Recent NHTSA Lane Keeping Support Research

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Presentation Overview

- What is LKS?
- 2016 Test Objectives and Methods
  - Evaluate contemporary systems
  - European NCAP and NHTSA procedures
  - Develop test maneuver automation using a steering robot
  - Results and observations
  - Problems associated with a steering robot
  - Future Plans for LKS Research

What is LKS?

- Lane keeping support (LKS)
  - Momentarily applies a steering torque and/or a braking input
  - Used to help restore lane position
  - Automated Vehicle SAE Level 0
- LKS is not Lane Centering Control (LCC)
  - LCC continuously applies steering inputs
  - Used to maintain lane position in the center of the lane
  - Automated Vehicle SAE Level 1

2016 Research Objectives

- Use a steering robot to improve test accuracy and repeatability
  - Evaluate consequences associated with a steering robot
- Assess the Euro NCAP and 2016 NHTSA (experimental) LKS test methods
- Evaluate LKS system responses of contemporary vehicles
  - Ability to recover from an imminent lane departure
  - Observe whether the first LKS response causes a secondary departure
    - Secondary departures may result from the LKS correction of the initial lane departure
    - NHTSA doesn't want to correct one safety problem only to introduce another

2010 NHTSA Lane Keeping Support Procedure

- A supplement within NHTSA's Lane Departure Warning (LDW) NCAP test procedure
- Historically used driver based steering control
- Includes two lateral velocity categories
  - **Low** - 0.1 to 0.6 m/s with a target lateral velocity of 0.5 m/s
  - **Iteratively Increased** - Increase in lateral velocity from 0.6 m/s to a magnitude where LKS can no longer prevent a lane departure from occurring

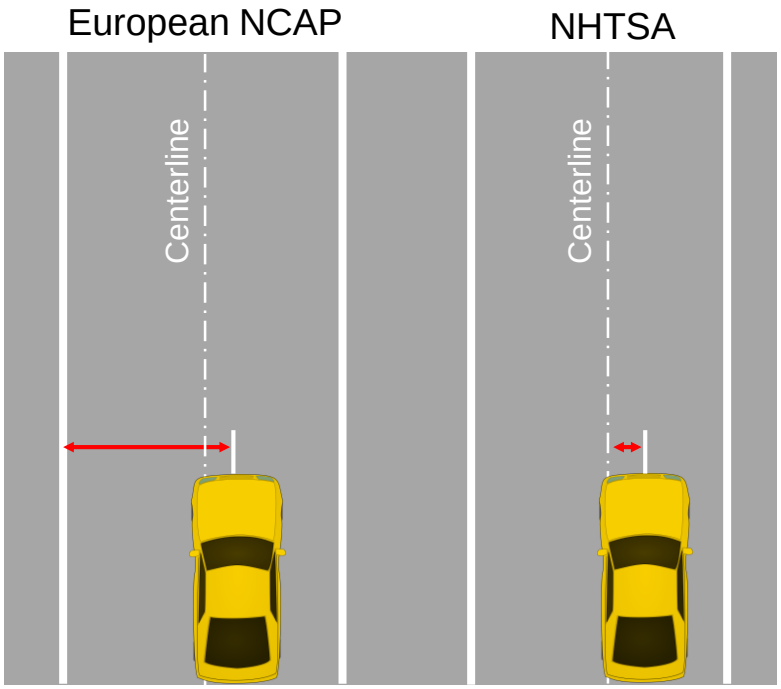
Lateral Velocity	Line Type	Departure Direction	Number of Trials
Low	Solid	L	5
		R	5
Iteratively Increased	Solid	L	10
		R	10

2016 NHTSA Experimental LKS Procedure
(used for work described in this presentation)

- Differs from 2010 LKS test procedure in the following ways:
  - Modelled after European NCAP LKS procedure
  - Automated using steering controller robot
  - Achieves lateral velocity by travelling partially through curved radius (R=1200 m)
  - Utilizes two-part baseline tests to determine steering control release point
  - Performed at multiple lateral velocities
    - 0.1 m/s to 1.0 m/s iteratively increased by 0.1 m/s

