SAFE-D

SAFETY THROUGH DISRUPTION

San Diego State University

Texas A&M Transportation Institute

VirginiaTech Transportation Institute

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

Safe-D 05-082

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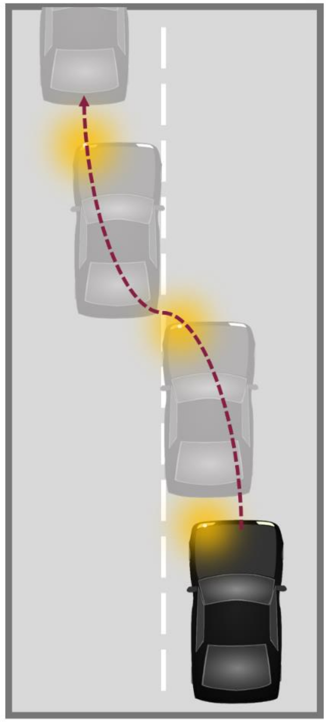


Signalized lane change

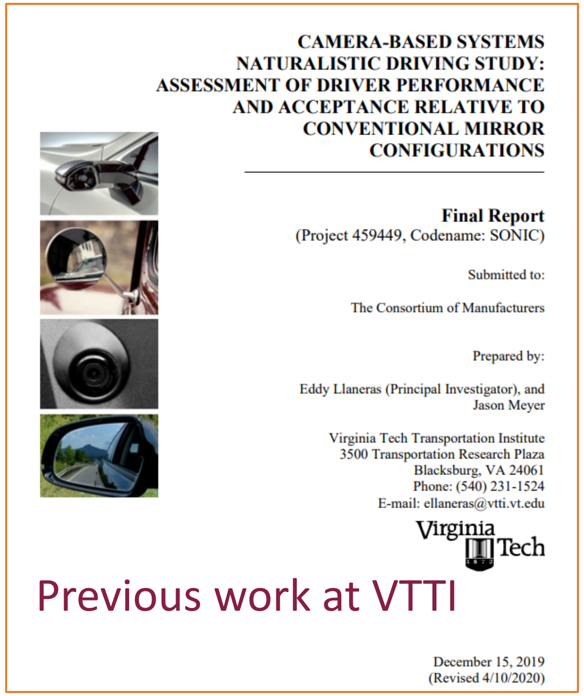
Camera based system

VS

Conventional mirrors

CAMERA-BASED SYSTEMS FOR LANE CHANGES

- Analysis carried out to support Federal Motor Vehicle Safety Standard 111 rulemaking efforts to investigate camera-based side view systems
- Earlier work at VTTI focused on
  - System influences on driver perceptual judgment to support lane change decisions
  - Driver acclimation to and reliance on camera-based systems
  - Impact of camera-based systems on driver eye glance behavior
  - Potential drive adaptation or unintended consequences
  - Influence of moderating factors (driver age, system experience, environmental conditions, etc.) on performance
  - Usability and driver acceptance of camera-based systems.


CAMERA-BASED SYSTEMS NATURALISTIC DRIVING STUDY: ASSESSMENT OF DRIVER PERFORMANCE AND ACCEPTANCE RELATIVE TO CONVENTIONAL MIRROR CONFIGURATIONS

Final Report
(Project 459449, Codename: SONIC)

Submitted to:

The Consortium of Manufacturers

Prepared by:

Eddy Llaneras (Principal Investigator), and
Jason Meyer

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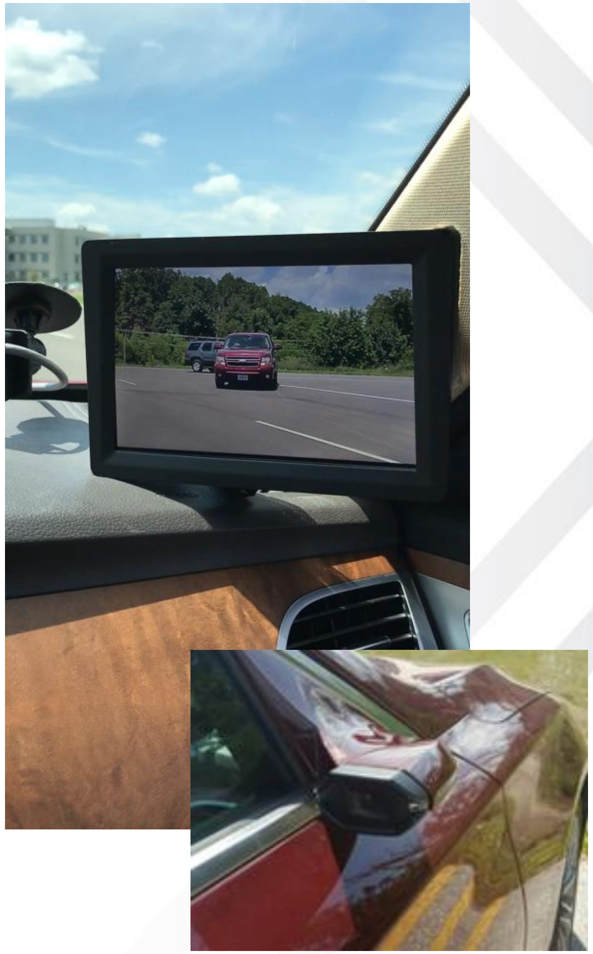
Virginia Tech

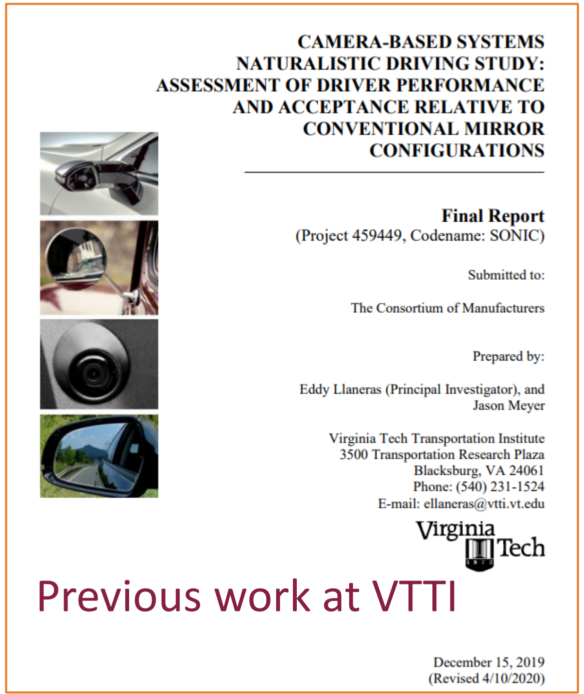
December 15, 2019
(Revised 4/10/2020)

Previous work at VTTI



CAMERA-BASED SYSTEMS FOR LANE CHANGES

- Analysis carried out to support Federal Motor Vehicle Safety Standard 111 rulemaking efforts to investigate camera-based side view systems
- Earlier work at VTTI found that camera-based displays
  - Increase the driver's field of view relative to conventional mirrors
  - Significantly reducing or eliminating blind spots
  - Increasing vehicle detection rates and leading to fewer conflicts
- In control tests, sole reliance on camera-based displays can make it harder for drivers to gauge vehicle distances and closing speeds to support lane change decisions.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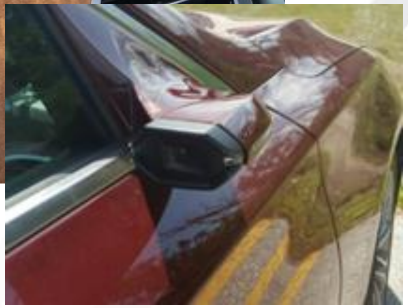
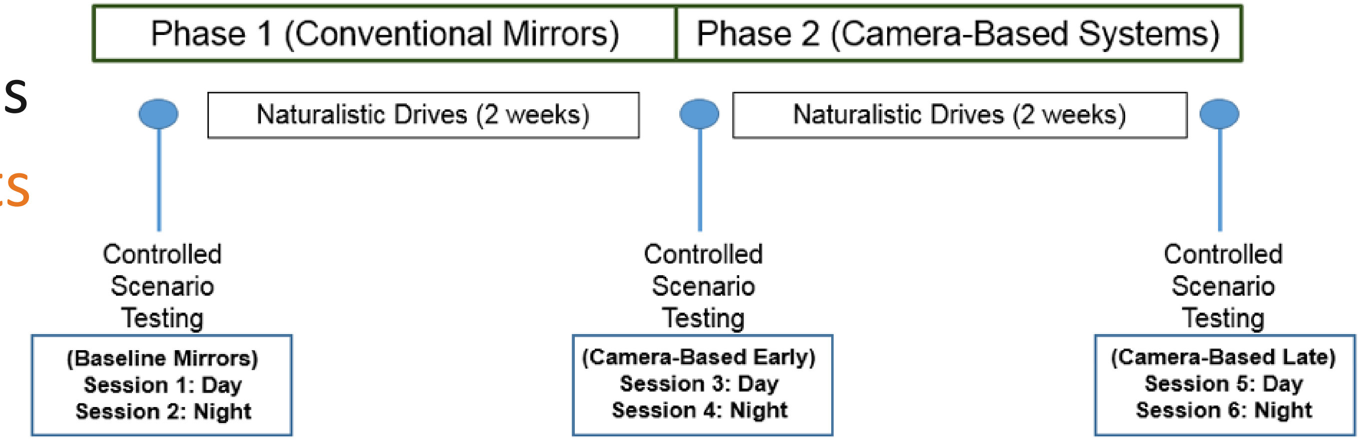


- **Objectives:**
  - Mine an existing set of radar data surrounding real-world lane change events
  - Lane change conflicts and hazard analysis using Time-To-Collision (TTC) values

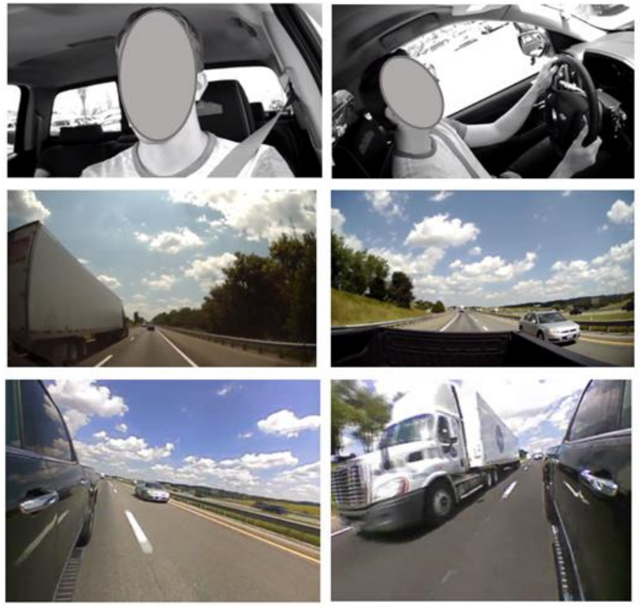
DATA COLLECTION

- 36 Drivers from Southwest, Virginia
- Participants are Virginia Tech employees
- Age from 25 – 63 years with 15 females and 21 males
- 1-month participation period
- Prototype camera-based systems
- Three types of light-vehicle fleets
  - Sedan A
  - Truck
  - Sedan B
- 90,880 miles driving data
  - 46,730 miles under conventional mirror systems,
  - 44,149 miles of travel under the prototype camera-based systems



VEHICLE INSTRUMENTATION

- All vehicles equipped with VTTI proprietary Data Acquisition System (DAS) – FlexDAS
  - To capture and record time-sync video and parametric measures from key-on through key-off
- Information from vehicle networks
  - Vehicle speed
  - Lateral and longitudinal acceleration
  - Yaw rate and steering angle
  - Turn signal indicators
  - GPS data
  - Transmission gear state
  - Brake and acceleration pedal inputs
- Lane marking information from VTTI's Road Scout
- Video footage from several cameras
- Following vehicle information from two rear facing corner radar units



SHORT RANGE RADAR (SRR320)

- Two Continental Radar PLC units with short range radar (SRR320)
- Operating frequency: 24 Hz
- Range accuracy: ±0.2 m
- Speed accuracy: ± 0.2 km/h
- Field of view: ±75º
- Range: 100 m
- Can track up to 40 targets

Source: continental-automotive.com/

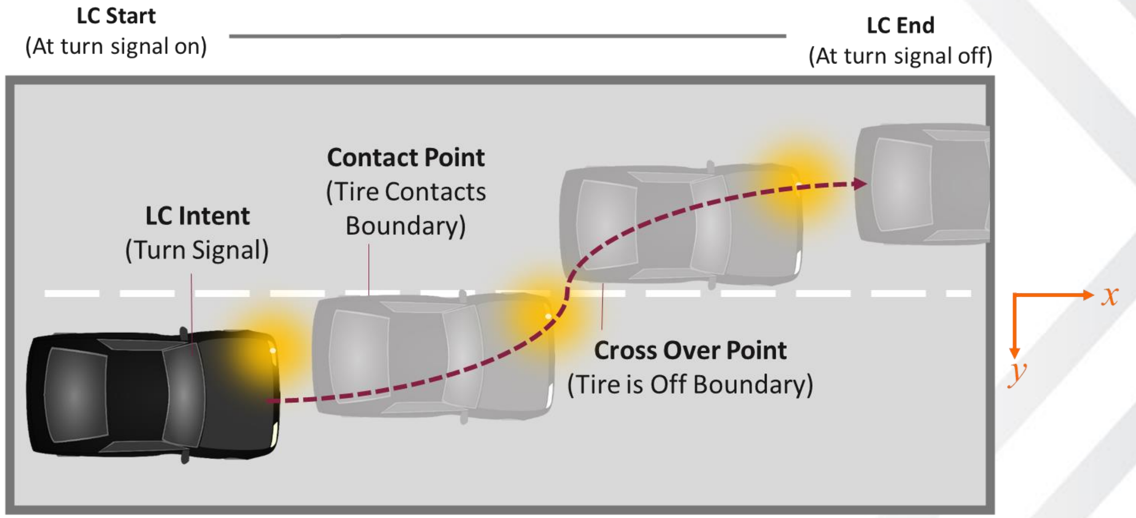
Measured variables

- **Object_ID** – index that assigned a unique identifier for a target being tracked, numbered 0 to 39
- **Range_x** – longitudinal distance between the target and the LV, measured in meters
- **Range_y** – lateral distance between the target and the LV, measured in meters
- **Rangerate_x** – time derivative of Range_x, measured in m/s
- **Rangerate_y** – time derivative of Range_y, measured in m/s
- **Age** – lifetime of the target, measured in milliseconds
- **Length** – target length, measured in meters
- **Width** – target width, measured in meters
- **Orientation** – orientation of the target with respect to the radar's face, measured in rads
- **Probability of Existence** – probability of the target's existence; ranges from 0 to 1, where 1 represents the highest probability of existence
- **RCS** – radar cross section of the target, measured in dBsm
- **Stable** – echo from the target is stable; denoted by true or false
- **Status** – status of the target tracked by radar: predicted, measured, or invalid

