RTCM Paper 091-2018-SC134-010

"High Integrity GNSS location and navigation services for Connected Vehicles and Autonomous Vehicles"

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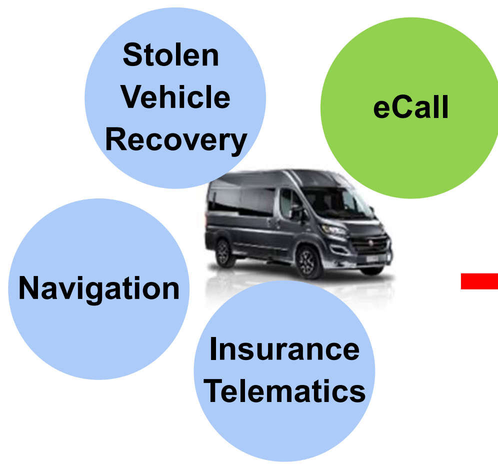
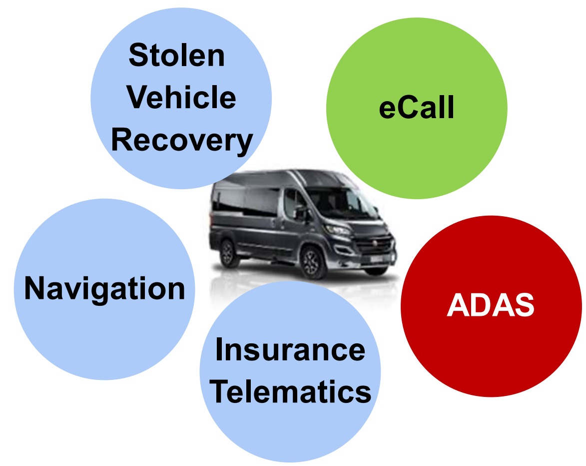
GNSS role in autonomous vehicles

Autonomous driving technology requires position and navigation

HIGH ACCURACY

HIGH INTEGRITY





NO individual technology can currently meet these requirements anywhere, anytime and under any condition, requirements.

sensor fusion is considered as the go-to-solution for the development of fully autonomous driving technology.

GNSS is an element of a sensor fusion based navigation system that includes LiDARs/Radars, Inertial sensors and cameras.

USE CASES

eCal
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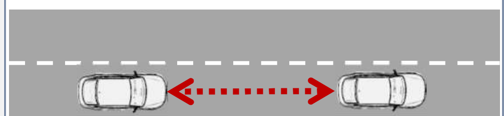
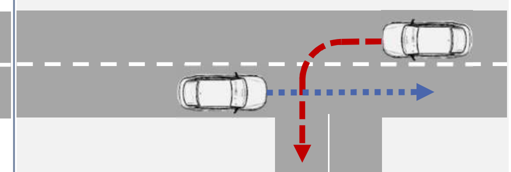
ISA



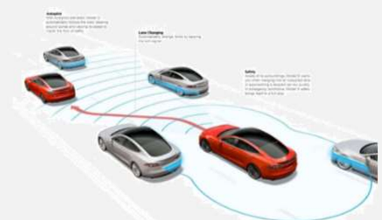
(Intelligent Speed Adaptation)

Cooperative Collision Avoidance

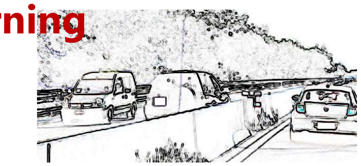


High Density Platooning

Automated Overtake



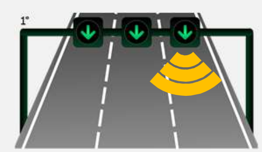
Cooperative Awareness &Traffic Hazards Warning



