SAE INTERNATIONAL

SURFACE VEHICLE RECOMMENDED PRACTICE

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Automated Driving System (ADS) Marker Lamp

RATIONALE

Automated Driving System (ADS)-equipped vehicles are becoming a reality in the market. The studies below suggest that road users prefer ADS-equipped vehicles to have additional signals to indicate when the vehicle's ADS is engaged and to indicate the vehicle's intended movement. National Highway Traffic Safety Administration's (NHTSA's) Federal Automated Vehicles Policy also supports the need for ADS-equipped vehicles to communicate with pedestrians and other road users to improve road users' perceived safety and comfort level as ADS-equipped vehicles are introduced. Moreover, UNECE Working Party on Lighting and Signalling (GRE) has established a Task Force for Autonomous Vehicle Signalling Requirements (AVSR) to evaluate the need for ADS equipped vehicle to communicate with others.

Additional lamps are a means of identifying ADS-equipped vehicles and communicating the ADS-equipped vehicle's movement or intended movement. There are many lighting concepts and proposals for ADS-equipped vehicles within the U.S. and internationally. There is no standard today. It is important to create and establish a standard for ADS lamps that is harmonized and recognized internationally to avoid confusion and complexity.

This Recommended Practice provides guidance in the development of a standardized lighting solution to meet these needs.

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FOREWORD

Research Studies:

Studies suggest that pedestrians and other road users will be more comfortable with ADS-equipped vehicles if they receive signals from ADS-equipped vehicles.

Center for Design Research, Stanford University:

> "With increasing capability of self-driving cars…each of the vehicle's occupants, including its operator, may become mere passengers…Long established practices of communication between drivers and road users outside the vehicle – such as making eye contact, nodding one's head, or giving hand signs – may no longer be possible. Pedestrians about to cross in front of a car would like to get a sign that they have been seen."

CityMobil2 project in Europe, University of Leeds:

> "The most important message that needs to be communicated to cyclists and pedestrians is whether they have been detected…At the moment, the most important thing is there is absolutely no information and communication between the vehicle and the people…So pedestrians don't know its intentions." On the whole, participants from this study preferred the use of lights to provide information about whether the vehicle was turning or stopping, and sound to indicate whether it was going to start moving and whether they had been detected. However, it should be noted that there were differences in preference across the three locations examined (Lausanne, Switzerland; La Rochelle, France; and Trikala, Greece), suggesting there may be some cultural differences in how the communication tools used by these vehicles are perceived. Results from this study suggest that other road users would like to receive some form of information from the AVs when the space is shared between these actors, and that knowing they have been detected by the AV is the most important message to pedestrians and cyclists.

Chalmers University of Technology Autonomous Vehicle's Interaction with Pedestrians (AVIP):

> "A conclusion from this is that pedestrians need additional feedback in the interaction with an automated vehicle to compensate for the loss of information due to the decoupled driver. At least, a method is needed to be able to identify a manually driven or automated vehicle, clarifying if the driver, or the vehicle itself, is responsible for the maneuvering control. The evaluation…shows that the interaction between the pedestrian and the automated vehicle could be improved with an external communication interface. The pedestrians were able to understand the information that was conveyed to them and the prototype helped them in the decision-making process. An additional conclusion is that this kind of interface would increase pedestrians' perceived safety when interacting with automated vehicles…it can be concluded that there is a need for an external communication interface…"

Semcon:

> Semcon also commissioned a survey by the analyst firm Inizio to research people's attitudes toward self-driving cars in countries such as Sweden, the United Kingdom, the United States, and Germany. That survey showed that more than 80% of people in the surveyed countries will at least occasionally seek eye contact with drivers before crossing a street with no traffic light. U.S. survey participants were also most likely to say they would "always" seek eye contact with drivers (60%). Many of those surveyed also had little trust in self-driving cars detecting and stopping for pedestrians. U.S. survey participants had the most trust in driverless vehicles, but 38% still said they were "quite unconfident" or "very unconfident" about self-driving cars stopping for pedestrians. Large numbers of survey respondents across all countries seemed uncertain about the technology by responding "neither confident nor unconfident." And no country had a majority of respondents saying they were "quite" or "very" confident (U.S. confidence was highest here, at 33%).

