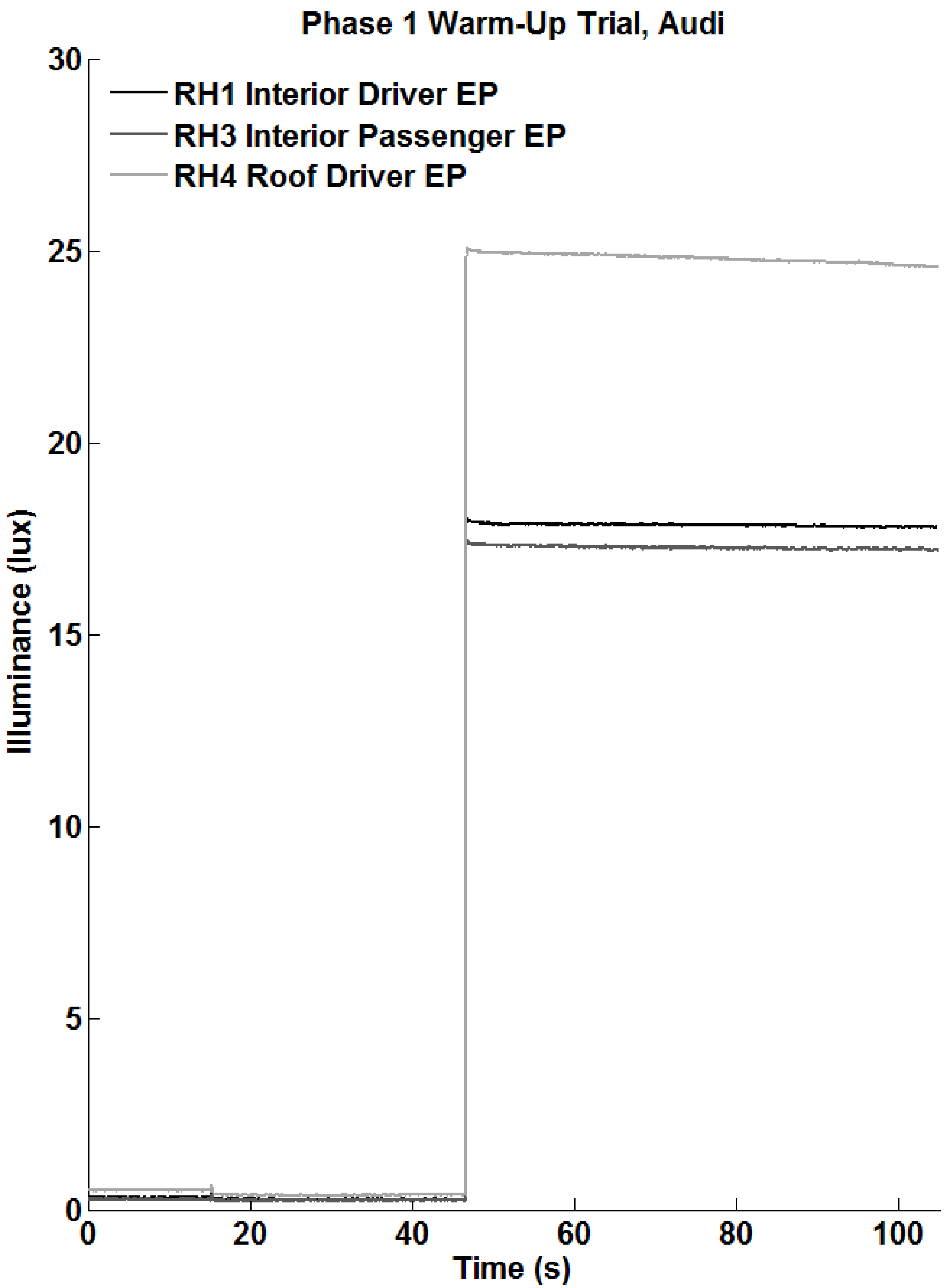

Figure 4. Example Warm-Up Trial, Audi A8 (Vertical Order of Channels Shown in Upper Beam Portion of Graph, From Top to Bottom, is RH4, RH1, RH3)

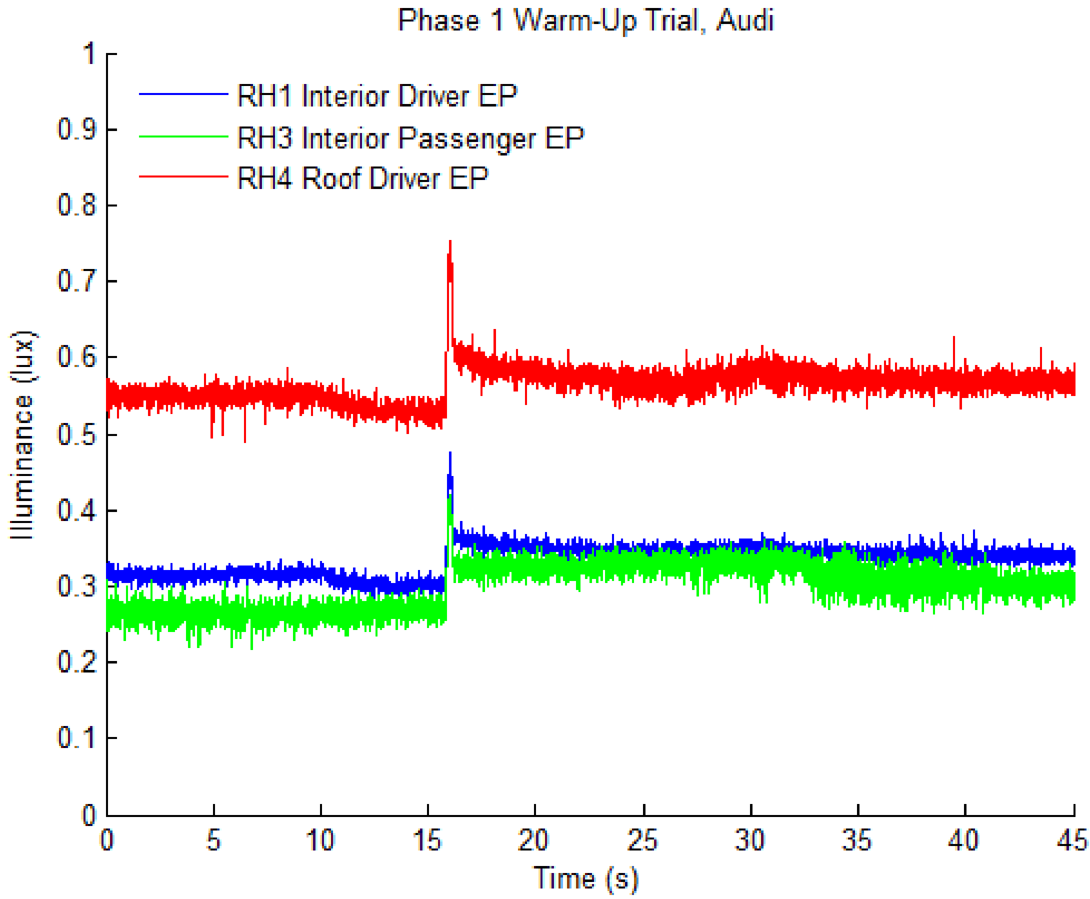

Figure 5. Example Warm-Up Trial First 45 Seconds, Audi A8 (Vertical Order of Graphed Channels From Top to Bottom is RH4, RH1, RH3)

The illuminance is greatest at the locations of receptor heads 8 (exterior A-pillar) and 4 (above the driver's eye point on the vehicle's roof), whose values are bounded at approximately 32 lux due to the upper measurement range limit of the illuminance meter used (i.e., the actual values were greater than 32 lux but were clipped due to the illuminance meter's range). A comparison of receptor heads 1 and 3 shows that illuminance decreases for measurement points increasingly further away laterally from the center of the headlamp beam. Receptor heads 1 and 3 were inside the vehicle and thus affected by filtering by the windshield, resulting in lower illuminance values than receptor head 4. Since the degree of filtering would likely differ by vehicle model, it was considered that exterior mounted receptor heads are preferred to permit isolation of the headlamp performance from any windshield effects.

5.3 ADB System Response to Camera Obstruction Results

Trials were conducted to observe ADB system response when the camera was obstructed. This test provided the opportunity to determine whether the tested ADB systems failed in a safe manner in conditions in which the forward camera image was unavailable. This test involved observation of ADB systems' responses to the cameras being fully obscured, simulating an obstruction of the camera by an environmental or other substance on the windshield. A desirable outcome of these trials would have the ADB system not defaulting to full upper beam illumination when detecting a problem with the camera image. Obscured ADB camera trials involved only qualitative observations noted by the research staff. These observations are summarized below.

Audi A8: The vehicle activated the ADB system when the activation speed threshold was crossed. In the initial trial, no ADB adaptation to the oncoming vehicle was observed. On the following trial only lower beams were illuminated and the following message was displayed: “Main beam assist: currently unavailable. No camera view.”

Mercedes-Benz E350: The vehicle activated the ADB system but did not activate upper beam headlamps and also gave no indication of an error to the driver. While the blue upper beam telltale was illuminated on the instrument panel, no other message was provided to the driver.

BMW X5: ADB activated after the vehicle crossed the activation speed threshold, and then reverted to lower beam mode after a few seconds. The vehicle still displayed the illuminated “Automatic Headlights” telltale, but no other messages were provided.

Lexus LS460 F Sport: On the first trial, the vehicle activated the ADB system after the speed threshold was passed, but ADB did not adapt to the oncoming DAS vehicle (i.e., full upper beam illumination was observed with no shading of the DAS vehicle). After passing the deactivation speed threshold the upper beams turned off as expected. On the second trial, the ADB again activated and illuminated the upper beams as the vehicle crossed the activation speed threshold. Near the end of the second pass the upper beams turned off as did the “Automatic Headlights” telltale. No message was provided to the driver indicating why the system turned off. A third trial was run in which the results were the same as were seen for the first trial.

Based on the results of these tests, a second version of this scenario was considered in which a partial, rather than fully obstructing, treatment would be placed over the ADB camera and the system’s response examined for each vehicle.

5.4 Measured Illuminance Values and Glare Limits for Oncoming Maneuver Scenario Trials

ADB performance was examined through comparison with lower beam illuminance and derived glare limit values. ADB systems are intended to allow upper beam illumination in some parts of the roadway, while shading the area in which other vehicles are located such as to not expose them to more glare than would be seen with lower beams. Applying derived lower beam glare limit values to illuminance data measured at points on the DAS vehicle can provide information as to whether ADB succeeds in achieving its goal. Therefore, the maximum illuminance values recorded over various distance ranges during oncoming maneuver scenario trials were compared to the derived glare limit values summarized in Table 1. The range is defined as the longitudinal distance from the ADB vehicle’s headlamps to the receptor head locations on the DAS vehicle.

The following data tables summarize results from lower beam and ADB conditions for selected maneuver scenarios. As indicated in Tables 4 through 6, some maneuver scenarios were conducted with the ADB-equipped vehicle in upper beam mode, in addition to lower beam and ADB mode conditions. These upper beam data are not shown here due to space constraints. Illuminance data from a single receptor head (receptor head 4, located external to the vehicle on the roof rack, above the driver’s eye point) are presented. Maximum and minimum values recorded for the various oncoming test scenarios over the specified longitudinal distance ranges for each of the four test vehicles are presented. Illuminance values exceeding the glare limits are in bold text with a shaded background. In addition, each table includes subjective glare ratings for each trial using the De Boer (De Boer, 1967) glare rating scale (see Table 7).

Table 9 shows the maximum (and minimum) illuminance values (RH4) and De Boer ratings for a single, oncoming vehicle in an adjacent lane scenario, in which the DAS and ADB vehicle were traveling the same speed (62 mph; 99.8 kph). Table 10 shows the same measures for a single vehicle, oncoming scenario conducted at 40 mph (64.4 kph) where both vehicles' paths were on a slight incline leading to a mild crest at the point where the vehicles passed each other. A comparison of results for these two trials shows differences, mainly for the BMW, and Audi. The BMW showed limit-exceeding values in the 0 to 60 meter range for the 62 mph (99.8 kph) scenario for both ADB and lower beam modes, but not for the 40 mph (64.4 kph) condition. Since the trials differed in terms of both speed and elevation, a conclusive direct comparison is not possible. Additional information regarding maneuver speed effects is presented in Section 5.6.

Table 9. Illuminance Value Data (lux) and Subjective Glare Ratings for Single Oncoming Vehicle in Adjacent Lane (RH4), Straight Road (Both 62 mph; 99.8 kph)

Headlighting System Setting	Distance (m)	Glare Limit (lux)	Illuminance Statistic	Audi	BMW	Lexus	Mercedes-Benz
Lower Beam	15-29.9	3.11	Max.	1.50	**3.42**	1.21	1.46
			Min.	1.10	2.02	0.84	0.73
	30-59.9	1.78	Max.	1.09	**2.02**	0.84	0.73
			Min.	0.42	0.62	0.29	0.26
	60-119.9	0.63	Max.	0.44	0.60	0.30	0.26
			Min.	0.02	0.09	0.06	0.03
	120-239.9	0.28	Max.	0.04	0.11	0.09	0.07
			Min.	0.00	0.01	0.02	0.00
	Max. Meas. Range (if < 240 m)			0.00	N/A	0.03	0.00
	De Boer Rating			7	9	8	9
ADB	15-29.9	3.11	Max.	1.63	**3.84**	1.23	1.61
			Min.	1.03	2.88	0.85	0.88
	30-59.9	1.78	Max.	1.03	**2.86**	0.85	0.88
			Min.	0.39	0.60	0.29	0.34
	60-119.9	0.63	Max.	0.39	0.60	0.30	0.36
			Min.	0.09	0.16	0.02	0.21
	120-239.9	0.28	Max.	0.14	0.17	0.10	0.73
			Min.	0.00	0.06	0.01	0.19
	Max. Meas. Range (if < 240 m)			N/A	N/A	0.04	0.45
	De Boer Rating			7	8	7	5

Table 10. Illuminance Value Data (lux) and Subjective Glare Ratings for Single Oncoming Vehicle in Adjacent Lane (RH4), Straight Road (Both 40 mph; 64.4 kph)

Headlighting System Setting	Distance (m)	Glare Limit (lux)	Illuminance Statistic	Audi	BMW	Lexus	Mercedes-Benz
Lower Beam	15-29.9	3.11	Max.	1.32	1.84	0.94	1.56
			Min.	0.77	1.12	0.68	0.76
	30-59.9	1.78	Max.	0.77	1.11	0.70	0.78
			Min.	0.35	0.18	0.28	0.36
	60-119.9	0.63	Max.	**2.35**	0.23	0.30	0.37
			Min.	0.09	0.07	0.06	0.18
	120-239.9	0.28	Max.	**5.16**	0.14	N/A	**0.29**
			Min.	0.12	0.02	N/A	0.14
	Max. Meas. Range (if < 240 m)			0.20	0.05	0.06	0.17
	De Boer Rating			6	9	8	9
ADB	15-29.9	3.11	Max.	1.74	1.97	1.02	1.66
			Min.	0.90	0.73	0.76	0.83
	30-59.9	1.78	Max.	0.91	0.71	0.75	0.84
			Min.	0.45	0.14	0.19	0.29
	60-119.9	0.63	Max.	0.45	0.28	0.22	0.33
			Min.	0.05	0.03	0.05	0.12
	120-239.9	0.28	Max.	0.25	**1.26**	**0.33**	0.17
			Min.	0.05	0.24	0.00	0.05
	Max. Meas. Range (if < 240 m)			0.16	**1.09**	0.00	0.07
	De Boer Rating			7	9	8	9

5.5 ADB Performance Relative to Lower and Upper Beam Headlamp Performance

Another means to characterize headlighting system performance was comparing measured illuminance for individual scenarios as a function of lower beam, ADB, and upper beam modes. As indicated in Tables 4 and 5, some maneuver scenarios were conducted with the ADB-equipped vehicle in upper beam mode, in addition to lower beam and ADB mode conditions. The figures below present some examples of illuminance measured for lower beam, ADB, and upper beam modes in specific maneuver scenarios. Figures 6 through 9 present data for a straight, oncoming maneuver scenario. Figures 10 through 13 present data for a scenario in which the vehicle traversed a straight road containing a series of dips. These figures generally show that the illuminance measured at the DAS vehicle when each test vehicle's headlighting system was in ADB mode, was similar to that measured for lower beam mode, suggesting appropriate ADB performance with respect to glare.

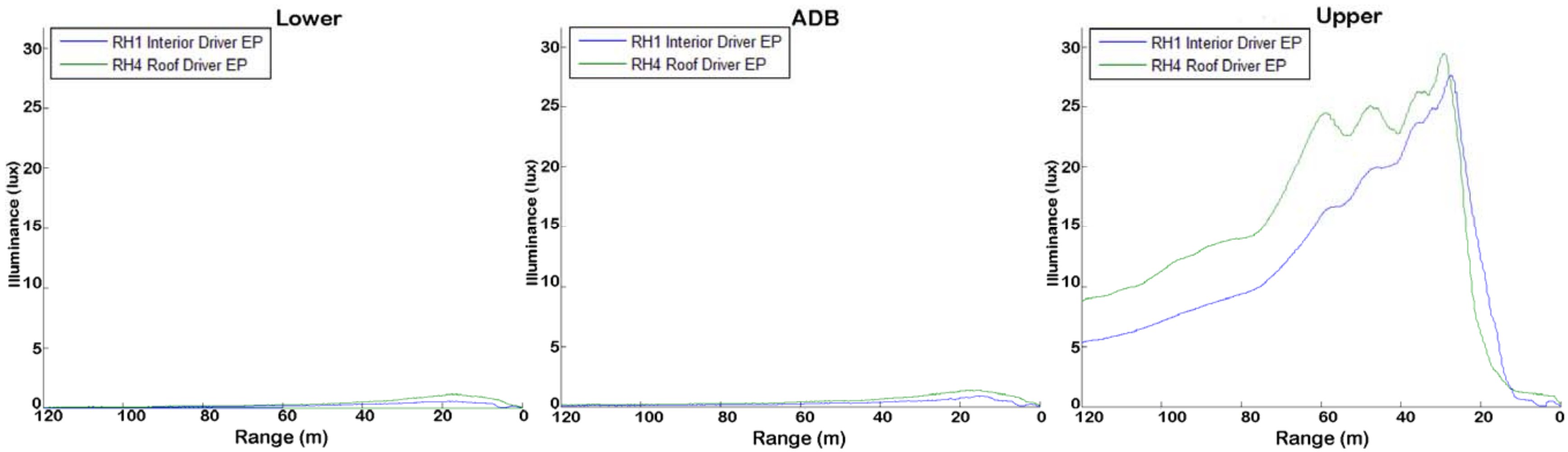

Figure 6. Illuminance Versus Distance by Headlighting System Mode - Straight, Oncoming, Adjacent Lane Maneuver, Small DAS, Audi

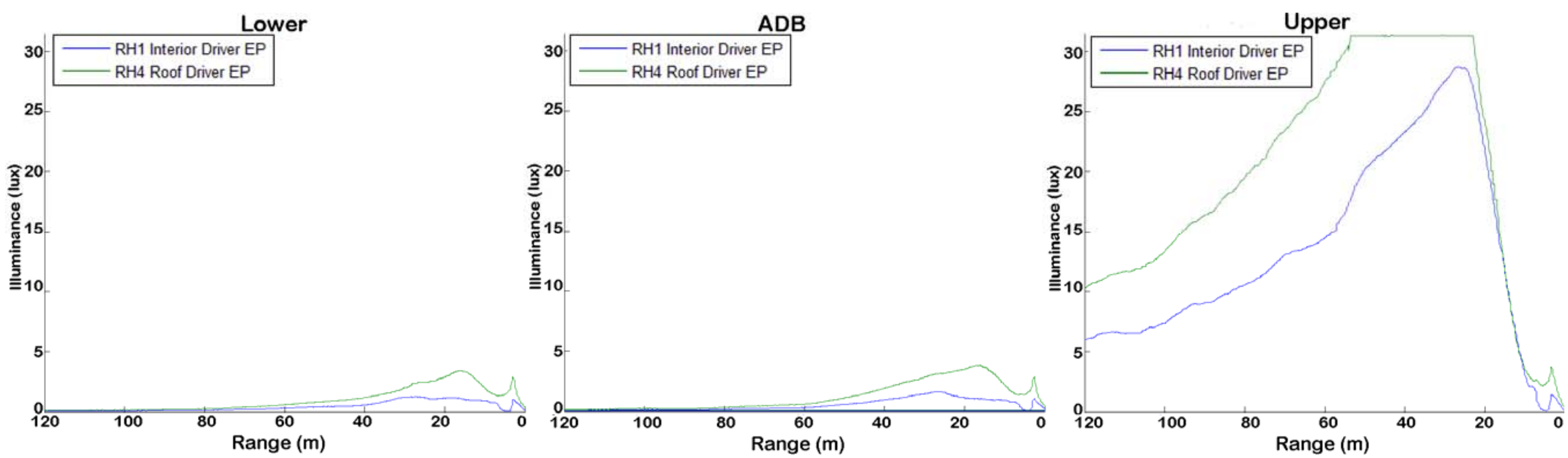

Figure 7. Illuminance Versus Distance by Headlighting System Mode - Straight, Oncoming, Adjacent Lane Maneuver, Small DAS, BMW

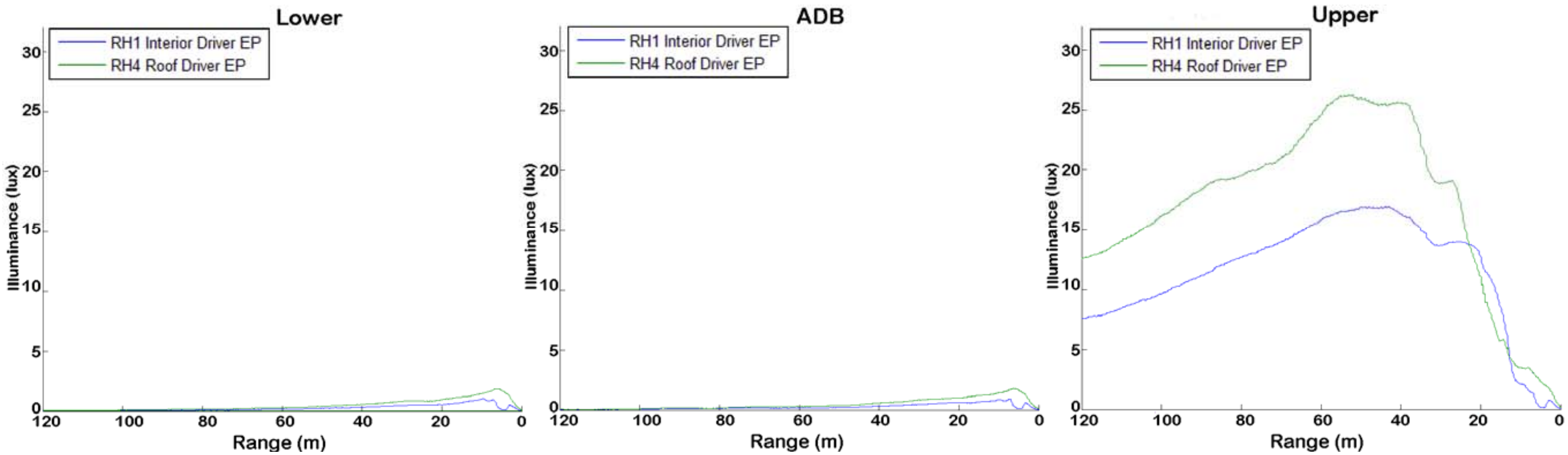

Figure 8. Illuminance Versus Distance by Headlighting System Mode - Straight, Oncoming, Adjacent Lane Maneuver, Small DAS, Lexus

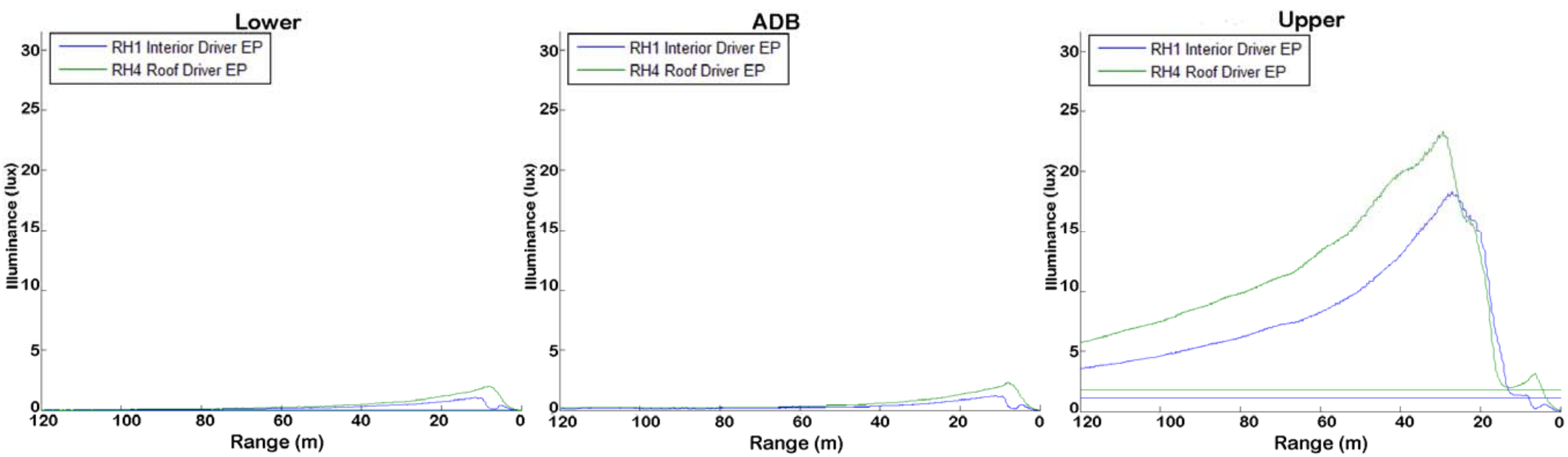

Figure 9. Illuminance Versus Distance by Headlighting System Mode - Straight, Oncoming, Adjacent Lane Maneuver, Small DAS, Mercedes-Benz

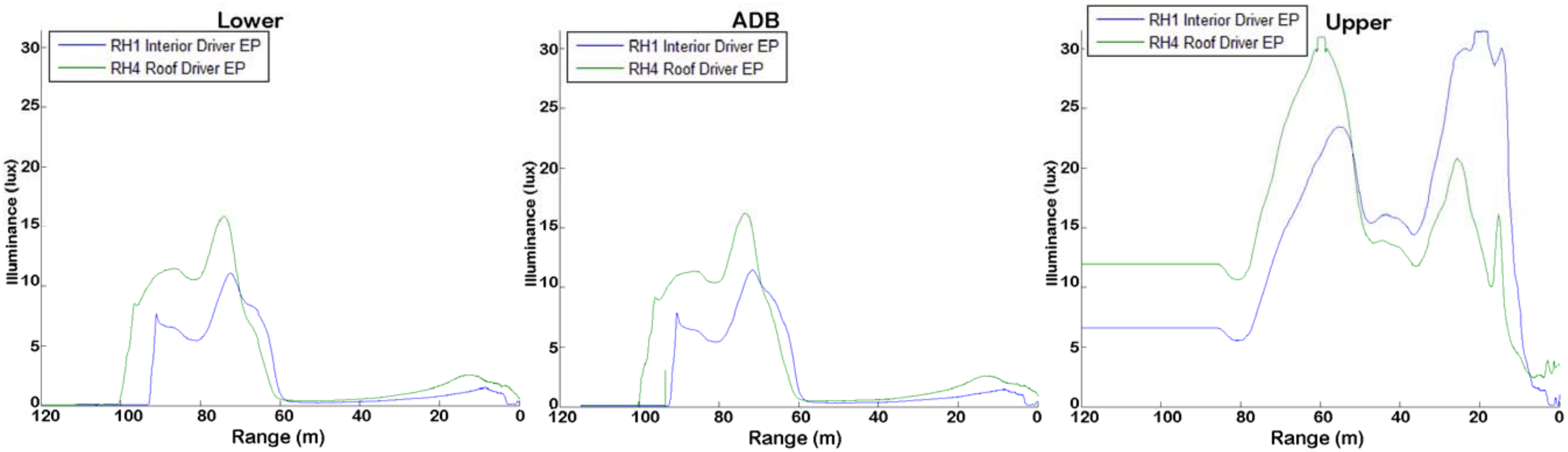

Figure 10. Illuminance Versus Distance by Headlighting System Mode - Dip Series (Straight) Oncoming, Adjacent Lane Maneuver, Small DAS 0 mph, Audi

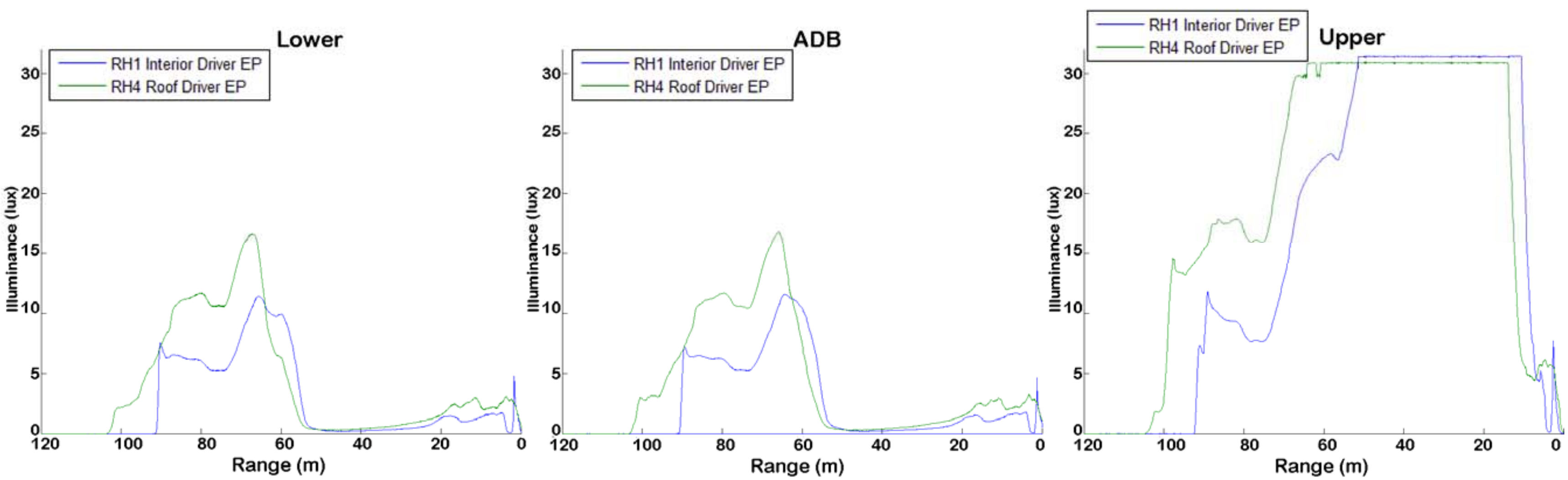

Figure 11. Illuminance Versus Distance by Headlighting System Mode - Dip Series (Straight) Oncoming, Adjacent Lane Maneuver, Small DAS 0 mph, BMW

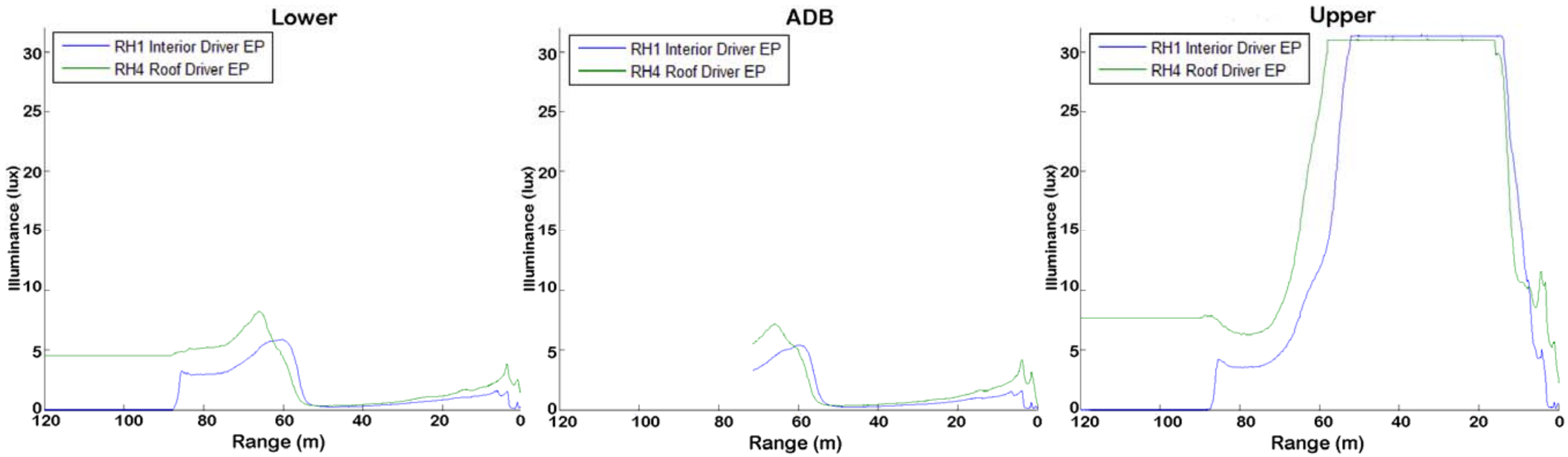

Figure 12. Illuminance Versus Distance by Headlighting System Mode - Dip Series (Straight) Oncoming, Adjacent Lane Maneuver, Small DAS 0 mph, Lexus

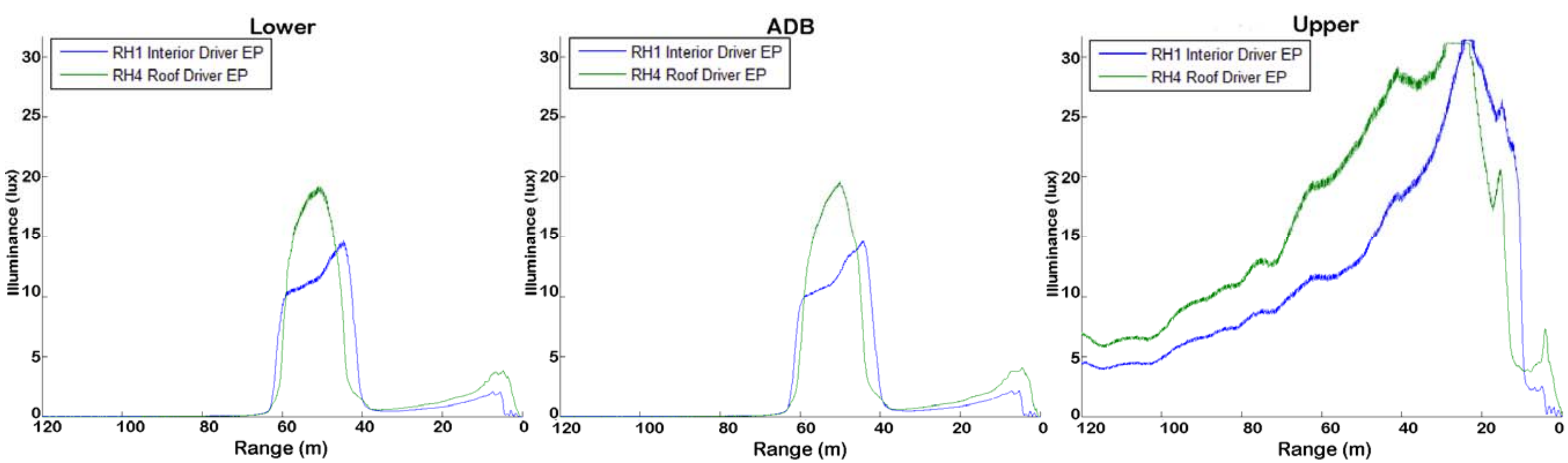

Figure 13. Illuminance Versus Distance by Headlighting System Mode - Dip Series (Straight) Oncoming, Adjacent Lane Maneuver, Small DAS 0 mph, Mercedes-Benz

ADB response to a headlamp-equipped oncoming bicycle showed a somewhat different degree of adaptation. The scenario mimicked a bicycle located on the road berm approaching an ADB-equipped vehicle on the passenger side. The approaching bicycle was simulated using a light mounted to the passenger side of the DAS vehicle, which was driven with its headlighting system off. The light met ECE road test procedure specifications for a bicycle light (150 cd, emitting area of 10 cm^2 +/- 3 cm^2). Overall, ADB adaptation to this light stimulus showed a noticeably smaller reduction in illuminance compared to upper beam illuminance levels than was seen in the oncoming DAS vehicle trials. This finding may be attributed to or contributed to by the fact that illuminance receptor heads were located not on the bicycle, but on the adjacent DAS vehicle. Furthermore, the oncoming bicycle approached the ADB-equipped vehicle on the passenger side, rather than the driver's side as was done in oncoming DAS vehicle trials. Specific results by vehicle follow.

The Audi appeared to exhibit ADB adaptation to the bicycle, but the response was inconsistent. More illuminance was seen with ADB than with the lower beam mode, but levels were clearly not those seen in the upper beam condition. Figure 14 shows lower beam, ADB, and upper beam illuminance levels for the Audi in an oncoming, stationary bicycle trial. A clear drop in illuminance, corresponding to ADB adaptation, can be seen at around the 4-second point of the center plot in this figure. This vehicle showed the most response to the bicycle lamp for the scenario of any of the four vehicles, however at close range (e.g., within 5 m) illuminance values can be seen to increase suggesting that substantial glare was cast on the bicycle and DAS vehicle's driver in that range (which was located 6 ft (1.8 m) to the left of the bicycle operator).

The BMW also appeared to detect the oncoming bicycle headlamp, although the response tended to be late. As a result, there was significant glare at near distances that were comparable to upper beam mode induced illuminance values. Figure 14 shows lower beam, ADB, and upper beam illuminance levels for the BMW in an oncoming, stationary bicycle trial. A clear drop in illuminance, corresponding to ADB adaptation, can be seen at around the 10-second point of the center plot in Figure 15. This drop occurred at close range to the DAS vehicle suggesting substantial glare cast on the bicycle and DAS vehicle's driver in that range (which was located 6 ft (1.8 m) to the left of the bicycle operator).

The Lexus seemed to detect the oncoming bicycle headlamp, with nearly three times the illuminance for ADB mode as was seen for lower beam mode, yet not as high as upper beam induced illuminance values. Figure 16 shows lower beam, ADB, and upper beam illuminance levels for the Lexus in an oncoming, stationary bicycle trial. Despite the apparent adaptation, there was still significant glare and the illuminance data does not show an obvious drop that corresponds to a detection of the bicycle lamp.

For the Mercedes-Benz, ADB mode showed higher illuminance than seen in the lower beam mode trial, but did not achieve upper beam induced illuminance values. Figure 17 shows lower beam, ADB, and upper beam illuminance levels in the 15 mph (24.1 kph) oncoming bicycle trial. There was still significant glare and, as was described for the Lexus response, no obvious point of adaptation.

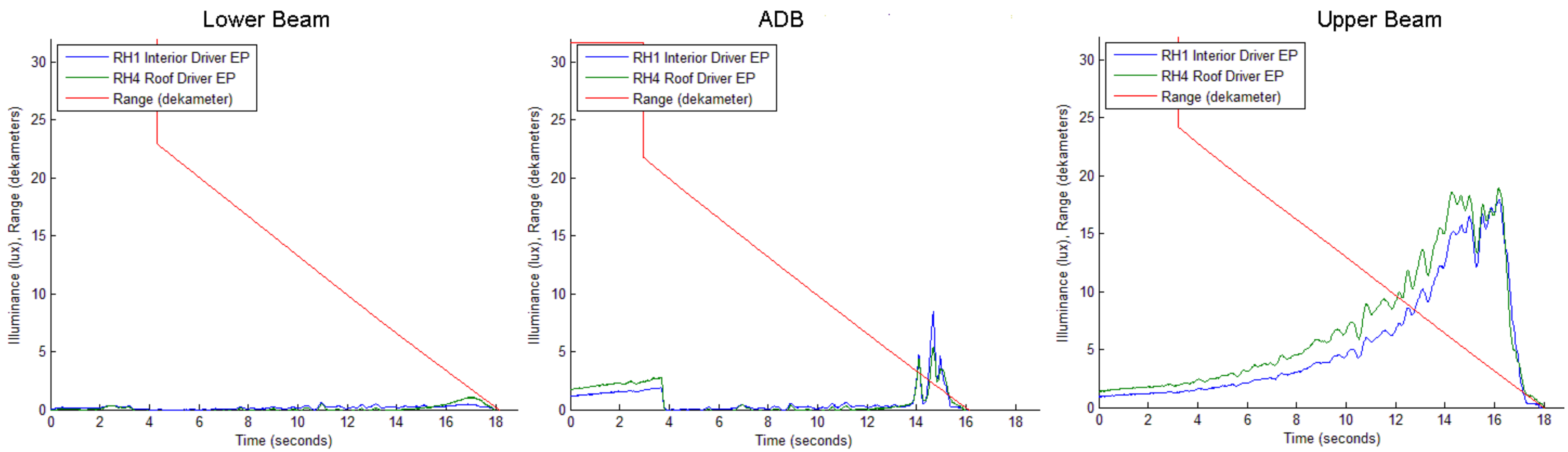

Figure 14. Straight, Oncoming, Adjacent Lane Maneuver Scenario Trials With Bicycle at 0 mph on Passenger Side, Audi

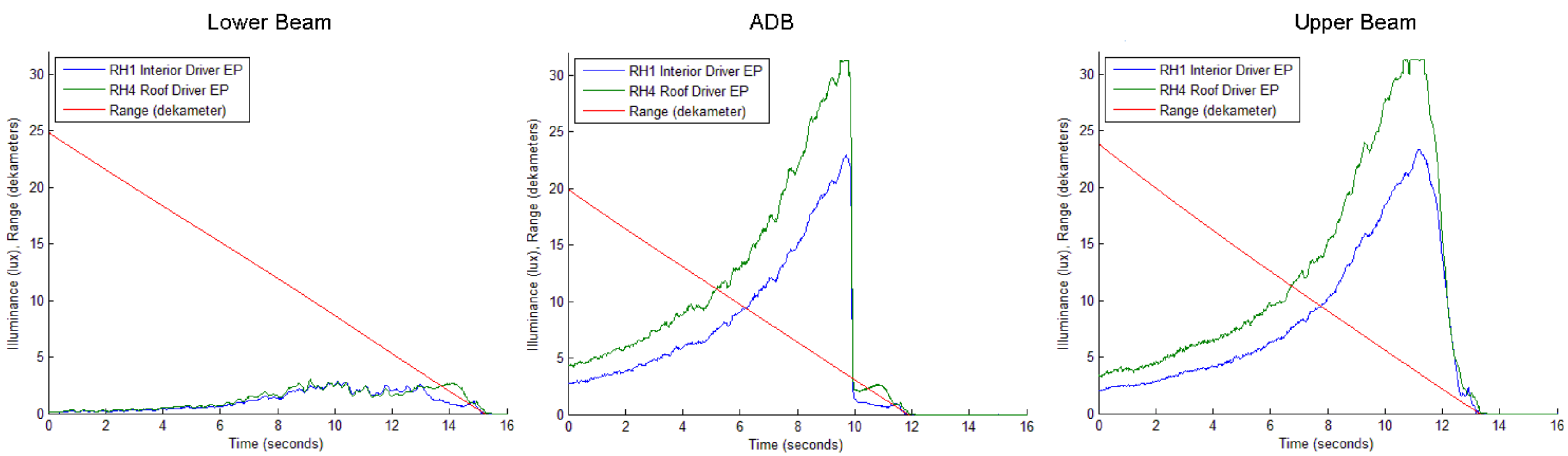

Figure 15. Straight, Oncoming, Adjacent Lane Maneuver Scenario Trials With Bicycle at 0 mph on Passenger Side, BMW

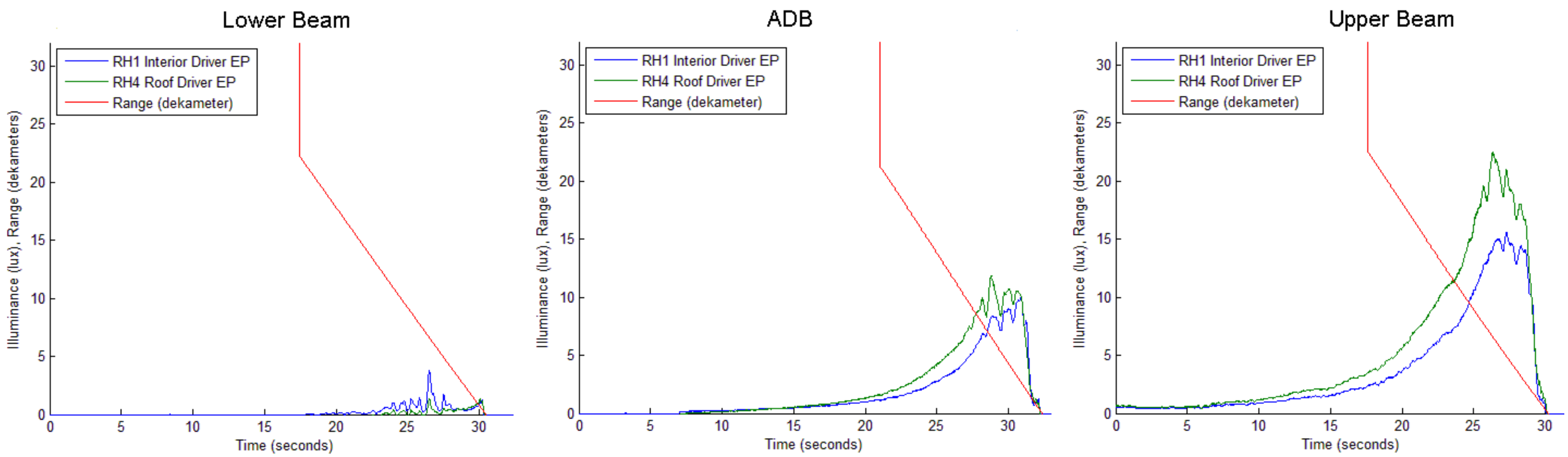

Figure 16. Straight, Oncoming, Adjacent Lane Maneuver Scenario Trials With Bicycle at 0 mph on Passenger Side, Lexus

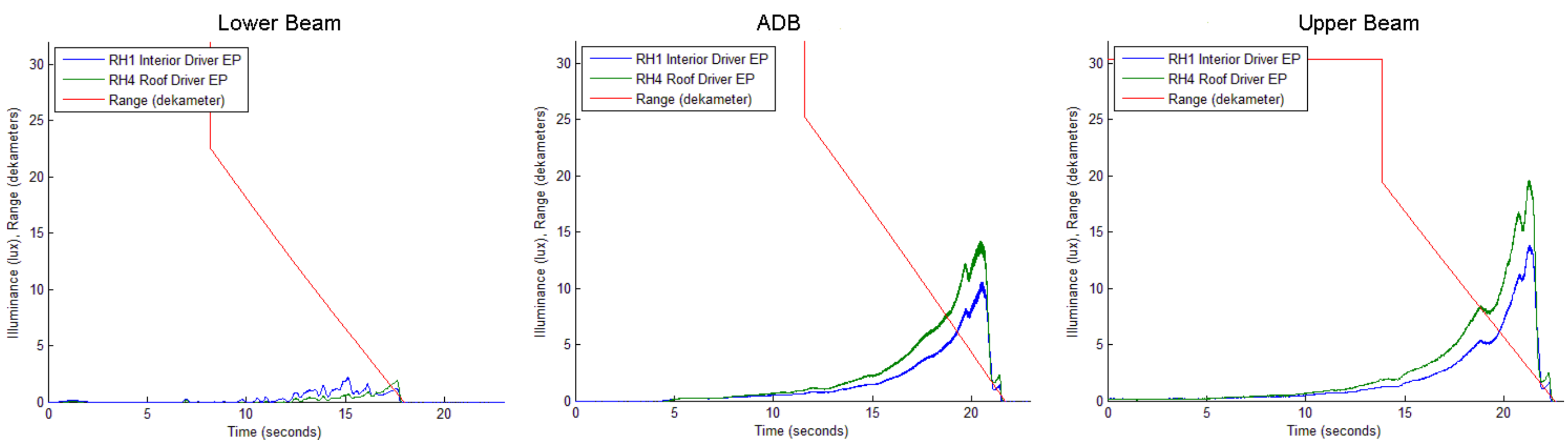

Figure 17. Straight, Oncoming, Adjacent Lane Maneuver Scenario Trials With Bicycle at 15 mph (24.1 kph) on Passenger Side, Mercedes-Benz

5.6 Maneuver Speed Effects

In examining the conditions in which ADB activity could be observed, a set of repeated trials were conducted to assess test repeatability, including the effect of vehicle speed on ADB performance. Repeated trials were conducted using only one vehicle due to time constraints.

Data from repeated trials were examined to assess whether maneuver speed may affect ADB performance repeatability in oncoming straight road maneuver scenarios. Plots of illuminance versus range data were examined to assess whether the data trace shape was similar and illuminance magnitudes were comparable between conditions. Figure 18 illustrates illuminance versus distance data for the Lexus vehicle in lower beam mode for a straight, oncoming maneuver. Two trials per graph pane are shown for each combination of ADB vehicle speed (40 mph (64.4 kph) or, 60 mph (96.6 kph)) and DAS vehicle speed (0 mph, 60 mph (96.6 kph)). DAS and ADB vehicle speeds do not appear to affect repeatability for this maneuver, test vehicle, and headlighting system mode. Figure 19 illustrates illuminance versus distance data for the Lexus vehicle in ADB mode for a straight, oncoming maneuver. DAS and ADB vehicle speeds do not appear to affect ADB performance repeatability for this vehicle in a straight roadway maneuver.

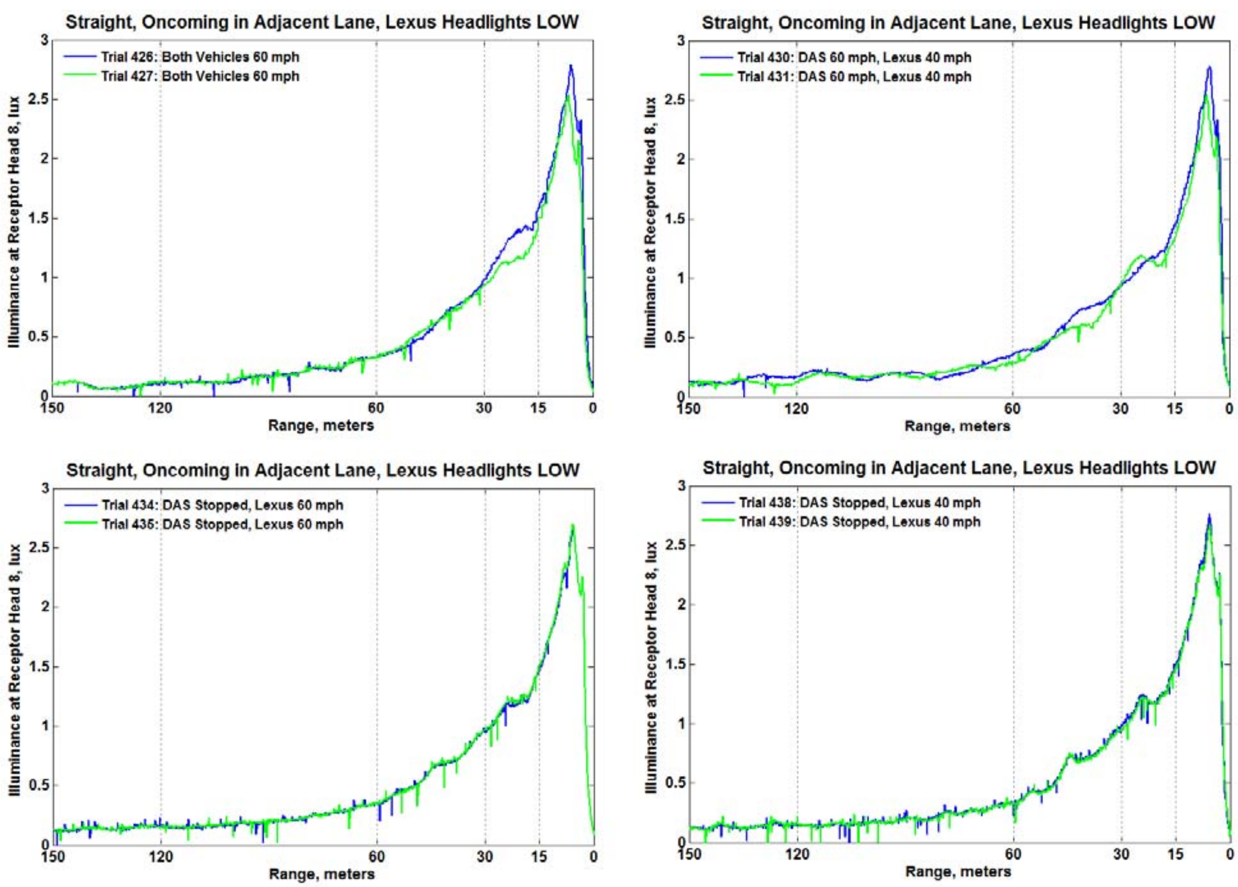

Figure 18. Illuminance Versus Distance as a Function of ADB and DAS Vehicle Speeds for Oncoming, Straight, Adjacent Lane Maneuver, Lower Beam Mode, Lexus

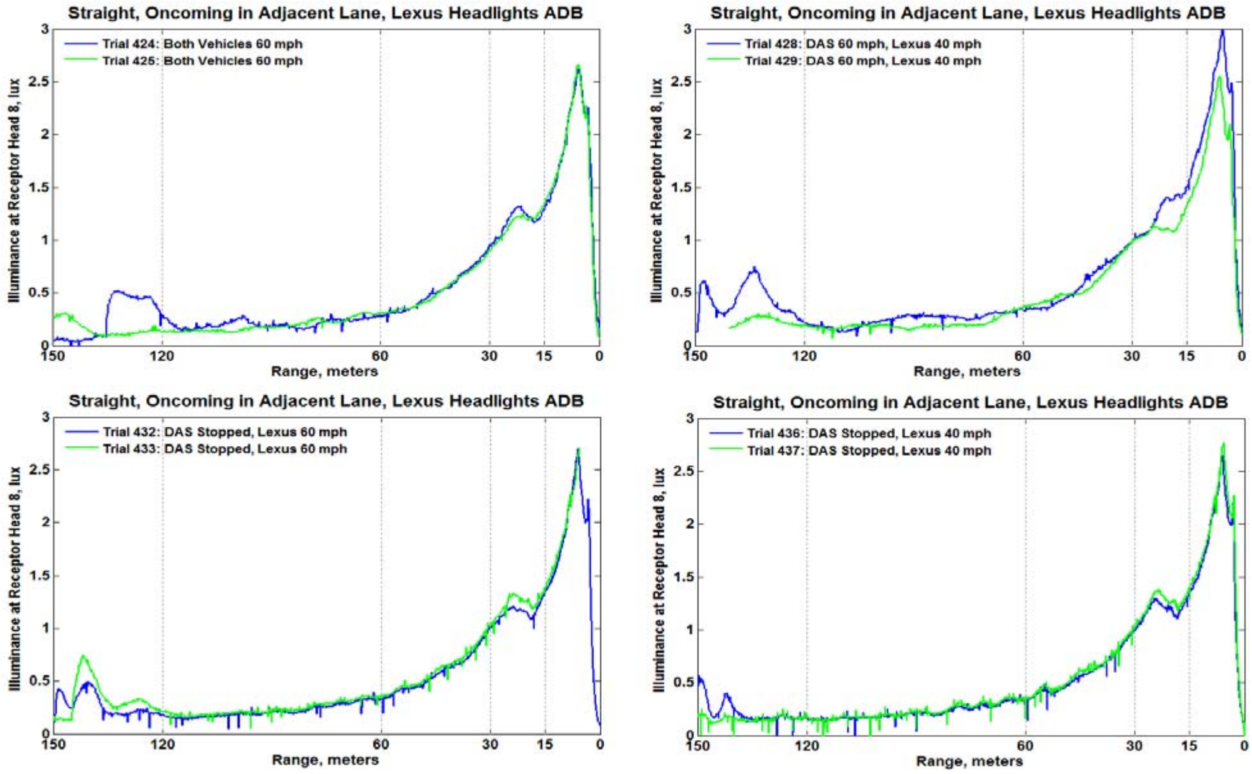

Figure 19. Illuminance Versus Distance as a Function of ADB and DAS Vehicle Speeds for Oncoming, Straight, Adjacent Lane Maneuver, ADB Mode, Lexus

Data from repeated trials (Lexus only) were also examined to assess whether maneuver speed may affect ADB performance repeatability in a curved roadway scenario having a 764 ft (231 m) radius of curvature. The Figure 20 illustrates illuminance versus distance data for the Lexus vehicle in ADB mode for a right curve maneuver. This graph shows four trials in which the ADB vehicle's speed was 60 mph (96.6 kph) and DAS vehicle's speed was either 0 mph or 60 mph (96.6 kph). In the 60 to 120 m range, there is a large difference in measured illuminance between the pairs of DAS vehicle stopped and moving trials. This is likely due to the fact that, in the moving DAS vehicle case, after the ADB sensor detected the oncoming DAS vehicle it continued to move closer to the ADB-equipped vehicle as the ADB system was responding. As a result, the ADB adaptation occurred when the vehicles were at a closer range. While not specifically measured, the ADB system adaptation time was likely the same across trials. After ADB adaptation, the illuminance is similar across trials. These data suggest that while ADB responses appear different based on whether or not the DAS vehicle was moving, the effect was a function how quickly the ADB system could respond and not the speed of the DAS vehicle during the test trial.

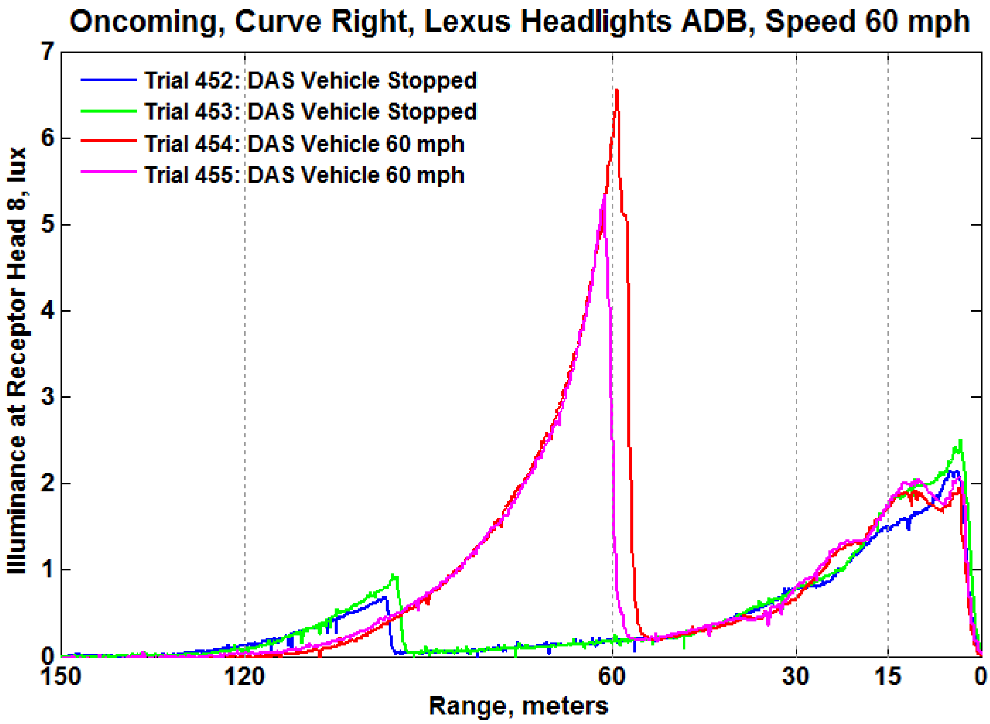

Figure 20. Illuminance Versus Distance for Lexus in ADB Mode Driving 60 mph (96.6 kph) in a Right Curved Roadway With DAS Vehicle Oncoming, Adjacent Lane at 0 or 60 mph (96.6 kph)

Data from repeated trials showed one phenomenon for the Lexus that seemed to be consistent across the vehicle speed combinations tested. In each repetition of a straight, oncoming maneuver scenario, the vehicle was observed to illuminate its driver-side upper beam headlamp briefly when it reached a distance of approximately 30 m from the DAS vehicle. The following figure illustrates six instances of variations of the straight, oncoming maneuver scenario in which this phenomenon was observable. The brief upper beam illumination is highlighted using a circle in each graph in the figure. The behavior is present both for trials in which the DAS vehicle was stationary and for trials in which it was in motion. The glare from this brief upper beam presentation was not disturbing, but was clearly noticeable to the oncoming driver. It was assumed that this behavior was unintended and potentially something that the manufacturer could address.

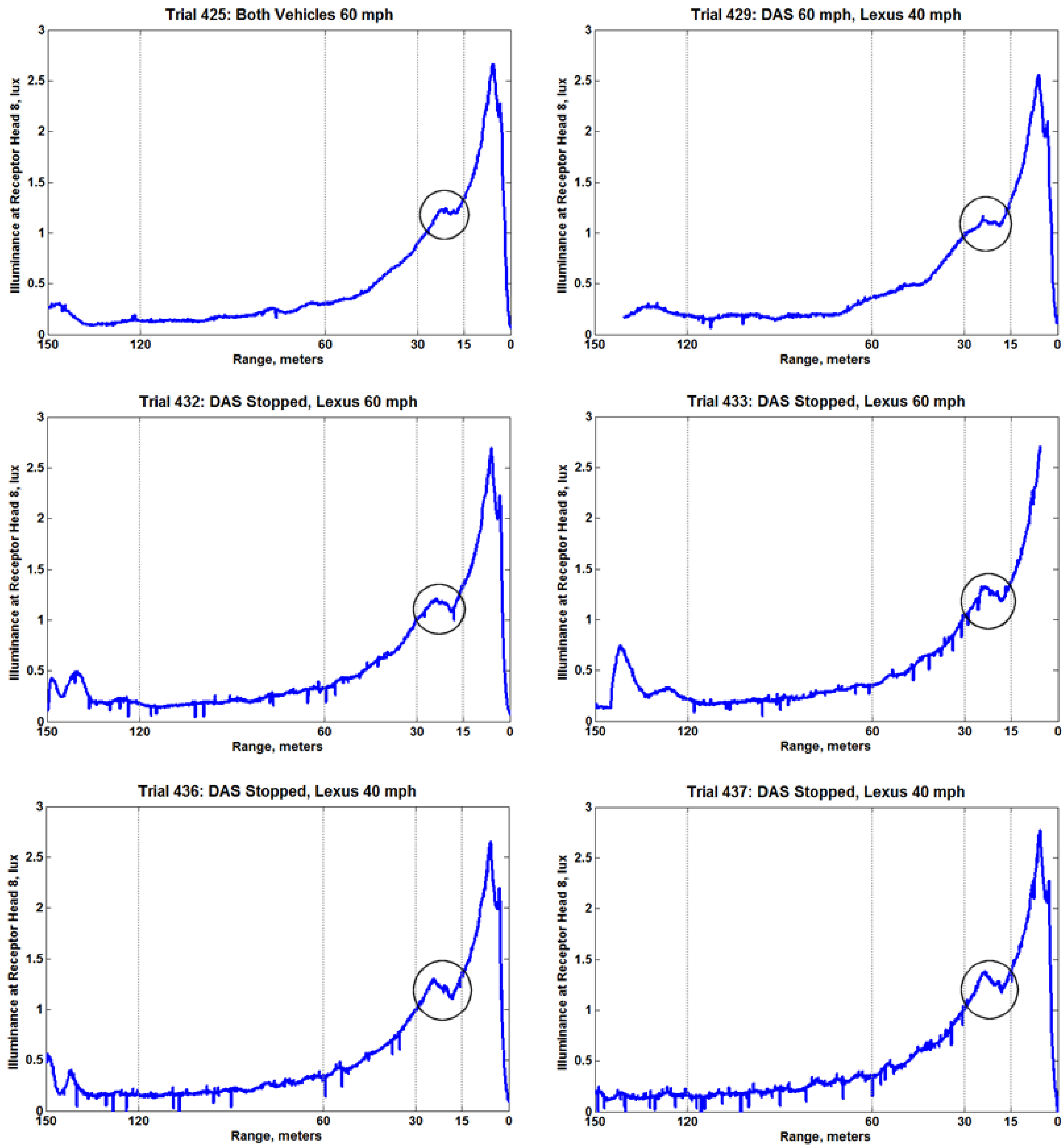

Figure 21. Example of Noteworthy ADB Headlighting System Behavior Documented in Trials With the Lexus Test Vehicle

5.7 ADB Activity by Maneuver Scenario

ADB adaptation activity was visibly observable by the driver for all four test vehicles, but to varying degrees. From the ADB vehicle driver's perspective, the shading of other vehicles was more visually apparent for some vehicles than for others.

