THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

Project 0-6849: Implications of Automated Vehicles on Safety, Design & Operation of the Texas Highway System

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Research Supervisor

Research Team

Dr. Jia Li

Task 1: Synthesis of Current Research & Development of CAV Technologies (Jan. 2015 – April 2015)

Dr. Kara Kockelman

Task 2: Anticipate AV & CV Market Penetration Rates in Texas over Time (Feb. 2015 – July 2015)

Drs. Kara Kockelman & Stephen Boyles

Task 3: Anticipate Long-Range Impacts of Automation Opportunities on Texas Traffic Safety (June – Nov. 2015)

Research Team

Dr. Stephen Boyles

Task 4: Define & Evaluate Opportunities for & Impacts of Changes in Infrastructure Design & System Operations (October 2015 – March 2016)

Drs. Kara Kockelman & Stephen Boyles

Task 5: Develop Best Practice Recommendations for Accelerating Deployment of CAVs in Texas, to Most Cost-Effectively Improve Safety (January – June 2016)

Drs. Kara Kockelman & Stephen Boyles

Task 6: Provision of Training Session/Webinar, Final Report & Summary Report (May - August 2016)

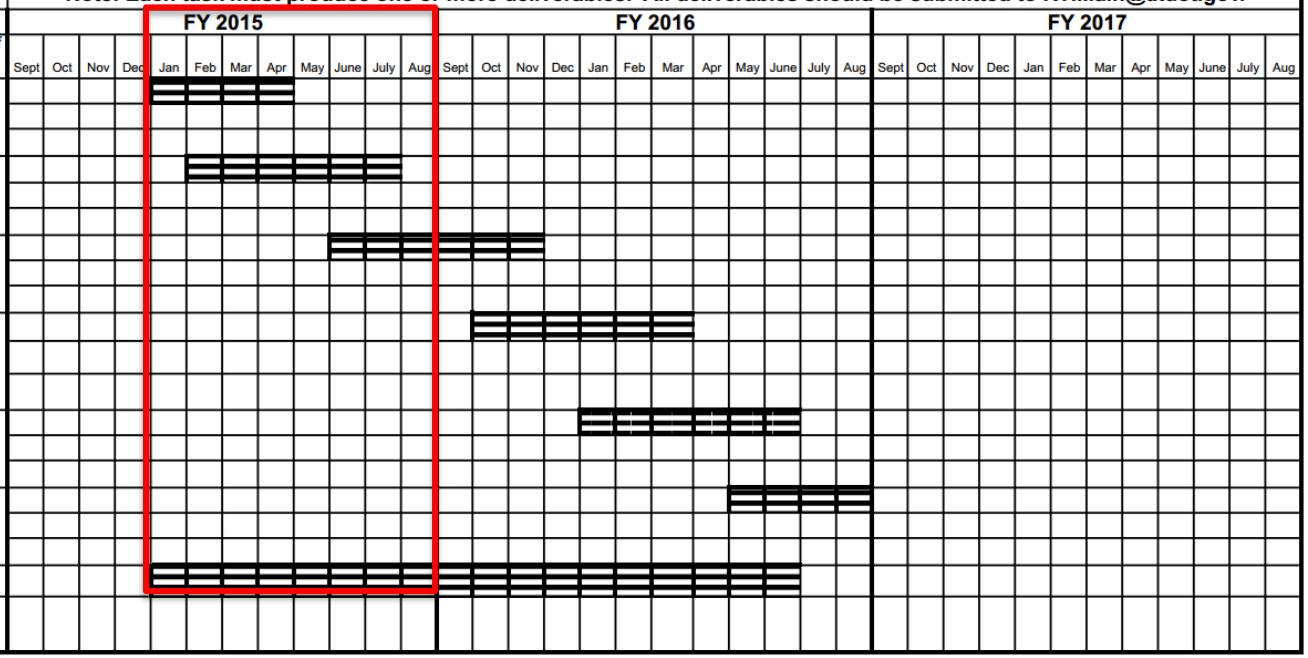
Schedule

Original Schedule
Work Completed
RRRRR Revised Schedule

Created Date: August 25, 2014

Note: Each task must produce one or more deliverables. All deliverables should be submitted to RTIMain@txdot.gov.

