SAE International Comments from the Subject Matter Experts of the CMS Test Protocols and Performance Requirements Task Force

Existing Industry Standards

1) Question 1
   a) *Please provide research data concerning the safety impacts of replacing rearview mirrors with CMS. Please explain your view of the significance of those data.*
      i) Generally, Schmidt et al. [1], already identified by NHTSA, has the highest significance of studies published to date. Additionally, Large et al. [2], also identified by NHTSA, is significant in its scope.
         (1) E. A. Schmidt, H. Hoffmann, R. Krautscheid, M. Bierbach, A. Frey, G. Jost, and C. Lotz-Keens, "Final Report Camera-Monitor Systems as a Replacement for Exterior Mirrors in Cars and Trucks," Federal Highway Research Institute, BASt, 2015. [1]
         (2) D. Large, E. Crundall, G. Burnett, C. Harvey and P. Konstantopoulos, "Driving without wings: The effect of different digital mirror locations on the visual behaviour, performance and opinions of drivers," *Applied Ergonomics*, vol. 55, pp. 138-148, 2016. [2]
      ii) We include here a brief discussion of the significance of these studies.
         (1) Glance frequency and duration
            (a) Glance frequency and duration are measurable indicators for how long the driver's eyes are off the road when viewing the CMS monitor compared to the traditional mirror. For CMS to be accepted in place of mirrors, we would expect glance frequency and duration for CMS to be less than or equal to that of traditional mirrors. This is generally confirmed by both Schmidt et al. [1] and Large et al. [2].
            (b) However, in both studies we see a divergence from conventional driver distraction guidance. One would expect priority information placed closer to the driver's field of view would result in lower glance frequency and duration (inferred using the phrase "eyes-off road time" in Large et al. [2], section 4.2. The glance frequency and duration are nearly equal or less than the mirror system for CMS Configurations 1, 2 and 3. However, in Configuration 4 where the digital displays are located directly in front of the driver and surrounding the steering wheel, the total off road glances are higher than that of Configurations 1-3. The authors consider several reasonable interpretations of these results, p. 146, including maintaining "aspects of real-world mapping" and "highly automated nature of glances to mirrors." Additionally, we suggest that Configuration 4 may have had a stronger accommodation component because of its apparent nearness to the driver's eye compared to the other locations.
            (c) In Schmidt et al. [1], glance frequencies and durations are studied for 3 different monitor positions. The glance frequency and duration are nearly equal or less than

the mirror system for positions 1 and 2 but are increased for monitor position 3. Monitor position 3 most closely resembles the position of a typical pair of outside mirrors and is closer to the driver's forward field of view. Again, conventional driver distraction guidelines [25] would suggest that the eyes-off-road time would decrease, not increase due to the position of the monitors relative to the forward field of view. The authors propose one reason for this result is that this position is "highly accepted by the drivers", p. 85.

(d) In both studies, we see other factors at play that suggest conventional glance duration and frequency methods require situational analysis to understand the impact of CMS on driver's behavior. Improved research methods may be needed. Also, we suggest that more data, especially naturalistic driving studies like the forthcoming VTTI Naturalistic Driving Study [3] are necessary to fully assess the safety impact of CMS.

(2) Comprehension of the image

(a) This concept is addressed in Large et al. [2] which presents data to show visual workload is reduced for CMS compared to the baseline mirror. The data presented also indicates shorter decision-making times to initiate a lane change. The authors suggest that these reductions in workload and decision making may be due to more ease in gathering salient information. Since this is a simulator study, this conclusion should be corroborated with a similar test in a realistic driving environment such as the VTTI study [3]. It is likely that monitor position, quality of information, and acclimation will have an influence on comprehension of the image.

(3) Judging distances

(a) The typical method of testing a driver's ability to judge distance and speed is referred to as the "last safe gap" method. Schmidt et al. [1] suggests that there is a conservative approach to determining when it is safe to make a lane change based on the speed and distance of an approaching vehicle. Speed is shown to be overestimated for the CMS. Similarly, the same study indicates that the drivers judged the distance of a stationary object relative to the vehicle to be closer than actual such that the distance is underestimated. The authors suggest this is a "…non-critical misjudgment of speed and of distance to the approaching object vehicle." They also note that when an interior rear-view mirror is available, it is expected that the information provided to the driver will support a more realistic estimation of distance, but suggest further study is needed to be conclusive.

(b) In Large et al. [2], the results suggest that the drivers initiated the lane change maneuver earlier with CMS compared to the traditional mirror, but the distance of the approaching vehicle at the start of the maneuver or the distance in front of the overtaken car with CMS versus the traditional mirror was statistically insignificant.

(c) In both cases the comparable or conservative response tends to support the conclusion that it is not safety critical, however, given the circumstances of the tests, it may be an area where additional study is needed to confirm the result.

(4) Limitations

(a) There are some limitations to both studies. For example, in Schmidt et al. [1] the prototype cameras that were used at that time would not be considered state-of-the-art today. Additionally, there were some problems with the electromagnetic compatibility. Another limitation is the fact that only low speeds were tested, i.e. no motorway speeds.

(b) Large et al. [2] also comes with some limitations in that the set-up of the used simulator is not designed according to the ISO 16505 parameters (e.g. magnification factors, equivalent system resolution …etc).

iii) Additional Research for Consideration

(1) J.S.M. Alia, F.F. Bazilah, "Mirrorless Car: A Feasibility Study," Applied Mechanics and Materials, Vol. 663, pp 649-654, 2014. [4]

(a) The work is a trial to test whether such a mirrorless car can create a better driving condition for the driver in terms of ergonomics, safety and comfortability. A passenger car equipped with a CMS was tested for its characteristics on safety, comfortability and ergonomics. Based on the comprehensive test drive the paper concludes, that the mirrorless cars are potentially feasible and compatible to be used on the road safely. In comparison to the conventional car with mirror, it was proved that mirrorless car with its cameras have wider views and therefore the blind spots can be eliminated thus leading to improved safety. Moreover, the mirrorless car has eliminated the repeated movements of the head of the driver, thus the mirrorless car has better ergonomics than conventional mirror car. Also, it is obvious that by removing the mirror, the drag will be reduced considerably which further leads to fuel economy. Thus, mirrorless cars show great potential as modern future cars with enhanced driving conditions in terms of comfort, safety, ergonomics and fuel economy. There is no reference to the standard ISO 16505 in this paper. There is also no information about the achieved latency of the used CMS and the other technical parameters of image quality.

(2) A. Terzis (ed.), "Handbook of Camera Monitor Systems - The Automotive Mirror-Replacement Technology based on ISO 16505", Series Augmented Vision and Reality, ISBN 978-3-319-29609-8, 534 pages, Springer International Publishing, March 2016

(a) This book aims to provide a comprehensive overview of the science and technology of CMS. The content ranges from the ISO 16505-based development aspects to practical realization concepts in vehicles. In addition, it serves as a single reference source with contributions from leading international CMS professionals and academic researchers combining technological as well as ergonomic aspects. Most of the authors, including the editor, have been involved in the international standardization and regulation of this technology over the last years. It is since 2016 the key reference in the field of automotive CMS for system designers, members of standardization and regulation committees, engineers, students and researchers.

(b) The book is organized into five parts.

(i) Part I "CMS System Design and Standardization and Regulation Aspects" is dedicated to the system design of passenger as well as commercial vehicles. It includes a contribution covering the CMS-specific standardization and regulation aspects. A key topic of CMS, which is addressed by a special contribution, is the resolution and the sharpness of the complete system.

(ii) Part II "Fundamentals of Automotive Technology for CMS" covers the relevant fundamentals of automotive imagers, video interface technology and embedded image processing components. All contributions present the content with regard to CMS. The optical effects in camera monitor systems in combination with optical measurement setups are presented in a special contribution.

(iii) Part III "Human Visual Perception and Ergonomic Design" starts by presenting the properties of human visual perception with respect to CMS. It includes contributions covering the ergonomic design of CMS for the very demanding commercial vehicles scenario.

(iv) Part IV "CMS Tests and Concepts for Passenger Cars and for Commercial Vehicles" includes a study (known as the BAST Study) comparing CMS and conventional exterior mirrors and which made its assessment using test drives and static tests under different external conditions. A contribution with concepts for commercial vehicles is also included in this part of the book.