ADB activity did not occur in all attempted phase 1 maneuver scenarios. The urban scenarios, for example, did not elicit ADB activity. Reasons include low ADB vehicle speeds and the close proximity of the other vehicles, as well as roadway lighting in the lighted roadway scenarios.

For the winding road scenario, the facility layout was not designed for driving at the appropriate travel speeds long enough to engage ADB.

Based on these difficulties, some changes to the maneuver scenario set for subsequent testing were considered. Modifications to the scenarios focused on situations and roadway and vehicle geometries that would be most likely to elicit ADB adaptation activity. Specific modifications are outlined in Section 6.

5.8 Summary of Phase 1 Findings

Results of the first phase of testing showed that measurement of headlamp illuminance using the whole vehicle, rather than a component-level test, can be accomplished in a repeatable manner. Furthermore, the initial results show that making such measurements outdoors in variable ambient illumination conditions can be performed in a valid way, by removing the measured ambient illumination from recorded headlighting system test trial data. ADB response timing seemed consistent across trials. Scenarios involving the DAS vehicle and ADB-equipped vehicle driving toward each other showed ADB adaptation occurring at closer range between vehicles than would be seen if the DAS vehicle is stationary due to the ADB response timing.

The first phase of testing also provided insight regarding how ADB performance may be assessed using scripted, dynamic maneuver scenarios based on ECE road test procedures. Maneuver scenarios were identified that would likely elicit ADB response.

Based on the first phase of testing, it was decided to replace the bicycle scenario with a motorcycle scenario. FMVSS No. 108 does not currently specify requirements for bicycles; however, it does contain requirements for motorcycle lighting. A FMVSS 108-compliant motorcycle is more likely to be encountered on U.S. roads having a speed range relevant to ADB engagement than a bicycle. Based on this logic, a motorcycle was selected for use as an ADB stimulus vehicle.

Phase 1 testing allowed for a preliminary assessment of the repeatability of test outcomes. Based on the results, other revisions were made to allow further examination of test repeatability in the second phase of testing. A thorough examination of repeatability could address multiple test procedure related questions, such as:

- Can dynamic, whole-vehicle testing of headlighting systems be performed in a repeatable manner? - Repeated trials using lower beam mode, having a consistent illumination level, would provide an opportunity for assessing test repeatability.
- Is ADB system performance repeatable and consistent? - Inconsistent ADB performance would make repeatable testing difficult. In addition, poor ADB performance consistency could cause low driver satisfaction with the system. Repeated trials using ADB mode would provide an opportunity for assessing ADB response repeatability.
- Are repeated trials necessary to observe any anomalous or peculiar behavior that may be seen in individual ADB systems? - Adding repeated maneuver scenario trials would seemingly allow for noteworthy or peculiar observations to be assessed for determination of whether the phenomenon was a rare or repeatable occurrence.

6.0 PHASE 2 TEST METHOD: MODIFIED TEST PROCEDURE

6.1 Phase 2 Test Scenarios

The second phase of testing subjected European ADB-equipped vehicles to a modified test procedure based on the lessons learned from Phase 1 testing. Changes to the test procedure were made to better engage ADB functionality, allow for ADB response observation in potentially challenging scenarios, and improve testing efficiency. Specific changes included:

- Excluding illuminated roadway scenarios;
- Excluding scenarios with more than two vehicles;
- Excluding most low-speed scenarios in which ADB is not designed to operate; and
- Replacing the winding road scenario with a more mildly winding scenario that could be performed at a higher speed.

To better characterize the test scenarios being performed on closed courses instead of public roadways, the maneuver scenarios were grouped into two main categories:

- Oncoming, including angled intersection approaches; and
- Same-direction maneuver scenarios.

Figure 22 uses similar table formats to compare the Phase 1 and 2 dynamic maneuver scenarios.

		Road Types		
		Multi-Lane	**Country**	**Urban**
ECE (Phase 1)	**Traffic Conditions**	Straight level >600 m; Curves left, right	2-4 lanes, *hills and/or slopes*, **dips**, **intersections**, and **winding** roads	*Sections with and without illumination*
	Oncoming (single, multiple)	x	x	x
	Preceding (single, multiple)	x	x	x
	Passing (active, passive)	x	x	
	Oncoming *Bicycle*	x		

		Road Trajectory			
Modified (Phase 2)	**Vehicle Approaches**	**Straight**	**Curve (L, R)**	**Dip series (straight)**	**Winding**
	Oncoming (180 deg. heading Δ)	x, **motorcycle**	x	x	x
	Preceding (same direction, 0 deg.)	x, **motorcycle**	x	x	
	Passing (0 deg., active, passive)	x	x		
	Intersection (60, 90, 120 deg.)	x			

Figure 22. Comparison of ECE and Phase 2 Test Procedures

Table 11 provides an overview of the specific maneuver scenarios used in Phase 2. Each maneuver scenario is described in terms of roadway geometry, driving actions, and other details. For comparison purposes, each maneuver was conducted twice, once with the headlighting system in lower beam mode and once in ADB mode for each set of test trials.

Table 11. Phase 2 Dynamic Maneuver Scenarios

SCENARIO DESCRIPTION	CONDITIONS (from *ADB vehicle perspective*)	LANE POSITION (i.e., stimulus vehicle is ___ as/from ADB vehicle)	SPEED DAS/ Stimulus Vehicle (mph)	SPEED ADB Vehicle (mph)	TEST COURSE USED
Oncoming (forward-facing receptor heads 1-4, and 10)	Straight	In adjacent lane	0	62 ± 5	Skid pad
			62 ± 5	62 ± 5	Skid pad
	Motorcycle (straight)		0	62 ± 5	Skid pad
			62 ± 5	62 ± 5	Skid pad
	ADB curves left (radius of curvature of 764 ft (231 m))		0	62 ± 5	VDA S Loop
			62 ± 5	62 ± 5	VDA S Loop
	ADB curves right (radius of curvature of 764 ft (231 m))		0	62 ± 5	VDA S Loop
			62 ± 5	62 ± 5	VDA S Loop
	Dip series		0	40 ± 5	PHRC
	Winding		0	45 ± 5	VDA
Intersection (side-facing receptor heads 8-9)	60 degrees	In adjacent lane	0	62 ± 5	VDA
	90 degrees		0	62 ± 5	VDA
	120 degrees		0	62 ± 5	VDA
Same Direction (rear-facing receptor heads 5-7)	Straight	DAS precedes, same lane	0	62 ± 5	Skid pad
			62 ± 5	62 ± 5	Skid pad
		DAS precedes, adjacent lane LEFT	62 ± 5	62 ± 5	Skid pad
		DAS precedes, adjacent lane RIGHT	62 ± 5	62 ± 5	Skid pad
	Motorcycle (straight)	Motorcycle precedes	0	62 ± 5	Skid pad
			62 ± 5	62 ± 5	Skid pad
	Dip series	DAS precedes	40 ± 5	40 ± 5	PHRC
	Curve left (radius of curvature of 764 ft (231 m))	DAS precedes, same lane	0	62 ± 5	VDA S Loop
			62 ± 5	62 ± 5	VDA S Loop
		DAS precedes, adjacent lane LEFT	0	62 ± 5	VDA S Loop
			62 ± 5	62 ± 5	VDA S Loop
		DAS precedes, adjacent lane RIGHT	0	62 ± 5	VDA S Loop
			62 ± 5	62 ± 5	VDA S Loop
	Curve right (radius of curvature of 764 ft (231 m))	DAS precedes, same lane	0	62 ± 5	VDA S Loop
			62 ± 5	62 ± 5	VDA S Loop
		DAS precedes, adjacent lane LEFT	0	62 ± 5	VDA S Loop
			62 ± 5	62 ± 5	VDA S Loop
		DAS precedes, adjacent lane RIGHT	0	62 ± 5	VDA S Loop
			62 ± 5	62 ± 5	VDA S Loop
Passing (Same Direction) (rear-facing receptor heads 5-7)	Straight	DAS follows then passes	62 ± 5	50 ± 5	Skid pad
		ADB follows then passes	50 ± 5	62 ± 5	Skid pad
	Curve left (radius of curvature of 764 ft (231 m))	DAS follows then passes	62 ± 5	45 ± 5	VDA S Loop
		ADB follows then passes	45 ± 5	62 ± 5	VDA S Loop
	Curve right (radius of curvature of 764 ft (231 m))	DAS follows then passes	62 ± 5	45 ± 5	VDA S Loop
		ADB follows then passes	45 ± 5	62 ± 5	VDA S Loop

NOTE: "VDA" refers to TRC's Vehicle Dynamics Area.
"WRC" refers to TRC's Winding Road Course.
"PHRC" refers to TRC's Paved Hilly Road Course.

For same-direction scenario trials in which the DAS vehicle was stationary (0 mph), the ADB-equipped vehicle would withdraw from the scenario by changing lanes when it reached close proximity to the DAS vehicle.

All same direction, or preceding, maneuver scenarios involved the DAS vehicle driving ahead of the ADB-equipped vehicle, either in the same lane or an adjacent lane. All preceding scenarios involved either a straight or single-direction (i.e., left or right) curved course. The preceding glare limit values found in Table 2 were applied to these maneuver scenarios.

Intersection maneuvers were grouped with oncoming scenarios since these scenarios involved a driver looking in the direction of approaching vehicles. This means that the driver turns his or her head toward the approaching vehicle and is exposed to any glare from the approaching vehicle's headlights. Given that drivers look toward the approaching vehicle's headlighting system as would be done in an oncoming maneuver, the derived glare limit values for oncoming maneuvers were applied to all three intersection scenarios examined (60, 90, and 120 degree angled approaches). These intersection maneuver scenarios are depicted in Figure 23. The oncoming scenario glare limit values were presented in Table 1. These limits were also applied to a winding maneuver scenario designed to have the ADB-equipped vehicle alternate between driving toward and away from the oncoming DAS vehicle. This maneuver scenario is depicted in Figure 24.

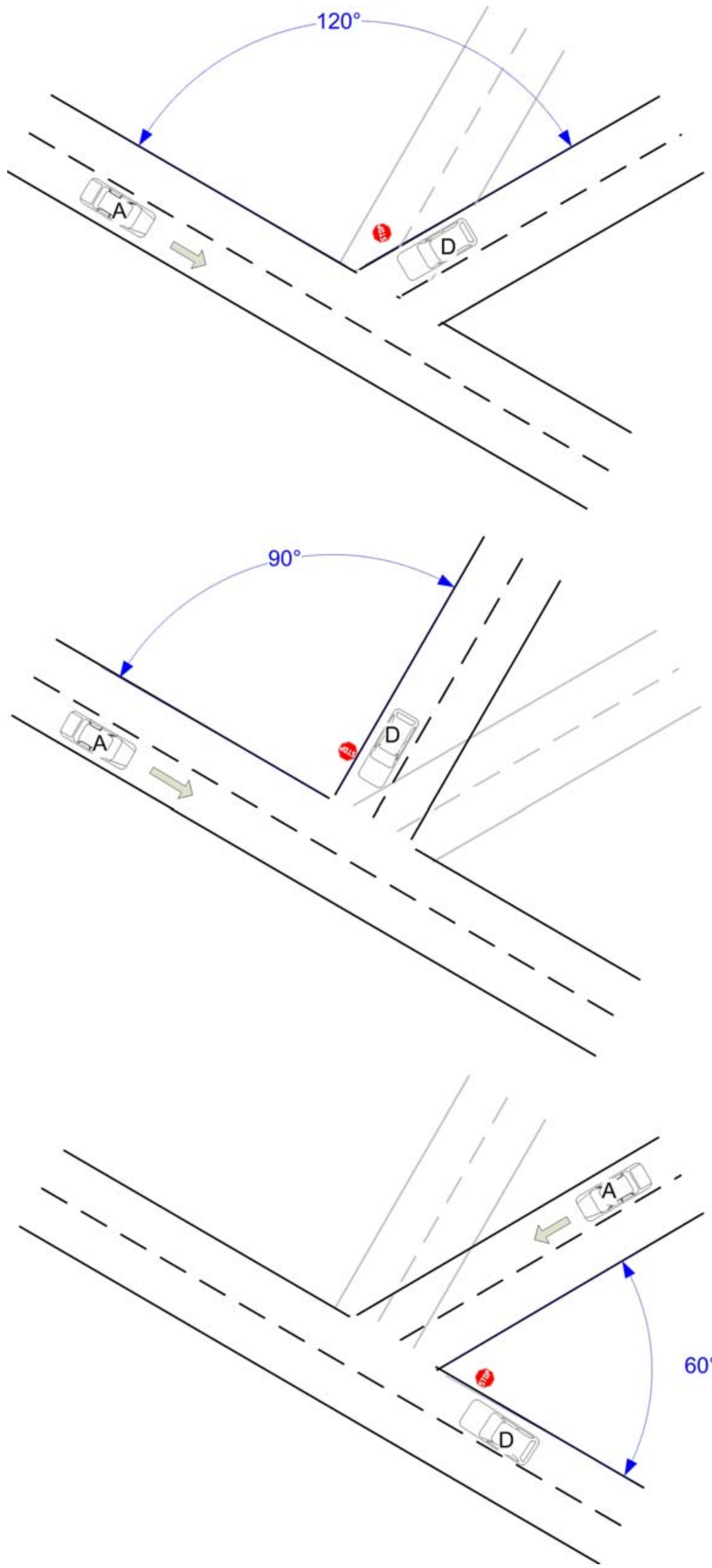

Figure 23. Intersection Scenarios: 60, 90, and 120-Degree Angled Approaches (A=ADB vehicle at 62 mph (96.6 kph); D = DAS vehicle at 0 mph)

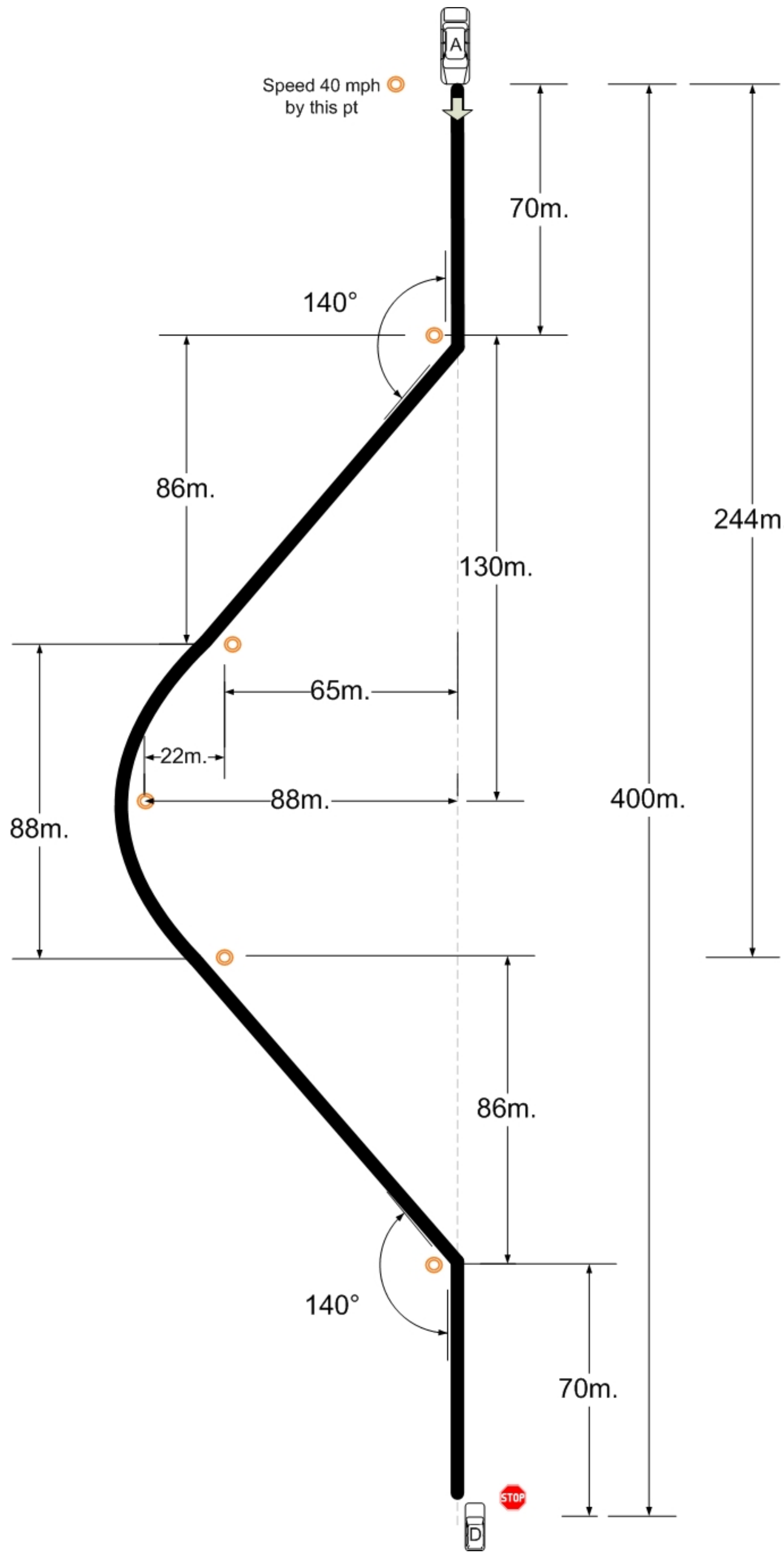

Figure 24. Winding Maneuver Scenario

Examination of the repeatability of test results was also a main focus of the second phase of testing. Each maneuver was repeated two to three times so that individual repetitions could be compared in terms of consistency of both test outcome (i.e., derived glare limit exceedance) and measured illuminance values. Starting or stationary positions specific to each trial or maneuver scenario were used for both vehicles to promote consistency in how individual test trials were conducted. In addition, instrumentation used to measure the distance between vehicles was also used during setup of test trials to promote consistency of inter-vehicle range during measurements.

6.2 Phase 2 Test Vehicles

Test vehicles included the following.

- Audi A8 (2014)
    - “MatrixBeam” system
    - The vehicle’s ADB activation speeds were reduced by the manufacturer from the original equipment European-specification setting to allow ADB to be engaged on shorter test courses. Activation speed was 19 mph (30.6 kph) and deactivation speed was 14 mph (22.5 kph). Original equipment settings have activation at 37 mph (59.5 kph), and deactivation below 25 mph (40.2 kph).
    - Audi indicated that the ADB system’s adaptation creates a shaded area in which the headlamp beam pattern is compliant with FMVSS No. 108 lower beam requirements.
- BMW X5 xDrive35i (2014)
    - “Adaptive High-Beam Assist”
    - Activation speed was 43 mph (69.2 kph) and deactivation speed was below 37 mph (59.5 kph).
    - Making this vehicle’s lower beam pattern compliant with FMVSS No. 108 would have required a hardware modification.
- Lexus LS460 F Sport (2014)
    - “Adaptive high-beam system (AHS)” (previously referred to as “All Zone Beam” (AZB))
    - Activation speed was 37 mph (59.5 kph) and deactivation speed was below 31 mph (49.9 kph).
    - Making this vehicle’s upper and lower beams compliant with FMVSS No. 108 would require a hardware modification.
- Mercedes-Benz E350 (2014)
    - “Adaptive Highbeam Assist”
    - Activation speed was 19 mph (30.6 kph) and deactivation speed was below 19 mph (30.6 kph).
    - The vehicle manufacturer applied a software modification to the vehicle to produce a FMVSS No. 108 compliant upper and lower beam pattern.

A specific member of the research team drove all tested ADB-equipped vehicles in all maneuver scenario trials.

6.3 Measurements and Instrumentation

The illuminance, distance, environmental conditions, and headlamp voltage information were recorded or obtained using the same measurement instrumentation as that described in Sections 4.3.2 of this report. However, the locations of the receptor heads were modified as described in the following section. Forward-looking video cameras were mounted inside both the ADB-equipped vehicle and the DAS vehicle for use in documenting test trials.

6.3.1 DAS Vehicles

The second phase of testing again implemented a test procedure that used a DAS vehicle to create driving maneuver scenarios and record objective data. The DAS vehicle provided the "other/stimulus vehicle" headlighting system stimulus that elicited the ADB response and also housed the equipment used to record test data. Equipment included a DAS, sensors, and other instrumentation to collect illuminance readings and relative vehicle positioning (the distance between the test vehicles and the data collection vehicle). The vehicle was fitted with a commercially available roof rack for ease of mounting exterior equipment, including the illuminance receptor heads. Two different DAS vehicles were used in the second phase of testing, as described below.

The same 2011 Ford Fiesta Titanium as was described for the first phase was also used in the second phase of testing. For phase 2, the Fiesta was referred to as the "Small DAS vehicle" since a second, higher profile vehicle (2010 Acura MDX) was also used as a DAS vehicle. Three repetitions of the test set with each of the four ADB-equipped vehicles were conducted with the Fiesta. The Small DAS vehicle, as instrumented for the second phase of testing, is pictured in Figures 25 and 26.

Figure 25. Small DAS (Ford Fiesta) Front

Figure 26. Small DAS (Ford Fiesta) Rear

A second DAS vehicle consisting of a higher profile model was used to permit assessment of whether DAS vehicle height (and possibly other characteristics) may impact test results. The "SUV DAS Vehicle" was a 2010 Acura MDX (VIN 2HNYD2H77AHxxxxxx). The vehicle was purchased in the U.S. and was certified to FMVSS. This vehicle was not chosen for any specific reason other than it was a higher profile vehicle and was available at no cost. It was acquired from an unrelated NHTSA project that no longer needed the vehicle. Due to time constraints, testing involving the SUV DAS vehicle was conducted with only two of the ADB-equipped vehicles (the Audi A8 and BMW X5). Photographs of the SUV DAS vehicle as instrumented for the second phase of testing are presented in Figures 27 and 28.

Figure 27. SUV DAS (Acura MDX) Front

As can be seen in Figure 27, the low-mounted fog lights on the SUV DAS were taped over to prevent any light from being emitted. Being able to turn off the lights on both the DAS vehicle and the ADB-equipped vehicles was a helpful feature when recording ambient illumination measurements since the vehicles' headlighting system needed to be off or absent. With the SUV DAS fog lights covered, it was possible to make ambient illumination measurements.

Figure 28. SUV DAS (Acura MDX) Rear

In all maneuver scenario trials for all tested ADB-equipped vehicles, the DAS vehicles were driven by the same person.

6.3.2 Additional Stimulus Vehicle

Newly added maneuver scenario trials involving a motorcycle used a 2012 Can-Am Spyder RS (VIN 2BXJADA16CVxxxxxx) to provide the other-vehicle headlighting system stimulus. This model was not chosen for any specific reason other than that it was a motorcycle and was available at no cost. However, its three-wheel design was found to make it easier to operate and maintain in a steady position for stationary trials. It was acquired from an unrelated NHTSA project that no longer needed the vehicle. The vehicle was purchased in the U.S. and was certified to FMVSSs. Lower beam illuminance values for this vehicle are provided later in Section 7.1. The motorcycle's headlighting system contains two headlamps each of which provides both an upper and lower beam and are mounted symmetrically disposed about the vertical centerline. The rear of the vehicle contains a multi-lamp arrangement containing two red tail lamps symmetrically disposed about the vertical centerline. Also the motorcycle contains a single red reflex reflector mounted on the vertical centerline, with two additional reflex reflectors mounted on the front wheel fenders facing the rear.

The motorcycle was not fitted with data recording equipment due to time constraints and equipment availability. Maneuver scenarios were run with the DAS vehicle stationary or driven next to the motorcycle, matching its speed as closely as possible. Data were recorded by the DAS vehicle to provide a range measurement with respect to the ADB-equipped test vehicle as well as illuminance readings. The DAS vehicle's headlighting system was off in these trials to ensure that the ADB-equipped vehicle was responding only to the motorcycle's lamps. Since illuminance receptors were located on the DAS vehicle rather than on the motorcycle in these trials, it should be kept in mind that there was an approximately 9 ft (2.7 m) lateral offset in the measurement points for motorcycle scenarios. This lateral offset off the illuminance receptor heads may have resulted in them being located outside of any ADB-shaded area surrounding the motorcycle.

In each relevant trial, the motorcycle's headlighting system was operated in lower beam mode. In lower beam mode, the two headlamps located at the base of the motorcycle's windscreen were illuminated, as well as the two smaller lamps located on the fenders. The mounting location dimensions of these lamps are given in Table 12 of Section 7 of this report. The vehicle is pictured in Figures 29 and 30.

Figure 29. Motorcycle Stimulus Vehicle (2012 Can-Am Spyder RS) Front

Figure 30. Motorcycle Stimulus Vehicle (2012 Can-Am Spyder RS) Rear

6.3.3 Modified Illuminance Measurement Scheme

Illuminance was measured using the same equipment as was used in the first phase. Changes were made to the illuminance receptor head locations to provide better coverage across the vehicle's daylight openings[2]. Since it was assumed that an effective ADB system would shade the entire passenger compartment to prevent glaring the driver and passengers, receptor heads were positioned at the horizontal bounds of each window area. This scheme allowed for examination of how illuminance values varied across those areas.

Locations of the 10 receptor heads are shown in the following figure. Five receptor heads were facing forward to capture the illuminance associated with oncoming scenarios. Three receptor heads were facing rearward to capture the illuminance associated with preceding (same direction) scenarios. Two receptor heads were facing outward from the right side of the vehicle to capture the illuminance associated with intersection scenarios.

[2] Per S3 of FMVSS No. 104, "daylight opening" means the maximum unobstructed opening through the glazing surface, as defined in paragraph 2.3.12 of section E, "Ground Vehicle Practice," of SAE Aerospace-Automotive Drawing Standards (1963).

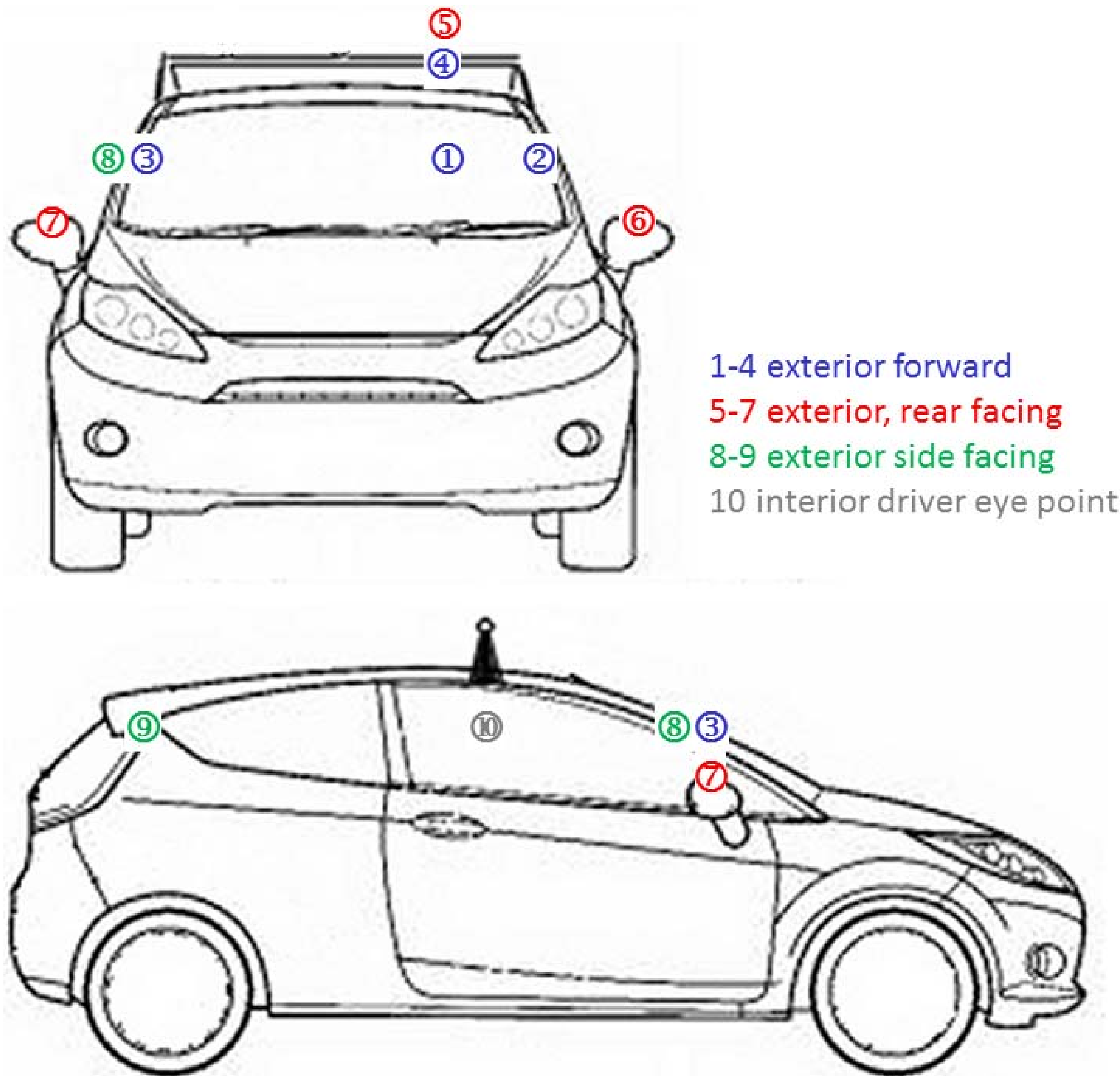

Figure 31. Illuminance Measurement Receptor Head Positioning on DAS Vehicle, Phase 2

6.4 Test Procedure

Three complete sets of test trials were run for all four test vehicles with the Small DAS vehicle. Two sets of test trials were run for the SUV DAS vehicle using only the Audi and BMW test vehicles (due to time constraints).

Prior to beginning any static or dynamic test trials, headlamp aim for each of the ADB-equipped test vehicles was documented through photographs taken in a laboratory setting. Test vehicles were positioned on a level surface 20 feet away from a vertical wall containing a dimensioned grid. Photographs were made of the headlight pattern projected on the wall grid for both lower and upper beam settings. Since the test vehicles were not U.S. models, no attempts were made to adjust headlamp aim.

Headlamp lenses, illuminance meter receptor heads, and the vehicles' windshields were cleaned before each evening of testing. Receptor heads were also cleaned any time during testing when it was noticed that debris had adhered to the sensor surface.

The test procedure involved a complete set of both static measurement trials and dynamic maneuver scenario trials being completed in one night for an individual ADB-equipped test vehicle. During each evening's test session, research staff performed the series of test scenarios following a test sheet, and made notes to document any noteworthy observed headlighting system behaviors, such as flicker and activation conditions. Environmental conditions during testing involved no precipitation, dry or mostly dry pavement, and minimal ambient illumination.

The following subsections describe the steps taken per vehicle followed by scenario-specific steps for an evening of testing. The scenario-specific test procedures were repeated on subsequent nights to provide data for understanding test repeatability.

6.4.1 Static Measurement Trials

To document ambient illumination conditions in which testing was conducted, as well as baseline output levels of the test vehicles' lighting systems, static measurement trials were conducted. These baseline illumination measurements allowed for determination of the contributions of environmental and DAS vehicle lighting to illuminance values recorded.

Toward the beginning of each evening's test session, a series of baseline illuminance levels were recorded. Measurements were made with the DAS vehicle stationary and the ADB-equipped vehicle or motorcycle positioned facing it in the adjacent lane (U.S. lane orientation) at multiple separation distances (30 m, 60 m, and 120 m). Different headlighting system setting combinations were used for the ADB and DAS vehicles at each distance. Baseline headlighting system illuminance values were recorded for both NW and SE facing directions that corresponded to the approach directions used in dynamic maneuver scenarios. In addition, ambient illumination conditions were measured periodically to document environmental conditions and changes throughout a test session.

Headlamp illuminance output was also measured periodically to document the stability of light output from the headlighting system over time, as well as to illustrate differences in illuminance values across receptor head locations. These "warm-up trials" were conducted with the DAS and ADB vehicles running and facing each other in adjacent lanes. The DAS vehicle's headlighting system was off and the ADB vehicle's headlighting system was cycled through off (or DRL mode, if DRL mode could not be turned off), lower beam, and upper beam mode settings. Each mode setting was held for 20 s while data were recorded. Typically two of these trials were completed per test set.

6.4.2 Determine Vehicle-Specific ADB Activation and Deactivation Speeds

This trial type was conducted as multiple repetitions on one night per vehicle to provide the opportunity to observe the speed at which ADB function became active and the speed at which ADB deactivated. This trial provided confirmation that test vehicles' ADB activation speed ranges were compatible with the chosen maneuver scenario trial speeds.

6.4.3 ADB Response to Camera Obstruction

The ADB systems were tested to see how they would perform, and what warnings would be presented, if there was an ADB camera obstruction. Two test conditions were created, one in which the camera was fully obscured and one in which the camera was considered to be partially obscured. In the fully obscured condition, the camera was blocked completely by applying black tape to the vehicle's windshield in front of the camera. In the partially obscured condition, a perforated black film was applied to the vehicle's windshield in front of the camera. The following figure shows the dimensions of the perforations and the separation between perforations. The perforated material was part of a commercially available product sold as a vehicle windshield sun shielding applique.

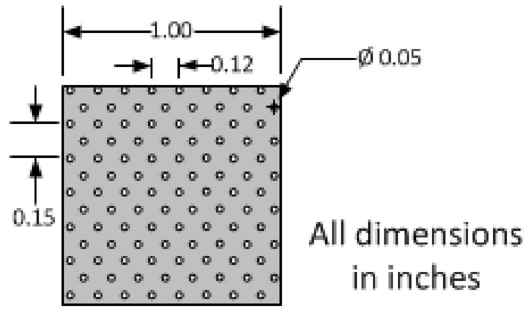

Figure 32. Illustration of a Section of the Material Used in Partial Camera Coverage Trials

6.4.4 ADB Adaptation Time Scenario

To examine how quickly ADB systems adapted to other vehicles' headlighting system, ADB systems' responses to the sudden appearance of an oncoming vehicle were observed. The Small and SUV DAS vehicles were used in these trials according to which DAS vehicle was being used in a test trial set. The scenario was not attempted with the motorcycle.

The DAS vehicle was stationary on a straight, level roadway with its headlighting system off while the ADB vehicle approached in an oncoming manner in the adjacent lane. When the ADB vehicle was approximately 120 m from the DAS vehicle, the DAS vehicle's driver was given the command to turn on the lower beam headlamps. Data were recorded as the ADB-equipped vehicle approached and responded to the light stimulus. Three to four response time trials were conducted per ADB-equipped vehicle and for both DAS vehicles.

Ideally, adaptation time would be measured from the time of the appearance of the light stimulus. However, since no data documenting the timing of the DAS vehicle's headlighting system output were available, the measured voltage to the DAS vehicles' headlamps had to be relied upon as an indication of when the DAS vehicle's headlighting system was turned on. Since it wasn't known at what degree of voltage application light would begin to be emitted from the DAS vehicle's headlamps, the onset of the voltage application to the headlamps was used as the start of the adaptation time.

Also ideally, it would make sense for the end of the adaptation time period to be the time at which the ADB system adjusted its light output to levels meeting the derived lower beam glare limit values. ADB adaptation time was defined as the time from onset of the spike in the DAS vehicle's headlamp voltage signal (signaling DAS lower beams had been activated) to the time when the measured illuminance value dropped to the appropriate glare limit value based on range. Since only two of the four European-specification test vehicles had their headlighting systems modified to meet U.S. beam patterns, it was acknowledged that not all the vehicles tested might adapt their output to levels meeting FMVSS No. 108-derived glare limits.

6.4.5 Dynamic Maneuver Scenario Trials

Dynamic maneuver scenarios, summarized earlier in Table 11, were designed to exercise the ADB to allow assessment of ADB performance and measurement of glare illuminance for comparison to lower beam performance for each vehicle. Maneuver scenarios were categorized according to maneuver geometry. Each geometry used a specific subset of illuminance receptor heads and either oncoming or preceding maneuver glare limit values. For example, oncoming maneuvers were analyzed based on data from forward-facing receptor heads 1-4, and 10. Intersection maneuvers were analyzed based on data from side-facing receptor heads 8 and 9 and values compared to derived glare limit values for oncoming maneuvers. Same direction maneuvers were analyzed based on data from rear-facing receptor heads 5-7. Thus, the three maneuver categories were established based on whether the maneuvers used forward-facing, rear-facing, or side-facing receptor heads.

As stated previously, each maneuver scenario was performed in both lower beam and ADB headlighting system modes. In addition, the complete set of maneuver scenarios was conducted three times with the Small DAS vehicle for each ADB-equipped test vehicle. Two complete sets of maneuver scenarios were conducted with the SUV DAS vehicle for two of the ADB-equipped test vehicles: the Audi A8 and BMW X5. A complete set of maneuver scenarios could be completed in a single evening.

For preceding maneuvers in which the DAS vehicle (or motorcycle) was stationary and in the same lane as the ADB vehicle, the ADB approached up to a distance of 95 m and then changed lanes to avoid the stationary DAS vehicle. For all preceding maneuvers in which the DAS vehicle (or motorcycle) was not stationary, the ADB vehicle started at an initial range of 120 m behind the DAS vehicle and closed in to at least 100 m during the maneuver.

In trials involving the motorcycle, the DAS vehicle drove with its headlighting system off in the lane adjacent to the motorcycle (which had no attached instrumentation) to facilitate range measurement since the motorcycle had no instrumentation.

Multi-lane road maneuver scenarios used both straight and curved roads with same and opposite direction travel (i.e., preceding (same direction) and oncoming other/stimulus vehicle). Active and passive passing maneuvers were conducted, as well as multi-vehicle (adding a third, oncoming vehicle) scenarios.

Maneuver scenarios involving a straight road, including those involving a motorcycle, were conducted on TRC’s Skid Pad facility. The facility has five paved lanes, each 12 feet in width and 3,600 feet long.

For curved maneuvers, the South loop of TRC’s Vehicle Dynamics Area was used. The 0.9-mile long curve has a radius of 764 feet (231 m) and the two lanes are each 12 feet in width.

The dip series maneuver was conducted on TRC’s Paved and Gravel Hilly Road Course. The section of the course used was a straight section with several dips. The section was approximately 2,100 feet long and 18 feet wide with no lane markings.

6.4.6 Subjective Glare Assessment

As was done in the first phase of testing, subjective glare assessment ratings were made by the research staff member driving the DAS vehicle for all dynamic maneuver scenario trials. These data were not analyzed.

6.5 Data Analysis

Data analysis involved summarizing measured illuminance values by scenario and distance (range between vehicles), for comparison to derived glare limit values. The data analysis approach was the same as that used in Phase 1, including performing similar data adjustment methods for illuminance and range data as was described in Section 4.6.1.

The focus of the Phase 2 data analysis was different than the previous phase. Phase 1 was focused on developing and then determining the effectiveness of the test procedures, whereas, Phase 2 was focused on ADB performance results and test repeatability. As part of this focus, for dynamic maneuvers, the scenarios were grouped into three categories:

- Oncoming maneuvers (including straight roads, curved roads, winding road, and dip series)
- Intersection maneuvers (60, 90 and 120-degree approaches)
- Same direction maneuvers (including straight roads, curved roads, lane changes, and dip series, where the DAS vehicle precedes the ADB vehicle at some point during the maneuver)

As stated previously, the illuminance reaching the eyes of a driver approached by an oncoming ADB-equipped vehicle was assessed with respect to the derived glare limit values developed by Flannigan and Sullivan [10] to determine whether or not the DAS vehicle driver experienced glare from the ADB vehicle. As was done in the first phase of testing, the maximum illuminance values recorded over various distance ranges during the maneuvers were compared to these glare limit values: 3.109 lux at a range of 15 m to 30 m, 1.776 lux at a range of 30 m to 60 m, 0.634 lux at a range of 60 m to 120 m, and 0.281 lux beyond 120 meters. The range is defined as the distance from the ADB vehicle's headlamps to the receptor head locations on the DAS vehicle. For oncoming maneuver scenarios, the longitudinal distance was used, while for intersection scenarios, the absolute distance was used. For same direction (preceding) maneuvers, the glare limit values are: 18.854 lux at a range of 15 m to 60 m, and 4.041 lux beyond 60 meters.

7.0 PHASE 2 TEST ADB PERFORMANCE RESULTS

Results for the second round of testing were examined to permit characterization of the performance of ADB systems tested relative to lower beam systems and FMVSS No. 108 derived lower beam glare limits. The ability of ADB systems to exhibit similar adaptation performance behavior across test trial repetitions was also assessed.

7.1 Headlighting System Illuminance Static Measurements

The mounting height and lateral location of front lighting components was measured for all vehicles involved in this testing. The following table summarizes position measurements for lamp equipment on the DAS vehicles and the stimulus motorcycle.

Table 12. Height and Lateral Position Measurements for DAS and Stimulus Vehicle Lamps That Illuminate for Lower Beam Mode

Lamps	Small DAS		SUV DAS		Motorcycle	
	Height (above ground; in)	**Lateral Distance** (from vehicle centerline; in)	**Height** (above ground; in)	**Lateral Distance** (from vehicle centerline; in)	**Height** (above ground; in)	**Lateral Distance** (from vehicle centerline; in)
Lower Beam Lamps	29.75	20.88	34.75	28.75	32.38	4.63
Fog Lamps	17.25	28.13	Not measured	Not measured*	N/A	N/A
Fender Lamps	N/A	N/A	N/A	N/A	20.25	25.88
Front Parking Lamps	26.75	17.75	37.5	29.75	N/A	N/A
Front Side Marker Lamps	31.25	27	37.25	30.88	N/A	N/A
Rear Side Marker Lamps	Not measured	Not measured	40.50	33.88	N/A	N/A
Tail Lamps	41.00	25.00	42.88	30.63	32.38	3.75
License Plate Lamp	36.25	5.75	42.00	5.00	16.00	0.00

*Note: Fog lamps on the SUV DAS vehicle were covered so they could not emit light. This is because they could not be turned off, which hindered ambient illumination measurement.

Location dimensions for upper and lower beam lamps on each of the ADB-equipped vehicles are summarized in Table 13. Values in the table represent the location of the center of each lamp. Additional lamps, such as fog lamps and parking lamps, may have been present but were not measured.

Table 13. Height and Lateral Position Measurements for ADB-Equipped Vehicle Front Lamps

Lamps	Audi		BMW*		Lexus		Mercedes-Benz	
	Height (above ground; in)	**Lateral Distance** (from vehicle centerline; in)	**Height** (above ground; in)	**Lateral Distance** (from vehicle centerline; in)	**Height** (above ground; in)	**Lateral Distance** (from vehicle centerline; in)	**Height** (above ground; in)	**Lateral Distance** (from vehicle centerline; in)
Headlamps – Lower Beam	25.20	27.50	33.19 34.13	23.13 29.38	28.63	29.25	24.63	22.00
Headlamps – Upper Beam	28.00	25.00	33.19 34.13	23.13 29.38	27.38	24.25	26.50	28.38

*Note: Two laterally adjacent headlamp modules were illuminated in both the lower and upper beam modes.

Figures 33 through 37 show photos of the driver-side headlamps for each ADB-equipped test vehicle.

Figure 33. Audi A8 Lamps

Figure 34. BMW X5 Lamps

Figure 35. Lexus LS460 Lamps

Figure 36. Mercedes-Benz E350 Lamps

The DAS vehicles' headlighting system was in lower beam mode in all trials except ones involving the motorcycle, in which they were off. To permit the illuminance from the DAS vehicle's headlighting system to be subtracted from the measured values recorded in the dynamic maneuver scenarios, measurements of the light produced by the front lamps of both DAS vehicles were made. Baseline headlamp output levels were measured over a 10-second period with the vehicles parked and their engines running. Measurements for both vehicles were made using the DAS instrumentation on the vehicle (i.e., the forward facing receptor heads mounted on the Small DAS vehicle were used to measure the light output in the forward direction from the DAS vehicle's headlamps). Therefore, in Table 14 there is no distance information, because there was only one vehicle involved in each measurement and the receptor heads were on that vehicle. Measurements were recorded for two different headings, NW and SE, since most maneuvers were run with the vehicle's travel paths aligned with these directions. Average illuminance over all measurements was 0.53 lux for the Small DAS and 0.67 lux for the SUV DAS. Table 14 presents overall average static baseline illuminance values for the Small and SUV DAS vehicles. For adjustment of illuminance data to remove the impact of DAS vehicle headlighting systems, maneuver scenario set-based values were used.

Table 14. Static Baseline Measured Illuminance Values for DAS Vehicle Lower Beam Headlamps (Receptor Head 1)

DAS Vehicle Heading	Distance	Small DAS (Ford Fiesta)					SUV DAS (Acura MDX)				
		n	Avg.	SD	Min.	Max.	n	Avg.	SD	Min.	Max.
NW	N/A	11	0.48	0.03	0.44	0.54	4	0.62	0.05	0.58	0.67
SE	N/A	11	0.58	0.09	0.49	0.79	4	0.72	0.02	0.70	0.74

Static baseline illuminance levels were also recorded for the lower beam headlamps of the motorcycle used as a stimulus vehicle in motorcycle scenarios. Baseline measurements were made with the motorcycle and DAS vehicles having their engines running and parked facing the same direction in adjacent lanes. Measurements with the motorcycle were only made for the SE heading, since all scenarios were conducted with the motorcycle facing that direction. Each trial measured illuminance over a 10-second period. Overall average statically measured illuminance values for the front lamps of the motorcycle are presented in the following table. For adjustment of illuminance data to remove the impact of DAS vehicle headlighting systems, maneuver scenario set-based values were used.

Table 15. Static Baseline Measured Illuminance Values for Stimulus Motorcycle Lower Beam Headlamps (Receptor Head 1)

DAS Vehicle Heading	Distance	Small DAS (Ford Fiesta)					SUV DAS (Acura MDX)				
		n	Avg.	SD	Min.	Max.	n	Avg.	SD	Min.	Max.
SE	N/A	11	0.17	0.03	0.13	0.24	4	0.16	0.02	0.15	0.18

Baseline illuminance levels for lower and upper beam modes of the ADB-equipped test vehicles were recorded for documentation and reference purposes. Measurements were made with the ADB and DAS vehicles having their engines running and parked facing each other in adjacent lanes in a U.S. lane orientation at multiple longitudinal separation distances. Measurements were made for three headlamp setting combinations for the two vehicles (ADB-DAS): lower-lower, lower-off, and upper-off. Each of these headlighting system mode combinations was measured at longitudinal separation distances of 30 m, 60 m, and 120 m. Measurements were also recorded for two different headings, NW and SE, since a majority of maneuvers were run with the vehicle’s travel paths aligned with these directions. Measured ambient illumination levels specific to each individual ADB-equipped vehicle’s test conditions were recorded. Ambient illumination for the initial phase of testing was generally lower than 0.15 lux. Table 16 presents data collected using the Small DAS vehicle and Table 17 presents data collected using the SUV DAS vehicle.

Table 16. Baseline Measured Illuminance Values by Headlighting System Mode and Ambient Conditions (Receptor Head 1), Small DAS

DAS Vehicle Heading	Distance	Vehicle Headlighting System Setting		Audi A8 (n=3)		BMW X5 (n=3)		Lexus LS460 (n=2)		Mercedes-Benz E350 (n=3)	
		ADB	DAS	Average (lux)	SD	Average (lux)	SD	Average (lux)	SD	Average (lux)	SD
NW	N/A	OFF (ambient)	OFF (ambient)	0.01	0.04	0.00	0.01	0.00	0.00	0.00	0.01
NW	30 m (98 ft)	OFF	LOWER	0.47	0.03	0.52	0.03	0.49	0.02	0.46	0.01
		LOWER	LOWER	1.41	0.57	2.02	0.06	1.59	0.10	1.74	0.05
		LOWER	OFF	1.27	0.04	1.51	0.10	1.09	0.08	1.27	0.05
		UPPER	OFF	31.48*	0.05	31.48*	0.02	31.48*	0.07	31.50*	0.05
NW	60 m (197 ft)	LOWER	LOWER	0.95	0.00	0.88	0.04	0.80	0.02	0.97	0.03
		LOWER	OFF	0.47	0.02	0.37	0.03	0.30	0.02	0.48	0.05
		UPPER	OFF	30.77*	1.15	31.49*	0.01	31.47*	0.01	22.95	5.50
NW	120 m (394 ft)	LOWER	LOWER	0.71	0.09	0.60	0.03	0.56	0.01	0.64	0.05
		LOWER	OFF	0.26	0.09	0.10	0.01	0.10	0.03	0.15	0.01
		UPPER	OFF	10.87	0.48	14.83	0.28	16.92	2.75	6.67	1.15
SE	N/A	OFF (ambient)	OFF (ambient)	0.03	0.03	0.12	0.07	0.07	0.07	0.02	0.01
SE	30 m (98 ft)	OFF	LOWER	0.53	0.03	0.72	0.10	0.59	0.07	0.52	0.03
		LOWER	LOWER	1.73	0.08	1.95	0.22	1.68	0.08	1.83	0.03
		LOWER	OFF	1.23	0.09	1.41	0.18	1.15	0.08	1.33	0.03
		UPPER	OFF	31.48*	0.07	31.46*	0.00	31.48*	0.01	31.50*	0.04
SE	60 m (197 ft)	LOWER	LOWER	0.96	0.01	1.00	0.13	0.90	0.07	0.98	0.01
		LOWER	OFF	0.41	0.10	0.47	0.08	0.38	0.06	0.48	0.01
		UPPER	OFF	28.69	0.56	31.46*	0.00	29.76	1.91	21.20	3.45
SE	120 m (394 ft)	LOWER	LOWER	0.75	0.03	0.74	0.12	0.67	0.06	0.77	0.10
		LOWER	OFF	0.23	0.05	0.21	0.08	0.16	0.07	0.23	0.03
		UPPER	OFF	10.73	0.31	13.96	1.44	16.91	2.05	6.85	1.05

*Note: Trials averaged to obtain these noted values include at least one instance of measurement clipping due to actual illuminance levels exceeding the measurement range of the illuminance meter.

Table 17. Baseline Measured Illuminance Values by Headlighting System Mode and Ambient Conditions (Receptor Head 1), SUV DAS

DAS Vehicle Heading	Distance	Headlighting System Setting		Audi A8 (n=2)		BMW X5 (n=2)	
		ADB	DAS	Average (lux)	SD	Average (lux)	SD
NW	N/A	OFF (ambient)	OFF (ambient)	-0.02	0.01	-0.02	0.03
	30 m (98 ft)	OFF	LOW	0.67	0.00	0.58	0.00
		LOWER	LOW	1.56	0.03	1.55	0.05
		LOWER	OFF	0.97	0.03	0.97	0.07
		UPPER	OFF	31.48*	0.01	31.45*	0.02
NW	60 m (197 ft)	LOWER	LOW	0.97	0.03	0.87	0.04
		LOWER	OFF	0.36	0.00	0.27	0.00
		UPPER	OFF	24.90	1.07	31.47*	0.05
NW	120 m (394 ft)	LOWER	LOW	0.73	0.02	0.63	0.01
		LOWER	OFF	0.12	0.03	0.05	0.01
		UPPER	OFF	9.39	0.01	13.21	2.22
SE	N/A	OFF (ambient)	OFF (ambient)	0.02	0.00	0.02	0.04
	30 m (98 ft)	OFF	LOW	0.72	0.01	0.72	0.03
		LOWER	LOW	1.59	0.02	1.75	0.13
		LOWER	OFF	0.95	0.01	1.11	0.13
		UPPER	OFF	31.49*	0.05	31.47*	0.05
SE	60 m (197 ft)	LOWER	LOW	1.01	0.00	0.95	0.03
		LOWER	OFF	0.37	0.00	0.31	0.01
		UPPER	OFF	23.74	1.35	31.46*	0.11
SE	120 m (394 ft)	LOWER	LOW	0.80	0.03	0.72	0.03
		LOWER	OFF	0.17	0.04	0.10	0.03
		UPPER	OFF	9.33	0.96	13.25	0.85

*Note: Trials averaged to obtain these noted values include at least one instance of measurement clipping due to actual illuminance levels exceeding the measurement range of the illuminance meter.

Illuminance data from "headlamp warm-up trials" were examined to assess which locations are best for reporting the amount of light reaching an oncoming driver's eyes. In these trials, the DAS and ADB vehicle were facing each other in adjacent lanes and the ADB vehicle's headlighting system was cycled through off, lower beam, and upper beam settings. Each mode setting was held for 20 s while data were recorded. This trial was intended for use in examining the stability of headlamp light output over time, as well as for illustrating differences in illuminance values across receptor head locations. The duration was reduced from the longer periods used in Phase 1 testing due to the relative stability that had been observed. Figures 37-48 present example warm-up trial data for each of the four test vehicles. For each vehicle, a graphical example of a full trial and a separate graphical example of the first 40 seconds of a trial is shown for all relevant DAS vehicles. As would be expected, receptor head 1 (adhered to windshield, directly forward of driver's eye point) tended to show higher values than receptor head 3 (at the passenger-side A-pillar, which was further away from the center of the oncoming headlighting system's beam pattern). Receptor head 4 tended to show values lower than both receptor heads 1 and 3, presumably due to being vertically further away from the center of the oncoming headlighting system's beam pattern. The magnitude of these differences varied by vehicle, with the Audi showing the largest differences (see Figures 37 and 38) between receptor head measured values.