Research Activity		Estimated Cost of Task
Task 1	Syn of Current Res on Dev of Vehicle Automation Tech	$30,294
Task 2	Anticipate AV + CV Market Penetration Rates in Texas	$55,080
Task 3	Anticipate Impacts of Automation on Texas Traffic Safety	$52,326
Task 4	Define & Eval Opps for & Impacts of Changes in Infrastr Design & System Operations	$52,326
Task 5	Best Practices for Accelerating Cost-Effective Deployment of CAVs in Texas	$49,572
Task 6	Training Workshop, Final Report, & Summary Report	$35,802
Monthly Progress Reports		
Total (should = 100% of total budget)		**$275,401**

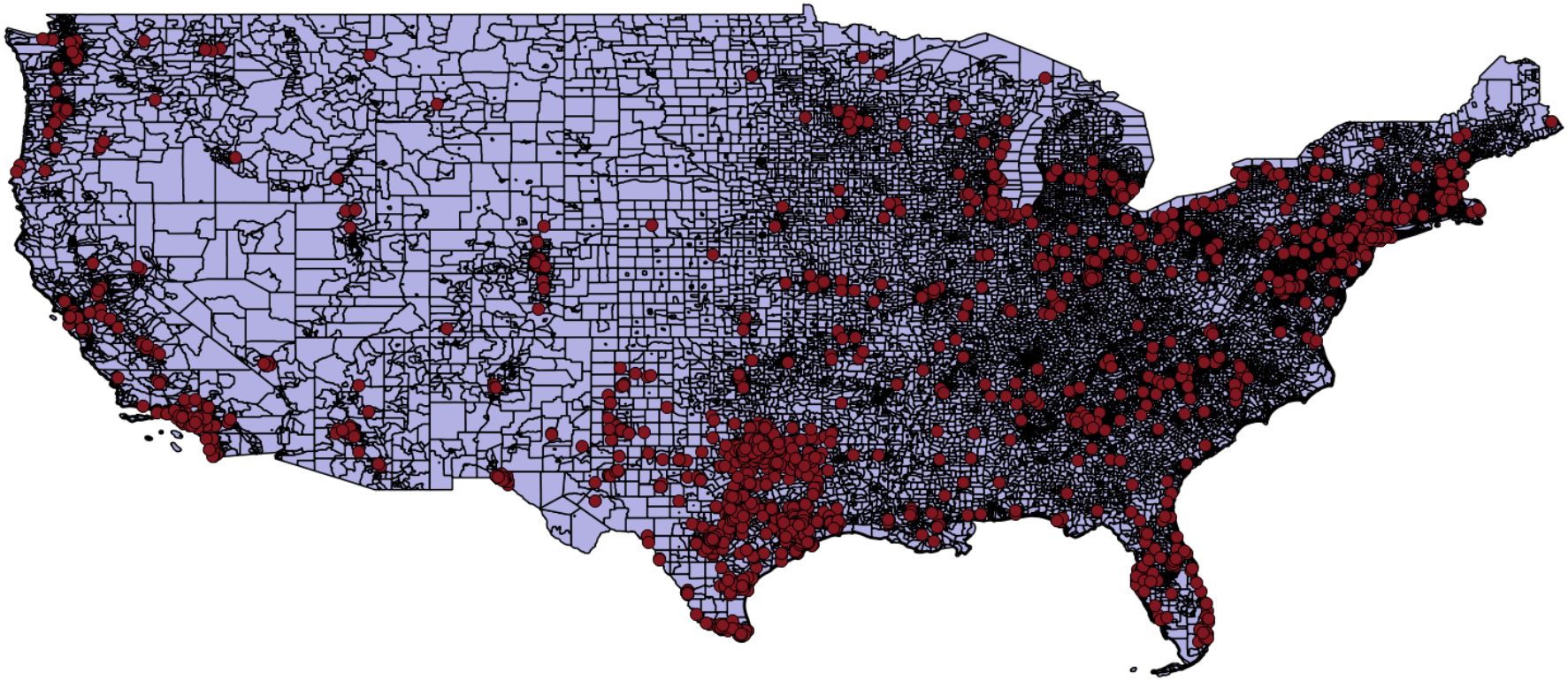


Task 2: Anticipating AV + CV Market Penetration Rates in the U.S. Over Time

Survey Instrument

- **Online survey** asking about:
  - Household's current vehicle holdings
  - Future **vehicle transaction decisions**
  - **Willingness to pay** for various C/AV technologies
  - Travel choices & demographics
- **Total, usable responses: 2,167 Americans** (1,364 TX)
- **Geocoded home** tracts & obtained **household- & person-level weights** using American Community Survey (ACS) data to counter sample biases.

Respondents' Locations



Geocoded Respondents Across Continental USA

Willingness to Pay

	Average WTP	Average WTP (of those with WTP > 0)	% of Respondents with $0 WTP
Level 1 or Level 2 Automation			
Electronic Stability Control	**$52**	**$79**	33.4%
Lane Centering	**$205**	**$352**	41.7%
Left Turn Assist	$119	$221	46.1%
Cross Traffic Sensor	$169	$252	32.8%
Adaptive Headlight	$203	$345	41.1%
Pedestrian Detect	$145	$232	37.5%
Adaptive Cruise Control	$126	$202	37.7%
Blind Spot Monitoring	$160	$210	**23.7%**
Traffic Sign Recognition	$93	$204	**54.4%**
Emergency Automatic Braking	$183	$257	28.7%
Level 3 Automation	**$2,438**	**$5,470**	**55.4%**
Self-parking Valet System	$436	$902	51.7%
Level 4 Automation	**$5,857**	**$14,196**	**58.7%**
Connectivity	**$67**	**$111**	**39.1%**