Road Hazard Warning

Vulnerable Road Users Discovery

Dynamic Emergency lane management



Use Cases: eCall

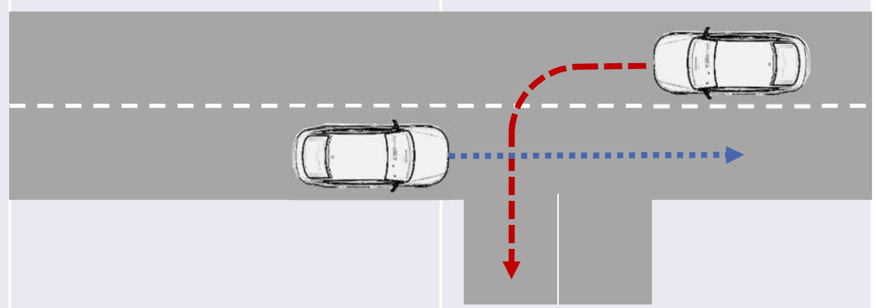
Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
eCall Pan-European eCall generates an automatic 112 emergency call and transmits an MSD containing the absolute position of the damaged vehicle At the PSAP, map-matching is performed to determine the physical location of the accident to which the emergency vehicles are dispatched All roads, all environments	• Probability of correct detection of the road (> 99%) • Probability of correct detection of the carriageway (> 95%) • Accuracy (95th percentile) of the longitudinal position along the road (< 50 m)	• position at the triggering moment (mandatory) • vehicle direction, or heading (mandatory) • previous 3 positions, with no time tag for privacy reasons (optional) • confidence bit (optional) • From other sources: ○ map of the road network	• Map-matching (at the carriageway level) performed off-line at the PSAP 

Use Cases: Road User Charging

Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
Road User Charging • Area-based charging Paying to drive in a particular area irrespective of the distance driven, • Distance-based charging – paying an amount that is proportional to the distance driven. • Time-based charging – paying an amount that is proportional to the time spent in a particular area. not deep urban	E2E overcharging rate (for a travelled segment) (< 10-6) E2E undercharging rate (for a travelled segment) (< 3%)	– position, time (mandatory) – velocity (optional) – integrity quantities (optional) External sources: – location of charging points, – map of road network	• Geofencing on a geo-object built around the charging point • Map-matching (optional)

Use Cases: COOPERATIVE COLLISION AVOIDANCE

Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
Cooperative Collision Avoidance Risk situations: • vs. another vehicle, • vs. other dynamic obstacles, • vs. static obstacles e.g.: • Pre-crash sensing warning • Across traffic turn collision risk • Merging traffic turn collision risk • Intersection collision risk • Forward collision risk • Hazardous location notification	• Trajectory handshake latency (<100 msec) • Trajectory Handshake loss rate (< 10-5) • Status message latency (<10 msec) • Status message loss rate (< 10-3) • Position accuracy (< 30 cm) • Status message rate (> 10 Hz)	• Vehicles and Road users ○ position, ○ speed, ○ direction (heading) • static obstacles ○ position,	• extrapolation of the trajectories and their uncertainties from the current pose and estimation of the risk of collision



Use Cases: Automated Overtake

Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
Automated Overtake It requires cooperation among vehicles on multiple lanes to create the gap in time to avoid collision with an oncoming vehicle	• Trajectory handshake latency (<100 msec) • Trajectory Handshake loss rate (< 10-5) • Status message latency (<10 msec) • Status message loss rate (< 10-3) • Position accuracy (< 30 cm)	• Vehicles and Road users ○ position, ○ speed, ○ direction (heading) ○ yaw rate • static obstacles ○ position,	• extrapolation of the trajectories and their uncertainties from the current pose and estimation of the risk of collision

Use Cases: Road Hazard Warning

Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
Road Hazard Warning • Emergency Electronic Break Light • Safety function out of normal condition warning • Roadwork warning • Decentralized floating car data	• Status message latency (<10 msec) • Status message rate (> 100 Hz) • Status message loss rate (< 10-6) • Position accuracy (< 30 cm)	• Vehicles ○ position, ○ speed, ○ direction (heading) ○ yaw rate	