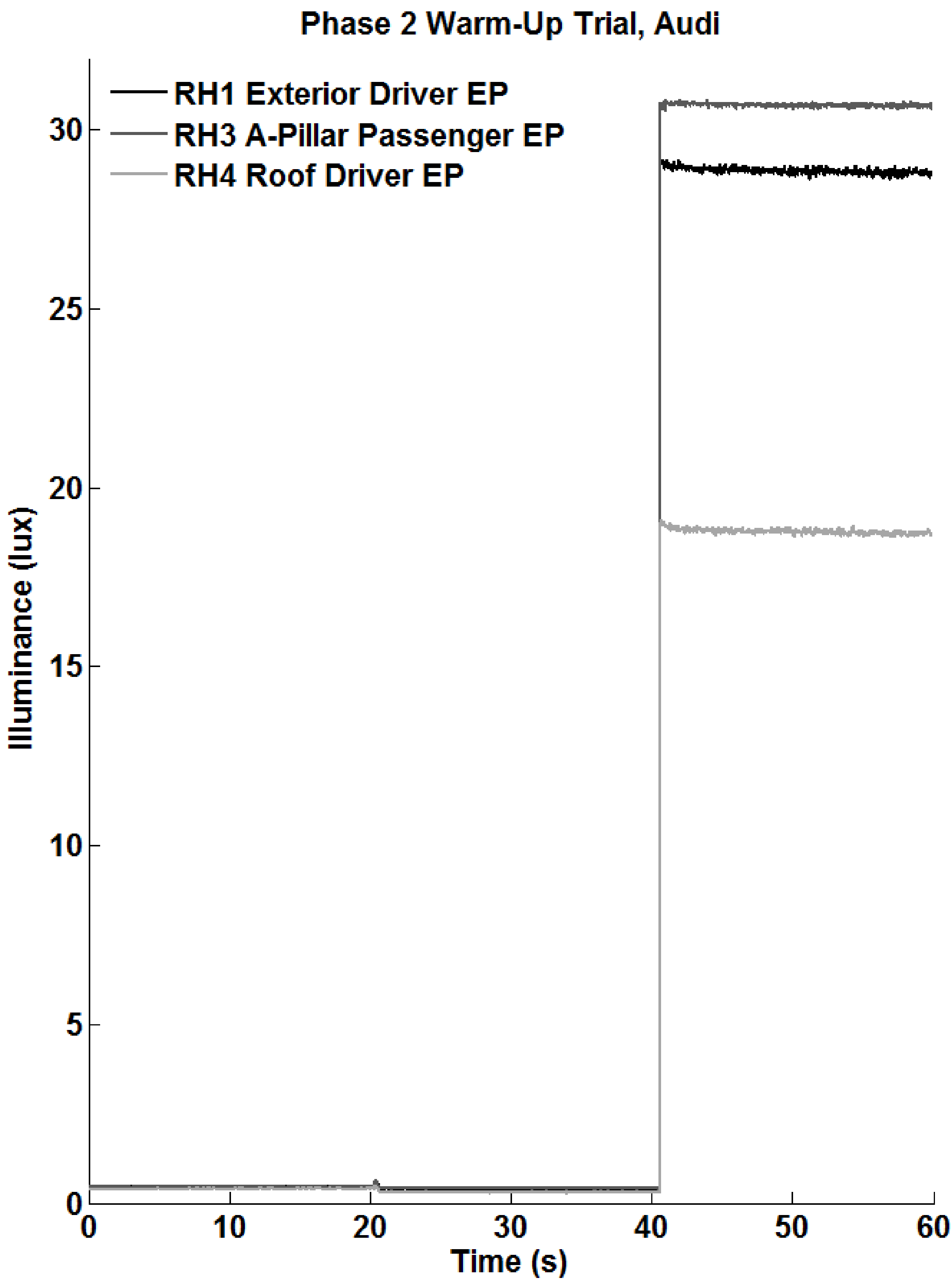

Figure 37. Audi Warm-Up Trial Example Showing DRL, Lower Beam, Upper Beam Modes for Small DAS Vehicle, Phase 2

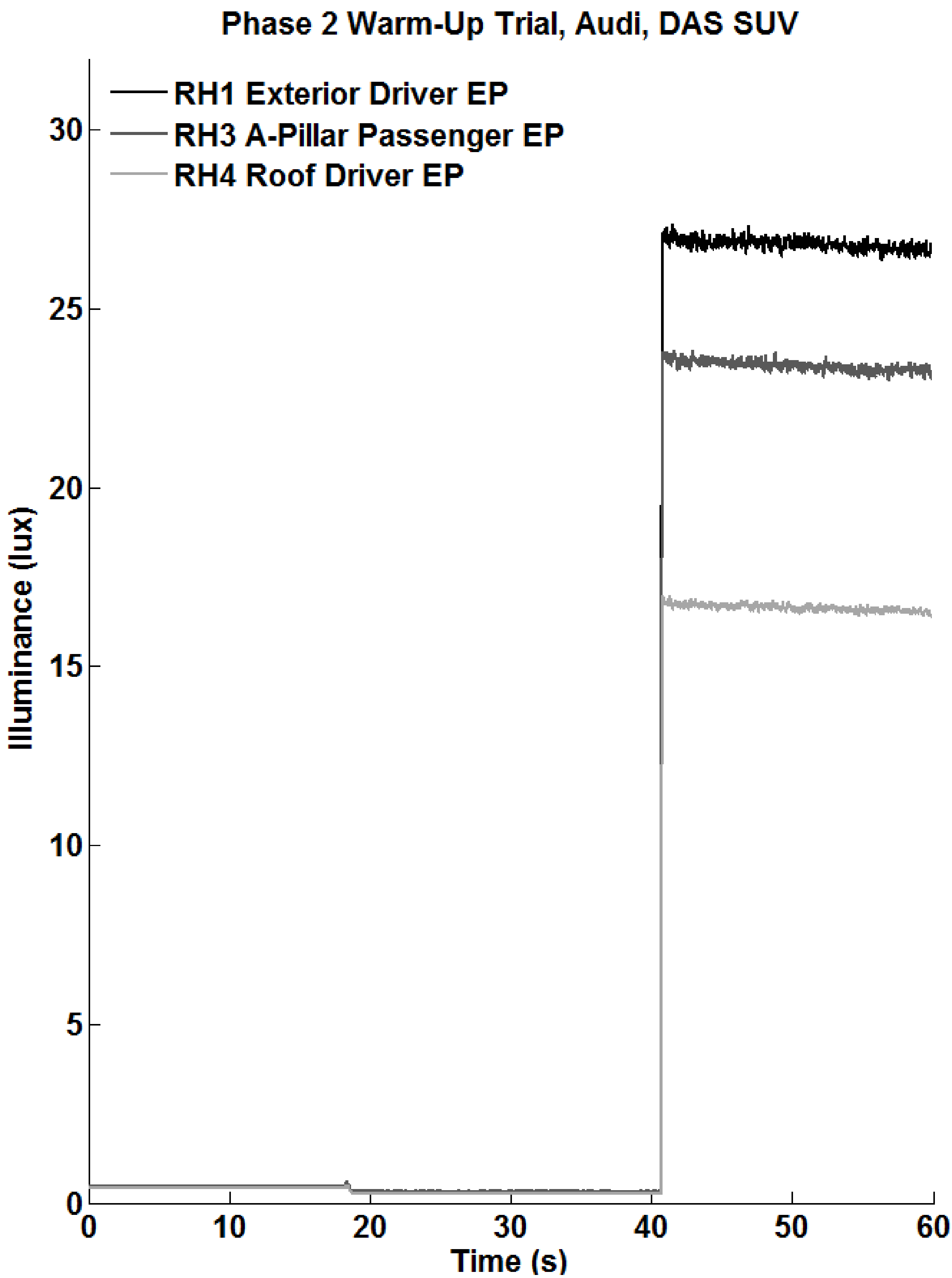

Figure 38. Audi Warm-Up Trial Example Showing DRL, Lower Beam, Upper Beam Modes for SUV DAS Vehicle, Phase 2

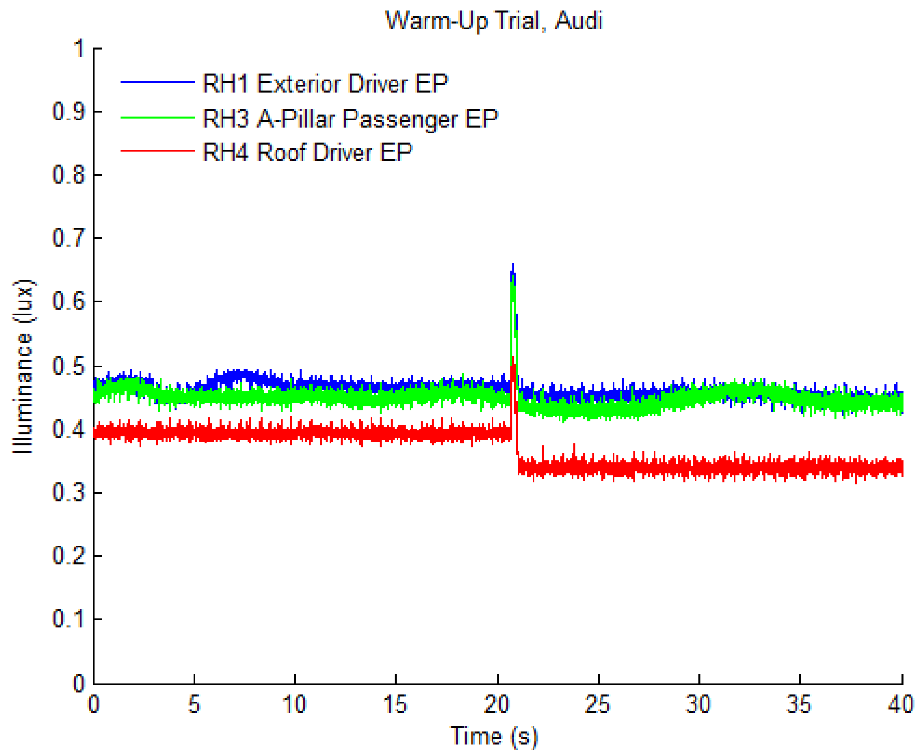

Figure 39. Audi Warm-Up Trial Example Showing DRL, Lower Beam Modes for Small DAS Vehicle, Phase 2

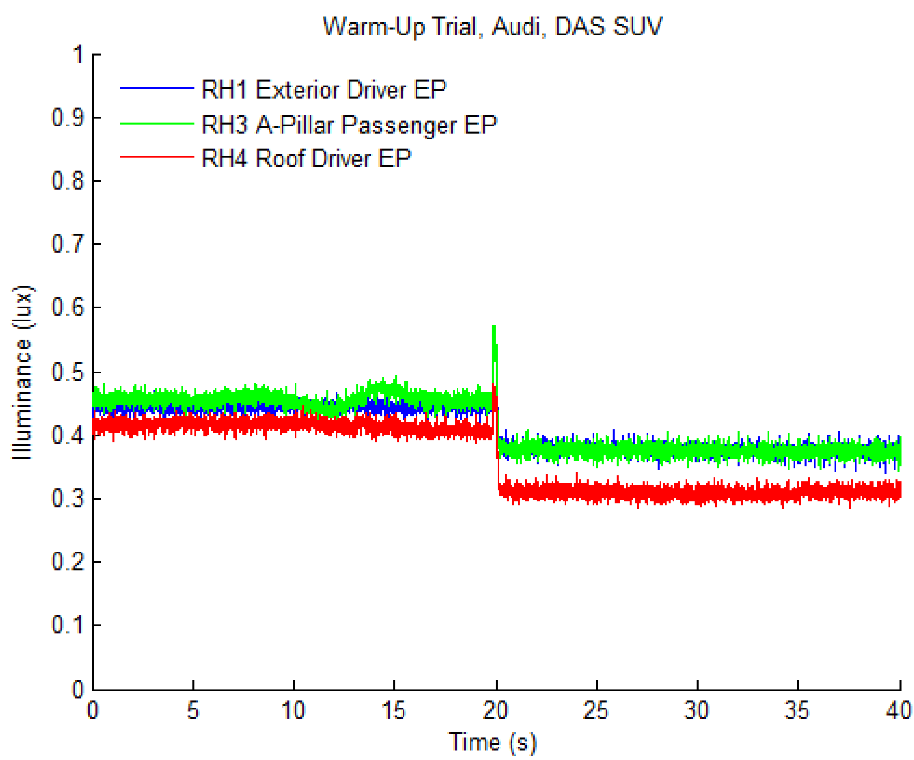

Figure 40. Audi Warm-Up Trial Example Showing DRL, Lower Beam Modes for SUV DAS Vehicle, Phase 2

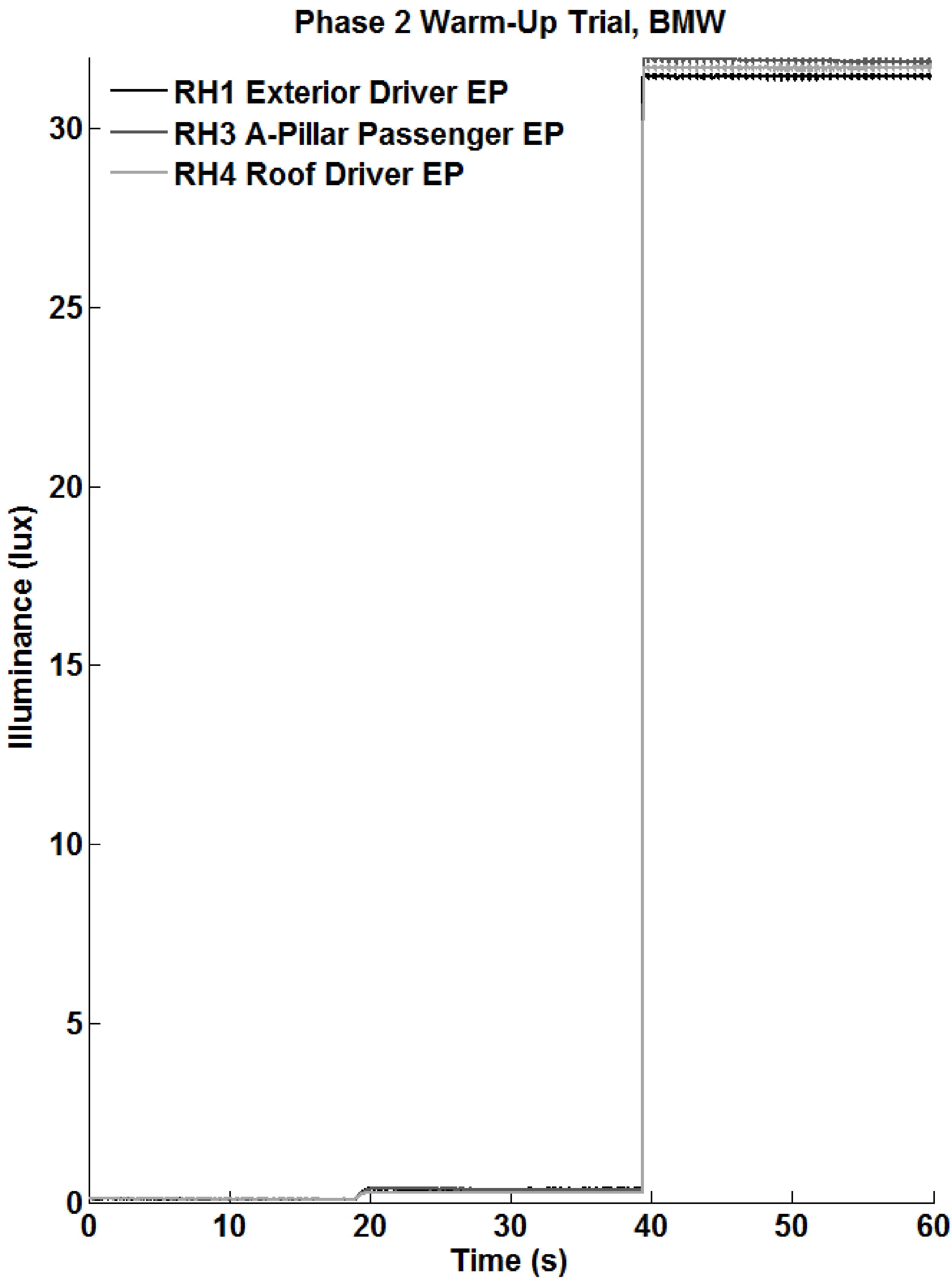

Figure 41. BMW Warm-Up Trial Example Showing DRL, Lower Beam, Upper Beam Modes for Small DAS Vehicle, Phase 2

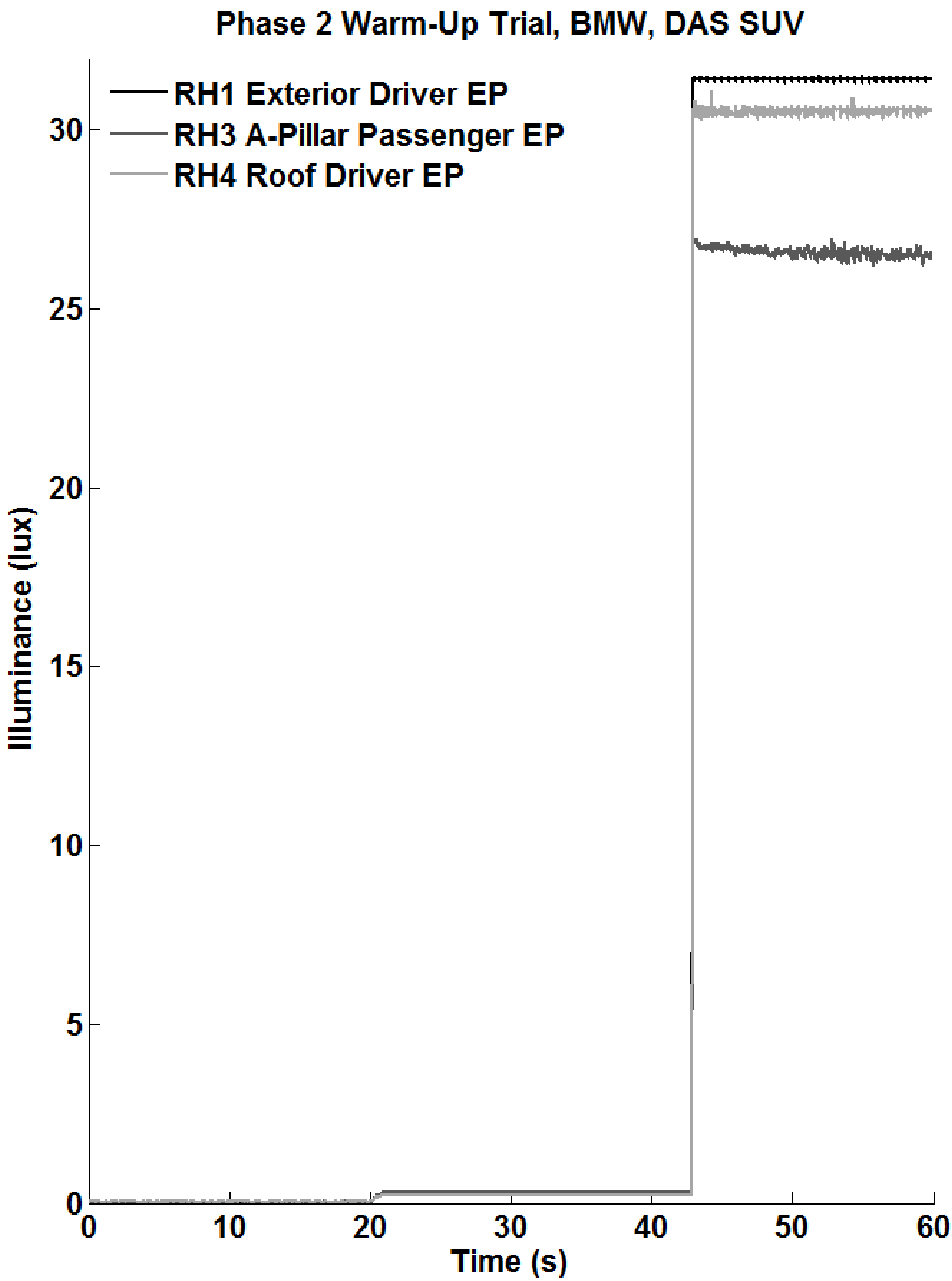

Figure 42. BMW Warm-Up Trial Example, SUV DAS Vehicle, Phase 2

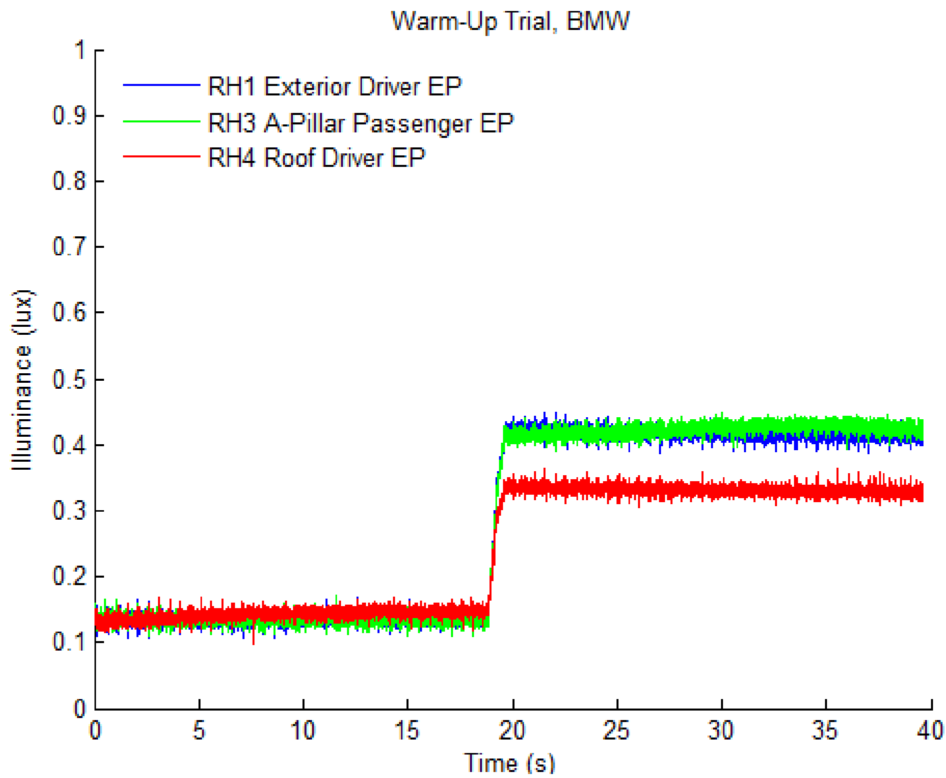

Figure 43. BMW Warm-Up Trial Example Showing Ambient Illumination, Lower Beam, Mode for Small DAS Vehicle, Phase 2

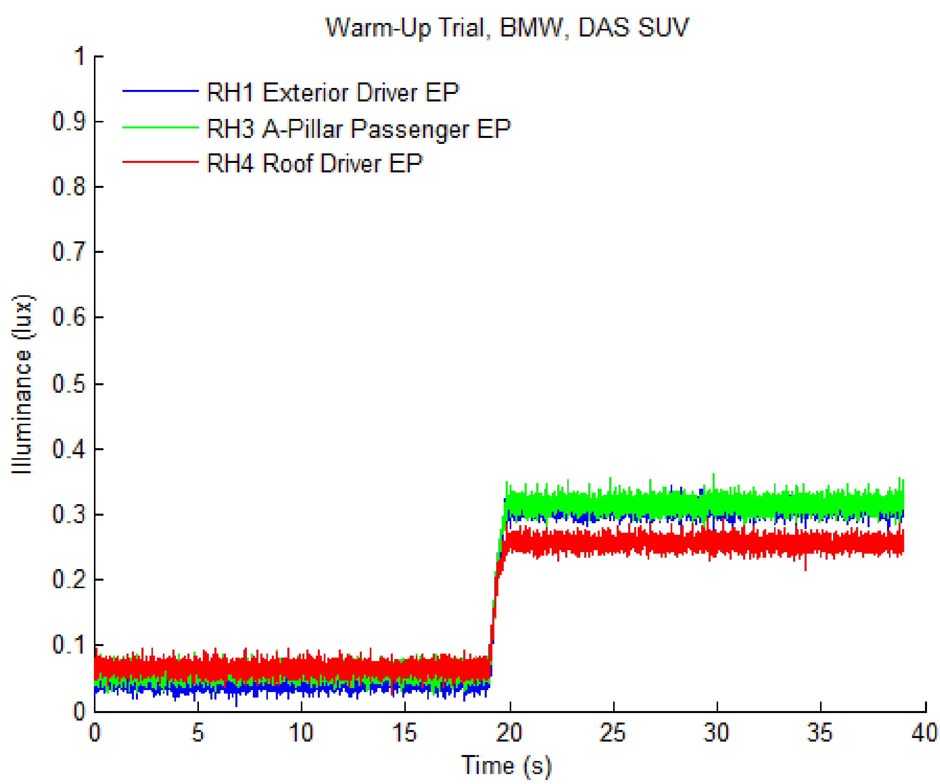

Figure 44. BMW Warm-Up Trial Example Showing Ambient Illumination, Lower Beam Mode for SUV DAS Vehicle, Phase 2

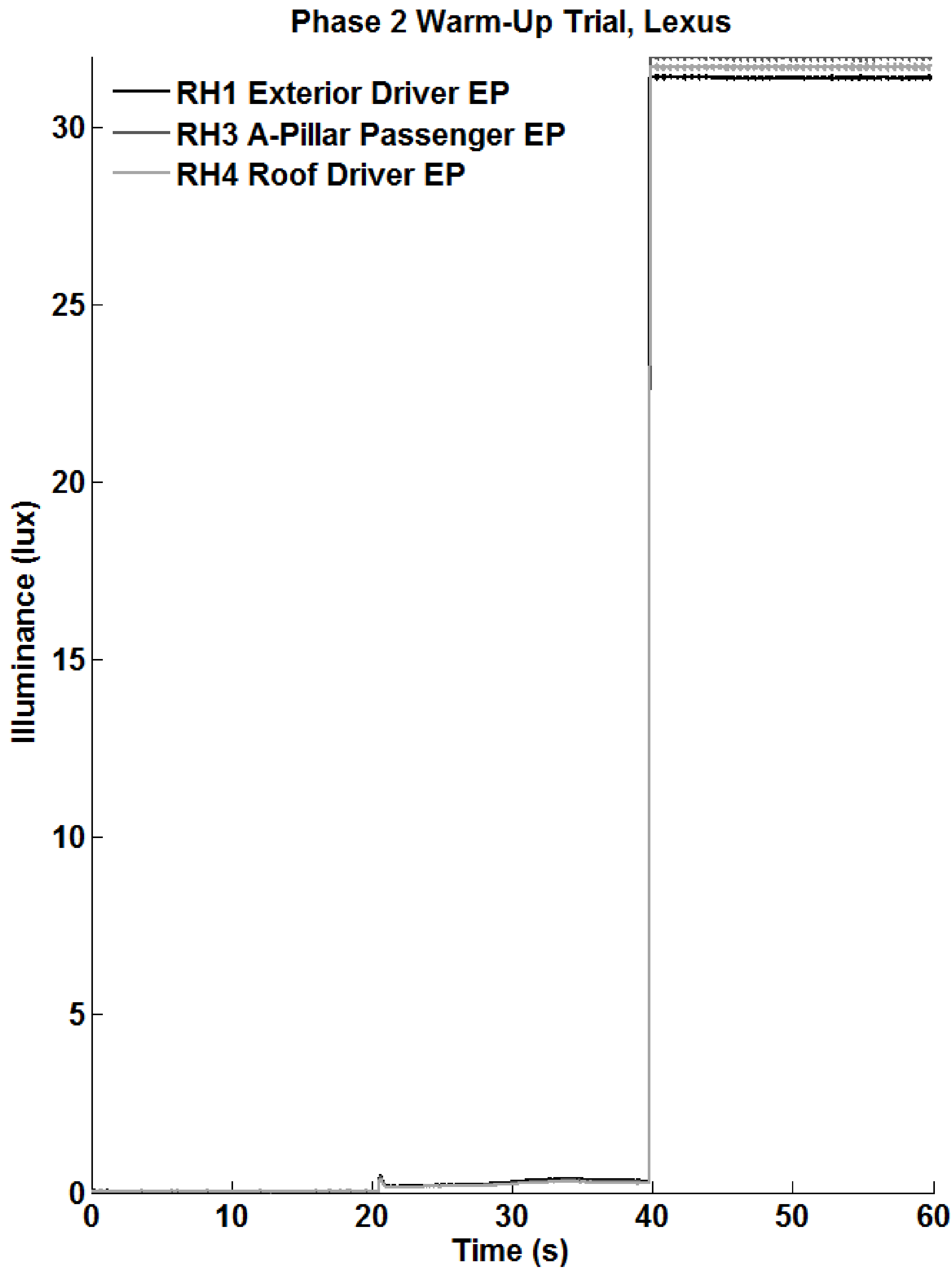

Figure 45. Lexus Warm-Up Trial Example Showing Ambient Illumination, Lower Beam, Upper Beam Modes for Small DAS Vehicle, Phase 2

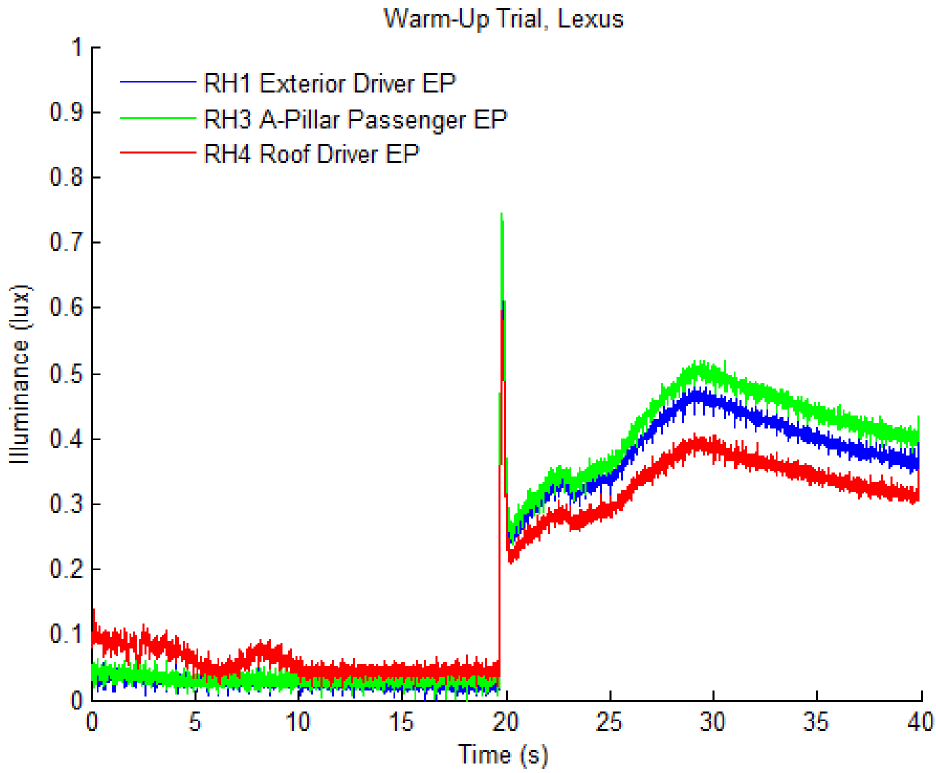

Figure 46. Lexus Warm-Up Trial Example Showing Ambient Illumination, Lower Beam Mode for Small DAS Vehicle, Phase 2

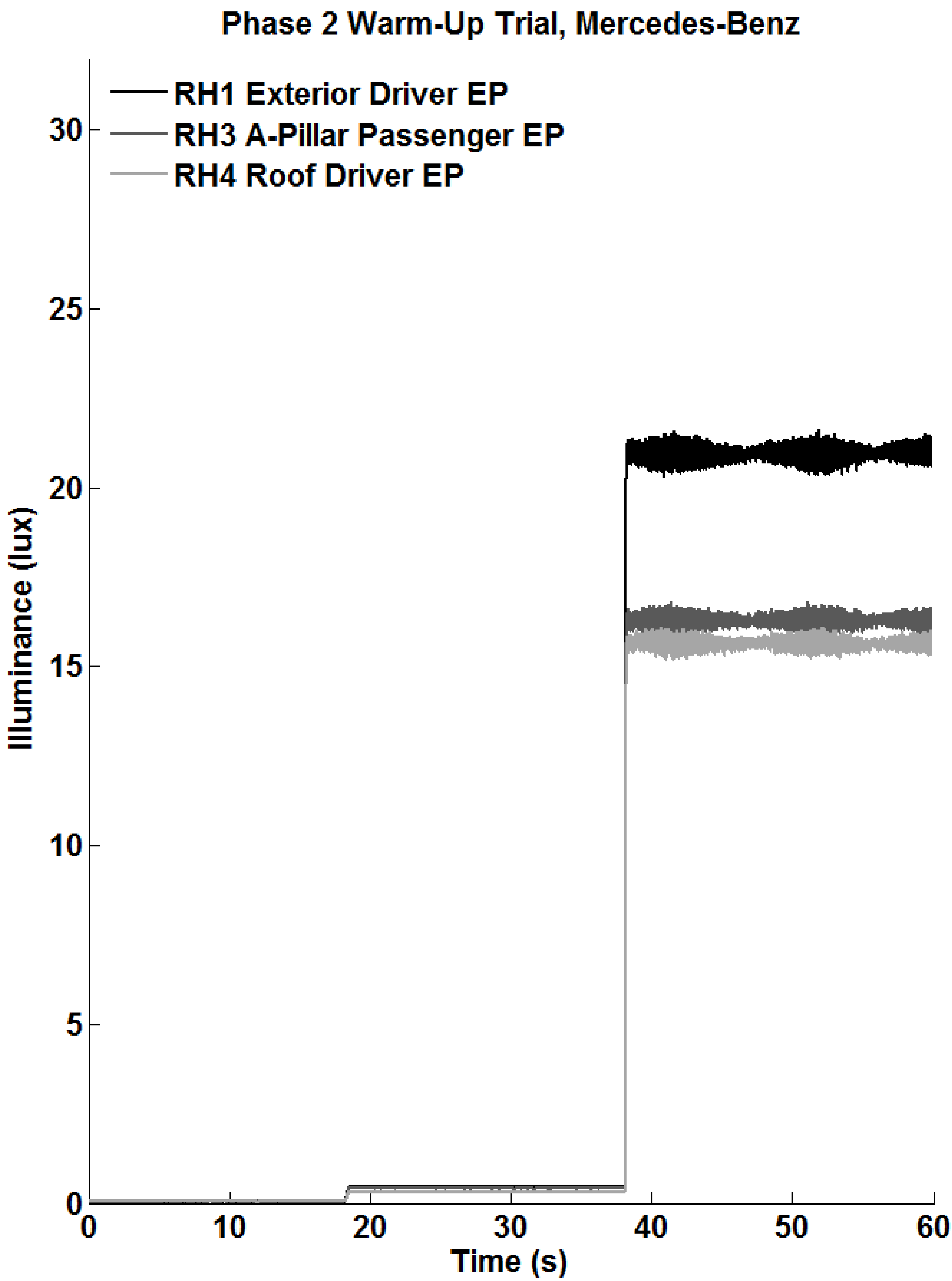

Figure 47. Mercedes-Benz Warm-Up Trial Example Showing Ambient Illumination, Lower Beam, Upper Beam Modes for Small DAS Vehicle, Phase 2

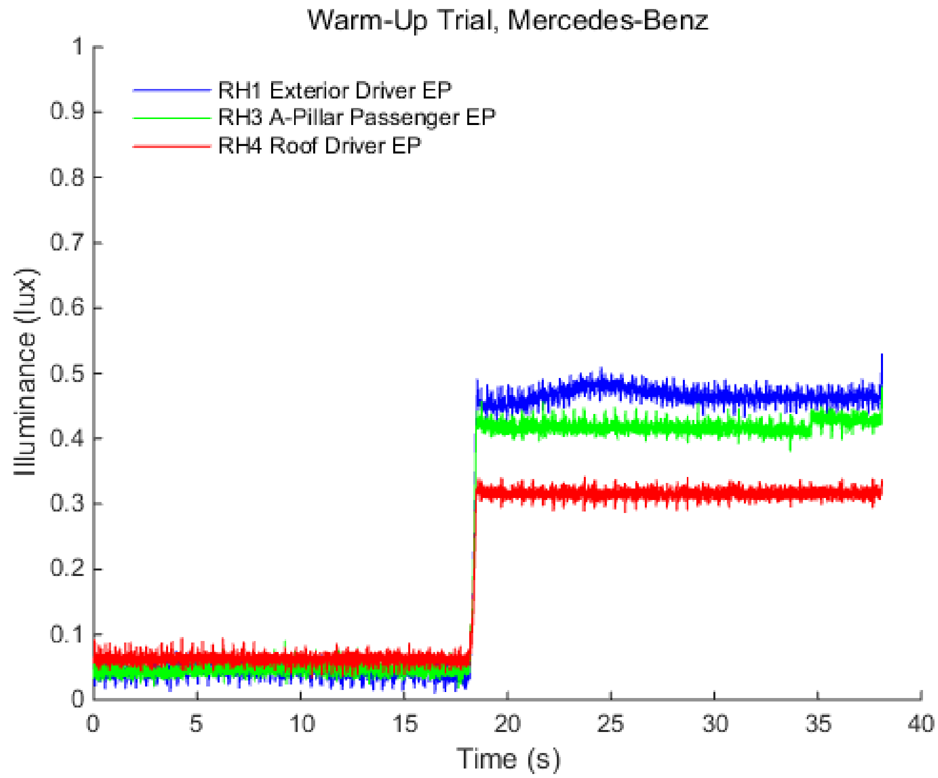

Figure 48. Mercedes-Benz Warm-Up Trial Showing Ambient Illumination, Lower Beam Mode for Small DAS Vehicle, Phase 2

7.2 Observed ADB Activation and Deactivation Speeds

Activation and deactivation speeds were not measured using instrumentation. Speeds were only estimated through speedometer viewing during testing. The speeds are summarized in Table 18 below.

Table 18. Approximate ADB Activation and Deactivation Speeds

ADB-Equipped Vehicle	Activation Speed (mph)	Deactivation Speed (mph)
Audi	20 (32.3 kph)	15 (24.1 kph)
BMW	30 (48.3 kph)	20 (32.3 kph)
Lexus	40 (64.4 kph)	25 (40.2 kph)
Mercedes-Benz	25 (40.2 kph)	15 (24.1 kph)

7.3 ADB Adaption Time Scenario Results

The adaptation of ADB systems in response to the sudden appearance of an oncoming vehicle's headlighting system was observed. In adaptation time trials, the DAS vehicle was stationary on a straight, level roadway with its headlighting system off while the ADB vehicle approached in an oncoming manner in the adjacent lane. When the ADB vehicle was approximately 120 m from the DAS vehicle, the DAS vehicle's driver was given the command to turn on the lower beam headlamps. Data were recorded as the ADB-equipped vehicle approached and responded to the light stimulus. Three to four response time trials were conducted per ADB-equipped vehicle and using each DAS vehicle.

ADB adaptation time was defined as the time from onset of the spike in the DAS vehicle's headlamp voltage signal (signaling DAS lower beams had been activated) to the time when the measured illuminance value dropped to the appropriate glare limit value based on range. For one vehicle (BMW X5), it was observed that the illuminance did not drop in a single, monotonic response. To better describe this type of multi-step adaptation, a "first minimum illuminance value" was noted and the time to this point was referred to as "response time."

Table 19 summarizes the timing of ADB adaptation for individual trials.

Table 19. ADB Adaptation Time Results Summary

				Reaches 1st Min. Illuminance Value				Meets Glare Limit		
ADB Vehicle	**DAS Vehicle Size**	**Set**	**Time of Voltage Spike Onset (s)**	**Time (s)**	**Illum. (lux)**	**Range (m)**	**Response Time (Time to 1st Min.) (s)**	**Time (s)**	**Range (m)**	**Adaptation Time (s)**
Audi	Small	1	25.77	N/A	N/A	N/A	N/A	26.41	68.85	0.635
		2	25.59	N/A	N/A	N/A	N/A	26.18	87.80	0.590
		3	22.42	N/A	N/A	N/A	N/A	22.97	84.07	0.550
	SUV	1	24.42	N/A	N/A	N/A	N/A	24.94	89.50	0.520
		1	24.05	N/A	N/A	N/A	N/A	24.61	75.10	0.560
		2	24.83	N/A	N/A	N/A	N/A	25.33	78.40	0.500
		2	23.32	N/A	N/A	N/A	N/A	23.86	81.21	0.540
BMW	Small	1	25.56	26.08	7.82	86.00	0.520	26.72	62.00	1.160
		3*	28.65	29.30	0.90	38.83	0.650	N/A	N/A	N/A
	SUV	1	24.94	N/A	N/A	N/A	N/A	26.86	65.18	1.920
		1*	28.98	29.70	8.61	80.74	0.720	N/A	N/A	N/A
		2*	27.35	27.82	7.63	85.60	0.470	28.33	74.10	0.980
		2*	26.67	27.23	8.34	83.16	0.560	27.47	78.10	0.800
Mercedes-Benz	Small	1	23.67	N/A	N/A	N/A	N/A	24.33	75.80	0.660
		2	20.91	N/A	N/A	N/A	N/A	21.58	74.64	0.670
		3	22.94	N/A	N/A	N/A	N/A	23.55	46.91	0.610
Lexus**	Small	2	33.92	N/A	N/A	N/A	N/A	34.85	77.39	0.930
		3	25.45	N/A	N/A	N/A	N/A	26.32	44.35	0.870

*Note: Data collection was inadvertently stopped early in a few trials. Of these four trials, only "BMW, SUV DAS, Set 1, Trial 2" did not capture enough of the maneuver to know whether full ADB adaptation would have occurred.
**Note: A problem was experienced with Lexus Set 1 resulting in data loss.

Generally, once adaptation commenced, all the vehicles tested were able to decrease illuminance levels to fall within glare limits in these adaptation time trials. Since the command to turn on the DAS vehicle's lower beam headlamps was given at a range of 120 m, it is not possible to know if the systems would have successfully adapted their headlamp outputs to lower beam output range at further distances. As indicated in the table above, the range at which adaptation occurred was in most cases between 75 and 85 meters.

Adaptation time values observed ranged from 0.50 s to 1.92 s overall. ADB adaptation time for the two ADB-equipped vehicles tested with both the Small and SUV DAS vehicles showed adaptation differences of magnitude 0.073 s or less between the two DAS vehicles. The following figure summarizes the average adaptation time values in response to a suddenly appearing forward vehicle's headlighting system.

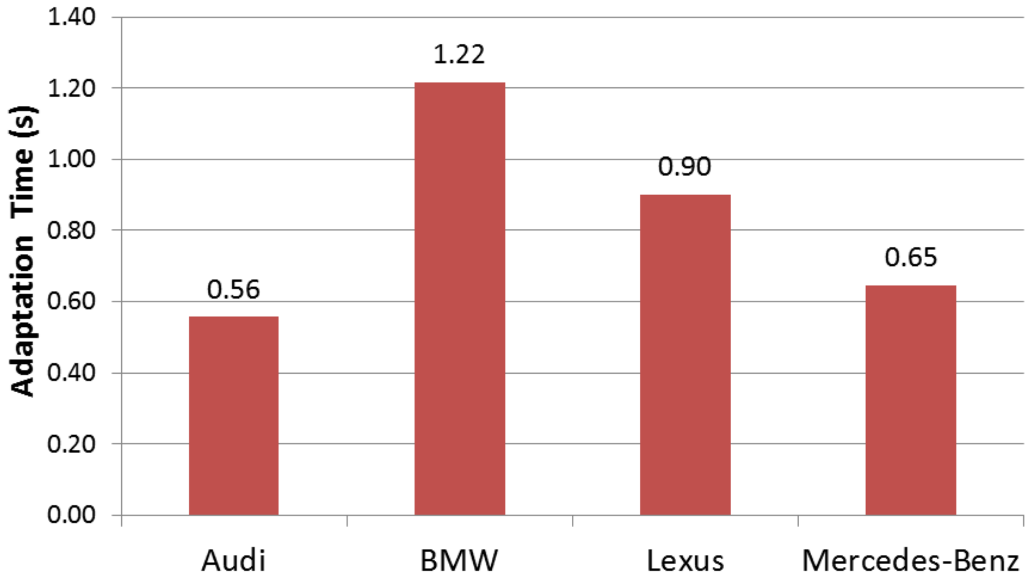

Figure 49. Average ADB Adaptation Time for Response to Suddenly Appearing DAS Vehicle Headlighting System

Figures 50-53 present representative data from adaptation time trials for each ADB-equipped vehicle. Only the DAS vehicle headlamp voltage and exterior driver's eye point illuminance (receptor head 1) channels are shown since these were the channels used to calculate ADB adaptation time.

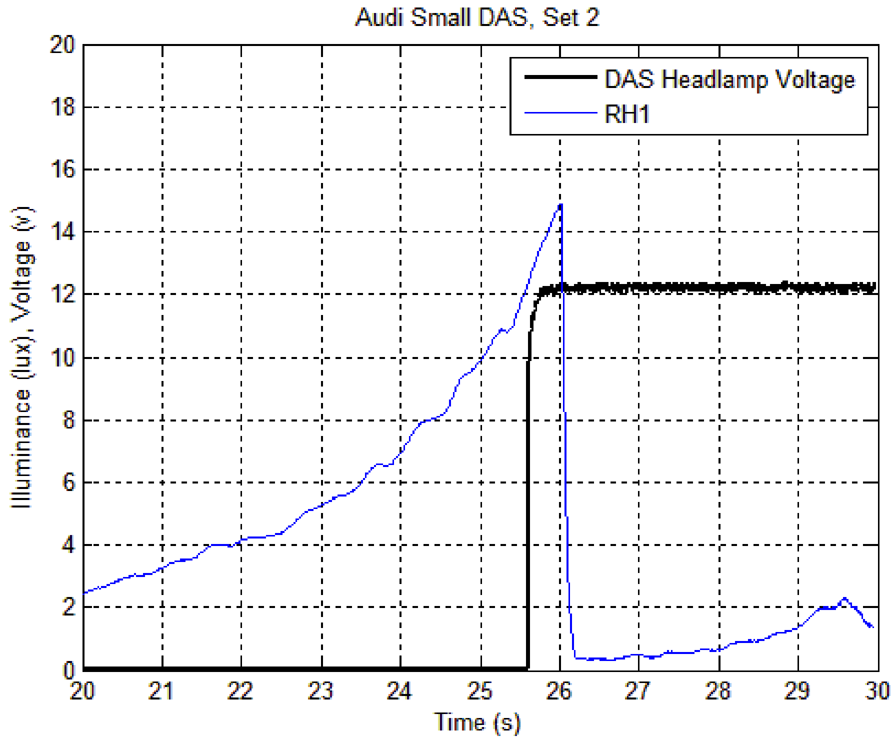

Figure 50. Graph of ADB Adaptation Response to Suddenly Appearing DAS Vehicle Headlighting System, Small DAS Vehicle, Audi

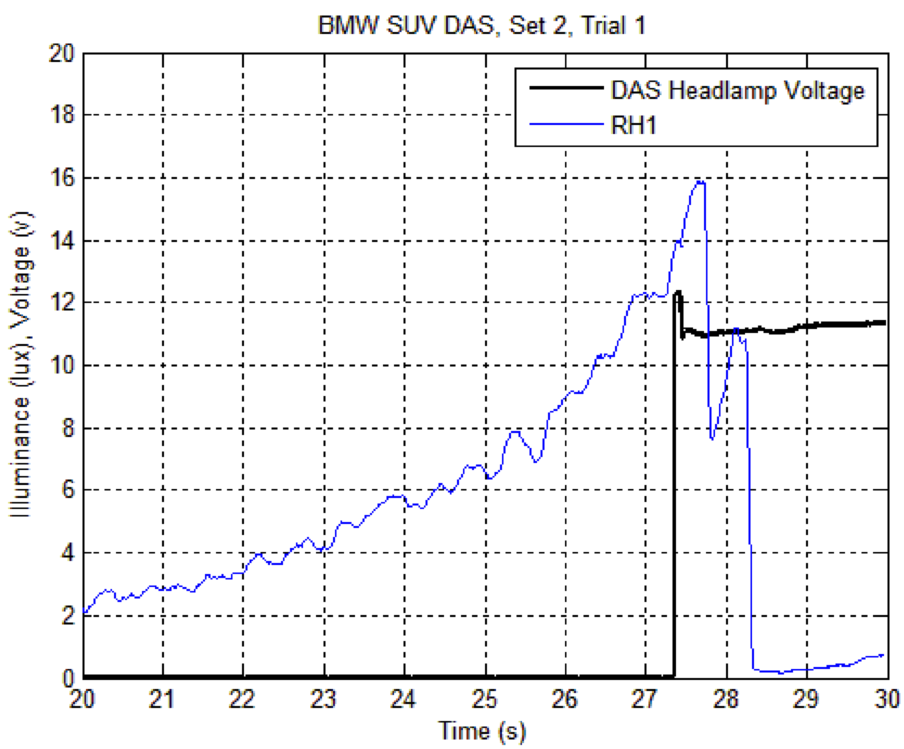

Figure 51. Graph of ADB Adaptation Response to Suddenly Appearing DAS Vehicle Headlighting System Illuminance, SUV DAS Vehicle, BMW

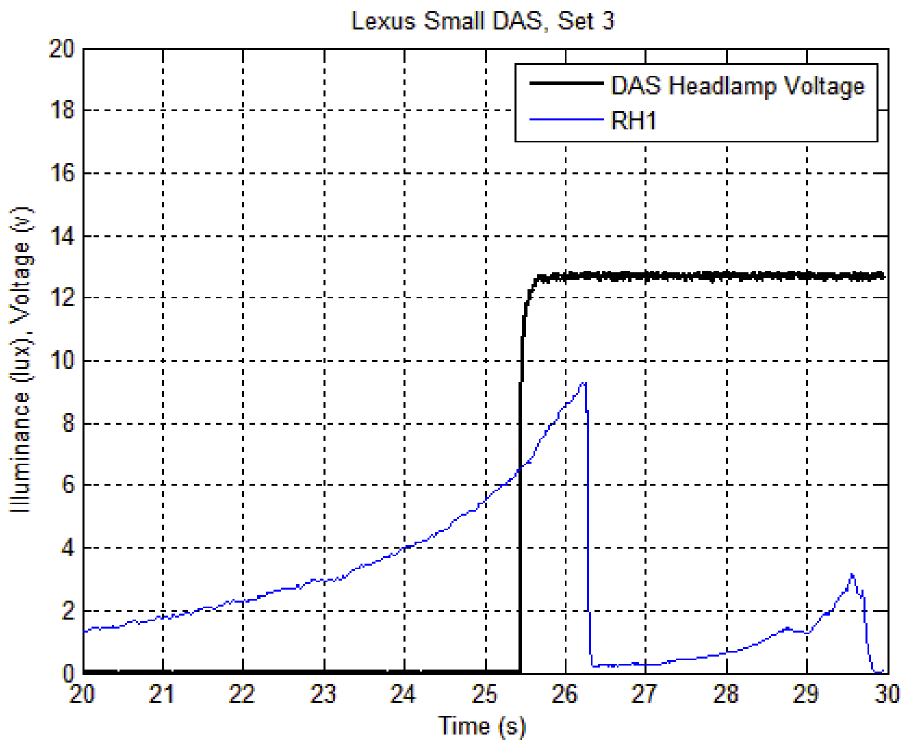

Figure 52. Graph of ADB Adaptation Response to Suddenly Appearing DAS Vehicle Headlighting System, Small DAS Vehicle, Lexus

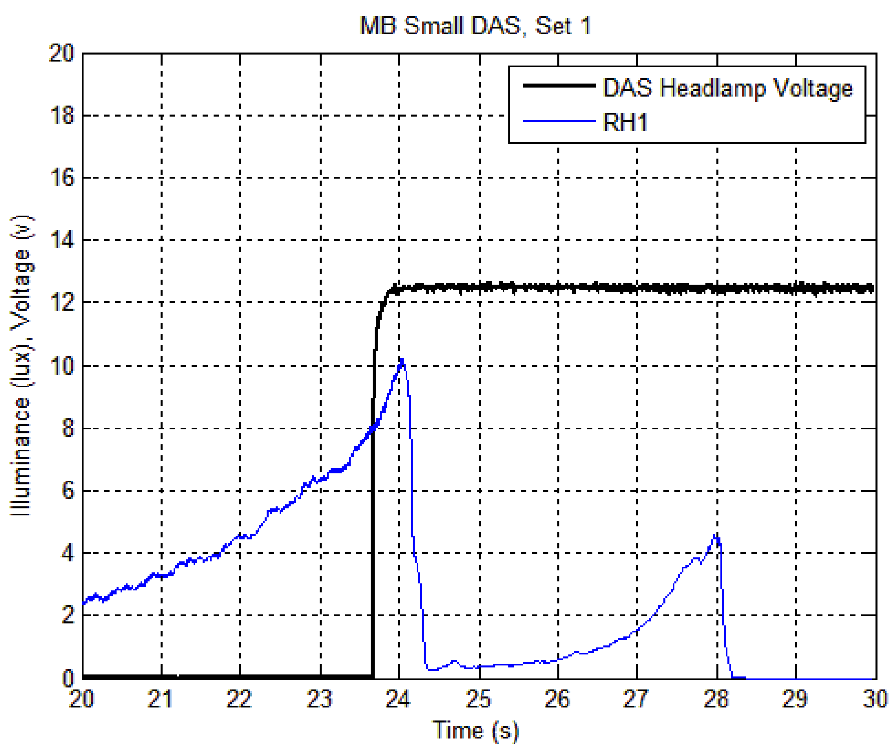

Figure 53. Graph of ADB Adaptation Response to Suddenly Appearing DAS Vehicle Headlighting System, Small DAS Vehicle, Mercedes-Benz

7.4 ADB System Response to Camera Obstruction Results

Trials were conducted to observe ADB system response when the camera was obstructed. This test provided the opportunity to determine whether the tested ADB systems failed in a safe manner in conditions in which the forward camera image was unavailable. A favorable outcome in the case of an obstructed camera would be consist of the vehicle's headlighting system deactivating ADB mode and reverting to lower beam mode. An undesirable outcome would be the vehicle's headlighting system activating ADB mode and due to the camera obstruction interfering with the ability to detect the other vehicle's lights producing full upper beam illumination that casts substantial glare on the oncoming driver.

This test involved observation of ADB systems' responses to the cameras being fully obscured, simulating an obstruction of the camera by an environmental or other substance on the windshield. The ADB-equipped vehicles were driven toward the stationary DAS vehicle (Small or SUV DAS vehicle, depending on the test set) that was parked in an adjacent lane. After passing the stationary DAS, the trial was over and the vehicle would decelerate and turn around to return to the other end of the course so another trial could be run. The camera obstruction scenario trials were part of the test trial set and therefore were completed for all ADB-equipped vehicles and relevant DAS vehicles. Obscured ADB camera trials involved only qualitative observations noted by the research staff. These observations are summarized below.

7.4.1 Audi A8 Obscured Camera Results

Full Coverage: In multiple trials with the Audi ADB with its camera fully obscured, ADB mode activated when the activation speed was reached and the upper beam headlamps illuminated. Likewise, ADB mode deactivated when the deactivation speed was reached. No adaptation of the upper beam headlamps' output in response to the oncoming vehicle's headlighting system illuminance was apparent and substantial glare was cast on the oncoming vehicle.

In one trial, the vehicle reached ADB activation speed and the upper beams illuminated, but during deceleration the ADB vehicle's upper beams turned off at a higher vehicle speed than seen in prior trials. No warning messages were provided in this trial and the vehicle's headlighting system stayed in automatic mode, as indicated by an illuminated white headlamp telltale with an 'A' inside of it.

Another slightly modified trial was run in which the vehicle maintained speed within ADB activation range for a longer distance to see if driving for a longer time would result in a warning being presented. As with prior trials, ADB mode activated and the upper beam headlamps were illuminated when the activation speed was reached. After driving for a slightly longer period the upper beam headlamps and ADB mode did eventually turn off and a warning message was presented. The warning consisted of the following message,

> "Headlight assist: Unavailable No camera view" along with an orange warning triangle that illuminated on the instrument panel. Due to the limited number of trials performed, it was not possible to determine whether driving time or length or both may have contributed to this different result.

After receiving any warning message, the headlighting system mode switch (not vehicle power) had to be cycled to reset the headlighting system in order for it to work properly again.

Partial Coverage: With the ADB camera partially obscured, the Audi ADB system appeared to adapt normally to the DAS vehicle's headlighting system in each trial. No warnings or telltales were observed.

7.4.2 BMW X5 Obscured Camera Results

Full Coverage: During most fully obscured camera trials, the BMW's ADB mode showed a favorable response of not engaging the upper beam headlamps. The BMW would urn ADB mode on when the ADB activation speed was reached, as indicated by a green headlamp symbol with an 'A' inside. While traveling at speeds within the ADB activation range and passing the stimulus vehicle, the upper beams did not illuminate. As the vehicle decelerated and reached deactivation speed, the vehicle would momentarily illuminate the upper beam headlamps after passing the stimulus vehicle despite that ADB mode no longer appear to be activated. No warnings messages were presented.

In some trials, the system would remain in ADB mode, but also display a warning message on the center display that read,

> "Daytime pedestrian warning; Daytime pedestrian alert function restricted. Front camera's field of view restricted i.e. by oncoming lights, rain, dirt, see Owner's Handbook."

The instrument panel also displayed a warning saying "Pedestrian alert restricted," along with an orange warning triangle. Both warnings also included a white telltale that appeared to be a pedestrian crossing a road. During other trials the system would display the warnings on the return trip, in preparation for the next trial. Some trials produced no warnings. After receiving any warning message, the vehicle's power had to be cycled to reset the headlighting system in order for it to work properly again.

Partial Coverage: With the ADB camera partially obscured, the BMW ADB system appeared to adapt normally to the DAS vehicle's headlighting system in each trial. No warnings or telltales were observed.

7.4.3 Lexus LS460 F Sport Obscured Camera Results

Full Coverage: The Lexus activated ADB mode after reaching the activation speed and illuminated the upper beams without adapting to the DAS vehicle's headlighting system. On the return trip, the ADB mode activated again after reaching the activation speed as indicated by an illuminated blue headlamp icon. After approximately 20 seconds the upper beams turned off, and then the AZB system turned off, indicated by the green headlamp telltale with 'AUTO' under it extinguishing. No warning was given. Trying to reset the system activated the manual upper beam and resulted in the message "Turn on the upper beams to activate AZB System" displayed on the instrument panel along with an orange warning triangle symbol. After receiving this message, the vehicle's power had to be cycled to reset the headlighting system in order for it to work properly again.

Partial Coverage: In most trials, the LS460 "AZB" headlighting system adapted normally to the DAS vehicle's headlighting system without any warnings or telltales. A few trials resulted in the AZB system turning off the upper beams in response to the DAS vehicle. In all but one of those trials the headlighting system automatic mode was also disabled. During these trials the Lexus did not issue a warning, and simply turned off the system, indicated by extinguishing the associated telltales. The vehicle did not require a power cycle to reactivate automatic mode in the following trials.

7.4.4 Mercedes-Benz E350 Obscured Camera Results

Full Coverage: In most trials, the Mercedes-Benz test vehicle upon reaching the ADB mode activation speed would turn off automatic headlight mode and issue the warning "Adaptive

Highbeam Assist Plus Currently Unavailable See Operator's Manual." In all but one trial, no upper beam illumination was seen in these fully obscured camera trials. After such a warning was presented, the vehicle's power had to be cycled in order to reset the headlighting system. In one trial, the ADB system did activate the upper beam headlamps momentarily, but then turned off the ADB mode and issued the same warning as was seen previously.

Partial Coverage: With the ADB camera partially obscured, the Mercedes-Benz ADB system appeared to adapt normally to the DAS vehicle's headlighting system in each trial. No warnings or telltales were observed.

7.4.5 Summary of Obscured Camera Results

In most fully obscured camera trials, both the BMW and Mercedes-Benz ADB systems seemed to detect the camera sensor blockage fairly quickly and did not turn on the upper beam headlamps. This was considered a favorable outcome since other drivers were not exposed to glare. For some trials, these vehicles did not revert to lower beams, but exhibited a brief period of upper beam illumination. It is not known why these vehicles reverted to lower beams for some, but not all, trials.

In fully obscured camera trials, the Audi and Lexus ADB systems did not detect the camera blockage as quickly. Both systems turned on the upper beam headlamps upon reaching ADB activation speed and did not adapt the beam pattern when passing the parked DAS vehicle. The Lexus did return a warning message after two trials of normal driving distance (approximately 3,000 ft (914 m)). The Audi did not respond within the standard distance after repeated trials, so an additional trial was run in which the vehicle was driven above ADB activation speed for a longer period of approximately 5,000 ft (1,524 m). This longer trial did result in the Audi's upper beam headlamps and ADB mode turning off and a warning message being presented. The Audi seemed to need the longest amount of time to detect a camera blockage, which could result in other drivers being exposed to full upper beam illumination for some time in situations of full camera blockage.

Partial camera coverage did not appear to hinder ADB activation and adaptation for any vehicle.

7.5 Headlamp Voltage of ADB-Equipped Vehicles in Maneuver Scenarios

Headlamp voltage data were recorded to allow examination of test trials for any voltage fluctuations that may have affected headlighting system performance or output. Average headlamp voltage and pooled standard deviation values for both lower beam and ADB modes of the ADB-equipped test vehicles in oncoming maneuver scenarios with the Small DAS vehicle are summarized in Tables 20 through 22. Bold values in dark gray shaded cells indicate values that exceeded a glare limit. Other average headlamp voltage and pooled standard deviation values can be found in Appendix B.

Headlamp voltage levels for the ADB-equipped vehicles tended to fall approximately within the range of 13.0 to 13.6 V for both lower beam and ADB modes. The one exception to this characterization was the Audi ADB system which tended to have slightly lower headlamp voltage, averaging approximately 12.8 V while the lower beam value was approximately 13 V.

Variability of headlamp voltage was similar for both headlighting system modes for all four ADB-equipped vehicles. However, the pooled standard deviation values for the Lexus were generally a factor of 10 lower than those of the other three vehicles. Average headlamp voltage for the Lexus test vehicle appeared to be very stable. Lexus pooled standard deviation values by maneuver scenario spanned a very small range of 0.037 (from 0.032 to 0.069). Pooled standard deviation values across maneuver scenarios spanned wider ranges for the other three vehicles: 0.558 for the Audi (pooled SD ranging from 0.030 to 0.588), 0.522 for the BMW (pooled SD ranging from 0.068 to 0.590), and 0.441 for the Mercedes-Benz (pooled SD ranging from 0.202 to 0.643).

Table 20. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation by Oncoming, Straight Maneuver Scenario and Headlighting System Mode for Small DAS Vehicle

	Audi (n=3)				BMW (n=3)				Lexus (n=3)				Mercedes-Benz (n=3)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
Straight, adj. lane, DAS 0 mph, ADB 62 mph	13.008	0.153	12.839	0.227	13.372	0.153	13.428	0.138	13.560	0.039	13.559	0.039	13.056	0.320	13.115	0.449
Straight, adj. lane, DAS 62 mph, ADB 62 mph	13.062	0.265	12.807	0.244	13.481	0.235	13.380	0.219	13.522	0.041	13.520	0.039	13.107	0.432	13.054	0.282
Motorcycle, straight, adj. lane, DAS 0 mph, ADB 62 mph	12.983	0.039	12.910	0.178	13.413	0.206	13.114	0.195	13.408	0.058	13.400	0.069	13.093	0.429	12.999	0.202
Motorcycle, straight, adj. lane, DAS 62 mph, ADB 62 mph	13.096	0.261	12.861	0.147	13.141	0.293	13.142	0.265	13.394	0.061	13.436	0.065	13.062	0.371	13.034	0.397
Dip series, adj. lane, DAS 0 mph, ADB 45 mph	13.029	0.363	12.753	0.361	13.385	0.405	13.155	0.342	13.392	0.032	13.381	0.035	13.121	0.489	13.093	0.523

Table 21. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation by Oncoming, Intersection Maneuver Scenario and Headlighting System Mode for Small DAS Vehicle

	Audi (n=3)				BMW (n=3)				Lexus (n=3)				Mercedes-Benz (n=3)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
60°, adj. lane, DAS 0 mph, ADB 62 mph	12.988	0.066	12.654	0.299	13.494	0.107	13.374	0.232	13.591	0.038	13.589	0.039	13.050	0.588	13.183	0.417
90°, adj. lane, DAS 0 mph, ADB 62 mph	13.058	0.243	12.850	0.393	13.591	0.407	13.405	0.369	13.585	0.041	13.590	0.041	13.234	0.572	13.125	0.435
120°, adj. lane, DAS 0 mph, ADB 62 mph	13.236	0.387	12.879	0.399	13.511	0.258	13.477	0.420	13.576	0.038	13.581	0.036	13.355	0.618	13.117	0.366

Table 22. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation by Oncoming, Curve Maneuver Scenario and Headlighting System Mode for Small DAS Vehicle

	Audi (n=3)				BMW (n=3)				Lexus (n=3)				Mercedes-Benz (n=3)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
ADB curves Left, adj. lane, DAS 0 mph, ADB 62 mph	13.019	0.151	12.592	0.167	13.389	0.087	13.299	0.071	13.590	0.036	13.590	0.035	13.145	0.483	13.079	0.491
ADB curves Left, adj. lane, DAS 62 mph, ADB 62 mph	12.958	0.047	12.597	0.183	13.440	0.091	13.299	0.100	13.602	0.037	13.598	0.042	13.082	0.392	13.092	0.401
ADB curves Right, adj. lane, DAS 0 mph, ADB 62 mph	13.051	0.203	12.886	0.294	13.447	0.102	13.338	0.101	13.647	0.037	13.642	0.036	13.000	0.263	13.071	0.397
ADB curves Right, adj. lane, DAS 62 mph, ADB 62 mph	13.034	0.134	12.821	0.217	13.414	0.076	13.261	0.111	13.645	0.038	13.656	0.041	13.066	0.359	13.056	0.277
Winding, DAS 0 mph, ADB 45 mph	13.161	0.457	12.837	0.446	13.607	0.400	13.510	0.384	13.577	0.040	13.570	0.049	13.113	0.480	13.194	0.522

7.6 ADB Performance - Comparison to Lower Beam Illuminance

As stated in Section 2, the goal of ADB is to improve roadway illumination while shading the area in which another vehicle is located. This shading is supposed to limit glare cast on other drivers to lower beam levels. If ADB is successful at this, then measured illuminance levels in the vicinity of a vehicle near an ADB-equipped vehicle should be comparable to those seen for lower beam headlighting system mode in the same driving scenario. To check this for ADB systems examined in this effort, measured ADB illuminance was divided by lower beam illuminance for each maneuver scenario and distance range. This quotient represents a quantitative indication of any relative difference in light provided by ADB systems over lower beam output.

The following subsections contain tables presenting these quotient values along with average maximum illuminance values (over 'n' trial repetitions) for scenario maneuver trials for both lower beam and ADB systems. In all tables in this section, bold values in dark gray shaded cells indicate measured illuminance values that exceeded a glare limit. Also throughout this section, high quotient values (e.g., greater than 3.0) are shown in red, bold text for emphasis.

7.6.1 ADB Versus Lower Beam - Oncoming Maneuver Scenarios

Results for oncoming straight, intersection, and curve scenarios are summarized in this section. The examination of results assumes that a properly performing ADB system will show illuminance values similar to that seen for lower beam mode for the same maneuver scenarios, resulting in a quotient value close to 1.0.

Table 23 summarizes results for straight maneuvers with the Small DAS vehicle. Values indicate that ADB generally performed within the derived lower beam glare limit values for these maneuvers. The exceptions to this characterization for the straight, oncoming scenarios with the Small DAS included one ADB value for the Lexus and four values for the BMW. However, it should be noted that these two vehicles were manufactured for sale in Europe and were not FMVSS compliant, which may explain the exceedances. For straight oncoming maneuvers, 4 of the 5 exceedances were for the stationary DAS vehicle trial, suggesting that a stationary oncoming vehicle may be more difficult for ADB systems to handle. Results for the dip series scenario, which was known to be one that would be difficult to perform without exceeding glare limits, did show glare limit exceedances for all vehicles and both headlighting system modes (lower beam and ADB) at distances greater than 30 m.

Results in Table 23 for the oncoming motorcycle trials with the Small DAS vehicle show glare exceedances for Audi ADB trials and for BMW lower beam and ADB trials. The Audi produced more glare with ADB than with lower beam in the 30 to 120 m range for both stationary and moving motorcycle trials. This higher glare with ADB may suggest insufficient ADB adaptation or may indicate that the region of shading that encompassed the motorcycle location did not extend laterally to the location of receptor head 1 on the DAS vehicle, approximately 9 feet away. BMW trial data show similar degrees of limit-exceeding glare in both lower beam and ADB modes for some ranges, suggesting that ADB likely limited glare to approximately that of lower beam levels. Motorcycle trial data for the Lexus and Mercedes-Benz vehicles show similar levels of illumination between lower beam and ADB modes, suggesting that the systems were able to detect and adapt to the motorcycle while exhibiting illuminance values falling within derived glare limit values. This latter result may indicate that the Lexus and Mercedes-Benz vehicles ADB systems produce a wider shaded area that was able to cover the motorcycle location as well as the adjacent DAS vehicle.

Table 23. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 1 and Quotient Values – Oncoming, Straight, Adjacent Lane Maneuvers With Small DAS Vehicle

			Audi (n=3)			BMW (n=3)			Lexus (n=3)			Mercedes-Benz (n=3)		
Maneuver Scenario	**Range (m)**	**Glare Limit (lux)**	**Lower Beam Illuminance (lux)**	**ADB Illuminance (lux)**	**Quotient (ADB / Lower Beam)**	**Lower Beam Illuminance (lux)**	**ADB Illuminance (lux)**	**Quotient (ADB / Lower Beam)**	**Lower Beam Illuminance (lux)**	**ADB Illuminance (lux)**	**Quotient (ADB / Lower Beam)**	**Lower Beam Illuminance (lux)**	**ADB Illuminance (lux)**	**Quotient (ADB / Lower Beam)**
Straight, DAS 0 mph, ADB 62 mph	15-29.9	3.109	1.63	2.00	1.23	2.58	**3.23**	1.26	1.67	1.50	0.90	2.27	2.50	1.10
	30-59.9	1.776	0.74	0.78	1.06	**2.01**	**1.85**	0.92	0.94	0.99	1.05	1.05	1.14	1.08
	60-119.9	0.634	0.35	0.32	0.90	0.29	0.37	1.28	0.33	0.44	1.34	0.36	0.41	1.16
	120-239.9	0.281	0.18	0.14	0.80	0.03	0.05	1.99	0.14	**0.37**	2.70	0.15	0.16	1.05
Straight, DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.50	2.89	1.93	2.98	2.99	1.01	1.73	1.49	0.86	2.27	2.34	1.03
	30-59.9	1.776	0.80	0.81	1.01	1.60	**1.95**	1.22	1.06	0.94	0.89	0.98	1.04	1.07
	60-119.9	0.634	0.45	0.42	0.93	0.29	0.38	1.33	0.34	0.35	1.04	0.36	0.39	1.09
	120-239.9	0.281	0.23	0.22	0.98	0.03	0.08	2.65	0.15	0.22	1.46	0.15	0.14	0.93
Motorcycle, straight, Motorcycle/DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.76	1.63	2.13	1.75	1.90	1.09	1.24	1.16	0.94	1.04	1.02	0.98
	30-59.9	1.776	0.67	**4.88**	**7.32**	1.31	1.51	1.15	0.77	0.70	0.91	0.78	0.78	1.00
	60-119.9	0.634	0.39	**2.00**	**5.13**	**0.94**	**1.28**	1.36	0.55	0.51	0.93	0.43	0.43	1.01
	120-239.9	0.281	0.24	0.22	0.91	**0.32**	**0.30**	0.93	0.20	0.21	1.04	0.19	0.20	1.04
Motorcycle, straight, Motorcycle/DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.00	1.61	1.62	1.55	1.93	1.24	1.28	1.12	0.88	1.00	0.90	0.90
	30-59.9	1.776	0.99	**4.45**	**4.51**	1.23	1.67	1.36	0.94	0.76	0.81	0.78	0.78	1.00
	60-119.9	0.634	0.39	**2.52**	**6.52**	**0.93**	**1.07**	1.16	0.51	0.39	0.77	0.40	0.42	1.03
	120-239.9	0.281	0.21	0.24	1.12	0.19	0.24	1.28	0.15	0.18	1.20	0.13	0.12	0.94
Dip series, DAS 0 mph, ADB 45 mph	15-29.9	3.109	2.73	2.87	1.05	**5.00**	**5.54**	1.11	**3.40**	2.65	0.78	**3.49**	**4.23**	1.21
	30-59.9	1.776	**31.42**	**31.43**	1.00	**31.15**	**31.11**	1.00	**22.59**	**22.57**	1.00	**31.32**	**30.82**	0.98
	60-119.9	0.634	**1.93**	**0.91**	0.47	0.38	**0.75**	1.96	**1.51**	**1.46**	0.97	**5.06**	**0.95**	0.19
	120-239.9	0.281	**6.73**	**6.61**	0.98	**4.82**	**4.90**	1.02	**3.67**	**2.34**	0.64	**4.99**	**4.39**	0.88

Figures 54 through 57 illustrate the comparison of lower beam and ADB illumination levels with respect to glare limit values. The red dashed horizontal lines indicate distance ranges in which the derived glare limit values were exceeded. These graphs present measured values of illuminance versus range for oncoming, straight scenarios involving the motorcycle and Small DAS vehicle. The two scenarios presented in these figures are the straight, oncoming stationary and moving motorcycle scenarios, which were highlighted in Table 23 as having high quotient values. Figures 54 and 55 show that the glare associated with ADB was greater than that for lower beam in some ranges for both the Audi and BMW in the oncoming motorcycle scenario with the Small DAS vehicle. The Lexus and Mercedes vehicles' ADB systems maintained glare levels within the derived lower beam limits in this scenario, as depicted in Figures 56 and 57.

