Lane Change Hazard Analysis Using Radar Traces to Identify Conflicts and Time-To-Collision Measures

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16. Abstract

This project analyzed existing data and assessed the safety equivalency of prototype video-based camera systems to support Federal Motor Vehicle Safety Standard 111 rulemaking efforts and investigate camera-based side view systems. The researchers mined an existing set of radar data surrounding real-world lane change events. The study was performed in Southwest Virginia using 36 drivers experiencing both conventional and camera-based systems over a month-long naturalistic exposure period (2 weeks conventional, 2 weeks camera-based). Study vehicles were instrumented with a data acquisition system to capture and record time-synchronized video and parametric measures from key-on through key-off (i.e., the entirety of each trip). Analyses focused on potential lane change conflicts and hazards identified using time-to-collision values (which in turn were derived from rear-mounted radar units) surrounding signalized lane change events. Results provided no compelling evidence to suggest that camera-based systems adversely affected lane change performance to lead to riskier or more hazardous lane changes compared to conventional mirror systems. Results instead suggested that camera-based systems, when appropriately designed, can help drivers detect potential conflicts because of the wider field of view afforded by these systems, enabling drivers to assess the presence of a vehicle in the target lane.

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Camera-based systems, time-to-collision, lane change hazard analysis, radar traces

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Abstract

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Acknowledgements

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Table Of Contents

List of Figures

List of Tables

Introduction and Background

Advancements in camera-based technologies have led to the development of prototype side view camera systems intended to replace exterior passenger-vehicle mirrors with camera-based equivalents. Because a large percentage of lane change crashes occur because drivers are not aware of the presence of a conflicting vehicle [1], camera-based systems may result in increased safety by providing a wider field of view that helps drivers detect potential conflicts. Nevertheless, Federal Motor Vehicle Safety Standard 111 currently prohibits the use of camera-based systems over conventional mirror systems. Consequently, investigation (and subsequent data) needed for camera-based side view systems to support rulemaking efforts. Impacts of camera-based systems on driver eye glance and lane change behavior are needed to assess influences on driver perceptual judgements (e.g., vehicle detection, distance and closing speeds, conflicts) under various conditions, including day and nighttime operations.

To assess the presence and magnitude of these impacts, we mined an existing set of radar data surrounding real-world lane change events. These lane changes were executed by drivers in a naturalistic driving study. The dataset provides valuable opportunities to develop computer-based algorithms for dealing with and managing radar traces to identify normative lane change signatures and signatures for conflict events (e.g., inappropriate lane changes, lane changes executed with small time gaps). In addition to allowing the assessment of camera-based system safety-relevant impacts, we expect this research to contribute to the development of automated and partially automated driving systems in three primary ways. First, these findings may contribute to developing and validating algorithms using radar trace data to classify “safe” and “unsafe” lane change situations, which may be used to guide the implementation and management of automated lane change systems. Second, this research can help to develop automated lane change systems that naturally mimic a good driver’s performance, thereby increasing driver acceptance and comfort. Third, this study may contribute to developing warnings for drivers operating partially automated systems under situations where drivers need to assume control, such as guarding against inadvisable lane changes. Understanding how drivers manage lane changes under manual driving situations (e.g., time-to-collision [TTC] judgements, conflicts) can greatly enhance and aid in the development and implementation of automated lane change and driver warning systems. Thus, the focus of this effort was to perform in-depth analyses to explore lane change conflicts using TTC data derived from radar signatures.

Method

This effort relied on an existing naturalistic driving dataset that captured normative driver interactions with conventional mirror and camera-based displays designed to characterize driver performance when fully relying on camera-based systems to make lane change judgements. The study was performed in Southwest Virginia using 36 drivers, sampled to represent a range of ages, with drivers experiencing both conventional and camera-based systems over a month-long naturalistic exposure period (i.e., 2 weeks conventional, 2 weeks camera-based). Three different prototype camera-based system implementations (and their corresponding conventional mirror equivalents) were evaluated, each provided by three participating OEMs. Camera fields of view ranged from 31 to 42 degrees (horizontal) and 20 to 22 degrees (vertical) with in-vehicle displays ranging in size between 5.6 and 7.0 inches. All test vehicle camera-based displays were located within the recommended visual angles in the National Highway Traffic Safety Administration (NHTSA) Visual-Manual Driver Distraction Guidelines. One of the research vehicles also replaced the inside rearview mirror with a camera-based equivalent, making it a true mirrorless vehicle. The other two vehicles retained a conventional rearview mirror. All vehicles were equipped with production Side Blind Zone Detection systems; these systems were disabled for the study to allow focused and non-confounded evaluations of the impacts of the camera-based systems.

All study vehicles were instrumented with a data acquisition system (DAS) to capture and record time-synchronized video and parametric measures from key-on through key-off (i.e., the entirety of each trip). The instrumentation package also included two rear-facing corner radar units, installed on the left and right sides of the vehicle but recessed behind the bumper, to capture distances and relative speeds of vehicles in the adjacent lanes. The dataset includes 25,655 signalized (referring to when the turn signal went from on to off) lane changes at highway speeds (i.e., travel at 55 mph or greater, see Table 1), with 12,695 of these lane changes executed under the camera-based displays. Events were identified by relying on the lane change indicator signal recorded by the DAS.

Table 1. Fleet Trip Summary Data for Conventional Mirror and Camera-based Displays for Signalized Lane Changes at Highway Speeds (55 mph+) and for All Fleet Subjects (n = 36)

	Overall (Total)	Conventional Mirror	Camera-Based displays
Number of trips	4,486	2,243	2,243
Total miles driven	90,880	46,730	44,149
Average miles per trip	20.26	20.83	19.68
Total aggregated number of signalized lane changes	25,655	12,960	12,695
Average number of signalized lane changes per trip			
Overall (All trips)	5.71	5.78	5.66
Trips over 20 miles	14.14	14.43	13.85
Signalized lane change rate per 100 miles			
Overall (All trips)	21.69	16.24	16.93
Trips over 20 miles	31.50	30.97	32.03
Signalized lane change direction			
Number of left-hand lane changes	12,090	6,092	5,998
Number of right-hand lane changes	13,565	6,868	6,697
Number of signalized lane changes by time of day			
Day	20,382	10,633	9,749
Night	3,845	1,649	2,196
Twilight	1,428	678	750
Number of signalized lane changes by fleet			
Sedan A	8,893	4,195	4,698
Truck	10,018	4,989	5,029
Sedan B	6,744	3,776	2,968

Reduction and Sampling Lane Change Epochs

The existing dataset of signalized lane changes was investigated to identify potential lane change conflicts; data from the rear-facing radar units was used to identify cases where a vehicle was present in the target lane and to characterize TTC judgements under mirror and camera-based systems. Several key points or landmarks surrounding these signalized lane change events were defined (as shown Figure 1) to include: 1) the point at which drivers activated the turn signal, referencing the intent to make a lane change (LC Intent point), 2) the point at which the vehicle's leading rear tire first contacted the lane boundary marker (Contact Point), and 3) the point at which the vehicle's trailing rear tire completely crossed over the lane boundary marker. Video reduction by trained analysts was used to reference the Contact Point and Cross Over Point.

