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COMPARISON OF EUROPEAN AND U.S. SPECIFICATION AUTOMOTIVE HEADLAMP PERFORMANCE

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Abstract

Vehicle headlamps are a primary safety system. Research data from the National Highway Traffic Safety Administration (NHTSA) reports approximately 25 percent of automotive travel occurs at night. However, nearly 52 percent of all driver fatalities and 71 percent of all pedestrian deaths occur during dark driving times (NHTSA, 2018). This data leads to the conclusion that driving in dark or low-light conditions increases the likelihood of a collision at least partially due to a combination of limited forward illumination by current automotive lighting systems and the speeds at which drivers travel (NHTSA, 2018). The efficacy of headlamps compliant with U.S. regulations may be a contributing factor. Research conducted by AAA determined that modern headlamps on low beam provide adequate lighting for speeds of only 39 mph to 52 mph, depending on the type of headlamp (AAA, 2015).

While urban roadways with overhead lighting can mitigate this problem, a minority of U.S. roadways have installed overhead lighting (Technology, 2014). Additionally, U.S. drivers are reluctant to use high beam headlamps out of concern for creating glare for oncoming or preceding drivers (Mary Lynn Buonarosa, 2008), (AAA, 2015).

Increasing roadway lighting without creating glare for other motorists should increase the safety of nighttime driving. This is the promise of adaptive driving beam headlamp technologies. NHTSA describes adaptive driving beam as, “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.”

The performance specifications for U.S. headlamps are defined by Federal Motor Vehicle Safety Standard 108 that sets requirements for original and replacement lamps, reflective devices, and associated equipment. Many of the specifications were developed for sealed beam headlamps and, even with updates to the regulations, have not kept pace with recent advances in lighting technology. Section 9.4 of the standard expressly prohibits simultaneous operation of high and low beam headlamps, thereby excluding adaptive driving beam headlamp systems from vehicles sold in the U.S.

This research project intends to evaluate the effectiveness and limitations of European specification vehicles equipped with adaptive driving beam technology. U.S. specification headlamp systems and adaptive driving beam technology available on European specification vehicles will be quantitatively and qualitatively compared.

The vehicles selected for testing were sourced from two vehicle manufacturers who provided both U.S. and European specification vehicles of the same model. The U.S. specification vehicles are equipped with LED headlamps and auto-dimming technology, which allows driving with high beams by default above a set speed, and automatic switching to low beam operation when oncoming or preceding traffic is detected. The European specification vehicles are equipped with LED headlamps and adaptive driving beam technology.

Research Questions:

1. How do U.S. and European specification low and high beam headlamps differ in static roadway illumination?
2. How do U.S. and European specification headlamps differ in producing glare?
3. How do U.S. and European specification headlamps differ in dynamic roadway illumination?

Key Findings:

1. During static testing of roadway lighting, driver perception of target illumination was similar among all vehicles tested.
    a. U.S. specification headlamps produced 1.9% more low beam illumination on targets.
    b. Average target illumination values for high beam was 12.5% higher for European specification as compared to U.S. specification headlamps.
2. All four test vehicles scored in the low perceived glare range of the evaluation scale, ranging from “Satisfactory” to “Just Acceptable”. One manufacturer’s European specification vehicle scored better than its U.S. specification counterpart did. Results for the other manufacturer’s vehicles were reversed.
3. European specification systems consistently provided more roadway lighting when an oncoming vehicle was approaching, or a preceding vehicle was close.
    a. Based on static target illumination data, the increase in roadway lighting could be as much as 86 percent (comparison of average European specification high beam to U.S. specification low beam).
    b. The adaptive driving beam (ADB) system maintained high beam operation in all areas except those intentionally shaded by the system to minimize glare.

c. In similar vehicle placement circumstances, the U.S. specification vehicles were forced to reduce headlamp operation to low beam in order to minimize the likelihood of producing glare to oncoming and preceding vehicles.

Roadways with hills were the most common driving scenario where other drivers were subjected to potential glare by an ADB capable vehicle. It should be noted that all headlamp systems currently available (manual high-low switching and automatic high-beam) produce glare to other drivers when cresting hills. In this situation, where glare potential is high, AAA research noted that it occurred less frequently with ADB capable European specification headlamp systems than with auto-dimming U.S. specification systems.

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1 Overview

Vehicle headlamps are a primary safety system. Research data from the National Highway Traffic Safety Administration (NHTSA) indicates that roughly 25 percent of automotive travel occurs at night. However, nearly 52 percent of all driver fatalities and 71 percent of all pedestrian deaths occur during dark driving times (NHTSA, 2018). This data leads to the conclusion that driving in dark or low-light conditions increases the likelihood of a collision at least partially due to limited forward illumination by current automotive lighting systems combined with the speeds at which drivers travel.

Previous AAA research concluded that low beam headlamp systems using halogen bulbs and reflector-type optics do not adequately illuminate the roadway at speeds in excess of 39 mph. Projector lens and LED light sources can extend the range of useful roadway illumination and provide sufficient illumination at speeds up to 45 mph, and LED headlamps up to 52 mph. (AAA, 2015).

High beam headlamps improve forward illumination up to 28 percent compared to low beams. Unfortunately, two-thirds (64 percent) of U.S. motorists who drive at night say they do not regularly use their high beam headlamps (AAA, 2015). To address this situation, many automakers are introducing headlamps that can be set to automatically switch between low and high beams based on driving conditions.

An optimal headlamp solution would provide sufficient forward illumination so that a driver, at any reasonable vehicle speed, would always have sufficient time to visually identify and appropriately react to any dangerous roadway condition, including pedestrians, animals and other obstacles. However, safe nighttime driving at posted speed limits on unlit roadways requires more forward illumination than is provided by headlamp systems currently available in the U.S.

Automakers and lighting system designers have worked to close the gap between the speeds at which motorists drive and the required amount of roadway illumination. However, a major challenge in the development of more advanced lighting systems has been limiting glare. Most options for increased roadway illumination can also create glare for oncoming and preceding motorists. Solutions have been developed and are available on selected vehicles sold in Europe and elsewhere in the world. Commonly called adaptive driving beam (ADB) headlamps, these systems allow driving with the high beams always on. Glare is prevented by dynamically controlling segments of the headlamp beam to create “shadowed” areas in the locations of oncoming and preceding vehicles. These dynamic, adaptive driving beam systems have the potential to deliver increased roadway illumination for safer driving at higher speeds while shielding other drivers from glare.

2 Regulatory limitations to allowing advanced headlamp systems in the U.S.

Federal Motor Vehicle Safety Standards (FMVSS) developed by NHTSA specify technical requirements for all vehicles sold in the United States. Automotive headlamps are regulated by FMVSS 108. This regulation clearly defines headlamp performance, installed position, luminescence, considerations for glare, and aiming for both low beams and high beams. Although FMVSS 108 does not specifically address or prohibit the use of ADB lighting systems, certain technical requirements have been interpreted to rule out their use. Two relevant sections of FMVSS 108:

- §9.4: Low and high beam headlight beams cannot be energized at the same time. This is a fundamental obstacle to allowing ADB headlamp systems in the U.S.
- §6.1.5.2.1 to §6.1.5.2.3: These sections detail scenarios where high and low beams are allowed to be used simultaneously, but they do not include the basic function of ADB systems.

FMVSS 108 also outlines detailed photometric requirements for both low and high beams. ADB headlamps use a combination of low and high beams at the same time, and deactivate the lights in specific areas to prevent glare. Unfortunately, this dynamic lighting control makes ADB headlamps unable to meet all of the requirements specified in the FMVSS standard.

2.1 Canadian Regulatory Requirements

Canadian regulations for vehicle headlamps (CMVSS - Canada Motor Vehicle Safety Standard) are very similar to those in the U.S. However, CMVSS 108, the Canadian counterpart to FMVSS 108, was amended in March 2018 to permit the use of European-style headlamps equipped with ADB capability (Canada, 2018). The regulation states that headlamps may be used, provided they comply with either the requirements detailed in the relevant United Nations Economic Commission for Europe (UNECE)[1] headlamp regulations as described below or the ADB test procedure described by the Society of Automotive Engineers (SAE) Recommended Practice J3069 201606..

[1] The World Forum for Harmonization of Vehicle Regulations is a working party of the Sustainable Transport Division of the United Nations Economic Commission for European (UNECE). It is tasked with creating a uniform system of regulations, called UN Regulations, for vehicle design to facilitate international trade.