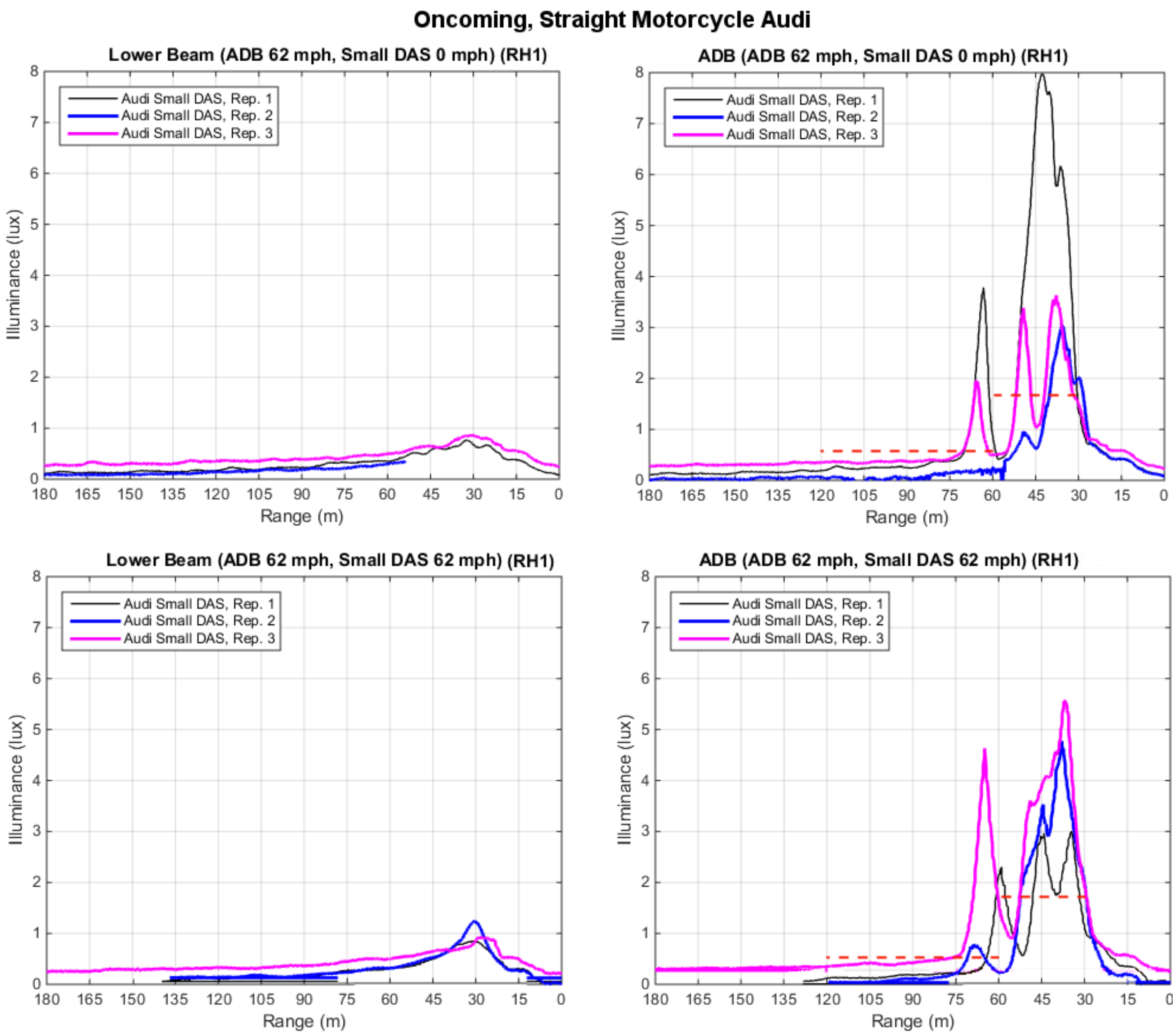

Figure 54. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight Maneuver Scenarios With the Motorcycle – Audi With Small DAS

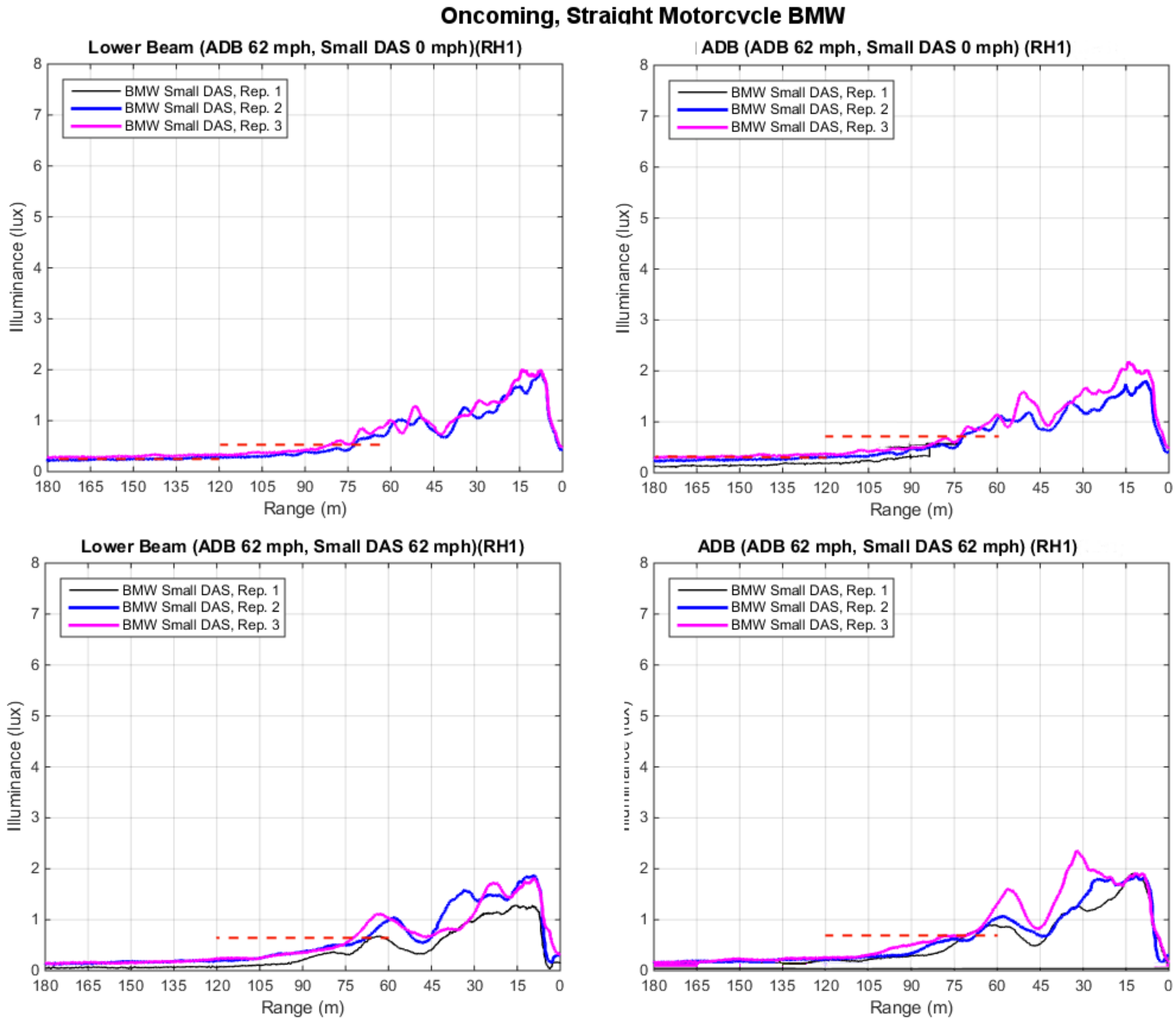

Figure 55. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight Maneuver Scenarios With the Motorcycle – BMW With Small DAS

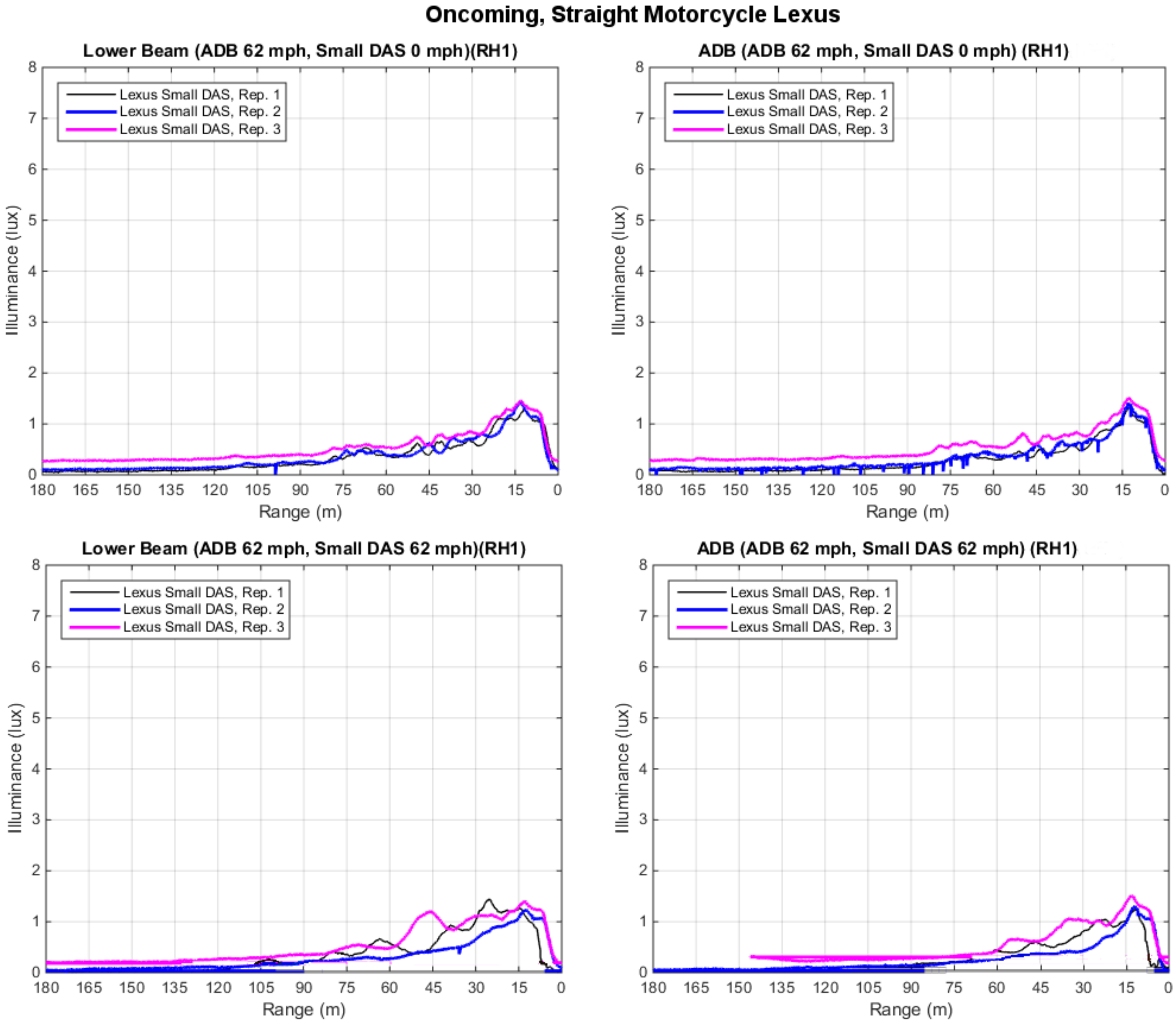

Figure 56. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight Maneuver Scenarios With the Motorcycle - Lexus With Small DAS

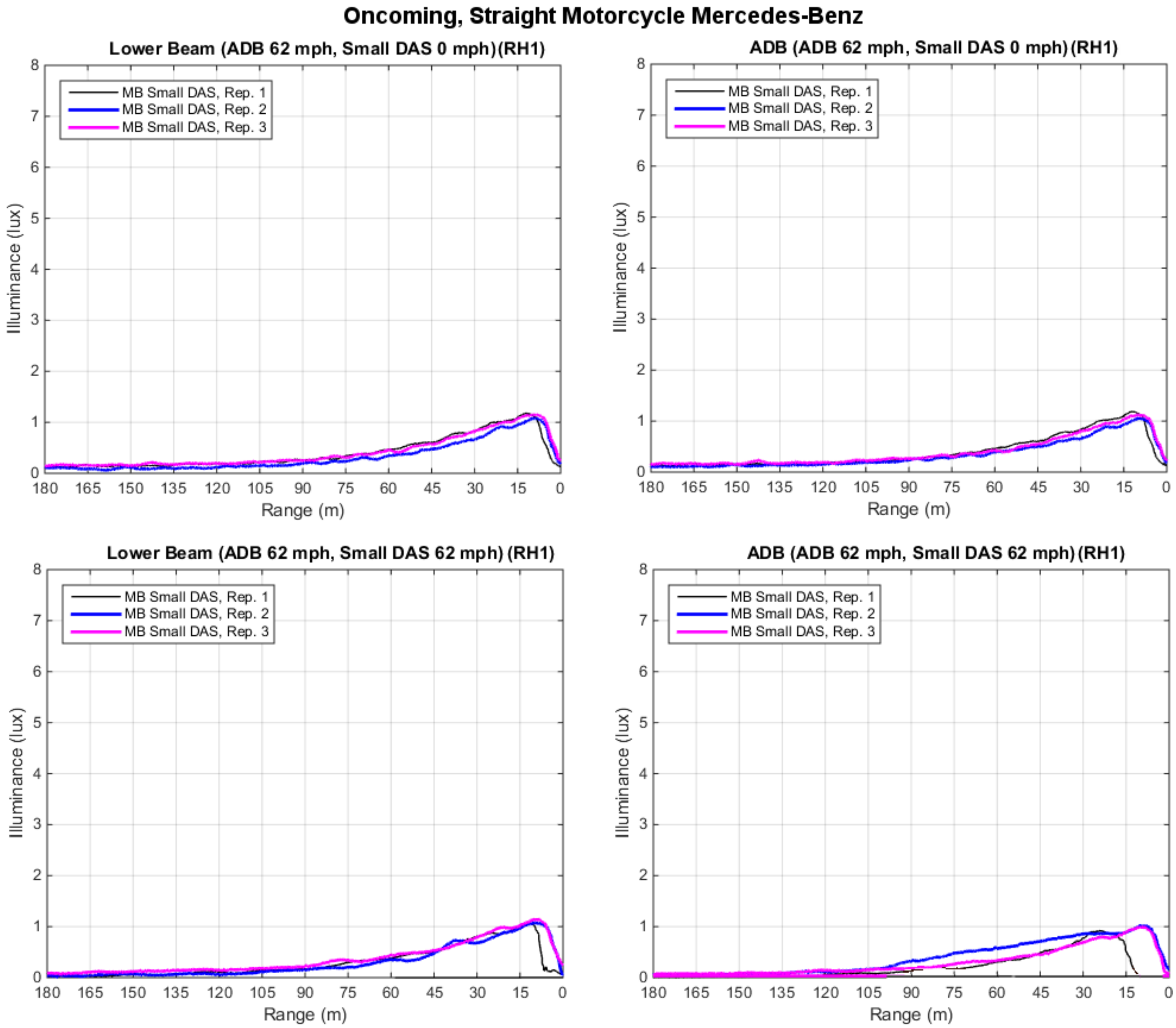

Figure 57. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight Maneuver Scenarios With the Motorcycle – Mercedes-Benz With Small DAS

Table 24 summarizes illuminance data for oncoming, straight maneuvers involving the SUV DAS vehicle in straight, oncoming maneuver scenarios. On average, the Audi produced slightly more glare in the lower beam condition than in ADB mode in the 120 to 240 m range. The BMW in straight, oncoming adjacent lane trials showed glare levels slightly exceeding limits in the 120 to 240 m range for the stationary DAS vehicle scenario.

Table 24. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 1 and Quotient Values – Oncoming, Straight, Adjacent Lane Maneuvers With SUV DAS Vehicle

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi (n=2) Lower Beam Illuminance (lux)	Audi (n=2) ADB Illuminance (lux)	Audi (n=2) Quotient (ADB / Lower Beam)	BMW (n=2) Lower Beam Illuminance (lux)	BMW (n=2) ADB Illuminance (lux)	BMW (n=2) Quotient (ADB / Lower Beam)
Straight, DAS 0 mph, ADB 62 mph	15-29.9	3.109	1.42	1.47	1.03	1.86	2.06	1.10
	30-59.9	1.776	0.89	0.92	1.03	1.39	1.52	1.10
	60-119.9	0.634	0.43	0.45	1.05	0.55	0.63	1.14
	120-239.9	0.281	**0.44**	0.27	0.63	**0.32**	**0.35**	1.10
Straight, DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.34	1.84	1.37	1.70	1.92	1.13
	30-59.9	1.776	0.75	0.83	1.11	1.26	1.43	1.14
	60-119.9	0.634	0.35	0.34	0.99	0.27	0.30	1.12
	120-239.9	0.281	0.13	0.10	0.72	0.04	0.10	2.66
Motorcycle, straight, adj. lane, Motorcycle/DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.67	1.35	2.02	0.99	1.04	1.04
	30-59.9	1.776	0.61	**4.80**	**7.83**	0.74	0.87	1.18
	60-119.9	0.634	0.38	**2.31**	**6.13**	0.49	0.55	1.12
	120-239.9	0.281	**0.30**	0.18	0.60	0.15	0.17	1.14
Motorcycle, straight, adj. lane, Motorcycle/DAS 62 mph, ADB 62 mph	15-29.9	3.109	0.55	1.18	2.14	0.85	1.01	1.18
	30-59.9	1.776	0.53	**4.84**	**9.14**	0.71	0.76	1.06
	60-119.9	0.634	0.29	**2.85**	**9.69**	0.56	0.57	1.03
	120-239.9	0.281	0.13	0.11	0.87	0.06	0.11	1.71
Dip series, adj. lane, DAS 0 mph, ADB 45 mph	15-29.9	3.109	2.33	**3.67**	1.57	1.72	2.80	1.63
	30-59.9	1.776	**30.89**	**31.15**	1.01	**30.91**	**31.40**	1.02
	60-119.9	0.634	0.49	**0.83**	1.70	0.15	**0.82**	**5.50**
	120-239.9	0.281	**3.29**	**6.48**	1.97	**4.22**	**4.61**	1.09

Summary data in Table 24 show the dip series again proved to be challenging, eliciting high levels of glare for both test vehicles. In particular, the BMW showed a high glare level in the 60 to 120 m range of the dip series scenario, where illuminance for ADB was 5.5 times greater than that for lower beam mode.

Motorcycle scenario values presented in Table 24 above show, on average, the Audi headlighting system produced substantially higher glare in the 30 to 120 m range, up to approximately 9 times greater than that seen for lower beam mode (quotient values ranging from 6.13 to 9.69). Audi data from one of three trials for each motorcycle scenario with the SUV DAS vehicle are depicted in Figure 58. These data appear very similar to those for motorcycle trials involving the Small DAS vehicle, shown in Figure 53. As was stated with respect to results for trials involving the Small DAS vehicle, this higher glare result for the Audi ADB system may indicate insufficient ADB adaptation or may indicate that the region of shading that encompassed the motorcycle location did not extend laterally to the location of receptor head 1 on the DAS vehicle, approximately 9 ft (2.7 m) away. In contrast, the BMW results with the SUV DAS vehicles appear slightly better with respect to ADB maintaining lux levels within lower beam glare limits than were seen with the Small DAS vehicle. BMW data for one trial of each motorcycle scenario are presented in Figure 59 to illustrate this.

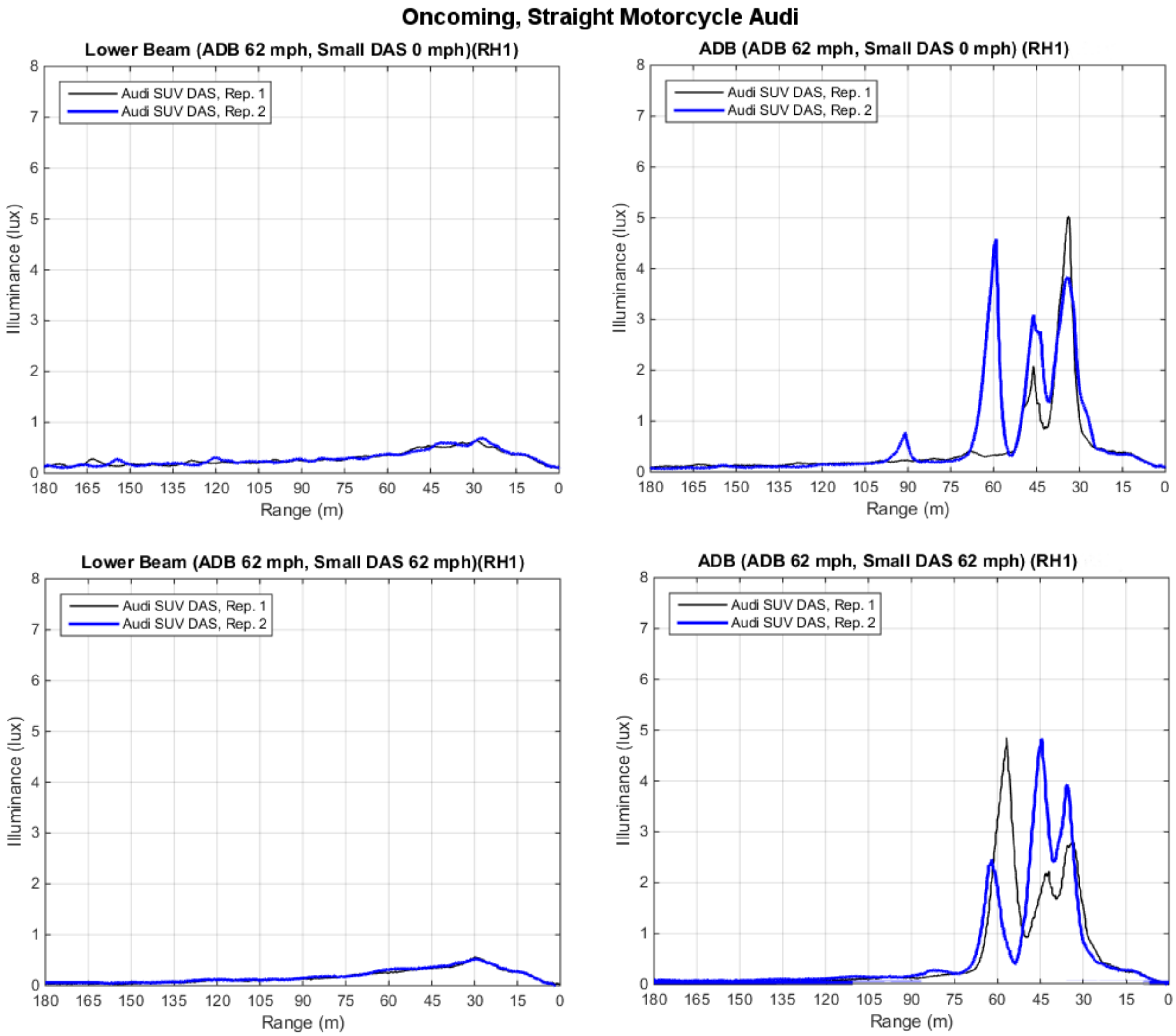

Figure 58. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight Maneuver Scenarios With the Motorcycle – Audi With SUV DAS

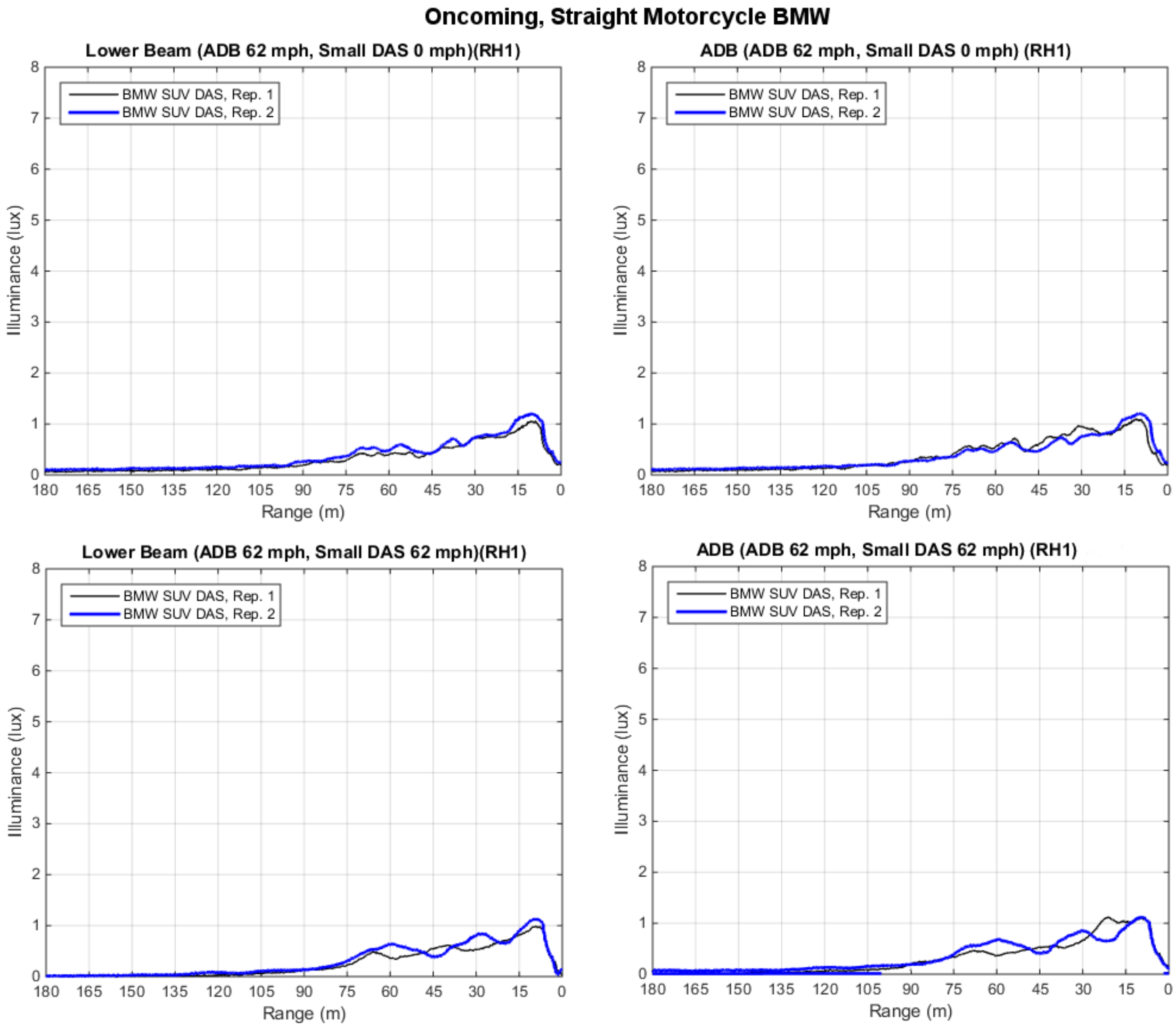

Figure 59. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight Maneuver Scenarios With the Motorcycle – BMW With SUV DAS

Results for average maximum illuminance for lower beam versus ADB intersection scenario trials summarized in Tables 25 and 26 show that all four vehicles' ADB systems exhibited more glare with ADB than for lower beam mode at nearly all ranges. Quotient values for all systems tended to indicate much higher glare for ADB mode compared to lower beam mode for all three intersection geometries. Glare levels seen for ADB mode were as much as 60 times higher than that seen for lower beam mode in intersection scenarios with the Small DAS vehicle (90-degree intersection, BMW, 120-240 m range) and as much as 100 times greater with the SUV DAS vehicle (60-degree intersection, BMW, 120-240 m range). The Mercedes-Benz ADB system had somewhat fewer instances of glare limit exceedances compared to the other three vehicles. For lower beam mode, illuminance for all four vehicles at all distance ranges fell within derived glare limit values. Plots showing illuminance versus distance data for maneuver scenarios in Tables 25 and 26 can be found in Appendix C.

Table 25. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 8 and Quotient Values - Intersection Maneuver Scenarios With Small DAS Vehicle

			Audi (n=3)			BMW (n=3)			Lexus (n=3)			Mercedes-Benz (n=3)		
Maneuver Scenario	Range (m)	Glare Limit (lux)	Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)
			Illuminance (lux)			Illuminance (lux)			Illuminance (lux)			Illuminance (lux)		
60 degrees, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.45	0.50	1.11	1.14	2.63	2.31	1.04	1.07	1.03	0.87	0.85	0.97
	30-59.9	1.776	0.54	**7.02**	**13.09**	0.70	**6.80**	**9.69**	0.68	1.68	2.47	0.53	0.81	1.54
	60-119.9	0.634	0.25	**8.88**	**35.04**	0.47	**7.03**	**14.86**	0.35	**3.51**	**10.07**	0.29	0.43	1.48
	120-239.9	0.281	0.13	**5.06**	**39.82**	0.09	**4.12**	**45.04**	0.14	**1.78**	**12.85**	0.14	**2.70**	**19.89**
90 degrees, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.38	0.41	1.08	0.99	3.27	3.31	0.92	2.31	2.50	0.79	0.77	0.98
	30-59.9	1.776	0.42	**7.50**	**18.01**	0.52	**7.95**	**15.42**	0.49	**5.60**	**11.37**	0.52	0.74	1.42
	60-119.9	0.634	0.26	**8.92**	**34.72**	0.50	**7.87**	**15.88**	0.41	**3.86**	**9.39**	0.31	0.45	1.43
	120-239.9	0.281	0.14	**5.29**	**38.06**	0.08	**4.91**	**59.45**	0.14	**2.09**	**14.72**	0.12	**2.75**	**22.25**
120 degrees, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.29	0.30	1.04	0.57	0.56	0.97	0.56	1.68	2.97	0.50	0.66	1.32
	30-59.9	1.776	0.30	**4.55**	**15.16**	0.44	**4.67**	**10.73**	0.40	**4.14**	**10.34**	0.41	**5.21**	**12.70**
	60-119.9	0.634	0.21	**4.57**	**21.71**	0.40	**6.39**	**15.93**	0.34	**3.36**	**9.92**	0.24	**4.82**	**20.47**
	120-239.9	0.281	0.10	**3.02**	**29.69**	0.08	**3.81**	**47.06**	0.13	**1.69**	**13.08**	0.12	**2.53**	**21.93**

Table 26. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 8 and Quotient Values - Intersection Maneuver Scenarios With SUV DAS Vehicle

			Audi (n=2)			BMW (n=2)		
Maneuver Scenario	Range (m)	Glare Limit (lux)	Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)
			Illuminance (lux)			Illuminance (lux)		
60 degrees, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.22	0.25	1.16	0.96	2.66	2.77
	30-59.9	1.776	0.28	**2.93**	**10.45**	0.41	**7.19**	**17.71**
	60-119.9	0.634	0.17	**5.72**	**34.22**	0.30	**7.25**	**23.92**
	120-239.9	0.281	0.08	**4.71**	**60.27**	0.04	**4.23**	**97.20**
90 degrees, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.22	0.25	1.11	0.80	1.82	2.29
	30-59.9	1.776	0.26	**3.02**	**11.74**	0.40	**7.70**	**19.48**
	60-119.9	0.634	0.20	**6.77**	**34.21**	0.32	**7.76**	**24.01**
	120-239.9	0.281	0.10	**5.21**	**53.60**	0.07	**4.77**	**70.38**
120 degrees, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.16	0.17	1.07	0.50	0.47	0.93
	30-59.9	1.776	0.22	**3.24**	**14.53**	0.31	**6.27**	**20.30**
	60-119.9	0.634	0.18	**5.22**	**28.57**	0.25	**6.44**	**26.16**
	120-239.9	0.281	0.14	**4.37**	**31.72**	0.07	**4.05**	**59.51**

Table 27 presents average maximum illuminance results for lower beam versus ADB in left and right curve scenarios with the Small DAS vehicle. In these scenarios, ADB exhibited more instances of high glare than did lower beam mode. Overall, curve maneuvers were associated with instances of high glare for both lower beam and ADB modes and at the same distance ranges, regardless of whether the DAS vehicle was moving or stationary. The BMW was the only vehicle that did not exhibit high lower beam glare in oncoming left and right curve scenarios. The winding scenario elicited glare from all vehicles and both headlighting system modes in the 60 to 240 m range. Plots showing illuminance versus distance data for maneuver scenarios in Table 27 can be found in Appendix C.

Table 27. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 1 and Quotient Values – Oncoming, Curve, Adjacent Lane Maneuver Scenarios With Small DAS Vehicle

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi (n=3) Lower Beam Illuminance (lux)	Audi (n=3) ADB Illuminance (lux)	Audi (n=3) Quotient (ADB / Lower Beam)	BMW (n=3) Lower Beam Illuminance (lux)	BMW (n=3) ADB Illuminance (lux)	BMW (n=3) Quotient (ADB / Lower Beam)	Lexus (n=3) Lower Beam Illuminance (lux)	Lexus (n=3) ADB Illuminance (lux)	Lexus (n=3) Quotient (ADB / Lower Beam)	Mercedes-Benz (n=3) Lower Beam Illuminance (lux)	Mercedes-Benz (n=3) ADB Illuminance (lux)	Mercedes-Benz (n=3) Quotient (ADB / Lower Beam)
ADB curves Left, DAS 0 mph, ADB 62 mph	15-29.9	3.109	1.90	2.05	1.08	2.00	2.22	1.11	2.19	2.24	1.02	2.61	2.77	1.06
	30-59.9	1.776	1.07	1.22	1.14	0.86	1.00	1.17	1.23	1.32	1.07	1.27	1.42	1.11
	60-119.9	0.634	0.55	**1.61**	2.92	0.18	0.38	2.14	0.58	**0.81**	1.41	0.62	**1.06**	1.71
	120-239.9	0.281	**0.46**	**0.50**	1.09	0.03	0.07	1.96	**0.44**	**0.49**	1.10	**0.47**	**0.59**	1.27
ADB curves Left, DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.93	2.08	1.08	1.92	2.11	1.10	1.94	1.88	0.97	2.54	2.77	1.09
	30-59.9	1.776	1.08	1.22	1.13	0.86	0.92	1.07	1.16	1.30	1.12	1.26	1.40	1.11
	60-119.9	0.634	0.57	**1.99**	**3.49**	0.21	**0.79**	**3.76**	0.59	**1.92**	**3.23**	**0.64**	**1.60**	2.49
	120-239.9	0.281	**0.47**	**0.50**	1.07	0.07	0.11	1.48	**0.47**	**0.51**	1.07	**0.49**	**0.60**	1.23
ADB curves Right, DAS 0 mph, ADB 62 mph	15-29.9	3.109	2.28	2.59	1.14	1.63	1.60	0.98	1.75	2.14	1.22	2.38	2.45	1.03
	30-59.9	1.776	1.63	1.61	0.98	0.78	0.77	0.98	1.21	1.21	0.99	1.35	1.39	1.03
	60-119.9	0.634	**0.78**	**2.95**	**3.77**	0.22	**1.24**	**5.58**	0.57	**1.64**	2.87	**0.77**	**1.14**	1.49
	120-239.9	0.281	**0.57**	**0.65**	1.15	0.07	0.14	1.98	**0.40**	**0.42**	1.05	**0.58**	**0.89**	1.53
ADB curves Right, DAS 62 mph, ADB 62 mph	15-29.9	3.109	2.54	2.64	1.04	1.79	1.78	0.99	1.73	2.36	1.36	2.44	2.74	1.12
	30-59.9	1.776	1.53	**1.95**	1.27	0.73	0.75	1.03	1.14	**11.19**	**9.80**	1.30	1.46	1.12
	60-119.9	0.634	**0.71**	**3.23**	**4.53**	0.16	**2.33**	**14.37**	0.54	**4.28**	**7.93**	**0.70**	**1.54**	2.21
	120-239.9	0.281	**0.54**	**0.61**	1.12	0.00	0.06	**275.97**	**0.37**	**0.40**	1.09	**0.52**	**0.84**	1.61
Winding, DAS 0 mph, ADB 45 mph	15-29.9	3.109	2.12	2.19	1.03	3.01	**4.45**	1.48	2.30	1.89	0.82	2.49	2.55	1.02
	30-59.9	1.776	1.35	1.77	1.31	1.59	**1.93**	1.22	**2.22**	**3.53**	1.59	1.45	1.33	0.92
	60-119.9	0.634	**2.42**	**11.75**	**4.86**	**4.53**	**8.17**	1.80	**9.86**	**12.27**	1.24	**7.92**	**7.97**	1.01
	120-239.9	0.281	**0.86**	**4.30**	**4.98**	**0.62**	**4.54**	7.30	**1.49**	**2.03**	1.36	**1.45**	**1.66**	1.14

Table 28 summarizes average maximum illuminance results for lower beam versus ADB in oncoming curve scenarios with the SUV DAS vehicle. In these scenarios, both the Audi and BMW produced more glare with ADB than with lower beam mode, typically in the 30 to 120 m range. The Audi had two ranges associated with glare limit exceedances for the left curve, but only a single range with an exceedance for the right curve. The BMW results had an opposite trend, with more ranges showing exceeding values for the right curve than the left curve. In the right curve scenario with the SUV DAS vehicle stationary, the BMW ADB system produced nearly 44 times more glare than in the corresponding lower beam trial in the 30 to 60 m range and 70 times more glare that lower beam in the 60 to 120 m range. This could be an example of show response time by the ADB system, which was apparent in some scenarios. As was the case with the Small DAS vehicle, the BMW in oncoming left and right curve scenarios involving the SUV DAS vehicle did not exhibit high lower beam glare. The Audi also in oncoming left and right curve scenarios involving the SUV DAS vehicle did not exhibit high lower beam glare, whereas this vehicle did exhibit high lower beam glare in trials with the Small DAS vehicle. Plots showing illuminance versus distance data for maneuver scenarios in Table 28 can be found in Appendix C.

Table 28. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 1 and Quotient Values – Oncoming, Curve, Adjacent Lane, Maneuver Scenarios With SUV DAS Vehicle

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi (n=2) Lower Beam Illuminance (lux)	Audi (n=2) ADB Illuminance (lux)	Audi (n=2) Quotient (ADB / Lower Beam)	BMW (n=2) Lower Beam Illuminance (lux)	BMW (n=2) ADB Illuminance (lux)	BMW (n=2) Quotient (ADB / Lower Beam)
ADB curves Left, DAS 0 mph, ADB 62 mph	15-29.9	3.109	1.10	1.20	1.09	1.80	1.83	1.02
	30-59.9	1.776	0.54	**2.87**	**5.36**	0.77	0.83	1.07
	60-119.9	0.634	0.13	**2.50**	**19.42**	0.19	**1.24**	**6.67**
	120-239.9	0.281	0.03	0.05	1.68	0.05	0.08	1.74
ADB curves Left, DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.05	1.07	1.02	1.69	1.80	1.07
	30-59.9	1.776	0.51	**3.92**	**7.68**	0.74	0.85	1.15
	60-119.9	0.634	0.13	**2.35**	**17.43**	0.18	**2.87**	**16.15**
	120-239.9	0.281	0.04	0.05	1.27	0.05	0.08	1.74
ADB curves Right, DAS 0 mph, ADB 62 mph	15-29.9	3.109	1.46	1.82	1.25	1.36	1.56	1.15
	30-59.9	1.776	0.86	0.93	1.08	0.70	**30.88**	**43.85**
	60-119.9	0.634	0.19	**3.21**	**17.29**	0.23	**16.30**	**70.10**
	120-239.9	0.281	0.01	0.08	**6.18**	0.08	0.11	1.39
ADB curves Right, DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.35	1.76	1.31	1.48	**16.26**	**11.01**
	30-59.9	1.776	0.78	0.89	1.13	0.66	**17.16**	**25.87**
	60-119.9	0.634	0.11	**3.20**	**28.23**	0.11	**8.84**	**77.84**
	120-239.9	0.281	0.00	0.02	N/A	0.00	0.04	N/A
Winding, DAS 0 mph, ADB 45 mph	15-29.9	3.109	1.30	1.38	1.07	1.83	1.99	1.09
	30-59.9	1.776	0.72	0.81	1.12	0.92	1.16	1.26
	60-119.9	0.634	**1.31**	**4.40**	**3.35**	**4.08**	**6.16**	1.51
	120-239.9	0.281	0.28	**3.88**	**13.92**	**0.64**	**2.65**	**4.14**

As was the case with the Small DAS vehicle, the winding scenario trials involving the SUV DAS vehicle tended to elicit glare levels above lower beam limits in the 60 to 240 m range for both vehicles and both headlighting system modes.

Additional plots showing illuminance versus distance data for lower beam and ADB trials can be found in Appendix C.

7.6.2 ADB Versus Lower Beam – Same-Direction Maneuver Scenarios

This section summarizes results for same direction straight and curved scenarios, as well as passing scenarios.

Table 29 summarizes results for straight, same-direction maneuver scenarios with the Small DAS vehicle. Results for trials in which the ADB vehicle followed the DAS vehicle in the same lane, or the left or right adjacent lanes, show that nearly all trials showed comparable maximum illuminance values for lower beam and ADB modes. The BMW showed very high illuminance for both lower beam and ADB modes in the 15 to 30 m range for the same lane, DAS stationary scenario. In addition, BMW results for same-direction trials with the Small DAS vehicle showed two scenarios where high glare levels were seen for the lower beams but not for ADB. The Audi had one instance in the same direction, same speed (62 mph; 99.8 kph) scenario of lower beam illuminance exceeding that seen for ADB mode. The dip series scenario run as a same direction trial was similarly challenging for all systems as was the oncoming dip series scenario. All four vehicles exceed the derived glare limit values for both lower beam and ADB modes in the dip series scenario.

Results in Table 29 show that preceding motorcycle scenarios appeared to challenge ADB's ability to maintain glare within derived lower beam limit values. In both the stationary and moving preceding motorcycle scenarios, ADB mode for all four test vehicles showed illuminance levels exceeding lower beam levels and exceeding lower beam glare limit values in at least one distance range. Same direction trials in which the moving motorcycle preceded the ADB-equipped vehicle showed glare limit exceedances for ADB mode generally in the 60 to 120 m range for the moving motorcycle trials, while glare limit exceedances spanned the 30 to 120 m range for the stationary motorcycle trials.

Table 29. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 6 and Quotient Values – Same Direction, Straight Maneuver Scenarios With Small DAS Vehicle

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi (n=3)			BMW (n=3)			Lexus (n=3)			Mercedes-Benz (n=3)		
			Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)
			Illuminance (lux)			Illuminance (lux)			Illuminance (lux)			Illuminance (lux)		
DAS precedes, straight, same lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	2.21	2.35	1.06	**20.08**	**32.01**	1.59	2.43	4.01	1.65	3.83	3.97	1.04
	30-59.9	18.854	1.71	1.67	0.98	11.26	2.28	0.20	2.94	0.84	0.29	1.63	1.20	0.74
	60-119.9	4.041	1.92	1.97	1.03	**5.38**	0.85	0.16	1.70	0.24	0.14	2.23	0.56	0.25
	120-239.9	4.041	0.48	0.45	0.94	0.48	0.58	1.21	0.10	0.11	1.10	0.17	0.30	1.76
DAS precedes, straight, same lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	60-119.9	4.041	1.36	1.52	1.12	0.64	0.68	1.06	0.18	0.75	**4.17**	0.36	0.44	1.22
	120-239.9	4.041	**4.11**	3.80	0.92	0.69	0.78	1.13	0.35	0.51	1.46	0.47	0.83	1.77
DAS precedes, straight, adjacent lane left, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	0.42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	60-119.9	4.041	1.88	1.70	0.90	0.60	1.19	1.98	0.17	1.25	**7.35**	0.32	0.39	1.22
	120-239.9	4.041	3.36	3.11	0.93	0.88	1.12	1.27	0.31	0.90	2.90	0.29	0.29	1.00
DAS precedes, straight, adjacent lane right, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	N/A	N/A	N/A	1.51	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	60-119.9	4.041	2.49	2.24	0.90	**4.40**	2.17	0.49	0.85	0.86	1.01	2.18	0.33	0.15
	120-239.9	4.041	2.62	3.64	1.39	2.18	1.76	0.81	2.07	1.90	0.92	1.55	1.61	1.04
Motorcycle precedes, straight, same lane, Motorcycle/DAS 0 mph, ADB 62 mph	15-29.9	18.854	0.70	6.50	9.29	1.12	14.05	**12.54**	2.96	5.73	1.94	1.45	**31.03**	**21.40**
	30-59.9	18.854	0.65	9.84	**15.14**	1.29	**31.65**	**24.53**	1.80	**22.64**	**12.58**	1.32	**31.75**	**24.05**
	60-119.9	4.041	1.01	**6.54**	**6.48**	2.22	**23.73**	**10.69**	2.28	**7.74**	**3.39**	1.50	**14.83**	**9.89**
	120-239.9	4.041	0.67	0.66	0.99	0.84	**4.62**	**5.50**	0.44	0.30	0.68	0.59	3.20	**5.42**
Motorcycle precedes, straight, same lane, Motorcycle/DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	1.64	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	1.09	N/A	N/A	7.02	1.71	0.24	6.86	12.19	1.78	N/A	13.09	N/A
	60-119.9	4.041	2.02	**4.46**	2.21	**5.79**	**11.04**	1.91	3.88	**4.32**	1.11	2.66	**9.56**	**3.59**
	120-239.9	4.041	3.71	**4.38**	1.18	1.48	1.76	1.19	1.64	1.48	0.90	1.38	2.61	1.89
DAS precedes, dip series, straight, same lane, DAS 40 mph, ADB 45 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	**31.77**	**31.79**	1.00	**21.82**	**20.98**	0.96	**22.58**	14.83	0.66	**29.42**	18.83	0.64
	60-119.9	4.041	**23.76**	**7.49**	0.32	**17.28**	**18.12**	1.05	**12.38**	**11.97**	0.97	**13.33**	**15.40**	1.16
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 30 summarizes results for same direction, straight maneuvers with the SUV DAS vehicle. A majority of illuminance values observed for the BMW ADB in such scenarios with the SUV DAS vehicle were comparable to lower beam values. The Audi showed higher glare for ADB mode than for lower beam mode in preceding stationary DAS vehicle and preceding stationary motorcycle scenarios. The Audi also showed high glare values for both headlighting system modes in multiple same-direction scenarios in which the SUV DAS vehicle driving at 62 mph (99.8 kph). Both stationary and moving motorcycle trials conducted with the SUV DAS vehicle showed ADB systems of the Audi and BMW to produce illuminance values exceeding glare limits in the 60 to 120 range. However, lower beam mode also exceeded glare limits for the Audi at the 120 to 240 m range for the moving motorcycle and for the BMW at the 60 to 120 m range for the stationary motorcycle. As noted previously, high glare values in motorcycle scenarios could be attributable to the receptor head(s) on the DAS vehicle being outside of the ADB shaded area. The dip series maneuver run with the SUV DAS vehicle tended to show glare limit exceedances both for lower beam and ADB modes, as it did with the Small DAS vehicle.

Table 30. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 6 and Quotient Values – Same Direction, Straight Maneuver Scenarios With SUV DAS Vehicle

			Audi (n=2)			BMW (n=2)		
Maneuver Scenario	**Range (m)**	**Glare Limit (lux)**	**Lower Beam Illuminance (lux)**	**ADB Illuminance (lux)**	**Quotient (ADB / Lower Beam)**	**Lower Beam Illuminance (lux)**	**ADB Illuminance (lux)**	**Quotient (ADB / Lower Beam)**
DAS precedes, straight, same lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	1.75	16.97	**9.70**	4.01	4.34	1.08
	30-59.9	18.854	1.11	16.42	**14.79**	4.14	3.38	0.82
	60-119.9	4.041	1.61	**12.07**	**7.50**	3.89	0.44	0.11
	120-239.9	4.041	0.46	**6.41**	**13.93**	0.11	0.18	1.64
DAS precedes, straight, same lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.74	1.08	1.46	0.36	0.79	2.19
	60-119.9	4.041	3.04	2.85	0.94	0.26	0.46	1.77
	120-239.9	4.041	**5.89**	**5.77**	0.98	0.23	1.45	**6.30**
DAS precedes, straight, adjacent lane left, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.23	0.17	0.74	0.31	0.34	1.10
	60-119.9	4.041	2.02	3.39	1.68	0.25	0.35	1.40
	120-239.9	4.041	3.74	3.87	1.03	0.20	0.37	1.85
DAS precedes, straight, adjacent lane right, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	60-119.9	4.041	2.69	2.09	0.78	**4.07**	0.93	0.23
	120-239.9	4.041	**4.19**	**4.33**	1.03	1.69	1.76	1.04
Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	0.47	4.50	**9.57**	1.35	16.55	**12.26**
	30-59.9	18.854	0.48	12.61	**26.27**	1.44	17.25	**11.98**
	60-119.9	4.041	0.86	**4.08**	**4.74**	2.92	**16.88**	**5.78**
	120-239.9	4.041	0.62	0.74	1.19	1.10	0.31	0.28
Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.69	N/A	N/A	N/A	N/A	N/A
	60-119.9	4.041	2.88	**9.75**	**3.39**	**6.38**	**7.74**	1.21
	120-239.9	4.041	**4.21**	**4.55**	1.08	1.00	1.25	1.25
DAS precedes, dip straight, same lane, DAS 40 mph, ADB 45 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	**29.81**	**21.05**	0.71	16.62	**27.85**	1.68
	60-119.9	4.041	**27.81**	**26.09**	0.94	**20.88**	**16.27**	0.78
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A

Tables 31 through 34 summarize average maximum illuminance results for same direction, curve maneuvers. Both the Audi and BMW exhibited more glare in ADB mode than in lower beam mode in same-direction, left curve scenarios in which the DAS vehicle was stationary and in the same lane or right adjacent lane, regardless of DAS vehicle size. However, while a number of instances of high quotient values can be seen in Tables 31 through 34, overall, most measured illuminance values fell within derived lower beam glare limit values for both headlighting system modes. In same-direction, curve maneuver scenarios, ADB showed fewer instances of high glare than were seen in oncoming maneuver scenarios.

Table 31. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 6 and Quotient Values – Same Direction, Curve Left Maneuver Scenarios With Small DAS Vehicle

			Audi (n=3)			BMW (n=3)			Lexus (n=3)			Mercedes-Benz (n=3)		
Maneuver Scenario	Range (m)	Glare Limit (lux)	Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)	Lower Beam	ADB	Quotient (ADB / Lower Beam)
			Illuminance (lux)			Illuminance (lux)			Illuminance (lux)			Illuminance (lux)		
DAS precedes, curve left, same lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	2.22	2.32	1.05	3.53	9.39	2.66	1.53	2.55	1.67	3.23	3.53	1.09
	30-59.9	18.854	1.05	8.74	**8.32**	1.56	2.77	1.78	0.93	0.85	0.91	1.10	1.12	1.02
	60-119.9	4.041	0.21	**5.73**	**27.29**	0.22	**4.48**	**20.36**	0.22	0.52	2.36	0.26	1.88	**7.23**
	120-239.9	4.041	0.05	0.12	2.40	0.06	0.22	**3.67**	0.07	0.11	1.57	0.07	0.56	**8.00**
DAS precedes, curve left, same lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.33	0.35	1.06	0.44	0.46	1.05	N/A	N/A	N/A	0.37	0.51	1.38
	60-119.9	4.041	0.22	0.26	1.18	0.27	0.37	1.37	0.15	0.30	2.00	0.28	0.26	0.93
	120-239.9	4.041	0.76	0.68	0.89	0.17	0.17	1.00	0.33	0.26	0.79	0.15	0.16	1.07
DAS precedes, curve left, adjacent lane left, DAS 0 mph, ADB 62 mph	15-29.9	18.854	0.38	3.47	**9.13**	0.57	0.62	1.09	0.53	0.49	0.92	0.65	0.73	1.12
	30-59.9	18.854	0.39	4.38	**11.23**	0.61	0.66	1.08	0.52	0.50	0.96	0.70	0.82	1.17
	60-119.9	4.041	0.13	1.85	**14.23**	0.19	1.10	**5.79**	0.15	0.56	**3.73**	0.22	0.90	**4.09**
	120-239.9	4.041	0.04	0.10	2.50	0.07	0.12	1.71	0.06	0.09	1.50	0.07	0.30	**4.29**
DAS precedes, curve left, adjacent lane left, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.23	0.13	0.57	0.37	0.39	1.05	0.19	0.28	1.47	0.37	0.39	1.05
	60-119.9	4.041	0.16	1.50	**9.38**	0.26	0.25	0.96	0.47	0.49	1.04	0.23	0.23	1.00
	120-239.9	4.041	1.13	1.16	1.03	0.30	0.44	1.47	0.62	0.52	0.84	0.23	0.31	1.35
DAS precedes, curve left, adjacent lane right, DAS 0 mph, ADB 62 mph	15-29.9	18.854	1.89	2.21	1.17	2.82	9.53	**3.38**	1.48	2.49	1.68	2.83	3.22	1.14
	30-59.9	18.854	1.05	**18.99**	**18.09**	2.06	1.58	0.77	0.97	0.89	0.92	1.09	1.18	1.08
	60-119.9	4.041	0.23	**7.95**	**34.57**	0.22	**4.59**	**20.86**	0.22	0.60	2.73	0.27	2.15	**7.96**
	120-239.9	4.041	0.06	0.13	2.17	0.07	0.28	**4.00**	0.06	0.14	2.33	0.06	0.71	**11.83**
DAS precedes, curve left, adjacent lane right, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.41	0.70	1.71	0.37	0.56	1.51	0.31	0.46	1.48	0.54	0.45	0.83
	60-119.9	4.041	0.31	1.20	**3.87**	0.30	0.31	1.03	0.20	0.20	1.00	0.29	0.34	1.17
	120-239.9	4.041	0.33	0.57	1.73	0.12	0.10	0.83	0.11	0.11	1.00	0.14	0.14	1.00

Table 32. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 6 and Quotient Values – Same Direction, Curve Left Maneuver Scenarios With SUV DAS Vehicle

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi (n=2) Lower Beam	Audi (n=2) ADB	Audi (n=2) Quotient (ADB / Lower Beam)	BMW (n=2) Lower Beam	BMW (n=2) ADB	BMW (n=2) Quotient (ADB / Lower Beam)
			Illuminance (lux)			Illuminance (lux)		
DAS precedes, curve left, same lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	1.94	2.57	1.32	2.57	**19.14**	**7.45**
	30-59.9	18.854	1.30	**28.11**	**21.62**	1.07	**19.78**	**18.49**
	60-119.9	4.041	0.26	**7.37**	**28.35**	0.22	**15.06**	**68.45**
	120-239.9	4.041	0.06	0.14	2.33	0.05	0.16	3.20
DAS precedes, curve left, same lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.41	0.41	1.00	0.30	0.28	0.93
	60-119.9	4.041	0.72	0.45	0.63	0.22	0.28	1.27
	120-239.9	4.041	1.68	1.29	0.77	0.16	0.13	0.81
DAS precedes, curve left, adjacent lane left, DAS 0 mph, ADB 62 mph	15-29.9	18.854	0.21	2.14	**10.19**	0.29	0.34	1.17
	30-59.9	18.854	0.35	7.21	**20.60**	0.40	0.42	1.05
	60-119.9	4.041	0.17	2.53	**14.88**	0.17	1.48	**8.71**
	120-239.9	4.041	0.06	0.14	2.33	0.04	0.09	2.25
DAS precedes, curve left, adjacent lane left, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.21	0.25	1.19	0.26	0.37	1.42
	60-119.9	4.041	1.20	1.04	0.87	0.18	0.20	1.11
	120-239.9	4.041	1.80	1.65	0.92	0.23	0.36	1.57
DAS precedes, curve left, adjacent lane right, DAS 0 mph, ADB 62 mph	15-29.9	18.854	1.73	1.93	1.12	2.50	17.36	**6.94**
	30-59.9	18.854	1.29	15.92	**12.34**	1.41	16.72	**11.86**
	60-119.9	4.041	0.30	**7.43**	**24.77**	0.23	**19.62**	**85.30**
	120-239.9	4.041	0.06	0.13	2.17	0.05	0.30	**6.00**
DAS precedes, curve left, adjacent lane right, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.48	N/A	N/A	0.35	0.47	1.34
	60-119.9	4.041	0.32	1.93	**6.03**	0.21	0.21	1.00
	120-239.9	4.041	0.57	0.21	0.37	0.09	0.09	1.00

Table 33. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 6 and Quotient Values – Same Direction, Curve Right Maneuver Scenarios With Small DAS Vehicle

			Audi (n=3)			BMW (n=3)			Lexus (n=3)			Mercedes-Benz (n=3)		
Maneuver Scenario	Range (m)	Glare Limit (lux)	Lower Beam Illuminance (lux)	ADB Illuminance (lux)	Quotient (ADB / Lower Beam)	Lower Beam Illuminance (lux)	ADB Illuminance (lux)	Quotient (ADB / Lower Beam)	Lower Beam Illuminance (lux)	ADB Illuminance (lux)	Quotient (ADB / Lower Beam)	Lower Beam Illuminance (lux)	ADB Illuminance (lux)	Quotient (ADB / Lower Beam)
DAS precedes, curve right, same lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	1.67	1.75	1.05	5.40	5.41	1.00	1.95	2.01	1.03	3.57	3.86	1.08
	30-59.9	18.854	0.58	1.93	**3.33**	1.81	1.94	1.07	0.56	0.79	1.41	1.10	1.23	1.12
	60-119.9	4.041	0.12	1.50	**12.50**	0.23	0.26	1.13	0.07	0.12	1.71	0.20	0.25	1.25
	120-239.9	4.041	0.04	0.05	1.25	0.05	0.06	1.20	0.03	0.03	1.00	0.04	0.08	2.00
DAS precedes, curve right, same lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.35	0.15	0.43	0.32	0.76	2.38	N/A	N/A	N/A	0.10	0.35	3.50
	60-119.9	4.041	0.57	0.70	1.23	0.23	0.33	1.43	0.29	0.04	0.14	0.21	0.35	1.67
	120-239.9	4.041	0.51	0.99	1.94	1.37	1.37	1.00	0.59	0.62	1.05	0.48	0.41	0.85
DAS precedes, curve right, adjacent lane left, DAS 0 mph, ADB 62 mph	15-29.9	18.854	0.14	0.13	0.93	0.33	0.36	1.09	0.10	0.17	1.70	0.13	0.15	1.15
	30-59.9	18.854	0.10	6.56	**65.60**	0.16	0.36	2.25	0.09	0.27	**3.00**	0.12	0.11	0.92
	60-119.9	4.041	0.07	1.37	**19.57**	0.06	0.60	**10.00**	0.03	0.11	**3.67**	0.06	0.07	1.17
	120-239.9	4.041	0.08	0.05	0.63	0.05	0.08	1.60	0.03	0.03	1.00	0.06	0.06	1.00
DAS precedes, curve right, adjacent lane left, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	0.17	N/A	0.05	0.26	**5.20**	N/A	0.08	N/A	0.06	0.20	3.33
	60-119.9	4.041	0.52	0.64	1.23	0.08	0.11	1.38	0.14	0.15	1.07	0.15	0.17	1.13
	120-239.9	4.041	0.63	0.63	1.00	0.63	0.92	1.46	0.25	0.16	0.64	0.24	0.20	0.83
DAS precedes, curve right, adjacent lane right, DAS 0 mph, ADB 62 mph	15-29.9	18.854	1.92	2.02	1.05	5.30	5.71	1.08	1.91	2.19	1.15	3.29	3.55	1.08
	30-59.9	18.854	0.65	2.43	**3.74**	2.35	2.47	1.05	0.76	0.99	1.30	1.19	1.34	1.13
	60-119.9	4.041	0.14	1.22	**8.71**	0.24	0.31	1.29	0.12	0.71	**5.92**	0.24	0.28	1.17
	120-239.9	4.041	0.04	0.05	1.25	0.04	0.06	1.50	0.02	0.03	1.50	0.05	0.06	1.20
DAS precedes, curve right, adjacent lane right, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	1.24	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	0.33	N/A	0.34	0.46	1.35	0.71	0.28	0.39	0.30	0.47	1.57
	60-119.9	4.041	0.59	0.91	1.54	0.26	0.27	1.04	0.64	0.61	0.95	0.59	1.37	2.32
	120-239.9	4.041	0.62	0.85	1.37	1.14	1.07	0.94	0.77	0.77	1.00	0.71	0.22	0.31

Table 34. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 6 and Quotient Values – Same Direction, Curve Right Maneuver Scenarios With SUV DAS Vehicle

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi (n=2) Lower Beam Illuminance (lux)	Audi (n=2) ADB Illuminance (lux)	Audi (n=2) Quotient (ADB / Lower Beam)	BMW (n=2) Lower Beam Illuminance (lux)	BMW (n=2) ADB Illuminance (lux)	BMW (n=2) Quotient (ADB / Lower Beam)
DAS precedes, curve right, same lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	1.68	10.45	**6.22**	2.78	2.99	1.08
	30-59.9	18.854	0.75	9.92	**13.23**	1.15	1.27	1.10
	60-119.9	4.041	0.18	3.51	**19.50**	0.19	1.28	**6.74**
	120-239.9	4.041	0.06	0.05	0.83	0.04	0.06	1.50
DAS precedes, curve right, same lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	0.42	N/A	N/A	N/A	N/A
	60-119.9	4.041	0.10	0.34	3.40	0.06	0.13	2.17
	120-239.9	4.041	0.72	0.53	0.74	1.09	1.12	1.03
DAS precedes, curve right, adjacent lane left, DAS 0 mph, ADB 62 mph	15-29.9	18.854	0.09	0.10	1.11	0.20	0.21	1.05
	30-59.9	18.854	0.08	0.31	3.88	0.09	0.35	**3.89**
	60-119.9	4.041	0.05	0.30	**6.00**	0.05	0.34	**6.80**
	120-239.9	4.041	0.05	0.05	1.00	0.05	0.05	1.00
DAS precedes, curve right, adjacent lane left, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.03	0.08	2.67	0.05	0.14	2.80
	60-119.9	4.041	0.06	0.24	**4.00**	0.06	0.13	2.17
	120-239.9	4.041	0.46	0.20	0.43	0.11	0.18	1.64
DAS precedes, curve right, adjacent lane right, DAS 0 mph, ADB 62 mph	15-29.9	18.854	1.70	1.70	1.00	2.74	2.65	0.97
	30-59.9	18.854	0.88	5.38	**6.11**	1.38	1.42	1.03
	60-119.9	4.041	0.17	1.44	**8.47**	0.22	0.23	1.05
	120-239.9	4.041	0.04	0.05	1.25	0.05	0.04	0.80
DAS precedes, curve right, adjacent lane right, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.52	0.40	0.77	0.46	0.64	1.39
	60-119.9	4.041	0.66	0.43	0.65	0.22	0.50	2.27
	120-239.9	4.041	0.70	0.71	1.01	0.80	1.28	1.60

Tables 35 and 36 summarize average maximum illuminance results for same direction, passing maneuver scenarios. All four test vehicles' ADB systems generally exhibited illuminance levels comparable to those of their corresponding lower beam modes in all passing scenarios examined. Only one case of ADB exhibiting more glare than lower beam mode was seen in a passing maneuver. Specifically, the BMW exhibited more glare with ADB than with lower beam in the active passing scenario involving the Small DAS vehicle. No instances of ADB producing more glare than lower beam mode were seen in passing maneuver scenarios involving the SUV DAS vehicle.