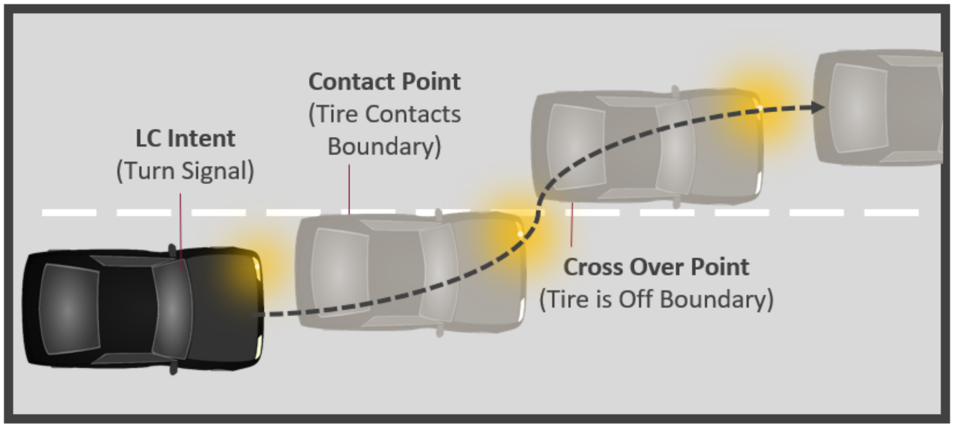


Figure 1. Signalized lane change landmark points.

Statistical analyses were performed using the SAS analysis software with main effects evaluated using the PROC GLM procedure (general linear model) to perform analysis of variance (ANOVA) tests. Alpha levels were set to 0.01, and experiment-wise error was controlled using Duncan's multiple range post hoc test to follow up significant main effects.

Identification of Principal Other Vehicle (POV) Using Processed Radar Traces

The lead (or host) vehicle (LV) was equipped with two Continental® Radar PLC units with short-range radar (SRR320) on the back bumper facing straight backward. One unit was located on the left side and the other one was located on the right side of the LV. The Continental radar is a Doppler radar with an operating frequency of 24 Hz, a range accuracy of ±0.2 m, a speed accuracy of ± 0.2 km/h, a field of view of ±75 degrees, and the ability to track vehicles within a range of about 95 m. The radar units were configured in such a way that the vehicles located in the blind spot in the rear and next to the LV were continuously recorded. This radar unit can track up to 40 targets using one of 40 object IDs. The information of the following variables was retained for each tracked object ID:

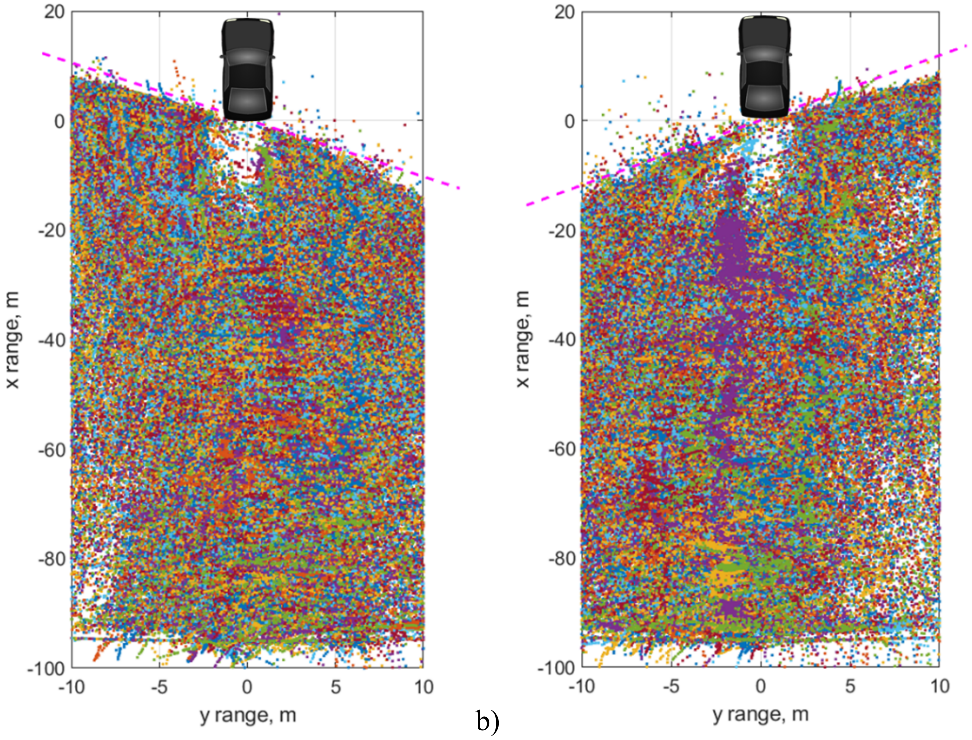
1. Object_ID – index that assigned a unique identifier for a target being tracked, numbered 0 to 39
2. Range_x – longitudinal distance between the target and the LV, measured in meters
3. Range_y – lateral distance between the target and the LV, measured in meters
4. Rangerate_x – time derivative of Range_x, measured in m/s
5. Rangerate_y – time derivative of Range_y, measured in m/s