2.2 United Nations Regulatory Requirements

UNECE regulations 48 and 123 (UNECE, 2018) include the most significant sections pertaining to the function and use of ADB headlamps in the European Union (EU). As part of the Transatlantic Trade and Investment Partnership, a study was completed comparing the differences between U.S. regulations and those enforced in EU countries. The differences are summarized below:

EU (UN Regulations)		US (FMVSS/SAE Standards)	
Signal [Applicability]	**Functional Intent**	**Signal [Applicability]**	**Functional Intent**
Adaptive Front-Lighting System (AFS) [Optional]	A lighting device that provides beams with differing characteristics for automatic adaption to varying conditions of use for the dipped-beam (passing-beam) and the main-beam (driving-beam) (R48, 2.7.28)	Full Adaptive Forward Lighting System (AFS) [Optional]	No formal definition in SAE standard (J2838)

Figure 1: Regulatory Requirement Differences Regarding ADB Systems, EU vs US (Broetjes, 2018)

The UN regulation directly defines the functional intent of adaptive driving beam headlamps and permits their use as part of its regulatory construct, while U.S. regulations do not. For a detailed description of the differences between U.S. and EU lighting requirements, refer to the full study cited in the bibliography.

3 Technology Description

U.S. and European regulations are similar in defining both low beam and high beam headlamps. The high beam is primarily for distance, and to illuminate the roadway when not closely following or meeting oncoming vehicles. The low beam is intended to illuminate the roadway and immediate area ahead of the vehicle when closely following or meeting an oncoming vehicle (Broertjes, 2018).

Some countries have changed from U.S. to UNECE regulations in the past: the UK in the 1970s, Australia in the 1980s, and Japan in the 1990s.

3.1 Allowances and Limitations of U.S. Regulations

The following points summarize U.S. regulatory requirements related to the twin goals of providing adequate roadway lighting and minimizing glare to oncoming and preceding drivers.

- According to U.S. regulations, low beam and high beam headlamps are required to operate independently. This requirement is interpreted to specifically excludes ADB lighting systems due to their always-on high beam with low beam projection where appropriate (shuttering oncoming or preceding vehicles).
- Illumination of targets to the side of the roadway has been found to be much higher with U.S. specification low beam headlamps (Federal Register, 2018).
- U.S. regulations allow higher mounting heights for headlamps (up to 52 inches, which is 6.77 inches (172mm) above the European limit). This can contribute to glare as the height of the headlamp approaches the level of the driver and mirrors in other vehicles. Compounding this problem, U.S. regulations do not require vertical aiming adjustment based on mounting height. (The higher the headlamp is mounted on the vehicle, the more it is angled downward.) This can result in large vehicles, such as pickup trucks and SUVs directing more light at greater elevations above the road. Current U.S. regulations only require headlamps to be compliant when tested in the lab. The practice of allowing headlamp mounting above the typical height is inconsistent with the goal of reducing glare to drivers of an oncoming or preceding vehicle (Federal Highway Administration, 2014).
- The measured limits of light output in headlamp beam areas that produce glare are over twice as large in U.S. regulation as compared to UNECE regulation limits (Official Journal of the European Union, 2018).
- Current U.S. regulations do not quantify glare.
- U.S. regulations treat cleaning (washing systems) of headlamps as optional.

3.2 Comparison to Automotive Lighting Standards in Europe

European lighting regulations are documented in United Nations Economic Commission for Europe UNECE regulations, which have been adopted by most countries in the world with the exception of the United Stated and Canada. Two differences in current UNECE regulations and those of the U.S. have to do with allowable high beam intensity and headlamp mounting height. Higher allowable limit for high beam intensity means more light on the roadway and better safety when using high beam headlights. The lower limit for headlamp mounting height in the UNECE regulations means that the source of automotive headlight beams is most likely below the height of eyes of drivers in oncoming or preceding vehicles, thereby reducing the chance for glare.

- European lighting standards (UNECE) allow over two times the light output from high beam headlight systems as compared to the U.S. (Broertjes, 2018). U.S. compliant systems allow a vehicle maximum of 150,000 candela while European compliant systems allow a vehicle maximum of 430,000 candela (Official Journal of the European Union, 2018). This provides for gains in sight distance, but also increases the potential for glare to affect oncoming and preceding traffic when high beams are not dimmed.
- The allowable mounting height limit of headlamps in UNECE regulated markets is 6.77 inches (177mm) lower than in the U.S. and UNECE regulations require increasing the downward inclination of the headlight beam as the mounting height is increased
    - Vehicles manufactured for a world market have a headlamp mounting height compliant with UNECE requirements, even in the U.S. version.

3.3 ADB Use Case Scenarios

The following visual representations of five use cases depict the on-road scenarios considered when evaluating the performance of ADB in terms of visibility for the driver and glare for other drivers. Use cases support the development of test cases that can be used throughout the automotive industry and with regulators.

Figure 2: Use Case Scenario 1 Preceding, Straight, Two Car (RH drive depicted)

Figure 3: Use Case Scenario 2 Oncoming, Straight, Two Car (RH drive depicted)

Figure 4: Use Case Scenario 3 Preceding, Curved, Two Car

Figure 5: Use Case Scenario 4 Oncoming, Curved, Two Car

Figure 6: Use Case Scenario 5 Oncoming, Curved Intersection, Two Car

3.1 ADB Certification and Testing for Regulatory Approval

Headlamp testing for regulatory compliance in the U.S. currently involves evaluating a headlamp as a separate piece of equipment in a lab. Fixed high and low beam patterns are measured with a static photometric test. While this static testing environment can capture photometric properties, it does not capture all aspects of on-road illuminance and performance, particularly for a dynamic system like adaptive driving beam. ADB adapts the light pattern based on the presence and location of other vehicles. The performance of ADB headlamps is dependent on the presence and location of other vehicles, as well as the camera/sensor, software, and mechanism used to control the beam pattern. Evaluation of ADB performance requires whole-vehicle track testing to replicate the presence of other vehicles and measure the glare perceived.

The Society of Automotive Engineers (SAE International) developed J3069, a recommended practice that includes test procedures, performance requirements, and design guidelines for ADB systems (SAE International, 2016). The road test conditions include a stationary fixture that represents a preceding or oncoming vehicle and houses sensors at locations representing drivers' eyes and rear-view mirrors for measuring glare. SAE International recommends that the illuminance at these locations should not exceed glare levels from low beam headlights that meet the current FMVSS 108 regulations. Glare level limits were derived from angular photometric requirements from the current standard FMVSS 108.

In addition to testing for ADB, NHTSA has considered the whole-vehicle testing approach for existing headlamp technology. The Insurance Institute of Highway Safety (IIHS) headlamp safety testing of currently available systems indicates that although a headlamp may meet the lab testing requirements, the on-road performance may not be as safe as desired due to systemic factors including headlamp aim (IIHS, 2016). If whole-vehicle testing were pursued, performance would be based on illuminance provided by the headlamps on the road as installed on the vehicle rather than the light properties of the headlamps as an individual component. By utilizing whole-vehicle testing, regulation can be based on dynamic road visibility and glare performance as perceived by end users.

3.2 U.S. Headlamps versus ADB

Improvements in visibility could be a factor in decreasing the number of road fatalities that occur at night. Numerous studies have highlighted that drivers infrequently use their upper beam headlamps. A study by the University of Michigan Transportation Research Institute (UMTRI) indicated that drivers turned on high beams only approximately 25 percent of the distance driven in nighttime situations where their use would be reasonable and advisable (Mary Lynn Buonarosa, 2008). This percentage was confirmed by a AAA survey in 2015 (AAA, 2015). There are several potential reasons for this lack of use per the IIHS. Some drivers may be concerned about causing glare for other drivers. Others may forget to use their high beams or not realize the benefit of high beams over low beam lighting. The added visibility provided by high beams gives drivers more stopping distance and may minimize damages in the event of an accident or prevent an accident from happening in the first place.

An ideal headlamp system maximizes visibility while limiting glare for others. Low beams offer low glare potential for others at the expense of visibility for the driver. High beams provide more visibility but can cause excessive glare for other drivers in the vicinity. High beam assist is a technology available that automatically switches between low beams and high beams, so drivers can have the visibility of high beams when other vehicles are not in the vicinity. When another vehicle is detected, the system automatically switches to the low beam setting until the other vehicle has passed. This technology is a remedy for the under-utilization of high beam, though ADB provides even further enhancements to visibility and safety. NHTSA states, “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 over oncoming and preceding vehicles. This functionality improves long-range visibility for the driver without causing discomfort, distraction, or glare to other road users.”

