The Effect of Vehicle Automation on Road Safety

11th Workshop on Planning, Perception and Navigation of Intelligent Vehicles

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Univ. Prof. Dr. Cristina Olaverri-Monreal

JOHANNES KEPLER UNIVERSITY LINZ

Vehicular Robots
Self-Driving Technologies in Use

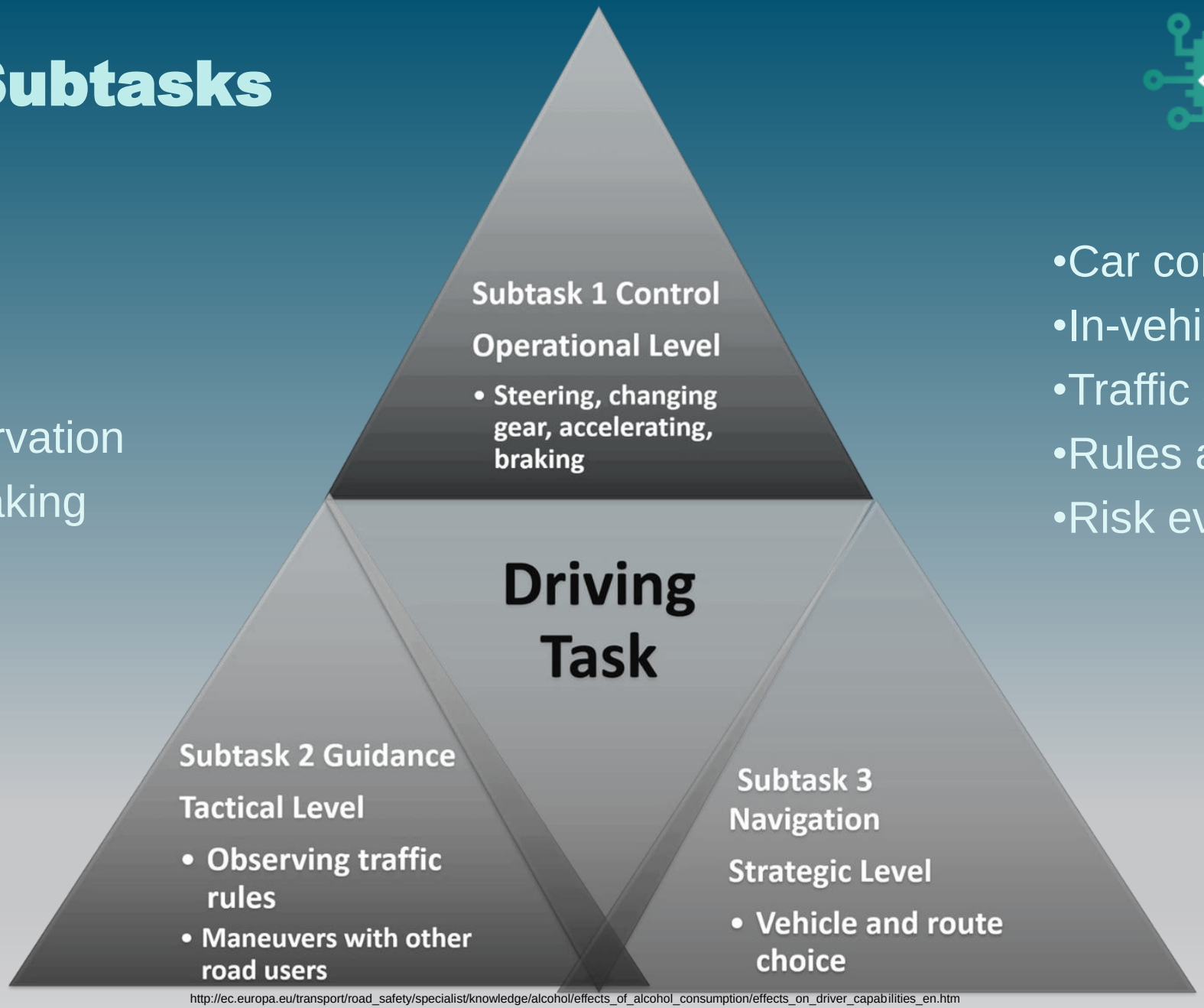
- **Drifting warning**
  alerts by lane deviation
- **Collision avoidance**
  Radar-, laser-, or camera-based
- **Blind-spot detectors**
  camera or radar-based
- **Enhanced cruise control**
  adapted distance to vehicle ahead
- **Self parking**
  camera or sonar-based

1

Driving Task Complexity
Driving Subtasks

Driving Subtasks

- Speed
- Distance
- Steering
- Traffic observation
- Decision making



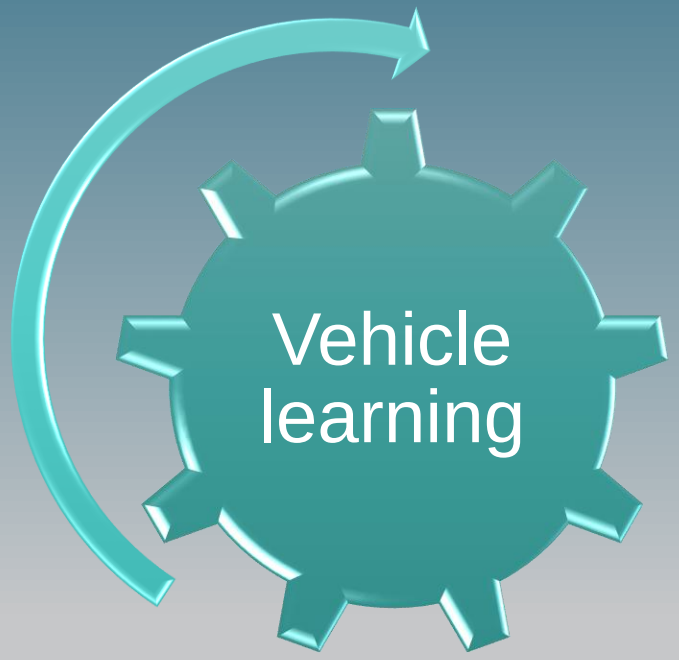
- Car controls
- In-vehicle information
- Traffic signs
- Rules awareness
- Risk evaluation

http://ec.europa.eu/transport/road_safety/specialist/knowledge/alcohol/effects_of_alcohol_consumption/effects_on_driver_capabilities_en.htm

Driving Instruction for Autonomous Vehicles

Recording data from humans sitting on vehicle

By giving examples and training the vehicle



- Speed
- Driving tasks
  - Longitudinal direction
  - Lateral direction
- All driving subtasks
  - merging into moving traffic,
  - driving in roundabouts
  - negotiating intersections
  - avoiding obstacles
- Interaction with other road users

Driving Instruction for Autonomous Vehicles

- Perception
- Expectations
- Judgement
- Memory
- Planning
- Decision making
- Risk assessment

Human Behavior

Unexpected situations

https://www.dolmanlaw.com/motorcyclists-steer-clear-aggressive-drivers/

Driving Instruction for Autonomous Vehicles

http://novacriminalattorney.com/aggressive-driving/aggressive-driving-and-the-consequences-in-virginia/

Emotional artificial intelligence through human monitoring and analysis

- gesture capture
- eye tracking
- head pose
- face detection
- body posture
- voice recognition
- vocal emotion
  - hesitations, frequency, variation, pitch, energy, speed

Driving Instruction for Autonomous Vehicles

Unclear situations + Sudden events = How drivers respond to traffic situations

Human Errors

Processing and Decision Making

https://www.fiveaa.com.au/news/SA-Police-Are-Cracking-Down-On-Running-Yellow-Lights

Information interpretation

CO-ADAS based on V2I

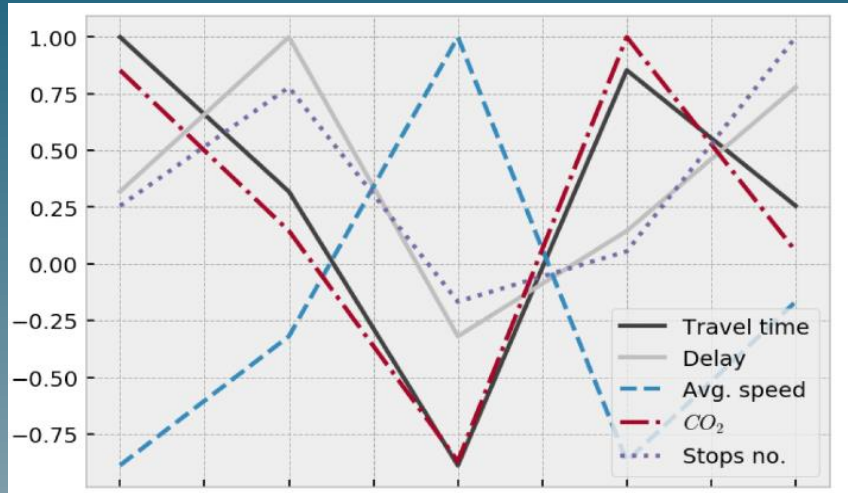
Olaverri-Monreal, C., Errea-Moreno, J., Diaz-Alvarez, A. (2018) "Implementation and Evaluation of a Traffic Light Assistance System in a Simulation Framework based on V2I Communication;, Journal of Advanced Transportation, Special Issue “Cooperative Systems for Autonomous Vehicles” (CSAV), Hindawi Publishing Corporation.