Opinion Summaries

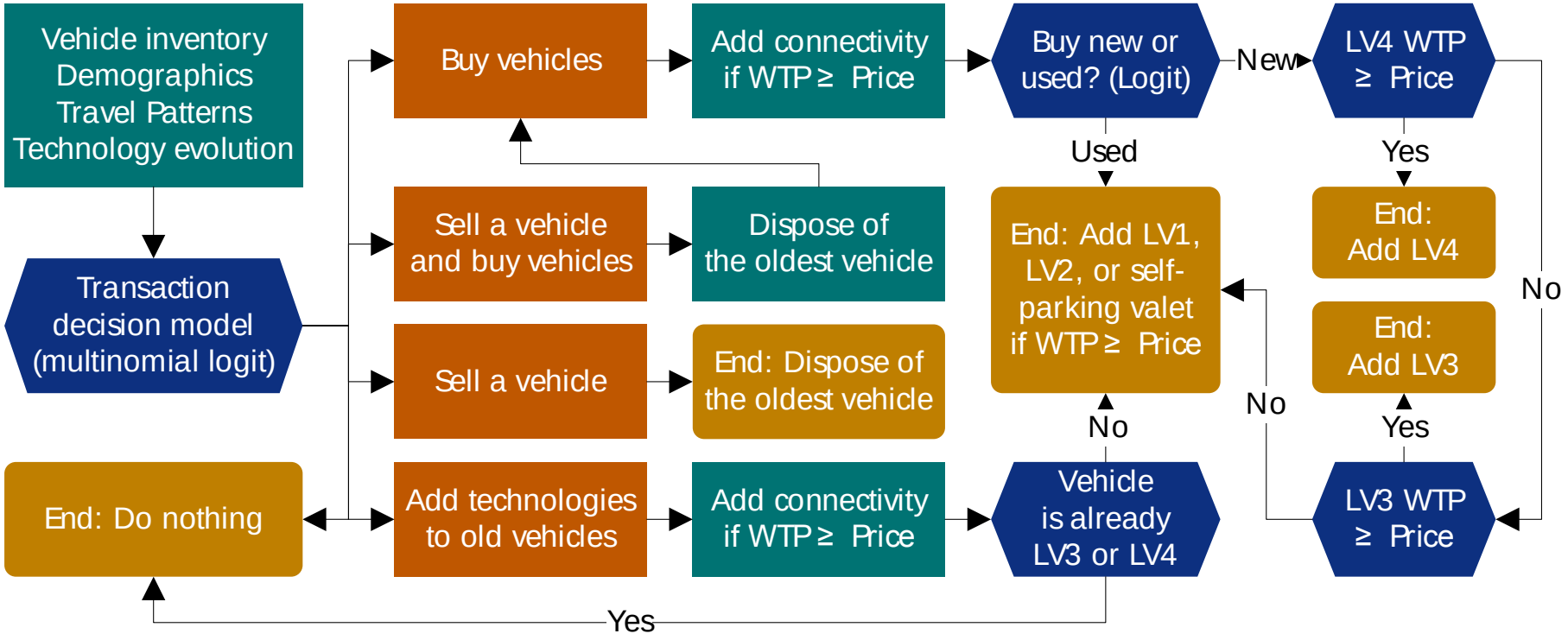
	Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
I believe that **I am a very** good driver myself.	**1.4%**	**1.2%**	**9.3%**	26.0%	**62.1%**
I think **self-driving vehicles** will drive more safely than my driving.	15.5%	**19.5%**	31.6%	21.6%	11.7%
Driving a car is something I enjoy.	3.5%	5.4%	15.4%	26.6%	49.0%
I generally wait for new technology to prove itself before purchasing.	2.2%	4.3%	14.2%	27.0%	52.2%
Self-driving vehicles (SDVs) are a useful advancement in transport.	9.2%	10.5%	26.0%	29.8%	24.6%
The idea of SDVs is not realistic.	11.2%	18.5%	26.8%	25.7%	17.8%
SDVs will be a regular mode of transport in 15 years.	8.8%	17.6%	**32.2%**	27.5%	13.8%
SDVs scare me.	11.3%	10.9%	19.4%	**31.1%**	27.4%
I have waited a long time for SDVs.	34.6%	18.4%	23.8%	13.0%	10.2%
I do not think that SDVs will function reliably.	8.1%	13.1%	29.8%	28.7%	20.3%
I am comfortable in sending my SDV out knowing that I am liable for any accident.	**42.2%**	18.3%	19.9%	**10.9%**	**8.6%**

More Opinions...

To develop Level 4 self-driving vehicles, I would trust…	Yes
Technology companies (Examples: Google)	**62.3%**
Mass-market vehicle manufacturers (Examples: Toyota)	**45.5%**
Luxury vehicle manufacturers (Examples: BMW)	49.5%

Comfort in allowing vehicle to transmit information to….	Very Uncomfortable	Slightly Uncomfortable	Neutral	Slightly Comfortable	Very Comfortable
Surrounding vehicles	16.9%	**12.9%**	**19.8%**	**26.1%**	**24.4%**
Vehicle manufacturers	16.6%	14.0%	26.5%	24.0%	18.9%
Insurance companies	**20.4%**	**16.0%**	26.5%	**19.7%**	17.3%
Transportation planners	**16.4%**	13.6%	29.2%	22.9%	18.0%
Toll operators	19.0%	14.3%	**30.9%**	20.3%	**15.6%**

Simulating Fleet Evolution



Same process for each household, every year.