(v) Part V "Advanced Topics" provides content with direct or indirect relevance to CMS. It begins with a discussion of demanding scenarios in CMS and includes image-quality criteria. A special contribution presents a novel approach for intuitive motion and depth visualization for rear-view camera applications. The book concludes with a dedicated contribution to the very important functional safety aspects of CMS based on ISO 26262. It explains what hazards could arise in the context of CMS and how they can be systematically investigated.

(3) S.M. Pampel, T.J.R. Southey and G. Burnett, "A driving simulator study investigating the effects of digital mirror failures on visual and driving behaviour, and mental workload," presented at the *electronic displays Conference* Nuremberg Germany, February 26-27, 2019. [6]

(a) Pampel et al. [6] suggests that drivers become distracted and lose confidence when they experience system failures. Mitigation and proper communication of system failures is essential. Potential counter measures could include back up power, redundant systems such as interchangeable inside mirrors, and/or audio and visual warnings to the driver.

(4) A. Zaindl, "Perception optimized development of a CMS for commercial vehicles," Ph.D. thesis, Technical University of Munich, Munich, Germany, 2018. Available at: http://mediatum.ub.tum.de/doc/1355826/1355826.pdf. [7]

(a) Zaindl [7] is helpful for considering CMS behavior for heavy truck drivers. This reference is published in German, so a sample of the abstract in English is included here: "The studies have repeatedly developed a CMS which allows the driver to monitor the area directly around the periphery while pursues his foveal task. The presentation of the three lateral fields of view in a continuous image (replacing the main, wide-angle, and close-proximity mirrors) should have a positive effect on driver stress and traffic safety. The CMS described in this work allows drivers to use the main mirror area as usual while keeping the area close to the vehicle peripherally in view. This will allow obstacles to be more easily detected than with conventional mirror systems or conventional mirror replacement systems which replace the respective mirrors individually. A suitable mirror replacement system can thus help to prevent serious accidents such as right-turn accidents running into cyclists"

(5) A. Habibovic, J. Andersson, V. Malmsten Lundgren, H. Staf, N. Sundberg, "Replacing side-¬view mirrors in trucks with integrated digital system to improve safety (DREAMS)," published by FFI partnership programme run jointly by the Swedish state and the Swedish automotive industry, 2017. [8]
   (a) There were two specific research questions addressed by the study. The first one concerned the contributing factors and causation patterns that can be identified when DREAM (Driving Reliability and Error Analysis Method) is applied on video-recordings of car-to-pedestrian incidents. The second one was whether these factors and patterns can inform design of ADAS. The study presents a novel approach, according to the authors, to analyze incident causation and demonstrates the advantage to be had by reviewing video-recordings collected in a naturalistic setting. The authors modified and used DREAM to classify causation patterns in video-recordings of car-to-pedestrian incidents. The classification was supported by observations of driver activities, driver gaze direction, pedestrian behavior, and visual obstructions in the traffic environment. The study reveals that incidents with similar car trajectories can be grouped to identify the most common causation patterns. The causation patterns in intersections explain that the majority of the drivers misunderstood the situation due to visual obstructions and/or attention allocation towards something other than the conflict pedestrian. The patterns for incidents away from intersections explain that pedestrians commonly behaved in an unexpected way. These patterns can inform design of ADAS as well as other safety countermeasures. The authors conclude that additional research should ascertain, among others, in how to integrate a DREAM analysis with a time-history analysis of the driver and pedestrian behavior, on order to provide a deeper insight into incident causation and its application to design of safety countermeasures.

(6) C. Seidler, S. Aydogdu, B. Schick, "User Experience in Real Test Drives with a Camera Based Mirror – Influence of New Technologies on Equipping Rate for Future Vehicles," in *HCI in Mobility, Transport, and Automotive Systems*, Krömker H. (eds): HCII 2019. Lecture Notes in Computer Science, vol 11596 pp. 270–281, 2019.[9]
   (a) Seidler et al. [9] is a recent study of user experience associated with a CMS. The study mentions that 10% of subjects reported focusing problems when using the system, while 15% reported have some trouble in focusing. 75% of subjects reported no problems in focusing on the CMS. This data may be helpful to NHTSA relative to the comment made in the ANPRM regarding motion sickness and depth-of-vision problems.

(7) The following studies address driver's gaze direction and generally show that driver's look where they drive and drive where they look. The implications suggest that placing CMS monitors in expected locations is preferred.
   (a) W.O. Readinger, A. Chatziastros, D.W. Cunningham, H.H. Buelthoff, "Gaze-eccentricity effects on road position and steering," *Journal of Experimental Psychology: Applied*, Vol. 8, No. 4, 247–258, 2002. [10]

(b) D. Shinar, “Looks Are (Almost) Everything: Where Drivers Look to Get Information,” *Human Factors*, Vol. 50, No. 3, pp. 380–384, 2008. [11]

(c) M.F. Land, D.N. Lee, “Where we look we steer,” *Letters to Nature, Nature* Vol. 369, pp. 742-744, 1994. [12]

(d) R.W. Wilkie, J.P. Wann, R.S. Allison, “Active Gaze, Visual Look-Ahead, and Locomotor Control,” *Journal of Experimental Psychology*, *Human Perception and Performance,* Vol. 34, No. 5, 1150–1164, 2008. [13]

(8) A. Lundin, N. Zaimovic, “Digital rear-view mirrors: Physical ergonomic implications of arranging digital rear-view mirrors in a truck cabin,” KTH Industrial Engineering and Management, Machine Design, Master of Science Thesis, Stockholm, Sweden, 2015. [14]

(a) Lundin and Zaimovic [14], a master’s thesis project carried out with Scania (heavy truck manufacturer based in Sweden), evaluated five different monitor arrangements in a truck cab. Most of the test participants preferred the A-pillar arrangement because it comes closest to representing the conventional mirror setup and such an arrangement minimizes the learning curve associated with the transition from physical mirrors to camera monitor systems.

(9) The following studies address the role of image magnification in driver perception of distance in rear vision displays (including both mirrors and video screens). The overall conclusions are the following. 1) Image magnification in rearview displays does not predict distance perception in a simple way. Other features, including pictorial cues and the optical distance of images seen in convex mirrors, are probably important. 2) Larger fields of view may diminish the effect of image magnification on distance perception. 3) At least in the context of mirrors, larger fields of view (with accompanying reduction of image size) seem to lead to fewer lane-change crashes than unit-magnification mirrors (with accompanying blind zones).

(a) J. Schumann, M. Sivak, M.J. Flannagan, “Are Driver-Side Convex Mirrors Helpful or Harmful,” The University of Michigan Transportation Research Institute (UMTRI), UMTRI-96-7, 1996. [15]

(b) M.J. Flannagan, M. Sivak and E.C. Traube, “Quantifying the Direct Field of View when Using Driver-Side Rearview Mirrors,” presented at SAE International Congress and Exposition, Detroit, Michigan, USA, March 1-4, 1999. [16]

(c) J. Luoma, M.J. Flannagan, M. Sivak, “Effects of Non-Planar Driver-Side Mirrors on Lane Change Crashes,” Transportation Human Factors, 2, 279-289, 2000. [17]

(d) M.J. Flannagan, M. J., Sivak, M. and Simpson, J. K. The relative importance of pictorial and nonpictorial distance cues for driver vision. Proceedings of the International Driving Symposium on Human Factors in Driving Assessment, Training and Vehicle Design, Aspen, CO, pp 214 – 218, 2001. [18]

(e) M.J. Flannagan, M.L. Mefford, “Distance perception with a camera-based rear vision system in actual driving,” The University of Michigan Transportation Research Institute (UMTRI), UMTRI-2005-38, 2005. [19]

(f) M.J. Flannagan, M. Sivak, “Distance cues and fields of view in rear vision systems,” SAE Technical Paper Series No. 2006-01-0947, SAE International, Warrendale, Pennsylvania, USA, 2006. [20]

(g) M.J. Flannagan, M. Sivak, J. Schumann, S. Kojima, E.C. Traube, “Distance perception in driver-side and passenger-side convex rearview mirrors: Objects in mirror are more complicated than they appear,” in A. G. Gale, I. D. Brown, C. M. Haslegrave, & S. P. Taylor (Eds.), Vision in Vehicles VIII (pp. 126-134). Leicestershire, UK: Applied Vision Research Centre, Loughborough University. E. C., 2012. [21]

(10) Review of additional publications listed in reference section required (References 27 through 33).