Traffic Light Assistance System

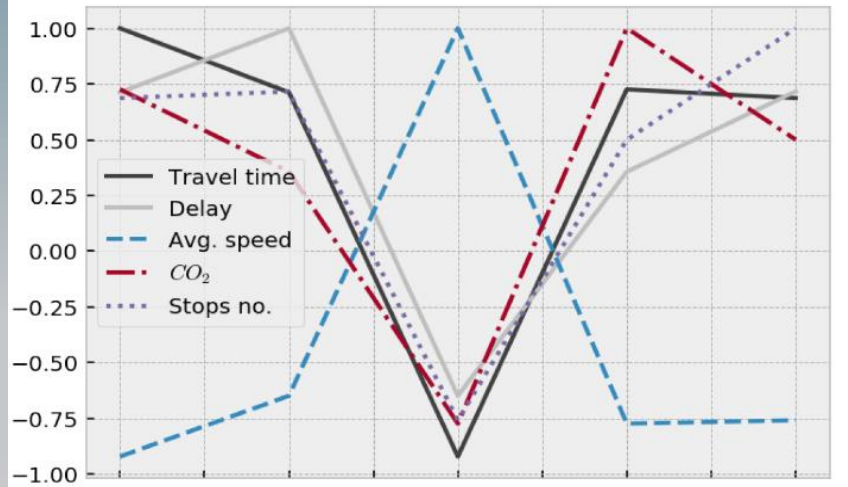
- Retrieves the traffic light timing program to calculate the optimal speed while approaching an intersection

- Shows recommended velocity based on:
  - vehicle’s acceleration
  - speed,
  - phase state of traffic light
  - remaining phase duration

CO-ADAS based on V2I



(a) Scenario 1 (with TLA)



Increase in driving efficiency after the drivers adjusted their velocity to the speed calculated by the system

- improvement of traffic flow
- reduced gas emissions
- waiting time at traffic lights

	W/o TLA		W/ TLA		T-Test ($\alpha = 0.05$)	
	Mean	*SD*	*Mean*	*SD*	*p*	*t(24)*
Travel time (s)	398	52.57	370.2	43.8	3.19	0.0038**
Delay (s)	108.59	35.82	71.38	26.64	6.82	4.69e−7***
Speed (kmh^{-1})	19.16	2.57	20.4	2.2	-2.88	0.008**
CO_2 (mg)	411.91	28.12	406.33	22.11	1.19	0.24
Stops no.	13.6	3.88	8.88	4.4	5.66	7.69e−6***

Olaverri-Monreal, C., Errea-Moreno, J., Diaz-Alvarez, A. (2018) "Implementation and Evaluation of a Traffic Light Assistance System in a Simulation Framework based on V2I Communication;, Journal of Advanced Transportation, Special Issue “Cooperative Systems for Autonomous Vehicles” (CSAV), Hindawi Publishing Corporation.

2

Interaction in a Vehicular Environment

Communication and Information Flow

Interaction in a Vehicular Environment

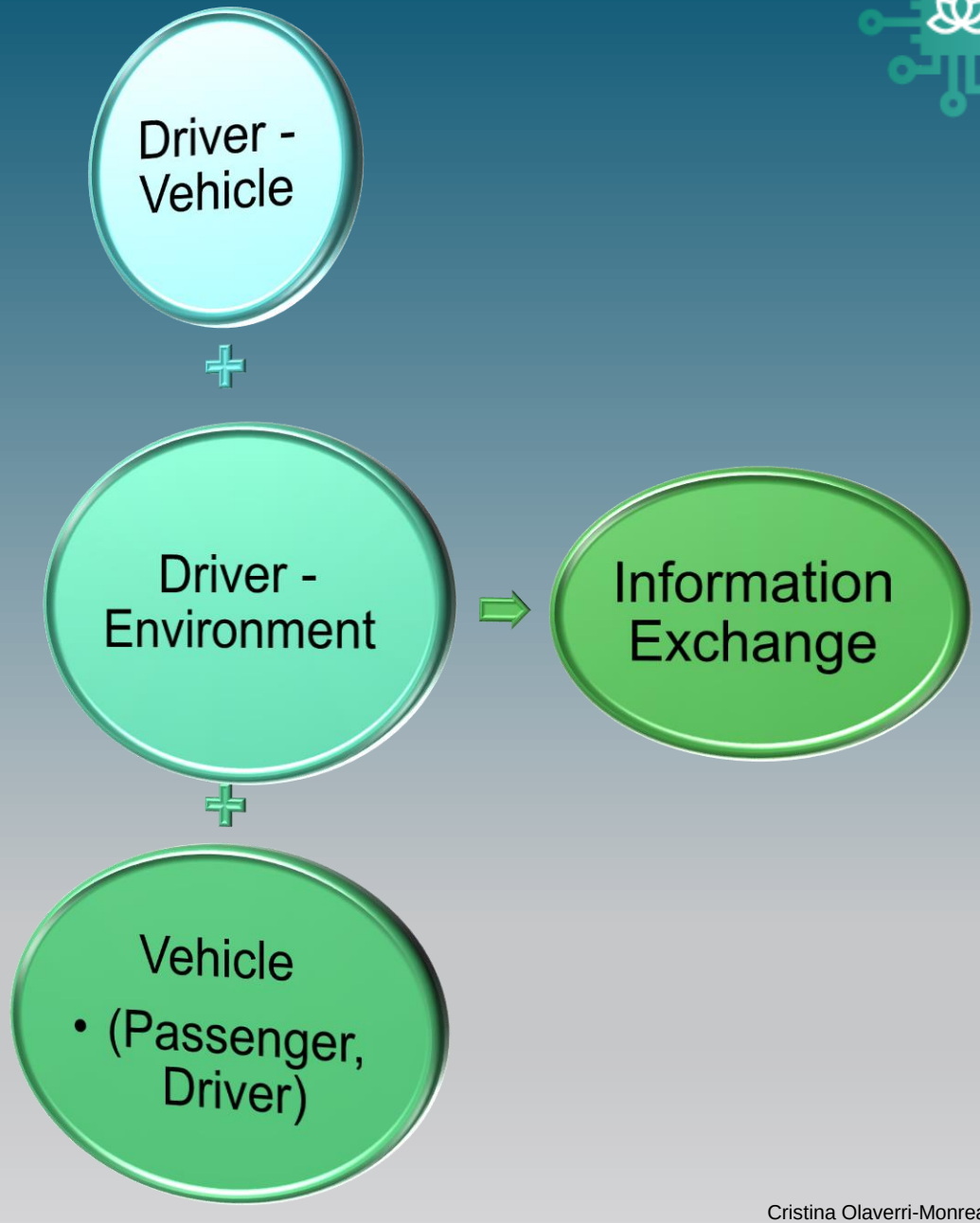
Social Traffic

Vehicular units

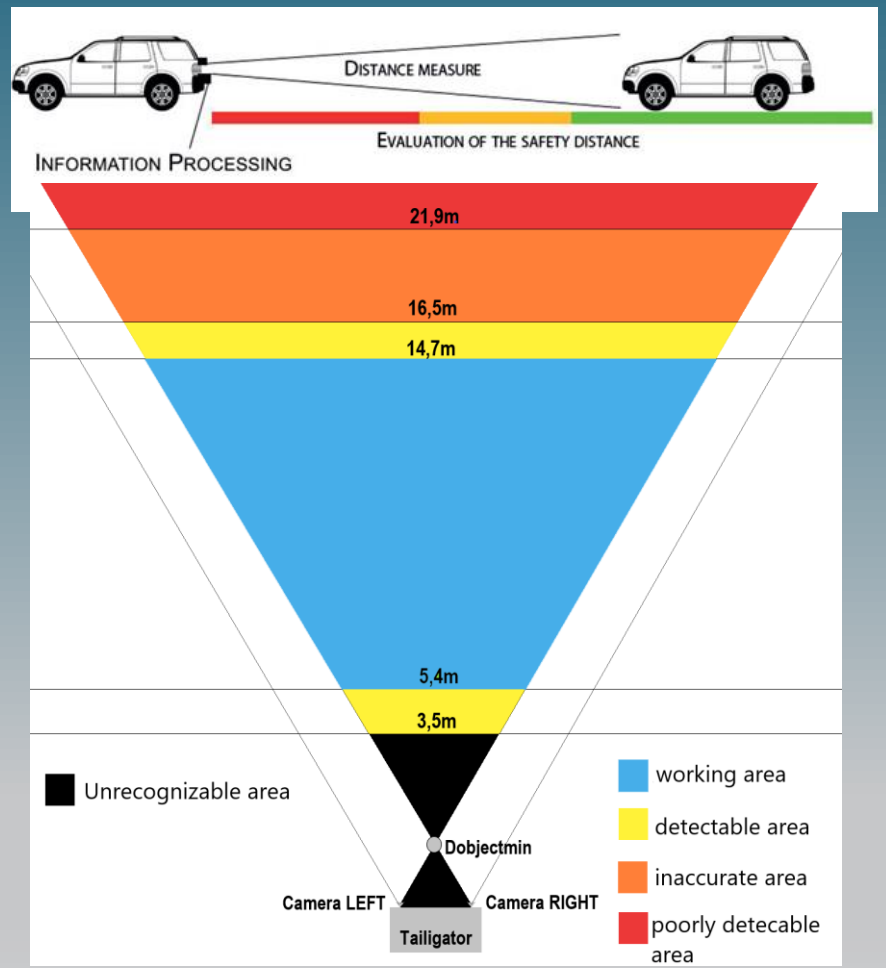
- share space
- take each other into account
- avoid a collision

Information Flow

Capacity of attentional resources and demand



Communication while Driving
Information Location



Krizek, G. C., Hausleitner, R., Böhme, L., Olaverri-Monreal, C. (2019) "Empirical Analysis of Safe Distance Calculation by the Stereoscopic Capturing and Processing of Images through the Tailigator System" in Sensors Journal

Olaverri-Monreal, C., Krizek, G.C., Michaeler, F., Lorenz,R., Pichler, M. (2018) "Collaborative Approach for a Safe Driving Distance Using Stereoscopic Image Processing", in Future Generation Computer Systems (FGCS) Journal. Special Issue on "Advanced Technologies and Systems for collaboration" https://doi.org/10.1016/j.future.2018.01.050 | Olaverri-Monreal, C., Lorenz, R., Michaeler, F., Krizek, G., Pichler, M. (2016) "Tailigator: Cooperative System for Safety Distance Observance", Proceedings 2016 International Conference on Collaboration Technologies and Systems, Orlando, Florida, USA, Nov. 2016, pp. 392 - 397.