6. Age – lifetime of the target, measured in milliseconds
7. Length – target length, measured in meters
8. Width – target width, measured in meters
9. Orientation – orientation of the target with respect to the radar's face, measured in rads
10. Probability of Existence – probability of the target's existence; ranges from 0 to 1, where 1 represents the highest probability of existence
11. RCS – radar cross section of the target, measured in dBsm
12. Stable – echo from the target is stable; denoted by true or false
13. Status – status of the target tracked by radar: predicted, measured, or invalid

The 25,655 signalized lane changes were associated with a total of 2,256 trips. For a typical trip, the distribution of lateral and longitudinal locations of the tracked objects in reference to the LV using the left and the right radars are presented in Figure 2. The raw data of the radar units was processed using the following conditions:

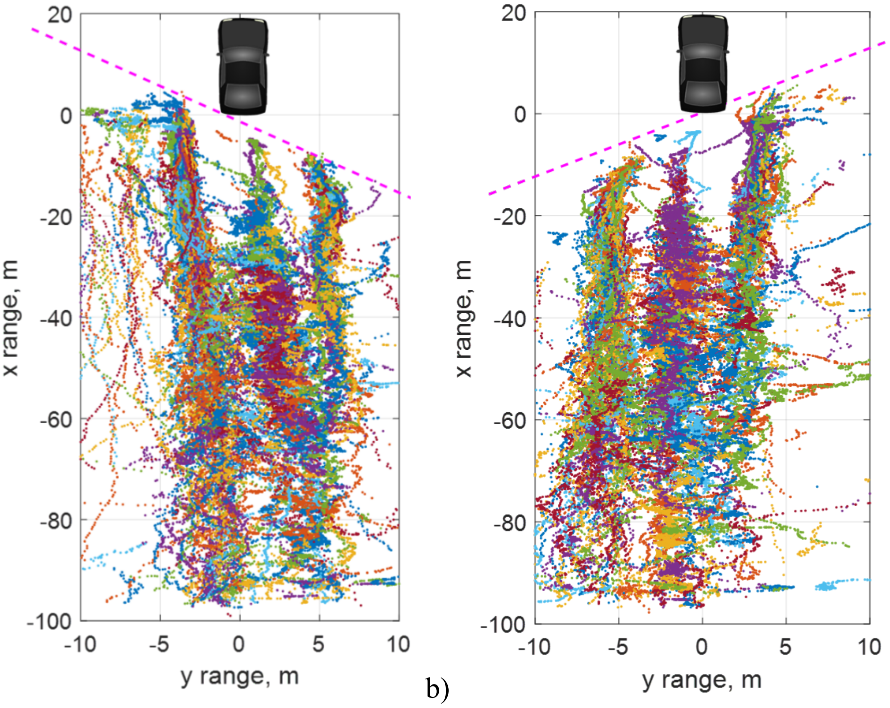
1. Delete all data where $Range_x \leq 0\ m$ and $Range_y < 0\ m$ for right radar and where $Range_x \leq 0\ m$ and $Range_y > 0\ m$ for left radar.
2. Delete all data where Probability of Existence < 0.99.
3. Delete all data which Status is not "measured" or "predicted."
4. Select all data where $-0.5\ rad \leq Orientation \leq 0.5\ rad.$
5. Select all data where $-10\ m \leq range\_y \leq 10\ m$.
6. Select all data where Age ≥ 15 s.
7. Select all data where Stable = 1.

Figure 3 shows the processed radar traces for the distribution of point clouds shown in Figure 2.



a) b)

Figure 2. Location distribution of detected objects by a) left side radar and b) right side radar (Each color represents the object ID, numbered from 0 to 39).



a) b)

Figure 3. Distribution of location of detected objects after processing data of a) left side radar and b) right side radar (Each color represents the object ID, numbered from 0 to 39).

The first objective is to identify the following vehicle that most likely conflicts with the LV during the lane change traveling in the same direction in the merging lane, referred as the principle other vehicle (POV). The next objective is to calculate the POV's TTC value. For identification of the POV during the LV lane changes, a bird's-eye plot of 2-D driving trajectories of the following vehicles and the LV from the raw radar data and the lane tracker, as illustrated in Figure 4, is created.

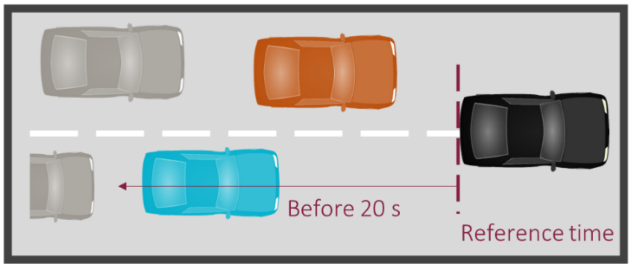


Figure 4. Schematic of car following scenario during a lane change.

A Virginia Tech Transportation Institute (VTTI)-developed lane tracker, called the "Road Scout," calculates the LV position relative to road lane markings using a custom machine vision process in real time at 10 Hz from video frames of the forward camera feed. The trajectory points of the path traveled by the following vehicles from the radar data were re-orientated in the space and temporal framework with reference to the LV's Lane Change Reference Point (the point when the LV is aligned with a lane divider). The rationale for choosing the LV's Lane Change Reference Point for the re-orientation is to align the origin points of the Road Scout and the radar measurements with the lane divider. The following steps are carried out to create the bird's-eye plot:

1. The Road Scout estimates the distance from the center of the LV to the left and right lane markings. Adjust the lateral position of the LV at every timestamp with respect to the line divider.
2. Identify the LV's Lane Change Reference Timestamp when the LV aligns with the lane divider. Here the LV's lateral position would be around zero.
3. Calculate the longitudinal trajectory of the LV's travel until it reaches the Lane Change Reference Timestamp by time-integrating the LV speed.
4. Select the right radar data for the right lane changes and the left radar data for the left lane changes.
5. Choose the radar data from the timestamp of when the LV has traveled 200 m longitudinally before reaching the LV's Lane Change Reference Point. The 200 m was assumed to be sufficiently larger than the distance traveled by the LV from the lane signal to the Lane Change Reference Point.
6. With reference to the LV's longitudinal and lateral positions, adjust the following vehicles' positions and times from the measured radar data at every timestamp.