(11) VTTI Naturalistic Driving Study [3] Summary and Key Findings (Con’t). References to how the participants felt regarding safety. “Most feel safe (83%) using Camera-based displays, and 53% felt it improved safety over conventional mirrors. Many Drivers (28%) credited the Camera system as have “saved” them from a potential conflict”

(12) De Vos, A. P. (2000, September). Non-planar driver’s side rearview mirrors: A survey of Mirror types and European Driver Experience and a Driver Behavior Study on the Influence of Experience and Driver Age on Gap Acceptance and Vehicle Detection (Report No. DOT HS 809 149). 106 pp. 14 refs. (SAE2001-01-0321 / NHTSA HS 809149)

(a) This paper details an experiment "in which it was investigated whether the type of mirror has effects on gap acceptance, on the detection of vehicles at close range besides and behind the driver and on visual sampling behavior. In this study the effects of experience a driver has with a specific type of mirror were analyzed as well as the effects of driver's age." The results of the experiment show that "in general, drivers accept smaller gaps in case of non-planar mirrors, due to image size reduction." The results also show that "non- planar mirrors give a vast reduction of the number of detection faults: from more than 30% in case of a planar mirror to less than 10% in case of non-planar mirrors." When trading off gap acceptance and detection faults, the report concludes that "the use of non-planar driver's side rearview mirrors should be beneficial for safety."

(13) (2008 July) Study of Driver Performance/ Acceptance Using Aspheric Mirrors in Light Vehicle Applications: Final Report (Report No. DOT HS 810 959). 249 pp. 50 ref

(a) This is a large report collecting a large number of other studies including the De Vos paper mentioned above. The report summarizes a number of advantages and disadvantages of Aspheric mirrors, including the key 'larger FoV, fewer crashes' and 'degraded distance judgement'. The report notes that "It is possible therefore that an aspheric (or convex) mirror may cause slightly smaller clearances during passing and merging, as well as an occasional collision. However, preliminary accident analyses performed by other researchers suggest that these types of collisions are more than offset by increased angular detection capability." The report goes on to recommend a fleet study is carried out before any change is made to a change in the standard.

(14) CAROL A. FLANNAGAN, ANDRÁS BÁLINT, KATHLEEN D. KLINICH, ULRICH SANDER, MIRIAM A. MANARY, SOPHIE CUNY, MICHAEL MCCARTHY, VUTHY PHAN, CAROLINE

WALLBANK, PAUL E. GREEN, BO SUI, ÅSA FORSMAN, HELEN FAGERLIND. "COMPARING MOTOR-VEHICLE CRASH RISK OF EU AND US VEHICLES" UMTRI-2015-1

(a) In support of the above two papers, the crash data compared by Flannagan et al also points to the fact that the wider FoV offered by EU mirrors contributes to fewer lane change crashes when compared with US mirrors. "mirrors in the EU vehicles on the driver's side help prevent lane-change crashes better than those in US vehicles"

b) *In addition, please explain your views on how CMS-equipped vehicles would impact light and heavy vehicle driver behavior and situational awareness while driving.*

   i) Acclimation - The time for acclimation of the 'expert' participants in the Schmidt et al. [1] was 158 minutes with a standard deviation of 96 minutes. This amount of variation is large and indicates further study is needed to understand the amount of time a driver will require to become comfortable with the CMS. Additionally, Acclimation is addressed in the VTTI Naturalistic Driving study [3]. From the section on Summary & Key Findings, it is stated that, "Nearly all drivers (94%) reported acclimating to the Camera system after 2-week exposure period". Given the limited number of participants in the VTTI study, this data is not considered conclusive.

   ii) Depth perception (2D video vs. 3D mirror) - Schmidt et al. [1] states "Likely reasons for different perceptions of distance and speed using exterior mirrors or camera-monitor systems are due to the limited availability of depth information provided by CMS." However, we note that the depth cue of binocularity (3D) is specialized for short distances <5–10 m. The required field of view for a CMS is far larger (than 5-10m) and therefore other "2D cues" are dominant for mirrors as well as for CMS, see [5] page 301, Fig. 14. Depth perception is addressed in the VTTI Naturalistic Driving study [3] as well in the section on Summary & Key Findings, it is stated that, "Camera systems perceived to increase FOV and eliminate blind spots, but some configurations were found to make it harder to judge distances and closing speeds"

   iii) Accommodation - Near field focus, bi-focal. There seems to be a general concern with people having to focus between the monitor (near field) and the outside environment (far field). The concern is due to uncertainty of whether this will cause stress to the eyes and affect his/her ability to operate the vehicle.

2) Question 2

   b) *Are the physical properties of mirrors necessary to meet the stated purpose of FMVSS No. 111 to provide a "clear and reasonably unobstructed view?" As an example, because each eye of a driver viewing objects reflected in a mirror has a slightly different angle of view of those objects, just as the eyes of a driver viewing those objects directly would have, mirrors provide depth perception similar to that provided by direct vision. As another example, mirrors offer drivers the possibility to modify their field of view rapidly by looking at the mirror from different angles.*

      i) Depth perception is a result of multiple cues, including the angular differences of binocular vision, but also pictorial, optical, linear, height and perspective and their relative importance.

ii) The enlarged field of view afforded by head and eye movement (27% increase according to our analysis) can be designed into the camera field of view and made available to the driver in the monitor by several methods: continuously available, as a function of speed and/or gear selection (D, R), when selected by the driver, etc.

iii) Another aspect not mentioned is that mirrors provide an accurate representation of lights in the rear scene. This includes trailing vehicle headlights, taillights and signal lights, emergency vehicle lights, overhead signals and electronic signage. However, with the advent of automotive LED lighting and expanded use of electronic signage, some camera systems produce distracting artifacts while interacting with these systems. This is caused by the interaction of the camera image sensor scan rate and the pulsed or pulse-width-modulated (PWM) drive scheme of the LED lighting. As a result, lights may appear to flicker in the CMS but not when viewed directly or in a mirror.

iv) Recent advances in image sensor technology are improving the performance of state-of-the-art CMS which include LED flicker mitigation, or LFM. LFM typically functions as a tradeoff between high dynamic range and reduced flicker. Even with LFM, flicker may be observed in more challenging scenarios such as a bright daytime scene with PWM LED headlamps in view.

b) *To what extent could possible CMS features which cannot be provided using mirrors (e.g., zoom, night vision) offset the loss of these mirror-specific properties?*

i) Light Vehicles
   (1) Eliminate approaching vehicle blind spots by increased field of view
   (2) Auto alignment of the CMS image to the real-world scene; avoid mirror misaim in the real world
   (3) Augmented reality by highlighting objects in the rear scene
   (4) Limit headlight glare
   (5) Multiple views
   (6) Improvement of forward field of view by removing mirrors
   (7) Reduced visual glance angle to CMS monitor vs. mirror
   (8) Fuel economy improvements are envisioned but may depend on the vehicle implementation.

ii) For heavy trucks, the field of view provided by camera monitor systems are greater than those provided by conventional mirrors even after accounting for torso and head movements. Additionally, camera monitor systems specifications can include features such as:
   (1) Trailer Panning: The field of view can automatically follow the trailer in a turn. This ensures that the side of the trailer and the trailer tires are always in view. Dynamically adjusting the field of view will result in larger fields of view that what can be obtained with a conventional mirror system and torso and head movements.
   (2) Manual Field of View Panning: Controls that allow users to manually pan the field of view can be provided.
   (3) Field of View Optimized for Slow Speed Maneuvering: Based on vehicle speed, the field of view could automatically switch over to one that is more appropriate for slow speed precision maneuvering. For example, while backing up, the FOV can automatically change to display an area that is more optimized for the backing task.

(4) Augmented Driver Assistance: Distance guidelines on the back of the trailer can indicate to the driver how close traffic is to the rear of a trailer or truck body. This feature improves situation awareness by allowing the driver to better judge the spatial relationship between the back of the trailer and surrounding traffic and objects. This feature can assist the driver with lane changes.
(5) Night Vision: CMS can improve night vision using methods such as IR illumination or digital augmentation.