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Communication while Driving
Information Location

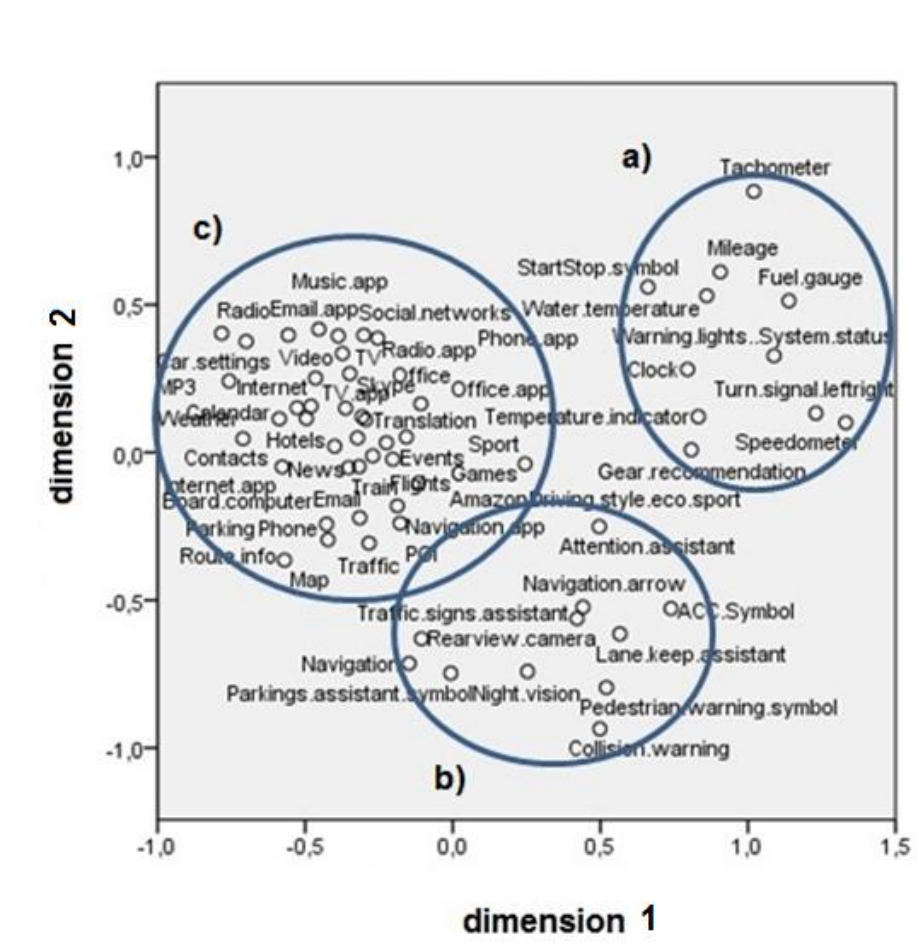
Metric	Baseline		In-Vehicle System		Leading-Vehicle System	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Velocity (km/h)	31.44	4.85	31.95	3.21	31.34	3.65
Headway (m)	9.87	1.65	12.12	1.71	10.72	1.68
TTC (s)	1.20	0.22	1.46	0.22	1.36	0.25
LP (m)	0.52	0.09	0.50	0.12	0.50	0.07
Deceleration change rate **((km/h)/s)**	0.43	0.17	0.62	0.29	0.60	0.28

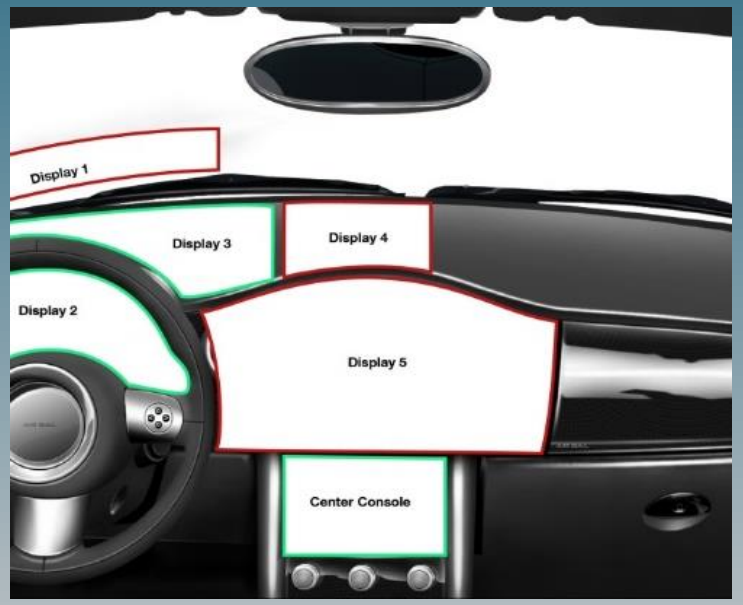
T-Test (α =0.05)

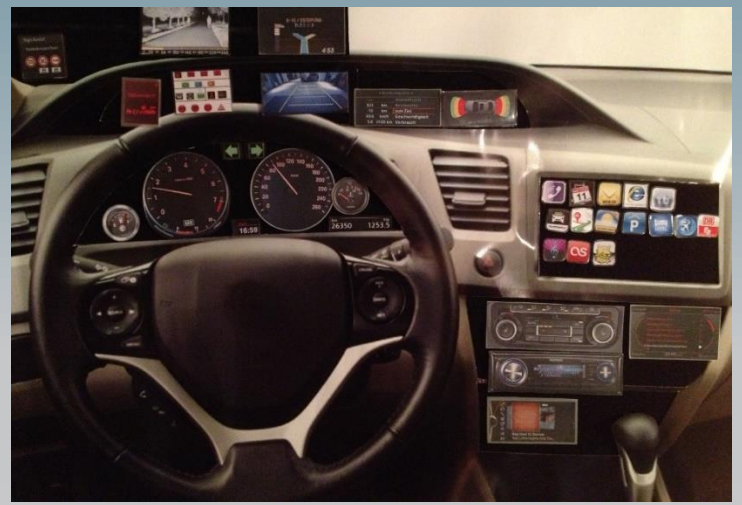
Metric	Baseline vs. In-Vehicle		Baseline vs. Leading-Vehicle System		In-Vehicle vs. Leading-Vehicle System	
	t(19)	*p*	*t(19)*	*p*	*t(19)*	*p*
Velocity (km/h)	-0.41	0.69	0.07	0.94	0.68	0.50
Headway (m)	-4.90	9.93E-05***	-2.32	0.031*	2.87	0.009**
TTC (s)	-5.33	3.81E-05***	-1.88	0.07	1.07	0.29
LP (m)	0.66	0.52	0.44	0.66	-0.19	0.84
Deceleration change ((km/h)/s) rate	-2.90	0.009**	-2.35	0.02*	0.30	0.76

Olaverri-Monreal, C., Gvozdic, M., Muthurajan, B. (2017) "Effect on Driving Performance of Two Visualization Paradigms for Rear-End Collision Avoidance", Proceedings IEEE Intelligent Transportation Systems Conference, Yokohama, Japan, October 2017, pp. 37-42.

Communication while Driving
Information Location







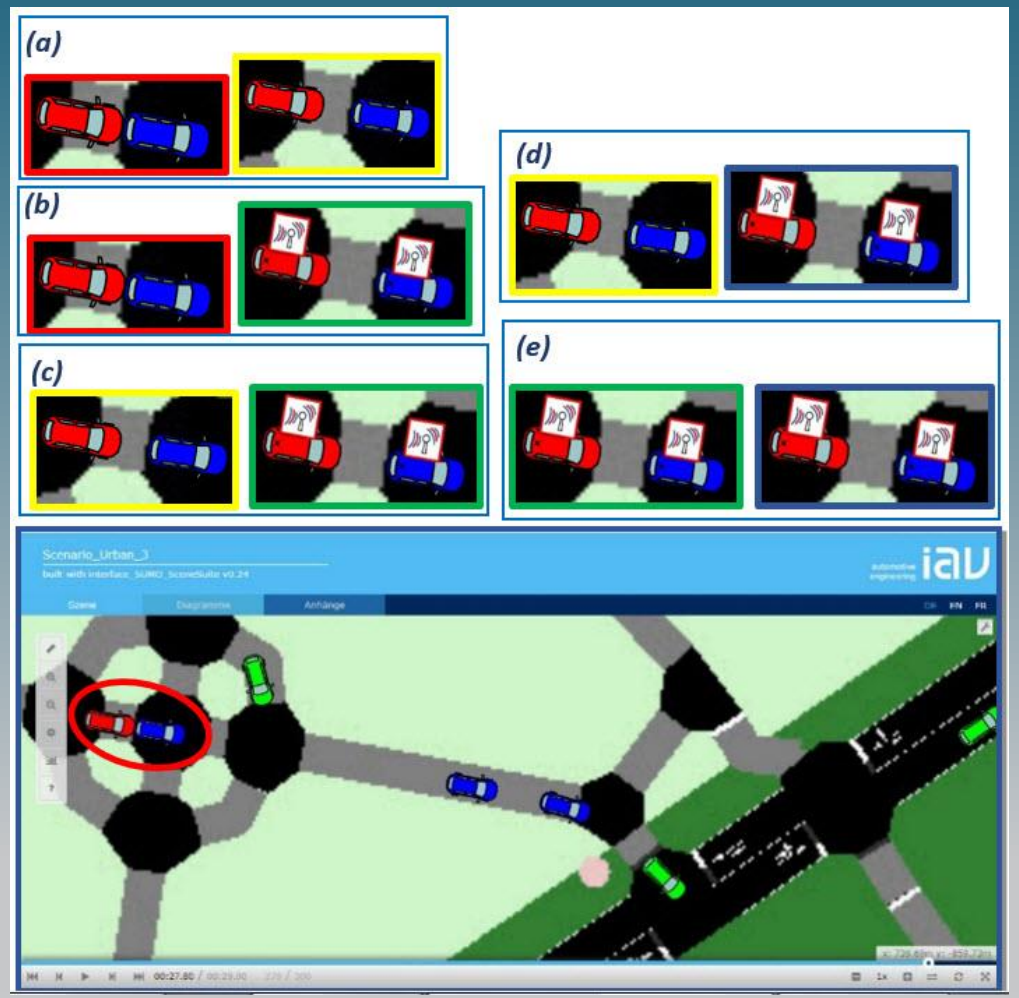
Claverri-Monreal, C., Hasan, A., Bulut, J., Körber, M., Bengler, K. (2014) “Impact of In-Vehicle Displays Location Preferences on Drivers’ Performance and Gaze”, IEEE Transactions on Intelligent Transportations Systems (IEEE T-ITS). Special Issue on “Human Factors in Intelligent Vehicles”. Volume 15 , Issue 4, pp. 1770 – 1780 | Olaverri-Monreal, C., Lehsing, C., Trübswetter, N., Schepp, C. A., Bengler, K. (2013) "In-Vehicle Displays: Driving Information Prioritization and Visualization", Proceedings IEEE Intelligent Vehicles Symposium, Gold Coast, Australia, pp. 660 – 665.