Use Cases: Co-operative Awareness

Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
Co-operative Awareness • Emergency vehicle warning • Slow vehicle warning • Motorcycle warning	• Status message latency (<100 msec) • Status message rate (emergency vehicle > 10 Hz) (slow vehicle and motorcycle > 2 Hz) • Status message loss rate (< 10-6) • Position accuracy • (< 30 cm)	• Vehicles ○ position, ○ speed, ○ direction (heading) ○ yaw rate	

Use Cases: Traffic hazards warning

Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
Traffic hazards warning • Wrong way driving warning • Stationary vehicle warning • Traffic condition warning • Signal violation warning	• Status message latency (<100 msec) • Status message rate (> 10 Hz) • Status message loss rate (< 10-6) • Position accuracy (< 30 cm)	• Vehicles ○ position, ○ speed, ○ direction (heading) ○ yaw rate	

Use Cases: Dynamic vehicle warning

Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
Dynamic vehicle warning • Overtaking vehicle warning • Lane change assistance • Co-operative merging assistance	• Status message latency (<100 msec) • Status message rate (> 10 Hz) • Status message loss rate (< 10-6) • Position accuracy • (< 30 cm)	• Vehicles ○ position, ○ speed, ○ direction (heading) ○ yaw rate	

Use Cases: High Density Platooning

Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing

High Density Platooning
 	
Vehicles will be driving very close to each other.
	• Status message latency (<10 msec)
	• Status message loss rate (< 10^{-6})
	• Position accuracy
	• (< 30 cm)
		• Vehicles and Road users
		  ○ position,
		  ○ speed,
		  ○ acceleration
		  ○ direction (heading)
		  ○ yaw rate
		
		• static obstacles
		  ○ position,
			• extrapolation of the trajectories and their uncertainties from the current pose and estimation of the risk of collision

Use Cases: Vulnerable Road User Discovery

Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
Vulnerable Road User Discovery VRUs equipped with a GNSS receiver announce their presence by broadcasting their status	• Missed Discovery rate (< 10-6) • False Discovery rate (<10-4) • Status message latency (<10 msec) • Status message loss rate (< 10-6) • Position accuracy (< 10 cm)	• Vehicles and Road users ○ position, ○ speed, ○ direction (heading) • static obstacles ○ position,	• extrapolation of the trajectories and their uncertainties from the current pose and estimation of the risk of collision