3) Question 3
   a) *We seek comment on the performance of current world-market vehicles equipped with CMS when evaluated according to the ISO 16505/UNECE R46 standards. In particular, we seek comment on the performance requirements in these standards, and the on-road performance of CMS that meet these standards. Please identify any performance requirements for CMS that you believe are not stringent enough, are too stringent, or are unnecessary, and explain the basis for your beliefs. Please identify any requirements that you believe should be added and explain the basis for your beliefs. Which CMS have performed relatively well, and which have performed relatively poorly, on the road? What explains the difference in performance?*
      i) Generally, all UNECE R46 requirements are necessary as they consider multiple use cases which can be found on the road (field of view, resolution, luminance conditions, image quality, etc.). Proposed values are also well correlated with the performance that could be achieved based on current technology. However, in some cases, improvements are necessary.
      ii) Below is a summary table of the UNECE R46 / ISO16505 requirements, expanded from the Appendix included in the NHTSA ANPRM. We have included citations included in UNECE / ISO16505, but not included in the NHTSA Appendix. Additionally, we have included associated citations for the forthcoming SAE Recommended Practice titled 'J3155 Camera Monitor Systems Test Protocols and Performance Requirements'. Below the table, we have added notes where appropriate to further address NHTSA's questions.
      iii) In summary, the following aspects of performance are different for SAE J3155 compared to UNECE R46 / ISO 16505:
         (1) Luminance and contrast rendering
         (2) Smear
         (3) Blooming and lens flare
         (4) Field of vision
         (5) Activation and deactivation
         (6) Magnification factor
         (7) Resolution
         (8) Magnification aspect ratio
         (9) Influences from weather and environment
         (10) Headlight flicker
         (11) Durability

Aspect of performance	Description	UNECE R46 Citation	Associated UNECE R46 Citation	Associated ISO16505:2019 Citation	Associated SAE J3155 Citation[1]

Included in NHTSA's ANPRM Appendix					
Structural design	Requirement that the CMS meet various size, shape, and material restrictions	6.2.2.1	n/a	n/a	n/a[2]
Monitor Luminance	Requirement that CMS monitor luminance be adjustable	6.2.2.3.1, 6.2.2.3.5.1	n/a	6.2.4, 7.2.4, 6.11.1.2, 7.11.1.2	4.1.9.4, 4.2.4.2
System availability indicator	Requirement that the CMS indicate to the driver if the system is unavailable	6.2.2.3.2, 16.1.2	n/a	6.3, 7.3	4.1.9.3
Monitor isotropy	Requirement that the monitor show a uniform image. Limits for luminance when measured at various viewing angles (directional uniformity) and at various locations on the screen (lateral uniformity).	6.2.2.3.3.1	n/a	6.8.1, 7.8.1	4.2.1.2
Luminance and contrast rendering	Monitor luminance and contrast limits for different conditions (direct sun light, diffuse ambient light, sunset, and night).	6.2.2.3.3.2	n/a	6.8.2, 7.8.2	4.2.1.3[3]
Grey scale rendering	Requirement that the CMS be able to display a minimum tonal range of distinguishable different grey steps	6.2.2.3.3.3	R46 Annex 12, paragraph 1.4, ISO14594:2009	n/a	4.2.1.5
Color rendering	Requirement that the CMS be able to accurately reproduce certain colors	6.2.2.3.3.4	Color coordinates per CIE 1976 UCS	6.8.3, 7.8.3	4.2.1.4
Image artifacts (aberrations)	Requirement that CMS image aberrations be noted in the owner's manual	6.2.2.3.3.5	n/a	6.8.4, 7.8.4	n/a[2]
Smear	Limits for the white stripes artifact appearing on an image created by very bright light sources	6.2.2.3.3.5.1	n/a	6.8.4.1, 7.8.4.1, 7.8.2 Test 4.1	4.2.3.1
Blooming and lens flare	Limits for the area of image loss caused by bright lights flooding the image (blooming) and light scattering inside the lens (lens flare).	6.2.2.3.3.5.2	n/a	6.8.4.2, 7.8.4.2, 7.8.2 Test 4.1, 4.2	4.2.3.1[4]
Point light sources	Requirements for CMS to show distinctively two point light sources (e.g., passing beam headlights).	6.2.2.3.3.5.3	R46 Annex 12, paragraph 1.3	6.8.4.3, 7.8.4.3	4.2.3.2

Sharpness	Requirements for the monitor to accurately show zones of different tones, or colors, without blurring the boundaries between set zones. Limits are provided for the horizontal and vertical direction.	6.2.2.3.3.6.1	n/a	6.8.5.1, 7.8.5.1	4.2.1.7
Depth of field	Requirements for resolution of the CMS to show a sufficiently clear image at various distances.	6.2.2.3.3.6.2	n/a	6.8.5.2, 7.8.5.2	4.2.1.7
Geometric distortion	Limits for the level of distortion of the CMS image relative to a rectilinear or pinhole projection.	6.2.2.3.3.7	ISO16505:2015 Annex G.3	6.8.6, 7.8.6, Annex G.3	4.2.1.8
Flicker	Requirement that the monitor be free of flicker	6.2.2.3.3.8.1	R46 Annex 12, paragraph 1.2, ISO13406–2:2001	6.8.7.2, 7.8.7.2	4.2.3.3
Frame rate	Requirement that the CMS operate at a minimum frame rate, and that the movements of objects in front of the camera be rendered smooth and fluid.	6.2.2.3.4.1.	n/a	6.9.1, 7.9.1	4.2.2.1
Image formation time	Limit on the amount of time permitted for the monitor to form an image	6.2.2.3.4.2	ISO 9241–305:2008	6.9.2, 7.9.2	4.2.2.2
System latency	Limit on the time delay between when an event occurs and when it is rendered on the monitor.	6.2.2.3.4.3	n/a	6.9.3, 7.9.3	4.2.2.3
Impact testing	Requirement that an externally mounted CMS camera meet certain impact requirements.	6.3.1	n/a	n/a	n/a[2]
Field of vision	Requirement that CMS devices meet the same minimum field of vision requirements as mirror	15.2.4	n/a	6.4, 7.4	4.1.1, 4.1.2[5]
Activation and deactivation	Requirements for when and under what conditions a CMS must activate or deactivate.	16.1.1	R46 Annex 12, paragraph 2	6.3, 7.3	4.1.9.2
Default view	In default view the system is required to show the minimum required field of vision.	16.1.1.1	R46 15.2.4	6.2.1, 7.2.1	4.1.9.1

Overlays	Requirements relating to what information may be overlaid on the CMS image, and limits on the size of overlays.	16.1.1.3	R46 15.2.4.9.1 R46 15.2.4.9.2	6.2.5, 7.2.5	4.1.9.5, 4.1.9.6
Magnification factor	Requirement that the magnification of the CMS image be within a certain range.	16.1.3.1	n/a	6.5.1, 6.5.2, 7.5.1, 7.5.2	4.1.3, 4.1.4[6]
Resolution	Requirement for the minimum distinguishable details observable in an image.	16.1.3.2	n/a	6.5.3, 7.5.3	4.1.5, 4.1.6[7]
Magnification aspect ratio	Limits for the ratio of horizontal to vertical magnification of the image	16.1.4	n/a	6.6, 7.6	4.1.3, 4.1.4[6]
Monitors	Requirements relating to where the monitors may be located inside the vehicle and how the left and right fields of vision may be displayed.	16.1.5	R46 12.1, 12.6	6.7, 7.7	4.1.10.1
Included in UNECE R46 and/or ISO16505 and NOT Included Above					
Luminance and contrast adjustment	Requirement that if manual adjustment is possible, the operator’s manual shall provide instructions to change the luminance and contrast	16.1.1.2	n/a	6.2.4, 7.2.4	n/a[2]
Driver's field of view	Requirement that obstructions to direct field of view be minimized	16.1.6	n/a	n/a	4.1.10.1
Decreasing accommodation	Requirement that the operator’s manual include information about decreasing ability of drivers to focus as they age	16.1.7	n/a	6.11.1.1, 7.11.1.1	n/a[2]
Safety of electronic systems	Requirements for the development of a safety concept for review with type approval agency	16.1.8	R46 Annex 12, paragraph 2	6.10, 7.10, 8	n/a[2]
System documentation	Requirement that the operator’s manual and technical specification be provided by the applicant to the type approval agency	n/a	n/a	6.1, 7.1	n/a[2]
Intended Use	Requirement that the operator’s manual shall include a description of the intended use	n/a	n/a	6.2, 7.2	n/a[2]