2016 Test Matrix

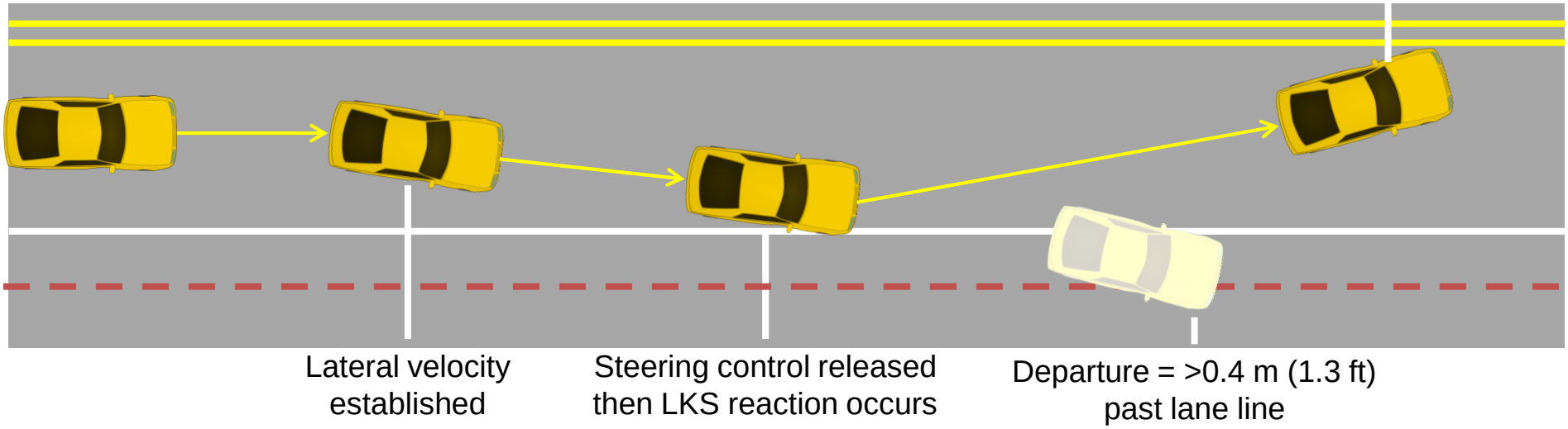
- Two test types
  - European NCAP
  - 2016 NHTSA (experimental)
- Three vehicles:
  - 2017 Audi A4
  - 2017 Volvo S90 } Steering-based
  - 2017 Mercedes E300 Brake-based



Lateral Velocity	Test Type	Departure Direction	Number of Trials
0.1 m/s to 1.0 m/s, iteratively increased by 0.1 m/s	Euro NCAP	L	3
		R	3
	NHTSA	L	3
		R	3

2016 Test Scenario

- Vehicle initially driven in a straight line
- Transitioned to a curved path (R = 1200 m) until desired heading angle is achieved using closed loop control
- Vehicle path straightened
- At a time based on a baseline output
  - Steering enters open loop control – vehicle path straightens
  - Constant throttle position is maintained



2016 Results

- Comment regarding additional tests performed with the Mercedes E300
  - Method 1: Constant throttle position after open loop control point
  - Method 2: Released throttle after open loop control point
- Key to results charts
  - No highlight (white/light blue): No tests resulted in a departure
  - Yellow: At least one, but not all tests resulted in a departure
  - Red: All tests resulted in a departure
- Red line indicates the cut-off lateral velocity for the European NCAP LKS test procedure
- “n/a” indicates no secondary departure possible because an initial recovery did not occur
- NOTE: European NCAP ratings do not consider secondary lane departures