3

Connected and Automated Technologies

Driving and Interaction with other Road Users

V2X and ADAS effect on Road Safety



Technologies and applications that use data collected by sensors located in other vehicles, infrastructure or road users (V2X) to assist the driver

Key step toward a significant reduction of accidents

Validi, A., Ludwig, T., Olaverri-Monreal, C. (2017) "Analyzing the Effects of V2X and ADAS-ACC Penetration Rates on the Level of Road Safety in Intersections; Evaluating Simulation Platforms SUMO and Scene Suite", IEEE 2017 International Conference on Vehicular Electronics and Safety (ICVES 2017), Vienna, Austria, pp. 38 – 43 | Validi, A., Ludwig, T., Hussein, A., Olaverri-Monreal, C. (2018) "Examining the Impact on Road Safety of Different Penetration Rates of Vehicle-to-Vehicle Communication and Adaptive Cruise Control", IEEE Intelligent Transportation Systems Magazine

Automation

Autonomous vehicles represent an opportunity to continue working for increased road safety

- Human Intervention not required
- Congestion and air pollution reduction (platooning)
- Automation will be in charge of driving sub tasks

Olaverri-Monreal, C. (2016) "Autonomous Vehicles and Smart Mobility Related Technologies", *In Infocommunications Journal*. June 2016, Volume 8, Nr. 2, pp. 17-24.

Automation Levels

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Adapted from SAE InTERnATIOnAl'S lEVEls Of DRIVIng AuTOMATIOn fOR On-ROAD VEhIclES. Issued January 2014, http://www.sae.org/misc/pdfs/automated_driving.pdf

Take Over Request (Level 3)

- Construction zones, orange signs, cones etc.
- Railroad crossing
- Cars stopped in the road
- Pedestrians, cyclists

- Narrow paths (mountain roads)
- Lidar problems due to sunlight
- Interferences with other electronic devices

Allamehzadeh, A.,Olaverri-Monreal, C. (2016) "Automatic and Manual Driving Paradigms: Cost-Efficient Mobile Application for the Assessment of Driver Inattentiveness and Detection of Road Conditions", Proceedings IEEE Intelligent Vehicles Symposium, IV '16, Gothenburg, Sweden. June 19-22, pp 26-31.

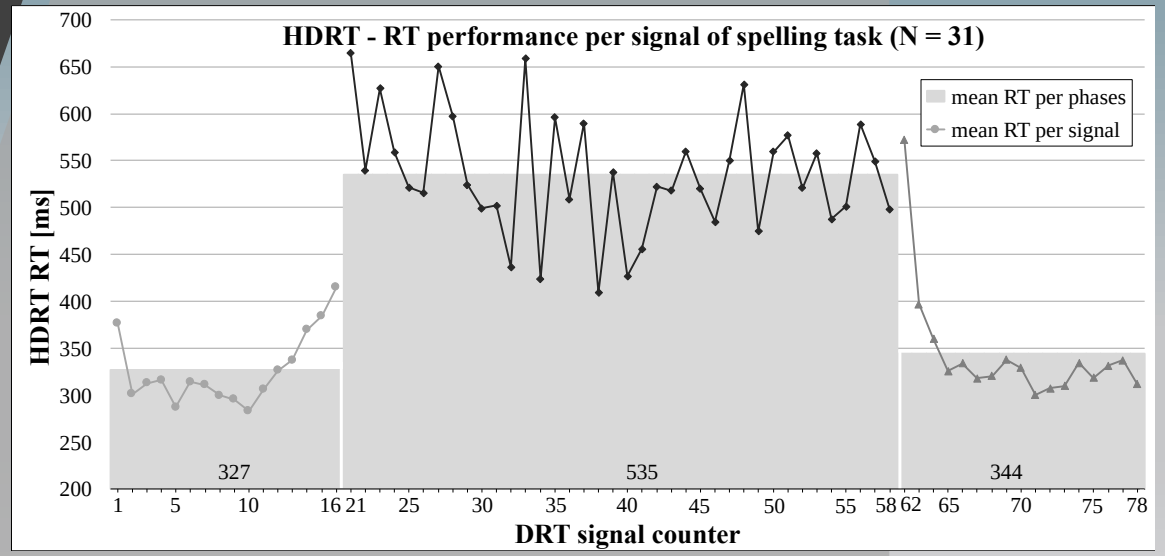
Take Over Request (Level 3)

- Hit Detection Response Task (HDRT) performance prior to and after a spelling task per signal and phases (before, during and post) spelling task (N = 31)

- It takes about 0.8 seconds for a driver to shift attention so that their eyes are on the road
- It takes even longer to assess the situation to make a helpful response.

- Drivers can be distracted up to 27 seconds after finishing a “highly distracting task and up to 15 seconds after a moderate one”

http://www.nationaltruckdrivingjobs.com/node/362



Winzer, O. M., Conti, A. S., Olaverri-Monreal, C., Bengler, K. (2017) "Modifications of driver attention post-distraction: a detection response task study ", In: Nah FH., Tan CH. (eds) HCI in Business, Government and Organizations. Interacting with Information Systems. HCIBGO 2017. Lecture Notes in Computer Science, vol 10293. Springer, Cham

Strayer, D., Cooper, J., and Siegel, L., “Up to 27 seconds of inattention after talking to your car or smartphone: Distraction rated ‘high’ for most devices while driving,“ 2015.

Hypovigilance (Level 3)

Task monotony

Driving performance decrease

Conditional Automation

Road vigilance decrement

Reduced driver workload

Allamehzadeh, A., Olaverri-Monreal, C. (2016) "Automatic and Manual Driving Paradigms: Cost-Efficient Mobile Application for the Assessment of Driver Inattentiveness and Detection of Road Conditions", Proceedings IEEE Intelligent Vehicles Symposium, IV '16, Gothenburg, Sweden. June 19-22, pp 26-31

Hypovigilance (Level 3)

Çapalar, J. and Olaverri-Monreal, C. (2017) "Hypovigilance in Limited Self-Driving Automation: Peripheral Visual Stimulus for a Balanced Level of Automation and Cognitive Workload", Proceedings IEEE Intelligent Transportation Systems Conference, Yokohama, Japan, October 2017, pp. 14-18.

- Luminescence-based unobtrusive method
- Relying on peripheral vision, which is processed subconsciously

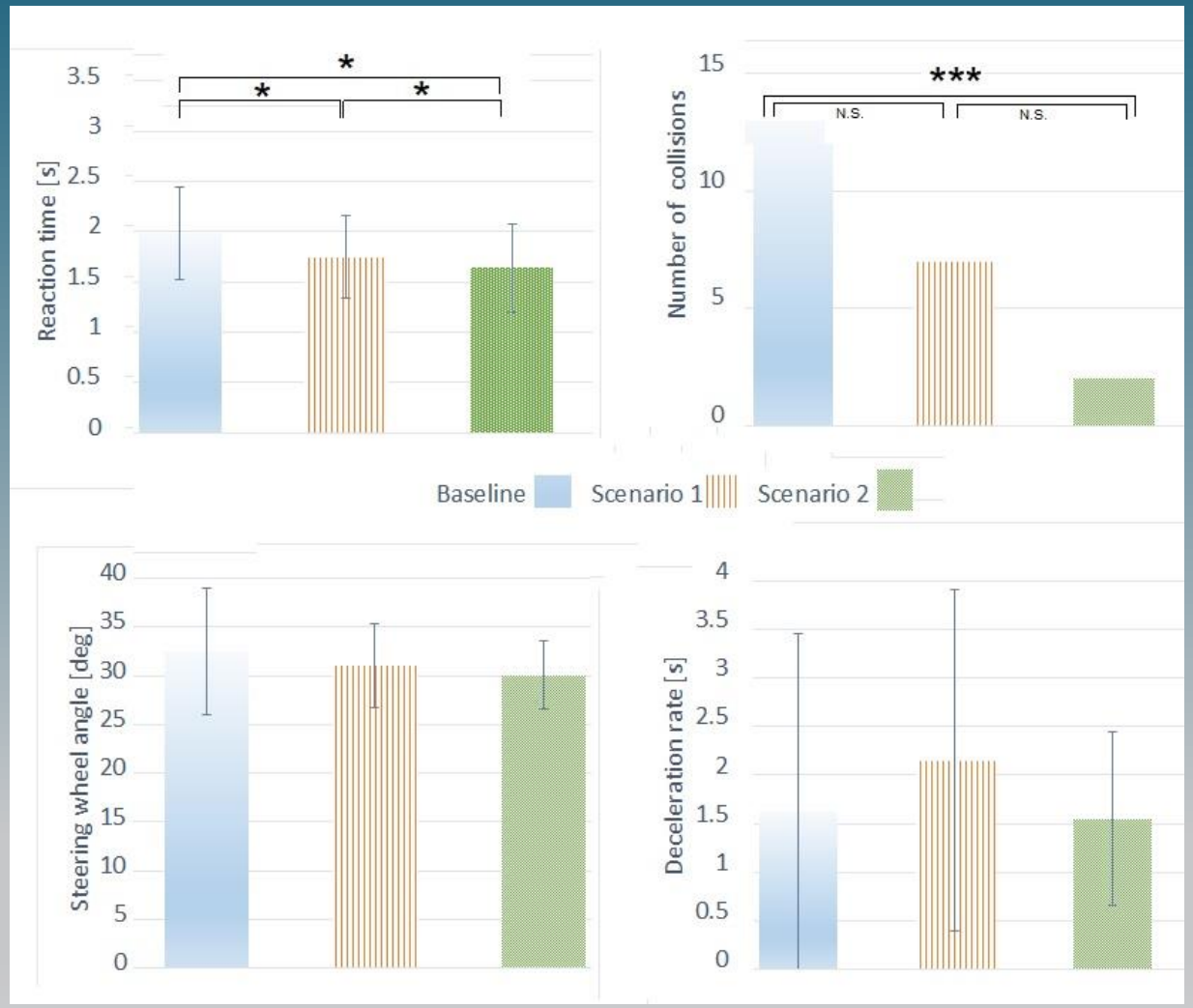
Tendency to respond faster to a TOR when peripheral vision detected stimulus

Take Over Request (Level 3)

- Baseline conditions: No IDCS system activated
- Scenario 1: TOR display activated
- Scenario 2: IDCS informs the driver through the three display panels

Olaverri-Monreal, C., Kumar, S., Díaz-Alvarez, A. "Automated Driving: Interactive Automation Control System to Enhance Situational Awareness in Conditional Automation". IEEE Intelligent Vehicles Symposium 2018.