SIGNALIZED LANE CHANGE EVENTS

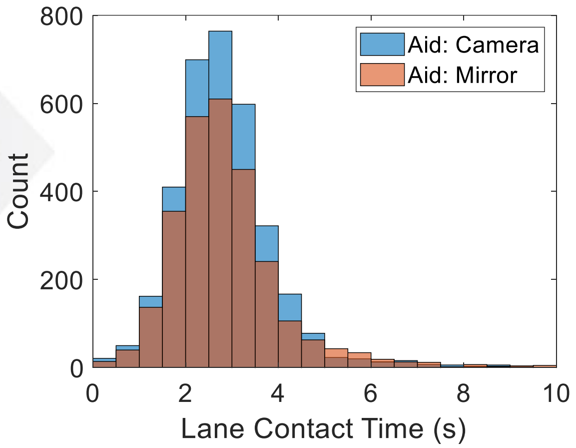
	Overall (Total)	Conventional Mirror	Camera-Based displays
Number of trips	4,486	2,243	2,243
Total miles driven	90,880	46,730	44,149
Average miles per trip	20.26	20.83	19.68
Total aggregated number of signalized lane changes	25,655	12,960	12,695
Average number of signalized lane changes per trip			
Overall (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

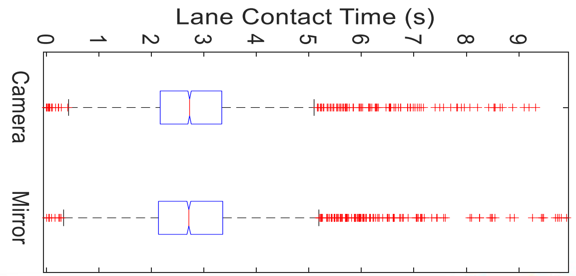
Schematic



DURATION OF LANE CHANGE EVENTS: SEDAN A

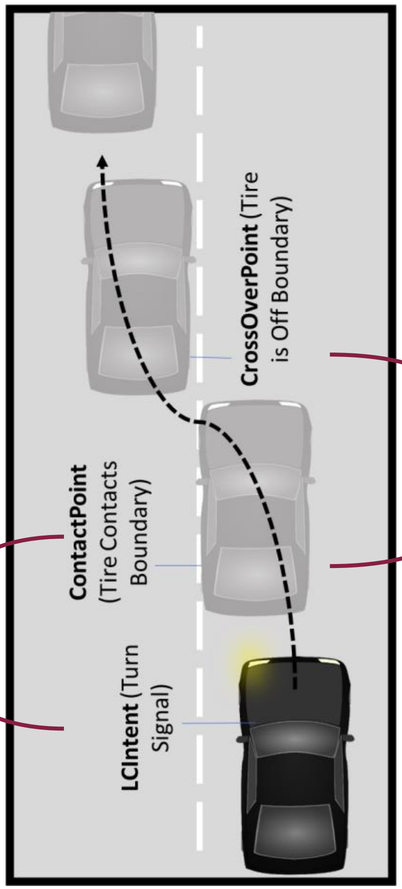
	Camera	Mirror
Number	3393	2770
Mean	3.02	3.45





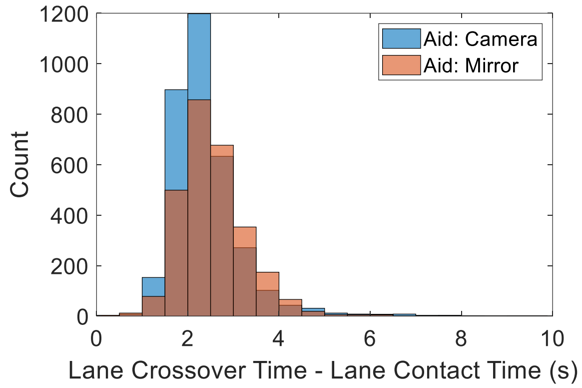
Duration of lane contact time from signal on

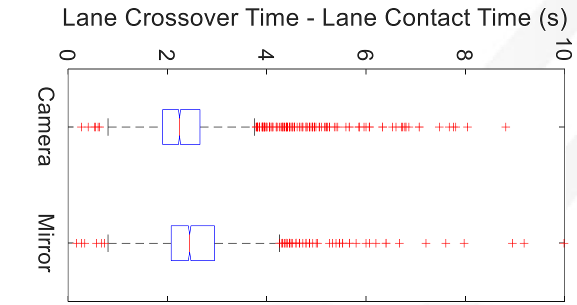
Sedan A



Duration between lane contact time and crossover time

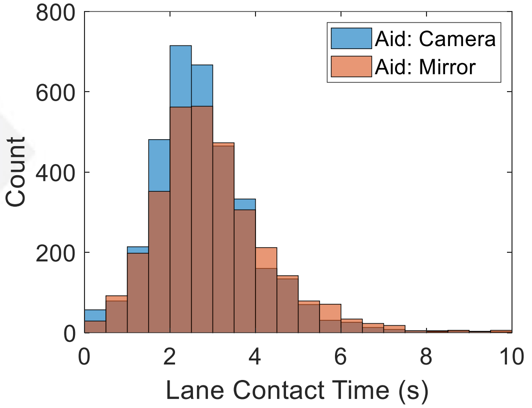
	Camera	Mirror
Number	3393	2770
Mean	2.58	2.79

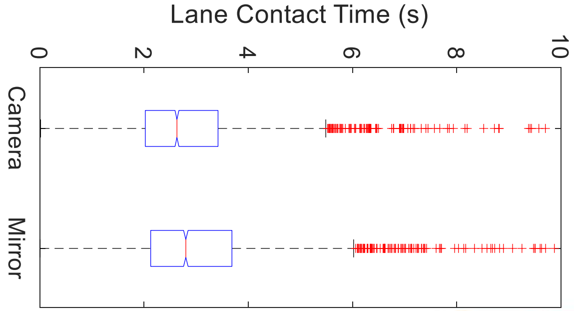




DURATION OF LANE CHANGE EVENTS: TRUCK

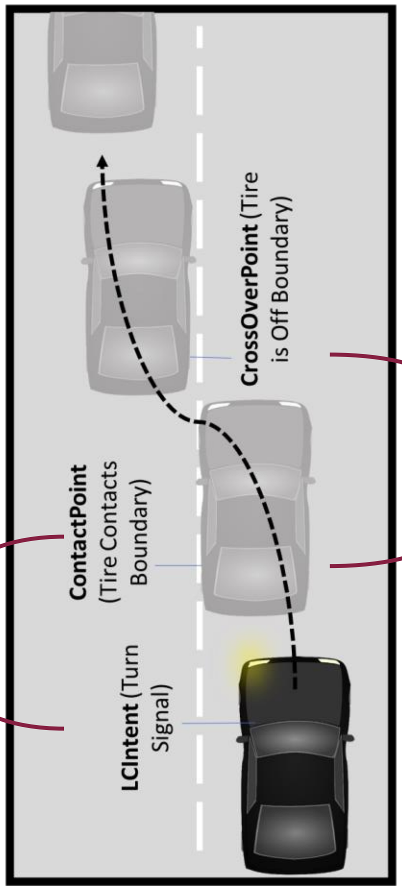
	Camera	Mirror
Number	3484	3193
Mean	2.93	3.14





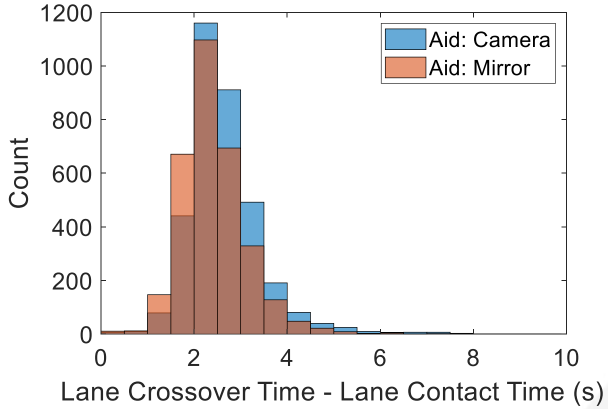
Duration of lane contact time from signal on

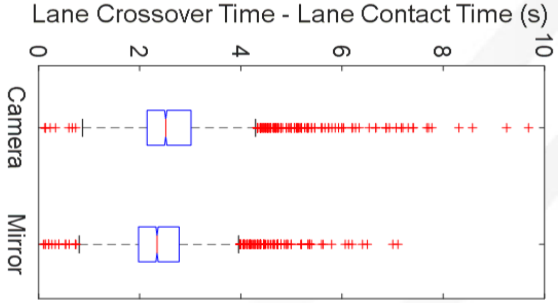
Truck



Duration between lane contact time and crossover time

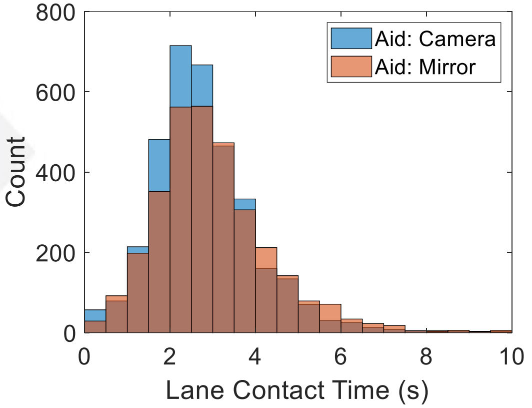
	Camera	Mirror
Number	3484	3193
Mean	2.80	2.57

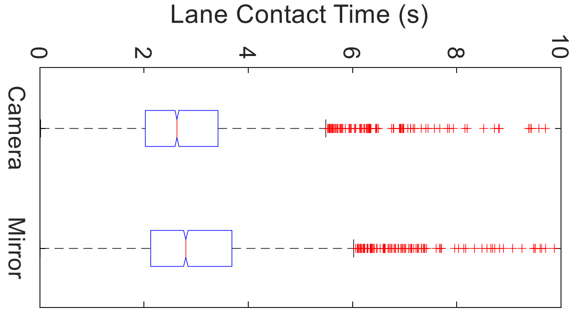




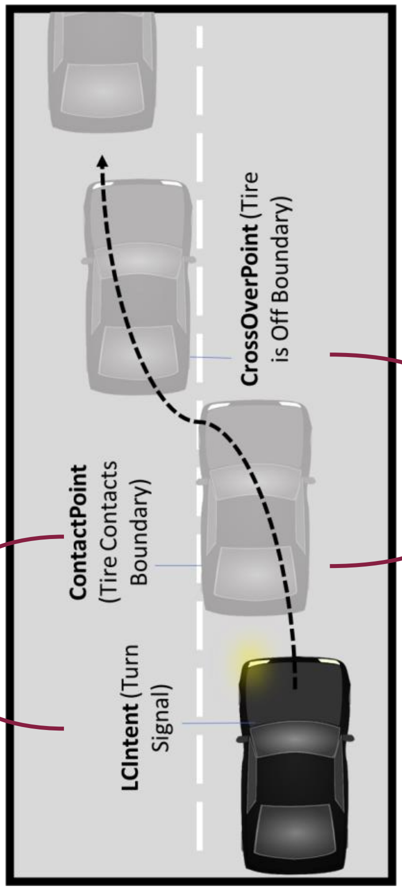
DURATION OF LANE CHANGE EVENTS: SEDAN B

	Camera	Mirror
Number	1971	2570
Mean	3.43	2.99



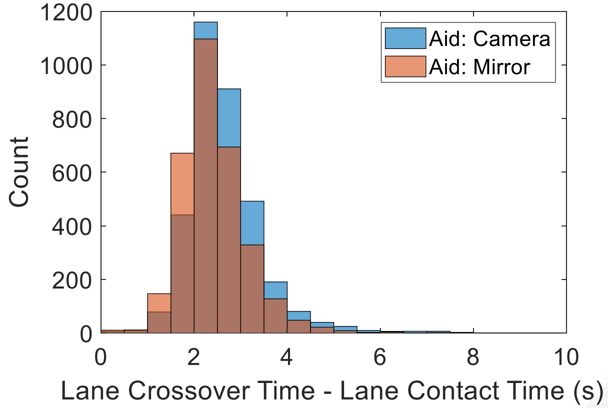


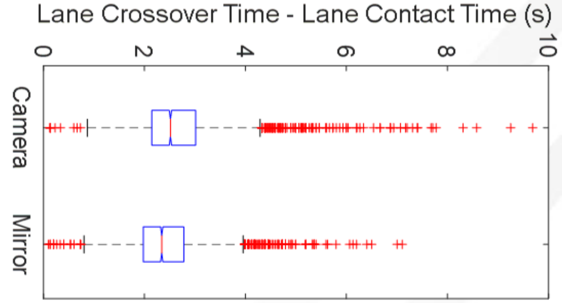
Duration of lane contact time from signal on