Table 35. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 6 and Quotient Values – Same Direction Passing Maneuver Scenarios With Small DAS Vehicle

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi (n=3)			BMW (n=3)			Lexus (n=3)			Mercedes-Benz (n=3)		
			Lower Beam Illuminance (lux)	ADB Illuminance (lux)	Quotient (ADB / Lower Beam)	Lower Beam Illuminance (lux)	ADB Illuminance (lux)	Quotient (ADB / Lower Beam)	Lower Beam Illuminance (lux)	ADB Illuminance (lux)	Quotient (ADB / Lower Beam)	Lower Beam Illuminance (lux)	ADB Illuminance (lux)	Quotient (ADB / Lower Beam)
DAS follows then passes, straight, same lane, DAS 62 mph, ADB 50 mph	15-29.9	18.854	1.22	0.66	0.54	1.70	2.32	1.36	0.79	0.99	1.25	0.81	0.78	0.96
	30-59.9	18.854	1.11	1.10	0.99	1.74	2.72	1.56	0.89	1.97	2.21	1.23	1.20	0.98
	60-119.9	4.041	N/A	N/A	N/A	0.38	0.78	2.05	N/A	N/A	N/A	0.62	0.34	0.55
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, straight, same lane, DAS 50 mph, ADB 62 mph	15-29.9	18.854	2.98	4.66	1.56	**20.33**	**21.27**	1.05	2.36	3.33	1.41	4.00	4.01	1.00
	30-59.9	18.854	9.40	10.88	1.16	13.41	2.62	0.20	3.32	1.00	0.30	1.73	1.40	0.81
	60-119.9	4.041	**8.01**	**12.98**	1.62	1.26	**5.43**	4.31	1.14	2.30	2.02	0.63	0.66	1.05
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DAS follows then passes, curve left, same lane, DAS 62 mph, ADB 45 mph	15-29.9	18.854	0.46	0.89	1.93	0.82	8.47	**10.33**	0.71	0.67	0.94	0.55	0.92	1.67
	30-59.9	18.854	0.54	0.80	1.48	0.90	1.13	1.26	0.71	0.70	0.99	0.78	0.91	1.17
	60-119.9	4.041	0.20	0.43	2.15	0.34	0.40	1.18	0.23	0.27	1.17	0.25	0.30	1.20
	120-239.9	4.041	N/A	N/A	N/A	0.08	N/A	N/A	0.07	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, curve left, same lane, DAS 45 mph, ADB 62 mph	15-29.9	18.854	3.21	2.98	0.93	4.47	7.18	1.61	2.18	2.32	1.06	3.61	3.41	0.94
	30-59.9	18.854	1.88	1.18	0.63	1.90	1.98	1.04	1.04	0.79	0.76	1.23	1.19	0.97
	60-119.9	4.041	0.71	0.55	0.77	0.31	0.31	1.00	0.33	0.30	0.91	0.34	0.35	1.03
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DAS follows then passes, curve right, same lane, DAS 62 mph, ADB 45 mph	15-29.9	18.854	0.71	0.99	1.39	0.50	0.80	1.60	0.41	0.40	0.98	0.25	0.77	**3.08**
	30-59.9	18.854	0.58	0.95	1.64	0.65	1.05	1.62	0.55	0.39	0.71	0.62	0.85	1.37
	60-119.9	4.041	N/A	N/A	N/A	0.24	0.34	1.42	N/A	0.12	N/A	N/A	0.21	N/A
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, curve right, same lane, DAS 45 mph, ADB 62 mph	15-29.9	18.854	1.71	2.06	1.20	6.27	9.35	1.49	1.92	1.77	0.92	3.76	3.59	0.95
	30-59.9	18.854	3.81	4.82	1.27	5.08	5.47	1.08	2.19	2.45	1.12	1.98	1.68	0.85
	60-119.9	4.041	**5.48**	**5.52**	1.01	3.24	2.50	0.77	1.06	1.56	1.47	0.54	0.42	0.78
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	0.56	0.33	0.59	N/A	N/A	N/A

Table 36. Average Maximum Illuminance by Headlighting System Mode for Receptor Head 6 and Quotient Values – Same Direction Passing Maneuver Scenarios With SUV DAS Vehicle

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi (n=2) Lower Beam Illuminance (lux)	Audi (n=2) ADB Illuminance (lux)	Audi (n=2) Quotient (ADB / Lower Beam)	BMW (n=2) Lower Beam Illuminance (lux)	BMW (n=2) ADB Illuminance (lux)	BMW (n=2) Quotient (ADB / Lower Beam)
DAS follows then passes, straight, same lane, DAS 62 mph, ADB 50 mph	15-29.9	18.854	0.14	0.80	**5.71**	0.19	0.43	2.26
	30-59.9	18.854	0.92	1.05	1.14	0.71	0.88	1.24
	60-119.9	4.041	N/A	0.68	N/A	0.43	0.33	0.77
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, straight, same lane, DAS 50 mph, ADB 62 mph	15-29.9	18.854	2.35	1.98	0.84	8.10	5.08	0.63
	30-59.9	18.854	5.10	5.62	1.10	10.53	2.94	0.28
	60-119.9	4.041	**8.44**	**8.73**	1.03	0.41	2.04	**4.98**
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A
DAS follows then passes, curve left, same lane, DAS 62 mph, ADB 45 mph	15-29.9	18.854	0.20	0.75	**3.75**	0.55	0.86	1.56
	30-59.9	18.854	0.56	0.87	1.55	0.74	0.87	1.18
	60-119.9	4.041	0.25	0.33	1.32	0.28	0.29	1.04
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, curve left, same lane, DAS 45 mph, ADB 62 mph	15-29.9	18.854	2.80	3.46	1.24	3.21	2.92	0.91
	30-59.9	18.854	1.40	1.35	0.96	1.53	1.41	0.92
	60-119.9	4.041	2.09	1.03	0.49	0.27	0.29	1.07
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A
DAS follows then passes, curve right, same lane, DAS 62 mph, ADB 45 mph	15-29.9	18.854	0.42	0.41	0.98	0.27	0.54	2.00
	30-59.9	18.854	0.69	0.71	1.03	0.48	0.53	1.10
	60-119.9	4.041	0.09	N/A	N/A	0.21	0.14	0.67
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, curve right, same lane, DAS 45 mph, ADB 62 mph	15-29.9	18.854	1.98	2.00	1.01	2.82	3.04	1.08
	30-59.9	18.854	3.45	2.37	0.69	3.53	2.60	0.74
	60-119.9	4.041	**4.11**	3.25	0.79	2.56	1.97	0.77
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A

7.7 ADB Performance - Comparison to Derived Lower Beam Glare Limit Values

Given that ADB is supposed to increase roadway illumination while limiting glare to lower beam levels in the location of other vehicles, evaluating measured illuminance data with respect to lower beam glare limits can provide clues as to whether the ADB systems tested achieve this goal. To this end, measured maximum illuminance values for both ADB and lower beam modes were compared to glare limit values derived from FMVSS No. 108 by Flannigan and Sullivan [10]. The following subsections contain tables presenting average maximum illuminance values (over 'n' trial repetitions) and standard deviation of illuminance values for scenario maneuver trials involving ADB mode. In this section, table cell values in bold text with dark gray shading indicate measured illuminance values that exceeded a glare limit. Also throughout this section, high quotient values (e.g., > 3.0) are shown in red, bold text for emphasis. Lower beam average maximum illuminance results for all vehicles according to maneuver scenario categories are presented in Appendix D.

7.7.1 ADB Versus Lower Beam Glare Limits - Oncoming Maneuver Scenarios

Illuminance data for the primary illuminance receptor head relevant to each maneuver scenario and both DAS vehicles are presented for oncoming maneuver scenarios in Tables 37 to 43. Table 37 presents average maximum illuminance and standard deviation values for receptor head 1 (on exterior windshield surface at driver eye point height and lateral coordinates) in oncoming, straight maneuver scenarios.

Table 37. Average Maximum Illuminance and Standard Deviation Using Receptor Head 1, ADB Mode - Oncoming, Straight Maneuver Scenarios - Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, Small DAS (n=3)		Audi, SUV DAS (n=2)		BMW, Small DAS (n=3)		BMW, SUV DAS (n=2)		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS (n=3)	
			Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Straight, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	2.00	0.06	1.47	0.20	**3.23**	0.55	2.06	0.06	1.50	0.13	2.50	0.33
	30-59.9	1.776	0.78	0.68	0.92	0.21	**1.85**	0.35	1.52	0.29	0.99	0.08	1.14	0.16
	60-119.9	0.634	0.32	0.29	0.45	0.22	0.37	0.02	0.63	0.02	0.44	0.20	0.41	0.04
	120-239.9	0.281	0.14	0.12	0.27	0.25	0.05	0.06	**0.35**	0.05	**0.37**	0.24	0.16	0.02
Straight, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	3.109	2.89	0.94	1.84	0.37	2.99	0.41	1.92	0.25	1.49	0.21	2.34	0.36
	30-59.9	1.776	0.81	0.68	0.83	0.07	**1.95**	0.09	1.43	0.11	0.94	0.07	1.04	0.14
	60-119.9	0.634	0.42	0.37	0.34	0.07	0.38	0.03	0.30	0.03	0.35	0.07	0.39	0.03
	120-239.9	0.281	0.22	0.22	0.10	0.02	0.08	0.03	0.10	0.03	0.22	0.11	0.14	0.02
Motorcycle, straight, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	1.63	0.34	1.35	0.48	1.90	0.22	1.04	0.09	1.16	0.13	1.02	0.09
	30-59.9	1.776	**4.88**	2.69	**4.80**	0.31	1.51	0.16	0.87	0.15	0.70	0.13	0.78	0.09
	60-119.9	0.634	**2.00**	1.76	**2.31**	2.66	**1.28**	0.34	0.55	0.05	0.51	0.13	0.43	0.04
	120-239.9	0.281	0.22	0.14	0.18	0.02	**0.30**	0.09	0.17	0.02	0.21	0.11	0.20	0.04
Motorcycle, straight, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.61	0.39	1.18	0.53	1.93	0.21	1.01	0.16	1.12	0.19	0.90	0.02
	30-59.9	1.776	**4.45**	1.31	**4.84**	0.02	1.67	0.59	0.76	0.14	0.76	0.31	0.78	0.08
	60-119.9	0.634	**2.52**	1.95	**2.85**	0.54	**1.07**	0.20	0.57	0.15	0.39	0.10	0.42	0.16
	120-239.9	0.281	0.24	0.17	0.11	0.01	0.24	0.03	0.11	0.06	0.18	0.12	0.12	0.04
Dip series, adj. lane, DAS 0 mph, ADB 45 mph	15-29.9	3.109	2.87	0.44	**3.67**	2.67	**5.54**	2.40	2.80	0.24	2.65	0.06	**4.23**	0.86
	30-59.9	1.776	**31.43**	0.19	**31.15**	0.34	**31.11**	0.37	**31.40**	0.02	**22.57**	1.32	**30.82**	0.93
	60-119.9	0.634	**0.91**	0.23	**0.83**	0.72	**0.75**	0.37	**0.82**	0.00	**1.46**	0.91	**0.95**	0.41
	120-239.9	0.281	**6.61**	0.34	**6.48**	0.49	**4.90**	0.48	**4.61**	0.08	**2.34**	0.09	**4.39**	0.03

For the Audi, average illuminance values for Small and SUV DAS vehicle by maneuver scenario were generally very similar. Like the Audi, the BMW results show that standard deviation of average maximum illuminance values were greater for maneuver distances ranges in which a glare limit was exceeded, but only for the Small DAS vehicle. Table 36 shows that standard deviation of average maximum illuminance ranged from 0.02 to 0.59 for scenarios in which glare limits were not exceeded, while scenarios with glare limit exceedances had SDs ranging from 0.00 to 2.40. Glare limit exceedances for the BMW did not show the sort of similar pattern between the Small and SUV DAS vehicles that was seen for the Audi.

Table 37 presents average maximum illuminance and standard deviation values per curve maneuver scenario measured by receptor head 1.

Table 38. Average Maximum Illuminance and Standard Deviation Using Receptor Head 1, ADB Mode - Oncoming, Curve Maneuver Scenarios - Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, Small DAS (n=3)		Audi, SUV DAS, (n=2)		BMW, Small DAS (n=3)		BMW, SUV DAS (n=2)		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS (n=3)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ADB curves Left, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	2.05	0.08	1.20	0.05	2.22	0.32	1.83	0.16	2.24	0.04	2.77	0.43
	30-59.9	1.776	1.22	0.02	**2.87**	0.16	1.00	0.10	0.83	0.02	1.32	0.04	1.42	0.15
	60-119.9	0.634	**1.61**	0.15	**2.50**	0.30	0.38	0.13	**1.24**	0.11	**0.81**	0.04	**1.06**	0.25
	120-239.9	0.281	**0.50**	0.00	0.05	0.03	0.07	0.01	0.08	0.00	**0.49**	0.07	**0.59**	0.07
ADB curves Left, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	3.109	2.08	0.12	1.07	0.10	2.11	0.22	1.80	0.18	1.88	0.11	2.77	0.37
	30-59.9	1.776	1.22	0.03	**3.92**	0.40	0.92	0.02	0.85	0.04	1.30	0.09	1.40	0.11
	60-119.9	0.634	**1.99**	0.05	**2.35**	0.27	**0.79**	0.03	**2.87**	0.52	**1.92**	0.28	**1.60**	0.14
	120-239.9	0.281	**0.50**	0.00	0.05	0.00	0.11	0.02	0.08	0.02	**0.51**	0.10	**0.60**	0.07
ADB curves Right, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	2.59	0.07	1.82	0.18	1.60	0.00	1.56	0.09	2.14	0.18	2.45	0.27
	30-59.9	1.776	1.61	0.04	0.93	0.06	0.77	0.09	**30.88**	0.01	1.21	0.31	1.39	0.07
	60-119.9	0.634	**2.95**	0.39	**3.21**	0.68	**1.24**	0.57	**16.30**	0.10	**1.64**	0.41	**1.14**	0.21
	120-239.9	0.281	**0.65**	0.03	0.08	0.05	0.14	0.07	0.11	0.03	**0.42**	0.35	**0.89**	0.14
ADB curves Right, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	3.109	2.64	0.30	1.76	0.16	1.78	0.04	**16.26**	20.69	2.36	0.25	2.74	0.43
	30-59.9	1.776	**1.95**	1.45	0.89	0.01	0.75	0.04	**17.16**	19.28	**11.19**	17.59	1.46	0.20
	60-119.9	0.634	**3.23**	2.29	**3.20**	0.30	**2.33**	0.96	**8.84**	0.28	**4.28**	1.38	**1.54**	0.66
	120-239.9	0.281	**0.61**	0.04	0.02	0.00	0.06	0.04	0.04	0.02	**0.40**	0.26	**0.84**	0.03
Winding, DAS 0 mph, ADB 45 mph	15-29.9	3.109	2.19	0.00	1.38	0.07	**4.45**	1.67	1.99	0.26	1.89	0.21	2.55	0.33
	30-59.9	1.776	1.77	0.56	0.81	0.11	**1.93**	0.40	1.16	0.29	**3.53**	0.74	1.33	0.10
	60-119.9	0.634	**11.75**	7.04	**4.40**	1.08	**8.17**	2.89	**6.16**	0.61	**12.27**	2.53	**7.97**	0.29
	120-239.9	0.281	**4.30**	0.11	**3.88**	0.43	**4.54**	0.06	**2.65**	2.76	**2.03**	0.05	**1.66**	0.19

Table 39 presents receptor head 8 values for average maximum illuminance and standard deviation per curve maneuver scenario.

Table 39. Average Maximum Illuminance and Standard Deviation Using Receptor Head 8, ADB Mode - Oncoming, Intersection Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, Small DAS (n=3)		Audi, SUV DAS, (n=2)		BMW, Small DAS (n=3)		BMW, SUV DAS, (n=2		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS, (n=3)	
			Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
60 degrees, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.50	0.02	0.25	0.06	**2.63**	0.68	**2.66**	0.47	1.07	0.12	0.85	0.08
	30-59.9	1.776	**7.02**	1.12	**2.93**	0.80	**6.80**	0.91	**7.19**	0.42	**1.68**	2.19	0.81	0.10
	60-119.9	0.634	**8.88**	0.31	**5.72**	0.81	**7.03**	0.50	**7.25**	0.47	**3.51**	0.84	0.43	0.01
	120-239.9	0.281	**5.06**	0.16	**4.71**	0.23	**4.12**	0.12	**4.23**	0.15	**1.78**	0.22	**2.70**	0.87
90 degrees, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.41	0.02	0.25	0.02	**3.27**	0.09	**1.82**	1.59	**2.31**	0.15	0.77	0.05
	30-59.9	1.776	**7.50**	0.62	**3.02**	0.00	**7.95**	0.38	**7.70**	0.95	**5.60**	0.15	0.74	0.04
	60-119.9	0.634	**8.92**	0.41	**6.77**	0.73	**7.87**	0.46	**7.76**	0.72	**3.86**	0.10	0.45	0.02
	120-239.9	0.281	**5.29**	0.24	**5.21**	0.40	**4.91**	0.13	**4.77**	0.46	**2.09**	0.14	**2.75**	0.25
120 degrees, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.30	0.04	0.17	0.02	0.56	0.08	0.47	0.02	1.68	0.60	0.66	0.34
	30-59.9	1.776	**4.55**	4.06	**3.24**	0.69	**4.67**	3.77	**6.27**	0.81	**4.14**	0.30	**5.21**	0.54
	60-119.9	0.634	**4.57**	4.07	**5.22**	1.27	**6.39**	0.74	**6.44**	0.68	**3.36**	0.15	**4.82**	0.31
	120-239.9	0.281	**3.02**	2.53	**4.37**	0.03	**3.81**	0.30	**4.05**	0.30	**1.69**	0.13	**2.53**	0.29

Table 40 presents receptor head 6 values for average maximum illuminance and standard deviation per same direction, straight maneuver scenario. While all test vehicle/DAS vehicle combinations showed glare limit exceedances in both the stationary and moving preceding motorcycle scenarios, the Lexus and Audi with Small DAS vehicle conditions were close to meeting glare limits. It appears that the stationary preceding motorcycle scenario was more challenging for the ADB systems than the moving preceding motorcycle scenario. High illuminance values in the preceding motorcycle scenarios may be due, at least in part, to the fact that the illuminance sensors were not located directly on the motorcycle (RH6 was approximately 9 ft (2.7 m) to the motorcycle's right side, on the DAS vehicle).

Table 40. Average Maximum Illuminance and Standard Deviation Using Receptor Head 6, ADB Mode - Same Direction, Straight Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, Small DAS (n=3)		Audi, SUV DAS (n=2)		BMW, Small DAS (n=3)		BMW, SUV DAS (n=2)		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS (n=3)	
			Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
DAS precedes, straight, same lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	2.35	0.08	16.97	20.95	**32.01**	0.64	4.34	0.35	4.01	0.37	3.97	0.49
	30-59.9	18.854	1.67	0.52	16.42	21.58	2.28	0.47	3.38	2.35	0.84	0.05	1.20	0.13
	60-119.9	4.041	1.97	0.25	**12.07**	14.47	0.85	0.67	0.44	0.01	0.24	0.03	0.56	0.18
	120-239.9	4.041	0.45	0.04	**6.41**	4.51	0.58	0.68	0.18	0.04	0.11	0.02	0.30	0.08
DAS precedes, straight, same lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	N/A	1.08	0.00	N/A	N/A	0.79	0.00	N/A	N/A	N/A	N/A
	60-119.9	4.041	1.52	1.00	2.85	2.31	0.68	0.68	0.46	0.08	0.75	0.14	0.44	0.05
	120-239.9	4.041	3.80	0.58	**5.77**	1.60	0.78	0.68	1.45	0.26	0.51	0.27	0.83	0.40
DAS precedes, straight, adjacent lane left, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.42	0.08	0.17	0.00	N/A	N/A	0.34	0.00	N/A	N/A	N/A	N/A
	60-119.9	4.041	1.70	1.10	3.39	0.27	1.19	1.46	0.35	0.04	1.25	0.36	0.39	0.02
	120-239.9	4.041	3.11	0.92	3.87	0.65	1.12	1.32	0.37	0.11	0.90	0.26	0.29	0.06
DAS precedes, straight, adjacent lane right, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	N/A	N/A	N/A	1.51	0.00	N/A	N/A	N/A	N/A	N/A	N/A
	60-119.9	4.041	2.24	0.92	2.09	0.72	2.17	1.32	0.93	0.75	0.86	0.51	0.33	0.08
	120-239.9	4.041	3.64	0.67	**4.33**	0.56	1.76	0.92	1.76	0.67	1.90	1.04	1.61	0.08
DAS precedes, dip series, straight, same lane, DAS 40 mph, ADB 45 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	**31.79**	0.09	**21.05**	15.30	**20.98**	12.10	**27.85**	1.88	14.83	1.27	18.83	1.55
	60-119.9	4.041	**7.49**	10.44	**26.09**	3.91	**18.12**	2.87	**16.27**	3.58	**11.97**	0.00	**15.40**	3.87
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	6.50	5.10	4.50	2.55	14.05	15.59	16.55	21.50	5.73	2.75	**31.03**	1.26
	30-59.9	18.854	9.84	4.48	12.61	1.99	**31.65**	0.07	17.25	20.54	**22.64**	15.84	**31.75**	0.03
	60-119.9	4.041	**6.54**	2.27	**4.08**	0.68	**23.73**	0.87	**16.88**	17.48	**7.74**	3.43	**14.83**	1.49
	120-239.9	4.041	0.66	0.03	0.74	0.10	**4.62**	7.20	0.31	0.25	0.30	0.35	3.20	0.16
Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	N/A	N/A	N/A	N/A	1.71	0.00	N/A	N/A	12.19	17.01	13.09	0.00
	60-119.9	4.041	**4.46**	0.90	**9.75**	6.05	**11.04**	5.67	**7.74**	6.41	**4.32**	3.84	**9.56**	3.22
	120-239.9	4.041	**4.38**	1.03	**4.55**	0.46	1.76	0.29	1.25	0.20	1.48	0.82	2.61	0.66

Table 41 presents receptor head 6 values for average maximum illuminance and standard deviation per same direction, left curve maneuver scenario.

Table 41. Average Maximum Illuminance and Standard Deviation Using Receptor Head 6, ADB Mode - Same Direction, Left Curve Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, Small DAS (n=3)		Audi, SUV DAS (n=2)		BMW, Small DAS (n=3)		BMW, SUV DAS (n=2)		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS (n=3)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DAS precedes, curve left, same lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	2.32	0.05	2.57	0.13	9.39	1.01	**19.14**	17.85	2.55	0.06	3.53	0.55
	30-59.9	18.854	8.74	13.28	**28.11**	0.17	2.77	0.95	**19.78**	16.99	0.85	0.16	1.12	0.05
	60-119.9	4.041	**5.73**	3.51	**7.37**	2.66	**4.48**	3.31	**15.06**	15.72	0.52	0.08	1.88	0.61
	120-239.9	4.041	0.12	0.04	0.14	0.01	0.22	0.02	0.16	0.03	0.11	0.02	0.56	0.08
DAS precedes, curve left, same lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.35	0.08	0.41	0.07	0.46	0.00	0.28	0.00	N/A	N/A	0.51	0.16
	60-119.9	4.041	0.26	0.06	0.45	0.25	0.37	0.08	0.28	0.04	0.30	0.18	0.26	0.02
	120-239.9	4.041	0.68	0.21	1.29	0.06	0.17	0.04	0.13	0.02	0.26	0.02	0.16	0.01
DAS precedes, curve left, adjacent lane left, DAS 0 mph, ADB 62 mph	15-29.9	18.854	3.47	4.77	2.14	2.91	0.62	0.13	0.34	0.01	0.49	0.04	0.73	0.17
	30-59.9	18.854	4.38	5.07	7.21	0.77	0.66	0.10	0.42	0.01	0.50	0.04	0.82	0.10
	60-119.9	4.041	1.85	1.39	2.53	0.08	1.10	0.13	1.48	0.37	0.56	0.04	0.90	0.33
	120-239.9	4.041	0.10	0.01	0.14	0.05	0.12	0.02	0.09	0.05	0.09	0.02	0.30	0.08
DAS precedes, curve left, adjacent lane left, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.13	0.00	0.25	0.08	0.39	0.01	0.37	0.07	0.28	0.04	0.39	0.08
	60-119.9	4.041	1.50	0.18	1.04	0.94	0.25	0.05	0.20	0.03	0.49	0.46	0.23	0.02
	120-239.9	4.041	1.16	0.86	1.65	0.63	0.44	0.10	0.36	0.18	0.52	0.28	0.31	0.20
DAS precedes, curve left, adjacent lane right, DAS 0 mph, ADB 62 mph	15-29.9	18.854	2.21	0.17	1.93	0.02	9.53	1.58	17.36	20.35	2.49	0.07	3.22	0.42
	30-59.9	18.854	**18.99**	11.38	15.92	3.15	1.58	0.10	16.72	21.40	0.89	0.03	1.18	0.07
	60-119.9	4.041	**7.95**	0.68	**7.43**	0.43	**4.59**	0.86	**19.62**	17.14	0.60	0.10	2.15	0.94
	120-239.9	4.041	0.13	0.00	0.13	0.04	0.28	0.04	0.30	0.04	0.14	0.05	0.71	0.10
DAS precedes, curve left, adjacent lane right, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.70	0.39	N/A	N/A	0.56	0.00	0.47	0.00	0.46	0.00	0.45	0.06
	60-119.9	4.041	1.20	1.48	1.93	2.02	0.31	0.02	0.21	0.07	0.20	0.08	0.34	0.03
	120-239.9	4.041	0.57	0.48	0.21	0.00	0.10	0.01	0.09	0.02	0.11	0.03	0.14	0.02

Table 42 presents receptor head 6 values for average maximum illuminance and standard deviation per same direction, right curve maneuver scenario. Some standard deviation values associated with average maximum illuminance values for the Audi and BMW exceeded the average value itself.

Table 42. Average Maximum Illuminance and Standard Deviation Using Receptor Head 6, ADB Mode - Same Direction, Right Curve Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, Small DAS (n=3)		Audi, SUV DAS (n=2)		BMW, Small DAS (n=3)		BMW, SUV DAS (n=2)		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS (n=3)	
			Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
DAS precedes, curve right, same lane, DAS 0 mph, ADB 62 mph	15-29.9	18.854	1.75	0.24	10.45	0.60	5.41	0.71	2.99	0.10	2.01	0.51	3.86	0.46
	30-59.9	18.854	1.93	1.13	9.92	1.12	1.94	0.17	1.27	0.10	0.79	0.23	1.23	0.07
	60-119.9	4.041	1.50	0.33	3.51	0.47	0.26	0.04	1.28	1.55	0.12	0.08	0.25	0.01
	120-239.9	4.041	0.05	0.01	0.05	0.03	0.06	0.00	0.06	0.01	0.03	0.03	0.08	0.02
DAS precedes, curve right, same lane, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.15	0.00	0.42	0.00	0.76	0.00	N/A	N/A	N/A	N/A	0.35	0.00
	60-119.9	4.041	0.70	0.60	0.34	0.24	0.33	0.45	0.13	0.02	0.04	0.03	0.35	0.18
	120-239.9	4.041	0.99	0.32	0.53	0.07	1.37	0.19	1.12	0.08	0.62	0.15	0.41	0.09
DAS precedes, curve right, adjacent lane left, DAS 0 mph, ADB 62 mph	15-29.9	18.854	0.13	0.03	0.10	0.05	0.36	0.04	0.21	0.00	0.17	0.05	0.15	0.01
	30-59.9	18.854	6.56	8.86	0.31	0.02	0.36	0.24	0.35	0.34	0.27	0.10	0.11	0.02
	60-119.9	4.041	1.37	1.51	0.30	0.03	0.60	0.32	0.34	0.21	0.11	0.11	0.07	0.01
	120-239.9	4.041	0.05	0.01	0.05	0.04	0.08	0.04	0.05	0.01	0.03	0.03	0.06	0.01
DAS precedes, curve right, adjacent lane left, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.17	0.14	0.08	0.01	0.26	0.00	0.14	0.03	0.08	0.11	0.20	0.07
	60-119.9	4.041	0.64	0.82	0.24	0.22	0.11	0.04	0.13	0.03	0.15	0.14	0.17	0.07
	120-239.9	4.041	0.63	0.14	0.20	0.10	0.92	0.31	0.18	0.06	0.16	0.16	0.20	0.17
DAS precedes, curve right, adjacent lane right, DAS 0 mph, ADB 62 mph	15-29.9	18.854	2.02	0.30	1.70	0.11	5.71	0.83	2.65	0.19	2.19	0.00	3.55	0.29
	30-59.9	18.854	2.43	1.45	5.38	6.25	2.47	0.18	1.42	0.02	0.99	0.08	1.34	0.09
	60-119.9	4.041	1.22	0.87	1.44	0.90	0.31	0.10	0.23	0.01	0.71	0.25	0.28	0.02
	120-239.9	4.041	0.05	0.01	0.05	0.03	0.06	0.02	0.04	0.01	0.03	0.02	0.06	0.01
DAS precedes, curve right, adjacent lane right, DAS 62 mph, ADB 62 mph	15-29.9	18.854	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	18.854	0.33	0.00	0.40	0.05	0.46	0.04	0.64	0.26	0.28	0.00	0.47	0.26
	60-119.9	4.041	0.91	0.64	0.43	0.24	0.27	0.09	0.50	0.22	0.61	0.37	1.37	0.63
	120-239.9	4.041	0.85	0.18	0.71	0.43	1.07	0.29	1.28	0.33	0.77	0.24	0.22	0.11

Table 43 presents receptor head 6 values for average maximum illuminance and standard deviation per same direction, passing maneuver scenario.

Table 43. Average Maximum Illuminance and Standard Deviation by Receptor Head for ADB Mode - Same Direction, Passing Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, Small DAS (n=3)		Audi, SUV DAS (n=2)		BMW, Small DAS (n=3)		BMW, SUV DAS (n=2)		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS (n=3)	
			Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
DAS follows then passes, straight, same lane, DAS 62 mph, ADB 50 mph	15-29.9	18.854	0.66	0.29	0.80	0.98	2.32	1.84	0.43	0.34	0.99	0.13	0.78	0.11
	30-59.9	18.854	1.10	0.14	1.05	0.41	2.72	1.26	0.88	0.39	1.97	1.27	1.20	0.05
	60-119.9	4.041	N/A	N/A	0.68	0.00	0.78	0.00	0.33	0.00	N/A	N/A	0.34	0.00
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, straight, same lane, DAS 50 mph, ADB 62 mph	15-29.9	18.854	4.66	2.62	1.98	0.00	**21.27**	8.99	5.08	1.65	3.33	0.45	4.01	0.41
	30-59.9	18.854	10.88	3.79	5.62	2.15	2.62	0.63	2.94	2.06	1.00	0.12	1.40	0.03
	60-119.9	4.041	**12.98**	4.49	**8.73**	1.79	**5.43**	1.58	2.04	2.19	2.30	0.18	0.66	0.01
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DAS follows then passes, curve left, same lane, DAS 62 mph, ADB 45 mph	15-29.9	18.854	0.89	0.14	0.75	0.34	8.47	6.70	0.86	0.20	0.67	0.26	0.92	0.43
	30-59.9	18.854	0.80	0.11	0.87	0.16	1.13	0.09	0.87	0.14	0.70	0.13	0.91	0.16
	60-119.9	4.041	0.43	0.00	0.33	0.00	0.40	0.05	0.29	0.04	0.27	0.03	0.30	0.01
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, curve left, same lane, DAS 45 mph, ADB 62 mph	15-29.9	18.854	2.98	0.53	3.46	1.00	7.18	0.67	2.92	0.30	2.32	0.21	3.41	0.34
	30-59.9	18.854	1.18	0.02	1.35	0.18	1.98	0.55	1.41	0.00	0.79	0.06	1.19	0.10
	60-119.9	4.041	0.55	0.22	1.03	0.95	0.31	0.02	0.29	0.05	0.30	0.02	0.35	0.05
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DAS follows then passes, curve right, same lane, DAS 62 mph, ADB 45 mph	15-29.9	18.854	0.99	0.22	0.41	0.17	0.80	0.11	0.54	0.38	0.40	0.06	0.77	0.53
	30-59.9	18.854	0.95	0.15	0.71	0.00	1.05	0.12	0.53	0.16	0.39	0.04	0.85	0.42
	60-119.9	4.041	N/A	N/A	N/A	N/A	0.34	0.00	0.14	0.00	0.12	0.00	0.21	0.00
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, curve right, same lane, DAS 45 mph, ADB 62 mph	15-29.9	18.854	2.06	0.40	2.00	0.22	9.35	4.14	3.04	0.08	1.77	0.46	3.59	0.24
	30-59.9	18.854	4.82	0.81	2.37	1.56	5.47	0.74	2.60	1.93	2.45	1.60	1.68	0.42
	60-119.9	4.041	**5.52**	0.85	3.25	2.50	2.50	0.42	1.97	1.64	1.56	1.32	0.42	0.09
	120-239.9	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.33	0.00	N/A	N/A

7.8 Examination of Number of Trials per Maneuver Scenario That Exceeded Derived Glare Limit Values

In addition to examining whether the average maximum illuminance calculated over multiple trials of a scenario exceeded derived glare limit values, the number of individual trials of a maneuver scenario in which a glare limit was exceeded were tabulated. Table 44 presents these data for oncoming maneuver scenarios and. In a large majority of cases, when a glare limit was exceeded for a particular vehicle and maneuver scenario, an exceedance was seen in more than one trial of that scenario. For two of the four test vehicles, oncoming maneuver scenarios in which a glare limit was exceeded involved at least two of the three trials having an exceedance. The Lexus test vehicle results showed two scenarios involving the Small DAS vehicle in which only one of the three trial repetitions indicated a derived glare limit value exceedance. The Audi results showed one scenario involving the SUV DAS vehicle in which only one of the three trial repetitions indicated a glare limit exceedance.

Table 44. Number of Trials Exceeding Derived Glare Limit Values by Vehicle and Maneuver Scenario, Oncoming

		Audi, Small DAS		**Audi, SUV DAS**		**BMW, Small DAS**		**BMW, SUV DAS**		**Lexus, Small DAS**		**Mercedes-Benz, Small DAS**	
		Lower (n=3)	ADB (n=3)	Lower (n=2)	ADB (n=2)	Lower (n=3)	ADB (n=3)	Lower (n=2)	ADB (n=2)	Lower (n=3)	ADB (n=3)	Lower (n=3)	ADB (n=3)
Straight	Straight, adj. lane, DAS 0 mph, ADB 62 mph	0	0	1	1	3	3	2	2	0	1	0	0
	Straight, adj. lane, DAS 62 mph, ADB 62 mph	3	3	2	2	3	3	2	2	3	2	3	2
	Motorcycle, adj. lane, DAS 0 mph, ADB 62 mph	1	3	2	2	2	3	0	1	1	1	0	0
	Motorcycle, adj. lane, DAS 62 mph, ADB 62 mph	3	3	2	2	3	3	2	2	3	2	3	3
	Dip, adj. lane, DAS 0 mph, ADB 45 mph	3	3	2	2	3	3	2	2	3	3	3	3
Curve	ADB curves Left, adj. lane, DAS 0 mph, ADB 62 mph	3	3	0	2	0	0	0	2	3	3	3	3
	ADB curves Left, adj. lane, DAS 62 mph, ADB 62 mph	3	3	2	2	3	3	2	2	3	3	3	3
	ADB curves Right, adj. lane, DAS 0 mph, ADB 62 mph	3	3	0	2	0	3	0	2	3	3	2	3
	ADB curves Right, adj. lane, DAS 62 mph, ADB 62 mph	3	3	2	2	3	3	2	2	2	3	3	2
	Winding, DAS 0 mph, ADB 45 mph	3	3	2	2	3	3	2	2	3	3	3	3
Intersection	60°, DAS 0 mph, ADB 62 mph	0	3	0	2	0	3	1	2	0	3	0	3
	90°, DAS 0 mph, ADB 62 mph	0	3	0	2	0	3	1	2	1	3	0	3
	120°, DAS 0 mph, ADB 62 mph	0	3	0	2	0	3	1	2	0	3	0	3

Table 45 presents same-direction, straight scenario results for the number of individual trials of a maneuver scenario in which a glare limit was exceeded. For same-direction, straight maneuvers, there were multiple cases in which only one of ‘n’ trials involved a glare limit exceedance. For same-direction straight and passing maneuver scenarios and ADB mode, only the BMW test vehicle had no scenarios involving only one trial having a glare limit exceedance. Fewer cases of single-trial exceedances were seen for passing scenarios than for straight, same-direction scenarios.

Table 45. Number of Trials Exceeding Glare Limits by Vehicle and Maneuver Scenario, Same Direction Straight and Passing

		Audi, Small DAS		Audi, SUV DAS		BMW, Small DAS		BMW, SUV DAS		Lexus, Small DAS		Mercedes-Benz, Small DAS	
		Lower (n=3)	ADB (n=3)	Lower (n=2)	ADB (n=2)	Lower (n=3)	ADB (n=3)	Lower (n=2)	ADB (n=2)	Lower (n=3)	ADB (n=3)	Lower (n=3)	ADB (n=3)
Straight	DAS precedes, same lane, DAS 0 mph, ADB 62 mph	0	0	0	1	3	3	2	0	0	0	0	1
	DAS precedes, same lane, DAS 62 mph, ADB 62 mph	3	1	2	2	0	0	0	0	0	0	0	0
	DAS precedes, adj. lane left, DAS 62 mph, ADB 62 mph	2	1	2	2	0	0	0	0	0	0	0	0
	DAS precedes, adj. lane right, DAS 62 mph, ADB 62 mph	0	1	2	1	3	0	1	0	0	0	0	0
	DAS precedes, dip, same lane, DAS 40 mph, ADB 45 mph	3	3	2	2	3	3	2	2	3	1	3	3
	Motorcycle precedes, adj. lane, DAS 0 mph, ADB 62 mph	0	3	0	2	1	3	0	2	0	3	0	3
	Motorcycle precedes, adj. lane, DAS 62 mph, ADB 62 mph	2	3	1	2	3	3	2	1	2	3	0	3
Passing	DAS follows then passes, straight, same lane, DAS 62 mph, ADB 50 mph	0	3	0	2	0	3	0	2	0	2	0	3
	ADB follows then passes, straight, same lane, DAS 50 mph, ADB 62 mph	2	3	2	2	2	3	1	0	1	0	0	0
	DAS follows then passes, curve left, same lane, DAS 62 mph, ADB 45 mph	0	3	0	2	0	3	0	2	0	2	0	3
	ADB follows then passes, curve left, same lane, DAS 45 mph, ADB 62 mph	0	0	0	0	0	0	0	0	0	0	0	0
	DAS follows then passes, curve right, same lane, DAS 62 mph, ADB 45 mph	0	3	0	2	0	2	0	2	0	1	0	3
	ADB follows then passes, curve right, same lane, DAS 45 mph, ADB 62 mph	2	2	1	1	3	2	2	2	0	0	0	0

Table 46 presents same-direction curve scenario results for the number of individual trials of a maneuver scenario in which a glare limit was exceeded. For same-direction, curve maneuvers, only the BMW test vehicle had scenarios (two) involving only one trial having a glare limit exceedance. Both such trials involved a stationary SUV DAS vehicle.

Table 46. Number of Trials Exceeding Glare Limits by Vehicle and Maneuver Scenario, Same Direction Curve

		Audi, Small DAS		**Audi, SUV DAS**		**BMW, Small DAS**		**BMW, SUV DAS**		**Lexus, Small DAS**		**Mercedes-Benz, Small DAS**	
		Lower (n=3)	ADB (n=3)	Lower (n=2)	ADB (n=2)	Lower (n=3)	ADB (n=3)	Lower (n=2)	ADB (n=2)	Lower (n=3)	ADB (n=3)	Lower (n=3)	ADB (n=3)
Curve	DAS precedes, curve left, same lane, DAS 0 mph, ADB 62 mph	0	2	0	2	0	2	0	1	0	0	0	0
	DAS precedes, curve left, same lane, DAS 62 mph, ADB 62 mph	0	0	0	0	0	0	0	0	0	0	0	0
	DAS precedes, curve left, adj. lane left, DAS 0 mph, ADB 62 mph	0	0	0	0	0	0	0	0	0	0	0	0
	DAS precedes, curve left, adj. lane left, DAS 62 mph, ADB 62 mph	0	0	0	0	0	0	0	0	0	0	0	0
	DAS precedes, curve left, adj. lane right, DAS 0 mph, ADB 62 mph	0	3	0	2	0	2	0	2	0	0	0	0
	DAS precedes, curve left, adj. lane right, DAS 62 mph, ADB 62 mph	0	0	0	0	0	0	0	0	0	0	0	0
	DAS precedes, curve right, same lane, DAS 0 mph, ADB 62 mph	0	0	0	0	0	0	0	1	0	0	0	0
	DAS precedes, curve right, same lane, DAS 62 mph, ADB 62 mph	0	0	0	0	0	0	0	0	0	0	0	0
	DAS precedes, curve right, adj. lane left, DAS 0 mph, ADB 62 mph	0	2	0	2	0	3	0	2	0	0	0	0
	DAS precedes, curve right, adj. lane left, DAS 62 mph, ADB 62 mph	0	0	0	0	0	0	0	0	0	0	0	0
	DAS precedes, curve right, adj. lane right, DAS 0 mph, ADB 62 mph	0	0	0	0	0	0	0	0	0	0	0	0
	DAS precedes, curve right, adj. lane right, DAS 62 mph, ADB 62 mph	0	0	0	0	0	0	0	0	0	0	0	0

7.9 Examination of the Degree of Glare Limit Exceedances and Impact of Increased Glare Limit Values

While the prior subsection examined the number of individual trials of a maneuver scenario in which a glare limit was exceeded, the current section examines how close the measured values were to the relevant glare limit values. Using 5 percent increments added to the actual glare limit values, each scenario's results were examined to see whether increasing the glare limit would have changed an exceeding result to a non-exceeding result. Glare limit values through 25 percent above the actual derived glare limit values were examined. Table 47 summarizes the glare limit values and incrementally increased values used to evaluate the test results. In the table, the actual derived glare limit value is stated as "0% Above Glare Limit."

Table 47. Oncoming Maneuver Glare Limits Derived From FMVSS No. 108 With 5 Percent Increases up to 25 Percent

	Illuminance (lux)					
Range (m)	0% Above Glare Limit	5% Increase in Limit	10% Increase in Limit	15% Increase in Limit	20% Increase in Limit	25% Increase in Limit
15.0 – 29.9	3.109	3.264	3.420	3.575	3.731	3.886
30.0 – 59.9	1.776	1.865	1.954	2.042	2.131	2.220
60.0 – 119.9	0.634	0.666	0.697	0.729	0.761	0.793
120.0 – 239.9	0.281	0.295	0.309	0.323	0.337	0.351

Results of this analysis showed that increasing the derived glare limit value by as much as 25 percent did not typically result in fewer exceeding trials. Since a large majority of vehicle and scenario combinations would not be impacted by increasing glare limit values, only trials that would be impacted are presented in the following tables to minimize redundancy.

Table 48 summarizes oncoming maneuver scenarios for which the outcome in terms of whether or not a glare limit exceedance would be changed with an increase in glare limit value. Shading is used to highlight scenarios where increasing the glare limit value to the value corresponding to the rightmost shaded column would result in the scenario illuminance results falling within the glare limits (i.e., no exceedances). The table shows that 16 permutations of vehicle-DAS vehicle-scenario-headlighting system mode combination outcomes would be changed with an increase in glare limit. However, of those 16, only four cases would result in an outcome changing from an exceedance to one that meets glare limits (i.e., no exceedances out of n trials). Of those four, only one case involves ADB: the Lexus with Small DAS vehicle in a stationary oncoming motorcycle scenario. The amount of increase above the derived glare limit values that would be required to cause the ADB to meet limits for this case is 20 percent.

Table 48. Glare Limit Exceedances by Oncoming Scenario Maneuver for All ADB-Equipped Vehicles, Only Scenarios With Outcome Changes

Vehicle			# of repetitions out of n repetitions, in which 1 or more range-specific glare limits exceeded the noted percentage:											
			0%	5%	10%	15%	20%	25%	0%	5%	10%	15%	20%	25%
ADB	**DAS**	**Maneuver – Oncoming**	**Lower Beam**						**ADB**					
Audi	Small (n=3)	Straight, adj. lane, DAS 62 mph, ADB 62 mph	**3**	**3**	**3**	**3**	**3**	**2**	3	3	3	3	3	3
Audi	Small (n=3)	Motorcycle, straight, adj. lane, DAS 62 mph, ADB 62 mph	**3**	**2**	**2**	**1**	**1**	**1**	3	3	3	3	3	3
Audi	SUV (n=2)	Motorcycle, straight, adj. lane, DAS 0 mph, ADB 62 mph	**2**	**1**	**1**	**0**	**0**	**0**	2	2	2	2	2	2
BMW	Small (n=3)	Straight, adj. lane, DAS 0 mph, ADB 62 mph	**3**	**3**	**2**	**2**	**2**	**1**	**3**	**3**	**3**	**3**	**3**	**2**
BMW	Small (n=3)	ADB curves left, adj. lane, DAS 62 mph, ADB 62 mph	3	3	3	3	3	3	**3**	**3**	**3**	**3**	**3**	**2**
BMW	Small (n=3)	ADB curves right, adj. lane, DAS 0 mph, ADB 62 mph	0	0	0	0	0	0	**3**	**3**	**3**	**3**	**2**	**2**
BMW	SUV (n=2)	Straight, adj. lane, DAS 0 mph, ADB 62 mph	**2**	**2**	**1**	**1**	**1**	**0**	**2**	**2**	**2**	**1**	**1**	**1**
BMW	SUV (n=2)	Straight, adj. lane, DAS 62 mph, ADB 62 mph	2	2	2	2	2	2	**2**	**2**	**2**	**2**	**2**	**1**
BMW	SUV (n=2)	Motorcycle, straight, adj. lane, DAS 0 mph, ADB 62 mph	0	0	0	0	0	0	**1**	**0**	**0**	**0**	**0**	**0**
Lexus	Small (n=3)	Motorcycle, straight, adj. lane, DAS 0 mph, ADB 62 mph	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**0**
Lexus	Small (n=3)	Motorcycle, straight, adj. lane, DAS 62 mph, ADB 62 mph	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**	**2**	**2**	**1**
Mercedes-Benz	Small (n=3)	Straight, adj. lane, DAS 62 mph, ADB 62 mph	3	3	3	3	3	3	**2**	**2**	**1**	**1**	**1**	**1**

For intersection scenarios, the number of test repetitions in which a glare limit was exceeded was also examined. Side-facing receptor heads 8 and 9 were used for this comparison. For these scenarios, shifting the glare limits upward by as much as 25 percent did not result in a net outcome change for any test vehicle and DAS vehicle combination.

The number of test trial repetitions in which a glare limit was exceeded for same-direction maneuvers was also examined. As was done with oncoming maneuvers, comparison glare limit values representing 5 percent step increases through 25 percent above the actual glare limit values were used. Table 48 summarizes the glare limit values and incrementally increased values used to evaluate the test results.

Table 49. Preceding Maneuvers Glare Limits Derived From FMVSS No. 108 With 5 Percent Increases up to 25 Percent

	Illuminance (lux)					
Range (m)	Actual Limit	5% Increase in Limit	10% Increase in Limit	15% Increase in Limit	20% Increase in Limit	25% Increase in Limit
15.0 – 29.9	18.854	19.797	20.739	21.682	22.625	23.568
30.0 – 59.9	18.854	19.797	20.739	21.682	22.625	23.568
60.0 – 119.9	4.041	4.243	4.445	4.647	4.849	5.051
120.0 – 239.9	4.041	4.243	4.445	4.647	4.849	5.051

Table 50 summarizes same-direction maneuver scenarios for which the outcome in terms of whether or not a glare limit exceedance would be changed with an increase in glare limit value. Shading is used to highlight scenarios where increasing the glare limit value to the value corresponding to the rightmost shaded column would result in the scenario illuminance results falling within the glare limits (i.e., no exceedances). The table shows that 32 permutations of vehicle-DAS vehicle-scenario-headlighting system mode combination outcomes would be changed with an increase in glare limit. However, of those 32, only 14 cases would result in an outcome changing from an exceedance to one that meets glare limits (i.e., no exceedances out of ‘n’ trials). Of those 14, only 6 cases involve ADB. Five of those 6 cases involve the Audi: four preceding straight same or adjacent lane scenarios and a DAS vehicle lane change scenario. The amount of increase in glare limit values that would be required to cause the ADB cases to meet glare limits ranged from 10 to 20 percent.

Overall, increases as large as 25 percent above the actual derived glare limit values did not substantially improve ADB test outcomes.

Table 50. Glare Limit Exceedances by Same Direction Scenario Maneuver for All ADB-Equipped Vehicles, Only Scenarios With Outcome Changes

Vehicle			# of repetitions out of n repetitions, in which 1 or more range-specific glare limits exceeded the noted percentage:											
			0%	5%	10%	15%	20%	25%	0%	5%	10%	15%	20%	25%
ADB	DAS	Maneuver – Oncoming	Lower Beam						ADB					
Audi	Small (n=3)	DAS precedes, straight, same lane, DAS 62 mph, ADB 62 mph	3	1	1	0	0	0	1	1	1	0	0	0
Audi	Small (n=3)	DAS precedes, straight, adj. lane left, DAS 62 mph, ADB 62 mph	2	2	1	1	1	1	1	1	0	0	0	0
Audi	Small (n=3)	DAS precedes, straight, adj. lane right, DAS 62 mph, ADB 62 mph	0	0	0	0	0	0	1	1	0	0	0	0
Audi	Small (n=3)	Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	2	1	0	0	0	0	3	3	3	3	3	3
Audi	Small (n=3)	DAS precedes, curve left, same lane, DAS 0 mph, ADB 62 mph	0	0	0	0	0	0	2	1	1	1	1	1
Audi	Small (n=3)	DAS passes, straight, same lane, DAS 62 mph, ADB 50 mph	0	0	0	0	0	0	3	3	3	2	2	2
Audi	Small (n=3)	ADB passes, curve right, same lane, DAS 45 mph, ADB 62 mph	2	2	2	2	2	2	2	2	2	2	2	1
Audi	SUV (n=2)	DAS precedes, straight, same lane, DAS 62 mph, ADB 62 mph	2	2	2	2	2	2	2	2	2	1	1	1
Audi	SUV (n=2)	DAS precedes, straight, adj. lane left, DAS 62 mph, ADB 62 mph	2	1	1	1	1	1	2	2	2	2	1	1
Audi	SUV (n=2)	DAS precedes, straight, adj. lane right, DAS 62 mph, ADB 62 mph	2	1	0	0	0	0	1	1	1	1	0	0
Audi	SUV (n=2)	Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	0	0	0	0	0	0	2	2	2	1	1	1
Audi	SUV (n=2)	Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	1	1	1	0	0	0	2	2	2	2	2	2
Audi	SUV (n=2)	DAS passes, curve left, same lane, DAS 62 mph, ADB 45 mph	0	0	0	0	0	0	2	1	1	1	0	0
BMW	Small (n=3)	DAS precedes, straight, same lane, DAS 0 mph, ADB 62 mph	3	3	3	3	2	1	3	3	3	3	3	3
BMW	Small (n=3)	DAS precedes, straight, adj. lane right, DAS 62 mph, ADB 62 mph	3	2	2	2	1	1	0	0	0	0	0	0
BMW	Small (n=3)	Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	1	0	0	0	0	0	3	3	3	3	3	3
BMW	Small (n=3)	DAS precedes, curve left, adjacent lane right, DAS 0 mph, ADB 62 mph	0	0	0	0	0	0	2	1	1	1	1	1
BMW	Small (n=3)	ADB passes, straight, same lane, DAS 50 mph, ADB 62 mph	2	2	2	2	2	2	3	3	2	2	2	2
BMW	SUV (n=2)	DAS precedes, straight, same lane, DAS 0 mph, ADB 62 mph	2	2	2	1	1	1	0	0	0	0	0	0
BMW	SUV (n=2)	DAS precedes, straight, adjacent lane right, DAS 62 mph, ADB 62	1	1	1	0	0	0	0	0	0	0	0	0
BMW	SUV (n=2)	Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	0	0	0	0	0	0	2	2	2	1	1	1
BMW	SUV (n=2)	ADB passes, straight, same lane, DAS 50 mph, ADB 62 mph	1	0	0	0	0	0	0	0	0	0	0	0
Lexus	Small (n=3)	DAS precedes, dip series, straight, same lane, DAS 40 mph, ADB 45	3	3	3	3	2	2	1	1	1	1	1	1
Lexus	Small (n=3)	Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	2	2	1	1	1	0	3	3	3	3	3	3
Lexus	Small (n=3)	DAS passes, straight, same lane, DAS 62 mph, ADB 50 mph	0	0	0	0	0	0	2	2	2	2	1	1
Lexus	Small (n=3)	ADB passes, straight, same lane, DAS 50 mph, ADB 62 mph	1	1	1	0	0	0	0	0	0	0	0	0
Lexus	Small (n=3)	DAS passes, curve left, same lane, DAS 62 mph, ADB 45 mph	0	0	0	0	0	0	2	1	1	1	0	0
Mercedes-Benz	Small (n=3)	DAS passes, curve right, same lane, DAS 62 mph, ADB 45 mph	0	0	0	0	0	0	3	3	2	2	2	2

8.0 TEST REPEATABILITY

In the second phase of testing, all maneuvers were run with vehicles positioned in specific locations of dynamic maneuver starting points. Therefore, each individual maneuver was run in the same roadway location, promoting road elevation and pavement condition consistency across trials. Despite this, some factors exist that may have contributed to test variability.

- Ambient illumination (e.g., moon phase and cloud effects)
- Ambient temperature
- Vehicle pitch changes caused by acceleration
- Variations in lane position of the vehicles during test trials
- Headlamp auto-leveling precision (lamp-based or suspension-based leveling)

Additional factors that can contribute to test repeatability but were controlled for in this testing

- Road surface irregularities
  - Well-maintained proving ground road surfaces were used. Surfaces were smooth and without bumps, creases, or potholes.
- Road elevation changes
  - Test courses used for level roadway maneuver scenarios had only minimal elevation angle to facilitate drainage. The test course used for the left and right curve maneuvers had a consistent 11-degree banking angle.
- Variations in road reflectance
  - Well-maintained proving ground road surfaces were used. The test course used for oncoming and same-direction maneuver scenarios was composed of brushed concrete having negligible reflectance. Intersection, dip series, and curve maneuvers were conducted on courses having asphalt surfaces. Conducting each maneuver on the same section of the same test course helped to ensure that pavement conditions were consistent across repeated trials.
- Headlamp cleanliness
  - Headlamp lenses were cleaned before beginning each test session.

Each maneuver scenario's ability to elicit similar test results across trial repetitions was assessed. Similarity of test results was assess based on the variability in measured illuminance values between trials of individual maneuvers and the consistency of maneuver scenario outcome by individual trial.

8.1 Trial Repeatability Based on Pooled Standard Deviation

The repeatability of measured illuminance values was examined for each distance range (i.e., 15-29.9 m, 30 - 59.9 m, etc.) of each maneuver scenario using pooled standard deviation. The pooled variance is defined by

$$s_p^2 = \frac{\sum_{i=1}^{k}(n_i - 1)s_i^2}{\sum_{i=1}^{k}(n_i - 1)}$$

The pooled standard deviation is the square root of this. The pooled variance is a *weighted mean* of the variances of the individual groups, the groups in this case being the six different test vehicle/DAS vehicle combinations. This ignores differences in the mean values for the different groups and compares only the variability within the groups. Standard deviations calculated by comparing all of the values to the overall mean are larger because that calculation includes variability between the groups. The *pooled standard deviation* method of measuring repeatability measures how well the values from one repetition to another of the same maneuver compare to each other for any test vehicle, even if the means for the different test vehicles are different.

In this analysis, any negative illuminance values (most likely stemming from problems with receptor head calibration) were retained.

8.1.1 Lower Beam Trial Repeatability

Tables 51 and 52 show statistics for each lower beam trial separately, collapsed over all ADB test vehicle/DAS vehicle combinations. Trials with the smallest pooled standard deviations for a particular distance range can be considered to be the most repeatable.

Table 51. Lower Beam Oncoming Trials' Average and Pooled Standard Deviation of Maximum Illuminance by Scenario and Distance Range

			15 to 29.9 m			30 to 59.9 m			60 to 119.9 m			120 to 240 m		
Maneuver Type	**Maneuver Category**	**Description**	**n**	**Overall Mean**	**Pooled Std. Dev.**	**n**	**Overall Mean**	**Pooled Std. Dev.**	**n**	**Overall Mean**	**Pooled Std. Dev.**	**n**	**Overall Mean**	**Pooled Std. Dev.**
ONCOMING	Straight	Adj. lane, DAS 62 mph, ADB 62 mph	16	1.97	0.43	16	1.08	0.36	16	0.32	0.30	16	0.09	0.26
		Adj. lane, DAS 0 mph, ADB 62 mph	16	1.94	0.30	16	1.15	0.48	16	0.37	0.09	15	0.17	0.05
		Motorcycle, adj., lane, Motorcycle/DAS 0 mph, ADB 62 mph	14	1.08	0.10	15	0.80	0.14	15	0.52	0.07	15	0.23	0.08
		Motorcycle, adj., lane, Motorcycle/DAS 62 mph, ADB 62 mph	16	1.08	0.16	16	0.89	0.22	16	0.52	0.14	16	0.15	0.08
		Dip series, adj. lane, DAS 0 mph, ADB 45 mph	16	3.25	1.29	16	29.57	0.41	16	1.74	3.22	15	4.82	0.18
	Curve Left	ADB curves Left, adj. lane, DAS 0 mph, ADB 62 mph	16	1.99	0.25	16	1.00	0.05	16	0.40	0.02	16	0.27	0.02
		ADB curves Left, adj. lane, DAS 62 mph, ADB 62 mph	16	1.90	0.22	16	0.98	0.07	16	0.42	0.03	16	0.29	0.05
	Curve Right	ADB curves Right, adj. lane, DAS 0 mph, ADB 62 mph	15	1.82	0.17	15	1.12	0.18	15	0.47	0.14	15	0.30	0.14
		ADB curves Right, adj. lane, DAS 62 mph, ADB 62 mph	16	1.95	0.21	16	1.06	0.12	16	0.42	0.11	16	0.25	0.11
	Winding	Winding	16	2.25	0.44	16	1.44	0.37	16	5.31	0.51	16	0.95	0.10

Table 52. Lower Beam Same Direction Trials' Average and Pooled Standard Deviation of Maximum Illuminance by Scenario and Distance Range

			15 to 29.9 m			30 to 59.9 m			60 to 119.9 m			120 to 240 m		
Maneuver Type	**Maneuver Category**	**Description**	**n**	**Overall Mean**	**Pooled Std. Dev.**	**n**	**Overall Mean**	**Pooled Std. Dev.**	**n**	**Overall Mean**	**Pooled Std. Dev.**	**n**	**Overall Mean**	**Pooled Std. Dev.**
SAME DIRECTION	Straight	DAS precedes, dip, same lane, DAS 40 mph, ADB 45 mph	n/a	n/a	n/a	16	25.60	10.41	14	19.42	2.99	n/a	n/a	n/a
		DAS precedes, straight, same lane, DAS 0 mph, ADB 62 mph	16	6.07	1.12	16	3.95	0.72	16	2.79	0.55	16	0.30	0.30
		DAS precedes, straight, same lane, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	2	0.55	n/a	16	0.89	0.60	16	1.82	0.43
		DAS precedes, straight, adj. lane Right, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	n/a	n/a	n/a	16	2.71	0.62	15	2.36	0.66
		DAS precedes, straight, adj. lane Left, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	2	0.27	n/a	16	0.84	1.01	16	1.40	0.63
	Curve Left	DAS precedes, curve Left, same lane, DAS 0 mph, ADB 62 mph	16	2.53	0.23	16	1.17	0.10	16	0.23	0.01	16	0.06	0.02
		DAS precedes, curve Left, adj. lane Right, DAS 0 mph, ADB 62 mph	16	2.22	0.21	16	1.31	0.10	16	0.24	0.02	16	0.06	0.01
		DAS precedes, curve Left, adj. lane Left, DAS 0 mph, ADB 62 mph	16	0.46	0.12	16	0.51	0.08	16	0.17	0.02	16	0.06	0.02
		DAS precedes, curve Left, adj. lane Right, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	12	0.42	0.16	16	0.27	0.08	15	0.20	0.15
		DAS precedes, curve Left, adj. lane Left, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	11	0.28	0.07	16	0.38	0.53	16	0.68	0.27
		DAS precedes, curve Left, same lane, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	11	0.37	0.09	16	0.29	0.22	16	0.50	0.09
	Curve Right	DAS precedes, curve Right, same lane, DAS 0 mph, ADB 62 mph	16	2.92	0.25	16	1.00	0.05	16	0.16	0.03	16	0.04	0.03
		DAS precedes, curve Right, adj. lane Right, DAS 0 mph, ADB 62 mph	16	2.88	0.32	16	1.21	0.14	16	0.19	0.03	16	0.04	0.03
		DAS precedes, curve Right, adj. lane Left, DAS 0 mph, ADB 62 mph	15	0.17	0.05	15	0.11	0.05	15	0.05	0.04	16	0.05	0.04
		DAS precedes, curve Right, adj. lane Right, DAS 62 mph, ADB 62 mph	1	1.24	n/a	8	0.41	0.07	16	0.50	0.38	16	0.79	0.38
		DAS precedes, curve Right, adj. lane Left, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	4	0.05	n/a	16	0.18	0.22	15	0.41	0.29
		DAS precedes, curve Right, same lane, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	4	0.27	0.01	16	0.26	0.29	16	0.78	0.27

Table 53 highlights maneuver variability tendencies by listing the maneuver scenarios in sorted order according to maximum pooled standard deviation values across all four scenario distance ranges. Same-direction and oncoming curve scenarios tended to have the smallest maximum pooled standard deviation values across all four distance ranges. Also, maneuvers involving the DAS vehicle being stationary tended to have smaller pooled standard deviations. This was especially true for curve maneuver scenarios in which the DAS vehicle was stationary, likely due to the short period of time in which the test vehicle's heading was in the direction of the DAS vehicle. Standard deviation values may be reduced with improved consistency of lane position in maneuver scenarios. Consistency improvements may be achieved through the use of additional lane markings or narrower course lanes.