Take Over Request (Level 3)



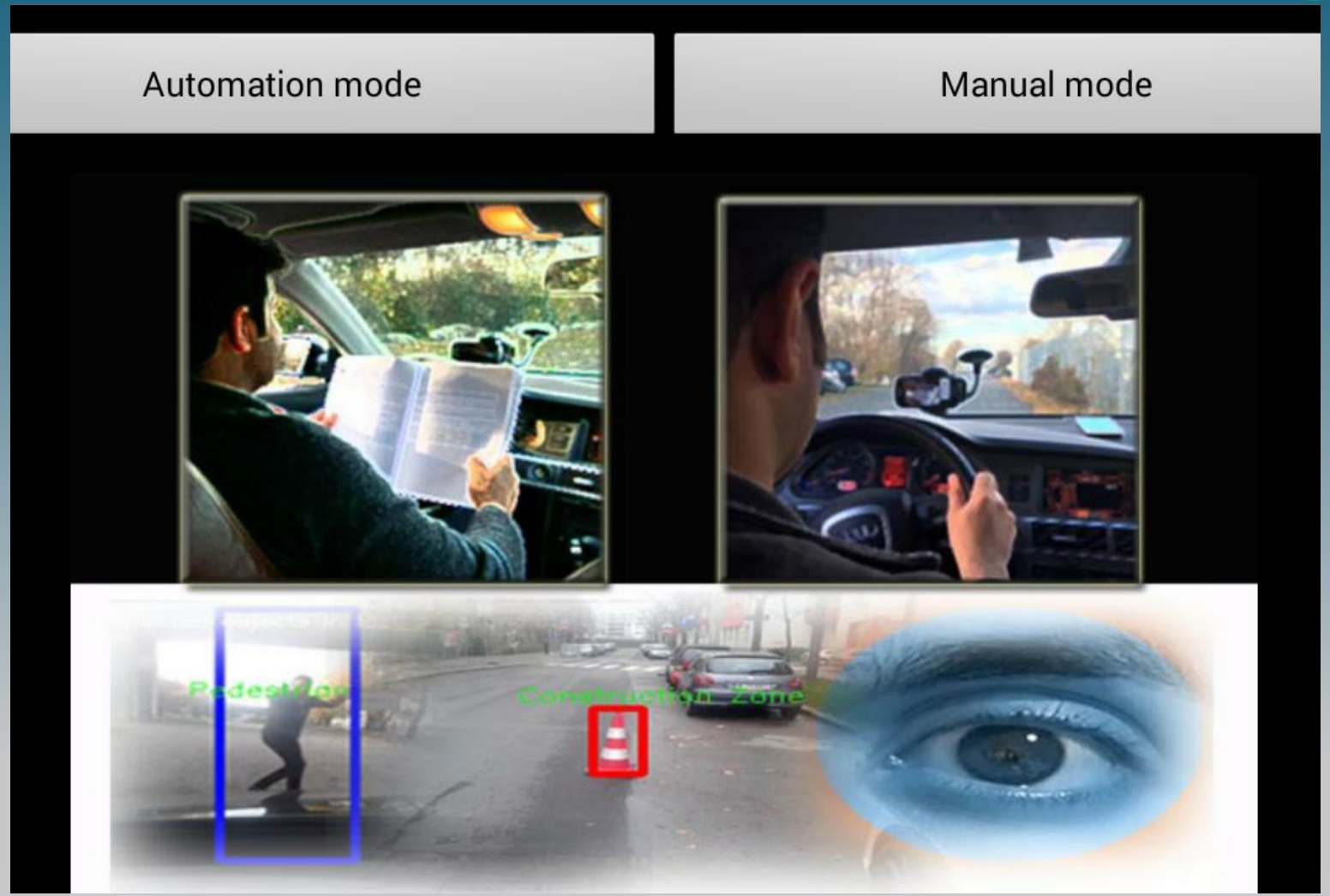
- Baseline conditions: No IDCS system activated
- Scenario 1: TOR display activated
- Scenario 2: IDCS informs the driver through the three display panels

Significant decrease in

- response time to TOR
- number of collisions

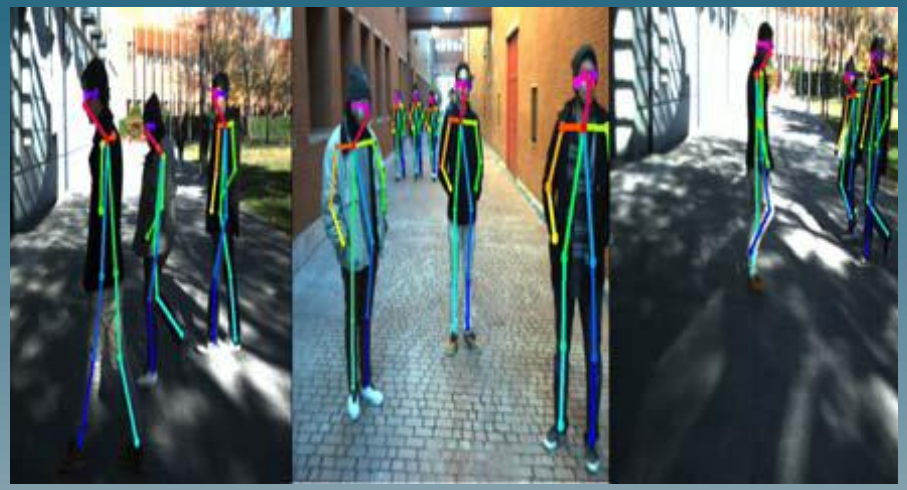
Olaverri-Monreal, C., Kumar, S., Dıaz-Alvarez, A. “Automated Driving: Interactive Automation Control System to Enhance Situational Awareness in Conditional Automation”. IEEE Intelligent Vehicles Symposium 2018.

Take Over Request (Level 3)



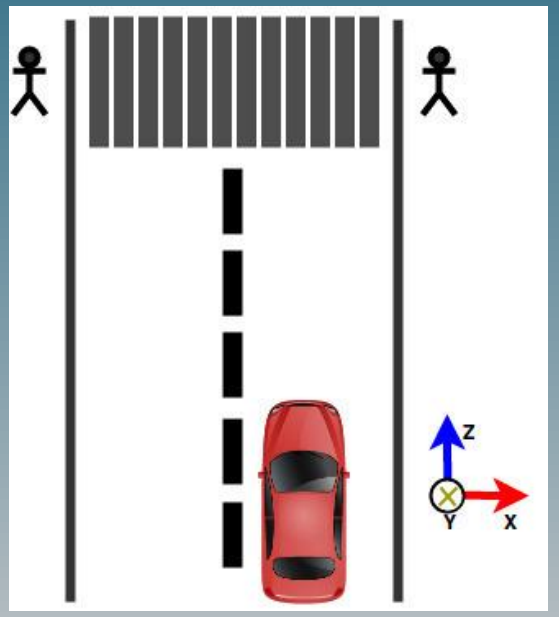
Allamehzadeh, A., Olaverri-Monreal, C. (2016) "Automatic and Manual Driving Paradigms: Cost-Efficient Mobile Application for the Assessment of Driver Inattentiveness and Detection of Road Conditions", Proceedings IEEE Intelligent Vehicles Symposium, IV '16, Gothenburg, Sweden. June 19-22, pp 26-31.

Vulnerable Road Users (VRU)



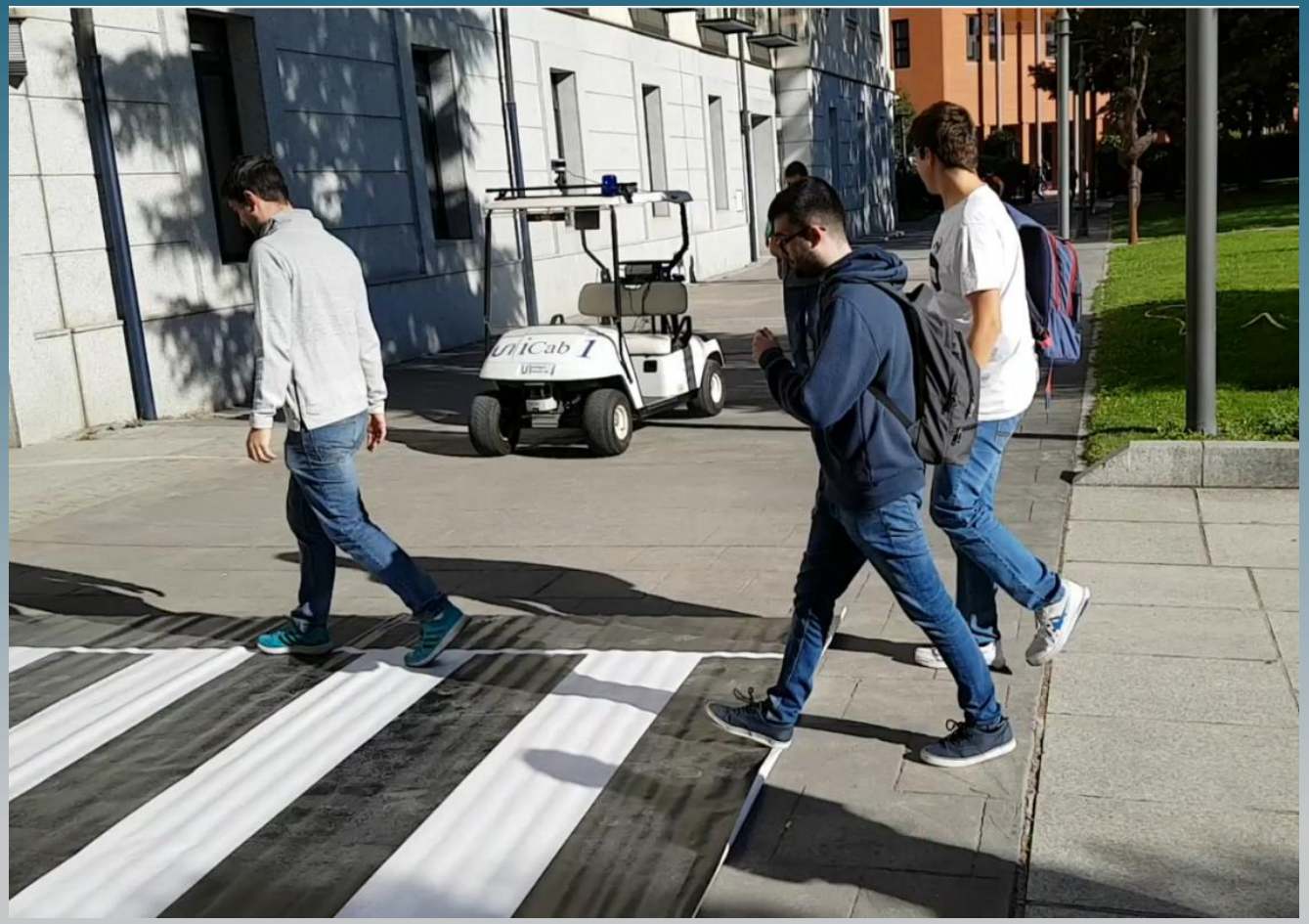
Pedestrian detection by pose estimation using Open-Pose