Duration between lane contact time and crossover time

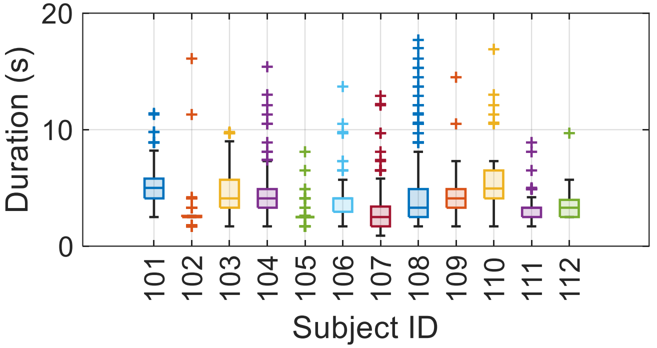
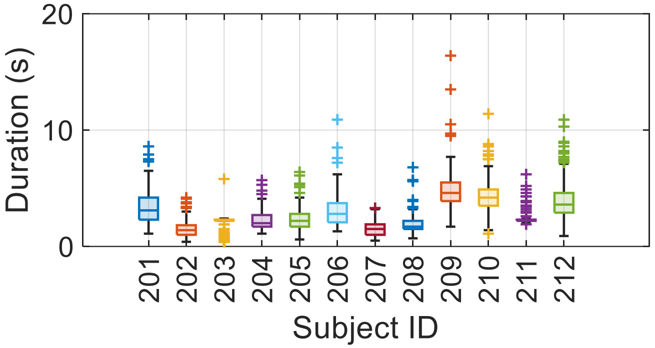
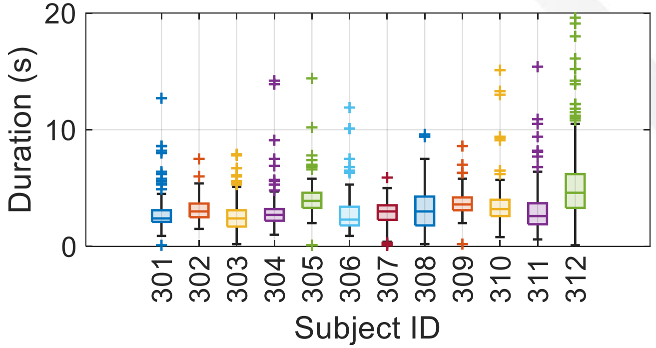
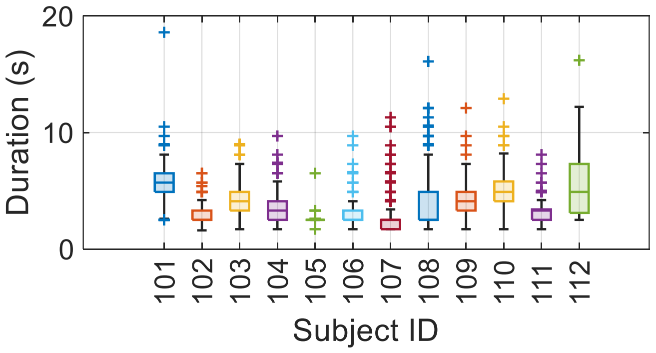
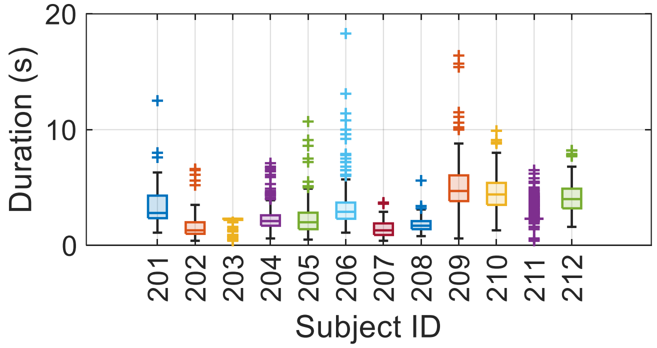
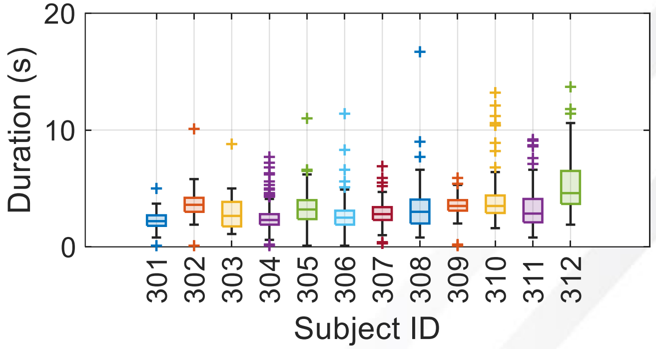
	Camera	Mirror
Number	1971	2570
Mean	2.47	2.51



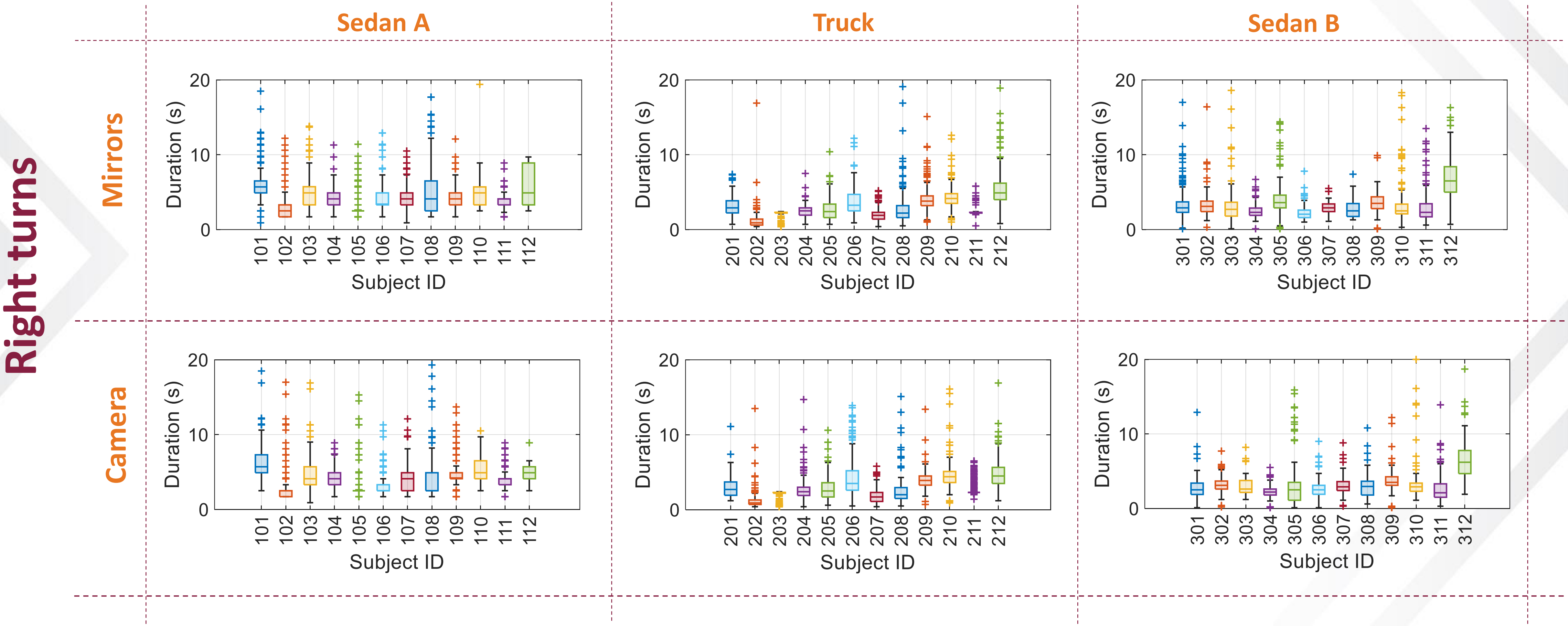


LANE CHANGE DURATION: SUBJECT WISE

Left turns

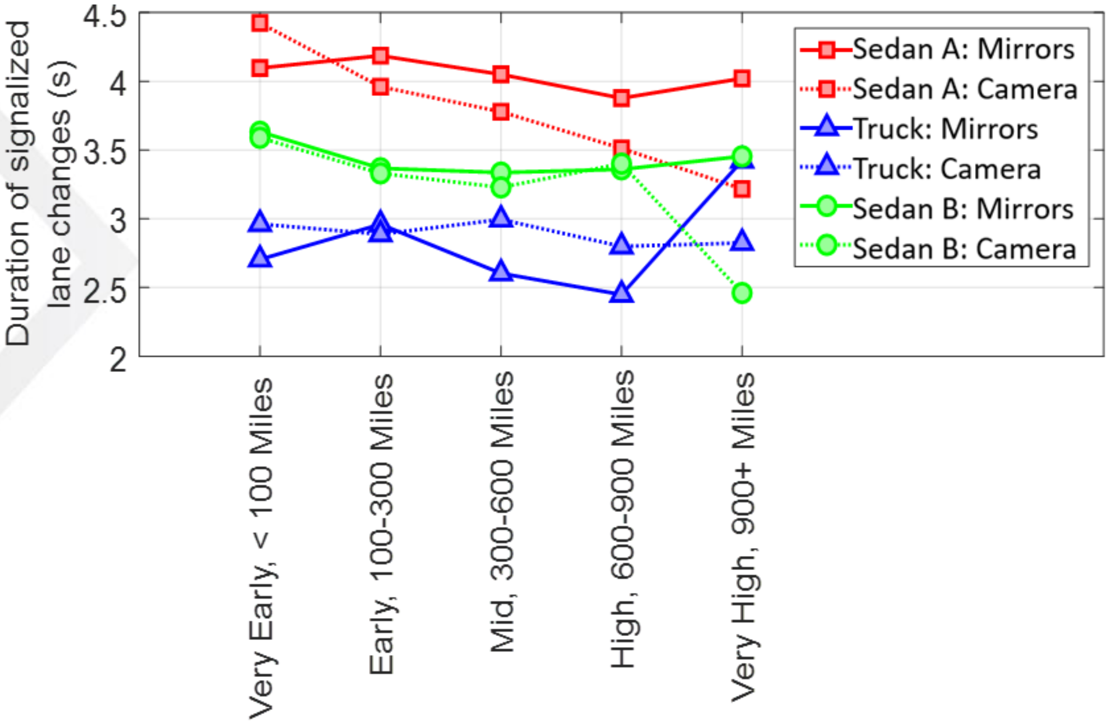
	Sedan A	Truck	Sedan B
Mirrors			
Camera			

LANE CHANGE DURATION: SUBJECT WISE

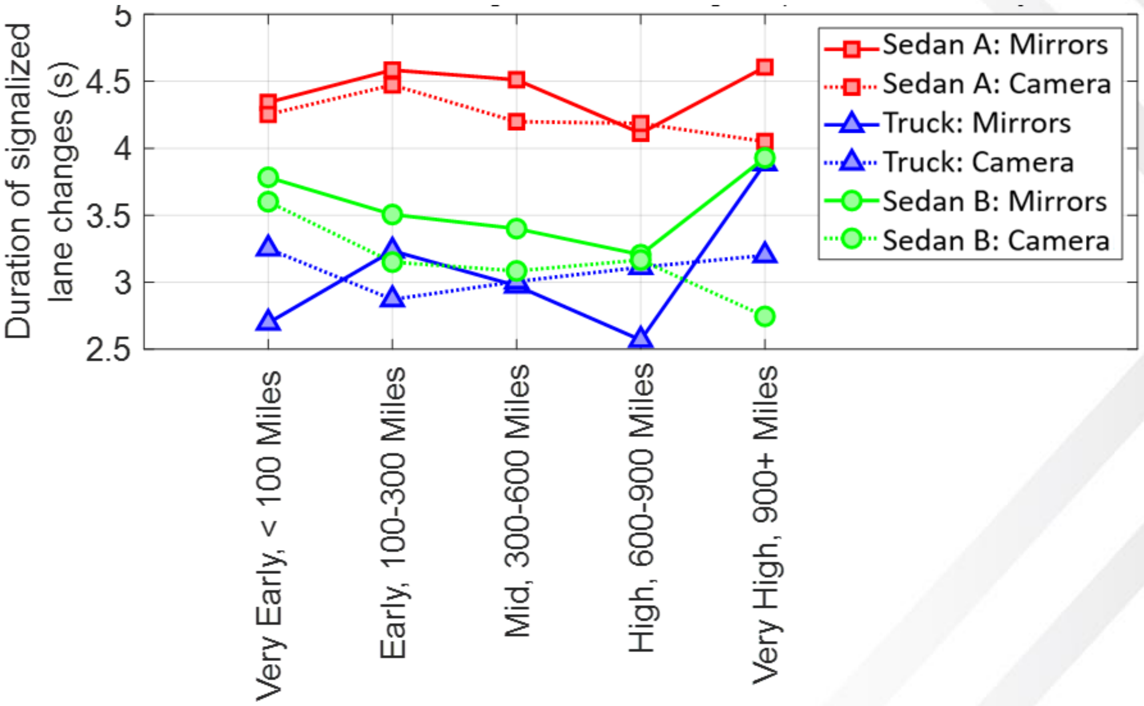


LANE CHANGE DURATION: DEPENDENCE ON MILES

Left lane changes (All fleet)

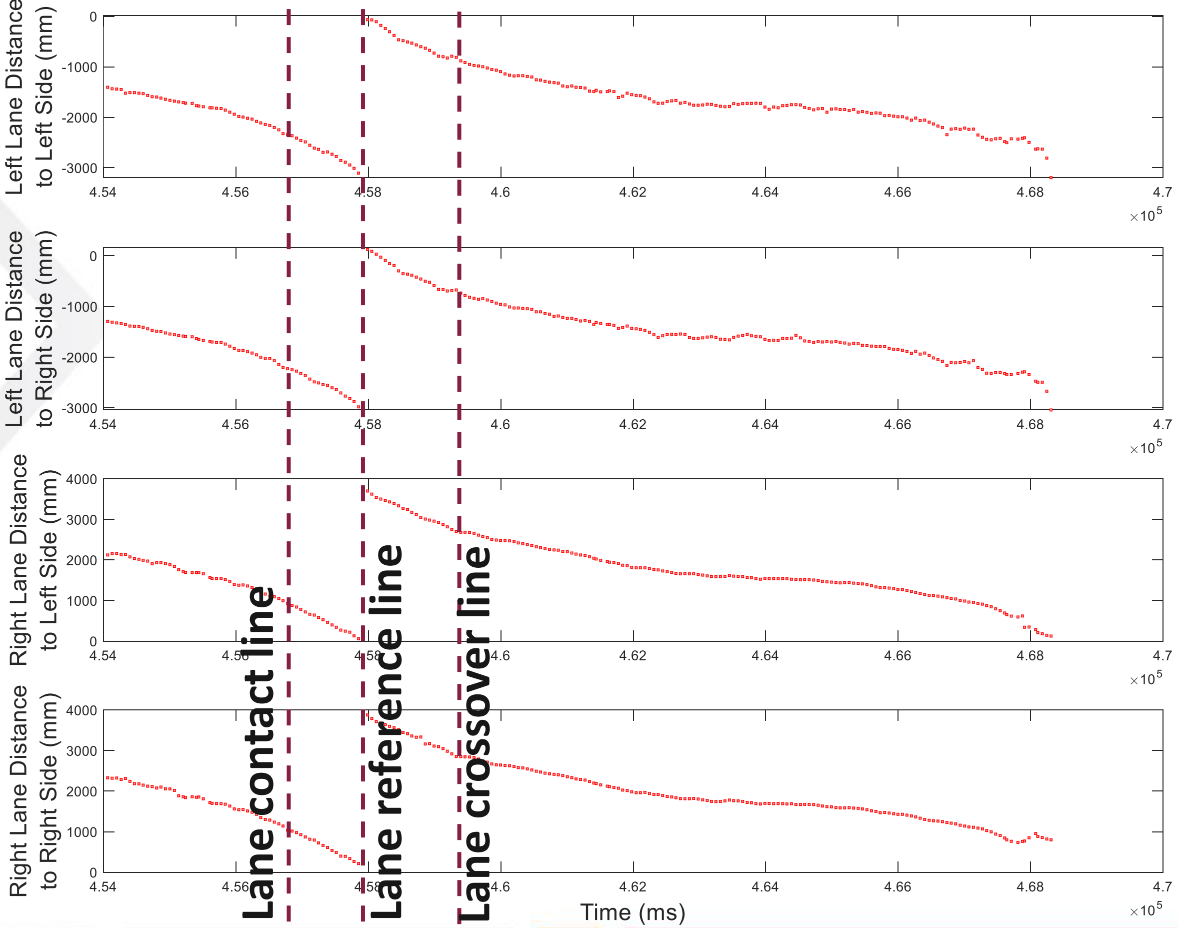


Right lane changes (All fleet)