Figure 5 presents the space and the time representation of trajectories of the vehicles behind the LV during a right lane change. The next task was to identify the POV during the lane changes, which was carried out using the following steps:

1. Select the following vehicles, which are those vehicles presenting radar signatures within a 0.5-s window past the LV's Lane Change Reference Point. For example, this parameter omits object 10 (right plot of Figure 5) as a following vehicle because the radar data for this object is not available for the 0.5 s preceding the LV Lane Change Reference Point.
2. Of the candidate following vehicles, select those within a lateral distance of [-5 m, 0] for right lane changes and [0, 5 m] for left lane changes during a 1-s window before the LV's Lane Reference Point. For example, object 13 in Figure 5 is omitted during the right lane change of LV.
3. If more than one following vehicle meets the step 2 criteria, the closest vehicle longitudinally in the merging lane is considered the POV. In Figure 5, note that the closest timestamp of the radar data measurement at the LV Lane Change Reference Point (at timestamp = 605448) is 605316. Object 2 is the POV and is located 48.3 m away longitudinally and 1 m away laterally at timestamp of 605316 in the merging lane from the LV Lane Change Reference Point.

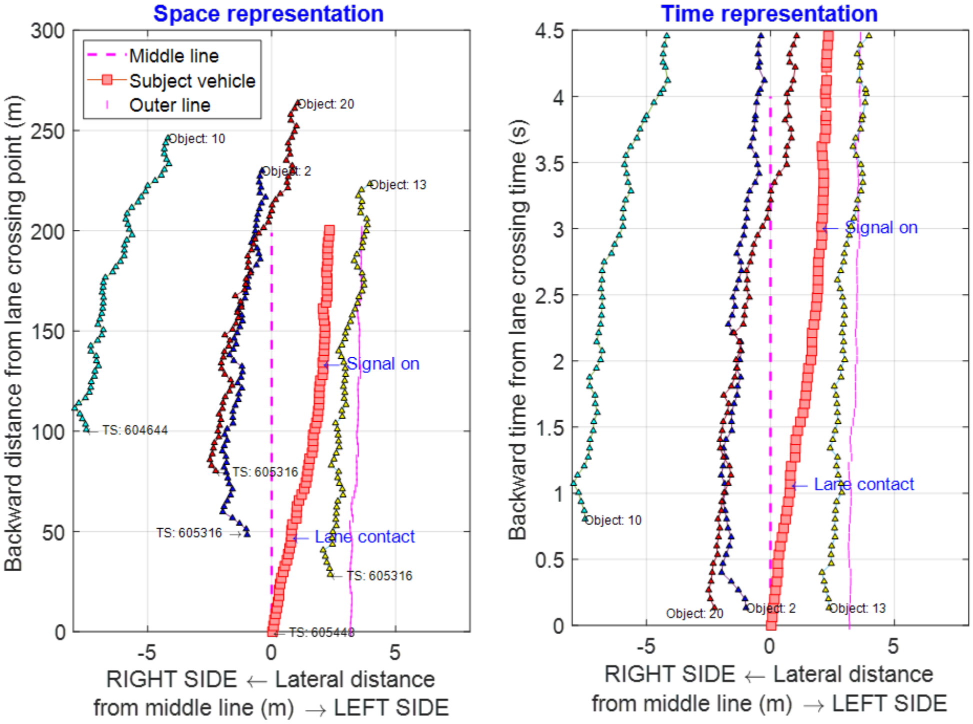


Figure 5. The space and time representation of trajectories of following vehicles during a signalized right lane change of LV.

The results from this algorithm were verified for more than 400 cases using video analysis. For a few lane change maneuver cases (less than five) exhibiting small roadway curvatures, the vehicles in adjacent lanes were incorrectly identified as the POV since the curvature of the road was not considered, which is a minor limitation of this approach. Out of 25,665 candidate signalized lane changes, a total of 7,425 had a POV present during the maneuver. For these events, the TTC values were calculated for these POVs based on range and range-rate in the longitudinal direction at the point the LV contacted the lane divider (Contact Point).

Results

This section addresses functional differences between conventional mirror and camera-based systems during highway signalized lane change maneuvers focusing on hazard-related metrics (e.g., TTC) to assess the relative safety of these camera-based systems. Analyses largely emphasize performance-based differences occurring at the point the vehicle is in the act of changing lanes (at the Lane Change Contact Point when the vehicle's tire contacts the lane lines). Data across the three individual vehicle types were pooled to increase sample sizes and statistical power for assessing differences between conventional and camera-based systems.

Distribution of TTC Values

Figure 6 presents the distribution of TTC values observed at the Lane Change Contact Point for lane changes executed under conventional mirrors and camera-based displays for both left and right lane changes. In all, 1,185 lane changes were captured (including left and right lane changes), with 607 events under conventional mirrors and 578 events under camera-based equivalents. The distributions of TTC are shown separately in Figure 7 for the left and the right lane changes. As shown, both systems yielded significant overlap in values depicted in the graph.

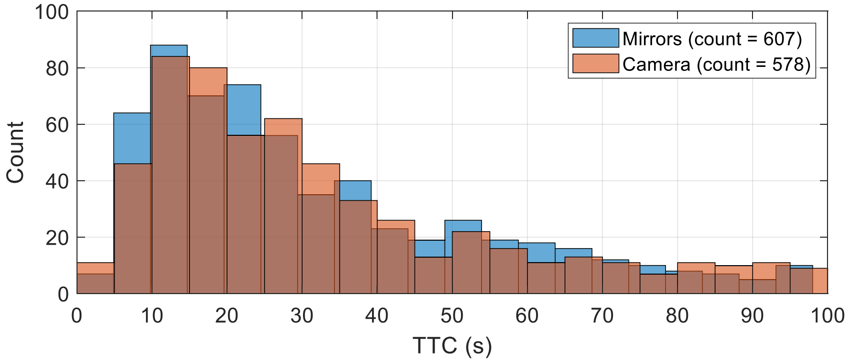


Figure 6. Histogram of TTC values at Lane Change Contact Point for mirrors and camera, all lane changes (*n* = 1,185).