Pedestrians crossing from both sides



Morales-Alvarez, W., Gomez-Silva, M. j., Fernandez-Lopez, G., Garcia-Fernandez, F., Olaverri-Monreal C. (2018) "Automatic Analysis of Pedestrian's Body Language in the Interaction with Autonomous Vehicles", Proceedings IEEE Intelligent Vehicles Symposium 2018, Changshu, China.

VRUs Response to Autonomous Vehicles

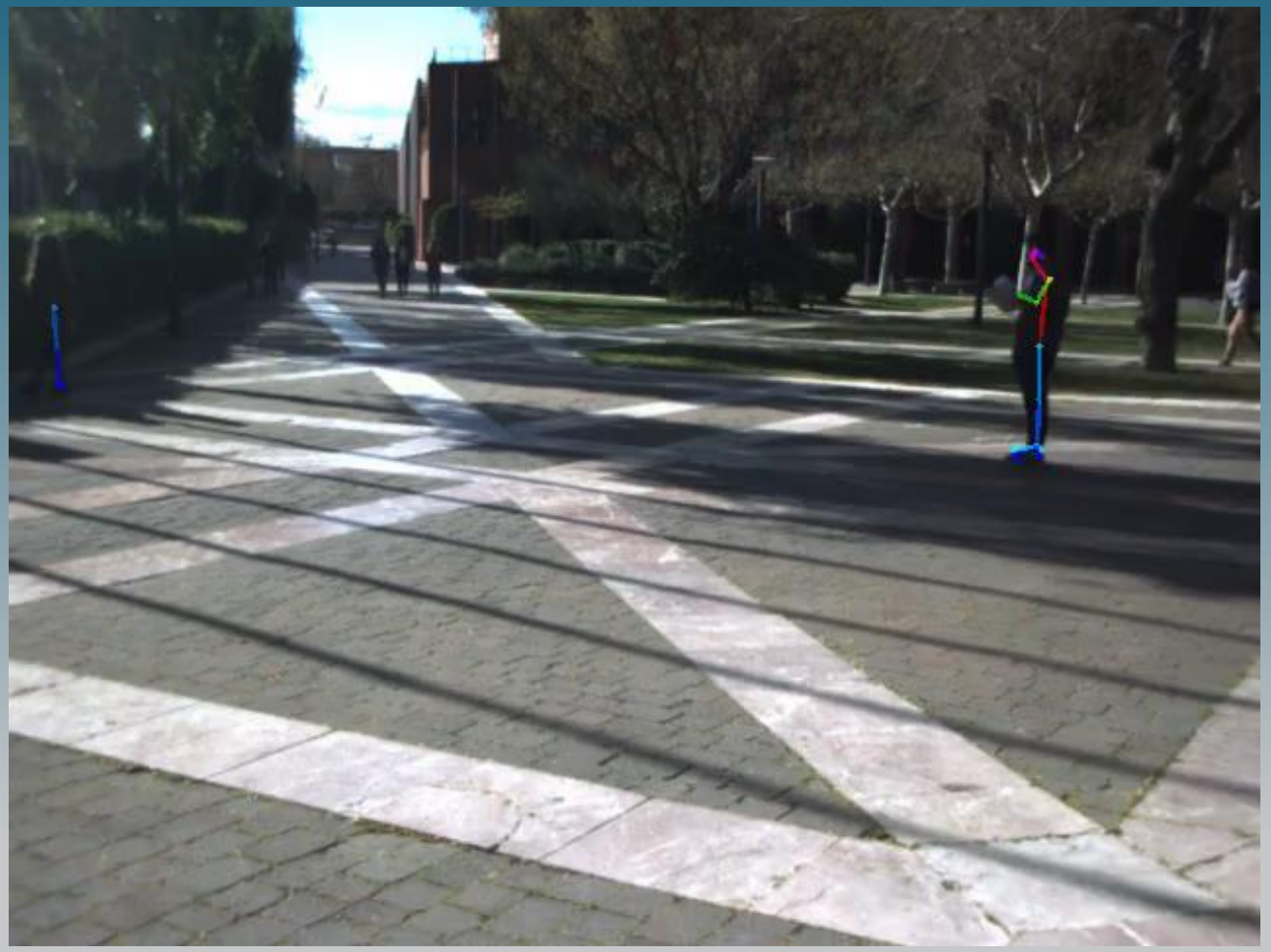


22 videos documented pedestrian behavior of 49 pedestrians in a marked crosswalk

Vehicle equipped with optical wheel encoders, a stereo-vision camera, a laser-range finder, a compass and GPS sensor

Morales Alvarez, W., de Miguel, M.A,, Garcia, F., Olaverri-Monreal, C. (2019) Analysis of VRUs response to communication signals from autonomous vehicles, IEEE ITSC 2019 Auckland, New Zealand
de Miguel, M.A., Fuchshuber, D., Hussein, A., Olaverri-Monreal, C. (2019) Perceived Pedestrian Safety: Public Interaction with Driverless Vehicles, IEEE IV 2019, Paris, France

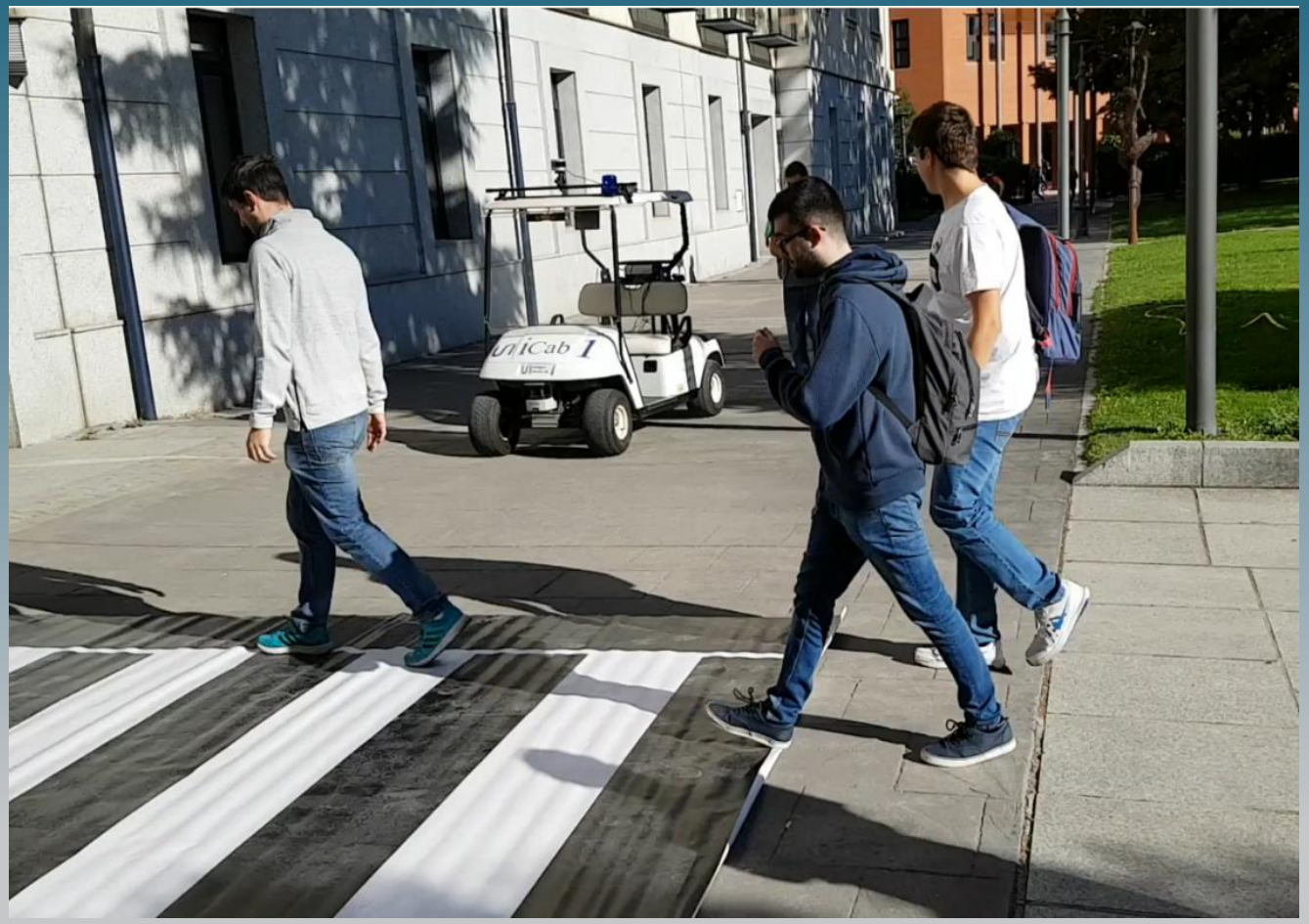
VRUs Response to Autonomous Vehicles



- Many pedestrians involved in the manipulation of their smartphones
- Vehicle attracted attention and curiosity
- Testing whether the vehicle really stopped
- Some pedestrians did not dare to approach it
- Uncertainty → hesitation before crossing