LANE CHANGE TRAJECTORIES

From Road Scout



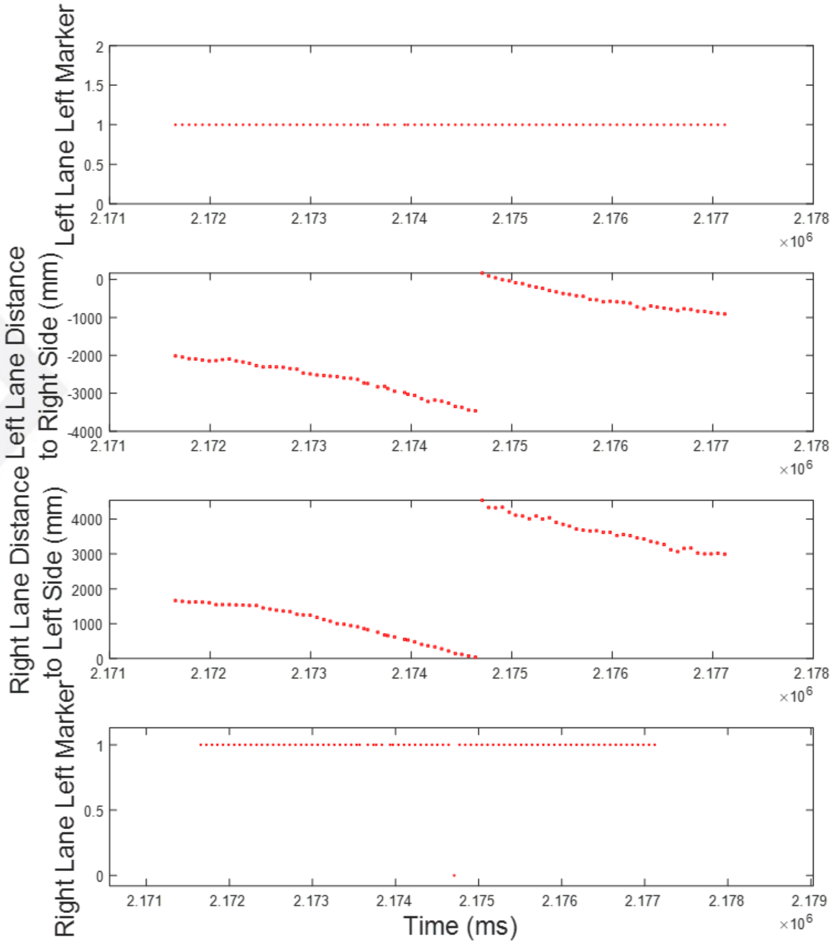
Example:

Lane reference time:
457920

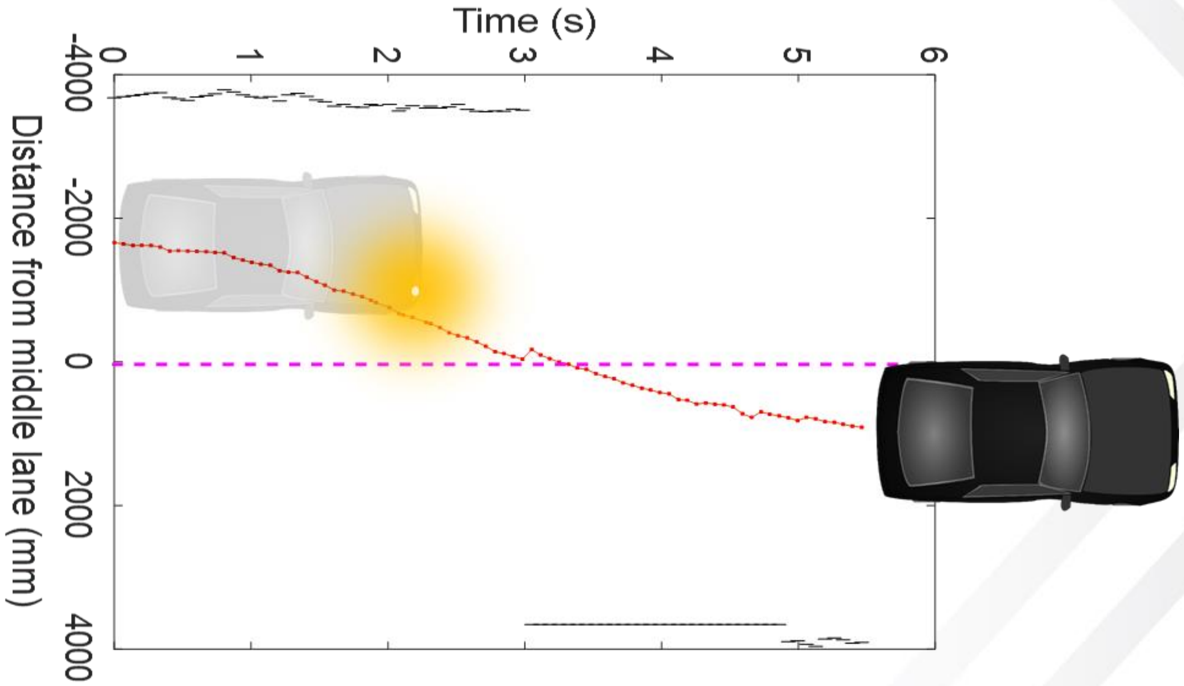
Lane contact time:
457048

Lane crossover time:
459664

TRAJECTORY OF LV RELATIVE TO LANES



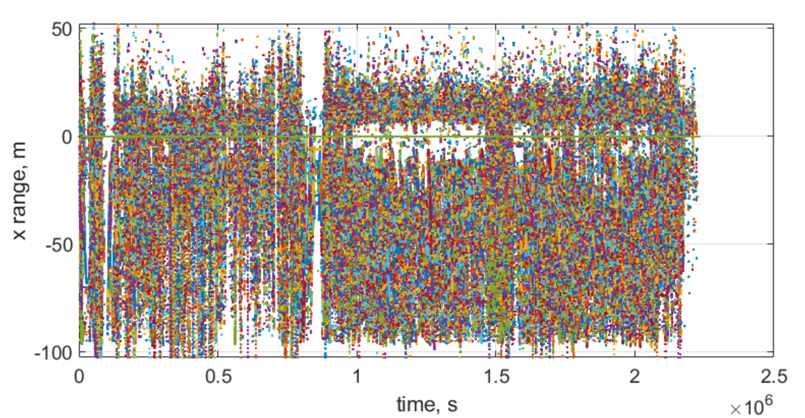
Right Turn



EXTRACTION OF RADAR TRACES

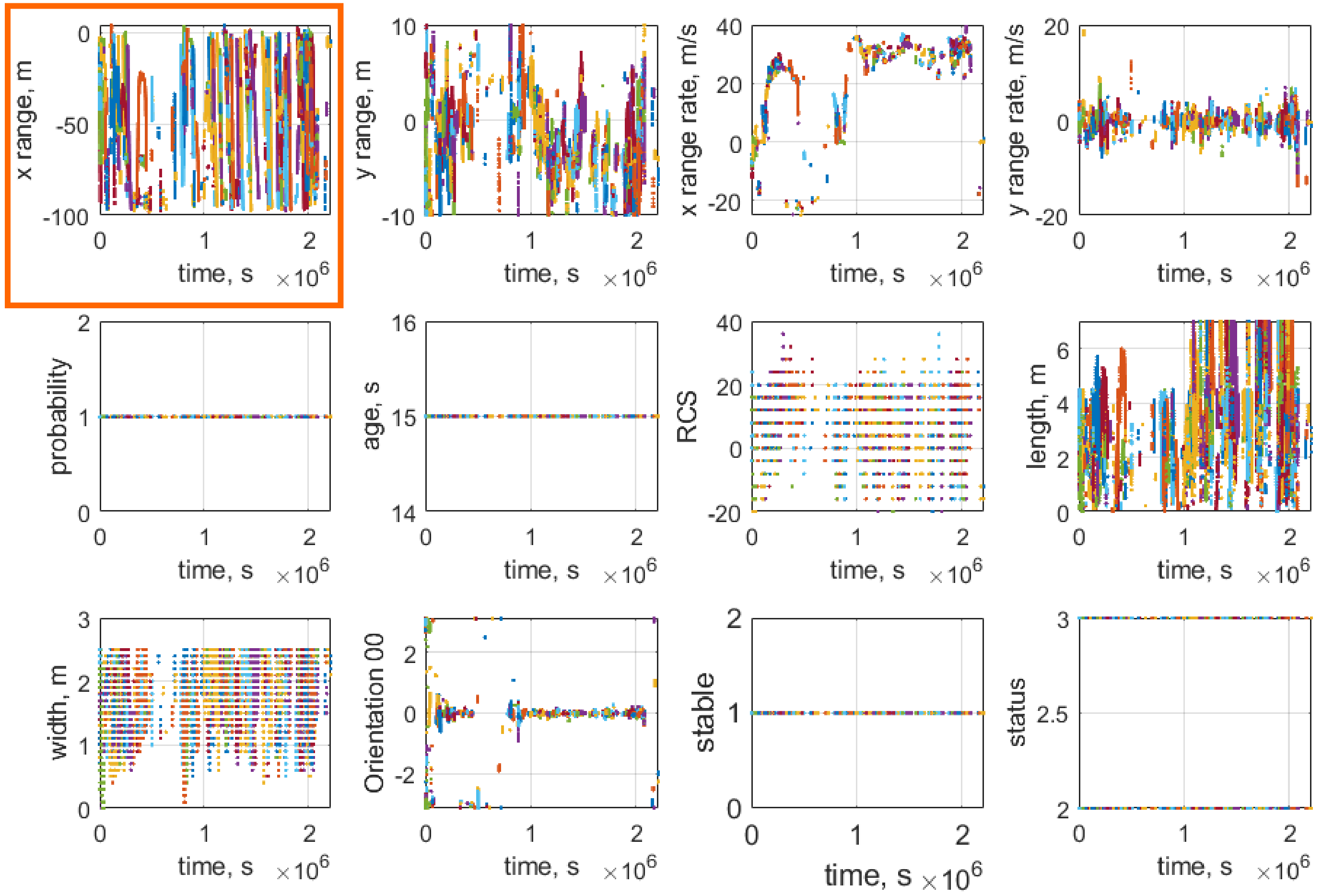
- Data of all 40 radar objects is included
- Radar trace of each object ID shown by color in Figs

Raw radar traces of all 40 objects

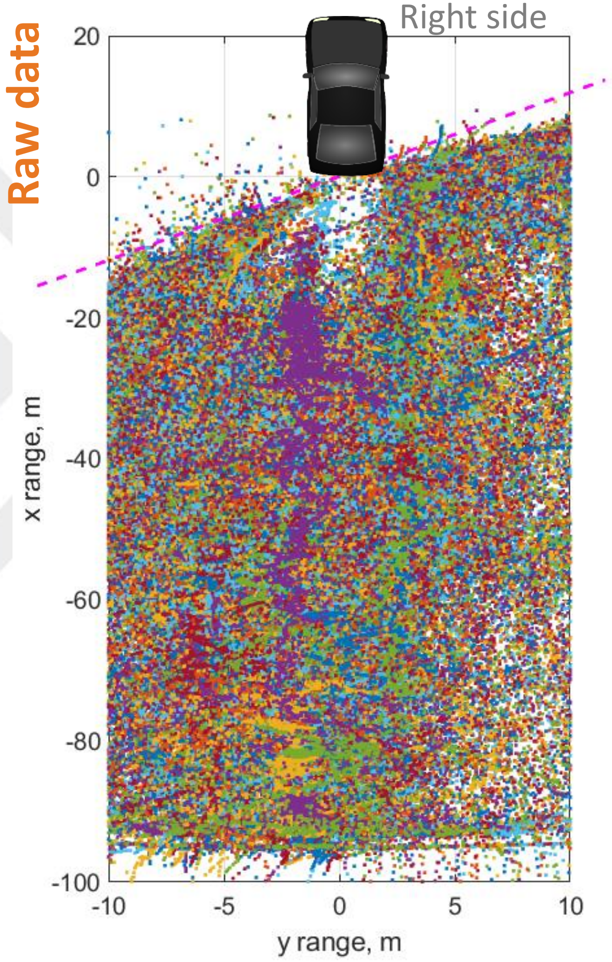


Conditions

Cleaned radar traces



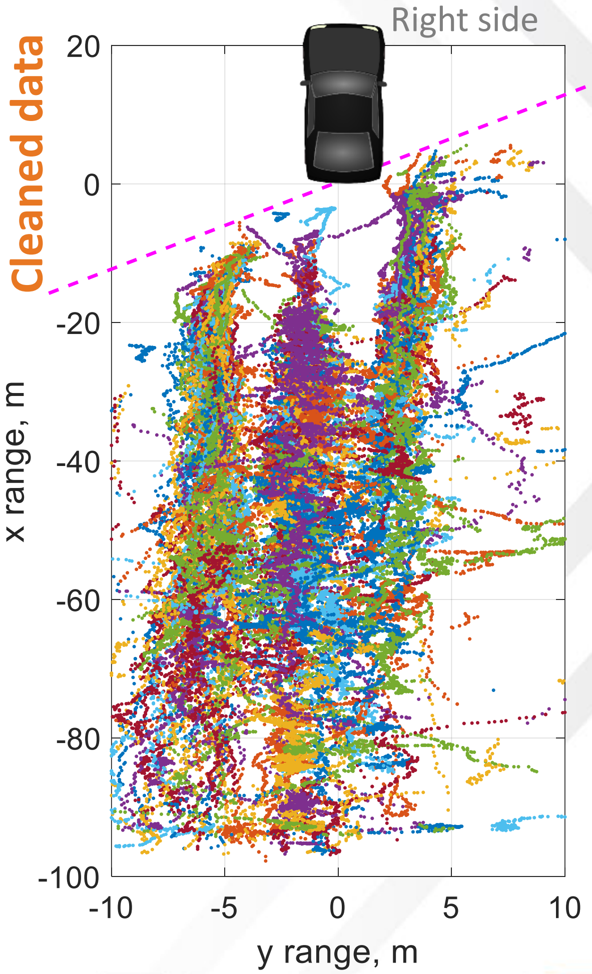
TRACES OF RIGHT RADAR OBJECTS



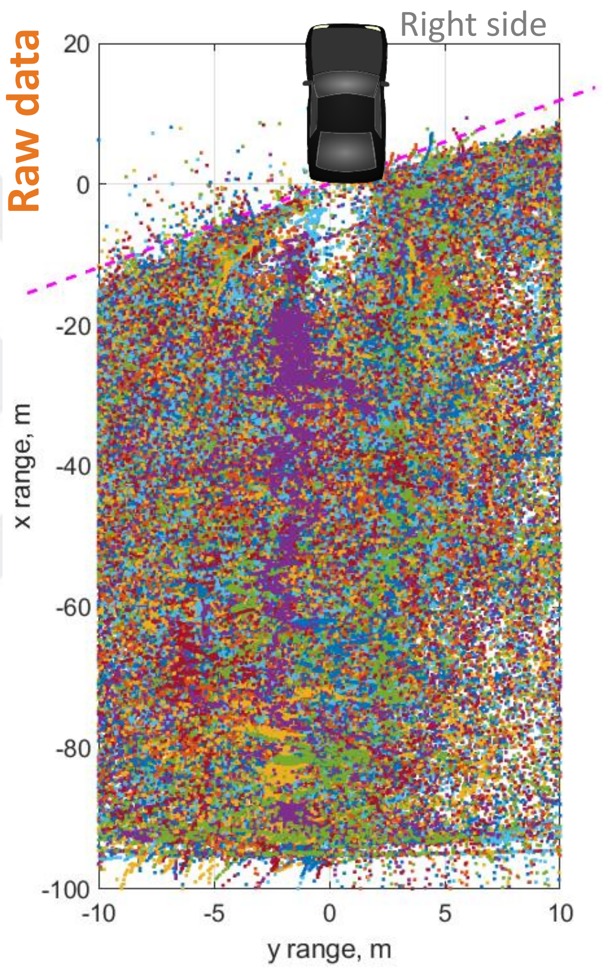
- For an entire trip duration of 40 min
- Data of all 40 radar objects is included
- Radar trace of each object ID shown by color in Figs