NHTSA Automated Driving Systems 2.0 - A Vision for Safety (Excerpt) - 6. Human Machine Interface:

> Considerations should be made for the human driver, operator, occupant(s), and external actors with whom the ADS may have interactions, including other vehicles (both traditional and those with ADSs), motorcyclists, bicyclists, and pedestrians. HMI design should also consider the need to communicate information regarding the ADS's state of operation relevant to the various interactions it may encounter and how this information should be communicated. Given the ongoing research and rapidly evolving nature of this field, entities are encouraged to consider and apply voluntary guidance, best practices, and design principles published by SAE International, International Organization for Standardization (ISO), National Highway Traffic Safety Administration (NHTSA), the American National Standards Institute (ANSI), the International Commission on Illumination (CIE), and other relevant organizations.

Examples of ADS Message Proposals:

SAE J3134

1. Vehicle's ADS is engaged
2. Vehicle's ADS is yielding*
3. Vehicle's ADS transition from yielding to not yielding*

* Removed from document towards end of development to await further studies.

CityMobil2

1. Whether it is stopping
2. Whether it is turning
3. How fast it is going
4. Whether it is going to start moving
5. Whether it has detected me

Chalmers University of Technology Autonomous Vehicle's Interaction with Pedestrians (AVIP), Gothenburg, Sweden, 2015

1. I'm in automated driving mode (AD mode)
2. I'm about to yield
3. I'm resting
4. I'm about to start

ISO Human Factors Committee

1. Driving
2. Yielding
3. About to drive

Usage of Pictorials or Symbols:

Pictorials, symbols, text, and other forms of communication are not addressed in this document, as they were deemed to fall outside the scope of the Task Force members' expertise. This document is not intended to preclude the use of such types of communication; however, it is strongly encouraged for manufacturers to consider certain aspects of SAE J3134 when using illuminated pictorials, symbols, and text, including color, photometry, installation location, and visibility.

ADS Lamps:

Current signal lamps (e.g., turn signals, stop lamps) indicating the vehicle's intended or change in movement would be retained on ADS-equipped vehicles. However, until the assumption of presence of a human driver wanes and the lack of a human driver becomes the norm, additional vehicle-to-road-user communication may be beneficial. ADS lamps(s) would indicate the ADS-equipped vehicle's ADS status, e.g., when the ADS is engaged.

ADS lamps in this Recommended Practice are intended to be seen from the front of the vehicle at close proximity. There may be no vehicle driver, or there may be a person sitting in the traditional driver's seating position that does not have the role to be involved in the driving tasks in an ADS-equipped vehicle. These ADS lamps provide information to the road user, in the absence of a driver, as to the vehicles' ADS status and intent, and may provide comfort and ease of acceptance as ADS-equipped vehicles are introduced into the market.

Concerns have been raised that the use of ADS marker lamps, which indicate the vehicle's ADS is engaged, could attract intentional interference from other road users. Early studies suggest that other road users' opinions are that they would prefer some type of indicator identifying when a vehicle's ADS is controlling the vehicle, and signals to indicate the vehicle is "yielding" or transitioning to "not yielding." However, there is no evidence that the absence of these signals poses any safety concern, and there is a concern that these signals may pose a safety hazard due to potential confusion over what a signal may be communicating. Therefore, this document provides a Recommended Practice for ADS lamps to reduce the risk that conflicting signals are executed in the field.

The photometric intensities and angles were determined considering the following unique features of the ADS lamps:

1. ADS lamps are intended to be visible to road users (i.e., nearby pedestrians, pedal cyclists, and motorists) in close proximity to the vehicle.

2. The ADS marker lamp is designed to be activated both in daytime and nighttime conditions. A 2.5 times multiplication factor for the minimum values is required for ADS lamps in close proximity to headlamps, fog lamps, and daytime running lamps. This 2.5 multiplication factor rationale is from the current Federal Motor Vehicle Safety Standards (FMVSS) 108 front turn signal requirement, but more research may be needed to determine the optimal multiplication factor for ADS lamps.