Morales Alvarez, W., de Miguel, M.A,, Garcia, F., Olaverri-Monreal, C. (2019) Analysis of VRUs response to communication signals from autonomous vehicles, IEEE ITSC 2019 Auckland, New Zealand |
de Miguel, M.A., Fuchshuber, D., Hussein, A., Olaverri-Monreal, C. (2019) Perceived Pedestrian Safety: Public Interaction with Driverless Vehicles, IEEE IV 2019, Paris, France

VRUs Response to Autonomous Vehicles

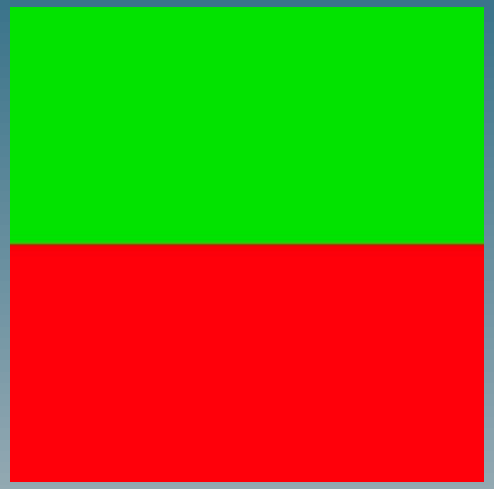


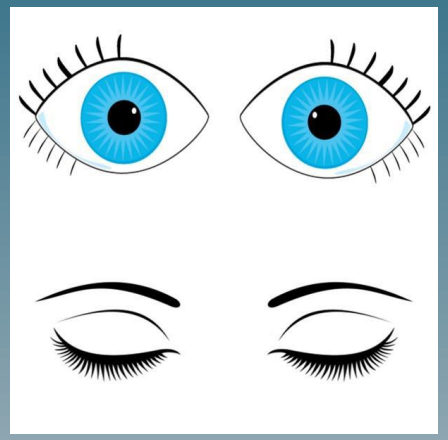
Crossing uncertainty due to:

- lack of knowledge about detection
- whether the vehicle was going to slow down
- not trusting the functioning of the sensors

Morales Alvarez, W., de Miguel, M.A,, Garcia, F., Olaverri-Monreal, C. (2019) Analysis of VRUs response to communication signals from autonomous vehicles, IEEE ITSC 2019 Auckland, New Zealand
de Miguel, M.A., Fuchshuber, D., Hussein, A., Olaverri-Monreal, C. (2019) Perceived Pedestrian Safety: Public Interaction with Driverless Vehicles, IEEE IV 2019, Paris, France

VRU Response to Communication Signals from Autonomous Vehicles





70% of people preferred the eyes image compared with 30% that selected the color coded.

No statistically significant differences (2(1, N = 21) = 7.54, p = .006).

Morales Alvarez, W., de Miguel, M.A,, Garcia, F., Olaverri-Monreal, C. (2019) Analysis of VRUs response to communication signals from autonomous vehicles, IEEE ITSC 2019 Auckland, New Zealand
de Miguel, M.A., Fuchshuber, D., Hussein, A., Olaverri-Monreal, C. (2019) Perceived Pedestrian Safety: Public Interaction with Driverless Vehicles, IEEE IV 2019, Paris, France

VRU Response to Communication Signals from Vehicular Robots

Pedestrian distance to the vehicle as well as TTC while crossing depending on the kind of display showed

Metric	Baseline		Red/green color		Opened/closed eyes	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Distance(m)	6.14	3.56	7.38	3.48	6.88	2.76
TTC (s)	7.31	4.64	4.9	6.23	5.10	7.91
T-Test (α =0.05)						
Metric	Baseline vs. Red/-green color		Baseline vs. Opened/Closed eyes		Red/green color vs. Opened/Closed eyes	
	t(92)	*p*	*t(92)*	*p*	*t(92)*	*p*
Distance(m)	1.27	0.20	0.85	0.39	0.67	0.55
TTC (s)	1.51	0.13	1.07	0.28	0.90	0.12

Effect of eye contact on interaction with the AV

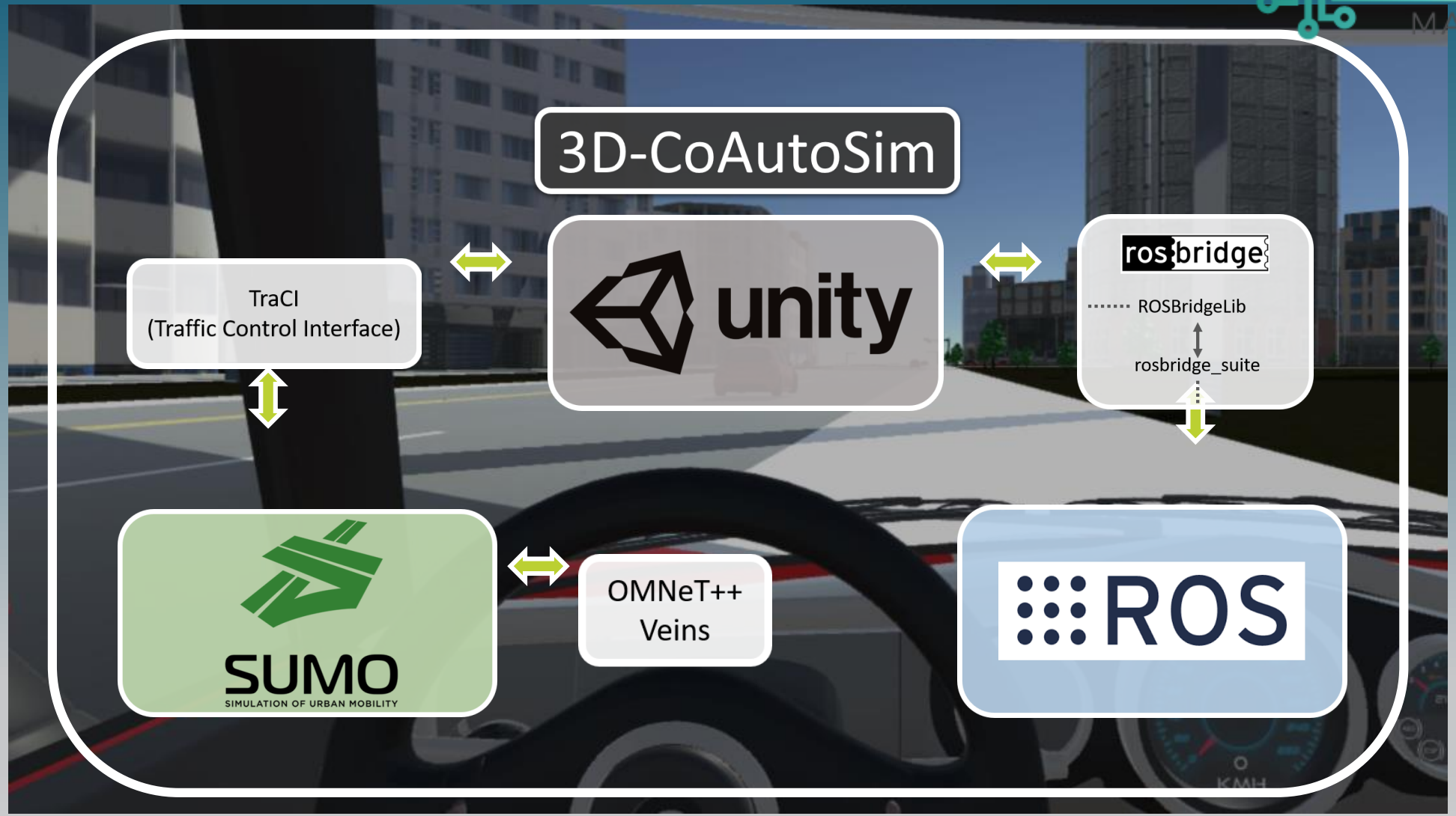
T-test (α=0.05)						
Metric	Without eye contact		Eye contact		T-Test($\alpha = 0.05$)	
	Mean	*SD*	*Mean*	*SD*	*t(133)*	*p*
Distance (m)	6.93	3.28	7.81	3.56	1.41	0.1599
TTC (m/s)	5.87	6.71	8.93	12.22	1.37	0.1726

Distributions of walked or stopped variables with red or closed eyes not statistically significant

The kind of display did not affect TTC neither the distance at which pedestrians crossed in front of the AV

Visual communication cues for are not necessarily required for a shared space in which informal traffic rules apply

Morales-Alvarez, W., Gomez-Silva, M. J., Fernandez-Lopez, G., Garcia-Fernandez, F., Olaverri-Monreal, C. (2018) "Automatic Analysis of Pedestrian's Body Language in the Interaction with Autonomous Vehicles", Proceedings IEEE Intelligent Vehicles Symposium 2018, Changshu, China.
Morales Alvarez, W., de Miguel, M.A,, Garcia, F., Olaverri-Monreal, C. (2019) Analysis of VRUs response to communication signals from autonomous vehicles, IEEE ITSC 2019 Auckland, New Zealand