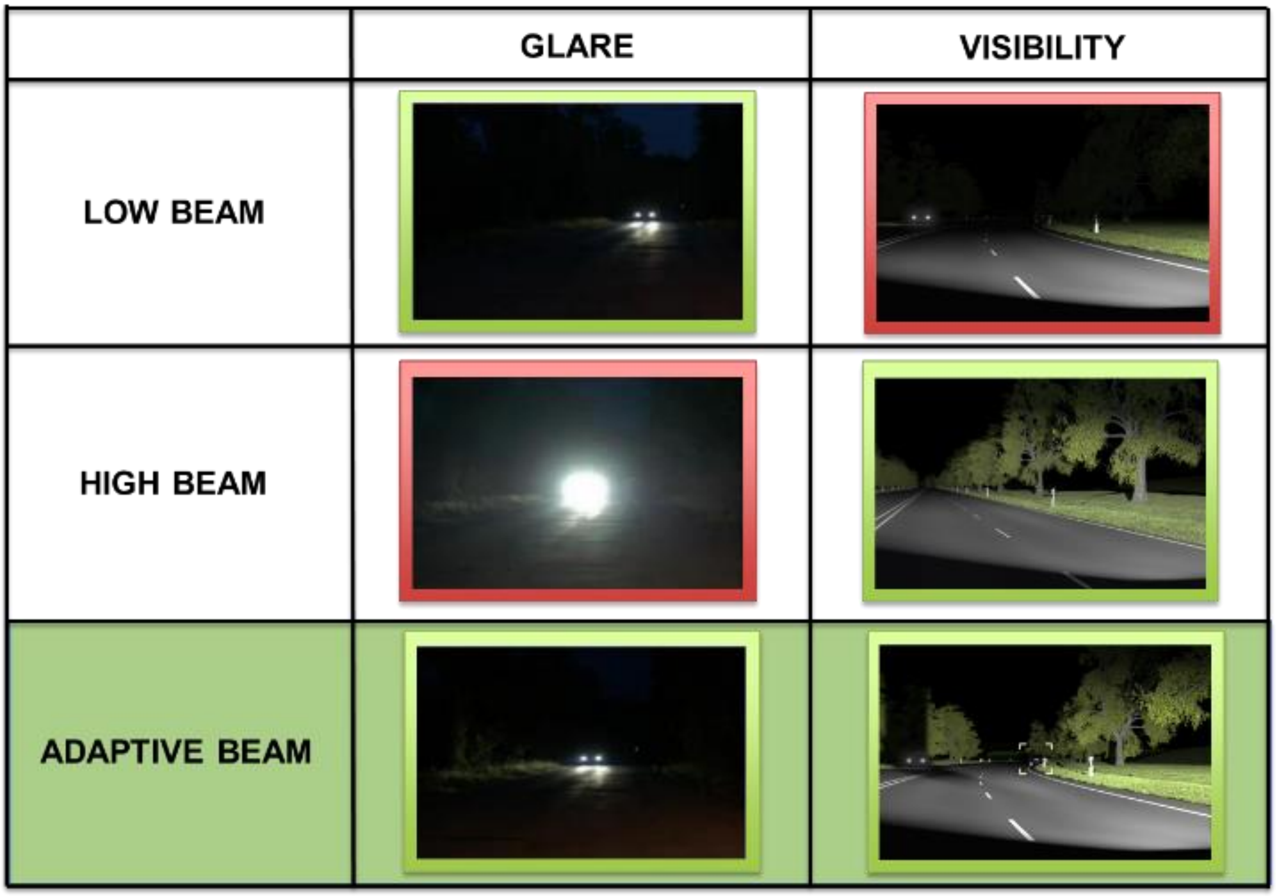


Figure 7: Comparison of glare and visibility provided by low beam, high beam, and adaptive beam. (Bullough, HELLAGroup)

Figure 8: Visual comparison of illumination – low beam versus adaptive beam (HELLAGroup)

3.1 Test Vehicles

Test vehicles were sourced from Volkswagen Group of America (Audi) and Mercedes-Benz USA. The vehicle description was obtained from a uniform set of questions answered by U.S. representatives of each vehicle manufacturer. Vehicle manufacturer representatives were present during static and closed course testing and verified proper operator selections to enable both automatic dimming (U.S. specification) and adaptive driving beam (European specification).

The following four vehicles were made available to AAA researchers for testing.

Figure 9: Test vehicles used in AAA research (image AAA)

3.1.1 2018 Audi A8

3.1.1.1 U.S. Specification vehicle

The test vehicle sourced from Audi Research and Development is a pre-development model with a headlamp system fully compliant for the U.S. market. Additional information about the test vehicle includes:

- Equipped with LED and auto-dimming headlamps
- Lighting package includes the HD Matrix design LED headlights and OLED taillights
    - Option price for this headlamp package is $3,400
    - Vehicles with this option package are sold in the U.S. and are fully compliant with U.S. regulations. Audi can update to full matrix beam (ADB) functionality with a software update should the regulations change
    - This lighting system is an upgrade. The entry-level system uses a different non-matrix LED system that has fewer modules installed and includes high beam assist.

3.1.1.2 European Specification Vehicle

The test vehicle sourced from Audi Research and Development is a pre-development model with a headlamp system fully compliant for the European market. Additional information about the test vehicle includes:

- Test vehicle is equipped with HD Matrix LED headlamps.
- Detailed information and feature description for the installed lighting package is accessible on the following VW/Audi website: https://bit.ly/2BSgF2T.
- The marketing name for the lighting package is LED mit Laserlicht and can be purchased independently of a package, which is common in Europe.
- An LED Matrix system is standard equipment on the European specification A8.

3.1.2 2018 Mercedes E-Class

3.1.2.1 U.S. Specification Vehicle

The test vehicle sourced from Mercedes Benz Research and Development and is a 2018 E300 4MATIC with headlamp system fully compliant for the U.S. market. Additional information about the test vehicle includes:

- Vehicle is manufactured in Germany, imported and available for sale in the U.S.
- Equipped with LED headlamps and ADB Assist, which is part of the LED Intelligent Light System headlamps application.
- Information and feature description for the installed lighting package is provided in the vehicle owner's manual (pages 114-118), accessible on the following Mercedes-Benz website: https://bit.ly/2QbiosC. The website URL and page reference are provided by the vehicle manufacturer.
- The LED Intelligent Light System headlamps are only available within the "Premium 2 Package" at an option price of $6,600.
- The marketing name, LED Intelligent Light System, is named MULTIBEAM LED in other markets where it also includes the full package of low and high beam functions.
- These specific headlights are only sold in the United States and Canada. Other markets have the same headlights and same hardware, but as MULTIBEAM LED, have more capabilities and better performance due to the use of different software.
- In the U.S., the tested lighting system is offered as an upgrade for E-Class models but comes as standard equipment for S-Class models (known as Intelligent Light System with Ultra Wide Beam headlamps).

3.1.2.2 European Specification Vehicle

The test vehicle sourced from Mercedes Benz Research and Development is a pre-development model with a headlamp system fully compliant for the European market. Additional information about the vehicle includes:

- The installed headlamps are available in European E-Class models since 2016.
- Equipped with LED Headlamps.
    - The marketing name of the ADB system is MULTIBEAM is consistent in all markets except U.S. and Canada (although Canada now allows MULTIBEAM). Full description of the MULTIBEAM LED is available at: https://bit.ly/2E04PF4, https://bit.ly/2BUEDul and https://bit.ly/1MhNosV.
    - The option price in Germany for the installed headlamp package is 2.320,50 Euro ($2,642 USD[2]).
    - The latest headlight technology includes an additional ULTRA RANGE high beam module. However the test vehicle in this study did not have this included. MULTIBEAM LED with ULTRA

[2] Online currency conversion December 6, 2018

RANGE high beams were first introduced in the Mercedes S-Class facelift for the 2018 model year. This headlight system is currently offered for C-Class models, CLS-Class models and will be available for other carlines in the future. Additional information is available is provided by the vehicle manufacturer: https://bit.ly/2SBtOD1 and https://bit.ly/2RCiPc2.

4 Inquiry #1: How do U.S. and European specification low and high beam headlamps differ in static roadway illumination?

4.1 Objective

Quantitatively and qualitatively, evaluate the light output of U.S. and European specification low and high beam headlamps to discern any differences between the two.

4.2 Methodology

The purpose of this evaluation is to quantify the effectiveness of low and high beam headlamp systems in illuminating the roadway ahead of the vehicle. AAA researchers independently conducted all testing on a closed-course.