Conditions

- Delete all data where $Range_x \leq 0$ m and $Range_y < 0$ m for right radar
- Delete all data where Probability of Existence < 0.99
- Delete all data whose Status is not “measured” or “predicted”
- Select all data where -0.5 rad $\leq$ Orientation ≤ 0.5 rad
- Select all data where -10 m $\leq Range_y \leq 10$ m
- Select all data where Age ≥ 15 s
- Select all data where Stable = 1



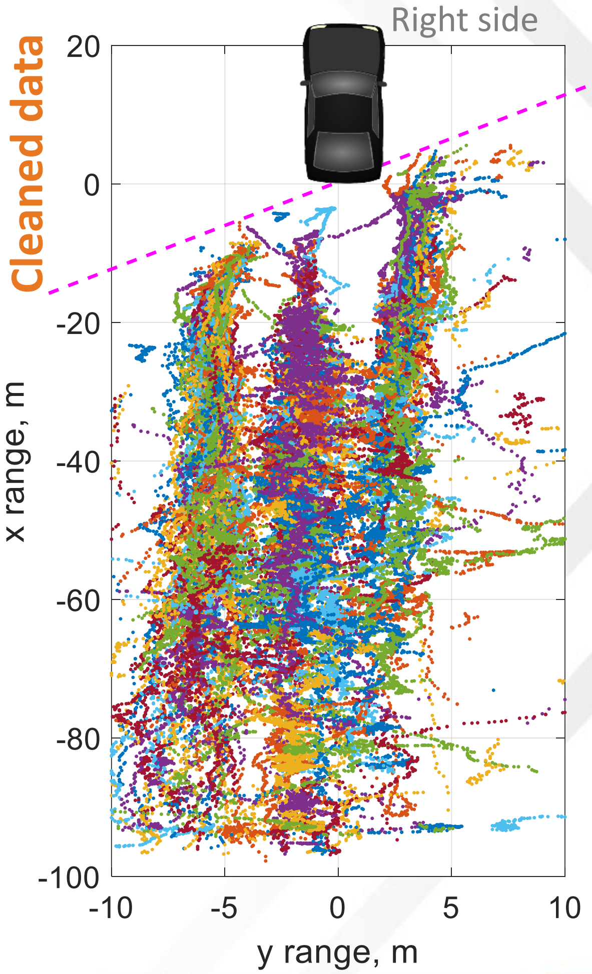
TRACES OF LEFT RADAR OBJECTS



- For entire trip duration of 40 min
- Data of all 40 radar objects is included
- Radar trace of each object ID shown by color in Figs

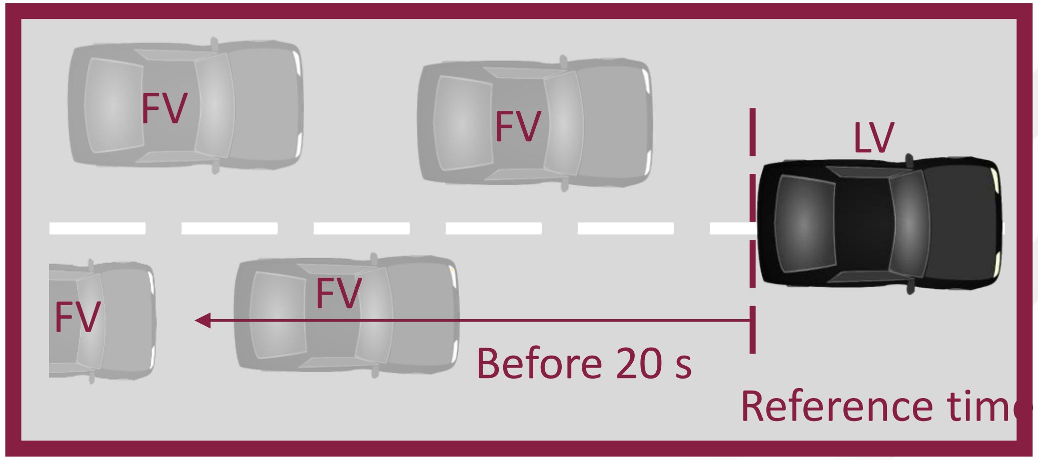
Conditions

- Delete all data where $Range_x \leq 0$ m and $Range_y > 0$ m for right radar
- Delete all data where Probability of Existence < 0.99
- Delete all data whose Status is not "measured" or "predicted"
- Select all data where -0.5 rad $\leq$ Orientation ≤ 0.5 rad
- Select all data where -10 m $\leq Range_y \leq 10$ m
- Select all data where Age $\geq$ 15 s
- Select all data where Stable = 1



IDENTIFICATION OF FOLLOWING VEHICLES (FV)

1. Reference time: Lane change time of LV (from road scout data)
2. Trimming road scout data of LV
   - Before 20 s form time of LV on the above lane during lane change (from road scout data)
3. Trim road scout data further by calculating
   - Accumulative longitudinal distance (calculated from speed) ≥ -200 m
4. Finding the LV's longitudinal and lateral position and corresponding time stamps from lane change reference position and the middle line between lanes (from road scout data)
5. Select radar for lane change
   - Left lane changes -> Left radar
   - Right lane changes -> Right radar
6. Using time stamps of LV's, trim cleaned radar data
7. With reference LV's longitudinal and lateral position, locate following vehicles' position and time (from trimmed radar)

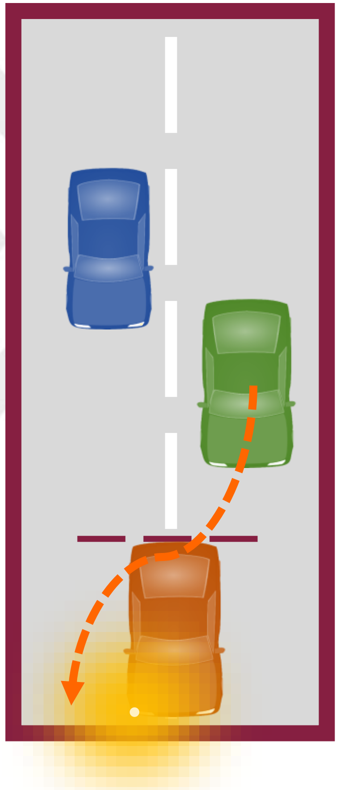


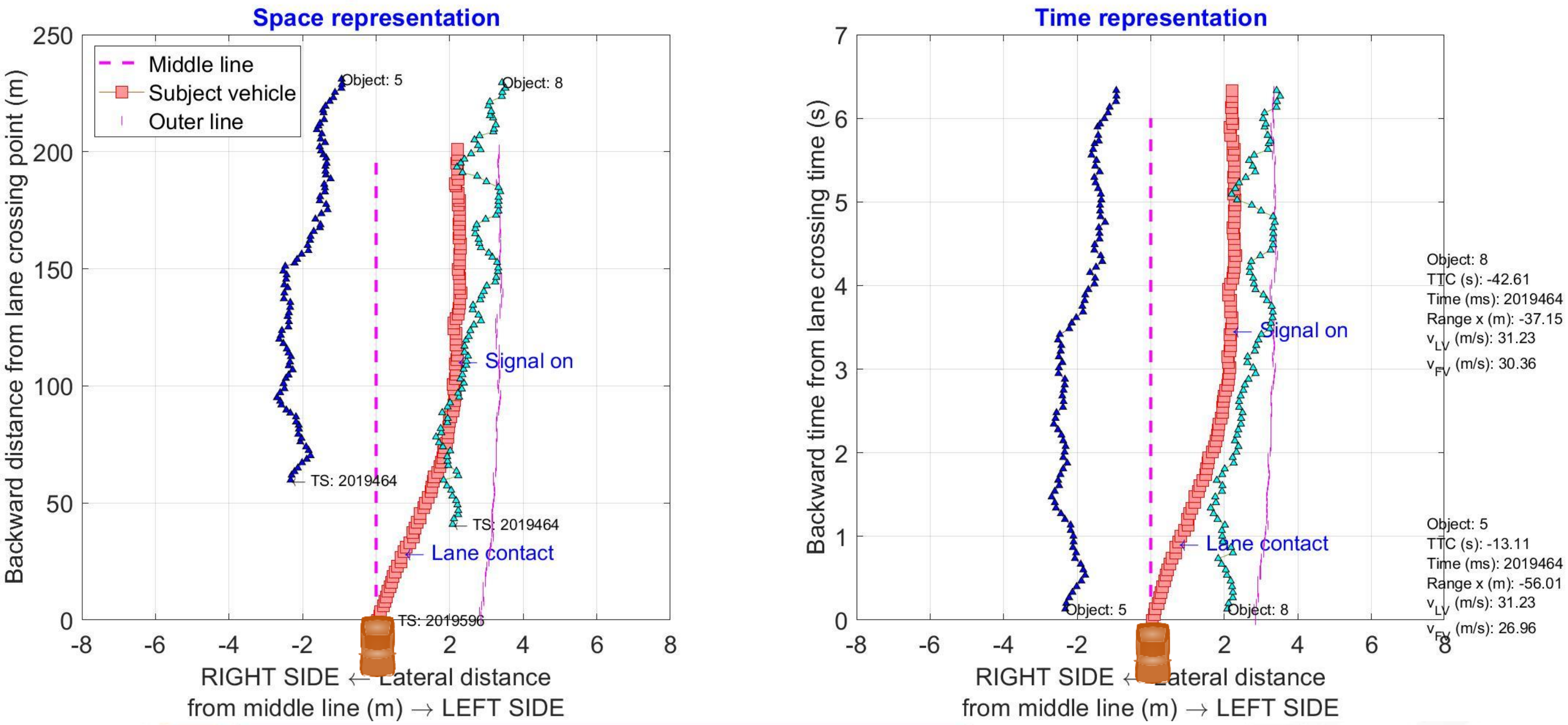
REPRESENTATION OF RADAR TRACES

Example: 1

Visually verified

Radar traces of File-ID = 28266
Sonic excel index = 3684; Roadscout excel index = 12497
Car: Sedan A; Direction = Right; Radar = RightSignal on time = 2016100; Signal off time = 2020200
Lane change time = 2019596; Lane contact time = 2018660; Lane crossover time = 2021644

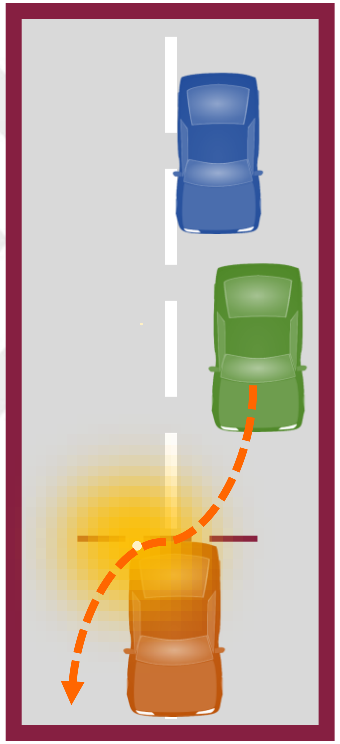


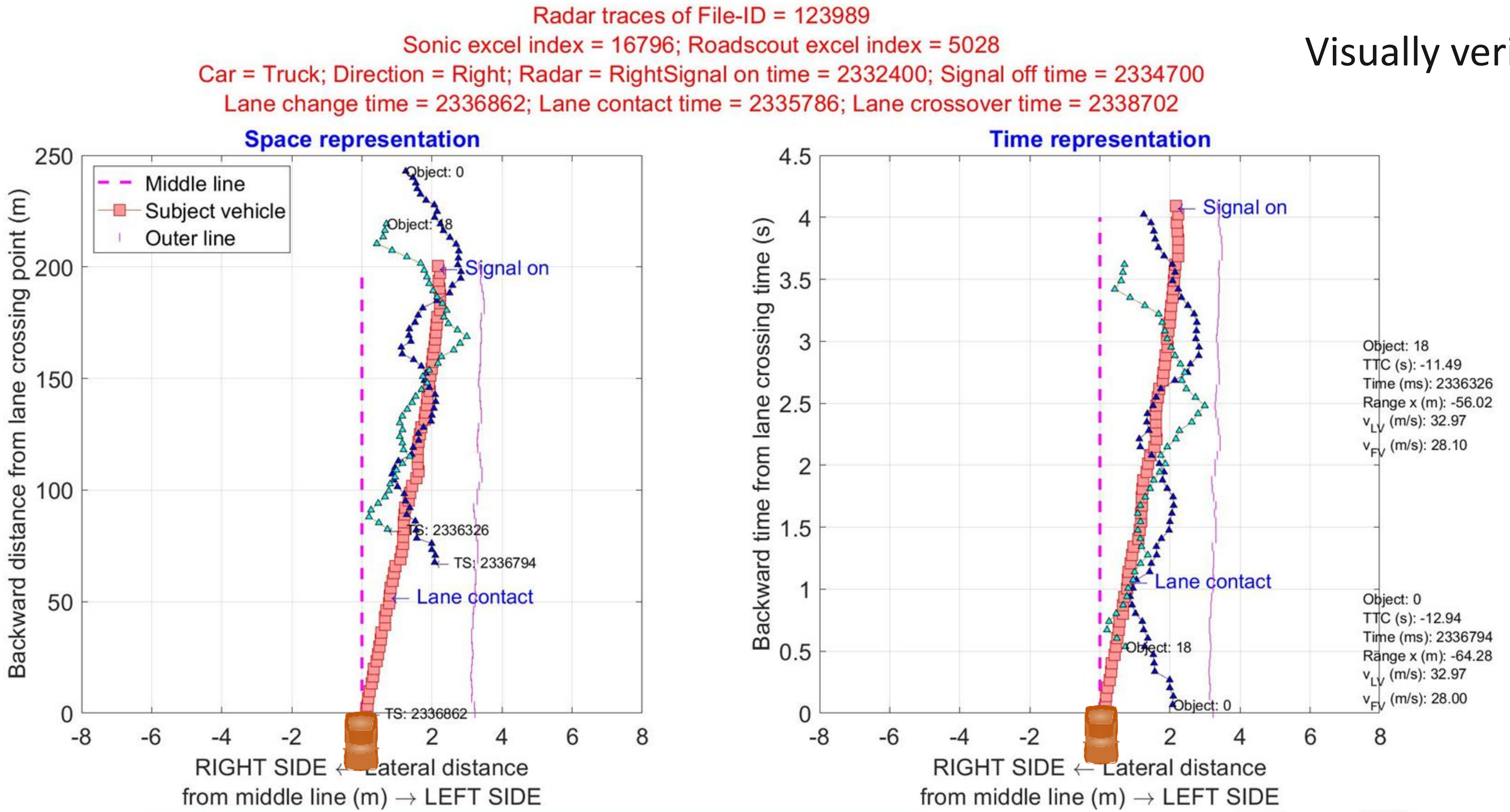


REPRESENTATION OF RADAR TRACES (CONT'D)