Adjusted default view	Allowance for an adjusted default view, statutory field of view may not be met	n/a	n/a	6.2.2, 7.2.2	4.1.9.1
Temporary modified view	Allowance for a temporary view under special situations	n/a	n/a	6.2.3, 7.2.3	4.1.9.1
Color noise	Guidance against disturbing color noise	n/a	n/a	6.8.4.4, 7.8.4.4	n/a[8]
Chromatic aberration	Guidance against disturbing chromatic aberration	n/a	n/a	6.8.4.5, 7.8.4.5	n/a[8]
Pixel faults	Requirement that the monitor meet a certain quality standard regarding pixel faults	n/a	n/a	6.8.7.1, 7.8.7.1	n/a[8]
Visual artifacts	Requirement that the image be free from artifacts listed in ISO9241-307, 5.3, Table 64	n/a	n/a	6.8.7.3, 7.8.7.3	n/a[8]
Gloss of the monitor housing	Requirement that the gloss of the monitor be restricted, reference ISO 2813	n/a	n/a	6.8.7.4, 7.8.7.4	4.2.4.3
Quality and further ergonomic requirements	Directed to the national body for further quality and ergonomic requirements	n/a	n/a	6.11, 7.11	n/a[8]
Influences from weather and environment	Requirement to consider various weather and environment influences	n/a	n/a	6.12, 7.12	4.1.8[9]
Included in J3155 and NOT Included Above					
Flickering Light Sources	Limits the influence of pulsed LED headlamps when viewed on a CMS	n/a	n/a	n/a	4.2.3.3[10]
Durability	Durability requirements for CMS	n/a	n/a	n/a	4.2.4.1

iv) Notes

(1) Unless otherwise stated, the forthcoming SAE J3155 requirement will be similar to or directly reference the associated requirement of UNECE R46 / ISO 16505 requirement.

(2) Items outside the scope of J3155 include requirements related to Structural Design, Impact Testing, Operators Manual or Technical Specification, and any requirement which requires agency type approval.

(3) A revision to Luminance and Contrast Rendering is necessary to change the inclination angle delta from 15 to 20 degrees as it was done in SAE J1757:2015 and ISO 15008:2017.

(4) A new work is under development for an improved Contrast, Blooming, and Flicker test protocol in effort to address concerns about blooming that NHTSA has previously raised. This work will be included in a future revision of J3155.

(5) As directed by ISO 16505, which requires the national body define the field of vision, a new work is under development for Field of Vision, or Field of View, that incorporates current FMVSS 111 minimum field of view for mirrors.

(6) The minimum magnification provided by UNECE / ISO 16505 may be correlated with a convex, European style mirror. The allowed radius of curvature in European mirrors results in a larger field of view and a distorted image. Since US drivers are used to a 1:1 magnification driver's side mirror, the typical North American driver may have a different expectation of acceptable image quality and size than is typical for a driver accustomed to convex mirrors. However, we believe that some expanded field of view would be beneficial to reduce blind spots in exchange for image size, see [15] through [21]. Additionally, we believe that the size of a monitor required to produce an image comparable to a 1:1 magnification mirror would be challenging to package in the cockpit [24]. Therefore, a new work is under development for Magnification Factor and Magnification Aspect Ratio using the term 'Size' in effort to align with NHTSA terminology already in place for FMVSS 111 Rear Visibility. The Size requirements are intended to employ a test object along with camera-based evaluation like that currently defined by NHTSA's FMVSS 111 rearview camera testing.

(7) A new work is under development for Resolution. The test method we are developing employs the same principles that were used to develop the ISO 16505 test protocols [4] but will be adjusted for a physical test set-up similar to FMVSS 111 rearview camera testing.

(8) These requirements do not have specific test protocols or are out of scope and were not carried over into SAE J3155.

(9) A new work is under development for a weather and environment test protocol in effort to address concerns NHTSA has previously raised. This work will be included in a future revision of J3155.

(10) A new work is under development for a Flickering Light Source~~s~~ test protocol. The intent of the test protocol is to limit the influence of pulsed LED headlamps when viewed on a CMS. Pulse LED headlamps interact with the image sensor's refresh rate on some CMS cameras. This work will be included in a future revision of J3155.

System Field of View and Related Test Procedures

4) Question 4

(1) We seek comment on whether and, if so, why minimum field of view requirements for CMS should differ from the current minimum field of view requirements for mirrors under FMVSS No. 111.

i. The minimum field of view requirements (targets) for CMS should not differ from that of mirrors under FMVSS No. 111. The minimum fields of view were developed more than 50 years ago after significant research into driver's field of view [22], [23]. This is also consistent with the ISO16505 / ECE Regulation No. 46 which requires that the existing minimum fields of view for mirrors form the minimum fields of view for CMS. In the recommended practice J3155 [27] we include a on image size and that discussion also references larger FoV's as these are intrinsic to the display size and hence image size debate. As part of this discussion, it should be noted that the ability of the OEM to offer a wider field of view is limited by the combination of image size and physical display size. Supporting the discussion is an article titled, COMPARING MOTOR-VEHICLE CRASH RISK OF EU AND US VEHICLES. [36] that states "mirrors in the EU vehicles on the driver's side help prevent lane-change crashes better than those in US vehicles"

ii. In the case of heavy trucks, the minimum fields of view are specified indirectly by the surface area of the mirrors. However, all heavy truck OEMs currently provide, as standard equipment, outside mirrors that provide expanded views larger than those required by FMVSS No.111. A CMS that only replicates the FMVSS No.111 would be less that what is provided to heavy truck drivers today. Therefore, the minimum fields of view for CMS must be established. Also, the test methods to evaluate CMS fields of view will differ from test methods used to evaluate mirror fields of view. So, these test methods must also be established.

iii. SAE has developed a draft Recommended Practice titled, J3155 Camera Monitor Systems Test Protocols and Performance Requirements, which recommends CMS fields of view and associated test procedures for passenger cars and heavy trucks. A brief overview of our work so far is included below.

(1) Inside Rearview CMS

a. The requirement for the Inside Rearview CMS field of view under J3155 is like that of S5.1.1 in FMVSS 111. CAD-based and physical test procedures to verify the field of view have been developed. One key difference for CMS is that the 'projected eye-point' must be established independent of the mirror. Therefore, SAE has developed 'E_{CMS}' as a standard projection distance that can be used for CAD-based or physical test procedures to verify the field of view. J3155 includes a physical test procedure that employs 'E_{CMS}' in a similar way that 'E' is used in TP-111V-01 [26] (pages 21-24).

(2) Outside Rearview CMS – Driver's Side

a. The requirement for the Outside Rearview CMS – Driver's Side field of view under J3155 is like that of S5.2.1 in FMVSS 111. CAD-based and physical test procedures to verify the field of view have been developed. J3155 includes a physical test procedure that employs elements of the 'Rearview Image Testing' TP-111V-01 [26] (page 44).

(3) Heavy Trucks – Main View

a. The requirement for the field of view for the main view is like that of S 15.2.4.2 in ECE R46. The projected eye point for CMS is derived like the center of the segment joining the two ocular points defined in S 12.2 in ECE R46. CAD-based and physical test procedures to verify the field of view have been developed

(4) Heavy Trucks – Wide Angle View

a. The requirement for the field of view for the wide-angle view is like that of S 15.2.4.4 in ECE R46. The projected eye point for CMS is derived like the center of the segment joining the two ocular points defined in S 12.2 in ECE R46. CAD-based and physical test procedures to verify the field of view have been developed

b. *Petitioners have stated that providing drivers with expanded views, larger than those required by FMVSS No. 111, would be advantageous. What data exist to support this assertion?*

i. Studies from Schmidt et al. [1] and Large et al. [2] provide subjective data that indicate the participants feel the expanded field of view is a positive as it reduces blind spots and provides an enlarged field of view to the rear of the vehicle. Large et al. [2] states that "… most participants were amenable to the concept of digital mirrors and felt that they would be able to adapt…" As per the answer to 4a, the article titled, COMPARING MOTOR-VEHICLE CRASH RISK OF EU AND US VEHICLES . [36] provides objective data and states "mirrors in the EU vehicles on the driver's side help prevent lane-change crashes better than those in US vehicles"

c. *What, if any, potential advantages, and disadvantages, such as increased eye glance durations, may be observed for wide-view images? Please provide research or data that addresses how wider views will affect image quality.*

   i. Studies from Schmidt et al. [1] and Large et al. [2] do not necessarily support the idea that a wider field of view would cause increased eye glance durations. Both studies measure eye glance durations for multiple monitor positions, presumably with larger fields of view than a traditional mirror. While glance frequency varies, glance durations do not demonstrate a statistically significant variation. One could deduce then that the increased field of view size is not causing increased glance durations. The VTTI study [3] may provide data to corroborate this.