Dynamic functionality, when the vehicle is driving[3] as opposed to stopped, of U.S. vehicles allows driving with high beam headlights on all the time and automatically switching to low beam when an oncoming or preceding vehicle is noted by the vehicle sensors. This functionality is active during the drive-by glare testing.

Dynamic functionality of the European specification vehicles, equipped with adaptive driving beam (ADB) headlamp systems, is activated during the drive-by glare testing.

Both vehicle manufacturers offer additional long-range headlamp functionality (for open road driving at sustained speeds) which was not evaluated in this test[4].

4.2.1 Quantitative Evaluation

The closed-course area used for this test consisted of an unlighted level asphalt surface approximately 1,300 feet long and 30 feet wide. Testing was initiated at least ninety minutes after sunset to ensure that ambient lighting was typical of an unlighted roadway during nighttime hours. Non-reflective black targets with a square cross-section (12” sides) were deployed throughout the testing lane. Targets were arranged to provide evaluation points directly ahead of the test vehicle as well as toward the left and right-hand sides of the roadway. Figure 11 describes the target placement for testing. All distances

[3] Automatic dimming headlamp systems and ADB work above a minimum speed, which is set by the vehicle manufacturer.
[4] Refer to “Test Vehicles”, section 3.8 for additional details and resources to learn more about optional lighting systems available in both the U.S. and European markets.

are in reference to the front center point of the test vehicle. A positive lateral distance is to the driver's side, or left of the vehicle, and a negative lateral distance is to the right.

For consistency, each test vehicle was placed in an identical orientation facing the targets. For European specification vehicles, the ADB system was switched off, and low beam or high beam mode was selected manually.

During testing, the vehicle's engine was allowed to idle to ensure a stable voltage supply to the headlamps. The instrument panel lighting was adjusted to mid-way between minimum and maximum settings. The low beam downrange light intensity was measured on the vehicle-facing surface of each target with a calibrated light sensor facing directly toward the test vehicle. After the light intensity at each target was measured, the high beams were switched on and the light intensity measurements were repeated at each target.

4.2.2 Qualitative Evaluation

The test setup described in Section 4.2.1 was used for qualitative evaluations. Five (5) AAA researchers participated in "driver" perception testing. A brief description of each researcher is provided below.

#	Sex	Age	Vision
1	M	50s	Glasses
2	M	50s	Glasses
3	M	20s	No Correction
4	M	30s	No Correction
5	M	40s	Reading Glasses

Figure 10: Researcher description

To ensure researchers were acclimated to the dark, a minimum of ninety minutes was spent in nighttime ambient conditions without the presence of light sources prior to test participation. For the evaluation, each researcher reported on his perception of each non-reflective target. Specifically, researchers would rate target perception in terms of one (1) out of three (3) possible outcomes.

1. Object is clear enough that you would take immediate measures as a driver to avoid it.
2. Object is noted, but its outline is unclear or vague enough that you would not take immediate action to avoid it.
3. Object is not discernable with a maximum of two seconds effort.

The scores from each researcher are summed for all test vehicles to provide a comparison of lighting efficiency while the vehicle is stopped (neither ADB or automatic dimming is active).

Target	Longitudinal Distance (ft)	Lateral Distance (ft)
1	100	24
2	100	-34
3	150	9
4	200	7
5	250	5
6	300	-9
7	350	-6
8	400	-3
9	500	0
10	600	6
11	700	0
12	800	-6
13	1000	0

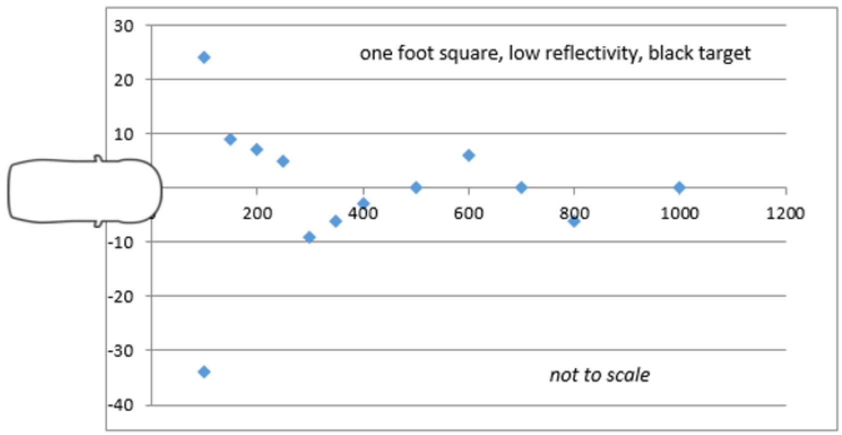


Figure 11: Placement of lights for target illumination evaluation

Each researcher performed the evaluation with low beam headlamps and then repeated the procedure with high beam headlamps. Each test vehicle was evaluated by researchers in the same sequence to minimize variation between vehicles.

The purpose of the evaluation is to determine whether researchers' abilities to discern non-reflective objects is affected by headlamp specification. Due to differences in eyesight, it is expected that this ability will vary somewhat between individuals.

4.3 Key Findings

Driver perception of target Illumination during static testing was similar among all vehicles tested.

The U.S. specification vehicles produced 1.9% more low beam illumination on targets. This finding is in line with NHTSA support of U.S. low beam patterns over European specification (Federal Register, 2018).

The average target illumination values for high beam was 12.5% higher for European specification vehicles compared to U.S. specification. This is unsurprising considering the higher output allowed for high beam operation in European specification vehicles (430,000 cd vs. 150,000 cd for U.S. specification).

All test vehicles (U.S. and European specification) were equipped with premium LED headlamps and performed in the expected range of that headlamp system.

4.4 Vehicle Testing Results

Individual vehicle results are anonymized in this report. Assignment of number 1 or 2 to Audi and Mercedes was accomplished by coin toss. The goal of this research is not to compare specific manufacturers, but to assess the differences between U.S. and European specification headlamps. Anonymized results are credited as follows:

- "U.S. specification, manufacturer 1"
- "European specification, manufacturer 1"
- "U.S. specification, manufacturer 2"
- "European specification, manufacturer 2"

Thirteen black targets, area approximately one-foot square and low reflectivity, were viewed by the panelists in an array as shown in the images in this section.

The sum total scores across all five panelists were tallied for each vehicle. In addition, the illumination from the test vehicle headlamps that fell on the targets was recorded and summed across all targets.

The European specification, manufacturer 1 low beam scored slightly lower than the U.S. specification manufacturer 1 low beam, with a score of 49 to 52 respectively. In high beam operation, the European specification, manufacturer 1 high beam performed better (with a score of 60) compared to the U.S. specification, manufacturer 1 high beam (with a score of 50). The total illumination on the targets for U.S. specification, manufacturer 1 low beam was a total of 103.9 lux on the targets versus 96.7 lux for the European, specification manufacturer 1 ADB. Both manufacturer 1 high beam totals were similar, with 141.48 lux for the U.S. specification headlamp versus 151.21 lux for the European specification manufacturer.

Figure 12: Target illumination view from U.S. specification mfg. 1, low beam

	U.S. Spec Manufacturer 1 - Low Beam					Target Illumination (Lux)
			researcher			
Target	2	4	1	5	3	
1	2	2	2		2	15.61
2	0	2	2		1	4.16
3	2	2	2		2	16.78
4	2	2	2		2	14.98
5	2	2	2		2	12.25
6	0	2	2		1	9.53
7	0	2	2		1	8.84
8	0	2	2		1	7.50
9	0	0	0		0	5.08
10	0	0	0		0	3.27
11	0	0	0		0	2.52
12	0	0	0		0	2.22
13	0	0	0		0	1.16
average	1.00				average	7.99
SUM	**52**				**SUM**	**103.90**

Figure 13: Target perception and illumination scores U.S mfg. 1, low beam

	U.S. Spec Manufacturer 1 - High Beam					Target Illumination (Lux)
			researcher			
Target	2	4	1	5	3	
1	2	2	2		2	12.39
2	0	2	0		0	2.88
3	2	2	2		2	41.15
4	2	2	2		2	26.05
5	2	2	2		2	17.00
6	0	2	2		1	9.90
7	0	2	2		1	8.41
8	0	2	2		0	7.44
9	0	1	1		0	5.40
10	0	0	0		0	4.12
11	0	0	0		0	2.88
12	0	0	0		0	2.42
13	0	0	0		0	1.44
average	0.96				average	10.88
SUM	**50**				**SUM**	**141.48**