Simulation Scenarios:

1. Constant WTP, **10%** annual **drop in tech. prices**
2. No zero-WTP persons, **5%** annual **drop** in tech. prices, + ESC & CV **regulations**
3. **10%** annual **rise in WTP**, **10%** annual drop in tech. prices, + **regulations**

% of US Light-duty Vehicles under Scenario 1: Constant WTP, 10% annual drop in tech. prices

Technology	2015	2020	2025	2030	2035	2040	2045
Electronic Stability Control	24.3%	25.3%	33.2%	43.3%	52.7%	58.2%	63.8%
Lane Centering	4.4	8.3	18.9	31.0	40.8	48.8	56.8
Left Turn Assist	3.8	9.9	20.1	32.4	41.8	50.3	58.1
Cross Traffic Sensor	10.9	12.9	22.6	35.1	45.1	52.6	60.3
Adaptive Headlights	10.2	9.7	18.8	30.9	41.0	49.2	58.0
Pedestrian Detection	3.7	10.6	21.7	34.5	44.1	52.6	59.8
Adaptive Cruise Control	13.3	14.9	24.1	35.2	44.7	52.2	59.8
Blind-spot Monitoring	11.7	15.0	26.1	38.5	48.2	55.1	62.1
Traffic Sign Recognition	2.0	7.7	18.0	30.0	39.8	48.9	57.0
Emergency Automatic Braking	5.6	11.8	24.4	37.1	46.9	54.6	61.6
Connectivity	0	17.7	34.8	44.7	51.1	53.0	59.5
Self-parking Valet	0	9.1	21.4	33.9	45.1	52.5	61.2
Level 3 Automation	**0**	**2.1**	**4.6**	**7.6**	**8.3**	**8.0**	**10.4%**
Level 4 Automation	**0**	**3.9**	**11.1**	**19.7**	**28.6**	**37.0**	**43.0%**

Scenario 2: No zero-WTP households, 5% annual drop in tech-prices, + regulations

Technology	2015	2020	2025	2030	2035	2040	2045
Electronic Stability Control	24.3%	88.9%	98.6%	99.8%	**100%**	**100%**	**100%**
Lane Centering	4.4	6.1	12.0	19.7	27.1	33.1	40.7
Left Turn Assist	3.8	7.9	14.2	21.3	28.1	35.1	42.5
Cross Traffic Sensor	10.9	11.7	16.8	22.9	31.9	39.1	47.4
Adaptive Headlights	10.2	7.6	11.2	18.3	26.4	32.6	39.9
Pedestrian Detection	3.7	8.3	15.0	23.2	30.7	38.3	45.5
Adaptive Cruise Control	13.3	13.2	18.4	25.7	33.2	39.2	46.5
Blind-spot Monitoring	11.7	13.8	20.3	29.7	39.6	45.7	53.5
Traffic Sign Recognition	2.0	5.4	10.5	17.7	24.9	31.4	38.1
Emergency Automatic Braking	5.6	8.6	15.6	26.1	34.7	43.4	51.2
Connectivity	0	36.5	88.2	98.4	99.7	**100**	**100**
Self-parking Valet	0	6.0	13.1	20.9	29.0	34.9	41.6
Level 3 Automation	**0**	**1.9**	**3.2**	**4.5**	**6.5**	**8.1**	**8.9%**
Level 4 Automation	**0**	**2.0**	**5.2**	**10.3**	**15.0**	**19.2**	**24.8%**

Scenario 3: 10% annual rise in WTP (all non-zero), 10% annual drop in tech-price, + regulations

Technology	2015	2020	2025	2030	2035	2040	2045
Electronic Stability Control	24.3%	89.1%	98.8%	99.9%	**100%**	**100%**	**100%**
Lane Centering	4.4	13.5	32.8	51.2	79.0	94.0	97.9
Left Turn Assist	3.8	14.1	34.1	60.9	87.3	96.4	98.4
Cross Traffic Sensor	10.9	18.2	39.3	63.6	87.0	96.6	98.5
Adaptive Headlights	10.2	13.4	32.8	55.8	81.4	95.5	98.2
Pedestrian Detection	3.7	15.3	37.6	63.7	87.9	96.8	98.7
Adaptive Cruise Control	13.3	20.3	40.4	60.2	83.2	95.4	98.2
Blind-spot Monitoring	11.7	20.5	45.5	66.4	85.9	96.3	98.6
Traffic Sign Recognition	2.0	10.9	30.0	57.9	86.4	96.4	98.4
Emergency Automatic Braking	5.6	16.6	41.5	68.4	90.0	97.3	98.9
Connectivity	0	41.3	89.4	99.0	99.9	**100.0**	**100.0**
Self-parking Valet	0	12.6	32.9	54.6	80.3	96.0	99.4
Level 3 Automation	**0**	**3.5**	**6.0**	**7.7**	**27.7**	**11.6**	**2.9%**
Level 4 Automation	**0**	**5.5**	**19.4**	**33.8**	**44.2**	**74.7**	**87.2%**