5) Question 5

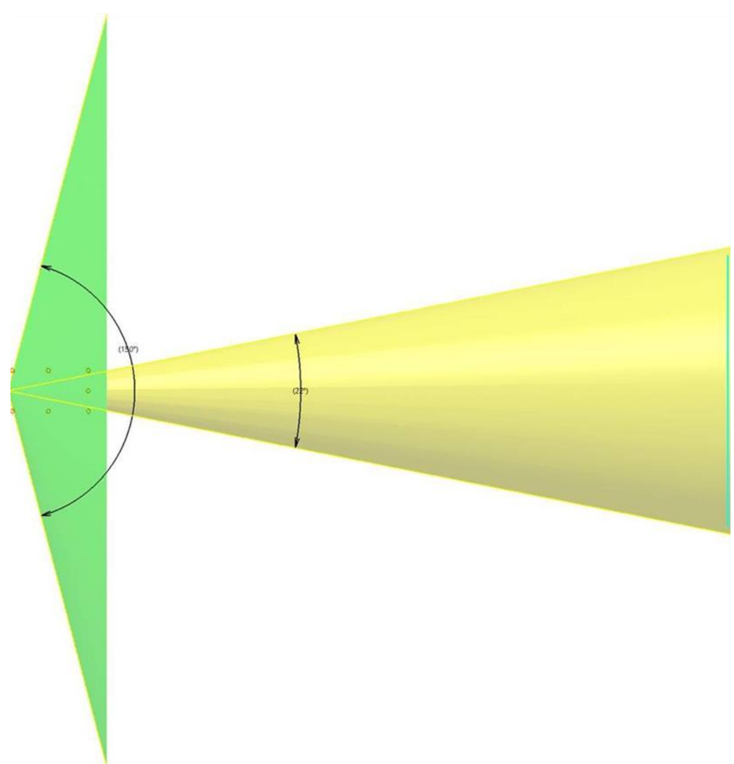
d. *We seek comment on whether NHTSA should permit CMSs that use multiple cameras to provide multiple fields of view to the driver in the same image display area. In particular, we seek comment on the safety benefits/disbenefits of permitting multiple fields of view. As an example, CMS that operate using multiple fields of view might have missing sections on the processed image, or image latency issues stemming from increased processing time. What are the concerns, if any, regarding a multi-camera visibility system and how can they be mitigated?*

   i. Light vehicles
      (1) Please see our response to Question 12.
   ii. Heavy Trucks
      (1) Conventional mirror systems in heavy trucks already display two separate fields of view in the same area: An upper flat mirror displays a narrow field of view, and the lower convex mirror displays a wider field of view. These two fields of view provide valuable information that drivers use to operate heavy trucks. Therefore, SAE recommends that NHTSA should permit multiple cameras to provide multiple fields of view to the driver in the same image display area. This will provide heavy truck manufacturers with the flexibility to offer two separate fields of view in the same monitor; the top portion of the display would display the main view, and the bottom section would display the wide-angle view. The main and wide-angle views could be obtained with just one camera or two cameras. Such an arrangement will be similar to what drivers are used to on nearly all heavy trucks in production today, and this will help minimize driver confusion and the learning curve associated with camera monitor systems. The main and wide-angle views will have the same specifications for latency and field evaluations with existing camera monitor systems have not revealed any image latency issues with these multiple views.

6) Question 6

a) *NHTSA considered whether there might be any opportunities to combine either the cameras or the displays for the CMS with the camera or display for backup camera system that is required by FMVSS No. 111. The agency tentatively concludes that there would not be any such opportunities. Although CMS and backup camera systems would likely operate in a similar way, the systems serve different safety purposes and are used in different circumstances. Specifically, the purpose of a CMS would be to assist the driver in avoiding all crashes during normal driving, while the purpose of a backup camera is to assist the driver in avoiding backover crashes while in reverse. Perhaps more important, given the likely differences between the field of view and display image quality parameters that would apply to CMS versus backup camera systems, NHTSA believes it is unlikely that it would be technically possible to combine the two systems in such a way that they share either a camera or display monitor. NHTSA requests comments on this tentative conclusion.*

   i) SAE has considered the possibility of combining the rearview camera and CMS cameras. In the illustration below, a rearview camera field of view of about 150 degrees that meets S5.5.1 of FMVSS 111 is shown in green with the rear visibility test objects in view. Overlaid and from the same vantage point, a CMS camera field of view of about 22 degrees that captures the minimum field of view for an inside rearview mirror is depicted in yellow. The CMS field of view is 22 degrees instead of 20 degrees because the CMS camera is placed at the rear of the vehicle instead of at the projected eye point. Clearly, the two fields of view are substantially different.



ii) Three aspects of image quality that illustrate the technical difficulties of combining the backup camera and CMS cameras are given below:
   (1) Field of View, Size and Resolution Tradeoff
      (a) CMS Field of View, Size and Resolution requirements developed by SAE must be considered in concert. A CMS meeting these requirements will have a relatively high resolution over a relatively narrow field of view when compared to the rearview camera. If the same camera is then used to also render the relatively wide field of view of the rearview camera image, the electro-optical design requirements become very challenging.
   (2) Frame rate
      (a) Typical rearview cameras have a frame rate of 25-30 frames per second (fps), which is enough for low-speed backing maneuvers. However, a CMS typically uses 30-60 fps which is necessary to avoid jitter in challenging uses cases such as a roundabout.
   (3) Dynamic range
      (a) Typical rearview cameras have a medium dynamic range which is enough for low-speed maneuvers at night that are illuminated by reverse or rear taillights. However, CMS cameras typically have a high dynamic range which is necessary to render nighttime scenes in the distance or objects in and outside a tunnel. An example of various scenes is shown below, photo courtesy of Ficosa International, S.A.