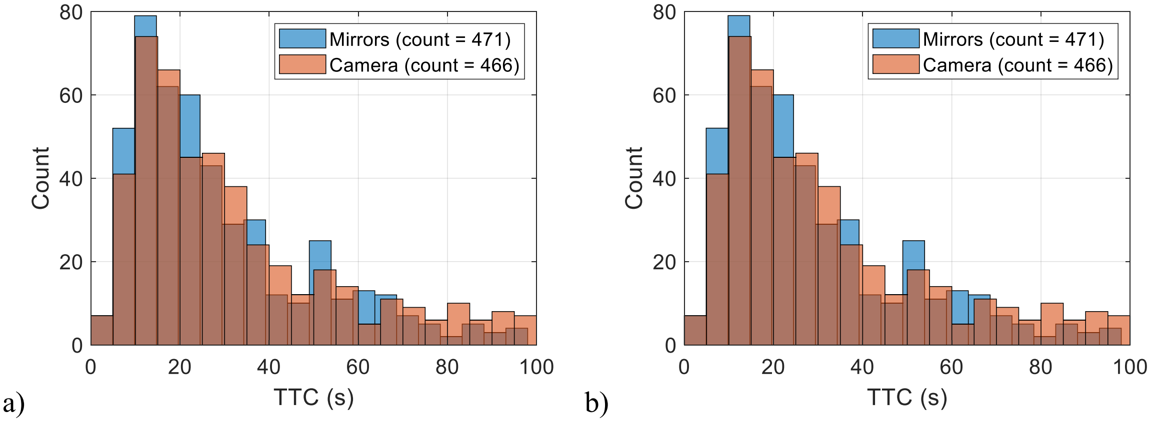


Figure 7. Histogram of TTC values at Lane Change Contact Point for mirrors and camera configurations during a) left lane changes (*n* = 937) and b) right lane changes (*n* = 248) collapsed across all the fleet.

Figure 8 plots the mean TTC values (overall and by lane change direction) for mirrors and camera-based systems. Mean TTC under the mirror configuration, collapsed across lane change direction, was 31.61 seconds compared to 32.75 seconds for the camera configuration; differences are not statistically significant [$F(1,1184) = 0.76$, $p = 0.38$].

In general, lane change direction did impact mean TTC values, with significantly lower TTC for left-hand lane changes (mean of 30.37 s) relative to right-hand lane changes (mean of 38.94 s). As shown below, mean TTC values for left lane changes were significantly lower under conventional mirrors relative to their camera-based counterparts [$F(1,936) = 5.49$, $p = 0.019$]. However, this trend was reversed for right lane changes where the mean TTC values were somewhat higher under the mirror configuration; differences were not statistically significant [$F(1,247) = 3.49$, $p = 0.06$].

Table 2 contains the mean TTC for mirror and camera configurations (collapsed across vehicle) at Lane Contact Point and overall and for left and right lane changes. In practical terms, the mean TTC values were relatively large (over 25 s under all configurations) and provide limited insight into potential conflicts or hazards. To investigate the effect of fleet dependence, Figure 9 presents the mean values of TTC at Lane Change Contact Point for three types of fleets for left and right lane changes, and the corresponding statistical data is listed in

Table 3. The differences of the mean TTC for mirrors and camera-bases systems are not statistically significant across these fleets.

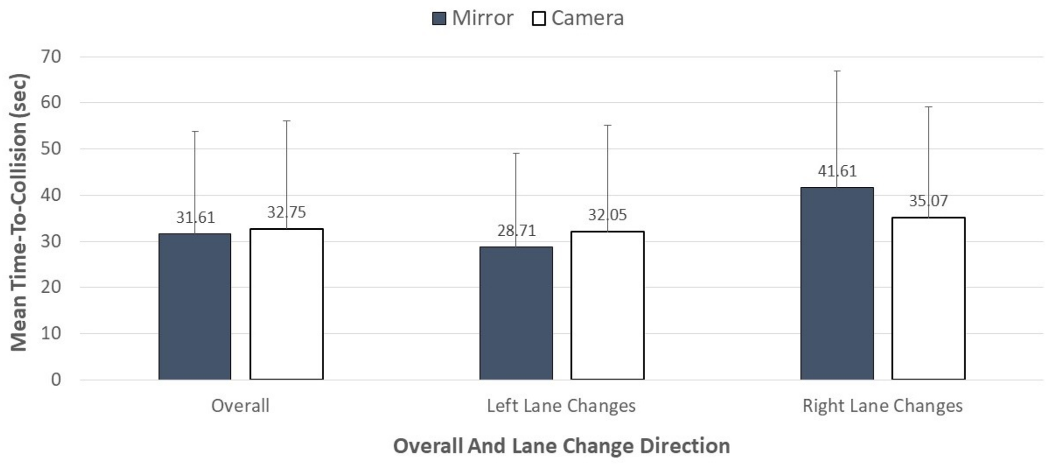
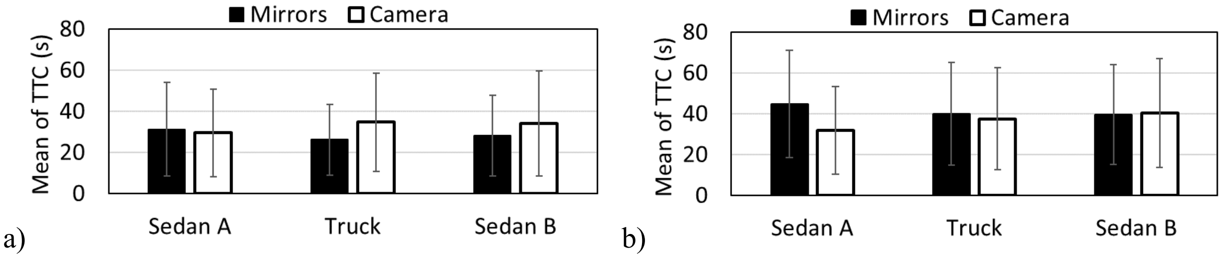


Figure 8. Mean TTC at Lane Change Contact Point for mirror and camera-based systems.

Table 2. Mean TTC Values at Lane Change Contact Point for Camera and Mirrors Configuration and for Lane Change Direction for All Fleet

Values	Left Mirror	Left Camera	Right Mirror	Right Camera	Overall Mirror	Overall Camera
Number	471	466	136	112	607	578
Mean	**28.72**	**32.05**	**41.61**	**35.70**	**31.61**	**32.76**
SD	20.38	23.08	25.35	24.07	22.23	23.30
Median	22.49	24.92	37.48	28.71	24.52	26.19
Min	1.65	2.48	4.96	0.98	1.65	0.98
Max	97.26	98.49	97.87	95.77	97.87	98.47



a)

b)

Figure 9. Mean TTC values at Lane Change Contact Point for a) left and b) right lane changes by configuration (conventional mirror and camera) and vehicle type.