Example: 2

Visually verified

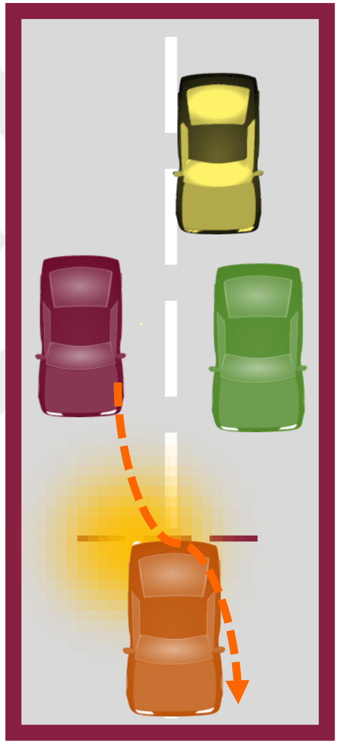


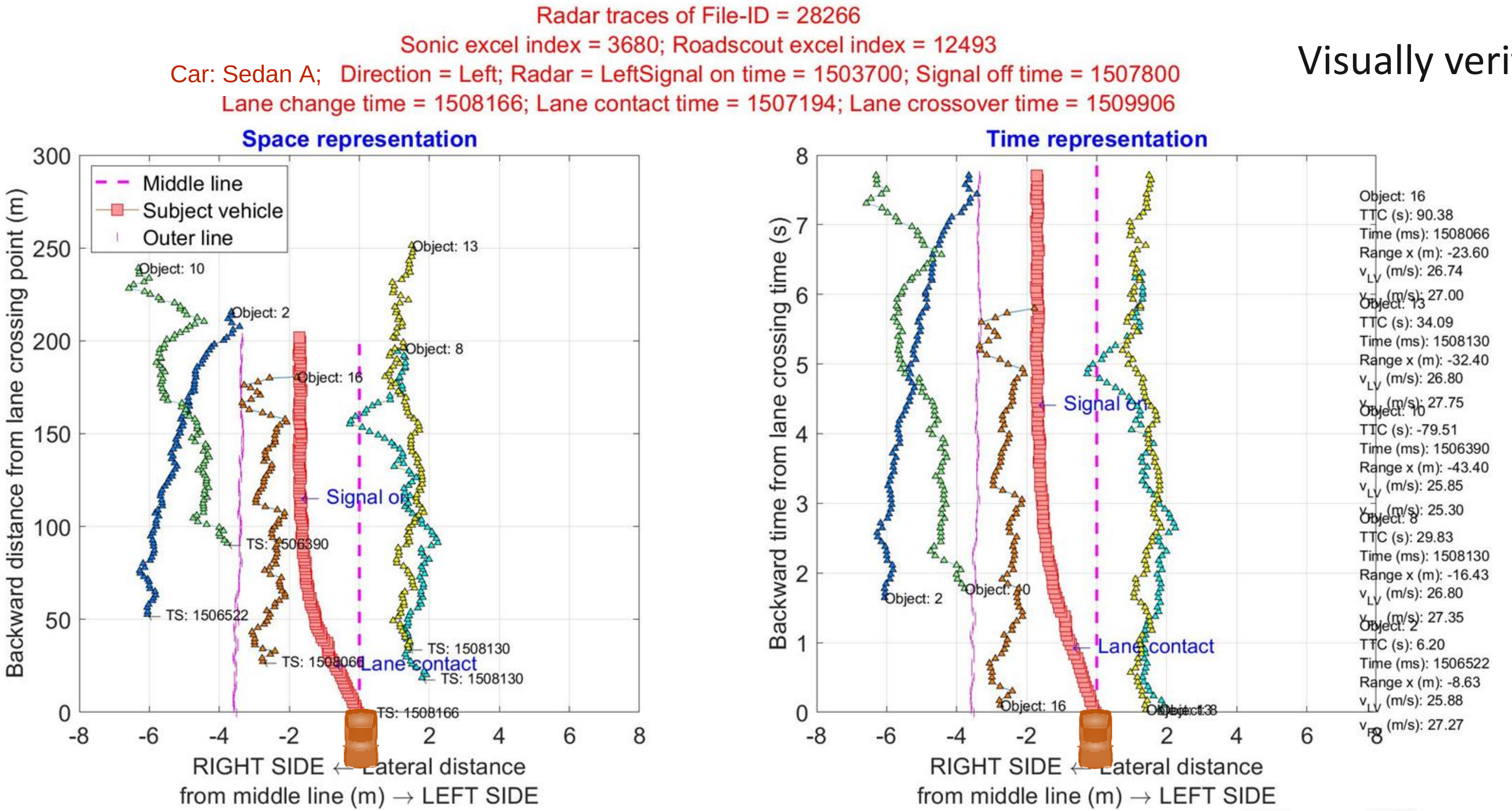


REPRESENTATION OF RADAR TRACES (CONT'D)

Example: 3

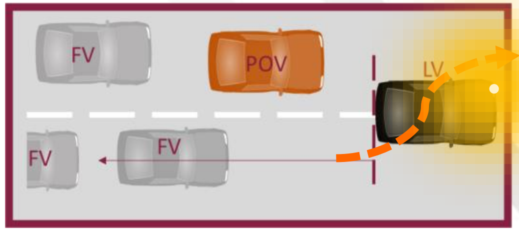
Visually verified



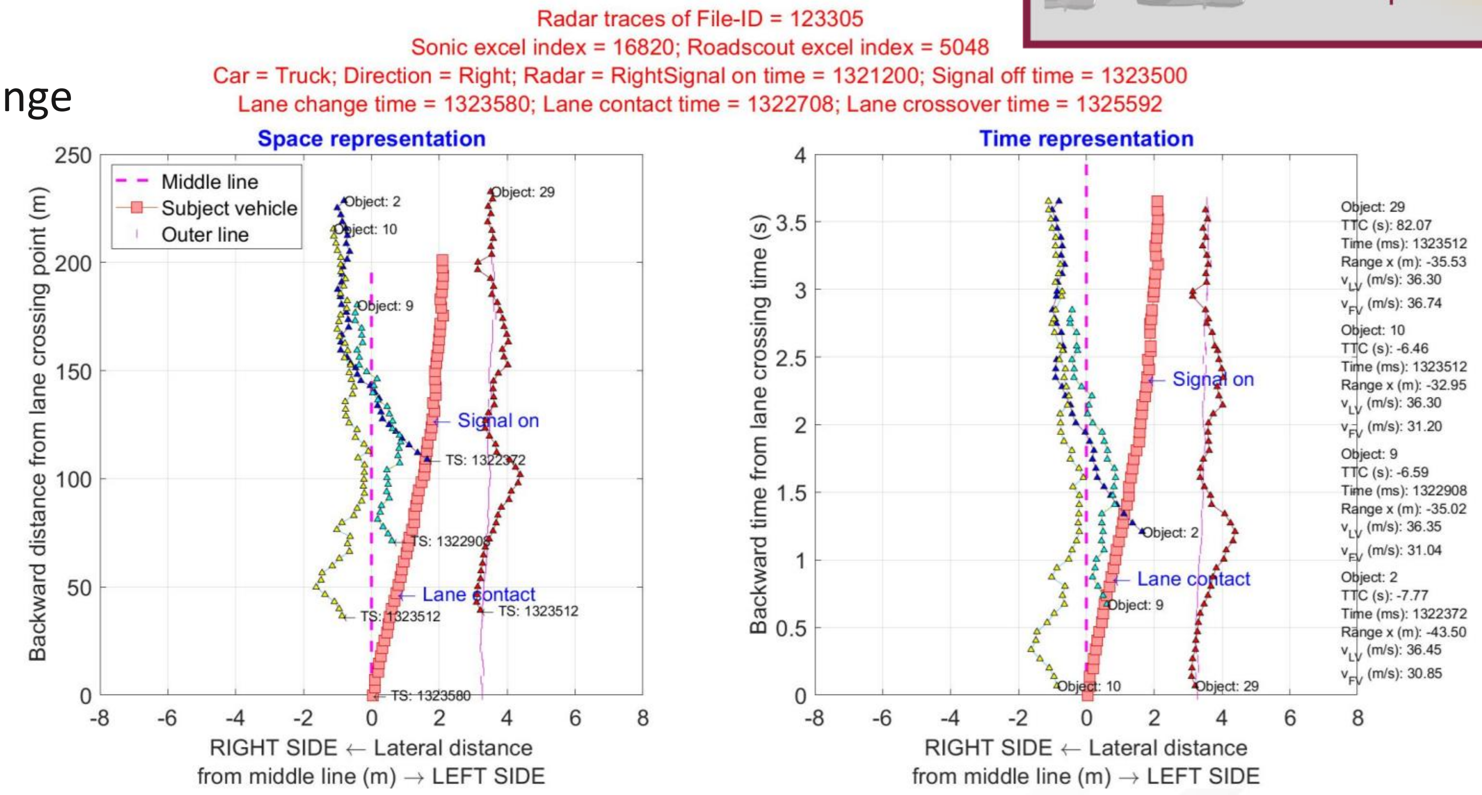


IDENTIFICATION OF PRINCIPAL OTHER VEHICLE (POV)

Steps & Conditions



- Omit the FVs ahead of LVs
- Select the FVs with
  - (start of FV's time stamp – lane change time of LV) ≤ 500 ms
  - (Objects 9 and 2 are eliminated in Figure)
- For right lane changes, select
  - -5m ≤ FV's lat. dist. ≤ 0
    (Object 10 selected in Fig)
- For left lane changes, select
  - 0 ≤ FV's lat. dist. ≤ 5 m
- More than one FV's satisfies
  - POV is FV closest to LV
    (Object 10 is POV)

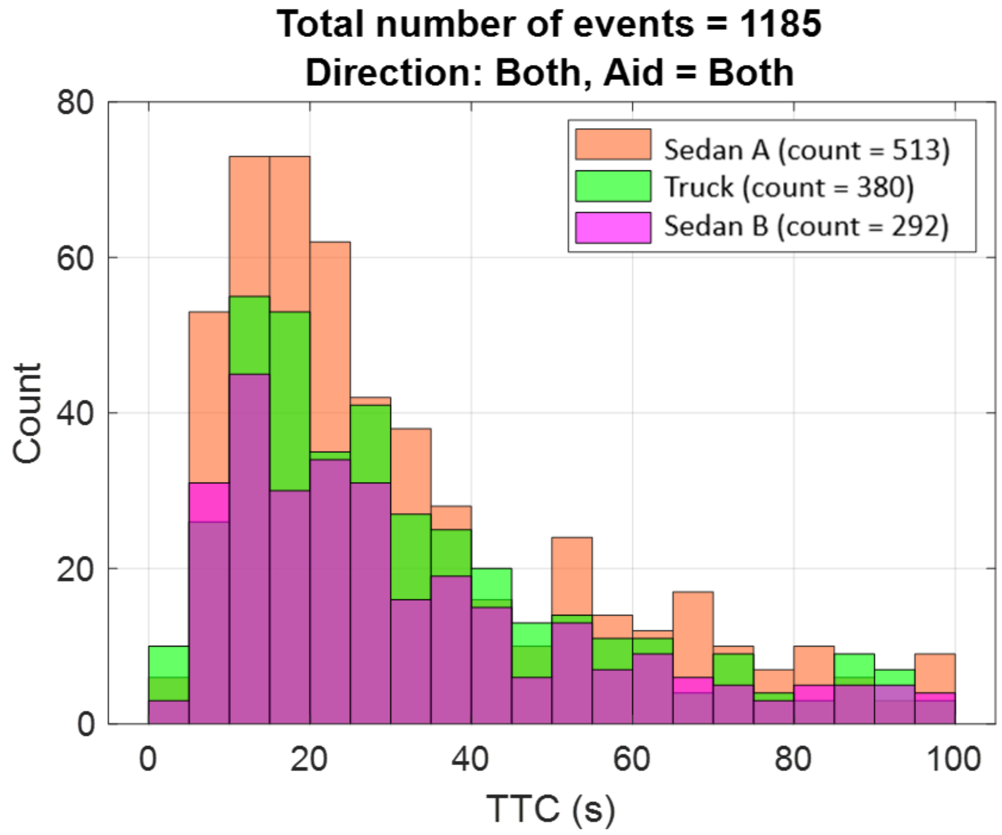


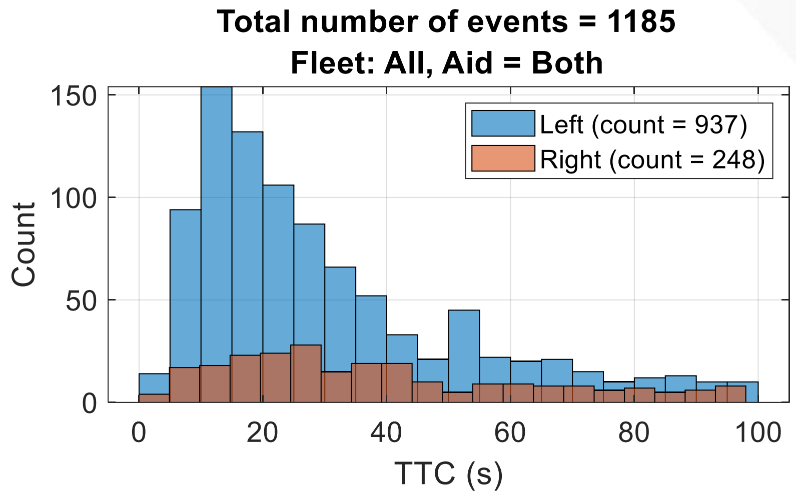
POV IDENTIFIED EVENTS

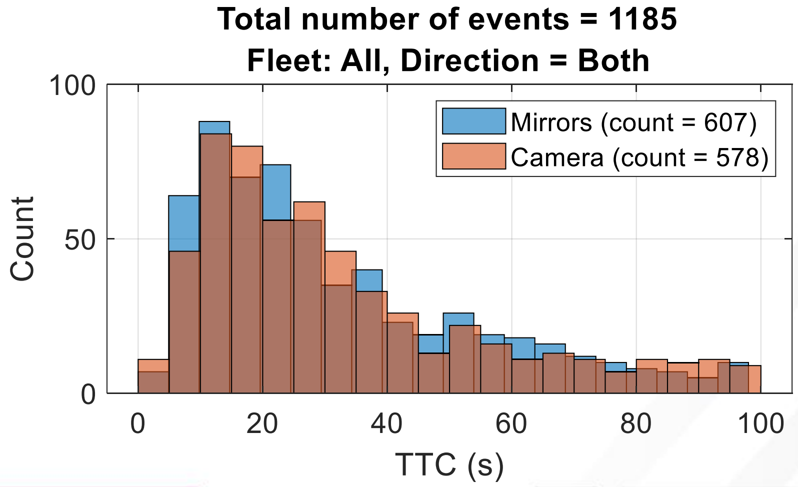
- Identified POV of 7425 signalized events
- 400+ events are visually verified using Hawkeye
  - < 10 misrepresentations because of road curves etc.
- Variables calculated at lane contact and lane crossover times
  - Radar number
  - Range, x and y; Range rate, $\dot{x}$ and $\dot{y}$
  - Time-to-Collision (TTC = -Range/Range rate)
- Selected TTC with $0 \leq TTC \leq 100\ s$
  - 1,185 lane changes were identified
  - 607 events under conventional mirrors
  - 578 events under camera-based systems