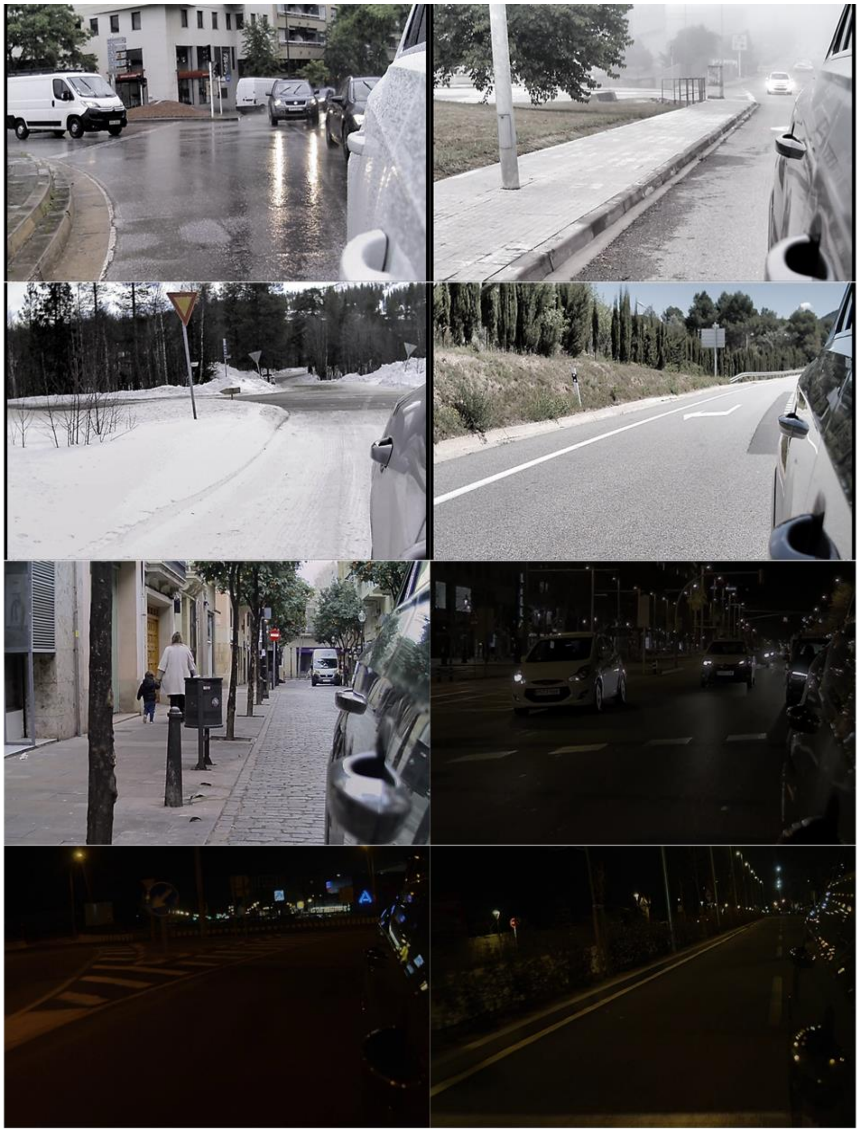


Figure 1. CMS performance evaluation on AUDI e-tron under multiple weather and lighting conditions ©FICOSA International SA

Image Quality and Related Test Procedures

7) *Question 7*
   a) *We seek comment on the minimum quality of the image presented on a CMS electronic visual display to provide the same level of safety as traditional FMVSS No. 111-compliant mirrors, as well as how image quality could be objectively measured. In particular, we seek comment on what would be the appropriate minimum camera and visual display parameters and performance metrics for a CMS (i.e., camera/display resolution, screen brightness, contrast, color, tone, and their adjustments).*
      i) *Please see our response to Question 3.*

b) *Should the parameters and metrics for a CMS differ from those for a backup camera system and, if so, how and to what extent? To what extent do existing CMS regulations (e.g., ISO 16505/UNECE R46) provide objective and repeatable performance requirements and test procedures to evaluate image quality? To the extent that those regulations do not provide such requirements and procedures, what changes or additions would need to be made? What new procedures, if any, would be needed to evaluate image quality appropriately and what has been done to develop such procedures?*
    i) Current FMVSS 111 requirements applicable to backup cameras should not be used as reference as the intended product usage is more limited and hence the requirements are not as restrictive as the ones applicable to a CMS. Please see our response to Question 6.

8) Question 8
    a) *We seek comment on what disruptive display aberrations (blooming, etc.) should be addressed if the agency were to develop a CMS performance standard. To what extent do existing CMS regulations (e.g., ISO 16505/UNECE R46) provide objective, and repeatable performance test procedures to evaluate display aberrations? What new procedures, if any, would be needed to evaluate display aberrations appropriately and what has been done to develop such procedures?*
        i) *Please see our response to Question 3, Smear, Blooming and Lens Flare.*

Rearview Image Display Type Related Human Factors

9) Question 9
    a) *We seek comment on what research has been done to identify and address human factors issues like eye strain or visual fatigue from long periods of intermittent electronic visual display viewing. While we are particularly interested in research comparing driver eye strain and/or visual fatigue for users of a CMS versus users of traditional rearview mirrors, other analogous research could be useful.*
        i) This continues to be an area of study for SAE, and we agree more research is necessary.

10) Question 10
    a) *We seek comment on research concerning differences in the ability of drivers to visually discern and focus on objects in an electronic visual display as compared to objects reflected by traditional rearview mirrors.*
        i) This continues to be an area of study for SAE, and we agree more research is necessary.

11) Question 11
    a) *We seek comment on how a driver should be alerted that a CMS is not operating correctly, such as during a malfunction or a software update.*
        i) UNECE R46 / ISO 16505 states that each OEM shall define the CMS systems behaviors for normal as well as abnormal operating conditions and that Tier I suppliers should implement OEM requirements based on ISO 26262 (functional safety). CMS systems behavior definitions shall also include all indications provided to the driver in case of malfunctions (e.g., visible / audible / haptic warning signal, message display, etc.).

Side Rearview Image Display Locations, Driver Acclimation, and Related Test Procedures

12) *Question 12*

a) *We seek comment on whether and how placing the CMS displays in non-traditional locations (e.g., in the center console) would affect vehicle safety, as compared to placing the displays close to where the outside rearview mirrors would be mounted near the A-pillars. In particular, we seek research concerning the impact of different image locations on the level of safety and performance among any driver demographic, and whether different image locations may lead to driver confusion.*

i) Light Vehicles

(1) Both Schmidt et al. [1] and Large et al. [2] study multiple monitor locations by assessing measures for last safe gap, glance frequencies and glance durations. Additionally, subjective assessments are included. From [1], “The most preferred positions were CMS 3 and CMS 2. More than half of the subjects (22 subjects) preferred CMS 3 and 38 % (15 subjects) preferred CMS 2. Only one subject chose CMS 1. Two subjects gave preference to CMS 3 on the left-hand side in combination with CMS 2 on the right-hand side. The analysis of the acceptance ratings of the CMS showed that acceptance is unrelated to experience gained by the subjects, i.e., the acceptance did not depend on whether and how long the CMS was used by the subject”. Figure 7 from [1] is given below for convenience.

Figure 7: **Schematic overview of the location of the positions CMS 1, CMS 2 and CMS 3.**

(2) It is interesting to note that the authors interpret the higher glance frequency of position 3 as positive vs. eyes off the road. In this case, eyes off the road doesn’t apply as position 3 appears largely in the forward field of view. It is also interesting to note that a center stack configuration is not considered. The authors note that, “With regard to the positions of the monitors, some subjects stated that information about the left side should always be displayed on the left-hand side. The same applies to the right side. They stated that information does not necessarily have to be displayed close to the A-pillar, but can also be displayed closer to the steering wheel.” Large et al. [2] considers 6 positions including the traditional mirror baseline. The authors conclude that the “…drivers clearly preferred configurations that most closely matched their expectation of existing mirror locations, where aspects of real-world mapping were preserved. Moreover, participants associated the more radical layouts with increased workload,

lower levels of trust, reduced situational awareness, greater distraction and poorer depth perception."

(3) In the two studies, glance frequency is associated with two conflicting possibilities. One is that more glances take the drivers eyes from the road, and the other is that more glances suggest the driver prefers that configuration. Drawing on Schmidt et al. [1], it seems the subjective data lends to the later interpretation while Large et al. [2] seems to suggest an interpretation of less glances equates to less eyes off the road.

(4) The position of the monitor relative to the driver's eye in these interpretations is important. If the position is within the immediate forward field of view, glances to the monitor may be the driver simply looking forward or that it's easier to look at the monitor, so they look more. There is subjective and objective evidence that placing the left monitor to the left of driver center line and the right monitor to the right of driver center line makes sense. The participants in Schmidt et al. [1] communicated this subjectively. Additionally, W.O. Readinger [10] provides data indicating there is a tendency to steer in the direction one is looking. If you look right to view the scene to the left, it could cause an unintended path or disorientation, potentially causing the driver to steer in the wrong direction. UNECE R46 has required left monitor be placed to the left of driver center line and the right monitor to the right of driver center line. We generally support this requirement, although recommend monitor position be considered in future studies.

(5) The VTTI Naturalistic Driving Study [3] lists the monitor position as a 'concern' from the perspective of the driver in the Summary & Key Findings section. This aspect is an area that may require further study.

(6) Ambient light should be considered regarding the monitor position as noted in SAE J1751-1. Position monitor such that it must be legible in high ambient light situations.

ii) Heavy Trucks

(1) A. Lundin, N. Zaimovic [14], a master's thesis project carried out with Scania (heavy truck manufacturer based in Sweden), evaluated five different monitor arrangements in a truck cab. The monitor arrangements evaluated were:

(a) A-pillar arrangement (AP): Driver and Passenger-side monitors mounted on the A-pillars.