Table 3. TTC Values at Contact Point by Configuration (Conventional Mirror and Camera) and Vehicle Type

Values	Sedan A Left Mirrors	Sedan A Left Camera	Sedan A Right Mirrors	Sedan A Right Camera	Truck Left Mirrors	Truck Left Camera	Truck Right Mirrors	Truck Right Camera	Sedan B Left Mirrors	Sedan B Left Camera	Sedan B Right Mirrors	Sedan B Right Camera
Number	191	220	54	48	138	163	43	36	142	83	39	28
Mean	31.16	29.47	44.61	31.71	26.06	34.56	39.79	37.47	28.01	33.97	39.47	40.26
SD	22.87	21.20	26.25	21.50	17.06	23.91	25.18	25.05	19.54	25.62	24.50	26.66
Median	22.17	22.20	39.53	27.78	21.65	28.44	35.56	30.39	23.31	25.52	31.48	35.09
Min	2.39	2.48	6.11	5.70	1.65	2.58	4.96	0.98	5.31	4.39	7.47	3.61
Max	97.26	98.47	97.87	95.78	96.65	96.82	95.12	86.83	88.44	96.68	94.27	92.98

Figure 10 depicts the observed TTC values and range (in meters) to the target vehicle at the Lane Change Contact Point under mirror and camera configurations for all lane changes with relatively few events falling below TTC values of 10 seconds under either configuration. The distribution locations, number, relative speed, and TTC values of POVs for the left and the right lane changes are presented in Figure 11 and Figure 12, respectively. Note that the POV is identified when the LV is on top of the lane divider (Lane Change Reference Point), not at the Contact Point. As indicated in Figure 13, the distribution of TTC values reveals that about 3 percent of all lane change events had TTC values under 5 seconds. Indeed, only two lane change events fell below a TTC of 2 seconds (one under each configuration), suggesting that conflicts are rare events and not necessarily negatively impacted by the use of camera-based systems.

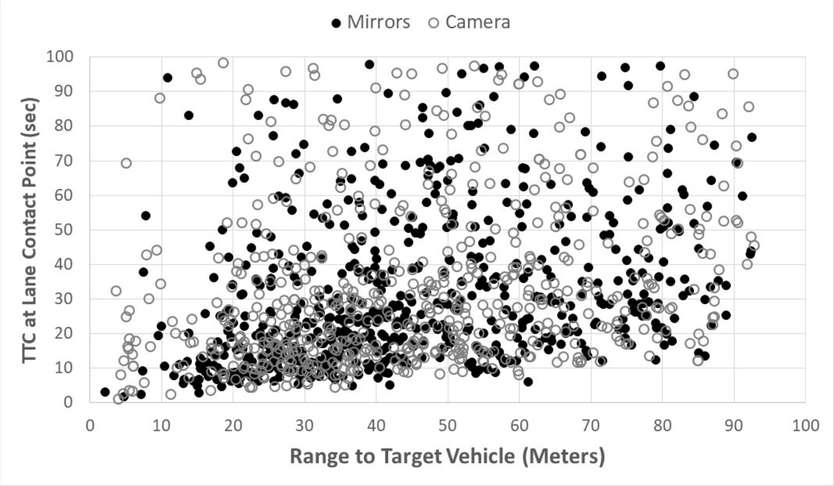


Figure 10. Observed TTC and vehicle range at Lane Change Contact Point under mirror and camera configurations (each data point represents POV during a lane change event).

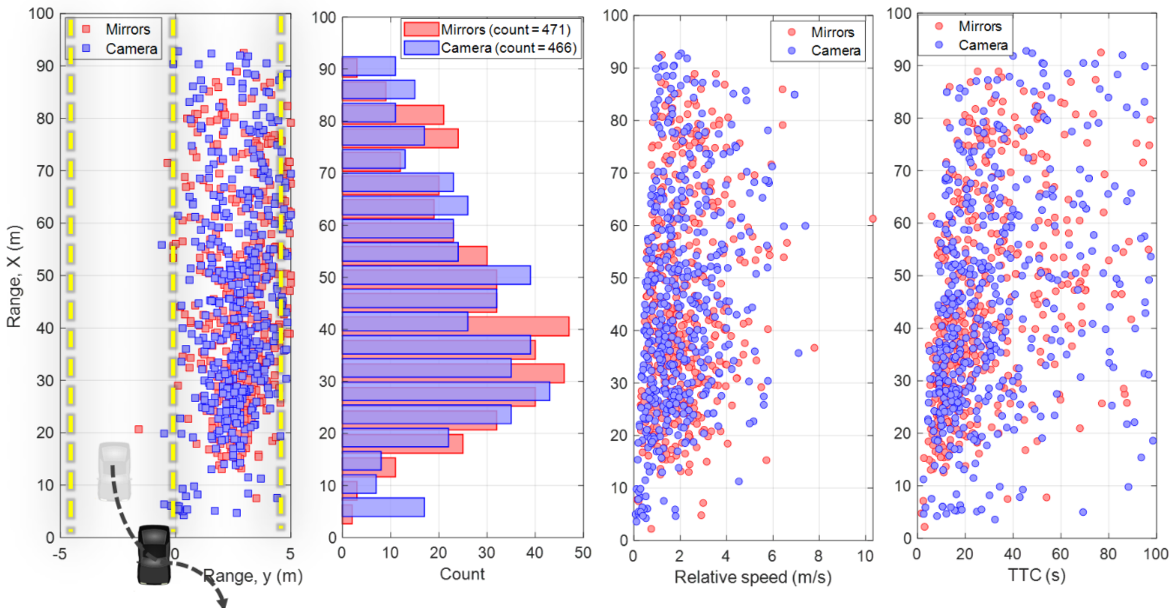


Figure 11. Location (lateral i.e., range *y* and longitudinal i.e., range *x*) and the distribution of frequencies, relative speed, and TTC values with reference to range *x* for POV during left lane changes at Lane Change Contact Point under mirror and camera configurations (each data point represents POV during a lane change event).