Figure 14: Target perception and illumination scores U.S mfg. 1, high beam

Figure 15: Target illumination view from European specification mfg. 1, low beam

	Euro Spec Manufacturer 1 - Low Beam					Target
			researcher			Illumination
Target	*2*	*4*	*1*	*5*	*3*	(Lux)
1	2	2	2	2	2	27.20
2	0	1	0	0	0	2.13
3	2	2	2	2	2	24.11
4	2	2	2	2	2	14.20
5	2	2	2	2	2	8.80
6	0	2	1	0	1	5.04
7	0	1	1	0	1	4.31
8	0	0	0	0	1	3.63
9	0	0	0	0	0	2.59
10	0	0	0	0	0	1.87
11	0	0	0	0	0	1.23
12	0	0	0	0	0	1.12
13	0	0	0	0	0	0.47
average	0.75				average	7.44
SUM	**49**				**SUM**	**96.70**

Figure 16: Target perception and illumination scores European mfg. 1, low beam

	Euro Spec Manufacturer 1 - High Beam					Target Illumination (Lux)
			researcher			
Target	2	4	1	5	3	
1	2	2	2	2	2	27.23
2	0	1	0	0	0	2.09
3	2	2	2	2	2	48.73
4	2	2	2	2	2	26.33
5	2	2	2	2	2	15.18
6	0	2	2	2	2	7.12
7	0	2	2	1	2	6.46
8	0	1	2	0	1	5.70
9	0	0	0	0	0	4.22
10	0	0	0	0	0	3.36
11	0	0	0	0	0	2.10
12	0	0	0	0	0	1.79
13	0	0	0	0	0	0.90
average	0.92				average	11.63
SUM	**60**				**SUM**	**151.21**

Figure 17: Target perception and illumination scores European mfg. 1, high beam

Figure 18: Target illumination view from U.S. specification mfg. 2, low beam

The target recognition for the U.S specification, manufacturer 2 low beam was lower with a score of 40, compared to the European specification, manufacturer 2, which scored 46.

	U.S. Spec Manufacturer 2 - Low Beam					Target Illumination (Lux)
	researcher					
Target	2	4	1	5	3	
1	2	2	2	2	2	14.88
2	0	0	0	0	0	4.57
3	2	2	2	2	2	13.98
4	2	2	2	2	2	8.63
5	2	2	2	2	2	5.93
6	0	0	0	0	0	3.04
7	0	0	0	0	0	2.70
8	0	0	0	0	0	2.54
9	0	0	0	0	0	1.98
10	0	0	0	0	0	1.54
11	0	0	0	0	0	1.00
12	0	0	0	0	0	0.94
13	0	0	0	0	0	0.44
average	0.62				average	4.78
SUM	**40**				**SUM**	**62.17**

Figure 19: Target perception and illumination scores U.S mfg. 2, low beam

	U.S. Spec Manufacturer 2 - High Beam					Target Illumination (Lux)
			researcher			
Target	2	4	1	5	3	
1	2	2	2	2	2	19.02
2	0	2	2	2	2	9.38
3	2	2	2	2	2	33.40
4	2	2	2	2	2	21.84
5	2	2	2	2	2	14.88
6	0	2	2	2	1	7.64
7	0	2	2	2	1	6.94
8	0	1	1	0	0	6.43
9	0	0	0	0	0	4.49
10	0	0	0	0	0	3.56
11	0	0	0	0	0	2.45
12	0	0	0	0	0	2.05
13	0	0	0	0	0	1.23
average	0.98				average	10.25
SUM	**64**				**SUM**	**133.31**

Figure 20: Target perception and illumination scores U.S mfg. 2, high beam

The European specification, manufacturer 2 high beam scored marginally better when compared to the U.S. specification, manufacturer 2 high beam with a score of 66 versus 64.

Figure 21: Target illumination view from European specification mfg. 2, high beam

	Euro Spec Manufacturer 2 - Low Beam					Target Illumination (Lux)
	researcher					
Target	2	4	1	5	3	
1	2	2	2	2	2	15.90
2	0	1	1	2	1	4.01
3	2	2	2	2	2	14.44
4	2	2	2	2	2	9.83
5	2	2	2	2	2	7.08
6	0	1	0	0	0	3.44
7	0	0	0	0	0	3.02
8	0	0	0	0	0	2.68
9	0	0	0	0	0	2.05
10	0	0	0	0	0	1.48
11	0	0	0	0	0	0.95
12	0	0	0	0	0	0.89
13	0	0	0	0	0	0.39
average	0.71				average	5.09
SUM	**46**				**SUM**	**66.16**

Figure 22: Target perception and illumination scores European mfg. 2 low beam

	Euro Spec Manufacturer 2 - High Beam					Target Illumination (Lux)
	researcher					
Target	2	4	1	5	3	
1	2	2	2	2	2	32.15
2	1	2	2	2	2	8.34
3	2	2	2	2	2	40.08
4	2	2	2	2	2	24.50
5	2	2	2	2	2	16.05
6	0	2	2	1	2	8.69
7	0	2	2	0	2	7.56
8	0	2	1	0	1	6.52
9	0	0	0	0	0	4.70
10	0	0	0	0	0	3.57
11	0	0	0	0	0	2.47
12	0	0	0	0	0	2.06
13	0	0	0	0	0	1.22
average	1.02				average	12.15
SUM	**66**				**SUM**	**157.91**

Figure 23: Target perception and illumination scores European mfg. 2, high beam

4.4.1 Illumination values measured at targets

The following table summarizes the illumination values in lux measured with a calibrated light meter at each target. Measurements were recorded for all four test vehicles for both low beam and high beam operation.

	Low beam	High beam
U.S. mfg. 1	103.90	141.48
Euro mfg. 1	96.70	151.21
U.S. mfg. 2	62.17	133.31
Euro mfg. 2	66.16	157.91

U.S. low beam average	83.0
U.S. high beam average	137.4
Euro low beam average	81.4
Euro high beam average	154.6

Euro low to U.S. low	**-1.9%**
Euro high to U.S. high	**12.5%**

Figure 24: Summary values for target illumination (lux)

5 Inquiry #2: How do U.S. and European specification headlamps differ in producing glare?

5.1 Objective

Evaluate the glare produced by U.S. automatic high beam headlights and ADB capable European specification headlamp systems when approaching a vehicle traveling in the opposite direction on a two-lane road.

5.2 Methodology

The de Boer scale was utilized to quantify distraction glare resulting from U.S and European specification headlamp systems. The five (5) AAA researchers that gave subjective feedback in Section 4.2.2 also participated in this evaluation.

All testing was conducted on a closed-course asphalt test lane approximately 1,300 feet long and 30 feet wide. A static observation vehicle was parked at one end of the evaluation section. The left side of the observation vehicle was parked approximately eight (8) feet laterally offset from the left side of the dynamic test vehicle during its approach. The low beam headlights of the stationary observation vehicle were engaged to provide stimulus to the headlamp system of the test vehicle, and the vehicle engine was idled to provide consistent voltage to the headlamps.

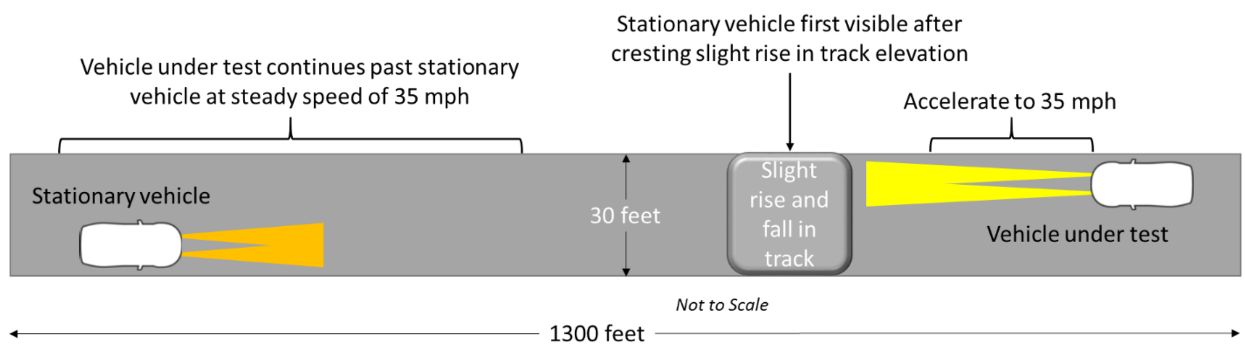


Figure 25: Schematic of drive-by glare test

From the opposite end of the test lane, the test vehicle was accelerated to a steady-state speed of 35 mph approaching the slight rise and fall in the test track. At a steady-state speed of 35mph, the test vehicle crested the slight hill and proceeded 760 feet on level surface past the stationary vehicle. Glare produced by the oncoming test vehicle was evaluated by participants sitting in the driver's front seat position of the observation vehicle.