Results – Initial Lane Departures

Initial Lateral Velocity (m/s)	NHTSA				EURO			
	Audi A4	Mercedes E300		Volvo S90*	Audi A4	Mercedes E300		Volvo S90*
		Held	Released			Held	Released	
0.1	0/6	0/6	0/6	-	2/6	0/6	0/6	0/6
0.2	0/6	0/6	1/6	-	0/6	0/6	1/6	0/6
0.3	0/6	0/6	0/6	-	0/6	1/6	0/6	0/6
0.4	0/6	0/6	0/6	-	1/6	1/6	0/6	0/6
0.5	0/6	0/6	1/6	-	0/6	0/6	0/6	0/6
0.6	0/6	0/6	0/6	-	0/6	6/6	6/6	1/6
0.7	0/6	3/6	3/6	-	1/6	0/6	0/6	1/6
0.8	1/6	2/6	0/6	-	2/6	5/6	2/6	4/6
0.9	4/6	5/6	3/6	-	2/6	6/6	6/6	3/3
1.0	0/6	3/3	3/3	-	0/6	6/6	6/6	3/3

***Volvo S90 testing has not been fully completed at this time**

Results – Secondary Lane Departures

Initial Lateral Velocity (m/s)	NHTSA				EURO			
	Audi A4	Mercedes E300		Volvo S90*	Audi A4	Mercedes E300		Volvo S90*
		Held	Released			Held	Released	
0.1	2/6	2/6	5/6	-	0/4	1/6	5/6	0/6
0.2	2/6	0/6	4/5	-	3/6	1/6	2/5	0/6
0.3	3/6	1/6	6/6	-	1/6	0/5	4/6	1/6
0.4	1/6	0/6	4/6	-	0/5	0/5	5/6	0/6
0.5	1/6	1/6	4/5	-	0/6	0/6	3/6	2/6
0.6	0/6	6/6	2/6	-	1/6	n/a	n/a	2/5
0.7	0/6	1/3	2/3	-	0/5	6/6	5/6	5/5
0.8	1/5	4/4	5/6	-	0/4	1/1	4/4	1/2
0.9	2/2	0/1	2/3	-	0/4	n/a	n/a	n/a
1.0	2/6	n/a	n/a	-	0/6	n/a	n/a	n/a

***Volvo S90 testing has not been fully completed at this time**

Testing Results Observations

- Discrepancies between Euro NCAP and NHTSA test scenarios' results
  - Higher lateral velocities
  - Secondary lane departures
- Steering robot: influence on vehicle performance
  - Drag from motor affecting LKS capabilities
  - Primarily for secondary departures, but possibly even initial departures

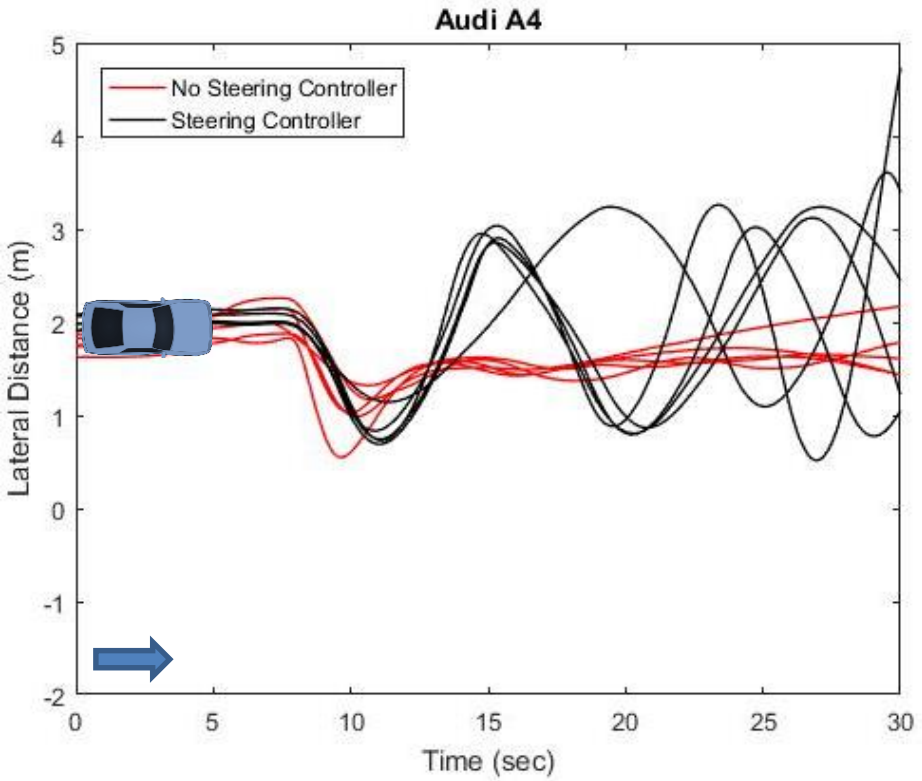
Effect of Steering Robot on Lateral Response