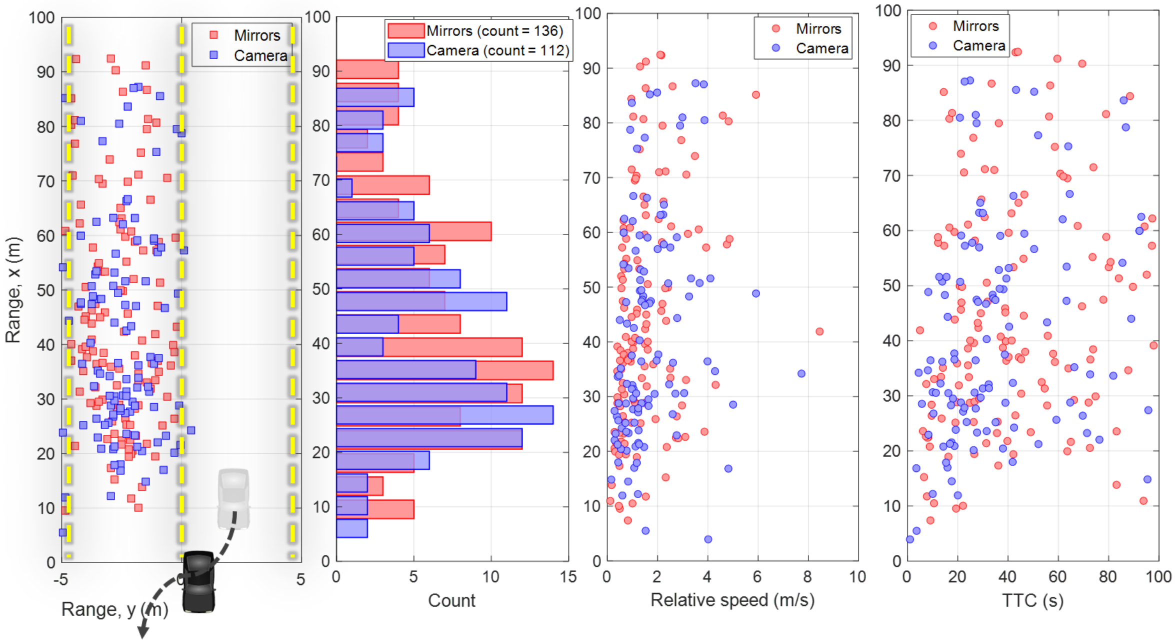


Figure 12. Location (lateral i.e., range *y* and longitudinal i.e., range *x*) and the distribution of frequencies, relative speed, and TTC values with reference to range *x* for POV during right lane changes at lane change contact point under mirror and camera configurations (each data point represents POV during a lane change event).

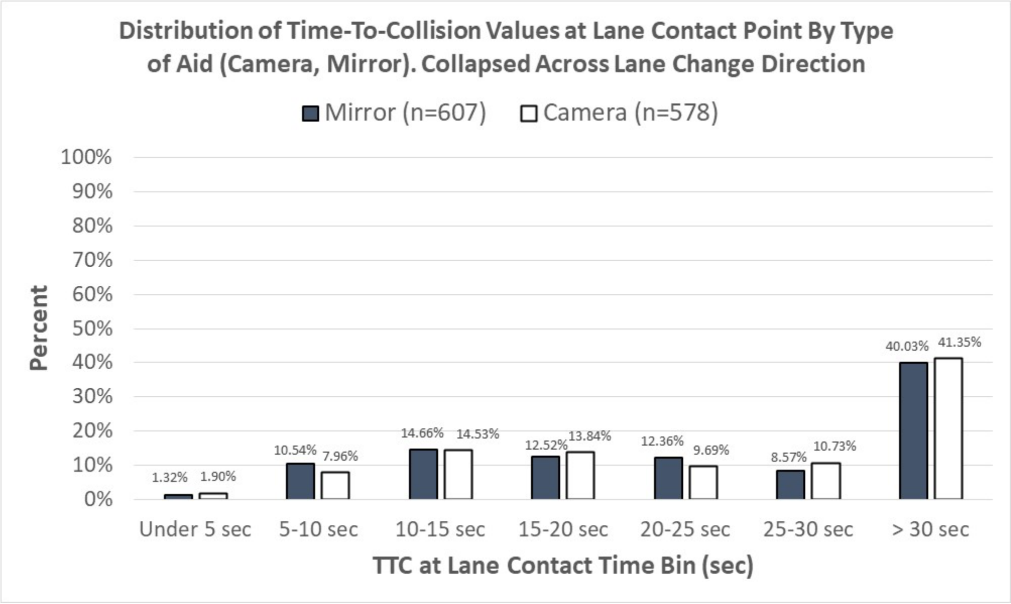


Figure 13. Distribution of TTC values at Lane Change Contact Point for mirror and camera configurations.

Mean Minimum TTC

Minimum TTC values during lane changes were calculated for each driver under both mirror and camera configurations. Figure 14 plots the mean minimum TTC values by aid and lane change direction. Significant main effects were found for lane change direction [$F(1,136) = 36.91$, $p < 0.01$], indicating that left-hand lane changes were associated with significantly lower mean minimum TTC (8.62 s) relative to right-hand lane changes (23.72 s). No significant differences between mirror and camera configurations were observed across all lane changes [$F(1,136) = .38$, $p = 0.54$], including left lane changes [$F(1,68) = .36$, $p = 0.55$] and right lane changes [$F(1,67) = .28$, $p = 0.59$]. No significant interactions were observed between aid and lane change direction [$F(1,136) = .16$, $p = 0.68$].

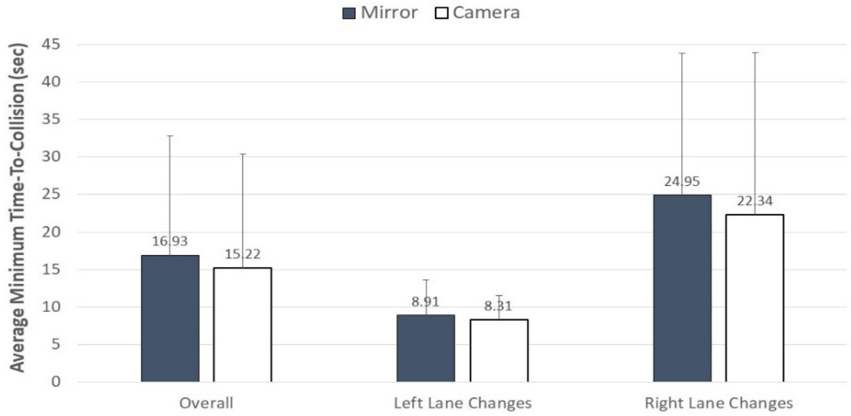


Figure 14. Mean minimum TTC under mirror and camera configurations for lane changes (overall and by direction).