Table 53. Select Lower Beam Maneuver Scenarios Sorted by Increasing Maximum Pooled Standard Deviation of Maximum Illuminance Values Across the Four Distance Ranges

Maneuver Type	Maneuver Category	Description	Min	Max
SAME DIRECTION	Curve right	DAS precedes, adj. lane Left, DAS 0 mph, ADB 62 mph	0.04	0.05
SAME DIRECTION	Curve left	DAS precedes, adj. lane Left, DAS 0 mph, ADB 62 mph	0.02	0.12
SAME DIRECTION	Curve left	DAS precedes, adj. lane Right, DAS 62 mph, ADB 62 mph	0.08	0.16
ONCOMING	Curve Right	ADB curves Right, adj. lane, DAS 0 mph, ADB 62 mph	0.14	0.18
ONCOMING	Curve Right	ADB curves Right, adj. lane, DAS 62 mph, ADB 62 mph	0.11	0.21
SAME DIRECTION	Curve left	DAS precedes, adj. lane Right, DAS 0 mph, ADB 62 mph	0.01	0.21
ONCOMING	Curve left	ADB curves Left, adj. lane, DAS 62 mph, ADB 62 mph	0.03	0.22
SAME DIRECTION	Curve left	DAS precedes, same lane, DAS 62 mph, ADB 62 mph	0.09	0.22
SAME DIRECTION	Curve left	DAS precedes, same lane, DAS 0 mph, ADB 62 mph	0.01	0.23
ONCOMING	Curve left	ADB curves Left, adj. lane, DAS 0 mph, ADB 62 mph	0.02	0.25
SAME DIRECTION	Curve right	DAS precedes, same lane, DAS 0 mph, ADB 62 mph	0.03	0.25
SAME DIRECTION	Curve right	DAS precedes, same lane, DAS 62 mph, ADB 62 mph	0.01	0.29
SAME DIRECTION	Curve right	DAS precedes, adj. lane Left, DAS 62 mph, ADB 62 mph	0.22	0.29
SAME DIRECTION	Curve right	DAS precedes, adj. lane Right, DAS 0 mph, ADB 62 mph	0.03	0.32
SAME DIRECTION	Curve right	DAS precedes, adj. lane Right, DAS 62 mph, ADB 62 mph	0.07	0.38
ONCOMING	Straight	Adj. lane, DAS 62 mph, ADB 62 mph	0.26	0.43
ONCOMING	Straight	Adj. lane, DAS 0 mph, ADB 62 mph	0.05	0.48
ONCOMING	Winding	Winding	0.10	0.51
SAME DIRECTION	Curve left	DAS precedes, adj. lane Left, DAS 62 mph, ADB 62 mph	0.07	0.53
SAME DIRECTION	Straight	DAS precedes, same lane, DAS 62 mph, ADB 62 mph	0.43	0.60
SAME DIRECTION	Straight	DAS precedes, adj. lane Right, DAS 62 mph, ADB 62 mph	0.62	0.66
SAME DIRECTION	Straight	DAS precedes, adj. lane Left, DAS 62 mph, ADB 62 mph	0.63	1.01
SAME DIRECTION	Straight	DAS precedes, same lane, DAS 0 mph, ADB 62 mph	0.30	1.12

8.1.2 ADB Trial Repeatability

Results for oncoming ADB trials are presented in Table 54 and for same-direction ADB trials in Table 55. Trials with the smallest pooled standard deviations for a particular distance range can be considered to be the most repeatable.

ge and Pooled Standard Deviation of Maximum Illuminance by Scenario and Distance Range, Oncoming
Scenarios

	15 to 29.9 m			30 to 59.9 m			60 to 119.9 m			120 to 240 m		
Description	n	Overall Mean	Pooled Std. Dev.	n	Overall Mean	Pooled Std. Dev.	n	Overall Mean	Pooled Std. Dev.	n	Overall Mean	Pooled Std. Dev.
AS 0 mph, ADB 62 mph	16	2.17	0.30	16	1.18	0.43	16	0.38	0.34	16	0.15	0.33
AS 62 mph, ADB 62 mph	16	2.29	0.52	16	1.17	0.32	16	0.34	0.28	15	0.10	0.29
s Left, adj. lane, DAS 0 mph, h	16	2.12	0.25	16	1.39	0.10	16	1.19	0.18	16	0.33	0.05
s Left, adj. lane, DAS 62 mph, h	16	2.02	0.22	16	1.51	0.14	16	1.83	0.23	16	0.34	0.05
s Right, adj. lane, DAS 0 mph, h	16	2.07	0.16	16	4.91	0.15	16	3.74	0.43	16	0.42	0.17
s Right, adj. lane, DAS 62 62 mph	15	4.12	6.90	15	5.38	10.51	15	3.78	1.36	15	0.33	0.13
j. lane, DAS 0 mph, ADB 62	15	1.33	0.25	15	2.23	1.28	16	1.15	1.16	16	0.22	0.09
j. lane, DAS 62 mph, ADB 62	16	1.32	0.28	16	2.14	0.66	16	1.25	0.90	15	0.17	0.08
AS 0 mph, ADB 45 mph	16	3.67	1.44	16	29.55	0.75	16	0.97	0.54	16	4.81	0.31
0 mph, ADB 62 mph	16	0.68	0.31	16	4.67	2.51	16	5.05	1.91	15	3.16	1.21
mph, ADB 62 mph	16	1.53	0.51	16	5.43	0.45	16	5.77	0.43	16	4.07	0.26
mph, ADB 62 mph	16	1.31	0.35	16	4.32	1.21	16	5.34	0.55	16	3.68	0.42
AS 0 mph, ADB 45 mph	15	2.52	0.81	15	1.86	0.45	16	8.85	3.61	15	3.09	0.94

Table 55. ADB Average and Pooled Standard Deviation of Maximum Illuminance by Scenario and Distance Range, Same-Direction Maneuver Scenarios

Same-Direction Maneuvers		**15 to 29.9 m**			**30 to 59.9 m**			**60 to 119.9 m**			**120 to 240 m**		
Maneuver Category	**Description**	**n**	**Overall Mean**	**Pooled Std. Dev.**	**n**	**Overall Mean**	**Pooled Std. Dev.**	**n**	**Overall Mean**	**Pooled Std. Dev.**	**n**	**Overall Mean**	**Pooled Std. Dev.**
Straight	DAS precedes, same lane, DAS 0 mph, ADB 62 mph	16	10.60	6.64	16	3.60	6.87	16	2.24	4.59	16	1.09	1.46
	DAS precedes, same lane, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	2	0.93	n/a	16	1.05	0.91	16	2.01	0.69
	DAS precedes, adj. lane Left, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	5	0.35	0.08	16	1.32	0.84	16	1.55	0.76
	DAS precedes, adj. lane Right, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	1	1.51	n/a	16	1.43	0.82	16	2.43	0.74
Curve Left	DAS precedes, curve Left, same lane, DAS 0 mph, ADB 62 mph	16	6.05	5.67	16	8.51	8.02	16	5.17	5.49	16	0.23	0.04
	DAS precedes, curve Left, adj. lane Left, DAS 0 mph, ADB 62 mph	16	1.30	2.33	16	2.15	2.28	16	1.33	0.65	16	0.14	0.04
	DAS precedes, curve Left, adj. lane Right, DAS 0 mph, ADB 62 mph	16	5.68	6.48	16	8.32	8.53	16	6.25	5.46	16	0.29	0.06
	DAS precedes, curve Left, same lane, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	8	0.41	0.11	16	0.31	0.12	16	0.42	0.10
	DAS precedes, curve Left, adj. lane Left, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	11	0.32	0.06	16	0.62	0.37	16	0.71	0.47
	DAS precedes, curve Left, adj. lane Right, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	9	0.54	0.28	16	0.65	0.92	15	0.21	0.23
Curve Right	DAS precedes, curve Right, same lane, DAS 0 mph, ADB 62 mph	16	4.12	0.50	16	2.50	0.63	16	1.00	0.53	16	0.05	0.04
	DAS precedes, curve Right, adj. lane Left, DAS 0 mph, ADB 62 mph	15	0.19	0.04	15	1.11	2.96	15	0.42	0.53	15	0.05	0.04
	DAS precedes, curve Right, adj. lane Right, DAS 0 mph, ADB 62 mph	16	3.07	0.42	16	2.20	2.08	16	0.68	0.50	16	0.04	0.03
	DAS precedes, curve Right, same lane, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	4	0.42	n/a	16	0.32	0.35	16	0.84	0.18
	DAS precedes, curve Right, adj. lane Left, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	12	0.15	0.09	16	0.25	0.38	16	0.40	0.20
	DAS precedes, curve Right, adj. lane Right, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	10	0.45	0.18	16	0.71	0.45	16	0.79	0.26
Motorcycle	Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	16	13.38	10.12	16	21.71	9.84	16	12.53	5.88	16	1.78	3.23
	Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	n/a	n/a	n/a	5	10.27	17.01	16	7.69	4.40	16	2.64	0.69
Dip series	DAS precedes, same Lane, DAS 40 mph, ADB 45 mph	n/a	n/a	n/a	16	22.32	7.34	13	16.33	5.12	n/a	n/a	n/a
Passing, Active	ADB follows then passes, straight, same lane, DAS 50 mph, ADB 62 mph	16	7.12	4.23	16	4.05	1.96	15	5.67	2.44	n/a	n/a	n/a
	ADB follows then passes, curve Left, same lane, DAS 45 mph, ADB 62 mph	16	3.78	0.54	16	1.31	0.26	15	0.45	0.33	n/a	n/a	n/a
	ADB follows then passes, curve Right, same lane, DAS 45 mph, ADB 62 mph	16	3.77	1.87	16	3.33	1.19	14	2.38	1.21	1	0.33	n/a
Passing, passive	DAS follows then passes, straight, same lane, DAS 62 mph, ADB 50 mph	16	1.05	0.90	14	1.55	0.80	4	0.53	n/a	n/a	n/a	n/a
	DAS follows then passes, curve Left, same lane, DAS 62 mph, ADB 45 mph	16	2.26	3.01	16	0.88	0.13	13	0.33	0.03	n/a	n/a	n/a
	DAS follows then passes, curve Right, same lane, DAS 62 mph, ADB 45 mph	16	0.67	0.29	14	0.75	0.24	4	0.20	n/a	n/a	n/a	n/a

Table 56 contains both oncoming and same-direction ADB trials sorted by the maximum pooled standard deviation values from across the four distance ranges. No clear order is apparent for ADB trials with increasing maximum pooled standard deviation.

Table 56. Select ADB Maneuver Scenarios Sorted by Increasing Maximum Pooled Standard Deviation of Maximum Illuminance Values Across the Four Distance Ranges

Maneuver Type	Maneuver Category	Description	Min	Max
SAME DIR.	Curve Left	DAS precedes, same lane, DAS 62 mph, ADB 62 mph	0.10	0.12
ONCOMING	Curve Left	ADB curves Left, adj. lane, DAS 62 mph, ADB 62 mph	0.05	0.23
ONCOMING	Curve Left	ADB curves Left, adj. lane, DAS 0 mph, ADB 62 mph	0.05	0.25
SAME DIR.	Passing, passive	DAS follows then passes, curve Right, same lane, DAS 62 mph, ADB 45 mph	0.24	0.29
SAME DIR.	Curve Right	DAS precedes, same lane, DAS 62 mph, ADB 62 mph	0.18	0.35
SAME DIR.	Curve Right	DAS precedes, adj. lane Left, DAS 62 mph, ADB 62 mph	0.09	0.38
ONCOMING	Straight	Adj. lane, DAS 0 mph, ADB 62 mph	0.30	0.43
ONCOMING	Curve Right	ADB curves Right, adj. lane, DAS 0 mph, ADB 62 mph	0.15	0.43
SAME DIR.	Curve Right	DAS precedes, adj. lane Right, DAS 62 mph, ADB 62 mph	0.18	0.45
SAME DIR.	Curve Left	DAS precedes, adj. lane Left, DAS 62 mph, ADB 62 mph	0.06	0.47
ONCOMING	Intersection	90º, DAS 0 mph, ADB 62 mph	0.26	0.51
ONCOMING	Straight	Adj. lane, DAS 62 mph, ADB 62 mph	0.28	0.52
SAME DIR.	Passing, Active	ADB follows then passes, curve Left, same lane, DAS 45 mph, ADB 62 mph	0.26	0.54
SAME DIR.	Curve Right	DAS precedes, same lane, DAS 0 mph, ADB 62 mph	0.04	0.63
SAME DIR.	Straight	DAS precedes, adj. lane Right, DAS 62 mph, ADB 62 mph	0.74	0.82
SAME DIR.	Straight	DAS precedes, adj. lane Left, DAS 62 mph, ADB 62 mph	0.08	0.84
SAME DIR.	Passing, passive	DAS follows then passes, straight, same lane, DAS 62 mph, ADB 50 mph	0.80	0.90
ONCOMING	Motorcycle	Straight, adj. lane, DAS 62 mph, ADB 62 mph	0.08	0.90
SAME DIR.	Straight	DAS precedes, same lane, DAS 62 mph, ADB 62 mph	0.69	0.91
SAME DIR.	Curve Left	DAS precedes, adj. lane Right, DAS 62 mph, ADB 62 mph	0.23	0.92
ONCOMING	Intersection	60º, DAS 0 mph, ADB 62 mph	0.35	1.21
ONCOMING	Motorcycle	Straight, adj. lane, DAS 0 mph, ADB 62 mph	0.09	1.28
ONCOMING	Dip Series	Adj. lane, DAS 0 mph, ADB 45 mph	0.31	1.44
SAME DIR.	Passing, Active	ADB follows then passes, curve Right, same lane, DAS 45 mph, ADB 62 mph	1.19	1.87
SAME DIR.	Curve Right	DAS precedes, adj. lane Right, DAS 0 mph, ADB 62 mph	0.03	2.08
SAME DIR.	Curve Left	DAS precedes, adj. lane Left, DAS 0 mph, ADB 62 mph	0.04	2.33
ONCOMING	Intersection	120º, DAS 0 mph, ADB 62 mph	0.31	2.51
SAME DIR.	Curve Right	DAS precedes, adj. lane Left, DAS 0 mph, ADB 62 mph	0.04	2.96
SAME DIR.	Passing, passive	DAS follows then passes, curve Left, same lane, DAS 62 mph, ADB 45 mph	0.03	3.01
ONCOMING	Winding	Winding, DAS 0 mph, ADB 45 mph	0.45	3.61
SAME DIR.	Passing, Active	ADB follows then passes, straight, same lane, DAS 50 mph, ADB 62 mph	1.96	4.23
SAME DIR.	Straight	DAS precedes, same lane, DAS 0 mph, ADB 62 mph	1.46	6.87
SAME DIR.	Dip series	DAS precedes, same Lane, DAS 40 mph, ADB 45 mph	5.12	7.34
SAME DIR.	Curve Left	DAS precedes, same lane, DAS 0 mph, ADB 62 mph	0.04	8.02
SAME DIR.	Curve Left	DAS precedes, adj. lane Right, DAS 0 mph, ADB 62 mph	0.06	8.53
SAME DIR.	Motorcycle	Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	3.23	10.12
ONCOMING	Curve Right	ADB curves Right, adj. lane, DAS 62 mph, ADB 62 mph	0.13	10.51
SAME DIR.	Motorcycle	Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	0.69	17.01

8.2 Plot Analysis of Trial Repeatability for Lower Beam and ADB

Visually examining data plots is another way to assess trial repeatability.

Figures 60 through 62 illustrate oncoming, straight maneuver scenarios involving the DAS vehicle stationary, DAS vehicle driving at 62 mph (99.8 kph), and motorcycle moving at 62 mph (99.8 kph), respectively.

In Figure 60 where the DAS vehicle is stationary, both lower beam and ADB trial repetitions look fairly consistent. The only really noticeable difference is seen in the lower beam and ADB trials for the Audi with Small DAS vehicle, in which one of the three trials (repetition #2) has a slightly different pattern than the other two trials for that condition.

In Figure 61 where the DAS vehicle is driving at 62 mph (99.8 kph), trials involving the Audi with small DAS vehicle show some variability and ADB also seems to produce more glare than did lower beam in all three trials. Also in Figure 60, the Audi with Small DAS vehicle again shows the ADB response in the second repetition to be substantially different from the other two repetitions. The reason for the very different ADB responses seen in the second set of Audi trials in Figure 60 and 61 could be due to malfunction of the illuminance meter. Those data are being examined further to see if a cause may be identified.

In Figure 62 that depicts the oncoming, straight maneuver scenario with the motorcycle driving at 62 mph (99.8 kph), all trials for all conditions look fairly similar, but the ADB plots for the Audi trials show that glare was not well controlled to lower beam levels.

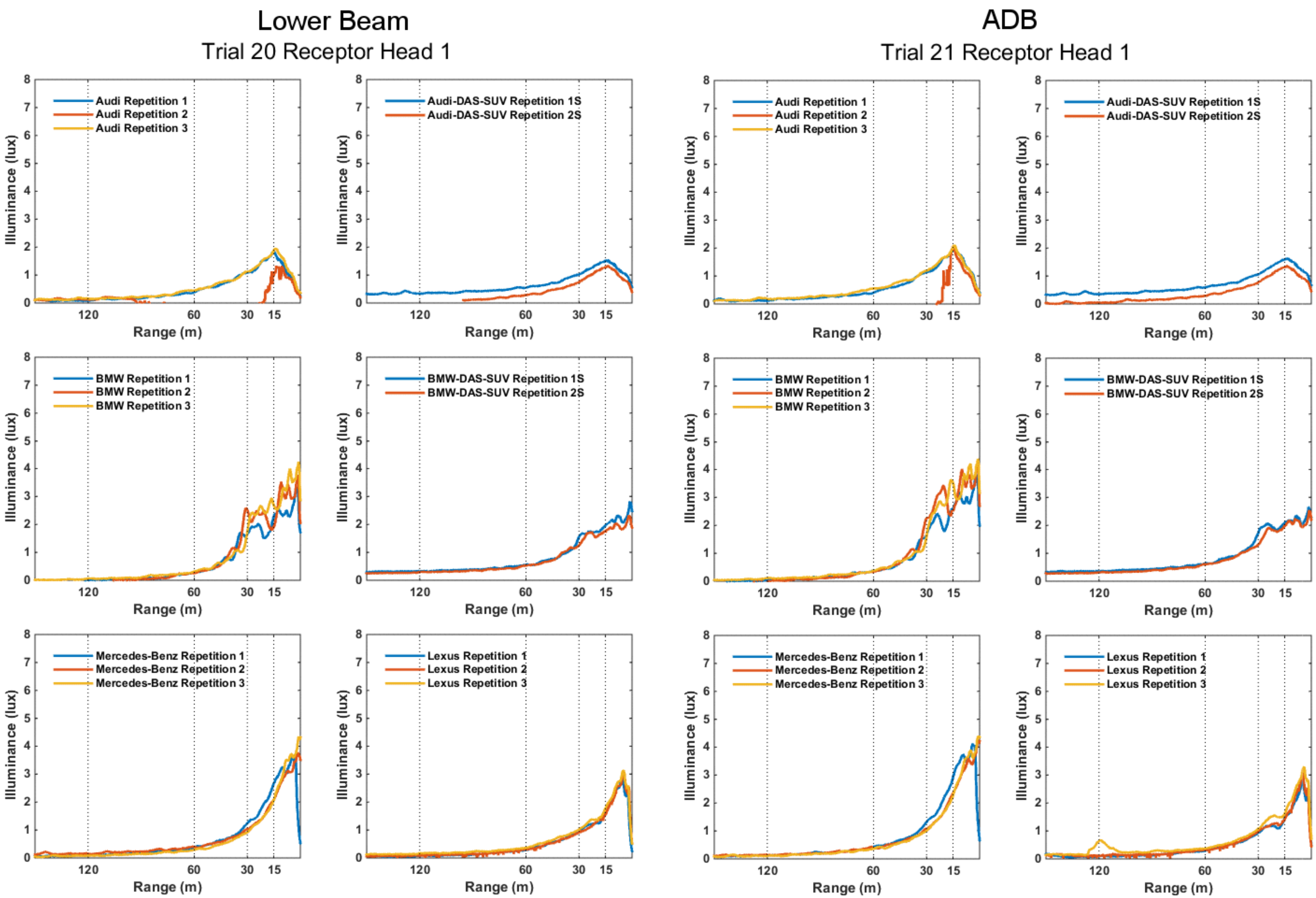

Figure 60. Lower Beam and ADB Illuminance Versus Distance for Oncoming Straight Maneuver Scenario With DAS Vehicle Stationary

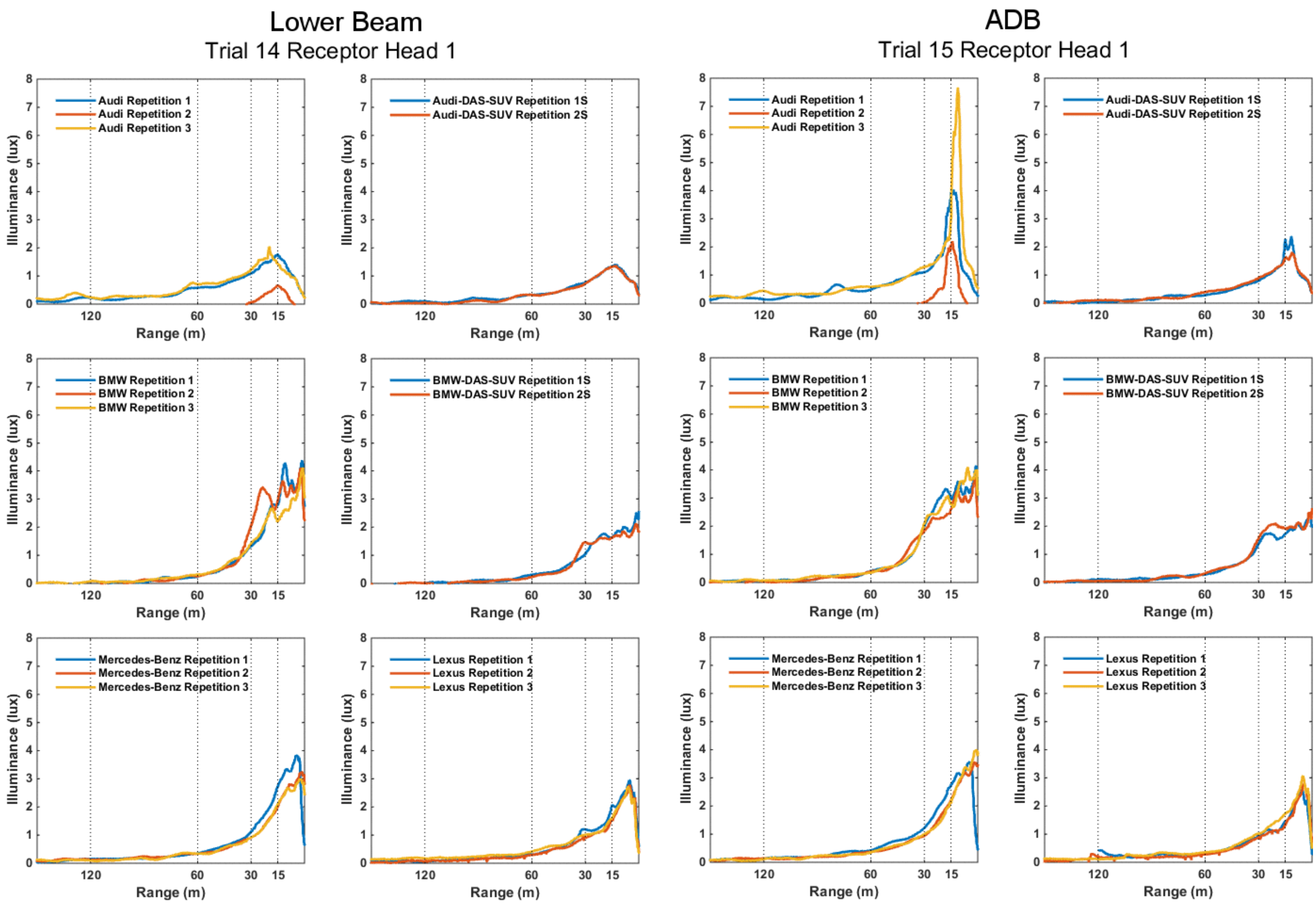

Figure 61. Lower Beam and ADB Illuminance Versus Distance for Oncoming Straight Maneuver Scenario With DAS Vehicle Driving 62 mph (99.8 kph)

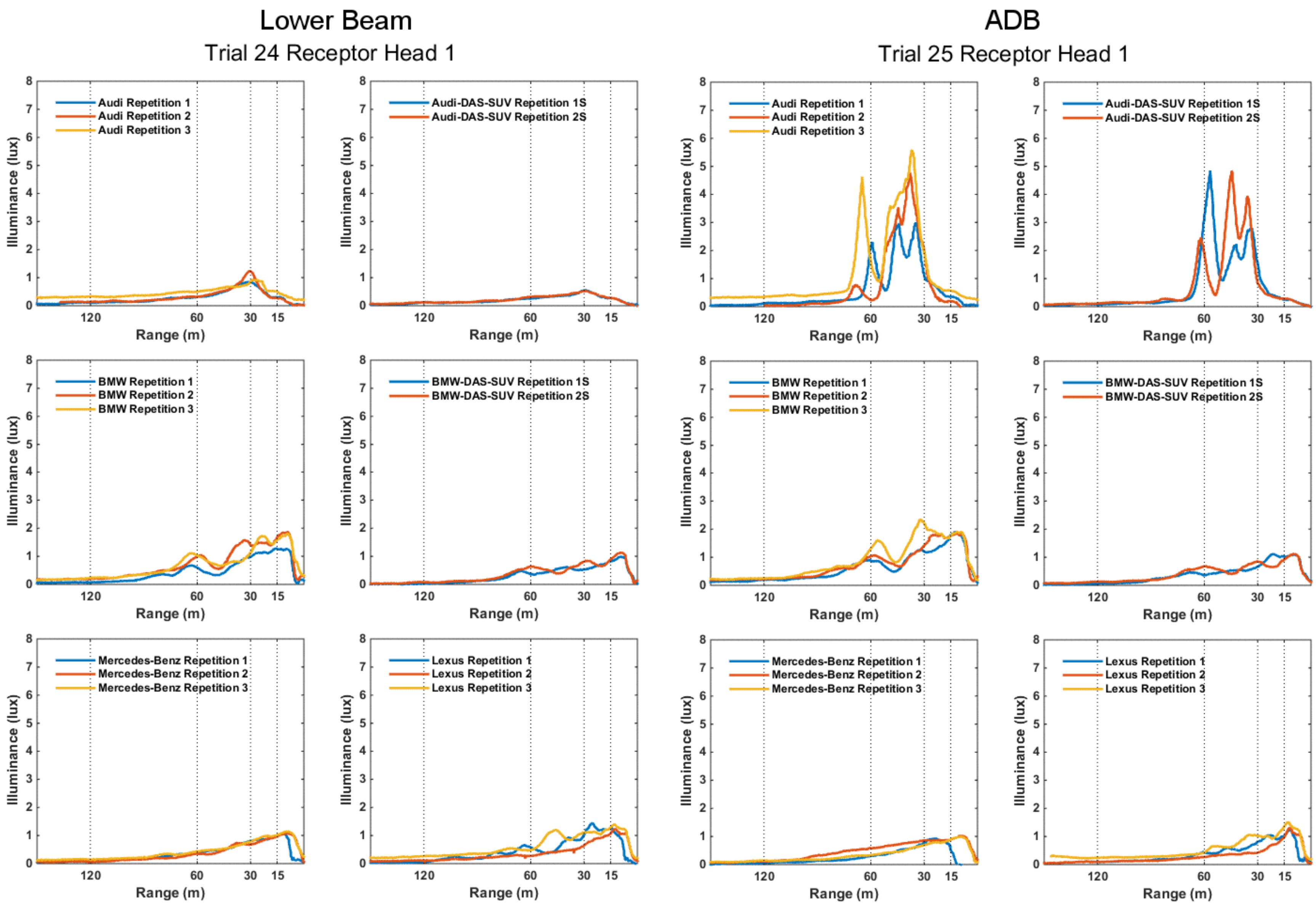

Figure 62. Lower Beam and ADB Illuminance Versus Distance for Oncoming Straight Maneuver Scenario With Motorcycle Driving 62 mph (99.8 kph)

Figures 63 through 65 illustrate oncoming, intersection scenarios involving straight, two-lane roads at angles of 60, 90, and 120 degrees, and the DAS vehicle stationary in each as if stopped at a traffic control device.

Range used in these intersection scenario plots was a calculated resultant range from receptor head 8 of the appropriate DAS vehicle to the nose of the ADB-equipped vehicle. As noted in Section 7.7 of this report, ADB illuminance for all four test vehicles exceeded derived lower beam glare limit values in all intersection scenarios. Figure 63, which depicts the 120-degree intersection, shows consistent lower beam illuminance patterns across all trials but shows variability in ADB responses in all except the Lexus and BMW with SUV DAS vehicle trials. In particular, the ADB response in the second repetition for the Audi with Small DAS vehicle looks very much like lower beam data. It is possible that an error occurred during testing that produced this result (e.g., the driver may have failed to properly enable the ADB system).

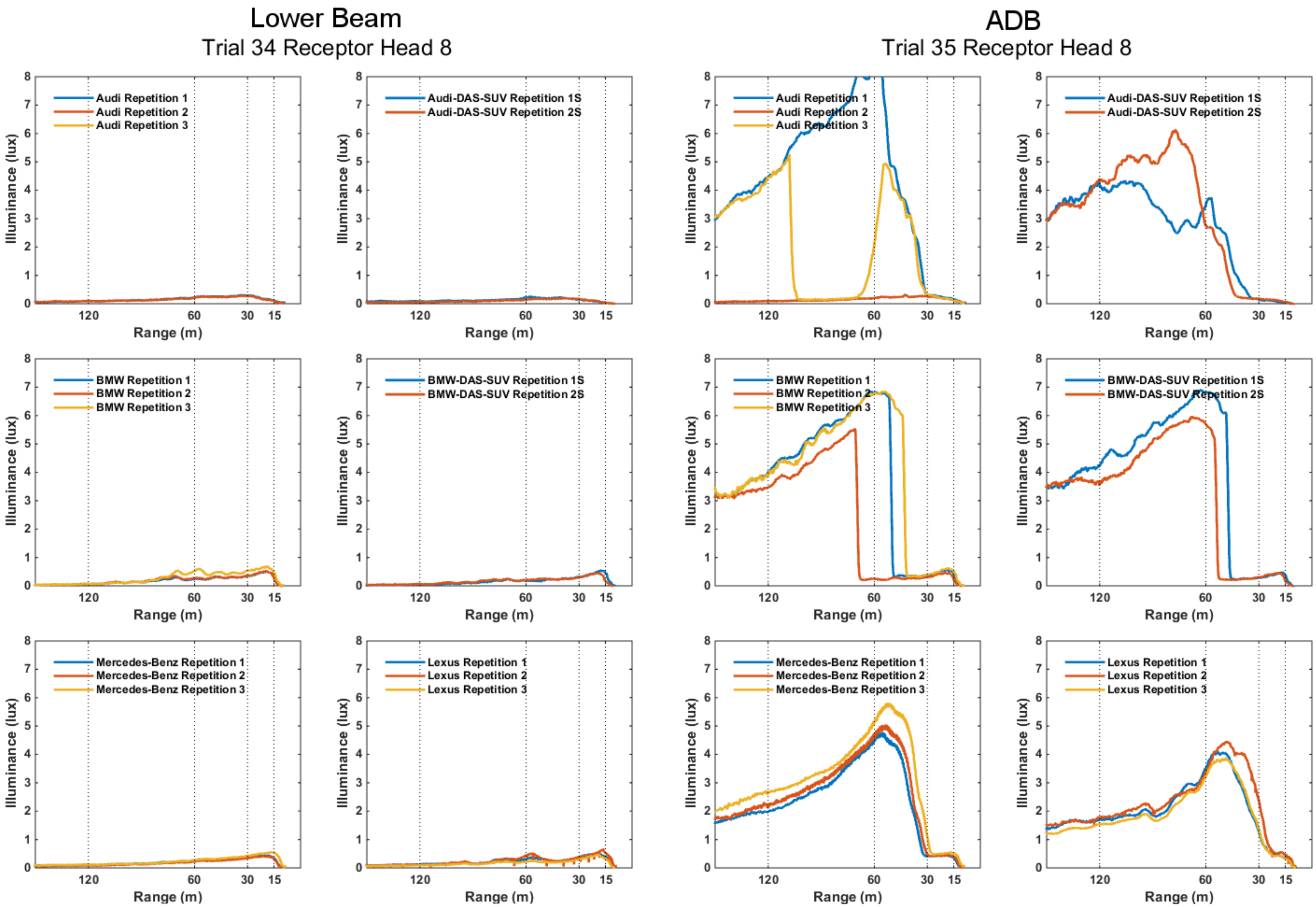

Figure 63. Lower Beam and ADB Illuminance Versus Distance for Oncoming 120° Intersection Maneuver Scenario With DAS Vehicle 0 mph, ADB Vehicle 62 mph (99.8 kph)

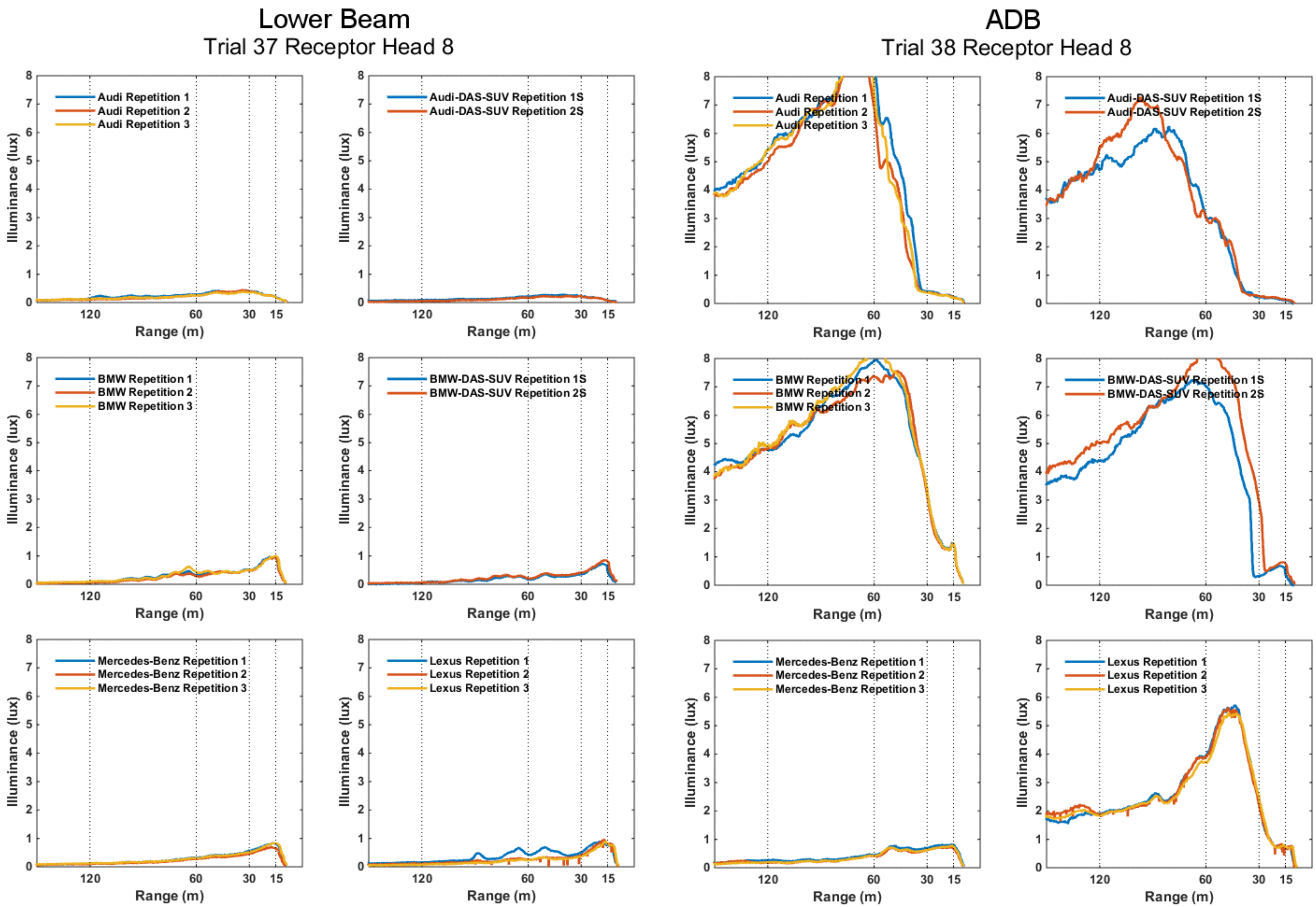

Figure 64. Lower Beam and ADB Illuminance Versus Distance for Oncoming 90º Intersection Maneuver Scenario With DAS Vehicle 0 mph, ADB Vehicle 62 mph (99.8 kph)

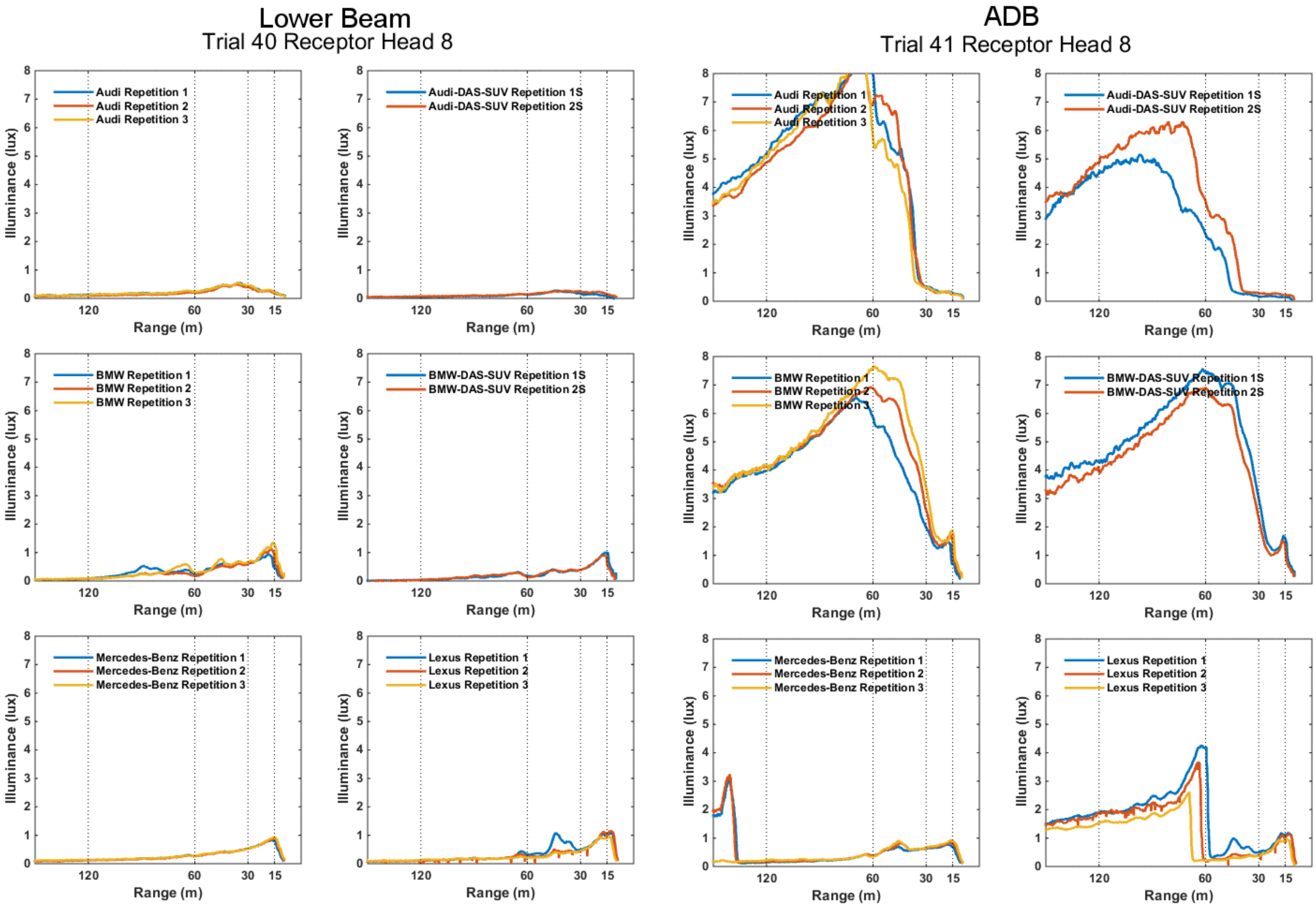

Figure 65. Lower Beam and ADB Illuminance Versus Distance for Oncoming 60º Intersection Maneuver Scenario With DAS Vehicle 0 mph, ADB Vehicle 62 mph (99.8 kph)

Figures 66 and 67 depict oncoming curve scenario trials in which the DAS vehicle was driving at 62 mph (99.8 kph). Left curve scenario results in Figure 66 show good consistency of data across trial repetitions. Some variability in ADB system response in the right curve scenario can be seen in Figure 67, in all conditions except the Audi with SUV DAS vehicle. All vehicles, however, exceeded a derived lower beam glare limit value in both scenarios depicted in these figures.

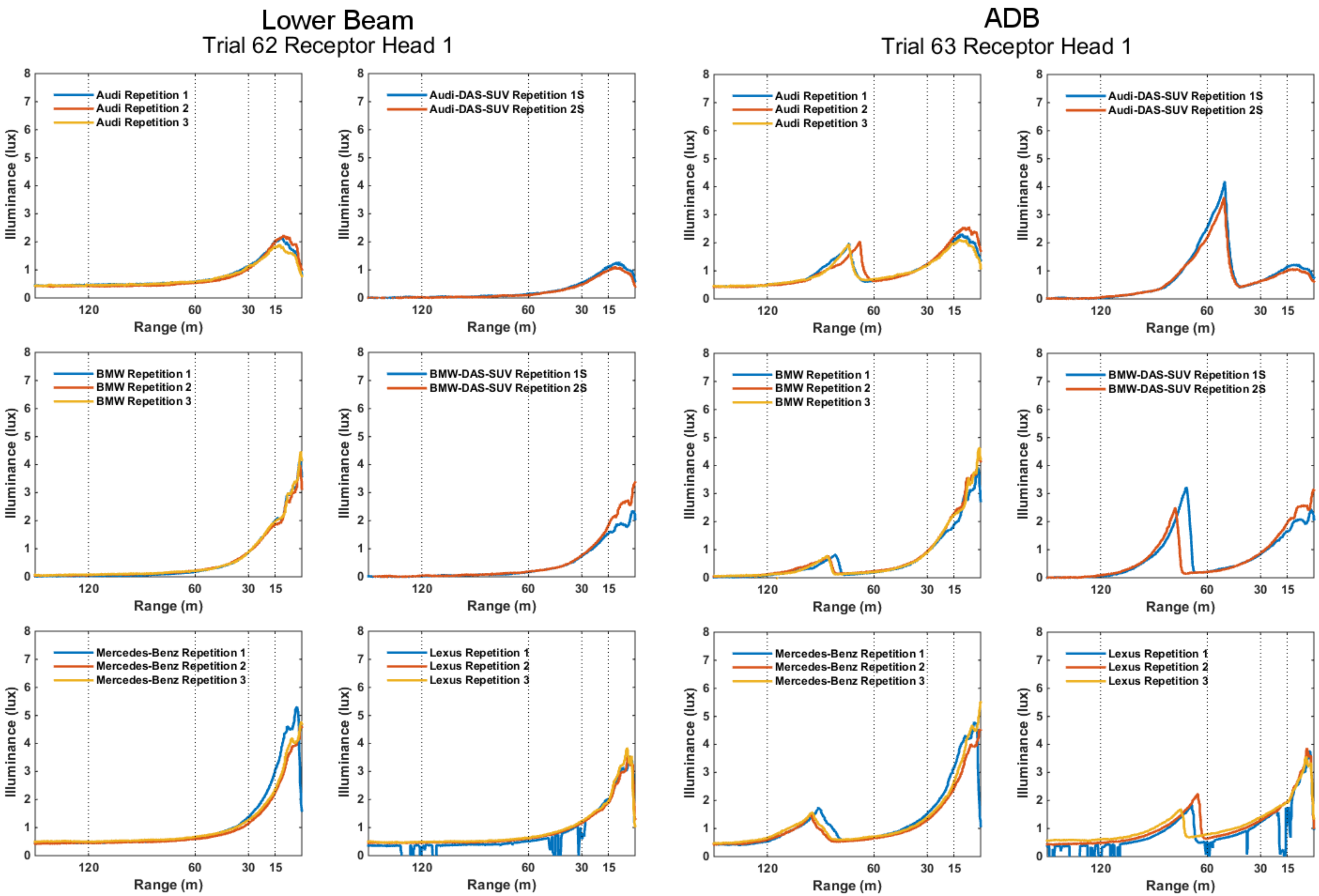

Figure 66. Lower Beam and ADB Illuminance Versus Distance for Oncoming Curve Left Scenario With DAS and ADB Vehicles Driving 62 mph (99.8 kph)

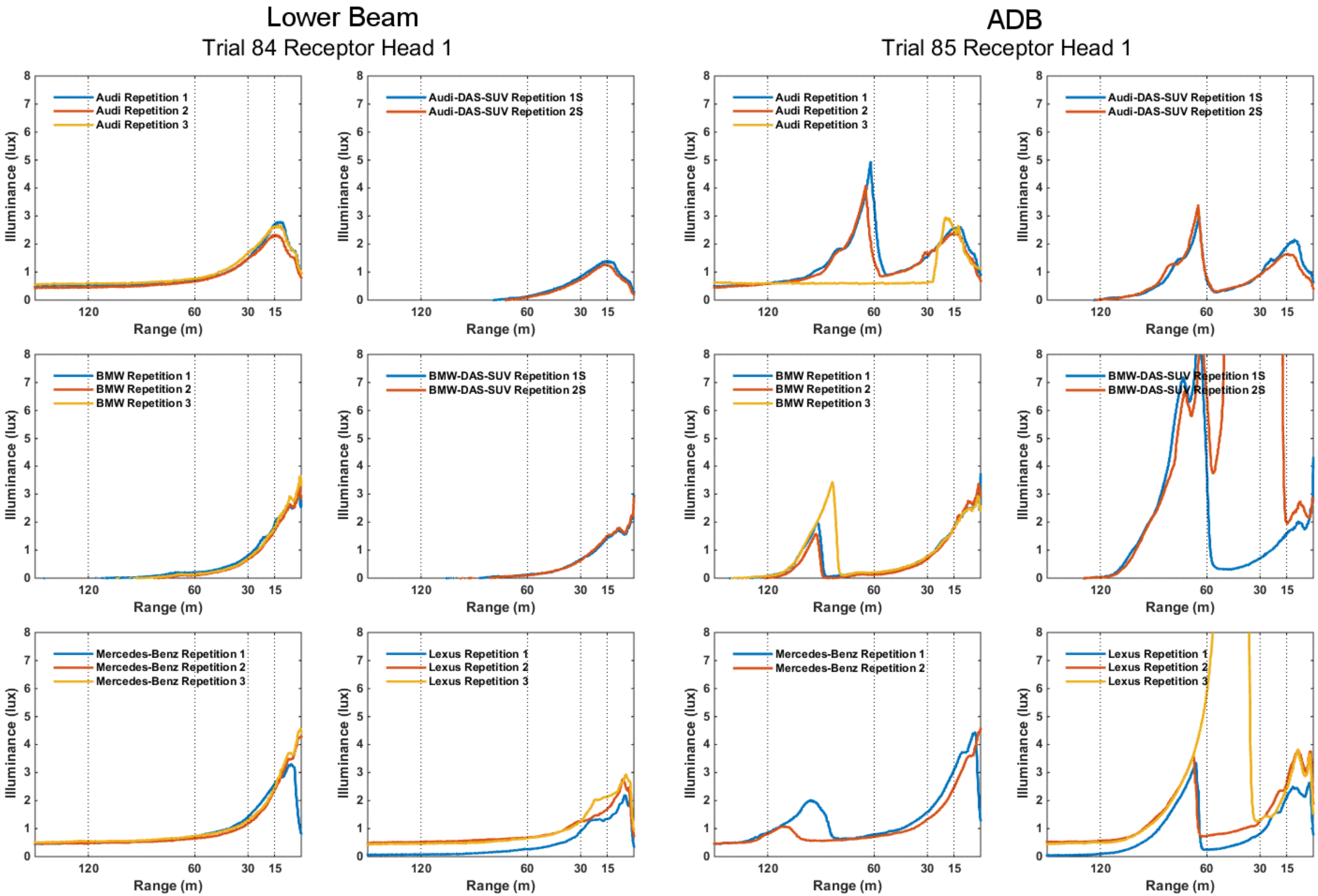

Figure 67. Lower Beam and ADB Illuminance Versus Distance for Oncoming Curve Right Scenario With DAS and ADB Vehicles Driving 62 mph (99.8 kph)

Figures 68 through 70 depict selected same-direction maneuver scenario trials. Same-direction trials are plotted with a different axis scheme than was used with oncoming scenarios, since the distance between the DAS and ADB-equipped vehicles in same-direction maneuvers only changed by 20 to 40 m. The specific trial instructions used stated: "Range start 120 m and close in to <=100m." The x-axis measure in these plots is time. Horizontal offset of plot traces in these figures does not indicate poor trial repeatability.

Figure 68 illustrates same-direction straight roadway scenario in which the motorcycle traveling at 62 mph (99.8 kph) and preceded by the stationary DAS vehicle in the same lane. The lower beam plots show reasonable consistency of illuminance value magnitudes, but ADB plots show some response variability and glare limit-exceeding illuminance values. Data for the same-direction left curve scenario with stationary DAS vehicle depicted in Figure 69 show consistency of illuminance value magnitudes for lower beam trials. ADB trial results show some variability in Figure 68, particularly for the Audi and BMW. Figure 70 illustrates the left curve scenario in which the DAS vehicle passes the ADB vehicle and shows general response consistency, but shows momentary high glare for the BMW in the SUV DAS vehicle condition.

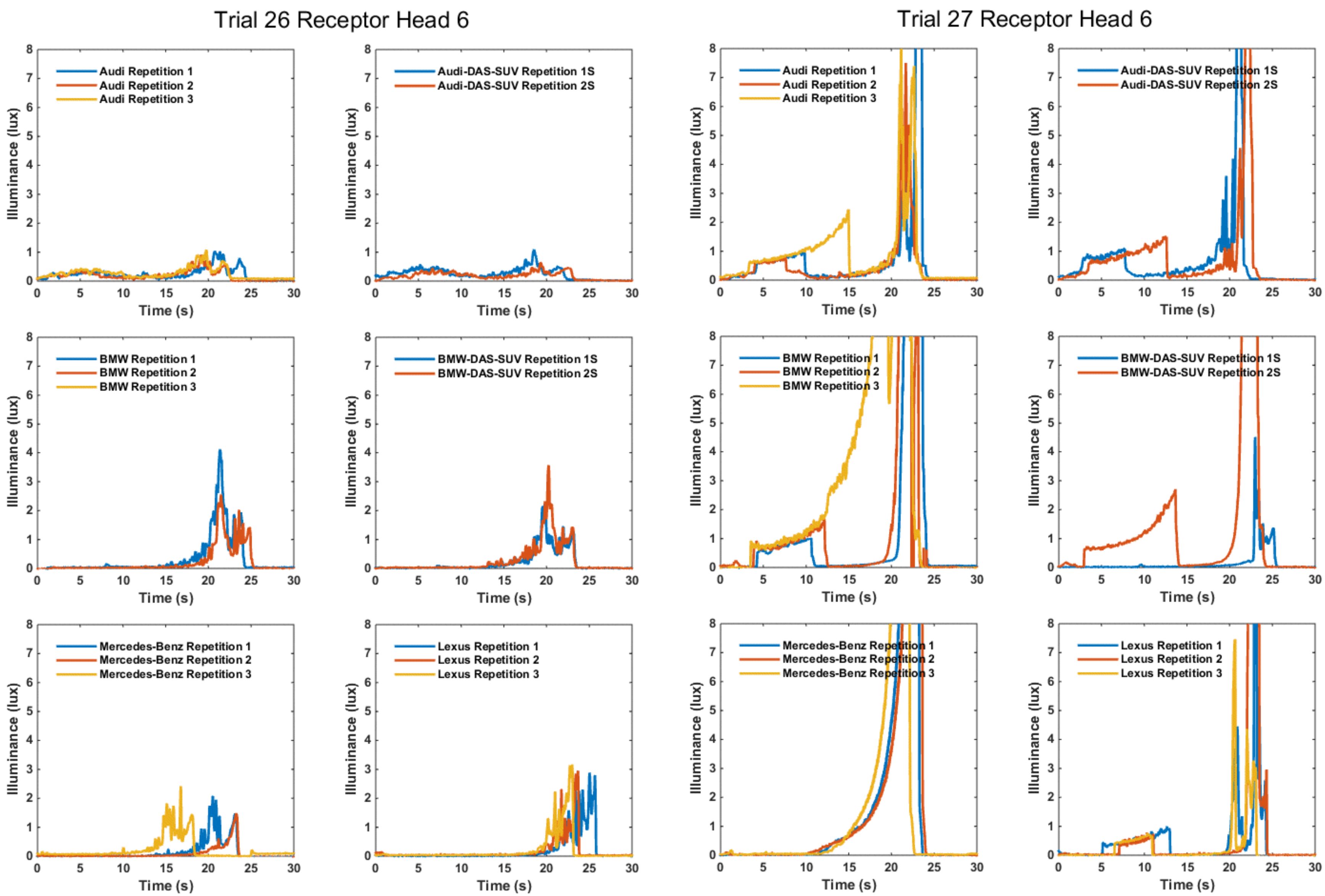

Figure 68. Lower Beam and ADB Illuminance Versus Distance for Same-Direction Straight Scenario With Motorcycle/DAS Vehicle 0 mph, ADB Vehicle 62 mph (99.8 kph)

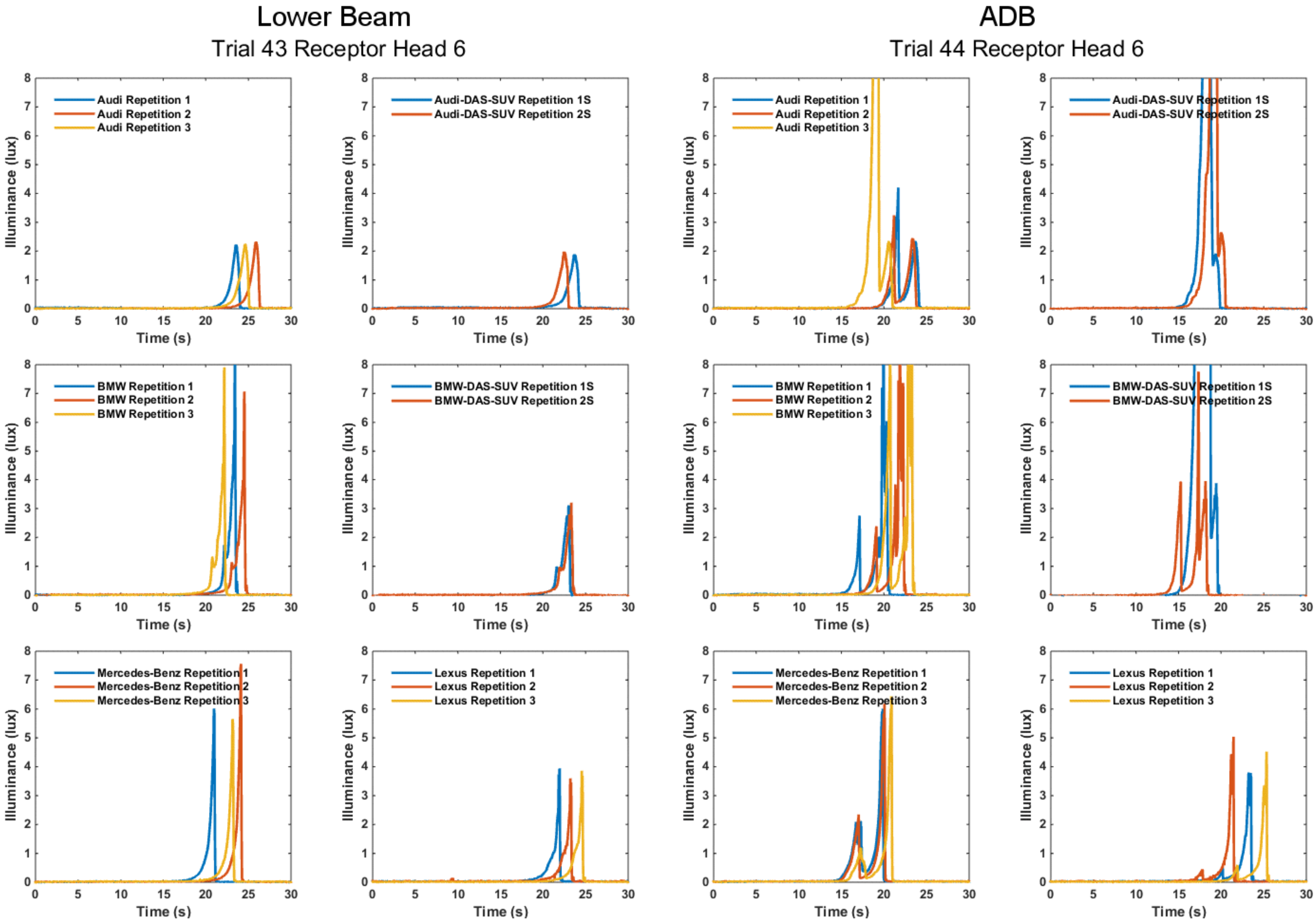

Figure 69. Lower Beam and ADB Illuminance Versus Distance for Same-Direction Curve Left Scenario DAS Vehicle 0 mph, ADB Vehicle 62 mph (99.8 kph)

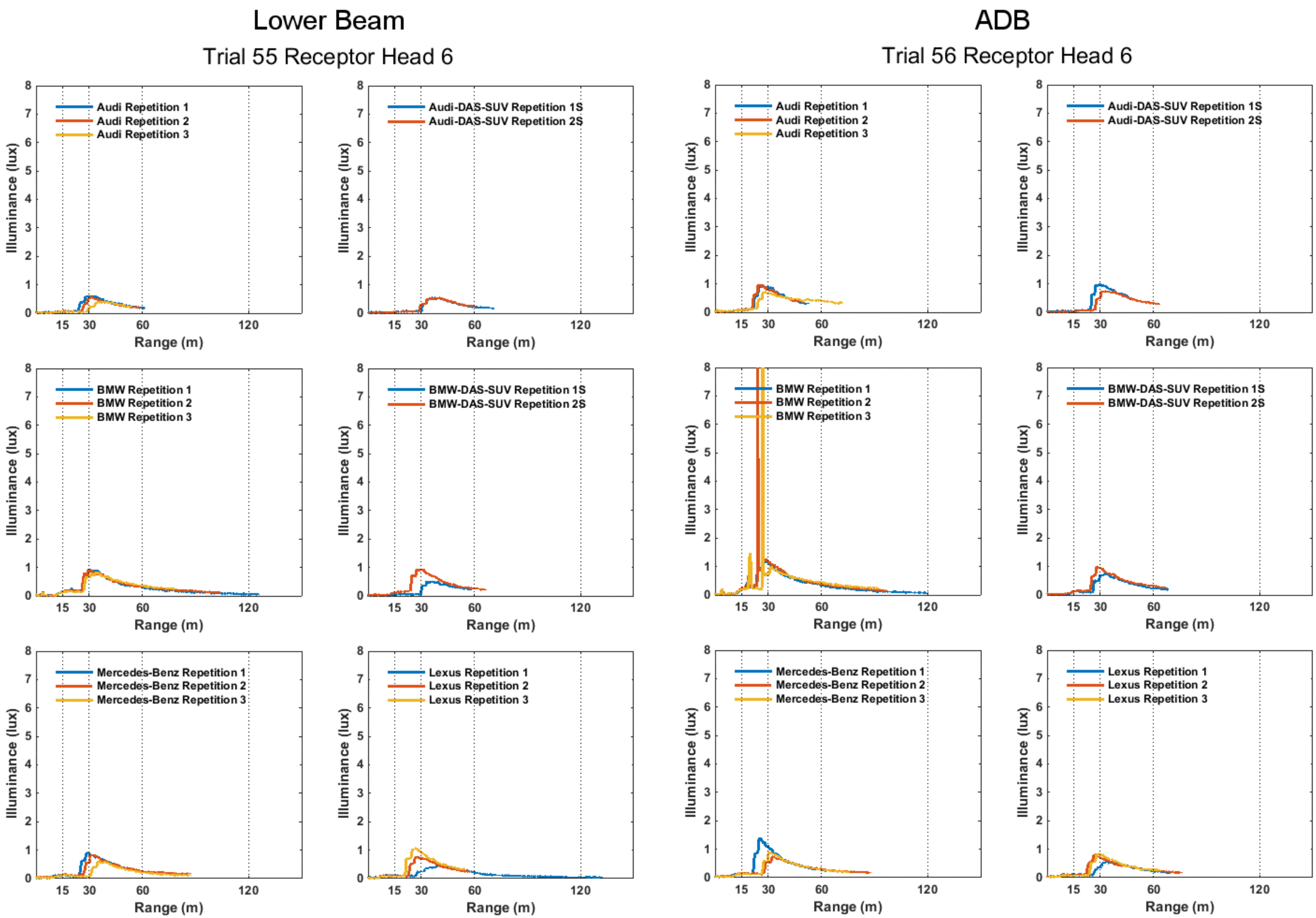

Figure 70. Lower Beam and ADB Illuminance Versus Distance for Same-Direction Curve Left Passive Passing (DAS Vehicle at 62 mph (99.8 kph) Passes ADB Vehicle at 45 mph (72.4 kph)) Scenario

9.0 ADDITIONAL TEST PROCEDURE EFFECT RESULTS

9.1 DAS Vehicle Size Effects

Figure 71 illustrates a direct comparison of the Small (plots in left column of Figure 71) and SUV (plots in right column) DAS vehicles without other confounding factors. The scenario represented is that of an oncoming, stationary motorcycle in which the DAS vehicles' headlighting system was off, leaving the motorcycle's headlighting system as the only stimulus for ADB systems. As a result, the only differences between trials were the mounting locations of the illuminance receptor heads, which were dependent on the vehicle's height and width, and the DAS vehicles' headlight beam patterns. Figure 71 presents the same comparison and similar scenario, except that the motorcycle was being driven at 62 mph (99.8 kph), along with the adjacent DAS vehicle.

Trials involving the Audi with stationary, oncoming motorcycle shown in Figure 71 appear to be similar for both DAS vehicle sizes. All other trials depicted in Figures 71 and 72 show some variability in measured illuminance for both lower beam and ADB. Lower beam trial data for same-direction (preceding) motorcycle scenario trials showed similar variability in most cases. Possible contributors to these differences include the DAS vehicles' dimensions (e.g., vehicle height and width) and any inconsistency in ADB vehicle acceleration rate across test trials (which may have caused differing vehicle pitch behavior and therefore changes in the beam center height).