HISTOGRAMS OF TTC AT CONTACT POINT

0 ≤ TTC ≥ 100 sec

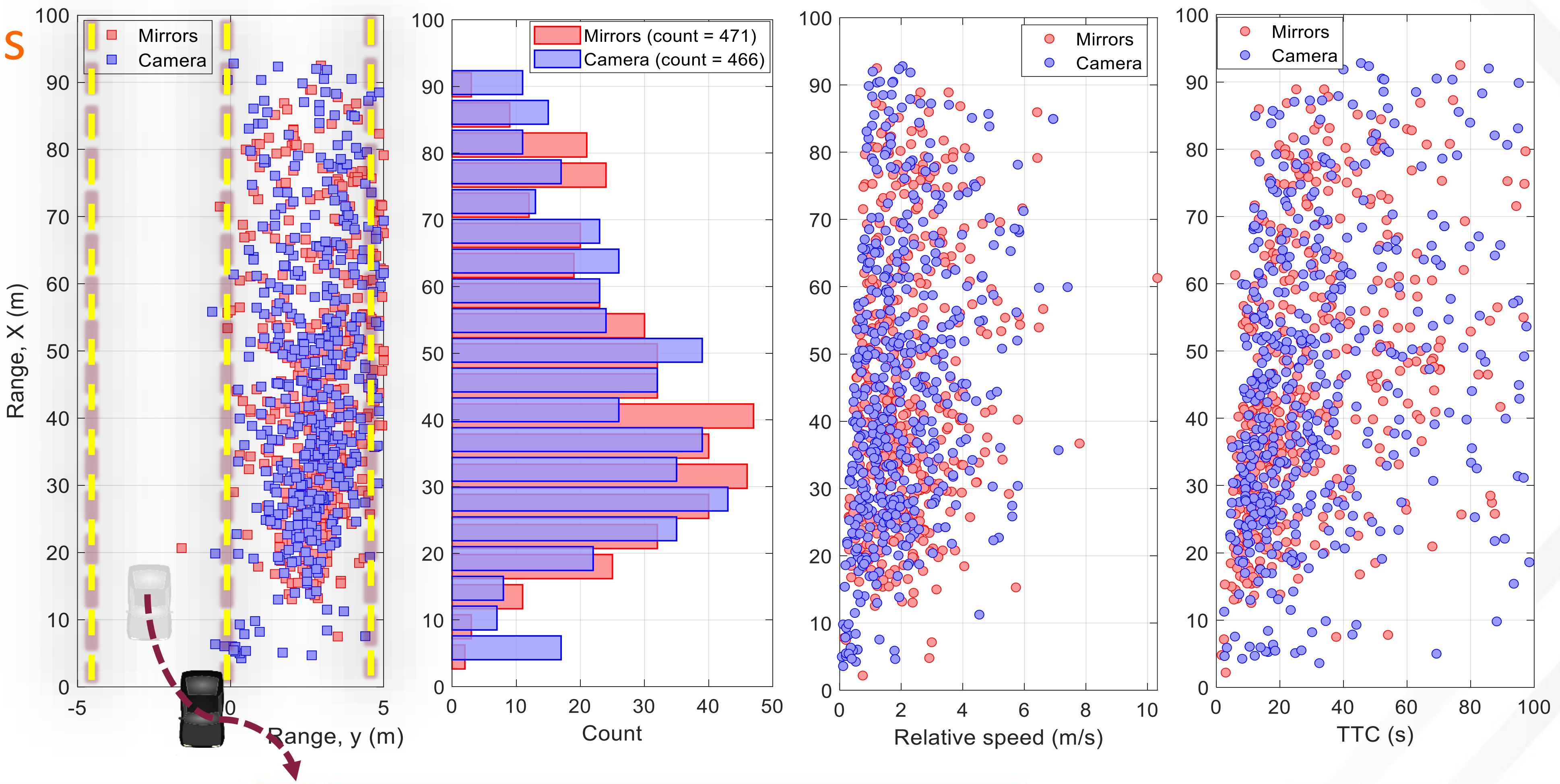






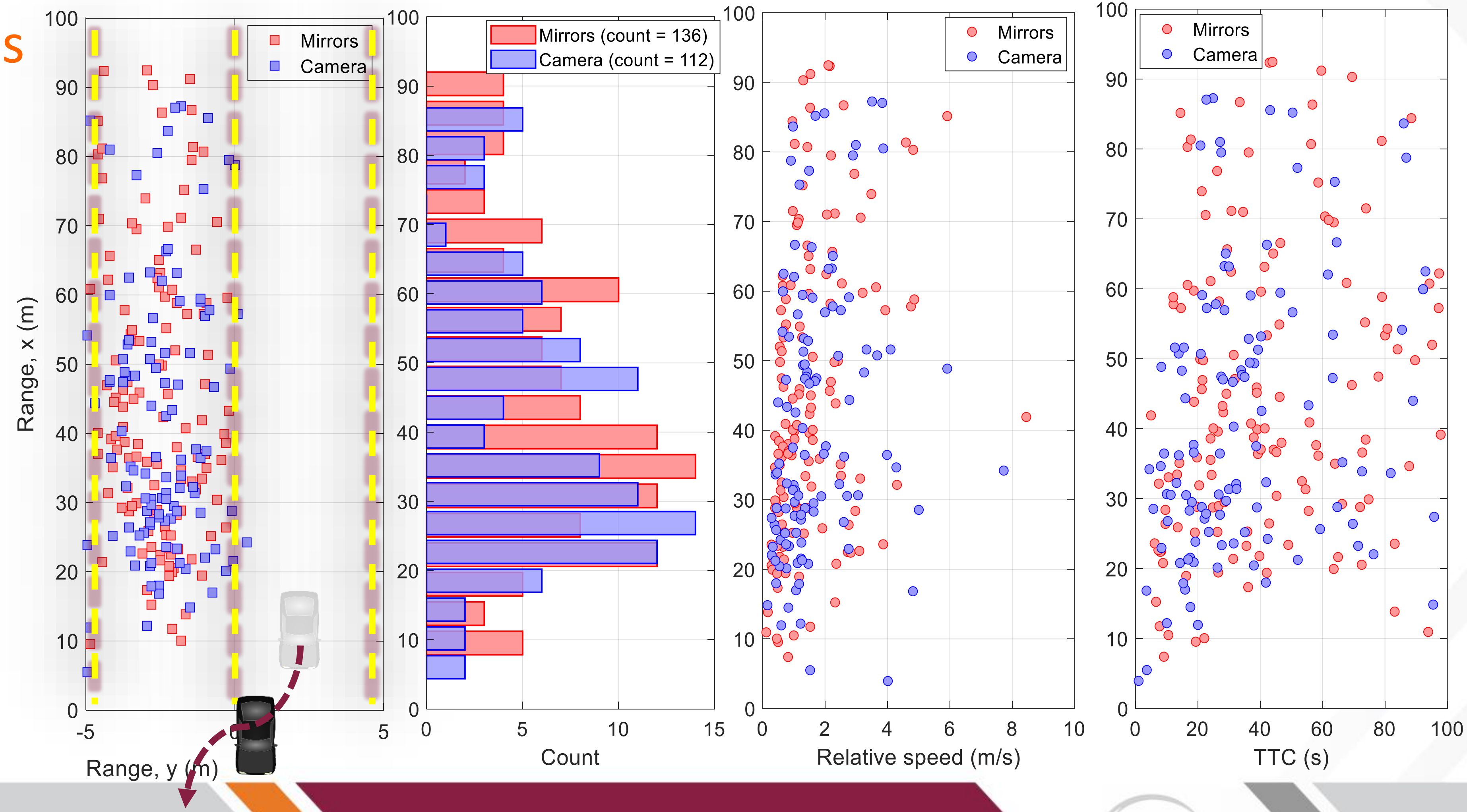
RELATIVE LOCATION OF POV VEHICLES

Left Turns



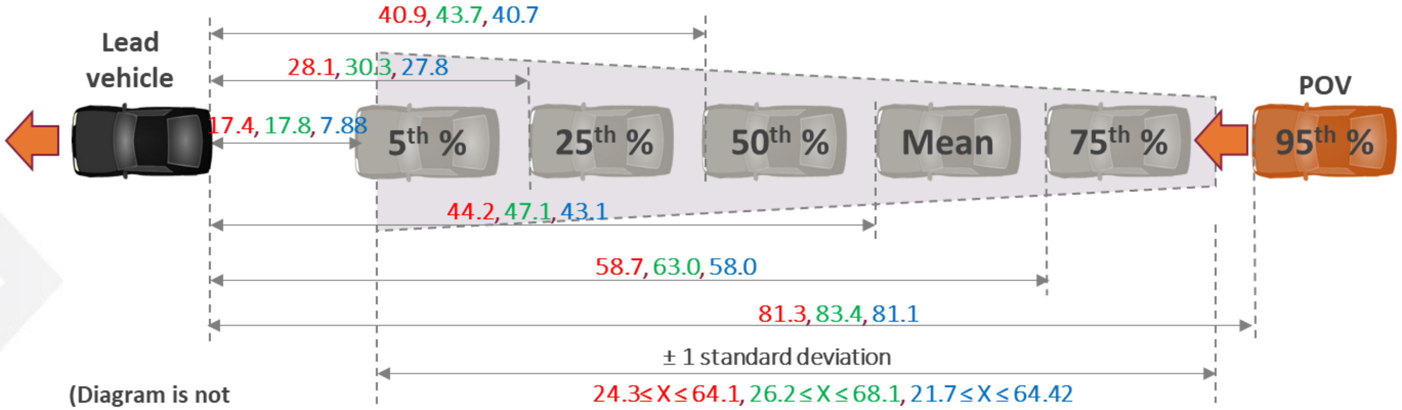
RELATIVE LOCATION OF POV VEHICLES

Right Turns



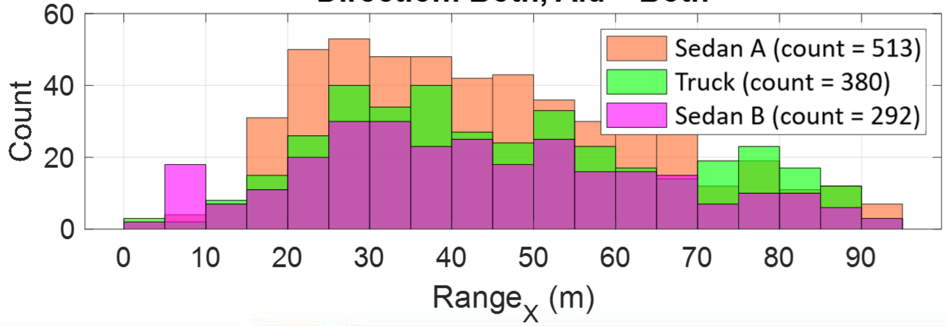
HISTOGRAM OF OCCURRENCES

Percentile Range (m) at time of LV on Lane Contact Point



(Diagram is not geometrically accurate)

Histogram of Range, X at Lane Contact Point
Total number of events = 1185
Direction: Both, Aid = Both

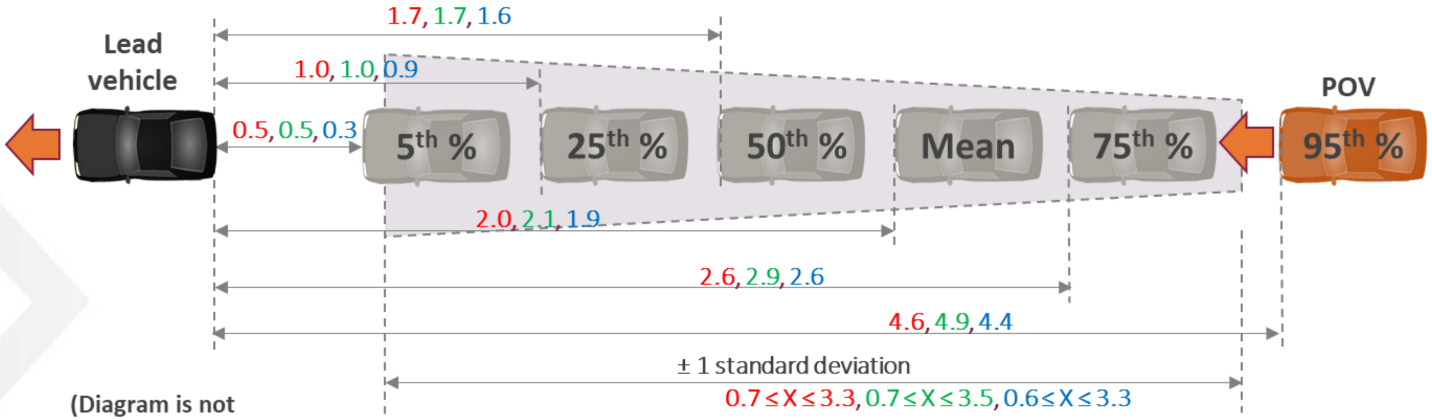


Range, X (m)

All Lane Changes (Left + Right)			
	Sedan A	Truck	Sedan B
Number	513	380	292
Mean	44.25	47.14	43.07
SD	19.90	20.95	21.35
Median	40.90	43.75	40.67
Min	2.20	3.95	4.25
Max	92.80	92.35	92.45
5th %-ile	17.38	17.80	7.88
25th %-ile	28.14	30.32	27.8
50th %-ile	40.90	43.75	40.67
75th %-ile	58.71	63.00	58.05
95th %-ile	81.35	83.40	81.12