Use Cases: ISA - Intelligent Speed Adaptation

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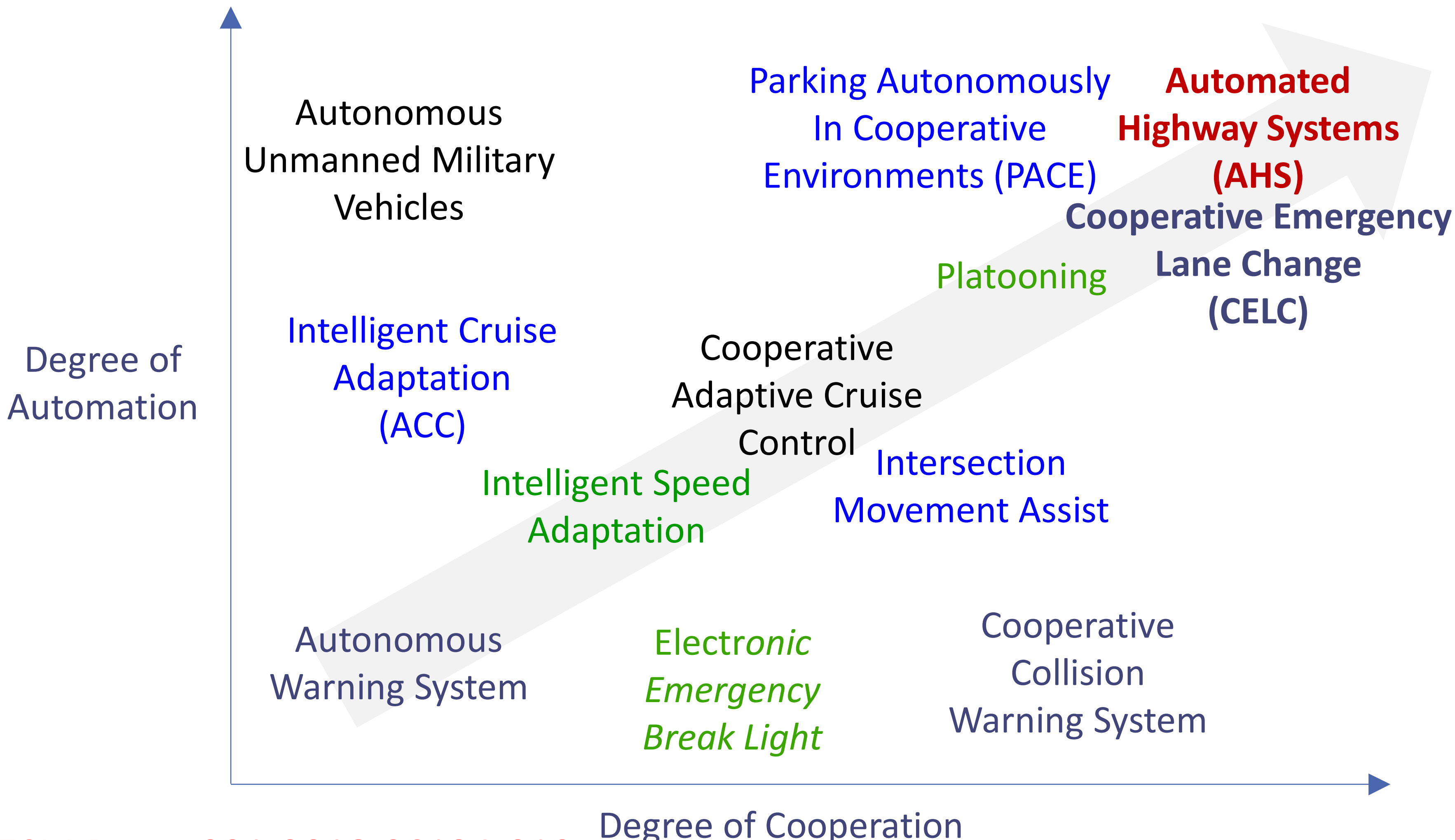
Use case & operational scenario	E2E performance indicators (indicative targets)	Information needed by the application	Application data processing
ISA - Intelligent Speed Adaptation The driving speed is monitored and compared with the prevailing speed limit on the road (or the lane) the vehicle is on	• Percentage of speed transitions correctly detected (< 99%) • Percentage of speed transitions falsely detected (<0.1%) • Percentage of speed transitions not detected (< 1%) within a defined duration or distance from a transition reference point (10 m)	• Vehicle ○ position, ○ speed, ○ time • From other sources: ○ Digital map with speed limit information ○ traffic ○ weather information	• Real-time longitudinal map-matching • Map-matching on-lane • Driving speed extraction from GNSS data or the vehicle's speedometer • Time synchronization (for variable speed limits)