3. The wide range of mounting heights of ADS lamps.

ADS Signals:

Early in the development of this document, the Task Force considered the following ADS messages: (1) ADS status (on or off), (2) yielding, (3) ready to go. These messages were matched with the following light signals from simplest to more complex: (1) steady, (2) flashing or sweeping, (3) sweeping or flashing. As the document progressed, the Task Force decided that further research and studies are needed to evaluate the use and effectiveness of flashing and sweeping light signals to communicate the ADS yield and ready to go messages. As a result, this document currently only focuses on a marker light to indicate the ADS status.

Color and Location:

Early in the development of this document, the Task Force considered using an existing, globally regulated and prescribed lamp color (e.g., white and yellow) and limiting the ADS lamp to a unique location (e.g., around the top and center of the windshield) to differentiate the ADS lamp from existing required lamps. As the document progressed, the Task Force determined that limiting the mounting of the ADS lamp to a unique location posed significant design constraints and installation issues. The Task Force decided to not limit the installation location of the ADS lamp. This then created a concern of using existing colors for the ADS lamp. Current regulations prescribe emitted colors for lighting functions in defined locations. Therefore, depending on the location, the use of these regulatory-prescribed colors for ADS lamps could be confused with existing required lamps, thereby diminishing the recognition and effectiveness of ADS lamps. A unique color was concluded to be used for the ADS lamps. Experts from OEMs, tier suppliers, and research institutions, such as University of Michigan Transportation Research Institute (UMTRI) and University of Tübingen in Germany, evaluated potential ADS lamp colors. These evaluations supported the use of blue-green light for ADS lamps, but not to the exclusivity of other colors evaluated. A unique color allows greater flexibility in mounting location and facilitates innovation for new automotive ADS lamps. This document recommends the use of a unique light color, i.e., blue-green (as defined in 6.2).

1. SCOPE

This SAE Recommended Practice provides guidelines for the use, performance, installation, activation, and switching of marking lamps on ADS-equipped vehicles.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J575 Test Methods and Equipment for Lighting Devices for Use on Vehicles Less than 2032 mm in Overall Width

SAE J576 Plastic Material or Materials for Use in Optical Parts Such as Lenses and Reflex Reflectors of Motor Vehicle Lighting Devices

SAE J578 Color Specification

SAE J759 Lighting Identification Code

SAE J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

2.1.2 CIE Publications

Available from CIE Central Bureau, Babenbergerstrasse 9/9A, 1010 Vienna, Austria, Tel: +43 1 714 31 87, www.cie.co.at.

CIE 1931 Standard - Colorimetry

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J387 Terminology - Motor Vehicle Lighting

SAE J1889 L.E.D. Signal and Marking Lighting Devices

SAE J2139 Tests for Signal and Marking Devices Used on Vehicles 2032 mm or More in Overall Width

SAE J2442 Harmonized Provisions for Installation of Exterior Lamps and Retro-Reflecting Devices on Road Vehicles Except Motorcycles

SAE J3114 Human Factors Definitions for Automated Driving and Related Research Topics

2.2.2 Other Publications

“Automated Driving Systems 2.0 - A Vision For Safety,” https://www.nhtsa.gov.

“AVIP**,** Autonomous Vehicles Interaction with Pedestrians - An Investigation of Pedestrian-Driver Communication and Development of a Vehicle External Interface,” T. Lagström; V. M. Lundgren, (2015) Chalmers University of Technology, Gothenburg. Sweden, http://publications.lib.chalmers.se/records/fulltext/238401/238401.pdf.

“Ghost Driver: A Field Study Investigating the Interaction Between Pedestrians and Driverless Vehicles,” D.Rothenbücher; J.Li; D.Sirkin; B.Mok; W.Ju, 2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), NewYork, NY, 2016, pp.795-802, http://www.wendyju.com/publications/RO-MAN2016-Rothenbucher.pdf.

“What do Vulnerable Road Users think about ARTS,” N. Merat; R. Madigan; T. Louw; M. Dziennus; A. Schieben, CityMobil2 Final Conference (2016) Donostia/San Sebastian, Spain, https://cordis.europa.eu/docs/results/314/314190/final1-final-publishable-report.pdf.