Some Conclusions

- **Blind spot monitoring** is of **greatest interest** among **Level 1 & Level 2** technologies.
- **Average WTP** to add Level 4 automation (**$5,857)** is **much higher** than that to add Level 3 **($2,438)**.
- Under **no-regulation scenario** (with 10%/yr. price reduction), around **44.7%** of U.S. privately-held **light-duty vehicles** may be **connected vehs.** in 2030, vs. **98.4% under regulations**.
- Assuming **10%** price reductions & 10% WTP increases each year, **87.2% of U.S. light-duty vehicles** are estimated to have **Level 4** Automation **by 2045**.

Task 3: Anticipate Long-Range Impacts of Automation Opportunities on Texas Traffic Safety

Relevant CV Technologies

- Forward Collision Warning (FCW)
- Intersection Movement Assist (IMA)
- Control Loss Warning (CLW)
- Blind Spot & Lane Change Warning (BSW+LCW)
- Do Not Pass Warning (DNPW)
- Lane Departure Warning (LDW)
- Cooperative Intersection Collision Avoidance Systems (CICAS)
- Red Light Violation Warning (RLV)
- Vehicle to Pedestrian & Pedalcyclist (V2P)

Relevant AV Technologies

- Electronic Stability Control (ESC)
- Adaptive Cruise Control (ACC)
- Lane Keeping Assist (LKA)
- Automatic Emergency Braking (AEB)

37 Pre-Crash Scenarios

No.	Pre-Crash Scenario	No.	Pre-Crash Scenario	Crash Type
1	Vehicle Failure	20	Vehicle(s) Making a Maneuver – Opposite Direction	**Opposite Direction**
2	Control Loss With Prior Vehicle Action	21	Vehicle(s) Not Making a Maneuver – Opposite Direction	
3	**Control Loss Without Prior Vehicle Action**	22	Following Vehicle Making a Maneuver	**Rear-End**
4	Running **Red Light**	23	**Lead Vehicle** Accelerating	
5	Running **Stop Sign**	24	Lead Vehicle Moving at Lower Constant Speed	
6	Road **Edge Departure** With Prior Vehicle Maneuver	25	Lead Vehicle Decelerating	
7	Road Edge Departure Without Prior Vehicle Maneuver	26	**Lead Vehicle Stopped**	
8	Road Edge Departure While Backing Up	27	**Left-turn Across Path** of Opp. Dirxn. at Signal. Junctions	**Crossing Paths**
9	**Animal** Crash With Prior Vehicle Maneuver	28	Vehicle Turning Right at Signalized Junctions	
10	Animal Crash Without Prior Vehicle Maneuver	29	**Left-turn Across Path** of Opp. Dirxn. at Non-Sig. Junxn.	
11	**Pedestrian** Crash With Prior Vehicle Maneuver	30	Straight **Crossing Paths** at Non-Signalized Junctions	
12	Pedestrian Crash Without Prior Vehicle Maneuver	31	Vehicle(s) **Turning** at Non-Signalized Junctions	
13	**Pedalcyclist** Crash With Prior Vehicle Maneuver	32	**Evasive Action** With Prior Vehicle Maneuver	**Run Off Road**
14	Pedalcyclist Crash Without Prior Vehicle Maneuver	33	Evasive Action Without Prior Vehicle Maneuver	
15	**Backing Up** Into Another Vehicle	34	Non-Collision Incident	**Other**
16	Vehicle(s) **Turning** – Same Direction	35	**Object Crash** With Prior Vehicle Maneuver	**Object**
17	Vehicle(s) Parking – Same Direction	36	Object Crash Without Prior Vehicle Maneuver	
18	Vehicle(s) Changing Lanes – Same Direction	37	Other	**Other**
19	Vehicle(s) Drifting – Same Direction			