This scenario replicated typical headlamp illumination from oncoming vehicles being transmitted through the windshield. The seating position of researchers in the static vehicle assured realistic positioning of the test participant's body and head relative to the roadway and test vehicle. Test participants were instructed to direct their gaze straight down the test lane rather than focusing on the approaching headlamp beam. This simulated typical driver behavior when encountering oncoming traffic.

Once the test vehicle passed the observation vehicle, participants rated glare according to the de Boer scale. Possible values consisted of integers between one (1) and nine (9). A value of one (1) corresponds to Unbearable glare, while a score of nine (9) corresponds to Just Noticeable glare. Video of each pass was captured for post-processing and analysis.

U.S. vehicles were evaluated with the headlamp automatic high beam system engaged. European specification vehicles were evaluated with the ADB system engaged. The test speed of 35 mph was sufficient to enable both automatic high beam switching and ADB system functionality for all test vehicles.

Figure 26: U.S. Specification Mfg. 2 Glare Drive-by with Headlamps Auto-dimmed to Low Beam

Figure 27: European Specification Mfg. 2 Glare Drive-By with Headlamps in ADB mode

5.3 Key Findings

All four test vehicles scored in the range of the evaluation scale indicating a low perceived glare. Ratings ranging from "Satisfactory" to "Just Acceptable". One manufacturer's European specification vehicle scored better than its U.S. specification counterpart did. Results for the other manufacturer's vehicles were reversed.

5.4 Vehicle/Component Specific Results

The European specification, manufacturer 1 vehicle with ADB headlamps had an average score of seven. This was slightly better than the U.S. specification, manufacturer 1 vehicle with an average score of six. This aligned with the real time impressions of the panelists who felt that the European specification, manufacturer 1 vehicle with ADB headlamps produced less glare than the U.S. specification, manufacturer 1 vehicle.

Glare Evaluation (de Boer scale)

researcher	U.S. mfg 2	Euro mfg 2	U.S.mfg 1	Euro mfg 1
2	8	7	7	9
4	5	6	6	7
1	8	4	6	7
5	8	5	5	7
3	7	6	6	5
average	7.2	5.6	6	7
SUM	**36**	**28**	**30**	**35**

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

Glare rated from 1 to 9, with 1 = **Unbearable**, and a 9 = **Just Noticeable**

Figure 28: Glare Evaluation (dynamic test)

The European specification, manufacturer 2 vehicle with ADB lamps first dimmed at a reasonable distance from the target car with the panelists. When the European specification, manufacturer 2 specification was within approximately 20 meters[5] of the target car, the panelists inside were subjected to a momentary increase of glare. This visible glare was experienced by nearly all of the panelists. Review of video timed the increase in glare at approximately one second, and was consistent over three trials. This momentary increase in glare was reflected in the evaluation scores. The U.S. specification, manufacturer 2 vehicle average score was 7.2, while the European specification, manufacturer 2 ADB average score was lower at 5.6. The lower score is almost entirely attributable to the late "flare" of light as the European specification vehicle came close to the stationary vehicle with the panelists. It should be noted that while late flare was noticed in this specific test, it was not noticed during the test evaluations on public roads in either ADB equipped vehicle.

[5] Distance estimate based on review of video.

6 Inquiry #3: How do U.S. and European specification Headlamps Differ in Dynamic Roadway Illumination?

6.1 Objective

Compare the roadway illumination and glare of U.S. and European specification headlamps while driving on both a closed course and public roadways.

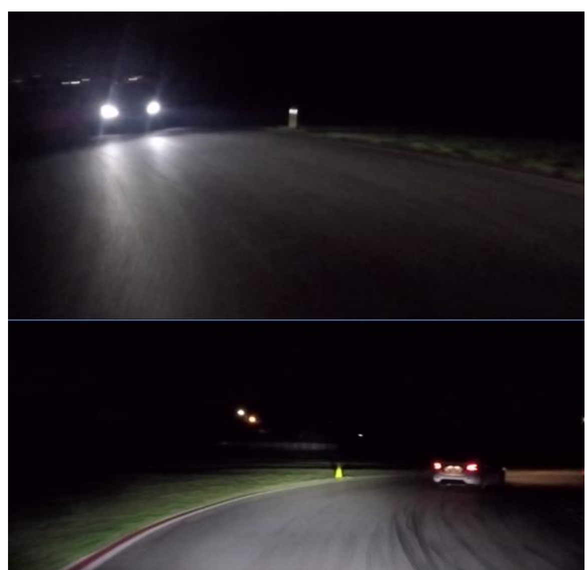
6.2 Methodology

Test vehicles were evaluated on a closed-course circuit and a predetermined route on public roadways. In both test environments, a preceding vehicle served as a target from which glare was evaluated.

6.2.1 Closed-Course Evaluation

The evaluation circuit was approximately 1.5 miles long with eleven (11) turns and multiple minor elevation changes. Surrounding lighting was extinguished during evaluations, and testing was initiated at least ninety minutes after sunset to ensure ambient lighting was minimized. The separation distance between the lead and test vehicles was kept as constant as possible throughout the evaluation circuit and, to the extent possible, each test vehicle was driven at a steady-state speed of 45 mph during the test.

U.S vehicles were evaluated with the automatic high beam system engaged. European specification vehicles were evaluated with the ADB system engaged. It was ensured that the vehicle test speed was high enough to allow the ADB headlamp systems on the European specification vehicles to be activated. For each test vehicle, the European version was evaluated first, followed by its U.S. specification counterpart.



Video was captured from the front of the test vehicle and the rear of the lead vehicle. Video was post-processed to enable direct comparisons between U.S. and European specification vehicle counterparts. Specifically, video was location-synched to provide a side-by-side comparison of roadway illumination. Evaluation of glare on the lead vehicle is made by video review and subjective impressions from the vehicle driver.

The image in figure 30 is from two time-synched videos. The top section is the view from the lead vehicle, looking back to the vehicle under test (either a U.S. or European specification vehicle).

The bottom section is the view from the vehicle under test, looking forward to the lead vehicle. In figure 30, the ADB shadow area is visible around both the oncoming and preceding vehicle. The vehicle under test is European specification with ADB.