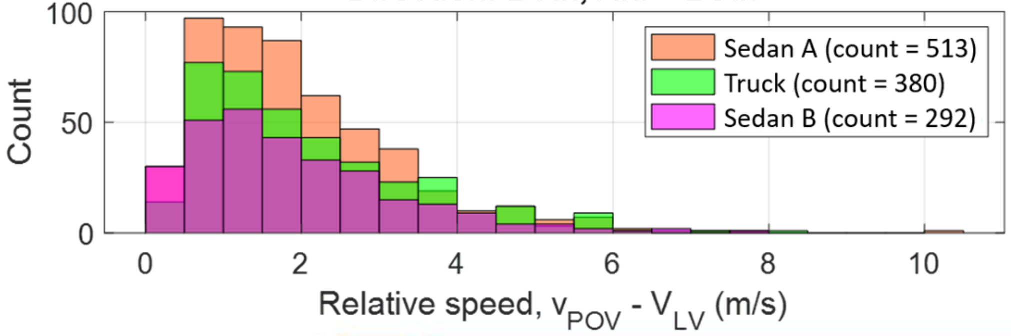
HISTOGRAM OF OCCURRENCES (CONT'D)

Percentile Relative Speed (m/s) at time of LV on Lane Contact Point



(Diagram is not geometrically accurate)

Histogram of Relative speed at Lane Contact Point
Total number of events = 1185
Direction: Both, Aid = Both

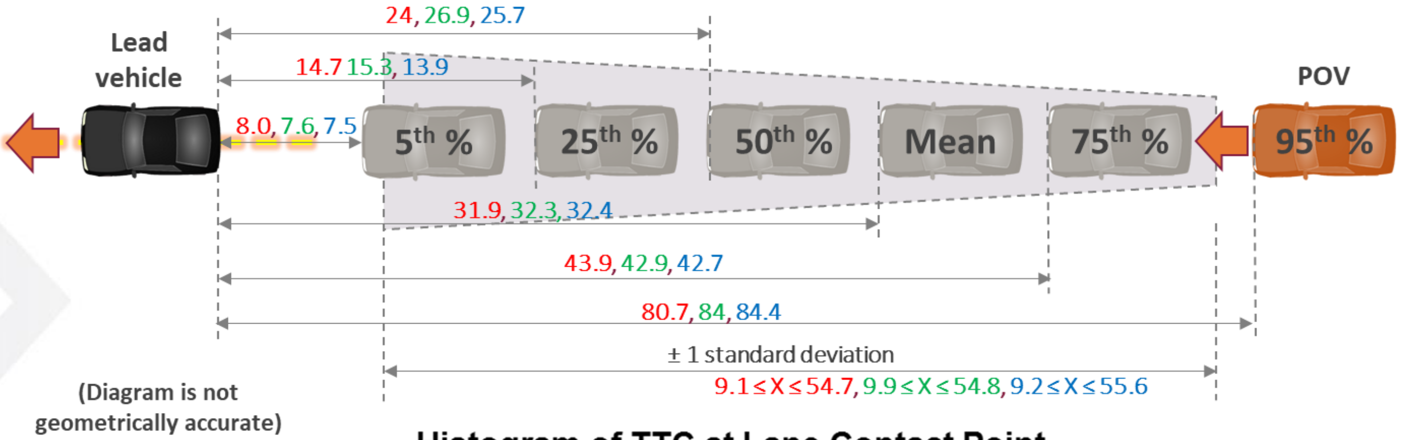


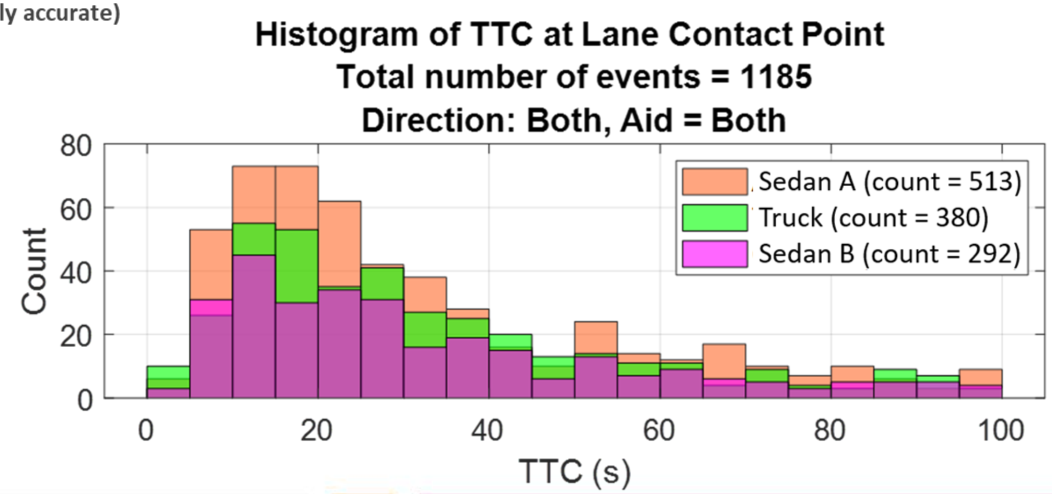
Relative speed (m/s) = $v_{POV} - v_{LV}$

All Lane Changes (Left + Right)			
	Sedan A	Truck	Sedan B
Number	513	380	292
Mean	1.99	2.09	1.91
SD	1.33	1.40	1.35
Median	1.67	1.68	1.56
Min	0.11	0.16	0.07
Max	10.32	8.45	7.73
5^{th} %-ile	0.47	0.52	0.33
25^{th} %-ile	1.02	1.05	0.94
50^{th} %-ile	1.67	1.68	1.56
75^{th} %-ile	2.62	2.89	2.60
95^{th} %-ile	4.63	4.90	4.45

HISTOGRAM OF OCCURRENCES (CONT'D)

Percentile TTC (s) at time of LV on Lane Contact Point



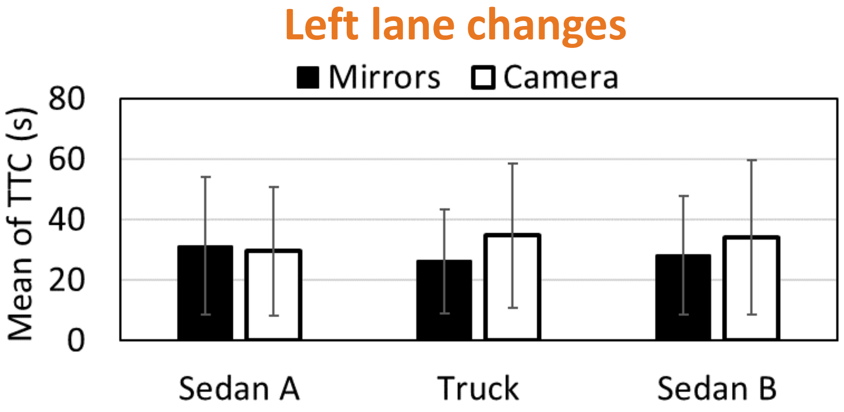


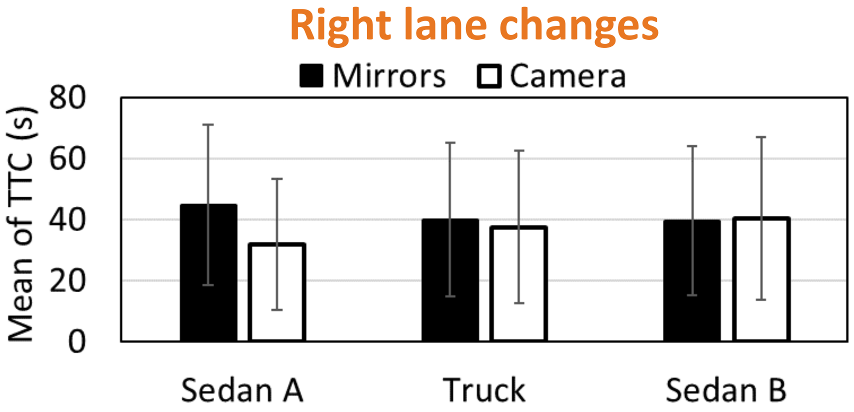
TCC (s)

All Lane Changes (Left + Right)			
	Sedan A	Truck	Sedan B
Number	513	380	292
Mean	31.90	32.34	32.41
SD	22.80	22.43	23.17
Median	24.00	26.45	25.66
Min	2.39	0.98	3.61
Max	98.47	96.82	96.68
5th %-ile	7.96	7.58	7.51
25th %-ile	14.66	15.26	13.89
50th %-ile	24.00	26.90	25.66
75th %-ile	43.87	42.89	42.66
95th %-ile	80.68	84.00	84.44

MEAN TTC VALUES AT LANE CONTACT POINT

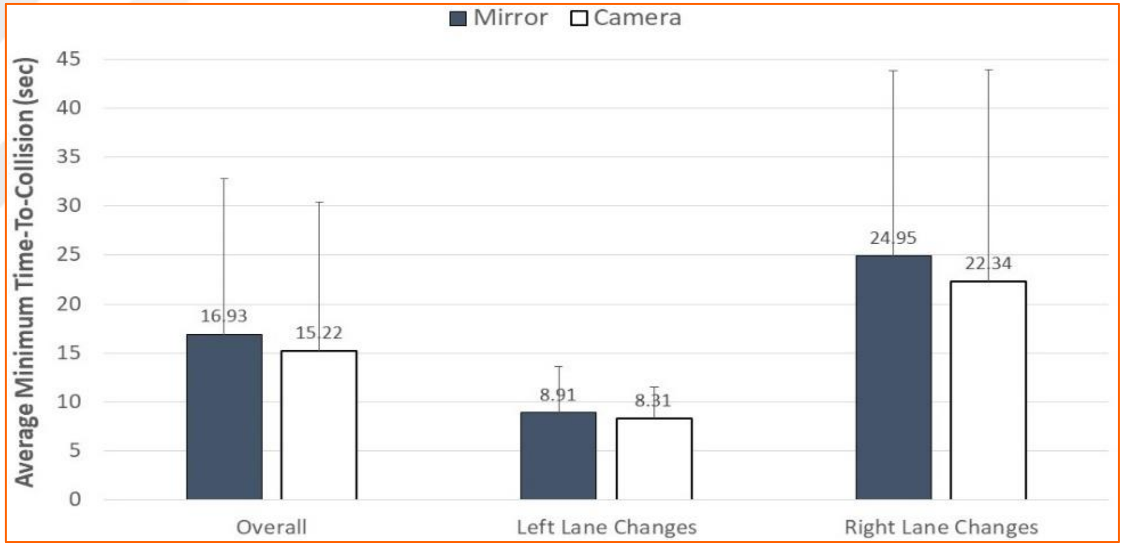
Values	Left Turns, Mirror	Left Turns, Camera	Right Turns, Mirror	Right Turns, Camera	Overall, Mirror	Overall, Camera
Number	471	466	136	112	607	578
Mean	**28.72**	**32.05**	**41.61**	**35.70**	**31.61**	**32.76**
SD	20.38	23.08	25.35	24.07	22.23	23.30
Median	22.49	24.92	37.48	28.71	24.52	26.19
Min	1.65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

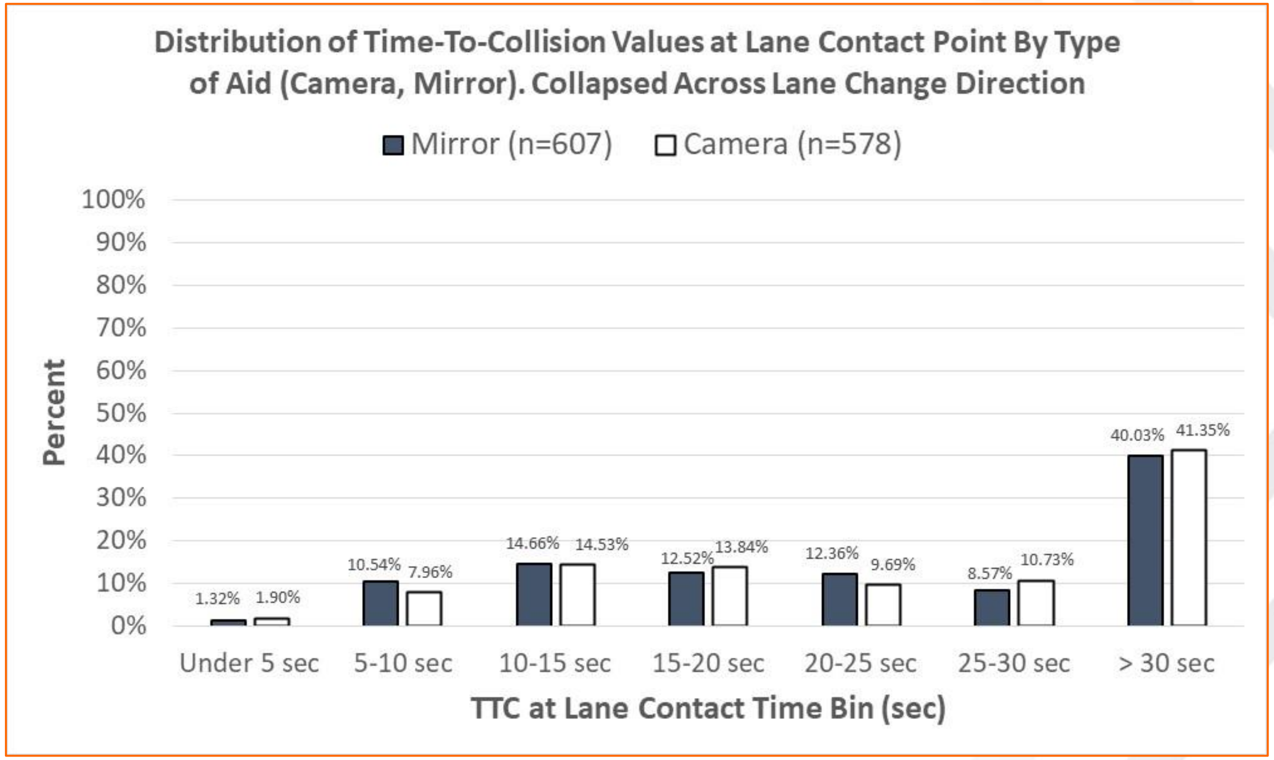




MEAN TTC VALUES AT LANE CONTACT POINT

Minimum TTC for each driver





SUMMARY

- No significant differences in TTCs were observed between conventional mirror and camera-based system across any of the vehicle fleets (for combined Left/Right lane changes)
- Analyses revealed no critical conflicts or patterns of ill-advised lane changes under camera displays
- Use of camera-based systems did not appear to impact functional performance associated with making and executing lane changes.
- Camera-based systems, when appropriately designed, can help drivers detect potential conflicts because of the wider field of view

Thank you for Attention!

Any Questions ?

Source: thomasnet.com