“Who Sees You When the Car Drives Itself?,” M. Carlsson; K. Eklund; P. Nilsson, Semcon, https://semcon.com/smilingcar/.

UNECE GRE Task Force Autonomous Vehicle Signalling Requirements (AVSR), “Taskforce Autonomous Vehicle Signalling Requirements,” http://www.unece.org.

3. DEFINITIONS

3.1 AUTOMATED DRIVING SYSTEM (ADS)

The hardware and software that are collectively capable of performing the entire dynamic driving tasks (DDT) on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a level 3, 4, or 5 driving automation system (refer to SAE J3016).

3.2 ADS MARKER LAMP

A device emitting light to indicate when a vehicle’s ADS is engaged in the operation of the vehicle.

3.3 DAYTIME

When exterior ambient light conditions do not warrant the use of headlamps.

3.4 NIGHTTIME

When exterior ambient light conditions warrant the use of headlamps.

4. LIGHTING IDENTIFICATION CODE

ADS marker lamp may be identified by lighting identification code AM.

5. TESTS

5.1 SAE J575 is a part of this document. The following tests are applicable with the modifications as indicated.

5.1.1 Vibration Test

5.1.2 Moisture Test

5.1.3 Dust Test

5.1.4 Corrosion Test

5.1.5 Photometry Test

5.1.6 Warpage Test for Devices with Plastic Components

5.2 Color Test

SAE J578 is a part of this document.

5.3 Materials

SAE J576 is a part of this document.

6. REQUIREMENTS

6.1 Performance Requirements

A device, when tested in accordance with the test procedures specified in Section 5, shall meet the following requirements per SAE J575, with the modifications indicated:

6.1.1 Vibration

6.1.2 Moisture

Does not apply to any lamps mounted inside the vehicle.

6.1.3 Dust

Does not apply to any lamps mounted inside the vehicle.

6.1.4 Corrosion

Does not apply to any lamps mounted inside the vehicle.

6.1.5 Photometry

6.1.5.1 Photometry Pattern

Each ADS marker lamp must meet photometry requirements specified in Figures 1A and 1B, except that when two ADS marker lamps are used, the inboard angle can be reduced to 20 degrees.

The lamps shall be designed to comply to photometry requirements as installed on the vehicle, with all vehicular obstructions considered, e.g., glazing for lamps mounted inside the vehicle.

6.1.5.1.1 Nighttime Photometry Requirements

Figure 1A shows the minimum luminous intensity values, in candela (cd), at the required measurement (angular) points for a ADS marker lamps operating in nighttime conditions.

For an ADS marker lamp(s) operating in nighttime conditions, the maximum luminous intensity is 125 cd and a minimum intensity of 0.5 cd within the photometric pattern

6.1.5.1.2 Daytime Photometry Requirements

Figure 1B shows the minimum luminous intensity values, in candela (cd), at the required measurement (angular) points for an ADS marker lamps operating in daytime conditions.

For an ADS marker lamp(s) operating in daytime conditions, the maximum luminous intensity is 300 cd and a minimum of 2.5 cd within the photometric pattern.

6.1.5.2 Photometry Requirements in Relation to Other Lamps

6.1.5.2.1 Spacing for a direct light source type design front turn signal lamp; that is, a lamp primarily employing a lens to meet photometric requirements (for example, a lamp that does not employ a reflector) shall be measured from the light source to the lighted edge of the low beam headlamp or any additional lamp used to supplement or used in lieu of the lower beam, such as an auxiliary low beam or fog lamp.

6.1.5.2.2 Spacing for a front turn signal lamp which primarily employs a reflector (for example, one of parabolic section), in conjunction with a lens to meet photometric requirements, shall be measured from the geometric centroid of the front turn signal's effective projected luminous area to the lighted edge of the low beam headlamp or any additional lamp used to supplement or used in lieu of the lower beam, such as an auxiliary low beam or fog lamp.

6.1.5.2.3 If the ADS marker lamp(s) is mounted within 100 mm from the lighted edge of a headlamp or fog lamp, the minimum luminous night time intensity values at all test points shown in Figure 1A shall be multiplied at least 2.5 times. The nighttime maximum luminous intensity value shall also be increase by 2.5 times.