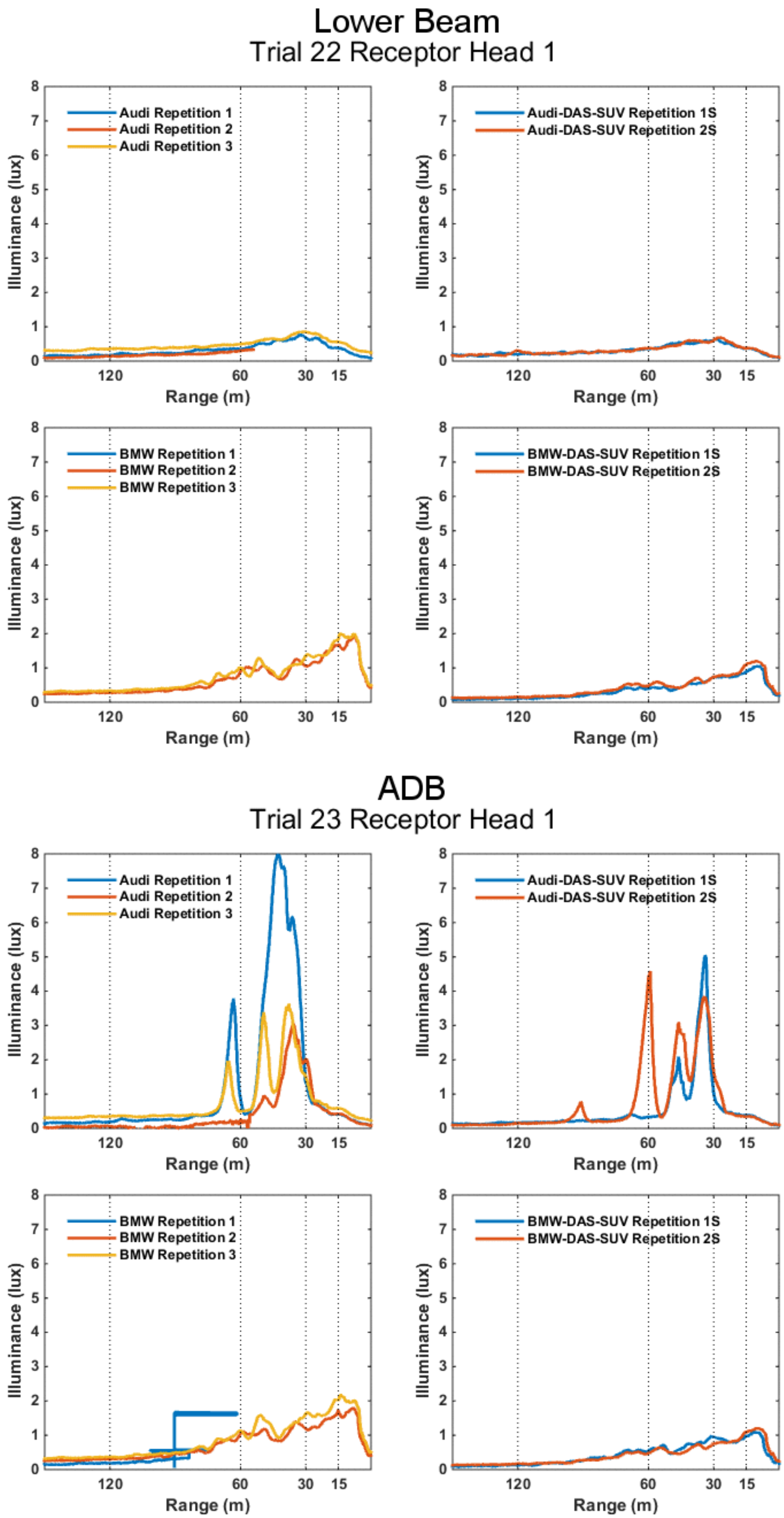

Figure 71. DAS Vehicle Size Effect Comparison Using Oncoming Motorcycle Scenario (DAS/Motorcycle 0 mph, ADB 62 mph (99.8 kph))

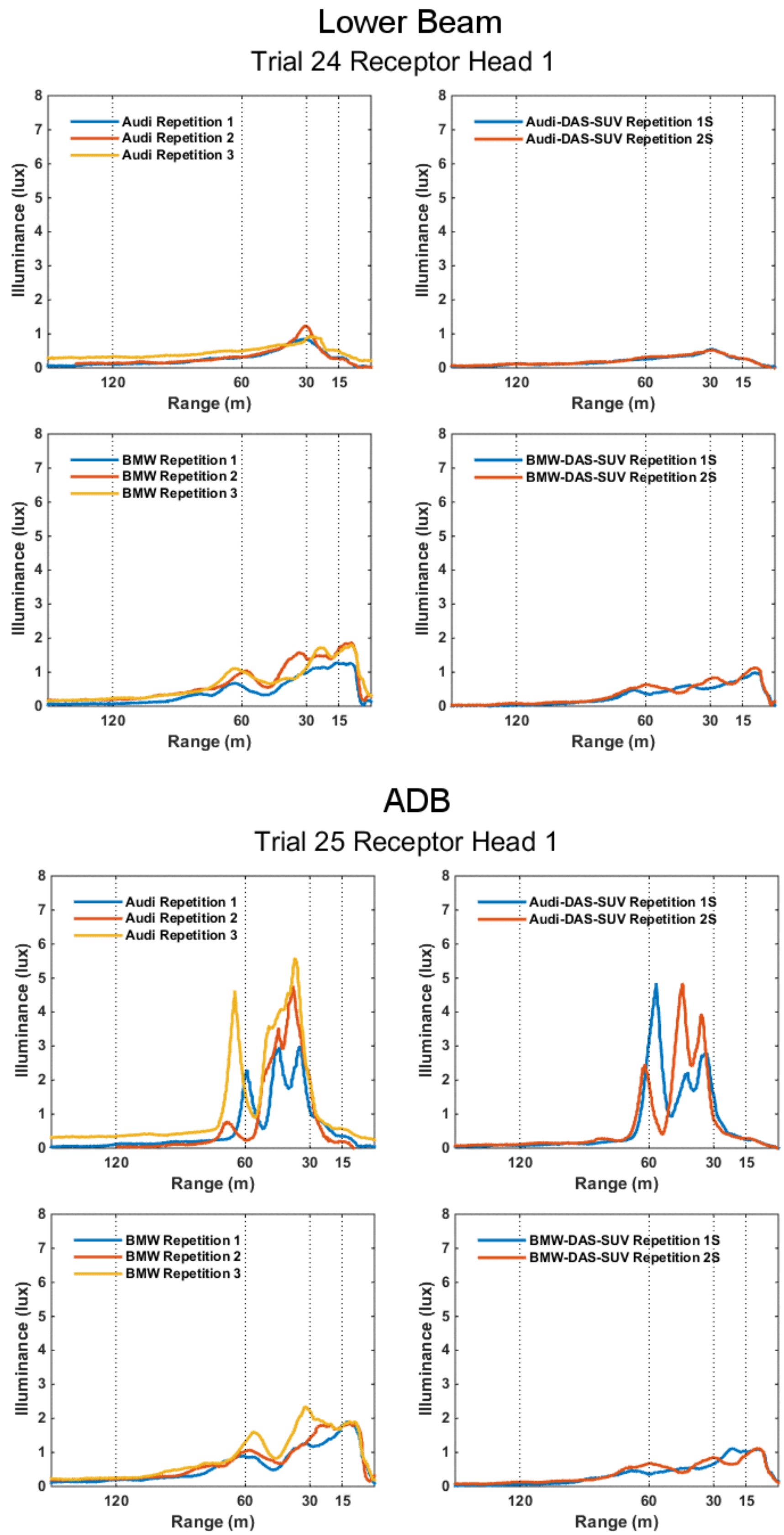

Figure 72. DAS Vehicle Size Effect Comparison Using Oncoming Motorcycle Scenario (Both vehicles traveling 62 mph; 99.8 kph)

9.2 Effects of Stationary Versus Moving DAS Vehicle

Certain maneuver scenarios were structured to have matched pairs, identical except for whether or not the DAS vehicle was moving. The pairs permit assessment of the extent to which DAS vehicle speed may be a factor in an ADB performance test.

Figure 73 presents plots of ADB illuminance for an oncoming, straight scenario in which the DAS vehicle was stationary or driving at 62 mph (99.8 kph). Except for the Audi with Small DAS vehicle, corresponding plots looks similar regardless of DAS vehicle speed.

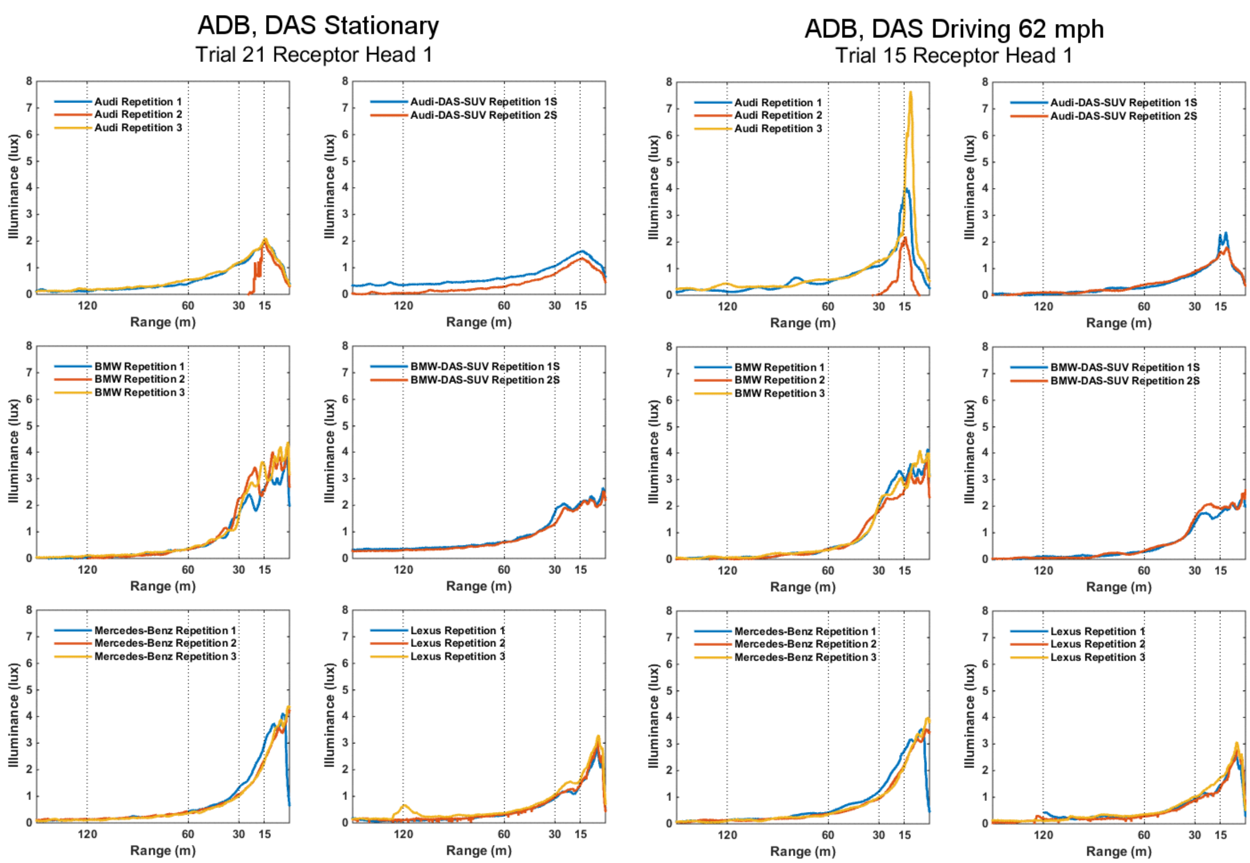

Figure 73. ADB Illuminance Versus Distance in Oncoming, Straight Maneuver Scenario for DAS Vehicle Stationary Versus Driving 62 mph (99.8 kph)

Figure 74 presents plots of ADB illuminance for an oncoming, left curve scenario in which the DAS vehicle was stationary or driving at 62 mph (99.8 kph). In these plots, most trials show slightly greater glare on the moving DAS vehicle trials than in trials where the DAS vehicle was stationary. Only the Audi with Small DAS vehicle appears to have approximately the same degree of glare for DAS vehicle moving and stationary.

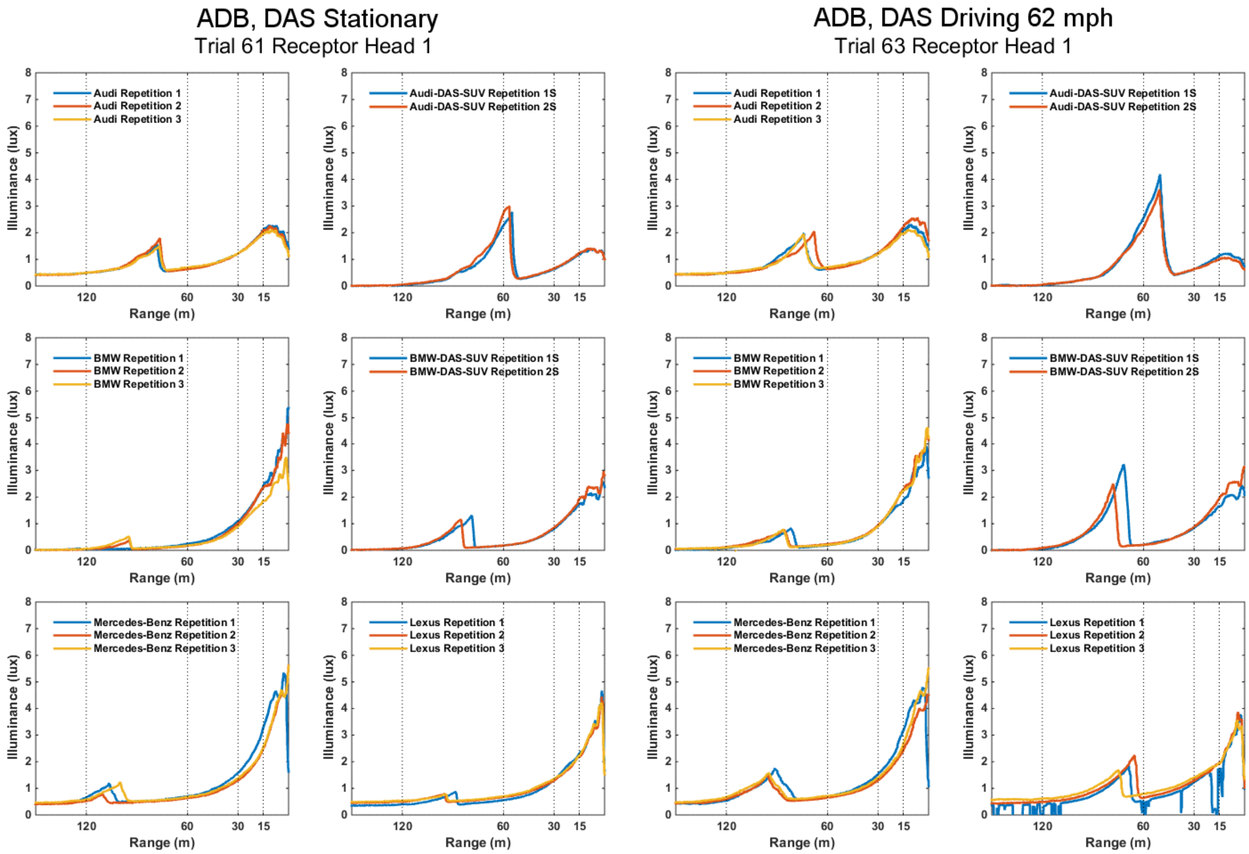

Figure 74. ADB Illuminance Versus Distance in Oncoming, Left Curve Maneuver Scenario for DAS Vehicle Stationary Versus Driving 62 mph (99.8 kph)

Figure 75 presents plots of ADB illuminance for an oncoming, right curve scenario in which the DAS vehicle was stationary or driving at 62 mph (99.8 kph). In these plots, there appears to be an inconsistent effect of DAS vehicle speed. In some cases, ADB seems to show more glare in the moving DAS vehicle trial than in the stationary DAS vehicle trial (Audi and BMW with Small DAS vehicle, Mercedes-Benz, Lexus). The Audi with SUV DAS vehicle trials do not seem affected by vehicle speed. The two trials for the BMW with moving SUV DAS vehicle seem to have different patterns and different magnitudes, with neither being the same as that seen with the stationary SUV DAS vehicle.

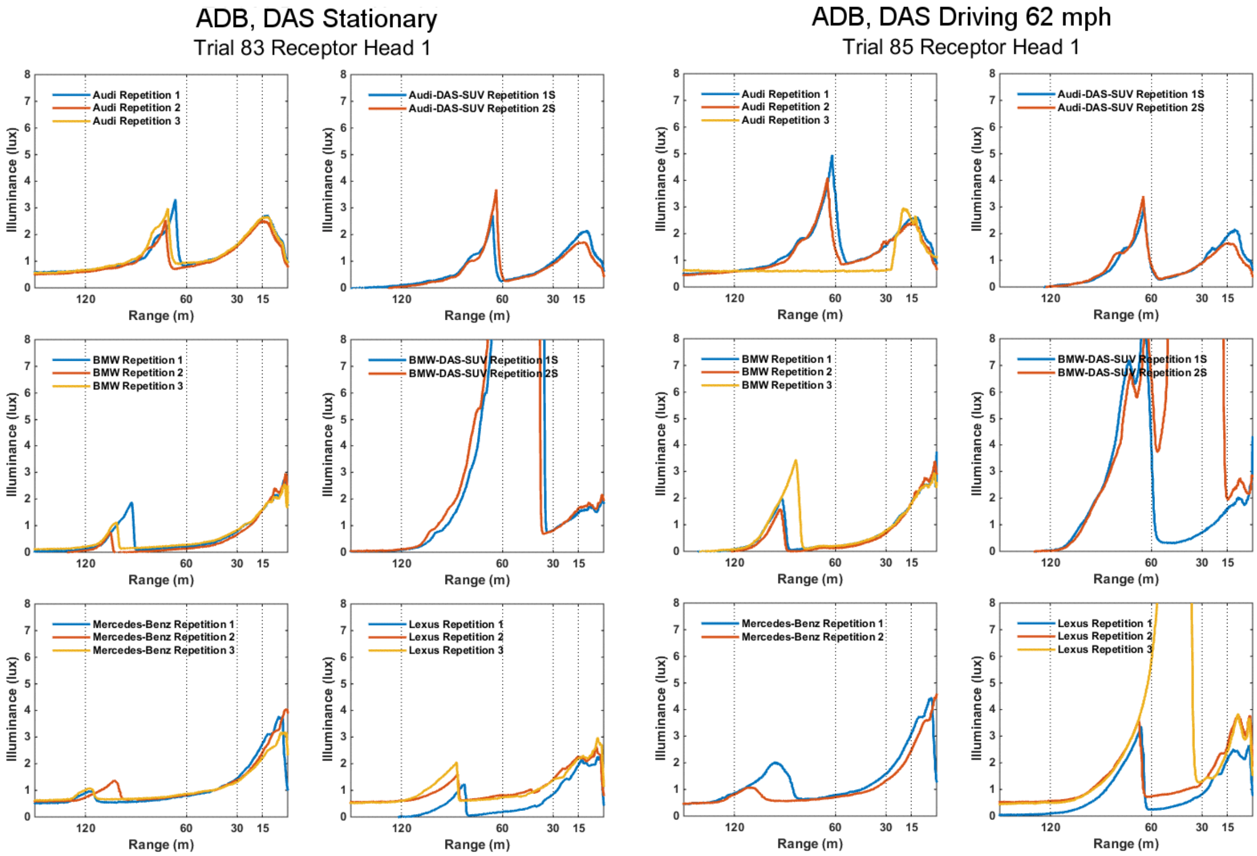

Figure 75. ADB Illuminance Versus Distance in Oncoming, Right Curve Maneuver Scenario for DAS Vehicle Stationary Versus Driving 62 mph (99.8 kph)

These data suggest that ADB responses are often different based on whether or not the DAS vehicle was moving. For curve scenarios, the cause of the difference may be attributable to the 15-degree camera field of view (15 degrees left and right) creating a “sudden appearance” situation that the ADB system takes time to react to. The ADB system adaptation time may be fairly consistent, but in moving DAS vehicle trials, more distance is traveled during the adaptation period, which results in increasing illuminance cast on the DAS vehicle before the adaptation is completed.

10.0 DISCUSSION

Overall in these tests, ADB appeared to provide noticeable additional roadway illumination. ADB adaptation was more apparent in some vehicles than others. Initially, ADB engagement may be a source of distraction for the driver of the ADB-equipped vehicle because of the visually discernible changing beam pattern.

However, in many cases ADB did not succeed in maintaining glare in the location of other vehicles to lower beam levels. The table below summarizes ADB performance based on whether the average maximum illuminance across test trial repetitions met derived lower beam glare limits. Generally, this summary shows that when an ADB system has a long preview of another vehicle, ADB can perform well. When an ADB system does not have a long preview of another vehicle, such as in an intersection scenario or when two vehicles are oncoming on a curved road, ADB does not have enough time to react to adapt its beam pattern. ADB adaptation times measured in response to a suddenly appearing oncoming vehicle were reasonable. However, adaptation times in some other dynamic maneuver scenarios seemed subjectively long ADB system detection of the motorcycle test vehicle used was also poor overall.

Table 57. Number of Vehicles per Scenario That Met Derived Glare Limit Values Based on Average Maximum Illuminance

Table Key:		
Green = All tested vehicles met glare limits	*Black = Good performance was observed for some vehicles, therefore is possible; but was not seen for all vehicles tested*	**Red = No test vehicles met glare limits**

	Road Trajectory:	**Straight**				**Curve Left**		**Curve Right**	
	Stimulus:	**Small DAS**	**SUV DAS**	**Motorcycle**		**Small DAS**	**SUV DAS**	**Small DAS**	**SUV DAS**
	DAS:	Small	SUV	Small	SUV	Small	SUV	Small	SUV
	Number of Trials per Vehicle:	4	2	4	2	4	2	4	2
Oncoming	(180 deg. heading difference)	*2/4*	*1/2*	*2/4*	*1/2*	**0/4**	**0/2**	**0/4**	**0/2**
Preceding (same direction)	Same lane	*2/4*	*1/2*	**0/4**	**0/2**	*2/4*	**0/2**	4/4	4/4
	Adjacent lane, Left	4/4	2/2			4/4	2/2	4/4	4/4
	Adjacent lane, Right	3/4	*1/2*			4/4	**0/2**	4/4	4/4
Passing (same direction)	ADB passes DAS	*2/4*	*1/2*			4/4	2/2	3/4	2/2
	DAS passes ADB	4/4	2/2			4/4	2/2	4/4	2/2
Intersection	60°	**0/4**	**0/2**						
	90°	**0/4**	**0/2**						
	120°	**0/4**	**0/2**						
Dip	Dip series	**0/4***	**0/4***						

Note: Trials with DAS stationary and moving are combined in this table

* In the dip series, lower beam also exceeded derived glare limit values.

While not specifically examined in this testing, ADB illumination appears to provide increased visibility of roadside areas and may aid drivers in better seeing and avoiding crashes with animals and other potential obstacles at night.

Some ADB system behaviors that were not expected and uncharacteristic of ADB's stated purpose were observed. For instance, peculiar cases of momentary engagement of upper beam headlamps, even in one case when the vehicle was being operated below ADB activation speed were observed. While a momentary exposure to upper beam illumination may not blind another driver, may confuse and concern the driver of the ADB-equipped vehicle that something may be wrong with the vehicle's headlighting system. On a public road drive with one ADB-equipped vehicle outside of the controlled test trials, the ADB system interpreted a reflective roadside sign to be another vehicle and suddenly darkened the forward roadway startling the driver. These types of peculiar behaviors and any degree of noticeable performance inconsistency could cause low driver satisfaction with ADB and lead to an increase in the already high number of headlighting system glare related complaints received by NHTSA.

The primary challenge in the development of a test procedure is the development of a repeatable vehicle-level objective test procedure for a standard that has only component-level tests to date. Based on this work, achieving a valid and repeatable, whole-vehicle test procedure for assessing ADB compliance with relevant performance criteria is considered technically feasible. While such testing may be deemed feasible for performance, such a vehicle-level test may present a challenge for aftermarket equipment manufacturers.

The testing conducted in this effort provides a variety of test scenario options that may be selected from to create a reasonable set of objective test maneuver scenarios and other measurements. Multiple trials of the selected scenarios seem necessary in order to confirm ADB performance repeatability and confirm maneuver scenario outcomes with respect to meeting the derived glare limits. The exact number of trials that would be most appropriate was not investigated in this effort. Based on the testing performed in this effort, more than the three trials per dynamic maneuver scenario may be needed in order to compensate for ADB performance variability and any issues with test repeatability. If available, automation aids for improvement of lane positioning and approach angles during test trials may help to improve test repeatability by enhancing maneuver scenario performance consistency.

Regarding the effects of DAS vehicle size, use of a "conformance region" in a glare evaluation test procedure would check that glare is limited in an area encompassing typical vehicle widths and statures. Figure 76 below depicts this measurement scheme using boxes to define the conformance region and showing illuminance receptor heads from phase 2 of testing described in this report. Illuminance measured anywhere within the box should not exceed defined limits. The height of the region would be set to encompass the estimated driver eye height locations (or some vehicle cabin height landmark) for vehicles ranging from small to large. The side-view region would be dimensioned to encompass either a maximum longitudinal cabin length or front seat area.

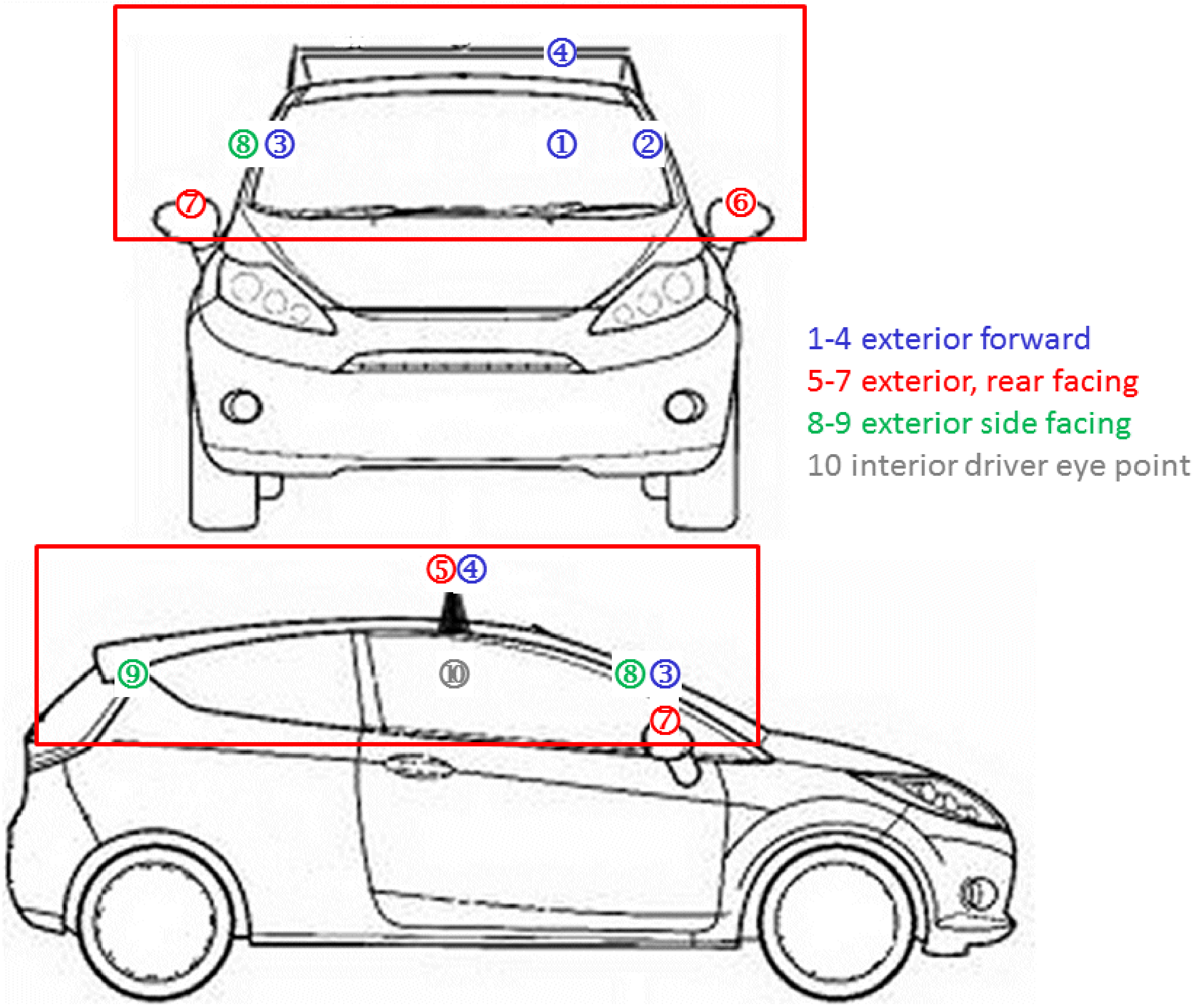

Figure 76. Possible Objective Test Illuminance Measurement Regions

If an objective test procedure were to include dynamic maneuver scenarios involving a motorcycle, a means of mounting relevant illuminance measurement equipment on the motorcycle itself would be needed. In this testing, sufficient equipment to instrument both the Small and SUV DAS vehicles as well as the motorcycle was not available. As a result, motorcycle scenario trials made use of the equipment installed on a DAS vehicle that was positioned adjacent to the motorcycle throughout the maneuver. This shift in measurement points resulted in a lateral offset in the illuminance measurement points of approximately 9 feet for those trials.

11.0 SUMMARY

Adaptive Driving Beam headlighting systems are designed to enhance roadway illumination while limiting the glare cast on other vehicles to lower beam levels. This report summarizes research that sought to learn about existing European ADB headlighting systems and the test procedures that address the technology.

NHTSA conducted research that sought to learn about adaptive driving beam systems and the existing European test procedures that address the technology. The specific objectives of this test program were to:

- Assess the performance of light vehicle ADB headlighting systems using existing ECE (R48) test procedures modified for performance on proving ground test courses.
- Assess whether existing ECE R48 test procedures may be modified to achieve an objective and repeatable objective test procedure that assesses an ADB system's ability to meet glare limit values derived from existing static beam pattern requirements of FMVSS No. 108.
- Conduct additional ADB performance testing using modified test procedures to gather objective data on ADB performance in a variety of vehicle traffic geometries.
- Gather information needed to develop a comprehensive objective test procedure consisting of a modified version of the ECE R48-based test procedure and incorporating use of the glare limit values derived from existing static beam pattern requirements of FMVSS No. 108.

Existing European standards [11, 12] were examined as a starting point for developing objective test procedures for ADB headlighting systems. This effort used the ECE approach of observing ADB performance in a variety of traffic scenarios and applied derived lower beam glare limit values to achieve an objective procedure. The first phase of testing consisted of subjecting production European-specification ADB-equipped light vehicles to a proving grounds implementation of the existing ECE R48 test procedures called "Test Drive Specifications for Adaptive Main-Beam Headlamps" [11].

To assess ADB performance in an objective manner, the ECE test procedure was augmented by the measurement of ADB headlighting system illuminance. Illuminance data were measured at points on an other/stimulus vehicle engaged in maneuver scenarios with an ADB-equipped vehicle. These data were used to assess whether ADB succeeded in achieving its goal of limiting glare cast on other vehicles to lower beam levels. Lower beam glare level limits were based on the current static test requirements in FMVSS No. 108 as derived by Flannigan and Sullivan [10] in a 2011 UMTRI research effort. These range-based requirements for maximum allowable glare limits provided a basis for assessing how ADB illuminance levels compare to current FMVSS No. 108 [9] standards.

The points below summarize the work and its findings:

- **ECE Test Procedures for ADB Headlighting Systems**:
    - Production European-specification ADB-equipped light vehicles were subjected to a proving grounds implementation of the existing ECE R48 test procedures called "Test Drive Specifications for Adaptive Main-Beam Headlamps." While not part of the ECE test procedure, ADB headlighting system illuminance was measured to allow assessment of light levels with respect to the requirements of FMVSS No. 111.

- Results of the first phase of testing showed that measurement of headlamp illuminance using the whole vehicle, rather than a component-level test, can be accomplished in a repeatable manner. Furthermore, results showed that assessing ADB performance using scripted, dynamic maneuver scenarios performed outdoors in variable ambient illumination conditions can be performed in a valid way, by removing the measured ambient illumination from recorded headlighting system test trial data.

- Based on the first phase of testing, the maneuver scenario set was refined to focus on scenarios that would likely elicit ADB response and cover a range of inter-vehicle geometries. Specific changes included:
  - Excluding illuminated roadway scenarios;
  - Excluding scenarios with more than two vehicles;
  - Excluding most low-speed scenarios in which ADB is not designed to operate;
  - Replacing the winding road scenario with a more mildly winding scenario that could be performed at a higher speed at which ADB could be active; and
  - Replaced ECE bicycle scenario with a motorcycle scenario based on the logic that a FMVSS-compliant motorcycle is more likely to be encountered on U.S. roads having a speed range relevant to ADB operational speed range than a bicycle.

- The second phase of testing subjected ADB-equipped vehicles to a modified test procedure based on the ECE R48 protocol. Improvements to the Phase 1 test protocol implementation were made to better engage ADB functionality, allow for ADB response observation in potentially challenging scenarios, and improve test efficiency. Examination of the repeatability of test results was also a main focus of the second phase of testing. Phase 2 maneuver scenarios were grouped into two main categories:
  - Oncoming, including angled intersection approaches; and
  - Same-direction maneuver scenarios.

- **General ADB Headlighting System Performance**:
  - In many cases ADB illuminance levels exceeded that of lower beam mode in the location of other vehicles. In most cases, the ADB systems consistently produced the same or greater glare than the lower beam of that vehicle.
  - ADB adaptation times measured in response to a suddenly appearing oncoming vehicle were reasonable. However, adaptation times in some other dynamic maneuver scenarios seemed subjectively long.

- **Maneuver Scenario-Specific Findings for ADB Performance**:
  - ADB in Straight Road Scenarios: The ADB systems produced similar glare as compared to that of lower beam on flat, straight roads when encountering oncoming and preceding passenger cars.
  - ADB in Intersection (Straight) Scenarios: All of the ADB systems produced considerably more glare in intersection scenarios than was seen with lower beam mode.

- ADB in Curve Maneuver Scenarios: ADB exceeded derived glare limit values in all but one vehicle-maneuver scenario combination for oncoming curve maneuver scenarios. However, same direction curve maneuver scenarios proved less problematic. Only left curve same-direction maneuver scenarios where the DAS vehicle was stationary were associated with high glare limit values for ADB. This was true for both the Small and SUV DAS vehicles. Some systems limited glare better than others. There were no derived glare limit values exceeded for same-direction, right curve maneuvers. It should be noted that no curve maneuver scenarios were run with the motorcycle.

- ADB in Passing Maneuver Scenarios: The Lexus and Mercedes-Benz ADB systems exhibited glare levels similar to that seen with lower beam and within derived lower beam glare limit values in all passing maneuver scenarios. High levels of glare with the BMW ADB system were only seen for the straight road passing maneuver with the Small DAS vehicle. The Audi ADB system produced high levels of glare in straight and right curve passing maneuvers with both sizes of DAS vehicle.

- Maneuver Scenario Approach Direction: In terms of data variability related to test procedure effects, oncoming maneuvers tended to have smaller standard deviation values than did same-direction scenarios, particularly for trials in which the DAS vehicle was stationary.

- ADB in Motorcycle Scenarios: One tested ADB system exceeded the derived glare limit values in a scenario involving an oncoming motorcycle (Audi). All the tested ADB systems produced excessive glare in a scenario involving a preceding motorcycle.

- ADB Performance in Encountering Stationary Versus Moving Vehicles: In some scenarios, ADB systems cast more glare on the moving DAS vehicle trial than on the stationary DAS vehicle. In scenarios involving both the ADB-equipped vehicle and other vehicle moving, illuminance measured for tested ADB systems exceeded derived lower beam glare limit values.

- **ADB System Response to Camera Obstruction**: ADB systems usually reverted to lower beam illumination when the camera sensor was blocked fully to simulate obstruction due to environmental conditions, but not all systems responded quickly in reverting to lower beam. No ADB system's performance was affected by partial camera coverage.

- **Development of ADB Test Procedures**:
  - This research shows that achieving a valid and repeatable, whole-vehicle test procedure for assessing ADB headlighting system performance with respect to relevant performance criteria is technically feasible.
  - ADB lighting system performance showed differences in oncoming and same-direction scenarios, as well as straight, curved, and intersection roadway geometries.
  - Multiple test trials per scenario may be warranted to account for variability in dynamic maneuver scenario performance as well as ADB performance variability.

- Use of a “conformance region” in a glare evaluation test procedure could serve to evaluate whether glare will be limited in driver locations for vehicle sizes spanning typical widths and statures.

- **Summary**:
  - This effort was successful in objectively assessing the performance of European ADB headlighting systems.

  - A comprehensive objective test procedure was achieved. The test procedure was developed based on driving scenarios from the ECE R48 test procedure and incorporated use of the glare limit values derived from existing static beam pattern requirements of FMVSS No. 108.

  - Overall in these tests, ADB was shown to have the ability to dynamically adapt the headlamp beams to shade oncoming and preceding vehicles. However:
    - In some cases, tested ADB systems did not succeed in shading other vehicles to lower beam illuminance levels derived from the current static test requirements in FMVSS No. 108.

  - Existing FMVSS No. 108 requirements and the work summarized here together can provide a basis for performance criteria and an objective test procedure for ADB headlighting systems.

12.0 REFERENCES

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7. Toyota petition

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9. 49 CFR Sec. 571.108, Standard No. 108; Lamps, reflective devices, and associated equipment.

10. Flannagan, M. J., & Sullivan, J. M. (2011). Feasibility of New Approaches for the Regulation of Motor Vehicle Lighting Performance. June 2011, submitted to Docket NHTSA-2011-0145.

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15. De Boer, 1967 (glare rating scale)

APPENDIX A: EXAMPLE OF RANGE AND ILLUMINANCE DATA ADJUSTMENTS

The following are example adjustments made to range and illuminance data from Phase 1 (as referenced in Section 3.6.1). This same method was also applied to Phase 2 data.

Before the illuminance data was analyzed, the distance and illuminance data were both adjusted to permit a more accurate comparison to the derived glare limit values. Since the measured distance was from GPS antenna to GPS antenna mounted on each vehicle, the longitudinal distance was adjusted such that the range used for analysis was from each receptor head's position on the DAS vehicle to the ADB vehicle's headlamp positions, instead of from antenna to antenna. In addition, illuminance was adjusted to remove the illuminance contribution from the DAS vehicle's headlighting system and any environmental ambient illumination.

Range Data Adjustments, Phase 1

For comparison to derived glare limit values, the longitudinal range data channel was used as the basis for the distance data, reduced by the approximate longitudinal position of the ADB vehicle's headlamps relative to the GPS antenna and by the longitudinal position of each illuminance sensor (receptor head) installed on the DAS vehicle relative to that vehicle's GPS antenna. For the four ADB vehicles, the corrections used were as follows:

Table 58. Correction to Longitudinal Range for ADB Vehicle Headlamp Position Relative to the Position of the GPS Antenna

ADB Vehicle	Correction to Longitudinal Range (m)
Audi	-2.934138
BMW	-2.998902
Lexus	-2.930343
Mercedes-Benz	-2.869934

The corrections to the longitudinal range to account for the sensor positions are as follows.

Table 59. Correction to Longitudinal Range for DAS Vehicle Sensor Positions Relative to the Position of the GPS Antenna

Receptor Head (RH) Number	Receptor Head Mounting Location	Mounting Location Side (Driver or Passenger)	Correction to Longitudinal Range (m)
RH1	Interior	Driver	-1.426007
RH2	Exterior, Rear-Facing	Driver	-0.893522
RH3	Interior	Passenger	-1.025574
RH4	Exterior	Driver	-1.022483
RH5	Exterior, Rear-Facing	Passenger	-0.893013
RH6	Exterior	Passenger	-1.024093
RH7-D-InteriorMini		Driver	-1.430541
RH8-D-ExtApillar		Driver	-1.939160

After applying these two corrections, a new range channel was created for each receptor head, to be used for data analysis. Thus, each new longitudinal range channel specifically contained the longitudinal distance from the ADB vehicle's headlamps to that particular receptor head.

Illuminance Data Adjustments, Phase 1

Corrections to receptor head illuminance readings were made to account for the ambient light by measuring the existing illuminance when either the ADB vehicle's headlighting system was turned off, or if this was not possible, with the ADB vehicle removed from the scene. Since ambient illumination varies due to environmental conditions, an "ambient" file was recorded, with the DAS vehicle's headlighting system on lower beam, during each testing session. An average reading for each receptor head for an "ambient" trial was subtracted from each receptor head's data in the scenario trials recorded during that session. New illuminance data channels were generated for each receptor head after making those corrections, as follows:

Table 60. Corrections to Illuminance Readings (Lux) to Account for Background (Ambient) Light, Subtracted from Each Evening's Trials

		Receptor Head (Showing Quantity Deducted from Receptor Head Readings (Lux))							
ADB Vehicle	**Test Date**	**RH1**	**RH2**	**RH3**	**RH4**	**RH5**	**RH6**	**RH7**	**RH8**
Audi	11/15/2013	0.2714	0.1127	0.1401	0.5001	0.1134	0.4948	N/A	N/A
	11/18/2013	0.0542	-0.0053	0.0193	0.0086	-0.0025	0.0065	N/A	N/A
	11/20/2013	0.2420	0.0255	0.1346	0.4391	0.0334	0.4390	N/A	N/A
	11/25/2013	0.2068	0.0579	0.1292	0.4769	0.0798	0.4725	N/A	N/A
	11/27/2013	0.1917	0.0007	0.1308	0.4732	0.0152	0.4717	N/A	N/A
	12/11/2013	0.2050	0.0145	0.1061	0.5049	0.0236	0.4974	0.3596	N/A
BMW	12/19/2013	0.0512	0.0259	3.1969	0.1423	0.0420	0.1318	0.1522	0.2257
	12/23/2013	0.1933	0.0560	0.1147	0.5151	0.0732	0.5082	0.3351	0.7279
Lexus	3/10/2014	0.1500	0.0366	0.0922	0.4200	0.0547	0.4148	0.2753	0.5982
	3/11/2014	0.1524	0.0192	0.0849	0.4201	0.0408	0.4272	0.2692	0.6200
	3/18/2014	0.1351	-0.0062	0.0840	0.4043	0.0052	0.4080	0.2665	0.5240
	4/1/2014	0.1661	0.0391	0.0746	0.4519	0.0593	N/A	N/A	0.6115
Mercedes-Benz	12/1/2013	0.1671	0.0056	0.1103	0.4131	0.0263	0.4036	N/A	N/A
	12/2/2013	0.1586	0.0267	0.1036	0.3993	0.0415	0.3909	N/A	N/A
	12/3/2013	0.1093	-0.0065	0.0763	0.3289	0.0125	0.3208	0.0285	N/A
	12/19/2013	0.0405	0.0759	2.1120	0.0959	0.0906	0.0834	0.0573	0.1443

APPENDIX B: HEADLAMP VOLTAGE DATA BY VEHICLE, HEADLIGHTING SYSTEM MODE, AND MANEUVER SCENARIO

Table 61. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation of Bb Oncoming, Straight Maneuver Scenario and Headlighting System Mode for SUV DAS Vehicle

	Audi (n=2)				BMW (n=2)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
Straight, adj. lane, DAS 0 mph, ADB 62 mph	13.148	0.228	12.915	0.146	13.530	0.184	13.381	0.092
Straight, adj. lane, DAS 62 mph, ADB 62 mph	13.165	0.298	12.937	0.267	13.435	0.095	13.474	0.285
Motorcycle, straight, adj. lane, DAS 0 mph, ADB 62 mph	13.130	0.153	12.921	0.122	13.535	0.135	13.447	0.075
Motorcycle, straight, adj. lane, DAS 62 mph, ADB 62 mph	13.081	0.042	12.891	0.162	13.442	0.124	13.467	0.178
Dip series, adj. lane, DAS 0 mph, ADB 45 mph	13.092	0.234	12.838	0.371	13.435	0.271	13.403	0.246

Table 62. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation of by Oncoming, Intersection Maneuver Scenario and Headlighting System Mode for SUV DAS Vehicle

	Audi (n=2)				BMW (n=2)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
60 degrees, adj. lane, DAS 0 mph, ADB 62 mph	13.367	0.464	12.747	0.333	13.393	0.101	13.364	0.230
90 degrees, adj. lane, DAS 0 mph, ADB 62 mph	13.163	0.194	12.954	0.448	13.459	0.238	13.467	0.337
120 degrees, adj. lane, DAS 0 mph, ADB 62 mph	13.231	0.293	12.922	0.355	13.472	0.145	13.506	0.365

Table 63. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation of by Oncoming, Curve Maneuver Scenario and Headlighting System Mode for SUV DAS Vehicle

	Audi (n=2)				BMW (n=2)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
ADB curve left, adj. lane, DAS 0 mph, ADB 62 mph	13.076	0.033	12.588	0.109	13.366	0.078	13.326	0.078
ADB curves Left, adj. lane, DAS 62 mph, ADB 62 mph	13.088	0.038	12.617	0.201	13.465	0.101	13.312	0.090
ADB curves Right, adj. lane, DAS 0 mph, ADB 62 mph	13.142	0.209	12.847	0.154	13.495	0.074	13.351	0.093
ADB curves Right, adj. lane, DAS 62 mph, ADB 62 mph	13.053	0.172	12.895	0.258	13.441	0.097	13.380	0.088
Winding, DAS 0 mph, ADB 45 mph	13.141	0.336	12.992	0.421	13.502	0.262	13.440	0.156

Table 64. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation of by Same Direction, Straight Maneuver Scenario and Headlighting System Mode for Small DAS Vehicle

	Audi (n=3)				BMW (n=3)				Lexus (n=3)				Mercedes-Benz (n=3)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
DAS precedes, straight, same lane, DAS 0 mph, ADB 62 mph	13.028	0.294	12.673	0.173	13.558	0.196	13.461	0.254	13.467	0.038	13.469	0.036	13.016	0.331	13.027	0.313
DAS precedes, straight, same lane, DAS 62 mph, ADB 62 mph	13.097	0.318	13.031	0.464	13.582	0.353	13.501	0.240	13.466	0.045	13.484	0.041	13.054	0.468	13.073	0.564
DAS precedes, straight, adj. lane Left, DAS 62 mph, ADB 62 mph	12.982	0.232	12.896	0.311	13.557	0.332	13.491	0.386	13.506	0.040	13.516	0.041	13.098	0.497	13.063	0.474
DAS precedes, straight, adj. lane right, DAS 62 mph, ADB 62 mph	13.056	0.258	12.779	0.330	13.527	0.376	13.538	0.345	13.501	0.038	13.497	0.039	13.130	0.523	13.072	0.419
DAS precedes, dip, straight, same lane, DAS 40 mph, ADB 45 mph	13.238	0.425	12.992	0.416	13.316	0.469	13.197	0.358	13.385	0.041	13.386	0.035	13.078	0.430	13.191	0.546
Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	13.129	0.355	12.761	0.181	13.276	0.104	13.234	0.206	13.409	0.055	13.461	0.058	13.022	0.353	13.054	0.499
Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	13.573	0.548	13.166	0.588	13.256	0.297	13.280	0.100	13.391	0.047	13.454	0.063	13.097	0.405	13.288	0.643

Table 65. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation of by Same Direction, Curve Maneuver Scenario and Headlighting System Mode for Small DAS Vehicle

	Audi (n=3)				BMW (n=3)				Lexus (n=3)				Mercedes-Benz (n=3)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
DAS precedes, curve left, same lane, DAS 0 mph, ADB 62 mph	13.024	0.166	12.561	0.148	13.484	0.106	13.366	0.154	13.600	0.044	13.597	0.045	13.068	0.322	13.037	0.430
DAS precedes, curve left, same lane, DAS 62 mph, ADB 62 mph	13.051	0.219	12.758	0.149	13.558	0.356	13.327	0.089	13.659	0.045	13.670	0.042	13.063	0.385	13.011	0.336
DAS precedes, curve left, adj. lane Left, DAS 0 mph, ADB 62 mph	12.992	0.034	12.592	0.152	13.429	0.096	13.315	0.068	13.621	0.049	13.642	0.038	13.069	0.470	13.086	0.493
DAS precedes, curve left, adj. lane Left, DAS 62 mph, ADB 62 mph	13.038	0.201	12.738	0.126	13.440	0.175	13.437	0.200	13.656	0.044	13.655	0.038	13.040	0.452	13.022	0.380
DAS precedes, curve left, adj. lane right, DAS 0 mph, ADB 62 mph	13.007	0.093	12.556	0.141	13.420	0.071	13.370	0.135	13.626	0.039	13.629	0.035	13.051	0.454	13.065	0.479
DAS precedes, curve left, adj. lane right, DAS 62 mph, ADB 62 mph	13.136	0.345	12.999	0.450	13.542	0.343	13.519	0.349	13.638	0.041	13.647	0.046	13.094	0.379	13.042	0.336
DAS precedes, curve right, same lane, DAS 0 mph, ADB 62 mph	12.984	0.225	12.843	0.268	13.522	0.114	13.383	0.110	13.610	0.037	13.615	0.034	13.078	0.526	13.078	0.465
DAS precedes, curve right, same lane, DAS 62 mph, ADB 62 mph	13.051	0.220	12.873	0.318	13.545	0.294	13.580	0.437	13.642	0.037	13.632	0.040	13.092	0.573	13.036	0.339
DAS precedes, curve right, adj. lane Left, DAS 0 mph, ADB 62 mph	13.040	0.210	12.780	0.119	13.438	0.070	13.330	0.105	13.617	0.040	13.611	0.044	13.068	0.307	13.051	0.338
DAS precedes, curve right, adj. lane Left, DAS 62 mph, ADB 62 mph	13.038	0.178	13.037	0.462	13.472	0.097	13.478	0.301	13.634	0.037	13.638	0.037	13.053	0.401	13.040	0.378
DAS precedes, curve right, adj. lane right, DAS 0 mph, ADB 62 mph	13.050	0.259	12.905	0.318	13.428	0.086	13.342	0.098	13.619	0.036	13.620	0.033	13.053	0.353	13.068	0.377
DAS precedes, curve right, adj. lane right, DAS 62 mph, ADB 62 mph	13.069	0.262	12.868	0.349	13.661	0.450	13.446	0.142	13.620	0.044	13.630	0.037	13.058	0.431	13.042	0.356

Table 66. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation of by Same Direction, Passing Maneuver Scenario and Headlighting System Mode for Small DAS Vehicle

	Audi (n=3)				BMW (n=3)				Lexus (n=3)				Mercedes-Benz (n=3)			
Maneuver Scenario	Lower Beam	Pooled SD	ADB	Pooled SD	Lower Beam	Pooled SD	ADB	Pooled SD	Lower Beam	Pooled SD	ADB	Pooled SD	Lower Beam	Pooled SD	ADB	Pooled SD
DAS follows then passes, straight, same lane, DAS 62 mph, ADB 50 mph	13.043	0.205	12.662	0.268	13.437	0.134	13.335	0.132	13.530	0.037	13.528	0.037	13.073	0.407	13.052	0.336
ADB follows then passes, straight, same lane, DAS 50 mph, ADB 62 mph	13.085	0.299	12.802	0.302	13.604	0.382	13.450	0.219	13.559	0.040	13.538	0.039	13.142	0.560	13.348	0.632
DAS follows then passes, curve left, same lane, DAS 62 mph, ADB 45 mph	13.083	0.240	12.664	0.271	13.448	0.235	13.262	0.279	13.675	0.036	13.675	0.038	13.045	0.305	13.043	0.298
ADB follows then passes, curve left, same lane, DAS 45 mph, ADB 62 mph	13.045	0.211	12.750	0.254	13.499	0.259	13.435	0.199	13.680	0.037	13.692	0.039	13.070	0.390	13.048	0.363
DAS follows then passes, curve right, same lane, DAS 62 mph, ADB 45 mph	13.136	0.307	12.878	0.327	13.419	0.074	13.229	0.178	13.637	0.036	13.636	0.035	13.100	0.444	13.043	0.304
ADB follows then passes, curve right, same lane, DAS 45 mph, ADB 62 mph	13.018	0.117	12.828	0.105	13.386	0.078	13.486	0.306	13.642	0.043	13.642	0.041	13.060	0.384	13.021	0.364

Table 67. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation of by Same Direction, Straight Maneuver Scenario and Headlighting System Mode for SUV DAS Vehicle

	Audi (n=2)				BMW (n=2)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
DAS precedes, straight, same lane, DAS 0 mph, ADB 62 mph	12.977	0.103	12.702	0.219	13.528	0.110	13.436	0.098
DAS precedes, straight, same lane, DAS 62 mph, ADB 62 mph	13.228	0.373	13.126	0.418	13.531	0.338	13.651	0.590
DAS precedes, straight, adj. lane Left, DAS 62 mph, ADB 62 mph	13.181	0.308	13.022	0.295	13.559	0.266	13.724	0.544
DAS precedes, straight, adj. lane right, DAS 62 mph, ADB 62 mph	13.159	0.294	12.843	0.257	13.503	0.194	13.469	0.302
DAS precedes, Dip series, straight, same lane, DAS 40 mph, ADB 45	13.257	0.346	13.018	0.318	13.433	0.209	13.441	0.212
Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	13.187	0.302	12.793	0.200	13.402	0.120	13.325	0.184
Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	13.189	0.315	12.922	0.155	13.509	0.109	13.345	0.094

Table 68. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation of by Same Direction, Curve Maneuver Scenario and Headlighting System Mode for SUV DAS Vehicle

	Audi (n=2)				BMW (n=2)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
DAS precedes, curve left, same lane, DAS 0 mph, ADB 62 mph	13.021	0.062	12.530	0.125	13.472	0.106	13.378	0.088
DAS precedes, curve left, same lane, DAS 62 mph, ADB 62 mph	13.156	0.272	12.935	0.349	13.465	0.130	13.444	0.320
DAS precedes, curve left, adj. lane Left, DAS 0 mph, ADB 62 mph	13.088	0.038	12.595	0.114	13.445	0.100	13.375	0.086
DAS precedes, curve left, adj. lane Left, DAS 62 mph, ADB 62 mph	13.133	0.278	12.860	0.310	13.481	0.205	13.485	0.278
DAS precedes, curve left, adj. lane right, DAS 0 mph, ADB 62 mph	13.092	0.030	12.562	0.097	13.425	0.081	13.379	0.090
DAS precedes, curve left, adj. lane right, DAS 62 mph, ADB 62 mph	13.115	0.173	12.861	0.252	13.575	0.377	13.434	0.095
DAS precedes, curve right, same lane, DAS 0 mph, ADB 62 mph	12.973	0.071	12.822	0.092	13.527	0.103	13.386	0.094
DAS precedes, curve right, same lane, DAS 62 mph, ADB 62 mph	13.156	0.212	12.894	0.185	13.448	0.119	13.475	0.363
DAS precedes, curve right, adj. lane Left, DAS 0 mph, ADB 62 mph	13.089	0.032	12.852	0.094	13.453	0.076	13.316	0.072
DAS precedes, curve right, adj. lane Left, DAS 62 mph, ADB 62 mph	13.116	0.127	13.037	0.323	13.653	0.392	13.566	0.465
DAS precedes, curve right, adj. lane right, DAS 0 mph, ADB 62 mph	13.101	0.032	12.856	0.106	13.474	0.082	13.373	0.103
DAS precedes, curve right, adj. lane right, DAS 62 mph, ADB 62 mph	13.285	0.449	12.904	0.253	13.587	0.301	13.543	0.366

Table 69. Headlamp Voltage for ADB Vehicle: Average and Pooled Standard Deviation of by Same Direction, Passing Maneuver Scenario and Headlighting System Mode for SUV DAS Vehicle

	Audi (n=2)				BMW (n=2)			
Maneuver Scenario	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**	**Lower Beam**	**Pooled SD**	**ADB**	**Pooled SD**
DAS follows then passes, straight, same lane, DAS 62 mph, ADB 50 mph	13.114	0.076	12.736	0.231	13.491	0.215	13.461	0.327
ADB follows then passes, straight, same lane, DAS 50 mph, ADB 62 mph	13.100	0.348	12.945	0.317	13.625	0.408	13.528	0.319
DAS follows then passes, curve left, same lane, DAS 62 mph, ADB 45 mph	13.124	0.075	12.688	0.230	13.487	0.234	13.345	0.192
ADB follows then passes, curve left, same lane, DAS 45 mph, ADB 62 mph	13.118	0.123	12.747	0.246	13.512	0.278	13.409	0.099
DAS follows then passes, curve right, same lane, DAS 62 mph, ADB 45 mph	13.158	0.183	12.872	0.311	13.494	0.198	13.334	0.176
ADB follows then passes, curve right, same lane, DAS 45 mph, ADB 62 mph	13.251	0.339	12.993	0.299	13.367	0.079	13.461	0.279

APPENDIX C: PLOTS OF ILLUMINANCE VERSUS RANGE FOR ONCOMING MANEUVER SCENARIOS

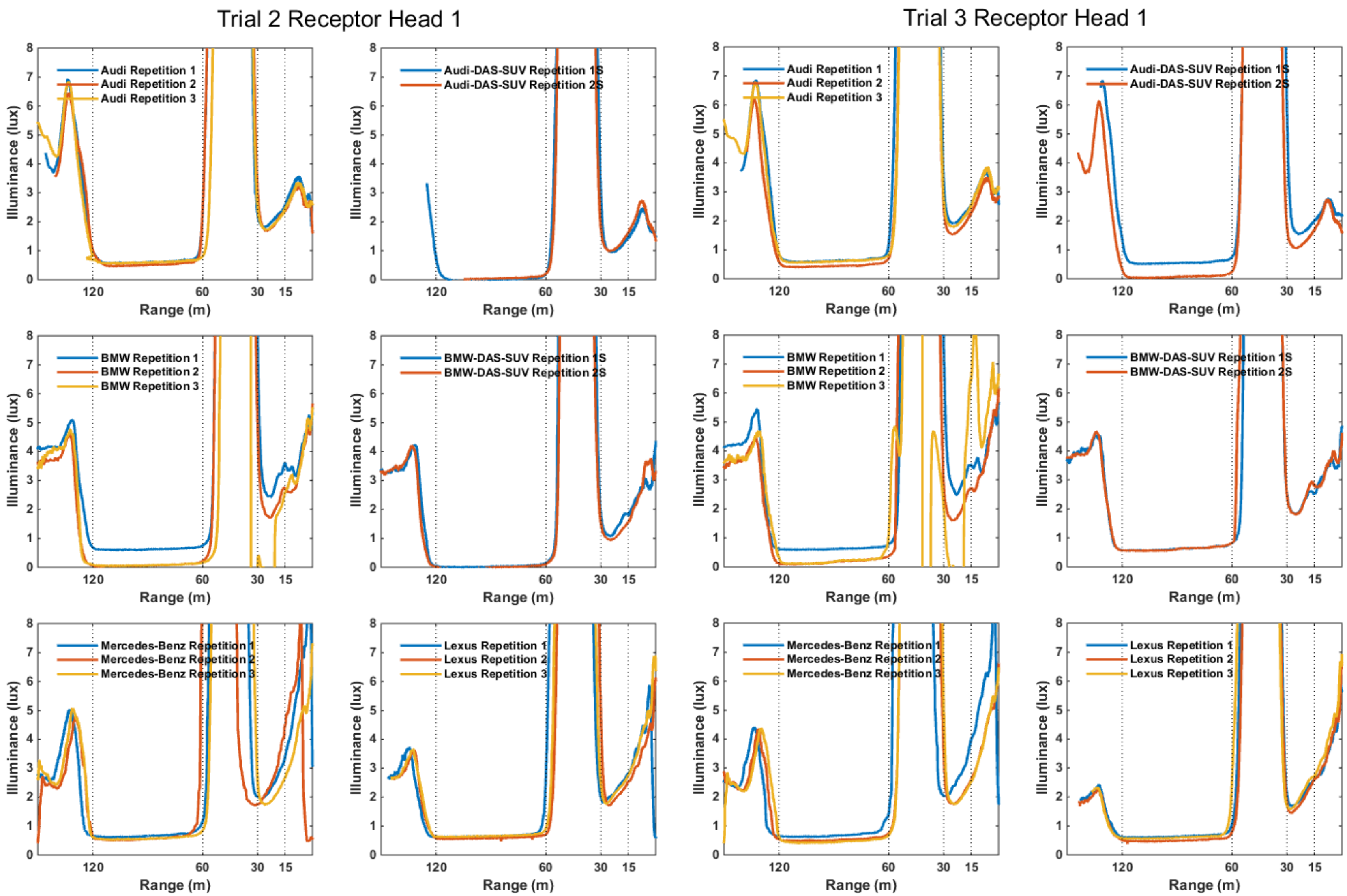

Figure 77. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight, Dip, Adjacent Lane, DAS 0 mph, ADB 62 mph, Trial 2 (Lower Beam) and Trial 3 (ADB)

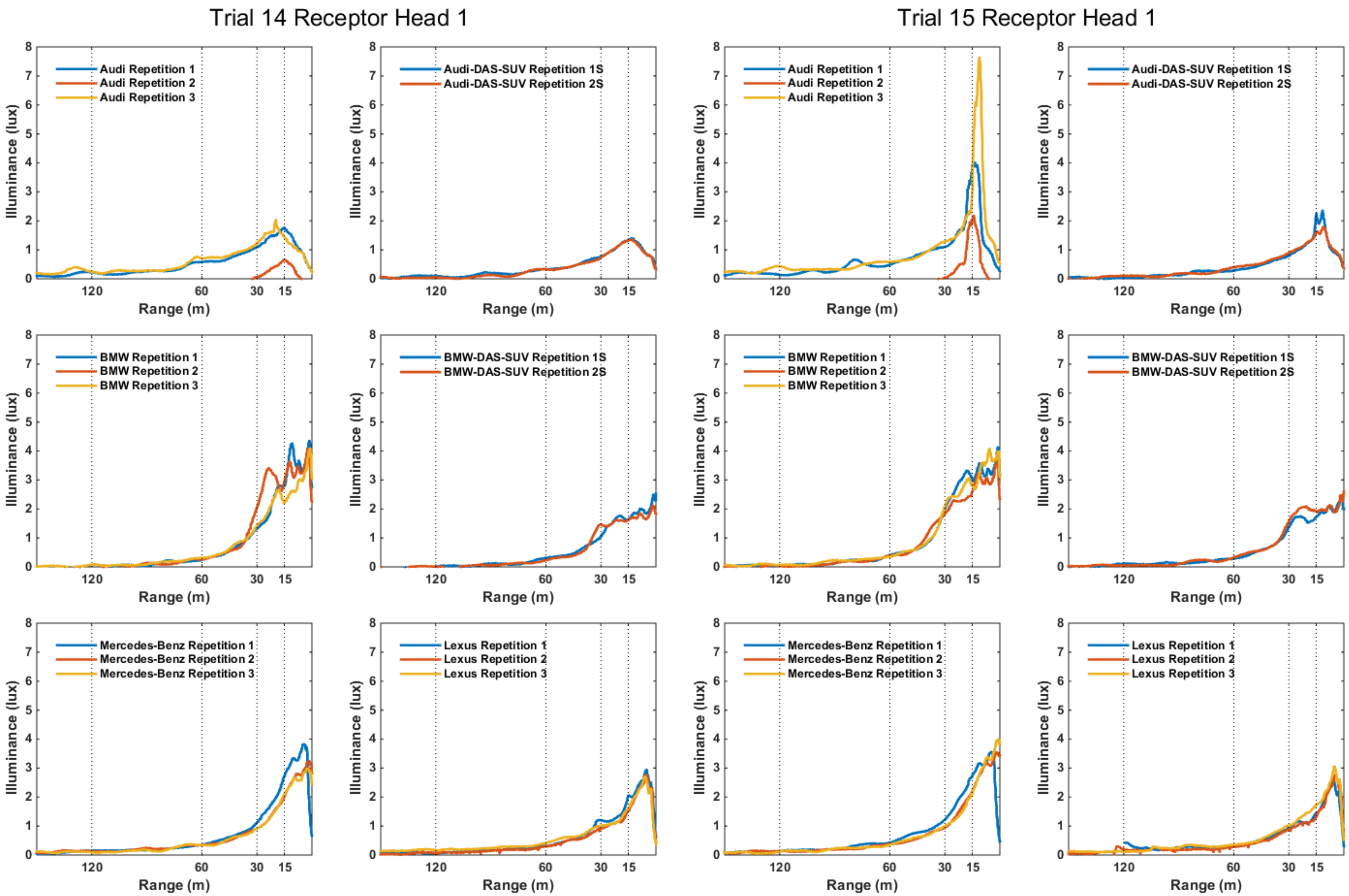

Figure 78. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight, Adjacent Lane, DAS 62 mph, ADB 62 mph, Trial 14 (Lower Beam) and Trial 15 (ADB)