Use Cases



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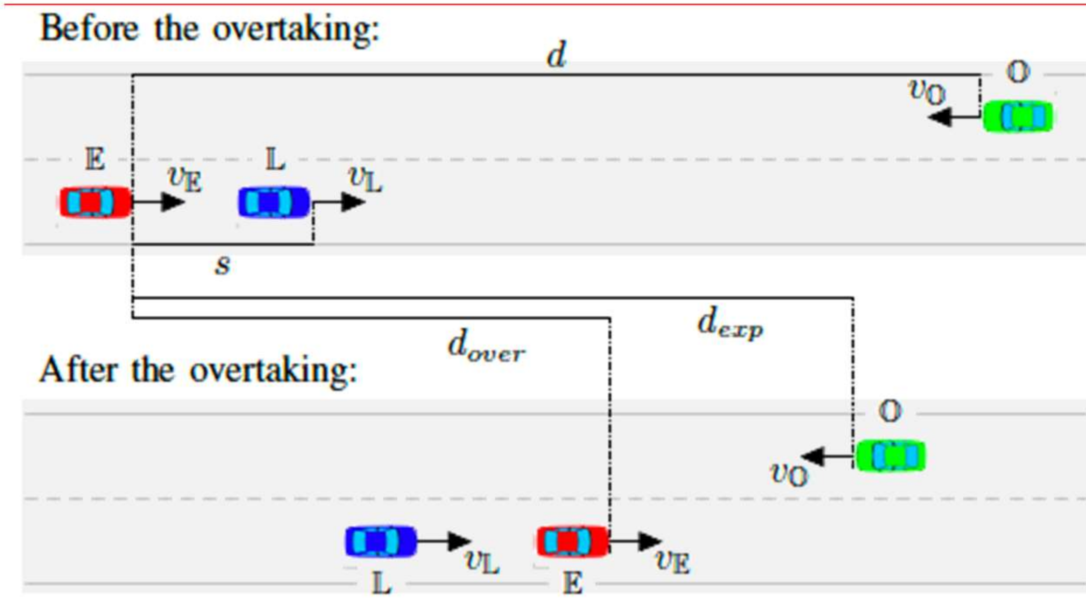
Kay Massow and Ilja Radusch, "A Rapid Prototyping Environment for Cooperative Advanced Driver Assistance Systems," Journal of Advanced Transportation, vol. 2018, Article ID 2586520, 2018.

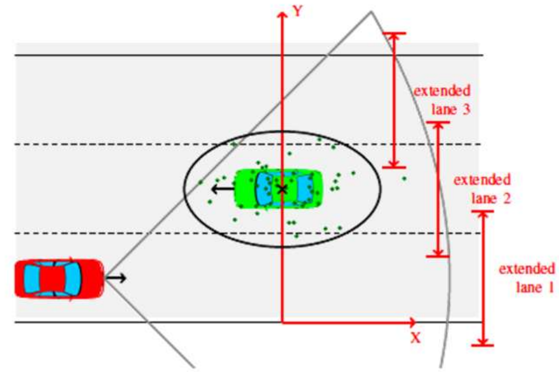
Levels of Cooperative Behaviour

<table>
<tr><td colspan="2">0 Non-Cooperative Behavior
Implicit communication Optimizes own utility</td></tr>
<tr><td rowspan="2">MB1 Cooperative Planning
Implicit communication
Optimizes estimated biased
total utility</td><td>IB1 Cooperative Perception
• Explicit communication of Sensor data & state information
• Optimizes own utility
• Tightly coupled perception</td></tr>
<tr><td>IB2 Cooperative Prediction
• Explicit communication of
Sensor data & state information Intentions & maneuvers
• Optimizes own utility
• Tightly coupled perception & prediction</td></tr>
<tr><td colspan="2">MB2 Negotiated Cooperation
• Explicit communication of Sensor data& state information, Intentions & maneuvers
• Maneuver options &associated utilities
• Optimizes biased total utility
Tightly coupled perception, prediction & planning</td></tr>
<tr><td colspan="2">MB3 Collaboration
• Explicit communication of Sensor data & state information,Intentions & maneuvers
• Maneuver options & associated utilities
• Optimizes fair total utility Tightly coupled system</td></tr>
</table>

C. Burger, P. F. Orzechowski, Ö. Ş. Taş and C. Stiller, "Rating cooperative driving: A scheme for behavior assessment," *2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC)*, Yokohama, 2017, pp. 1-6.

Overtaking Scenario





M. Vasic, G. Lederrey, I. Navarro and A. Martinoli, "An overtaking decision algorithm for networked intelligent vehicles based on cooperative perception," *2016 IEEE Intelligent Vehicles Symposium (IV)*, Gothenburg, 2016, pp. 1054-1059.