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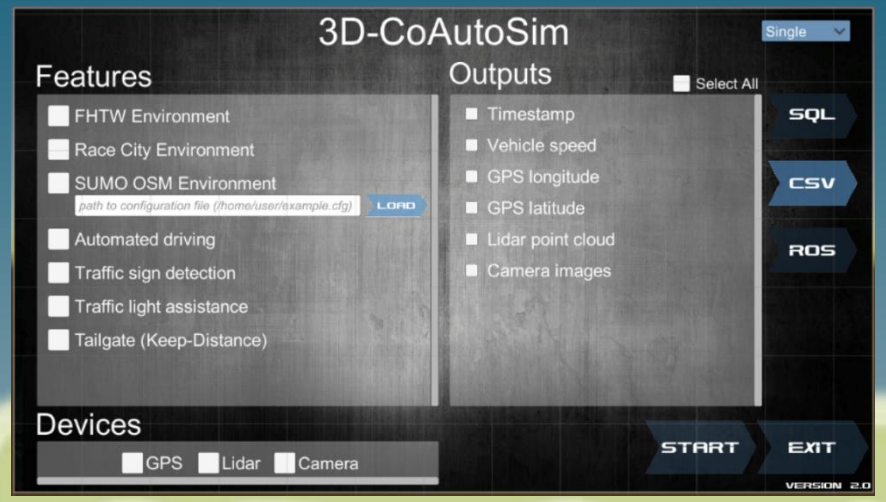


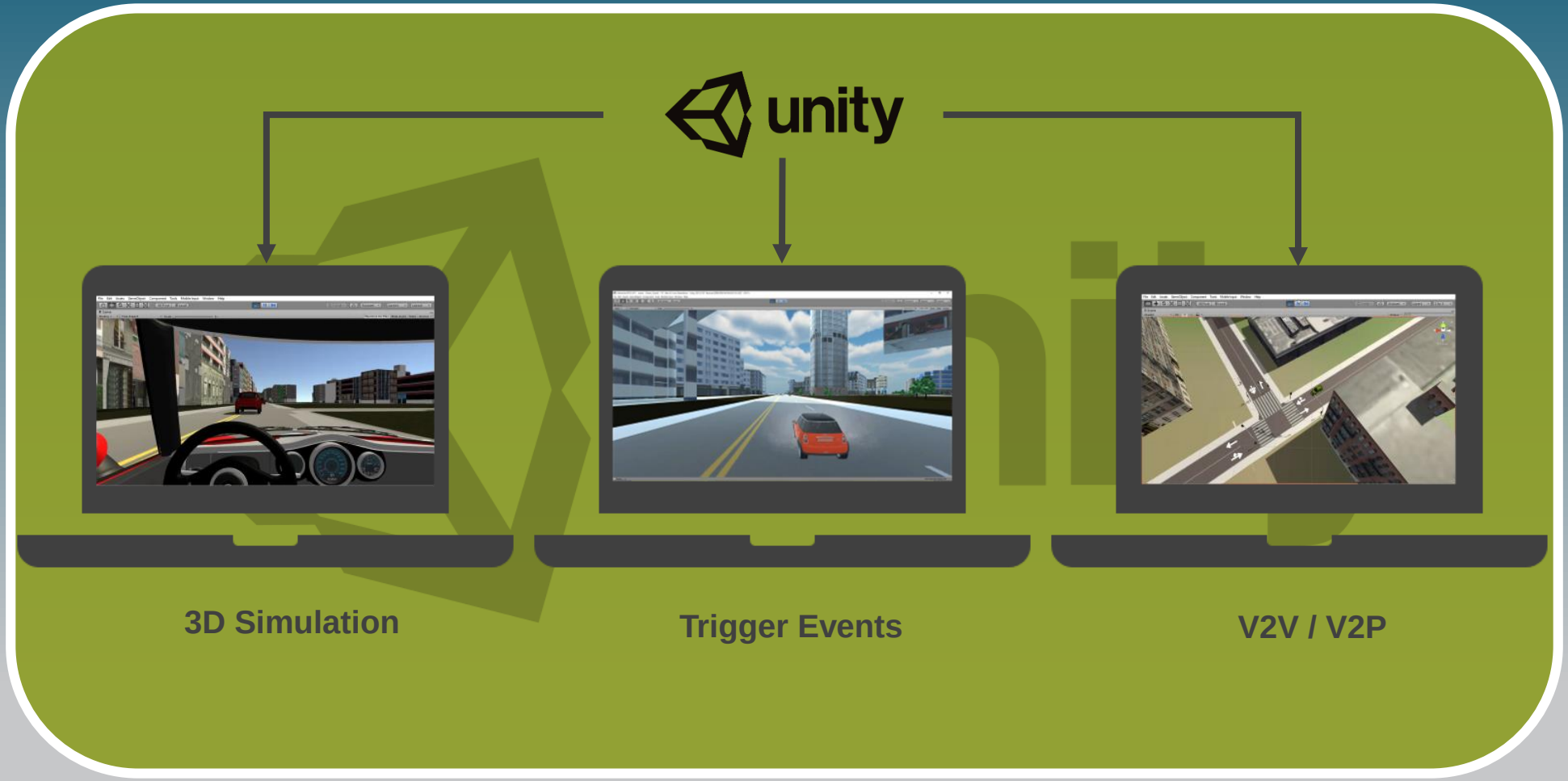
ClubSport Pedale V3

CSL Elite Wheel Base

ClubSport steering wheel Universal Hub

ClubSport steer wheel Classic

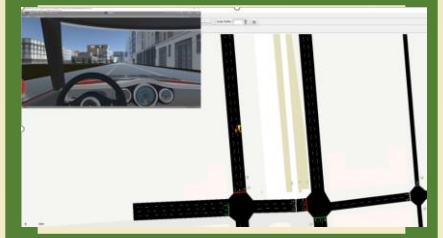
ClubSport Shifter SQ V 1.5


unity
3D Simulation
Trigger Events
V2V / V2P

SUMO
SIMULATION OF URBAN MOBILITY

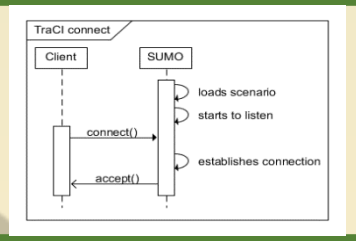
V2X Traffic Simulation

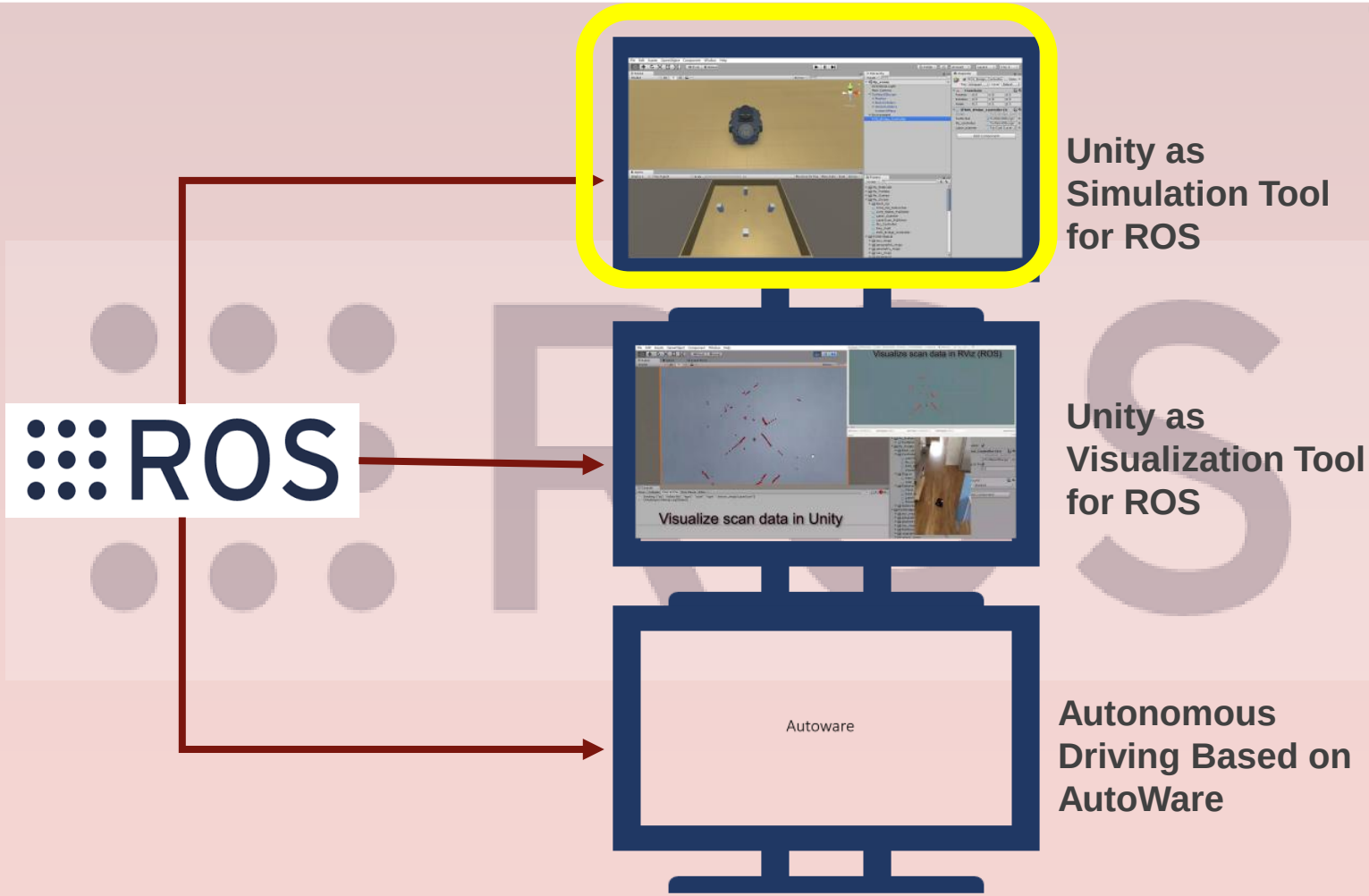
Visualization of Sumo with Unity



Traffic Simulation + V2X

Unity interacts with SUMO via TraCi





Unity as Simulation Tool for ROS

Unity as Visualization Tool for ROS

Autonomous Driving Based on AutoWare

Thank You!

Univ.-Prof. Dr. Cristina Olaverri-Monreal
cristina.olaverri-monreal@jku.at