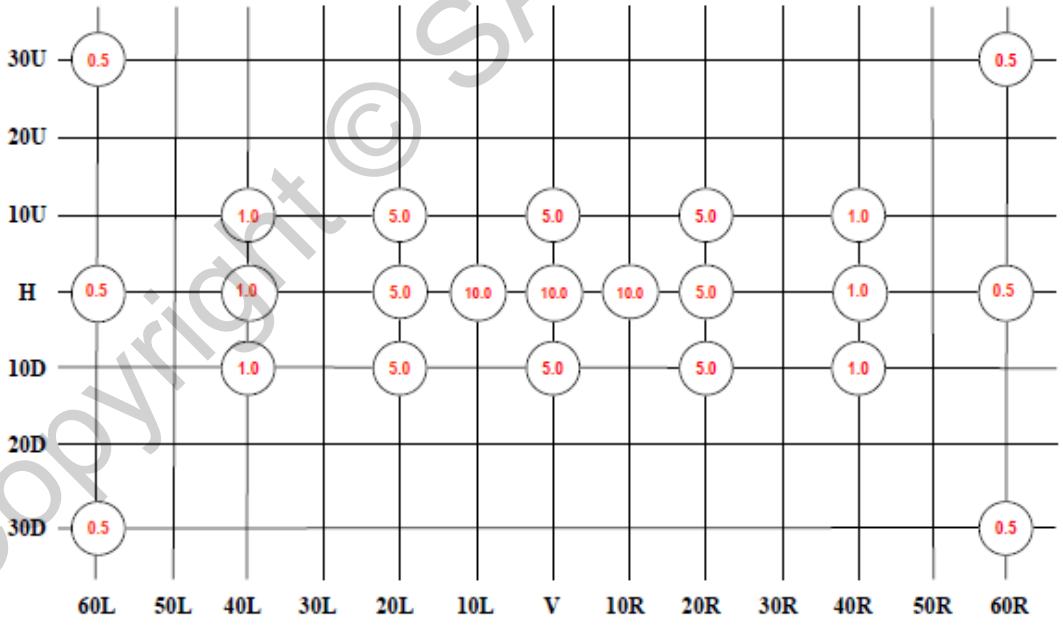
6.1.5.2.4 If the ADS marker lamp(s) is mounted within 100 mm from the lighted edge of a DRL, the minimum luminous day time intensity values at all test points shown in Figure 1B shall be multiplied at least 2.5 times. The daytime maximum luminous intensity value shall also be increase by 2.5 times.

6.1.5.3 Multiple ADS Lamp Configuration

All lamps shall be activated at the same time.

6.1.5.4 ADS Marker Lamp - Nighttime

The ADS marker lamp shall meet the minimum requirements of Figure 1A for nighttime conditions.