(b) A-pillar and instrument panel arrangement (AP/IP): Driver-side monitor mounted on the A-pillar and Passenger-side monitor was housed in the instrument panel.

(c) Instrument panel arrangement (IP): Driver and passenger-side monitors were housed next to each other, to the right of the driver, in the instrument panel.

(d) Instrument panel and shelf arrangement (AP/S): Driver-side monitor mounted on the A-pillar and passenger-side monitor mounted above the windshield on the overhead console/shelf.

(e) A-pillar and windscreen arrangement (AP/WS): Driver-side monitor mounted on the A-pillar and passenger-side monitor mounted on the windshield at the same height as the driver-side monitor and towards the right of the driver.

(2) The impacts to image size, viewing angles, and direct vision obstruction were considered for each of these monitor arrangements. Of the five monitor arrangements, the AP/WS arrangement was not evaluated further because of concerns that monitors mounted on

the windshield would significantly degrade direct visibility. The remaining four arrangements were evaluated further with a driving simulator; objective and subjective measurements were obtained from the simulator study. Additionally, quantitative analyses for metrics such as vision time, head movement, and eye movement were completed using digital human models.

(3) Most of the test participants preferred the AP arrangement. The AP arrangement comes closest to representing the conventional mirror setup and such an arrangement

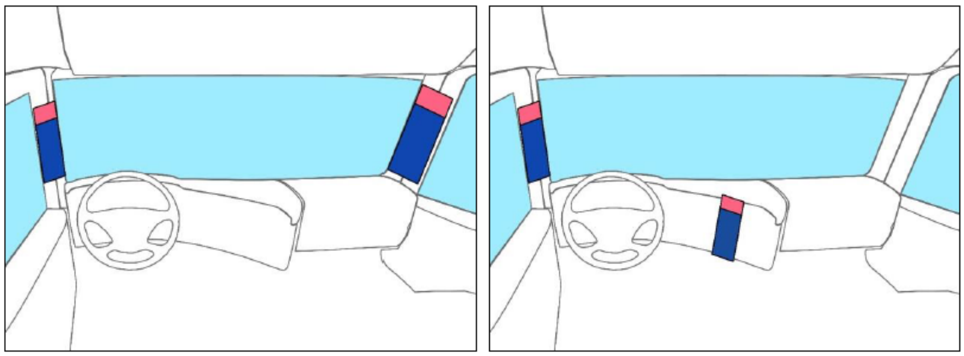


Figure 36. Illustrations of the two arrangements that are proposed for further development. To the left, the AP arrangement is shown, and to the right, the AP/IP arrangement is shown.

minimizes the learning curve associated with the transition from physical mirrors to camera monitor systems. However, the results from the driving simulator were in favor of the AP/IP arrangement in terms of detection distance and standard deviation of lane position. Both the AP and AP/IP arrangements were recommended for further development and evaluation. This thesis project highlighted that while the monitors mounted in the windshield were the most preferred option, there are alternate arrangements that could be deemed feasible based on the arrangements' effects on driver acceptable, direct, and indirect visibility. Figure 36 from [14] is given below for convenience.

(4) The SAE Driver Vision Committee - CMS Task Force (SAE) has developed a draft Recommended Practice titled 'J3155 Camera Monitor Systems Test Protocols and Performance Requirements' which includes a section titled 'Monitor Positioning Guidelines'. This section provides recommendations for how to integrate monitors inside heavy trucks.

13) Question 13

a) *We seek comment on whether research has been performed concerning the impacts of glare from sunlight and other vehicles' headlights on the CMS display, and whether test procedures have been developed to measure glare. If performance requirements and test procedures have not yet been developed to address these problems, when and how can they be developed? What are potential strategies to mitigate glare to ensure that useful images would be provided to drivers over the greatest range of conditions possible.*

i) *Please see our response to Question 3, Luminance and Contrast Rendering.*

ii) Ambient light should be considered regarding the monitor position as noted in SAE J1751-1. The monitor should be positioned such that it is legible in high ambient light situations.

Camera Durability, Reliability, and Related Test Procedures

14) Question 14
    a) *We seek comment on the anticipated lifespan of the electronic visual display and camera components that would be installed in a typical CMS. Will the performance (e.g., display brightness) of components be maintained within specifications consistent with desired image quality over that lifespan, or will performance decrease due to age and/or being subject to outdoor conditions with wide temperature ranges and precipitation?*
        i) *Please see our response to Question 3, Durability.*

15) Question 15
    a) *We seek comment on the anticipated reliability of CMS as compared to outside rearview mirrors, including any reliability data that may be available for production or prototype CMSs.*
        i) Equivalent reliability requirements apply between CMS and outside rearview mirrors.

16) Question 16
    a) *We seek comment on the anticipated replacement cost for a CMS that becomes inoperable due to damage or malfunction, and how that cost compares to the replacement cost of traditional powered and unpowered outside rearview mirrors.*
        i) This continues to be an area of study for SAE.

17) Question 17
    a) *We seek comment on whether and, if so, how a CMS can be weatherproofed to prevent condensation, or large water droplets, forming inside the camera enclosure, which could reduce image clarity. NHTSA has observed condensation in cameras mounted on the underside of outside rearview mirrors of recent model year production vehicles resulting in part of the camera view being unusable (e.g., the water blocks a portion of the camera's field of view). How should adequate weatherproofing be defined? Would the durability tests in FVMSS No. 111, S14.3 for backup cameras be sufficient, and if so, why? What other test procedures exist for demonstrating adequate weatherproofing of cameras, and have those procedures been validated?*
        i) *Please see our response to Question 3, Influences from Weather and Environment.*

18) Question 18
    a) *Depending on the mounting location, cameras may be subject to environmentally-caused lens obstructions (e.g., dirt, ice, rain drops). We seek comment on how to prevent or mitigate such lens obstructions. What performance requirements and associated test procedures simulating these conditions have been developed to evaluate whether the camera is providing a useful image?*
        i) *Please see our response to Question 3, Influences from Weather and Environment.*

System Availability When Vehicle Ignition Is Off

19) Question 19
    a) *Although it is not one of the primary safety purpose of rearview mirrors, drivers often use the outside rearview mirrors after turning off the ignition and preparing to exit the vehicle to*

determine whether it is safe to open the vehicle door when parked alongside a traffic lane. We seek comment on whether NHTSA consider requiring that a CMS be capable of serving this function by being operational in some capacity either at all times or for a specified period of time after opening the driver's car door. What new performance criteria would need to be developed for this purpose and what has been done to develop those criteria?

i) The mirror is always 'on' but not always available for the driver. State of the art automotive mirrors can have "switchable functions" like folding or dimming. It may take up to 7 seconds before the folding process is completed and the mirror is available to the driver. It is also possible to fold the mirrors while driving. SAE J3155 Recommended Practice [27] includes specific requirements for system activation / deactivation as defined under ECE R46. These requirements have been defined considering the use case proposed to give additional time to the driver when the ignition is off to assure a safe exit (e.g., activation and deactivation signals may include front door opening to enable the CMS operation and certain amount of time is defined before CMS deactivation).

Miscellaneous

20) Question 20

a) *Are there any other safety concerns that are closely related to the performance of CMS that are not addressed in this notice? If so, what are they, and what is the degree of their importance?*

i) Scenarios for which the CMS underperforms the traditional mirror as noted in Schmidt et al. [1] are: 1) viewing approaching vehicles in roundabouts, 2) fast periodic changes from light to dark such as on rural roads surrounded by forest where trees create shadows and openings in the trees allow direct sunlight ([1], pp. 25), and 3) behavior in snow or fog ([1], pp. 32). Given the current data or lack thereof, further study is recommended.

21) Question 21

a) *We seek comment on the potential short-term and long-term economic impacts of CMS. In particular, we seek comment on the level of consumer interest in vehicles equipped with CMS. We also seek comment on the extent of reduced drag associated with the installation of CMS and on the resulting amount of improved fuel economy. Finally, we seek comment on the magnitude of the cost differential between equipping a vehicle with CMS and equipping a vehicle with rearview mirrors, and on the extent to which improved fuel economy would offset increased equipment costs associated with CMS.*

i) This continues to be an area of study for SAE.

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