Figure 29: Track and road driving points of view

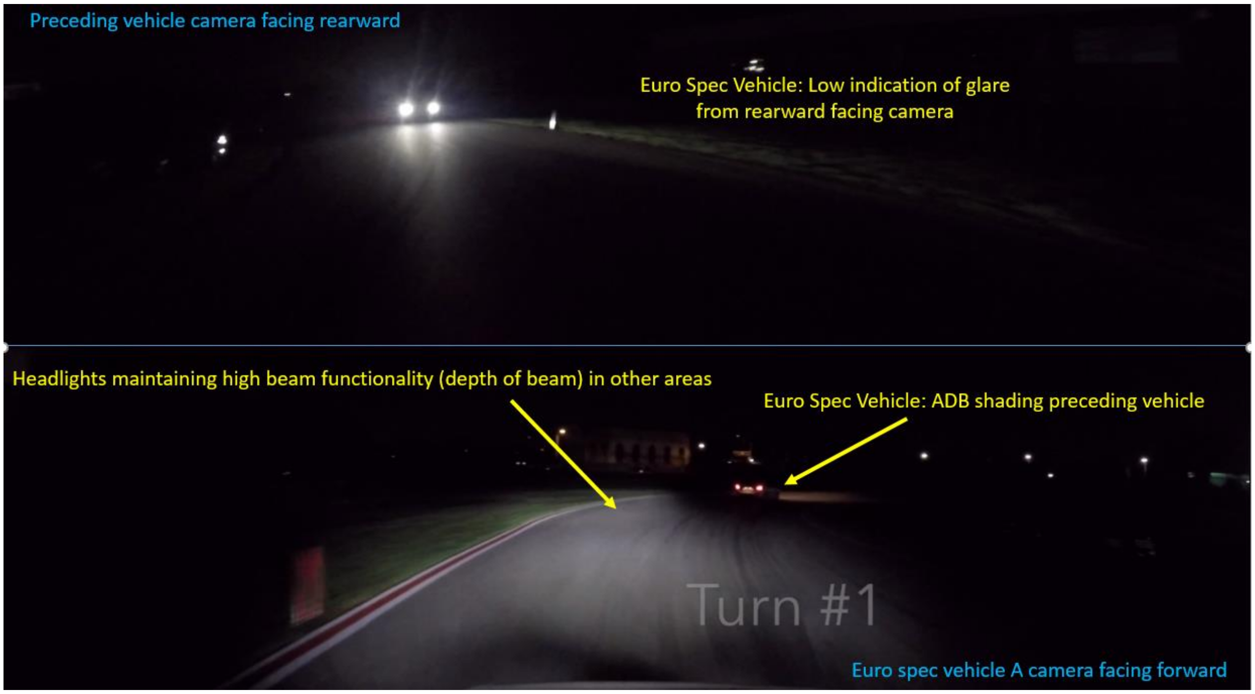


Figure 30: European specification vehicle dynamic testing on closed course

6.2.2 Public Roadway Evaluation

The public roadway evaluation[6] route was predetermined to include moderate curves, hills and straight driving sections that allowed for a steady-state speed of 35-45 mph. Additionally, no overhead lighting was present throughout the majority of the route. Testing was initiated at least ninety minutes after sunset to ensure ambient lighting was minimized. When possible, a consistent following distance of approximately 200 feet was maintained between the vehicle under test and the lead vehicle.

It is important to note that exact comparisons of lighting performance between the test vehicles on public roadways is not possible. The nature of public roadway evaluation introduces a multitude of random variables that are inherently inconsistent between vehicles. Furthermore, it would be virtually impossible to evaluate a single vehicle on the same route under identical conditions with no variations, even if the route was consecutively driven many times. However, general comparisons of roadway illumination and glare on the lead vehicle are possible. The primary purpose of public roadway

[6] European specification vehicles were properly licensed and insured by the respective manufacturers for operation on U.S. roadways. AAA personnel were documented as authorized drivers of all vehicles involved in the test.

evaluation was to gain insight on headlamp system performance in a naturalistic environment consisting of oncoming traffic, cross traffic, background lighting from buildings, and traffic signals.

Video was captured from the front of the test vehicle and the rear of the lead vehicle. General observations relating to roadway illumination and causing glare to the driver of the lead vehicle were note. U.S. specification vehicles were evaluated with the automatic high beam system engaged. European specification vehicles were evaluated with the ADB system engaged. For each test vehicle, the U.S. version was evaluated first, followed by its European specification counterpart.

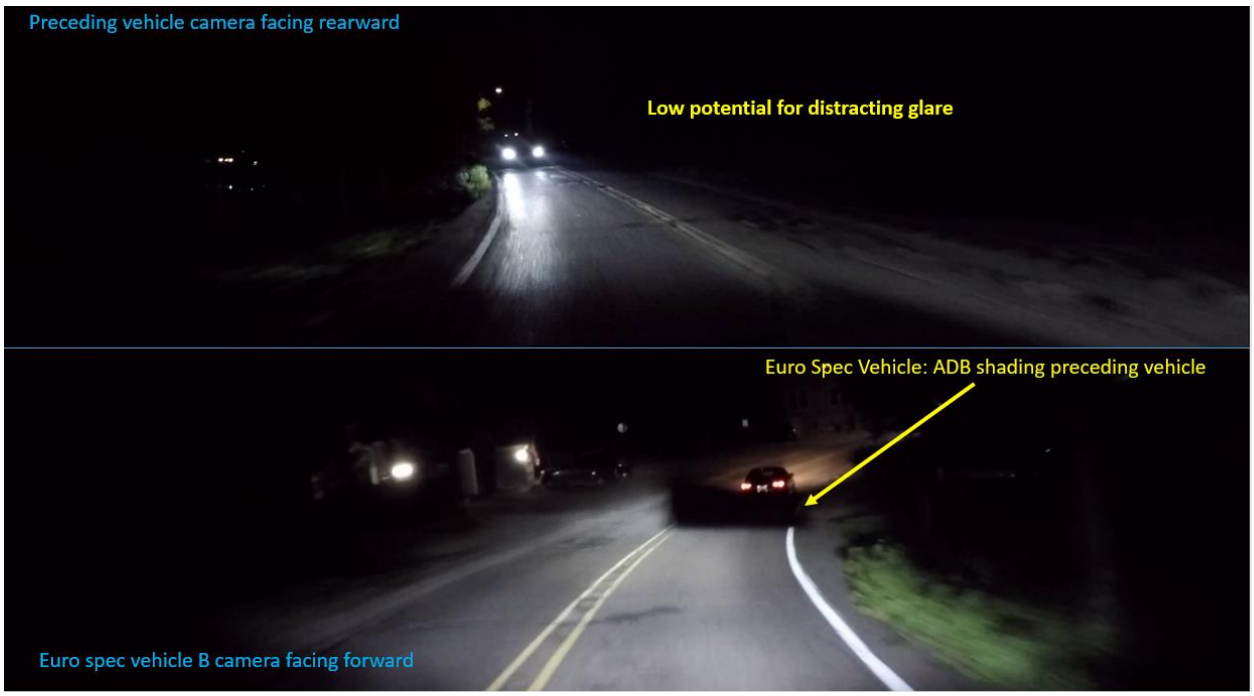


Figure 31: European specification vehicle dynamic testing on public roadway

In figure 33, the lead vehicle is fully illuminated by the headlamps of the U.S. specification vehicle. This vehicle has auto-dimming headlamps, which have switched to low beam operation due to the closeness of the lead car. Unfortunately, the vertical inclination of the headlamps increases as the U.S. specification vehicle crests a small hill. This creates a dazzling amount of light into the passenger compartment of the lead vehicle, as shown in the top section of the photograph. Through the rearview mirror(s), this is likely to cause glare. The non-adaptive driving beam headlamps that were evaluated had no means of compensating for this type of roadway undulation. It should be noted that glare caused by this type of scenario is not unique to ADB equipped vehicles and is a common phenomenon that is exhibited by any low beam headlamp system. By shadowing oncoming or preceding vehicles, ADB equipped vehicles have the potential to avoid creating this glare.

Figure 32: U.S. specification vehicle B auto-dimming headlamps and glare

Researchers experienced a small number of instances where the European specification vehicles appeared to be slow to make vertical corrections to the ADB shadow area on a preceding vehicle. The effect is the same as shown with the U.S. specification vehicle subjected to a road elevation change. However, this glare occurrence was less frequent with the ADB equipped vehicles than with the U.S. specification vehicles equipped with auto-dimming headlamps.

Figure 33: European specification vehicle losing vertical alignment of ADB shadow and correcting

Figure 34: ADB function with oncoming traffic

In figure 35, the European specification vehicle is tracking both the preceding vehicle and the oncoming car. Both are shadowed to minimize the chance of creating glare.

6.3 Key Findings

Researchers concurred that the European specification systems consistently provided more roadway lighting when an oncoming vehicle was approaching, or a preceding vehicle was close. This observation was supported by extensive review of video. Based on static target illumination data collected in Inquiry #1, the increase in roadway lighting could theoretically be as much as 86 percent (comparison of average European specification high beam to average U.S. specification low beam).

The rationale for comparing European high beam to U.S. low beam is that the ADB system is able to maintain high beam operation in all areas except those intentionally shaded by the system to minimize glare. In similar vehicle placement circumstances, the U.S. specification vehicles were forced to reduce headlamp operation to low beam in order to minimize the likelihood of producing glare to other vehicles.

In three nights of driving on public roads[7] with moderate traffic, researchers reported zero instances of oncoming traffic "flashing" to indicate being glared by any of the test vehicles. Both the automatic high beams (U.S. specification) and ADB (European specification) were effective in mitigating glare in real world traffic conditions.

7 The Cost of Inadequate Lighting

The overall business case for the implementation of ADB headlamp systems involves balancing the cost of the technology with its potential positive impact on safety and any associated savings. In 2010, NHTSA conducted extensive research regarding the implied economic and societal costs of vehicle collisions within the United States. There are extensive indirect costs outside of vehicle damage that must be considered to understand the full impact of an accident. NHTSA research identified these factors, and their contribution to overall economic impact as seen in figure 35 below.