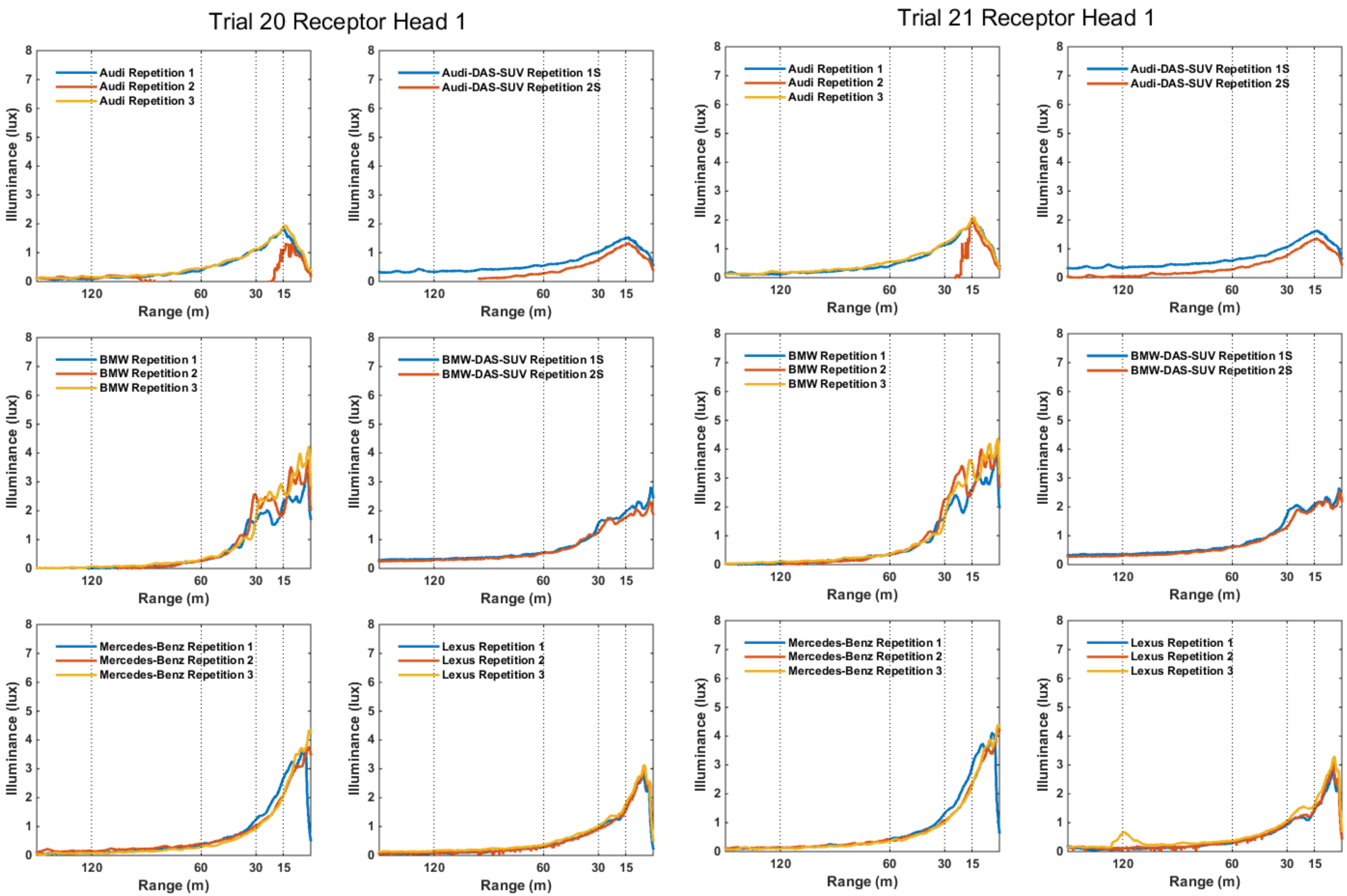

Figure 79. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight, Adjacent Lane, DAS 0 mph, ADB 62 mph, Trial 20 (Lower Beam) and Trial 21 (ADB)

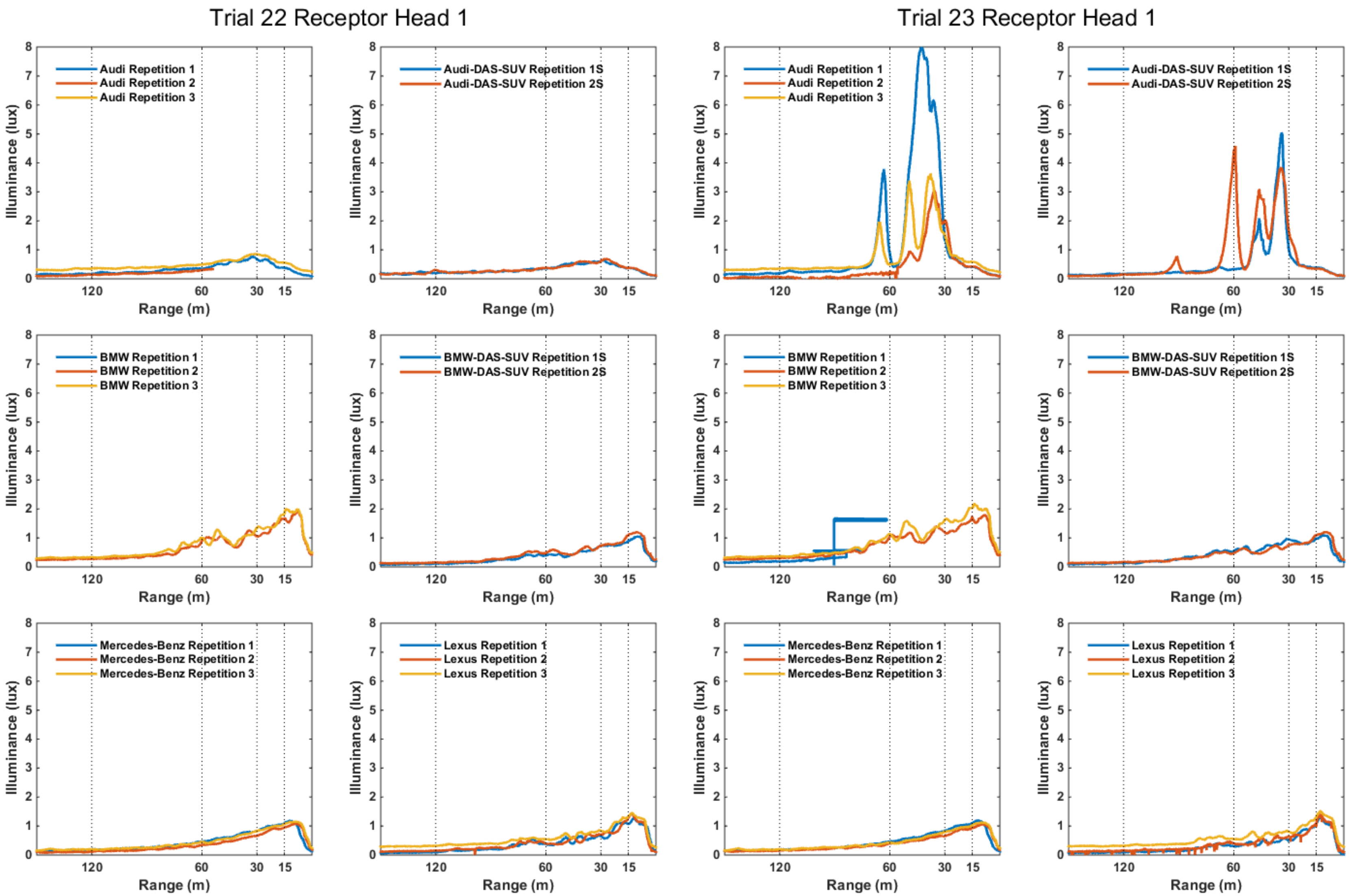

Figure 80. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight, Motorcycle, Adjacent Lane, DAS 0 mph, ADB 62 mph, Trial 22 (Lower Beam) and Trial 23 (ADB) NOTE: NO VALID RANGE DATA for BMW Repetition 1 (Small DAS) for Trial 22 and only for range > 80 m for Trial 23

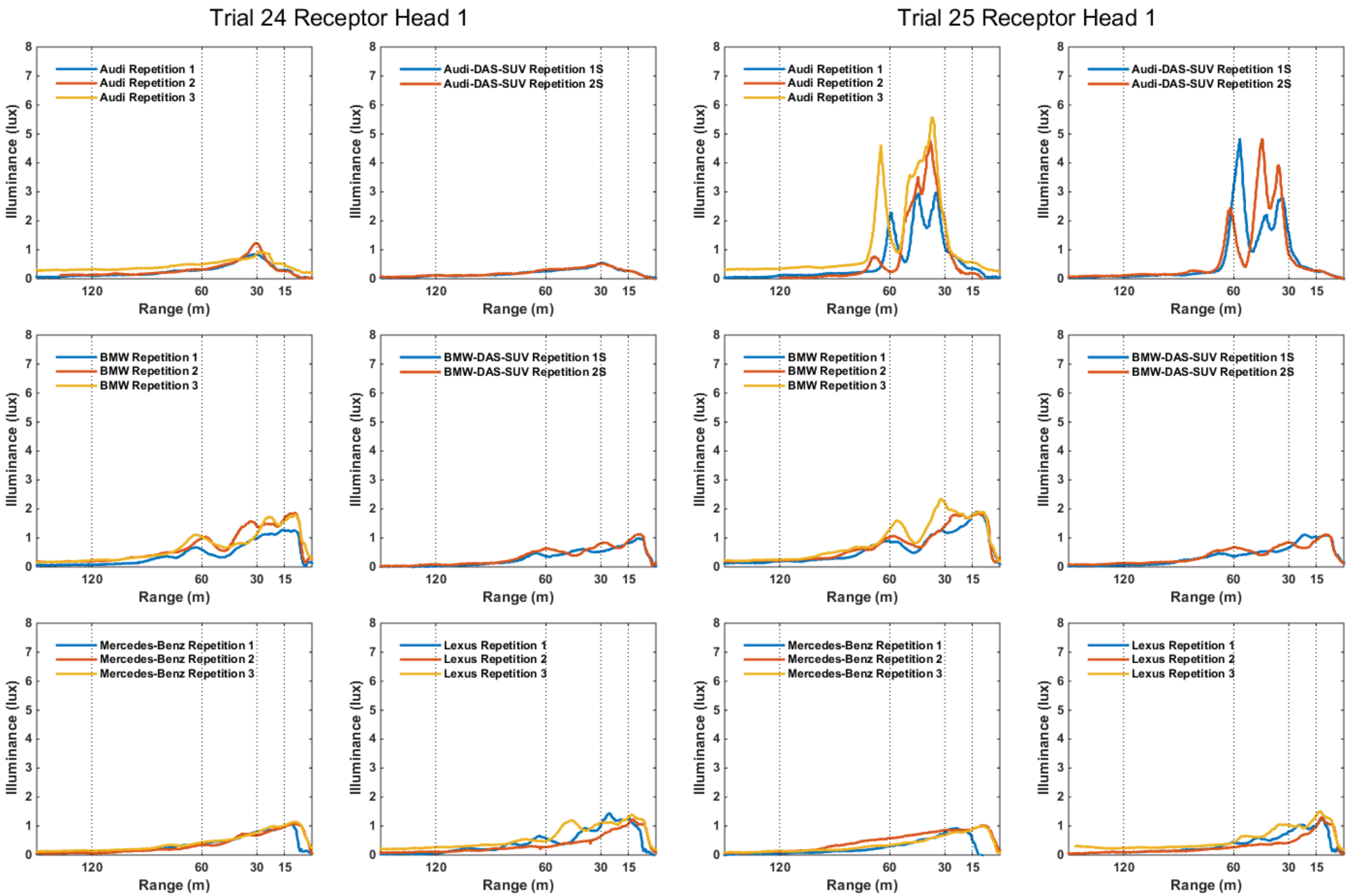

Figure 81. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Straight, Motorcycle, Adjacent Lane, DAS 62 mph, ADB 62 mph, Trial 24 (Lower Beam) and Trial 25 (ADB)

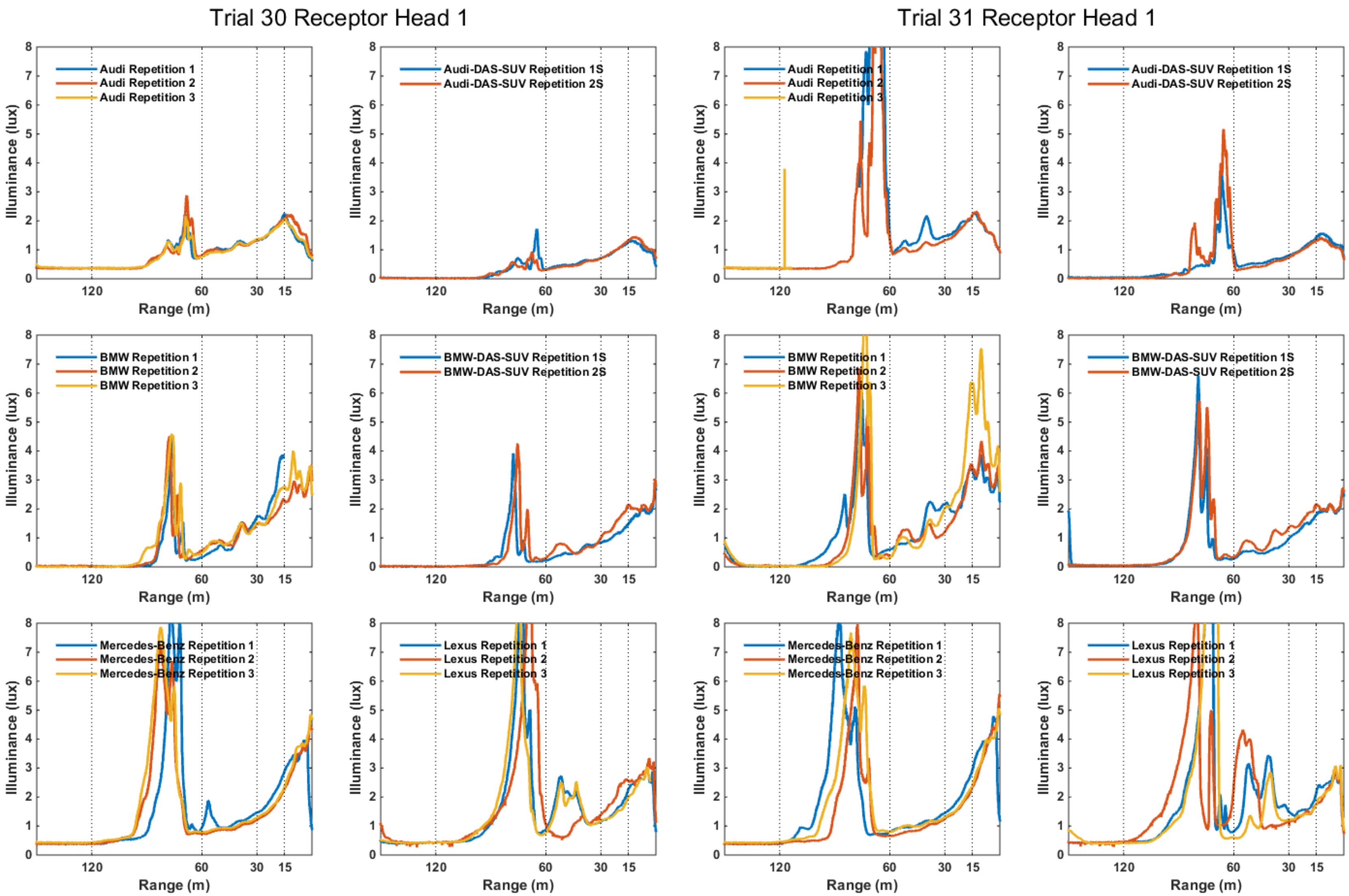

Figure 82. Lower Beam and ADB Illuminance Versus Distance for Oncoming, Winding, DAS 0 mph, ADB 62 mph, Trial 30 (Lower Beam) and Trial 31 (ADB)

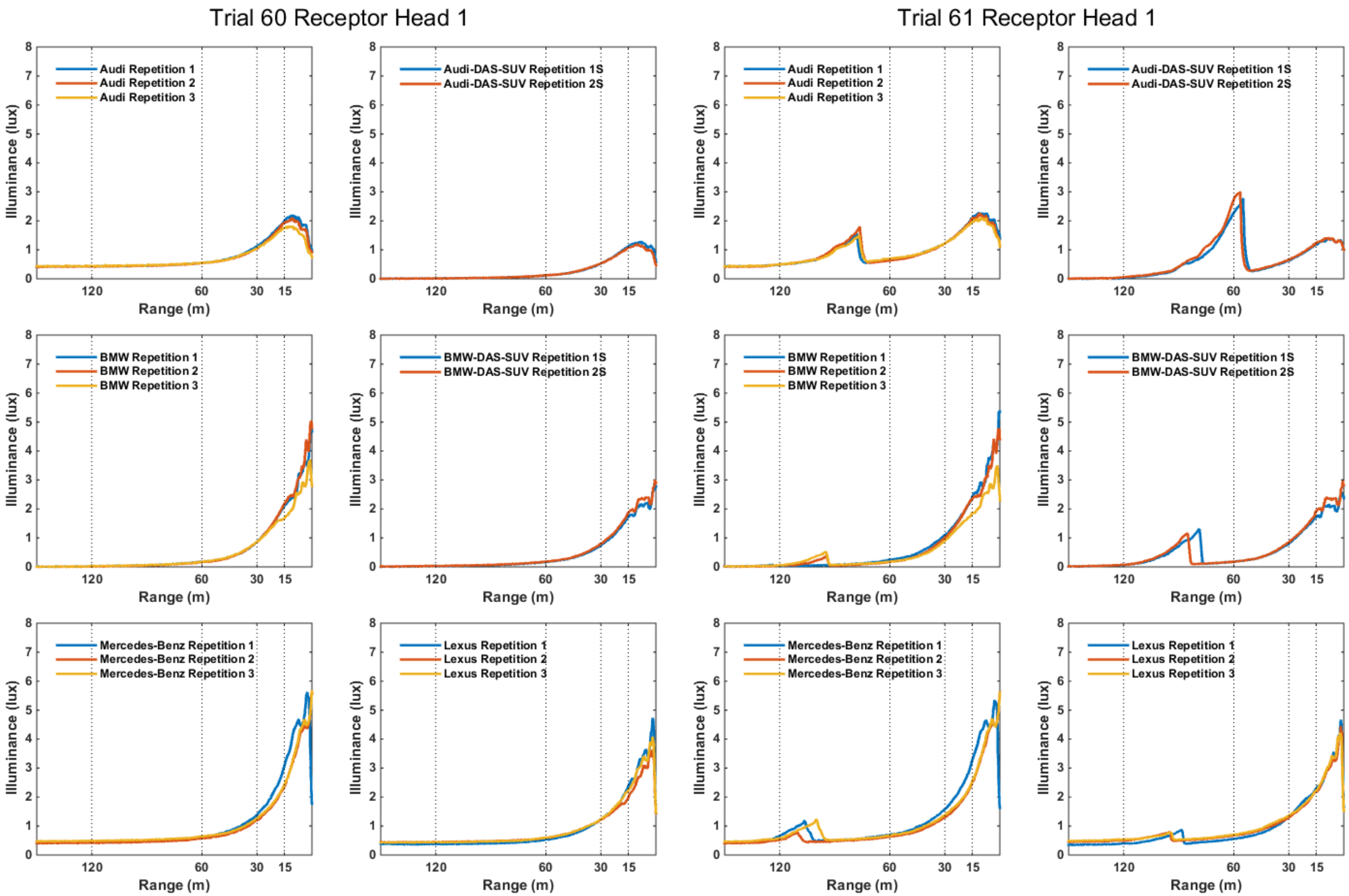

Figure 83. Lower Beam and ADB Illuminance Versus Distance for Oncoming, ADB Curves Left, Adjacent Lane, DAS 0 mph, ADB 62 mph, Trial 60 (Lower Beam) and Trial 61 (ADB)

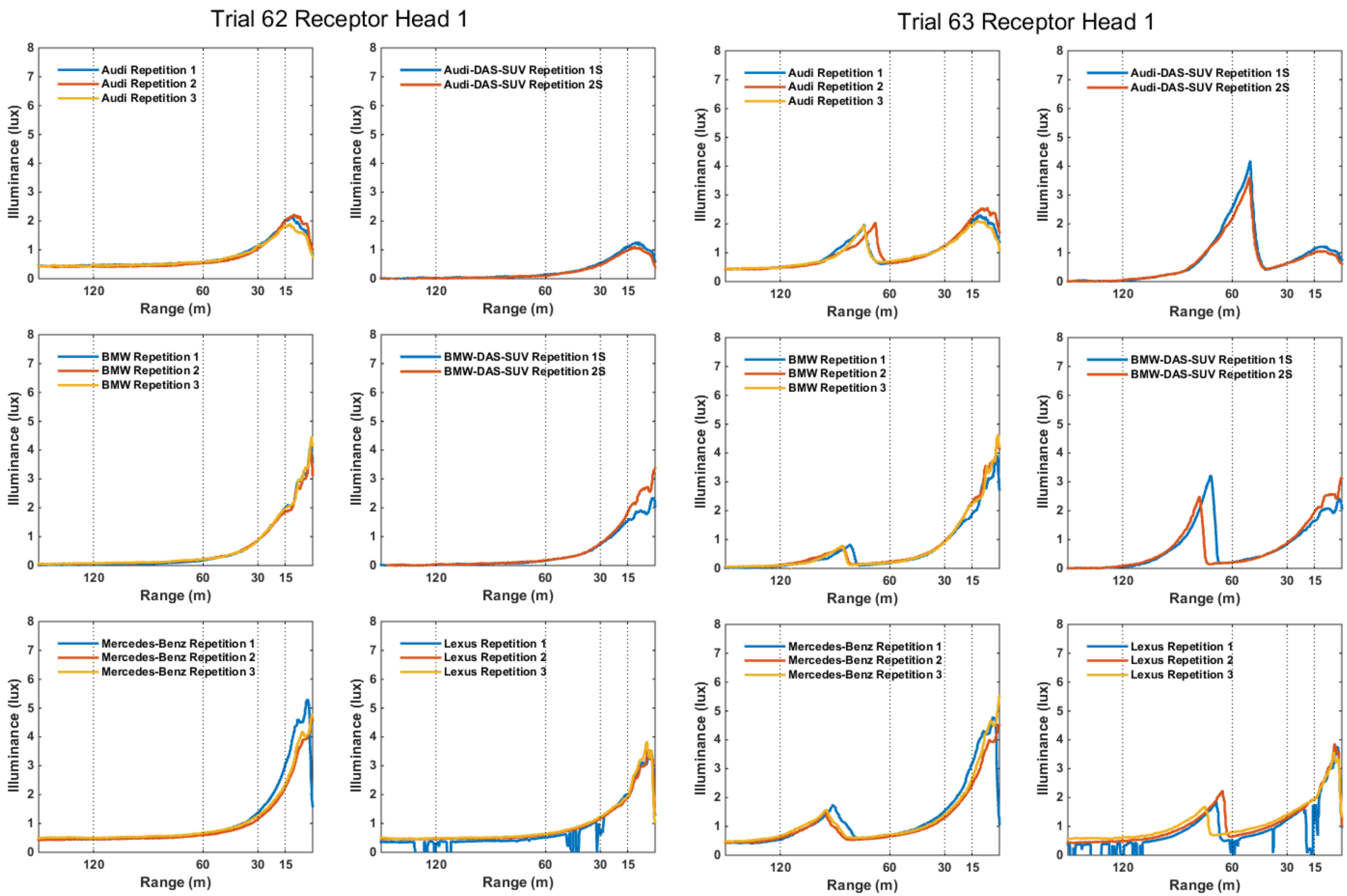

Figure 84. Lower Beam and ADB Illuminance Versus Distance for Oncoming, ADB Curves Left, Adjacent Lane, DAS 62 mph, ADB 62 mph, Trial 62 (Lower Beam) and Trial 63 (ADB)

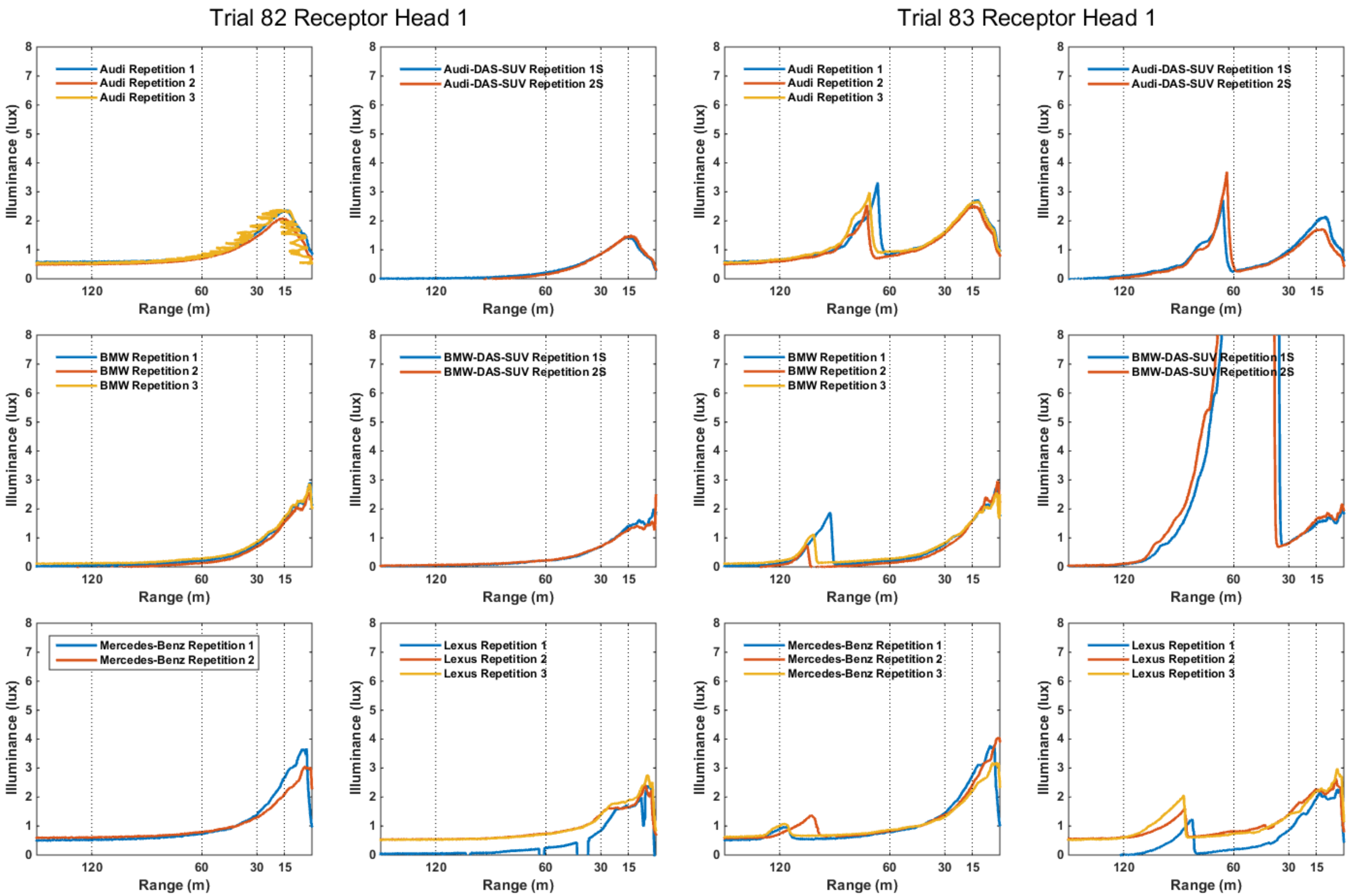

Figure 85. Lower Beam and ADB Illuminance Versus Distance for Oncoming, ADB Curves Right, Adjacent Lane, DAS 0 mph, ADB 62 mph, Trial 82 (Lower Beam) and Trial 83 (ADB)

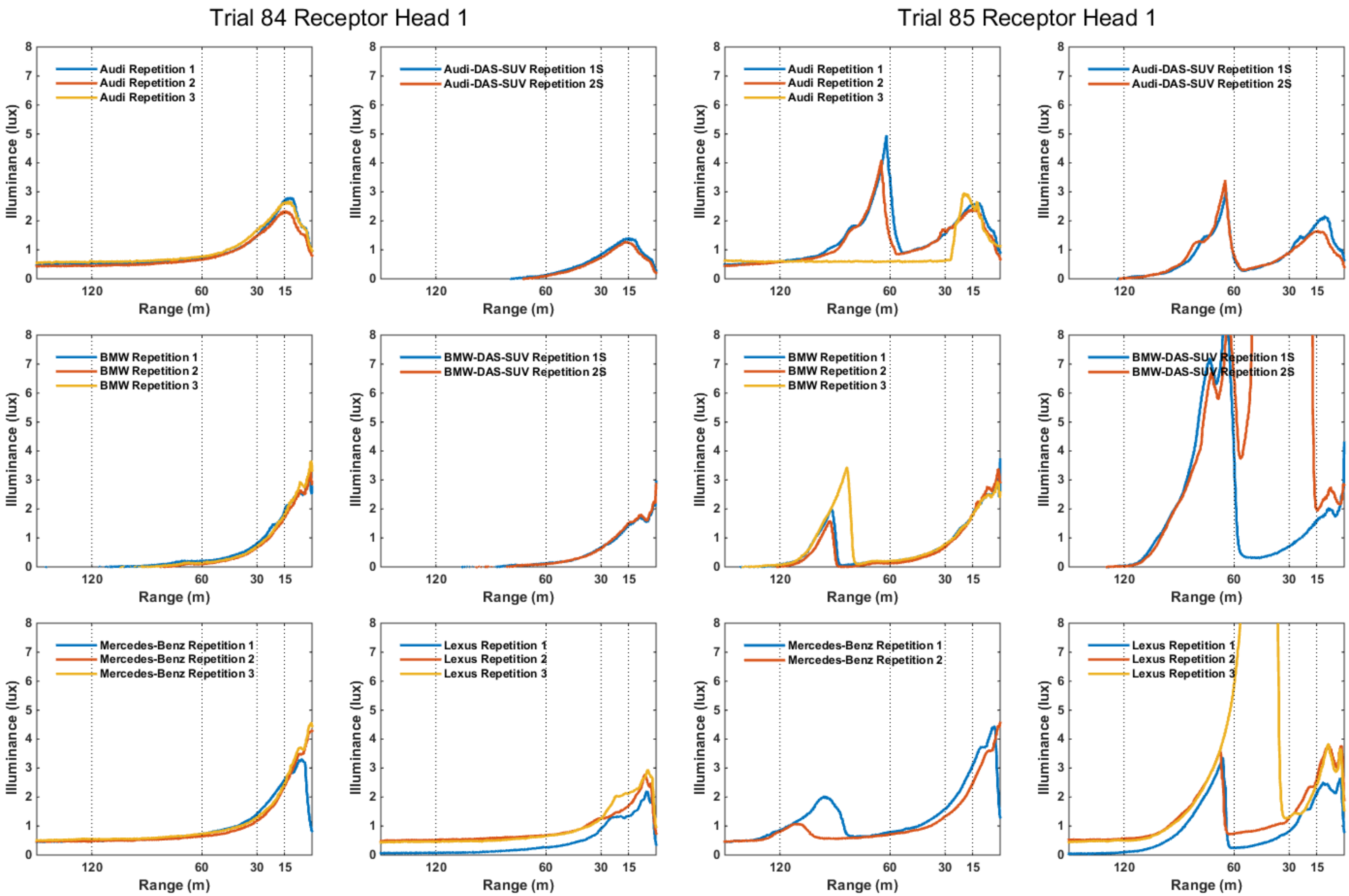

Figure 86. Lower Beam and ADB Illuminance Versus Distance for Oncoming, ADB Curves Right, Adjacent Lane, DAS 62 mph, ADB 62 mph, Trial 84 (Lower Beam) and Trial 85 (ADB)

APPENDIX D: LOWER BEAM AVERAGE MAXIMUM ILLUMINANCE AND STANDARD DEVIATION

Lower beam average maximum illuminance results for all vehicles according to maneuver scenario categories are presented in Tables 69 through 75. Dark gray shaded cells indicate lower beam values that exceeded derived glare limit values.

Table 70. Average Maximum Illuminance and Standard Deviation Values Using Receptor Head 1, Lower Beam Mode - Oncoming Straight Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, Small DAS (n=3)		Audi, SUV DAS (n=2)		BMW, Small DAS (n=3)		BMW, SUV DAS (n=2)		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS (n=3)	
			Avg.	**SD**	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**
Straight, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	1.63	0.43	1.42	0.17	2.58	0.33	1.86	0.15	1.67	0.11	2.27	0.34
	30-59.9	1.776	0.74	0.64	0.89	0.19	**2.01**	0.50	1.39	0.21	0.94	0.06	1.05	0.16
	60-119.9	0.634	0.35	0.12	0.43	0.20	0.29	0.02	0.55	0.01	0.33	0.04	0.36	0.06
	120-239.9	0.281	0.18	0.06	**0.44**	0.00	0.03	0.04	**0.32**	0.03	0.14	0.03	0.15	0.07
Straight, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.50	0.73	1.34	0.01	2.98	0.39	1.70	0.09	1.73	0.28	2.27	0.38
	30-59.9	1.776	0.80	0.64	0.75	0.03	1.60	0.38	1.26	0.31	1.06	0.13	0.98	0.12
	60-119.9	0.634	0.45	0.40	0.35	0.00	0.29	0.04	0.27	0.07	0.34	0.07	0.36	0.01
	120-239.9	0.281	0.23	0.21	0.13	0.08	0.03	0.04	0.04	0.00	0.15	0.05	0.15	0.01
Straight, Motorcycle, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.76	0.12	0.67	0.04	1.75	0.11	0.99	0.14	1.24	0.11	1.04	0.08
	30-59.9	1.776	0.67	0.27	0.61	0.01	1.31	0.06	0.74	0.01	0.77	0.08	0.78	0.09
	60-119.9	0.634	0.39	0.10	0.38	0.01	**0.94**	0.10	0.49	0.07	0.55	0.06	0.43	0.06
	120-239.9	0.281	0.24	0.12	**0.30**	0.02	**0.32**	0.04	0.15	0.03	0.20	0.11	0.19	0.04
Straight, Motorcycle, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.00	0.20	0.55	0.03	1.55	0.23	0.85	0.07	1.28	0.18	1.00	0.03
	30-59.9	1.776	0.99	0.22	0.53	0.01	1.23	0.32	0.71	0.13	0.94	0.28	0.78	0.03
	60-119.9	0.634	0.39	0.11	0.29	0.05	**0.93**	0.22	0.56	0.10	0.51	0.18	0.40	0.05
	120-239.9	0.281	0.21	0.12	0.13	0.00	0.19	0.08	0.06	0.04	0.15	0.10	0.13	0.04

Table 71. Average Maximum Illuminance and Standard Deviation Values Using Receptor Head 8, Lower Beam Mode - Intersection Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, DAS Small (n=3)		Audi, DAS SUV (n=2)		BMW, DAS Small (n=3)		BMW, DAS SUV (n=2)		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS (n=3)	
			Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
60 degrees, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.54	0.03	0.26	0.03	0.79	0.07	0.58	0.01	0.71	0.06	0.66	0.01
	30-59.9	1.776	0.48	0.03	0.28	0.01	0.65	0.12	0.40	0.02	0.67	0.35	0.43	0.01
	60-119.9	0.634	0.25	0.07	0.13	0.01	0.45	0.14	0.27	0.00	0.23	0.03	0.26	0.01
	120-239.9	0.281	0.13	0.02	0.06	0.01	0.08	0.01	0.04	0.01	0.13	0.02	0.13	0.01
90 degrees, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.42	0.03	0.25	0.02	0.73	0.03	0.58	0.05	0.73	0.10	0.67	0.06
	30-59.9	1.776	0.39	0.03	0.26	0.03	0.52	0.10	0.38	0.02	0.47	0.20	0.43	0.04
	60-119.9	0.634	0.25	0.02	0.17	0.01	0.43	0.05	0.32	0.03	0.36	0.18	0.26	0.02
	120-239.9	0.281	0.13	0.00	0.10	0.04	0.08	0.01	0.05	0.02	0.13	0.04	0.12	0.01
120 degrees, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	0.23	0.13	0.21	0.00	0.52	0.09	0.42	0.03	0.46	0.04	0.45	0.05
	30-59.9	1.776	0.20	0.11	0.22	0.03	0.42	0.16	0.27	0.01	0.38	0.13	0.34	0.04
	60-119.9	0.634	0.20	0.02	0.14	0.02	0.40	0.13	0.25	0.00	0.30	0.06	0.23	0.03
	120-239.9	0.281	0.10	0.01	0.14	0.00	0.07	0.01	0.06	0.00	0.13	0.03	0.11	0.02

Table 72. Average Maximum Illuminance and Standard Deviation Values Using Receptor Head 1, Lower Beam Mode - Oncoming Curve Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Glare Limit (lux)	Audi, Small DAS Vehicle (n=3)		Audi, SUV DAS Vehicle (n=2)		BMW, Small DAS Vehicle (n=3)		BMW, SUV DAS Vehicle (n=2)		Lexus, Small DAS (n=3)		Mercedes-Benz, Small DAS (n=3)	
			Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
Curve, ADB curves Left, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	1.90	0.13	1.10	0.04	2.00	0.27	1.80	0.12	2.19	0.20	2.61	0.41
	30-59.9	1.776	1.07	0.04	0.54	0.01	0.86	0.01	0.77	0.04	1.23	0.01	1.27	0.10
	60-119.9	0.634	0.55	0.01	0.13	0.00	0.18	0.01	0.19	0.00	0.58	0.04	0.62	0.04
	120-239.9	0.281	**0.46**	0.01	0.03	0.00	0.03	0.00	0.05	0.01	**0.44**	0.04	**0.47**	0.03
Curve, ADB curves Left, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	3.109	1.93	0.11	1.05	0.09	1.92	0.06	1.69	0.21	1.94	0.08	2.54	0.43
	30-59.9	1.776	1.08	0.05	0.51	0.04	0.86	0.02	0.74	0.04	1.16	0.08	1.26	0.11
	60-119.9	0.634	0.57	0.02	0.13	0.03	0.21	0.02	0.18	0.01	0.59	0.06	**0.64**	0.03
	120-239.9	0.281	**0.47**	0.03	0.04	0.01	0.07	0.02	0.05	0.00	**0.47**	0.09	**0.49**	0.04
Curve, ADB curves Right, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	3.109	2.28	0.16	1.46	0.03	1.63	0.08	1.36	0.09	1.75	0.12	2.38	0.41
	30-59.9	1.776	1.63	0.19	0.86	0.01	0.78	0.08	0.70	0.01	1.21	0.32	1.35	0.06
	60-119.9	0.634	**0.78**	0.08	0.19	0.04	0.22	0.09	0.23	0.00	0.57	0.28	**0.77**	0.04
	120-239.9	0.281	**0.57**	0.04	0.01	0.02	0.07	0.07	0.08	0.01	**0.40**	0.29	**0.58**	0.06
Curve, ADB curves Right, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	3.109	2.54	0.19	1.35	0.09	1.79	0.08	1.48	0.06	1.73	0.39	2.44	0.11
	30-59.9	1.776	1.53	0.10	0.78	0.07	0.73	0.08	0.66	0.03	1.14	0.20	1.30	0.13
	60-119.9	0.634	**0.71**	0.06	0.11	0.02	0.16	0.05	0.11	0.01	0.54	0.23	**0.70**	0.05
	120-239.9	0.281	**0.54**	0.08	0.00	0.00	0.00	0.00	0.00	0.00	**0.37**	0.24	**0.52**	0.04

Table 73. Average Maximum Illuminance and Standard Deviation Values by Receptor Head for Lower Beam Mode - Same Direction, Straight Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Audi, Small DAS (n=3)				Audi, SUV DAS (n=2)				BMW, Small DAS (n=3)				BMW, SUV DAS (n=2)				Lexus, Small DAS (n=3)				Mercedes-Benz, Small DAS (n=3)			
		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7	
		Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
a. DAS precedes, straight, same lane, DAS 0 mph, ADB 62 mph	15-29.9	2.21	0.16	0.13	0.10	1.75	0.00	0.07	0.00	**20.08**	2.45	0.49	0.64	4.01	0.42	0.13	0.02	2.43	0.06	0.10	0.03	3.83	0.41	0.08	0.00
	30-59.9	1.71	0.61	0.59	0.33	1.11	0.05	0.58	0.05	11.26	1.37	2.83	0.96	4.14	0.03	1.92	0.63	2.94	0.57	1.77	0.33	1.63	0.12	0.73	0.33
	60-119.9	1.92	0.50	1.63	0.85	1.61	0.09	1.76	0.23	**5.38**	0.78	**4.64**	0.39	3.89	0.80	**4.63**	0.92	1.70	0.15	1.75	0.65	2.23	0.54	2.93	0.65
	120-239.9	0.48	0.04	0.68	0.06	0.46	0.06	0.68	0.09	0.48	0.66	0.46	0.64	0.11	0.01	0.16	0.06	0.10	0.01	0.14	0.01	0.17	0.02	0.20	0.04
b. DAS precedes, straight, same lane, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	N/A	N/A	N/A	N/A	0.74	0.00	0.79	0.00	N/A	N/A	N/A	N/A	0.36	0.00	0.61	0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	60-119.9	1.36	0.73	1.62	0.84	3.04	1.28	3.36	1.02	0.64	0.65	1.09	0.47	0.26	0.12	0.83	0.46	0.18	0.02	0.29	0.03	0.36	0.06	0.50	0.05
	120-239.9	**4.11**	0.39	**4.26**	0.31	**5.89**	0.85	**5.27**	1.10	0.69	0.58	1.22	0.55	0.23	0.02	0.81	0.01	0.35	0.11	0.55	0.25	0.47	0.20	1.23	0.63
c. DAS precedes, straight, adj. lane left, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	N/A	N/A	N/A	N/A	0.23	0.00	0.89	0.00	N/A	N/A	N/A	N/A	0.31	0.00	0.48	0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	60-119.9	1.88	1.16	2.14	1.40	2.02	2.58	2.66	3.42	0.60	0.62	0.56	0.60	0.25	0.12	0.33	0.13	0.17	0.02	0.19	0.03	0.32	0.06	0.34	0.07
	120-239.9	3.36	1.21	3.98	1.39	3.74	0.75	**4.93**	1.09	0.88	0.49	0.85	0.49	0.20	0.01	0.25	0.01	0.31	0.11	0.33	0.12	0.29	0.06	0.49	0.33
d. DAS precedes, straight, adj. lane right, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	60-119.9	2.49	0.41	2.25	0.33	2.69	0.78	2.15	0.54	**4.40**	0.95	**4.48**	0.38	**4.07**	0.55	3.19	0.43	0.85	0.53	1.76	0.79	2.18	0.36	2.31	0.08
	120-239.9	2.62	0.48	2.28	0.57	**4.19**	0.14	3.39	0.16	2.18	0.95	2.90	0.91	1.69	0.58	1.90	0.84	2.07	0.76	2.89	0.51	1.55	0.29	1.77	0.15
e. DAS precedes, dip series, straight, same lane, DAS 40 mph, ADB 45 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	**31.77**	0.14	**31.80**	0.07	**29.81**	0.33	**29.24**	1.43	**21.82**	17.21	**23.10**	14.99	16.62	21.35	18.75	18.45	**22.58**	3.69	**27.09**	4.71	**29.42**	1.98	**28.41**	2.86
	60-119.9	**23.76**	1.35	**23.34**	1.74	**27.81**	2.64	**26.76**	1.79	**17.28**	1.30	**19.09**	1.04	**20.88**	0.86	**25.00**	0.71	**12.38**	0.52	**13.39**	0.32	**13.33**	7.53	**15.78**	3.41
	120-239.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
f. Motorcycle precedes, straight, adj. lane, DAS 0 mph, ADB 62 mph	15-29.9	0.70	0.09	0.06	0.03	0.47	0.01	0.02	0.01	1.12	1.00	0.10	0.10	1.35	0.11	0.03	0.00	2.96	0.16	0.04	0.02	1.45	0.03	0.03	0.01
	30-59.9	0.65	0.12	0.17	0.10	0.48	0.04	0.02	0.01	1.29	1.12	0.02	0.02	1.44	0.03	0.04	0.00	1.80	0.49	0.07	0.06	1.32	0.96	0.13	0.13
	60-119.9	1.01	0.09	0.75	0.07	0.86	0.32	0.54	0.16	2.22	2.08	1.80	1.57	2.92	0.92	1.97	0.29	2.28	0.04	1.73	0.43	1.50	0.78	1.53	0.85
	120-239.9	0.67	0.04	0.65	0.04	0.62	0.19	0.49	0.13	0.84	0.81	1.36	1.22	1.10	0.08	1.48	0.05	0.44	0.31	0.82	0.36	0.59	0.40	1.08	0.72
g. Motorcycle precedes, straight, adj. lane, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.64	0.00	0.09	0.00	N/A	N/A	N/A	N/A
	30-59.9	1.09	0.30	0.69	0.19	0.69	0.00	0.28	0.00	7.02	0.00	2.53	0.00	N/A	N/A	N/A	N/A	6.86	0.00	3.61	0.00	N/A	N/A	N/A	N/A
	60-119.9	2.02	0.99	1.73	0.91	2.88	0.34	2.20	0.12	**5.79**	1.11	**4.89**	0.29	**6.38**	0.50	3.66	0.04	3.88	1.01	3.52	1.48	2.66	0.74	2.71	0.41
	120-239.9	3.71	0.95	3.36	0.77	**4.21**	0.51	3.51	0.39	1.48	0.38	2.05	0.68	1.00	0.29	1.45	0.11	1.64	0.93	2.24	0.57	1.38	0.75	1.64	0.25

Table 74. Average Maximum Illuminance and Standard Deviation Values by Receptor Head for Lower Beam Mode - Same Direction, Left Curve Maneuver Scenarios, Small and SUV DAS, All Vehicles

Maneuver Scenario	Range (m)	Audi, Small DAS (n=3)				Audi, SUV DAS (n=2)				BMW, Small DAS (n=3)				BMW, SUV DAS (n=2)				Lexus, Small DAS (n=3)				Mercedes-Benz, Small DAS (n=3)			
		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7	
		Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
DAS precedes, curve left, same lane, DAS 0 mph, ADB 62 mph	15-29.9	2.22	0.02	0.09	0.02	1.94	0.06	0.07	0.01	3.53	0.31	0.26	0.03	2.57	0.05	0.18	0.01	1.53	0.06	0.13	0.02	3.23	0.39	0.14	0.02
	30-59.9	1.05	0.05	0.11	0.04	1.30	0.04	0.06	0.02	1.56	0.15	0.30	0.18	1.07	0.01	0.08	0.00	0.93	0.10	0.12	0.04	1.10	0.09	0.24	0.14
	60-119.9	0.21	0.01	0.06	0.01	0.26	0.01	0.03	0.01	0.22	0.01	0.07	0.03	0.22	0.02	0.04	0.00	0.22	0.01	0.07	0.03	0.26	0.01	0.09	0.03
	120-239.9	0.05	0.02	0.04	0.01	0.06	0.01	0.03	0.01	0.06	0.01	0.03	0.01	0.05	0.03	0.04	0.01	0.07	0.02	0.07	0.06	0.07	0.01	0.06	0.01
DAS precedes, curve left, same lane, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	0.33	0.13	0.27	0.18	0.41	0.01	0.12	0.09	0.44	0.11	0.30	0.20	0.30	0.13	0.07	0.03	N/A	N/A	N/A	N/A	0.37	0.05	0.23	0.09
	60-119.9	0.22	0.04	0.07	0.03	0.72	0.69	0.04	0.01	0.27	0.05	0.09	0.03	0.22	0.03	0.05	0.02	0.15	0.04	0.09	0.05	0.28	0.01	0.12	0.04
	120-239.9	0.76	0.17	0.19	0.14	1.68	0.01	0.10	0.04	0.17	0.05	0.02	0.03	0.16	0.06	0.04	0.01	0.33	0.10	0.10	0.09	0.15	0.01	0.14	0.01
DAS precedes, curve left, adj. lane left, DAS 0 mph, ADB 62 mph	15-29.9	0.38	0.07	1.92	0.11	0.21	0.16	2.76	0.12	0.57	0.13	3.26	0.18	0.29	0.00	3.24	0.12	0.53	0.06	2.38	0.03	0.65	0.17	3.35	0.31
	30-59.9	0.39	0.03	0.70	0.06	0.35	0.06	0.93	0.02	0.61	0.12	1.21	0.01	0.40	0.04	1.23	0.04	0.52	0.05	0.84	0.04	0.70	0.12	1.09	0.07
	60-119.9	0.13	0.02	0.13	0.01	0.17	0.01	0.09	0.07	0.19	0.01	0.18	0.01	0.17	0.02	0.16	0.01	0.15	0.01	0.16	0.02	0.22	0.02	0.20	0.02
	120-239.9	0.04	0.01	0.05	0.01	0.06	0.01	0.03	0.00	0.07	0.01	0.03	0.00	0.04	0.04	0.04	0.02	0.06	0.02	0.03	0.01	0.07	0.01	0.05	0.01
DAS precedes, curve left, adj. lane left, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	0.23	0.00	0.30	0.00	0.21	0.07	0.24	0.10	0.37	0.00	0.32	0.00	0.26	0.06	0.34	0.03	0.19	0.08	0.23	0.15	0.37	0.07	0.42	0.09
	60-119.9	0.16	0.04	0.15	0.02	1.20	1.49	0.15	0.01	0.26	0.05	0.19	0.07	0.18	0.05	0.17	0.02	0.47	0.53	0.26	0.12	0.23	0.02	0.25	0.02
	120-239.9	1.13	0.12	0.31	0.08	1.80	0.74	0.25	0.11	0.30	0.05	0.09	0.03	0.23	0.00	0.08	0.01	0.62	0.25	0.26	0.10	0.23	0.02	0.14	0.01
DAS precedes, curve left, adj. lane right, DAS 0 mph, ADB 62 mph	15-29.9	1.89	0.25	0.08	0.01	1.73	0.13	0.04	0.01	2.82	0.09	0.21	0.06	2.50	0.29	0.18	0.04	1.48	0.06	0.11	0.02	2.83	0.32	0.12	0.02
	30-59.9	1.05	0.06	0.08	0.02	1.29	0.05	0.02	0.01	2.06	0.12	0.11	0.04	1.41	0.21	0.08	0.02	0.97	0.05	0.09	0.02	1.09	0.09	0.08	0.01
	60-119.9	0.23	0.02	0.05	0.01	0.30	0.00	0.02	0.00	0.22	0.02	0.04	0.01	0.23	0.04	0.04	0.00	0.22	0.02	0.04	0.01	0.27	0.02	0.06	0.00
	120-239.9	0.06	0.01	0.05	0.01	0.06	0.01	0.02	0.00	0.07	0.01	0.03	0.00	0.05	0.03	0.04	0.01	0.06	0.01	0.05	0.04	0.06	0.01	0.06	0.01
DAS precedes, curve left, adj. lane right, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	0.41	0.16	0.06	0.01	0.48	0.00	0.04	0.00	0.37	0.10	0.07	0.10	0.35	0.00	0.07	0.00	0.31	0.08	0.07	0.04	0.54	0.21	0.08	0.02
	60-119.9	0.31	0.16	0.09	0.05	0.32	0.05	0.03	0.01	0.30	0.02	0.08	0.03	0.21	0.02	0.04	0.02	0.20	0.03	0.07	0.02	0.29	0.02	0.07	0.01
	120-239.9	0.33	0.34	0.06	0.00	0.57	0.27	0.03	0.00	0.12	0.04	0.00	0.00	0.09	0.01	0.04	0.01	0.11	0.03	0.05	0.04	0.14	0.02	0.09	0.01

Table 75. Average Maximum Illuminance and Standard Deviation Values by Receptor Head for Lower Beam Mode - Same Direction, Right Curve Maneuver Scenarios, All Vehicles

Maneuver Scenario	Range (m)	Audi, Small DAS (n=3)				Audi, SUV DAS (n=2)				BMW, Small DAS (n=3)				BMW, SUV DAS (n=2)				Lexus, Small DAS (n=3)				Mercedes-Benz, Small DAS (n=3)			
		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7	
		Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
DAS precedes, curve right, same lane, DAS 0 mph, ADB 62 mph	15-29.9	1.67	0.17	0.16	0.08	1.68	0.00	0.05	0.00	5.40	0.11	0.60	0.07	2.78	0.08	0.16	0.10	1.95	0.40	0.26	0.09	3.57	0.35	0.39	0.30
	30-59.9	0.58	0.01	0.23	0.05	0.75	0.01	0.20	0.03	1.81	0.07	0.59	0.07	1.15	0.02	0.35	0.06	0.56	0.03	0.30	0.06	1.10	0.08	0.61	0.10
	60-119.9	0.12	0.00	0.10	0.00	0.18	0.02	0.13	0.00	0.23	0.02	0.19	0.02	0.19	0.00	0.18	0.02	0.07	0.06	0.09	0.02	0.20	0.01	0.21	0.01
	120-239.9	0.04	0.00	0.04	0.00	0.06	0.03	0.03	0.00	0.05	0.01	0.04	0.02	0.04	0.01	0.04	0.01	0.03	0.02	0.03	0.01	0.04	0.01	0.06	0.01
DAS precedes, curve right, same lane, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	0.35	0.00	0.31	0.00	N/A	N/A	N/A	N/A	0.32	0.01	0.45	0.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.10	0.00	0.27	0.00
	60-119.9	0.57	0.50	0.53	0.43	0.10	0.03	0.15	0.04	0.23	0.16	0.29	0.06	0.06	0.01	0.15	0.03	0.29	0.33	0.40	0.37	0.21	0.18	0.44	0.35
	120-239.9	0.51	0.40	0.52	0.38	0.72	0.26	0.79	0.28	1.37	0.21	1.66	0.20	1.09	0.05	1.22	0.13	0.59	0.36	0.81	0.46	0.48	0.06	0.59	0.05
DAS precedes, curve right, adj. lane left, DAS 0 mph, ADB 62 mph	15-29.9	0.14	0.01	1.99	0.43	0.09	0.03	1.96	0.29	0.33	0.03	2.45	0.06	0.20	0.03	2.26	0.11	0.10	0.08	1.50	0.13	0.13	0.00	2.39	0.12
	30-59.9	0.10	0.03	1.04	0.12	0.08	0.04	1.34	0.05	0.16	0.01	1.14	0.02	0.09	0.03	1.09	0.06	0.09	0.08	0.86	0.05	0.12	0.02	1.02	0.03
	60-119.9	0.07	0.04	0.21	0.01	0.05	0.03	0.30	0.00	0.06	0.01	0.23	0.00	0.05	0.02	0.27	0.02	0.03	0.03	0.21	0.03	0.06	0.01	0.26	0.01
	120-239.9	0.08	0.05	0.75	1.24	0.05	0.02	0.04	0.01	0.05	0.01	0.05	0.01	0.05	0.01	0.05	0.00	0.03	0.02	0.03	0.02	0.06	0.01	0.06	0.01
DAS precedes, curve right, adj. lane left, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	30-59.9	N/A	N/A	N/A	N/A	0.03	0.00	0.47	0.00	0.05	0.00	0.23	0.00	0.05	0.00	0.27	0.00	N/A	N/A	N/A	N/A	0.06	0.00	0.55	0.00
	60-119.9	0.52	0.46	0.58	0.44	0.06	0.02	0.24	0.21	0.08	0.01	0.22	0.01	0.06	0.01	0.25	0.02	0.14	0.12	0.30	0.15	0.15	0.10	0.26	0.09
	120-239.9	0.63	0.57	0.77	0.38	0.46	0.01	1.27	0.04	0.63	0.20	1.17	0.14	0.11	0.12	1.63	0.17	0.25	0.06	0.51	0.09	0.24	0.15	0.35	0.01
DAS precedes, curve right, adj. lane right, DAS 0 mph, ADB 62 mph	15-29.9	1.92	0.16	0.12	0.08	1.70	0.00	0.06	0.00	5.30	0.52	0.31	0.25	2.74	0.02	0.09	0.01	1.91	0.36	0.15	0.08	3.29	0.30	0.23	0.22
	30-59.9	0.65	0.01	0.23	0.03	0.88	0.06	0.15	0.01	2.35	0.29	0.90	0.12	1.38	0.07	0.27	0.01	0.76	0.09	0.28	0.02	1.19	0.09	0.51	0.04
	60-119.9	0.14	0.01	0.12	0.00	0.17	0.05	0.10	0.00	0.24	0.04	0.19	0.01	0.22	0.03	0.17	0.00	0.12	0.02	0.12	0.01	0.24	0.02	0.23	0.01
	120-239.9	0.04	0.01	0.05	0.01	0.04	0.04	0.03	0.01	0.04	0.01	0.04	0.01	0.05	0.01	0.05	0.00	0.02	0.02	0.03	0.01	0.05	0.00	0.06	0.00
DAS precedes, curve right, adj. lane right, DAS 62 mph, ADB 62 mph	15-29.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.24	0.00	0.22	0.00	N/A	N/A	N/A	N/A
	30-59.9	N/A	N/A	N/A	N/A	0.52	0.00	0.23	0.00	0.34	0.09	0.27	0.06	0.46	0.00	0.31	0.00	0.71	0.00	0.31	0.00	0.30	0.01	0.27	0.01
	60-119.9	0.59	0.26	0.63	0.29	0.66	0.43	0.81	0.49	0.26	0.03	0.22	0.02	0.22	0.02	0.22	0.02	0.64	0.58	0.76	0.60	0.59	0.49	0.60	0.46
	120-239.9	0.62	0.48	0.65	0.45	0.70	0.13	0.79	0.17	1.14	0.08	1.00	0.02	0.80	0.02	0.82	0.06	0.77	0.56	0.94	0.54	0.71	0.41	0.76	0.40

Table 76. Average Maximum Illuminance and Standard Deviation Values by Receptor Head for Lower Beam Mode - Same Direction, Passing Maneuver Scenarios, All Vehicles

Maneuver Scenario	Range (m)	Audi, Small DAS (n=3)				Audi, SUV DAS (n=2)				BMW, Small DAS (n=3)				BMW, SUV DAS (n=2)				Lexus, Small DAS (n=3)				Mercedes-Benz, Small DAS (n=3)			
		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7		RH6		RH7	
		Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
DAS follows then passes, straight, same lane, DAS 62 mph, ADB 50 mph	15-29.9	1.22	0.87	2.85	1.31	0.14	0.02	1.99	0.19	1.70	0.27	7.84	1.03	0.19	0.05	2.51	0.01	0.79	0.43	2.06	0.60	0.81	0.73	2.90	0.28
	30-59.9	1.11	0.03	3.30	0.35	0.92	0.01	1.70	0.05	1.74	0.56	8.79	1.64	0.71	0.10	4.19	2.46	0.89	0.19	1.15	0.19	1.23	0.34	1.94	0.71
	60-119.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.38	0.00	2.74	0.00	0.43	0.02	2.78	0.75	N/A	N/A	N/A	N/A	0.62	0.00	0.82	0.00
	120-239.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, straight, same lane, DAS 50 mph, ADB 62 mph	15-29.9	2.98	1.19	0.65	0.96	2.35	0.13	0.54	0.00	**20.33**	10.71	14.16	15.37	8.10	3.17	1.67	2.18	2.36	0.43	0.37	0.30	4.00	0.48	1.03	0.18
	30-59.9	9.40	5.64	10.59	5.07	5.10	2.81	6.47	3.69	13.41	9.02	**19.72**	5.60	10.53	0.32	11.45	1.75	3.32	1.00	3.02	0.76	1.73	0.16	3.06	0.35
	60-119.9	**8.01**	0.48	**8.67**	1.19	**8.44**	2.13	**9.60**	1.53	1.26	0.87	**4.05**	1.70	0.41	0.10	3.46	1.08	1.14	0.48	2.74	1.63	0.63	0.21	1.03	0.48
	120-239.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DAS follows then passes, curve left, same lane, DAS 62 mph, ADB 45 mph	15-29.9	0.46	0.21	1.33	0.17	0.20	0.15	1.65	0.25	0.82	0.13	2.65	0.20	0.55	0.56	2.61	0.44	0.71	0.41	1.91	0.41	0.55	0.40	2.77	0.04
	30-59.9	0.54	0.10	0.88	0.09	0.56	0.00	1.19	0.03	0.90	0.04	1.41	0.00	0.74	0.30	1.26	0.02	0.71	0.24	0.91	0.07	0.78	0.14	1.19	0.09
	60-119.9	0.20	0.00	0.10	0.00	0.25	0.01	0.08	0.05	0.34	0.03	0.09	0.02	0.28	0.00	0.05	0.00	0.23	0.00	0.06	0.00	0.25	0.03	0.18	0.03
	120-239.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.08	0.00	0.00	0.00	N/A	N/A	N/A	N/A	0.07	0.00	0.03	0.00	N/A	N/A	N/A	N/A
ADB follows then passes, curve left, same lane, DAS 45 mph, ADB 62 mph	15-29.9	3.21	0.46	0.56	0.39	2.80	0.46	0.51	0.12	4.47	1.36	1.38	1.30	3.21	0.05	0.98	1.13	2.18	0.34	0.10	0.05	3.61	0.62	0.61	0.47
	30-59.9	1.88	0.37	1.15	0.25	1.40	0.05	0.69	0.08	1.90	0.50	1.22	0.43	1.53	0.37	0.81	0.22	1.04	0.05	0.28	0.06	1.23	0.07	0.63	0.14
	60-119.9	0.71	0.13	0.38	0.11	2.09	0.07	0.44	0.10	0.31	0.04	0.19	0.03	0.27	0.02	0.12	0.08	0.33	0.05	0.19	0.06	0.34	0.04	0.27	0.13
	120-239.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DAS follows then passes, curve right, same lane, DAS 62 mph, ADB 45 mph	15-29.9	0.71	0.22	2.85	0.20	0.42	0.31	2.87	0.03	0.50	0.21	2.81	0.27	0.27	0.01	2.72	0.07	0.41	0.31	2.26	0.71	0.25	0.14	2.86	0.26
	30-59.9	0.58	0.01	0.94	0.03	0.69	0.04	1.24	0.08	0.65	0.28	1.59	0.11	0.48	0.05	1.54	0.02	0.55	0.18	0.89	0.03	0.62	0.08	1.27	0.14
	60-119.9	N/A	N/A	N/A	N/A	0.09	0.00	0.20	0.00	0.24	0.00	0.34	0.00	0.21	0.00	0.37	0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	120-239.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ADB follows then passes, curve right, same lane, DAS 45 mph, ADB 62 mph	15-29.9	1.71	0.15	0.46	0.06	1.98	0.66	0.38	0.35	6.27	2.02	1.53	0.13	2.82	0.40	0.81	0.03	1.92	0.51	0.32	0.11	3.76	0.52	0.82	0.13
	30-59.9	3.81	0.77	2.58	0.56	3.45	1.16	2.26	0.91	5.08	0.77	5.29	0.45	3.53	2.69	4.54	1.71	2.19	1.62	2.69	2.35	1.98	0.56	4.84	1.20
	60-119.9	**5.48**	1.81	**4.61**	1.65	**4.11**	1.64	2.90	1.25	3.24	2.50	**4.71**	0.45	2.56	2.74	**4.50**	0.32	1.06	0.74	1.91	1.23	0.54	0.08	1.41	0.80
	120-239.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.56	0.00	0.82	0.00	N/A	N/A	N/A	N/A