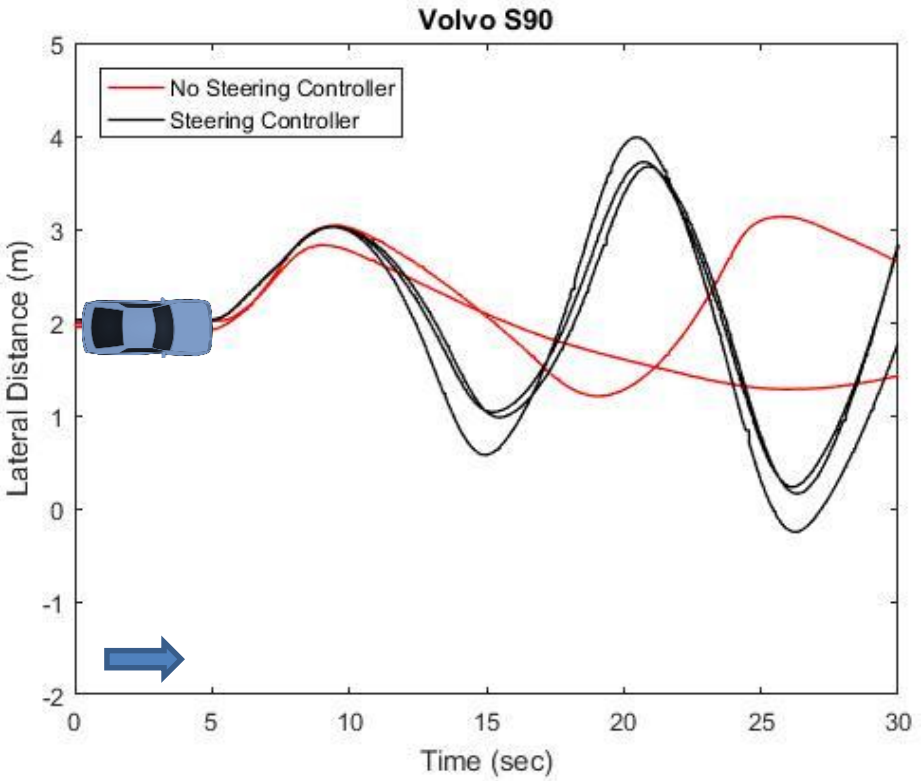
- Steering robot is needed to insure test accuracy and repeatability, however…
- Vehicle response can be affected

LKS Test Performance Without Steering Robot

LKS Test Performance With Steering Robot

Effect Of Steering Robot Installation On Lateral Response





Summary

- 2016 LKS testing
  - LKS test maneuvers were performed using steering and braking controller robots to achieve highly repeatable steering and throttle inputs
    - Compared to driver-based inputs, test accuracy and repeatability was improved
    - Discovered use of steering controller may confound the ability accurately examine LKS system performance
  - Gained experience with the European NCAP test procedure
- Anticipated NHTSA LKS testing for 2017
  - Complete the evaluation initiated during 2016
  - Identify a way to reduce the effect of using robotic steering control

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THANK YOU!

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