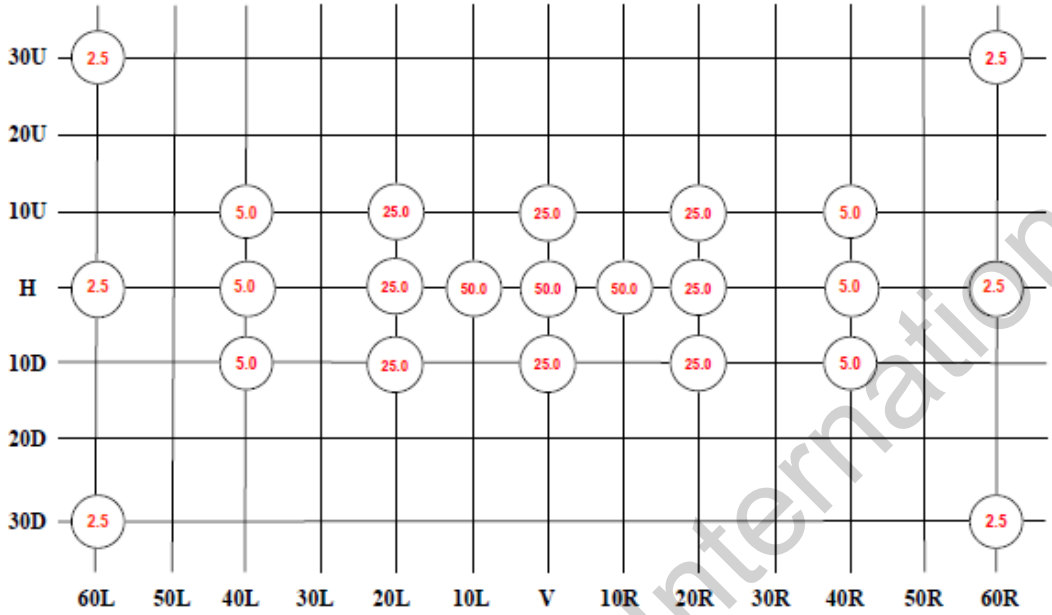


1. The photometric intensity values between test points must not be less than the lower specified minimum value of the two closest adjacent test points on an horizontal or vertical line

Figure 1A - Photometric requirements (nighttime)
Minimum luminous intensity (cd)

6.1.5.5 ADS Marker Lamp - Daytime

The ADS marker lamp shall meet the minimum requirements of Figure 1B for daytime conditions.



1. The photometric intensity values between test points must not be less than the lower specified minimum value of the two closest adjacent test points on an horizontal or vertical line

Figure 1B - Photometric requirements (daytime)
Minimum luminous intensity (cd)

6.1.6 Warpage

6.2 Color

6.2.1 The color of light emitted from the ADS lamp shall be “blue-green” per CIE 1931 coordinate system. Blue-green shall fall within the following boundaries (vertices defined):

x=0.012, y=0.495

x=0.200, y=0.400

x=0.200, y=0.320

x=0.040, y=0.320

6.2.2 The lamps shall be designed to comply to color requirements as installed on the vehicle, with all vehicular obstructions considered, e.g., glazing for lamps mounted inside the vehicle.

6.3 Materials

Plastic materials used in the optical parts shall meet the requirements per SAE J576.

Note that SAE J576 reference to SAE J578 does not include the blue-green color as defined in 6.2.1. Use the chromaticity coordinates as defined in 6.2.1 to fulfill this requirement.

6.4 Installation, Color, and Activation

The ADS lamp shall meet the characteristics as outlined in Table 1.

Table 1 - ADS lamp characteristics and installation

<table>
<tr><th>Lighting Device</th><th>Number</th><th>Mounting Location</th><th>Mounting Height</th><th>Device Activation</th></tr>
<tr><td rowspan="3">ADS Marker Lamp</td><td>1</td><td>Towards the front, facing forward, including glazing, with the lamp center on the vertical centerline as viewed from the front</td><td rowspan="3">Center of lamp not less than 38 cm to the road surface</td><td rowspan="3">Steady burning. Must only be activated while the ADS is engaged and actively controlling driving functions of the vehicle or when the vehicle is operated by a remote driver (as defined in SAE J3016)</td></tr>
<tr><td colspan="2">OR</td></tr>
<tr><td>2</td><td>Towards the front, facing forward, including glazing, symmetrically about the vertical centerline</td></tr>
</table>

7. GUIDELINES

The following guidelines apply to the devices as used on the vehicle, but are not to be considered part of the requirements.

7.1 Lamps may be mounted inside or outside of the vehicle. If mounted on the inside, the vehicle should have means provided to minimize reflections from the light of the lamp upon the front glazing that might be visible to interior of the vehicle.

7.2 Currently, there is ongoing activity at state and federal agencies to examine regulatory barriers (including vehicle lighting) that may need to be updated or changed to allow the operation of ADS-equipped vehicles. The user is cautioned that some recommended features of the ADS marker lamp (e.g., mounting location, light intensity, or color) may be restricted by regulatory agencies; as such, proper alternatives should be considered, where appropriate.

8. NOTES

8.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE J3134 TASK FORCE OF THE SIGNAL AND MARKING DEVICES STANDARDS COMMITTEE OF THE SAE LIGHTING SYSTEMS GROUP