[7]Secondary roadways and interstate highway without overhead lighting

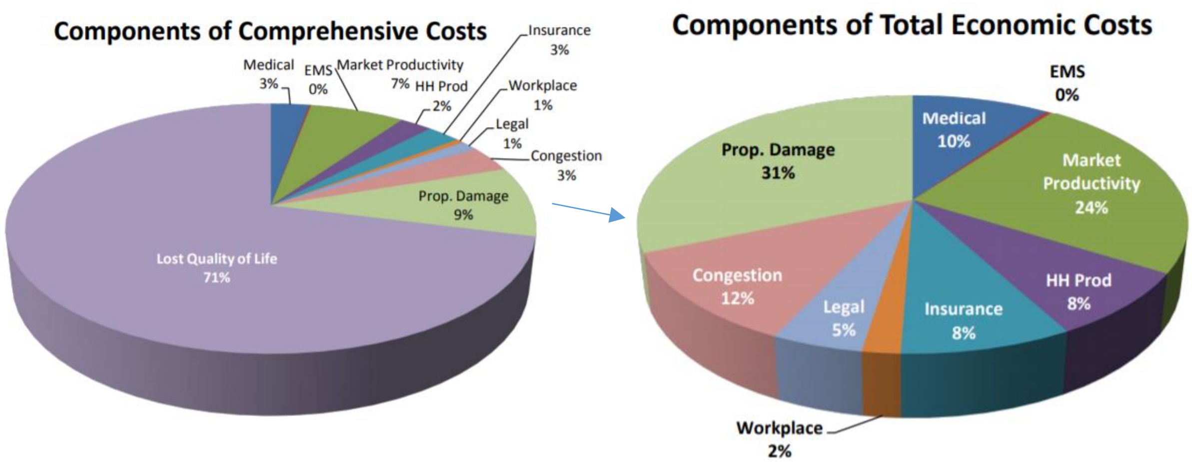


Figure 35: Components of Total Economic Costs for Vehicular Incidents (NHTSA, 2010)

For the purpose of this research, the findings of AAA's headlamp study are assumed relevant to the average vehicular crash. The results for scenarios detailed in the NHTSA research are used for average estimates of per-crash costs.

The estimate of cost savings as a result of adopting ADB headlamps in the United States depends on the number of crashes the technology will help prevent compared to traditional headlamps. Researchers associated with Rensselaer Polytechnic Institute, in conjunction with the Transportation Lighting Alliance, published findings in 2014 concluding that the application of ADB systems could reduce visibility-related nighttime crashes by six to seven percent compared to the visibility provided by low beam headlamp systems (Bullough, 2016). For this study, a visibility-related crash was assumed to be any nighttime incident involving pedestrians, cyclists, or wildlife in which no alcohol was found present in either the driver or victim. The justification for using low beam headlamps as the baseline for visibility improvements is related to additional findings in which it was concluded that vehicle operators do not use their high beams in most driving conditions, whether due to oncoming traffic, preceding traffic or negligence. The following sections describe the quantity and cost of incidents involving pedestrians, cyclists and wildlife.

7.1 Pedestrians

Using NHTSA's Fatality Analysis Reporting System (FARS) Encyclopedia, it was determined that in 2015 there were 2,753 instances in which pedestrians were fatally struck by vehicles and neither the driver nor the pedestrian had alcohol present in their systems. Seventy-four percent of those instances occurred during dark or low-light conditions that would require headlamp use. In addition, approximately 31,000 pedestrian injuries occurred in similar conditions.

Even after eliminating crashes in which alcohol was detected in the driver or pedestrian, there remained 25,000 instances of pedestrian death or injury as a result of being struck by a motor vehicle in dark lighting conditions. Applying the average economic and societal harm cost rates from the 2010 NHTSA study results in approximately $13.25 billion in damages annually. If there were a six percent reduction in such crashes from universal adoption of ADB headlamp systems, nearly 1500 pedestrian deaths and injuries could be prevented, and the cost savings would be in excess of $861 million annually.

7.2 Cyclists

A roughly equal number of vehicle collisions with cyclists occurred in light and dark driving conditions. This may mean that nighttime bicycling is less frequent than walking, or that bicyclists are typically more visible in dark conditions. There were a total of 511 fatalities and 28,350 injuries in collisions where a cyclist was struck by a vehicle and there was no alcohol present in either party. Of those events, 14,430 occurred in dark conditions.

Applying the average economic and societal harm cost rates from the 2010 NHTSA study results in approximately $7.66 billion in damages annually. If there were a six percent reduction in such crashes from universal adoption of ADB headlamp systems, roughly 850 cyclist deaths and injuries could be prevented, and the cost savings would be in excess of $498 million annually.

7.3 Wildlife Impact

A 2008 report on wildlife-vehicle collisions (WVCs) by the Federal Highway Administration Research and Technology group found that an estimated 292,000 WVC occur annually. The crashes most frequently occur in the early morning (5:00 – 9:00 am) and evening (4:00 pm –12:00 am), times when wildlife is often feeding and more active. These times also correspond with periods when headlamp use would be necessary for visibility due to low natural light levels.

Based on available data, the financial implications for public agencies, medical, property, and potential loss of life result in an estimated annual cost of WVCs in the area of $8.39 billion. If there were a six percent reduction in WVCs from universal adoption of ADB headlamp systems, nearly 18,000 collisions could be avoided for a potential cost savings of $503 million annually.

It is noted in the research that approximately 95 percent of WVCs do not involve vehicle occupant injury. However, the rate of collisions has been steadily increasing, largely due to wildlife population growth and reduced habitat.

8 Summary of Findings

Inquiry #1: How do U.S. and European specification low beam headlamps differ in static roadway illumination?

- Average target illumination values for high beam was 12.5% higher for European specification vehicles compared to U.S. specification.
- U.S. specification vehicles produced 1.9% more low beam illumination on targets.
- Driver perception of target Illumination during static testing was similar among all vehicles tested, European and U.S. specification.
- All test vehicles (U.S. and European specification) were equipped with premium LED headlamps and performed in the expected range of that headlamp system.

Inquiry #2: How do U.S. and European specification headlamps differ in producing glare?

- All four test vehicles scored in the low perceived glare range of the evaluation scale, ranging from “Satisfactory” to “Just Acceptable”. One manufacturer’s European specification vehicle scored better than its U.S. specification counterpart did. Results for the other manufacturer’s vehicles were reversed.

Inquiry #3: How do U.S. and European specification Headlamps Differ in dynamic roadway illumination?

- The European specification systems consistently provided more roadway lighting when an oncoming vehicle was approaching, or a preceding vehicle was close.
    - Based on static target illumination data, the increase in roadway lighting could be as much as 86 percent (comparison of average European specification high beam to U.S. specification low beam).
    - The adaptive driving beam (ADB) system maintained high beam operation in all areas except those intentionally shaded by the system to minimize glare.
    - In similar vehicle placement circumstances, the U.S. specification vehicles were forced to reduce headlamp operation to low beam in order to minimize the likelihood of producing glare to other vehicles.

- Roadways with hills were the most common driving scenario where other drivers were subjected to potential glare by an ADB capable vehicle. It should be noted that all headlamp systems currently available (manual high-low switching and automatic high-beam) produce glare to other drivers when cresting hills. In this situation, where glare potential is high, AAA research noted that it occurred less frequently with ADB capable European specification headlamp systems than with auto-dimming U.S. specification systems.

8.1 Forward Looking Statement

There is an obvious development path for ADB headlamp system software and hardware. Refinements have been swift over the last several model years while ADB headlamp systems have been available in Europe and other markets. Auto-dimming systems (and manual high-low beam switching) are inherently limited. These systems must switch to low beam in the presence of traffic, resulting in a sharp reduction in roadway lighting. All headlamp systems which are limited to either high or low beam operation cannot avoid causing glare to other vehicles when driving on undulating roadways and cresting hills.

ADB headlamp systems, with selective activation or shading of specific elements of the headlight beam, hold the promise to successfully address this major shortcoming of all current headlamp systems. In order to improve vertical tracking of the adaptive driving beam shadow region, refinements in vehicle tracking with the camera(s), image processing speed, and the speed of updating the shaded region location are required. In the future, high definition matrix systems should be able to compensate for this as their reaction performance and significantly increased resolution will offer greater opportunities for optimization.

9 Summary Recommendations

- Support NHTSA's proposed rulemaking to allow ADB headlamp systems in the United States
- Advocate for performance based testing for ALL headlamp systems as part of type certification for automobiles in an effort to increase the efficiency of forward lighting for all vehicles on the roadway
- Advocate for increasing the high beam output threshold to match European standards (over two times the U.S. limit) for vehicles with ADB systems that meet or exceed a prescribed performance threshold.

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