Discussion

This project investigated the relative safety impacts of camera-based aids intended to replace exterior mirror units for light passenger vehicles. Data were mined from an existing naturalistic study with 36 drivers, each of whom experienced both conventional mirror and camera-based units over a month-long participation period (2 weeks under each configuration). Analyses focused on potential lane change conflicts and hazards using TTC values (derived from rear-mounted radar units) surrounding signalized lane change events. Results found no compelling evidence to suggest that camera-based systems adversely impacted lane change performance leading to risker or more hazardous lane changes compared to conventional mirror systems.

Overall (i.e., collapsed across lane change direction) mean TTC values under the mirror configuration were not significantly different than their camera-based counterparts (mean TTC were 31.61 seconds under the mirror configuration and 32.75 seconds for the camera configuration). In fact, the only significant result was related to mean TTC values for left-hand lane changes; these were significantly lower under conventional mirrors relative to their camera-based counterparts, suggesting that drivers were more conservative when executing left-hand lane changes under the camera configuration. The distribution of TTC values at the point the vehicle contacted the lane divider (Lane Change Contact Point) reveals than about 3 percent of all lane change events had TTC values under 5 seconds. Only two lane change events fell below a TTC of 2 seconds (one under each configuration), suggesting that conflicts are rare events and not necessarily negatively impacted by the use of camera-based systems. Analysis of the mean minimum TTC values found that left-hand lane changes were associated with significantly lower mean minimum TTC (8.62 s) relative to right-hand lane changes (23.72 s). More importantly, no significant differences in the mean minimum TTC between mirror and camera configurations were observed across lane changes, including left or right lane changes.

Although 25,655 signalized lane change events were captured in the raw dataset (12,960 under the conventional mirror configuration and 12,695 under camera-based system), the final set of analysis cases relied on a much smaller sample of 1,185 lane changes. This reduction was due to the relatively few lane changes that included a vehicle in the target lane (i.e., within a 100-meter range); furthermore, screening excluded cases where the target TTC values were large (i.e., over 100 s). Findings in this analysis suggest comparable levels of performance between configurations, and earlier work reported in NHTSA Docket 2019-22036 [2] found that drivers did in fact rely on camera displays when making lane changes and did not exclusively rely on rearview mirrors. Results of this earlier study [2] found that camera-based systems increase a driver's ability to detect vehicles located within the blind spot region, potentially leading to fewer conflicts during test track evaluations. Driver interactions under naturalistic settings on public roadways found that drivers use multiple information sources (e.g., rearview mirror, over-the-shoulder glances) in addition to the camera-based displays and typically make more than a single glance to exterior mirrors when executing lane changes in real-world situations.

Conclusions and Recommendations

Results suggest that camera-based alternatives to conventional light passenger vehicle exterior mirrors can potentially be designed to provide relatively safe levels of performance. Analyses revealed no critical conflicts or pattern of ill-advised lane changes (e.g., those with small time gaps) under camera displays, suggesting that camera-based systems, when appropriately designed, can help drivers detect potential conflicts. This is largely a result of the wider field of view afforded by camera-based systems, which enables drivers to assess the presence of a vehicle in the target lane and represents a potential safety benefit over and above conventional mirror systems with blind spots.

Earlier work [2] found that camera-based displays can increase the driver's field of view relative to conventional mirrors, significantly reducing or eliminating blind spots and increasing vehicle detection rates. Controlled tests (requiring drivers to exclusively rely on camera displays) also found that some camera configurations made it harder for drivers to gauge vehicle distances and closing speeds to support lane change decisions, potentially increasing a driver's propensity to accept smaller time gaps if relying on the display alone. However, concerns with small gap acceptance under camera-based displays were not necessarily realized under naturalistic driving settings due to drivers typically using multiple information sources (e.g., rearview mirror, over-the-shoulder glances) when planning and executing lane changes in real-world situations.

Additional Products

The Education and Workforce Development (EWD) and Technology Transfer (T2) products created as part of this project can be downloaded from the project page on the Safe-D website. The final project dataset is located on the Safe-D Dataverse.

Education and Workforce Development Products

The project has financially supported a Ph.D. student and coauthor of this report, Balachandar Guduri, from July 2022 to October 2022. The knowledge and education gained from this project helped him acquire a full-time research faculty position in the Division of Data and Analytics at VTTI in Blacksburg, VA.

The project team developed two MATLAB modules currently being used internally at VTTI. One module focuses on processing noisy radar data acquired from Continental® Radar PLC units with short-range radar (SRR320) and detecting radar traces for signalized lane change events. Another module identifies the POV using processed radar data during signalized lane change events. The project's outcomes supported a proposal to the National Surface Transportation Safety Center for Excellence (NSTSCE) on "Risk Assessment of Automatic Lane Change Systems Under Extreme Conditions using Naturalistic Driving Studies," and approval of this proposed project is currently pending.

Technology Transfer Products

The target audience for this work is the transportation industry. The developed algorithms and findings will have commercial value for OEMs interested in deploying automated vehicles capable of executing automated lane changes. The project team is focusing on presenting this work in webinars or presentations. The project team is making efforts to disseminate the findings of this project through publications in proceedings and industry conferences.

Data Products

A subset of data collected as part of the study is available via the Safe-D collection on the Safe-D Dataverse. This data includes metrics related to time-to-collision at lane change and lane crossover points.

References

1. Tijerina, L. Operational and Behavioral Issues in the Comprehensive Evaluation of Lane Change Crash Avoidance Systems. *Journal of Transportation Human Factors*, Vol. 1, No. 2, 1999, pp. 159–176.
2. NHTSA Docket 2019-22036. Driver Performance and Acceptance of Camera-Based Systems Relative to Conventional Mirror Configurations: Smart Road and Naturalistic Driving Study. Response to NHTSA's advanced notice of proposed rulemaking and public comment related to camera-based rear visibility systems.