Top 10 Most Common Pre-Crash Scenarios Based on 2013 GES

	Pre-crash Scenario	Freq.	Rel. Freq.
1	Lead Vehicle Stopped	975,000	**16.41%**
2	Control Loss without Prior Vehicle Action	529,000	**8.90%**
3	Vehicle(s) Turning at Non-Signalized Junctions	435,000	7.32%
4	Lead Vehicle Decelerating	428,000	7.20%
5	Vehicle(s) Changing Lanes – Same Direction	338,000	5.69%
6	Road Edge Departure without Prior Vehicle Maneuver	334,000	5.62%
7	Animal Crash without Prior Vehicle Maneuver	305,000	5.13%
8	Straight Crossing Paths at Non-Signalized Junctions	264,000	4.44%
9	Running Red Light	254,000	4.27%
10	Vehicle(s) Turning – Same Direction	222,000	3.73%

Mapping Results of Technologies & Crash Types

	Combination of Technologies	Crash Types
1	Cooperative Intersection Collision Avoidance Systems (CICAS) + Self-Driving	Crossing Paths
2	Do Not Pass Warning (DNPW) + Self-Driving	Opposite Direction
3	Forward Collision Warning (FCW) + Adaptive Cruise Control (ACC)	Rear-End
4	Lateral Drift Warning (LDW) + Lane Keeping Assist (LKA)	Run-Off-Road
5	Automatic Emergency Braking (AEB)	Run-Off-Road, Animal, Object & Other
6	Control Loss Warning (CLW) + Electronic Stability Control (ESC)	Run-Off-Road
7	Blind Spot & Lane Change Warning (BSW+LCW) + Automated Driving	Lane Change
8	Vehicle to Pedestrian & Pedalcyclist (V2P) + Automated Driving	Pedestrian & Pedalcyclist
9	Red Light Violation Warning (RLVW) + Automated Driving	Crossing Paths
10	Stop Sign Violation Warning (SSVW) + Automated Driving	Crossing Paths

Estimates of Annual U.S. Light-Duty-Vehicle Crash Benefits

No.	Technology Combinations	**Economic Savings**, 2013	Functional-**Person-Years Saved** 2013
1	Cooperative Intersection Collision Avoidance Systems (**CICAS**) + Self-Driving Vehicle (**AV**)	$53.1 B/yr	677,600 person-yrs
2	Do Not Pass Warning (**DNPW**) + Self-Driving (AV)	$16.3 B/yr	186,400 person-yrs
3	Forward Collision Warning (**FCW**) + Adaptive Cruise Control (**ACC**)	$15.6 B/yr	159,200 person-yrs
4	Lateral Drift Warning (**LDW**) + Lane Keeping Assist (**LKA**)	$9.9 B/yr	214,400 person-yrs
5	Automatic Emergency Braking (**AEB**)	$7.8 B/yr	142,400 person-yrs
6	Control Loss Warning (**CLW**) + Electronic Stability Control (**ESC**)	$4.4 B/yr	87,200 person-yrs
7	Blind Spot & Lane Change Warning (**BSW+LCW**) + Self-Driving (**AV**)	$3.1 B/yr	32,800 person-yrs
8	Vehicle to Pedestrian & Pedalcyclist (**V2P**) + Self-Driving (**AV**)	$2.7 B/yr	62,400 person-yrs
9	Red Light Violation Warning (**RLVW**) + Self-Driving (**AV**)	$2.2 B/yr	33,600 person-yrs
10	Stop Sign Violation Warning (**SSVW**) + Self-Driving (**AV**)	$0.4 B/yr	7,200 person-yrs
	Totals	***$115.6 B/yr***	***1,603,200 person-yrs***

Questions & Suggestions?

Papers can be found at caee.utexas.edu/prof/kockelman