The Overtaking Risk is associated to the probability that an oncoming vehicle will occupy the overtaking lane

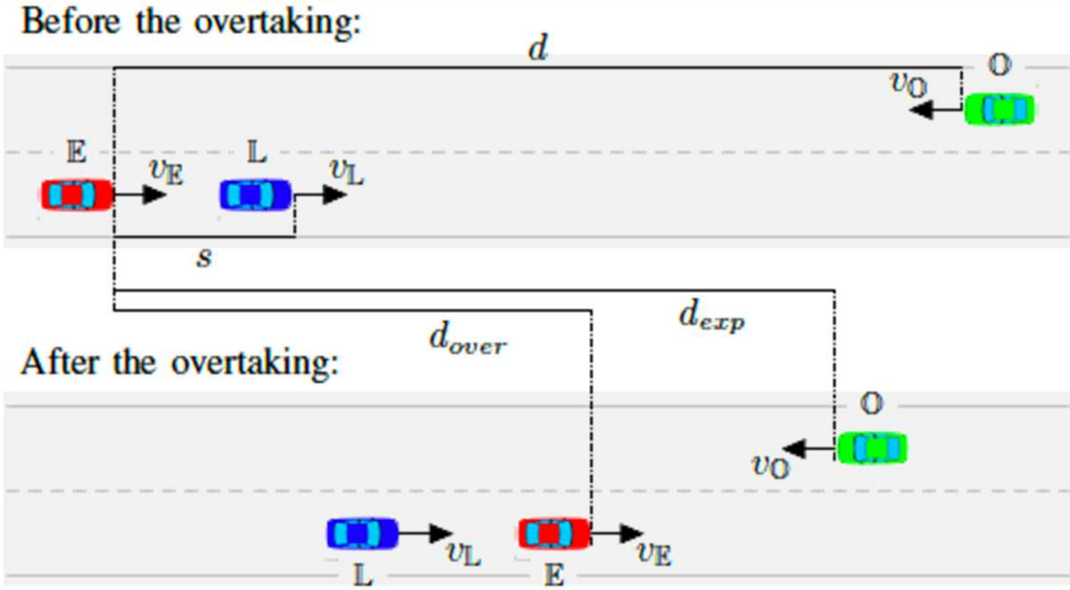
$$d_{over} = \frac{1}{2} a_E t_{over}^2 + v_E t_{over}$$

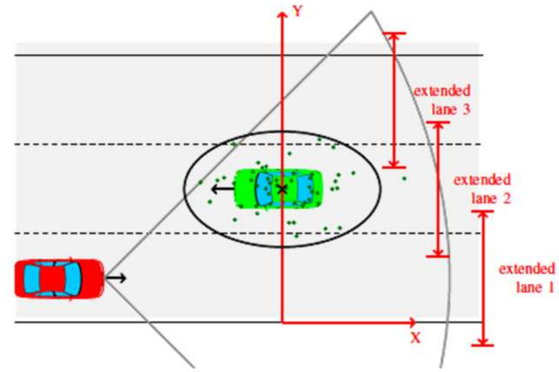
$$d_{\exp} = d_i - v_O t_{\exp}$$

$$\hat{L}_{over} + k_L \sigma_L + L_{margin} = \frac{1}{2} a_E t_{over}^2 + \left(v_E - v_L\right) t_{over} + k_v \sigma_{\Delta v} t_{over}$$

$$\hat{d}_{\exp} - k_d \sigma_{d_{\exp}} \geq \hat{L}_{over} + k_L \sigma_L + L_{margin}$$

Cooperative Overtaking Scenario





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The Overtaking Risk is associated to the probability that an oncoming vehicle will occupy the overtaking lane

$$d_{over} = \frac{1}{2} a_E t_{over}^2 + v_E t_{over}$$

$$d_{\exp} = d_i - v_O t_{\exp} + \frac{1}{2} a_O t_{\exp}^2$$

$$\hat{L}_{over} + k_L \sigma_L + L_{margin} = \frac{1}{2}\left(a_E + a_O\right) t_{over}^2 + \left(v_E - v_L\right) t_{over} + k_v \sigma_{\Delta v} t_{over}$$

$$\hat{d}_{\exp} - k_d \sigma_{d_{\exp}} \geq \hat{L}_{over} + k_L \sigma_L + L_{margin}$$

SAE J2735 Messages

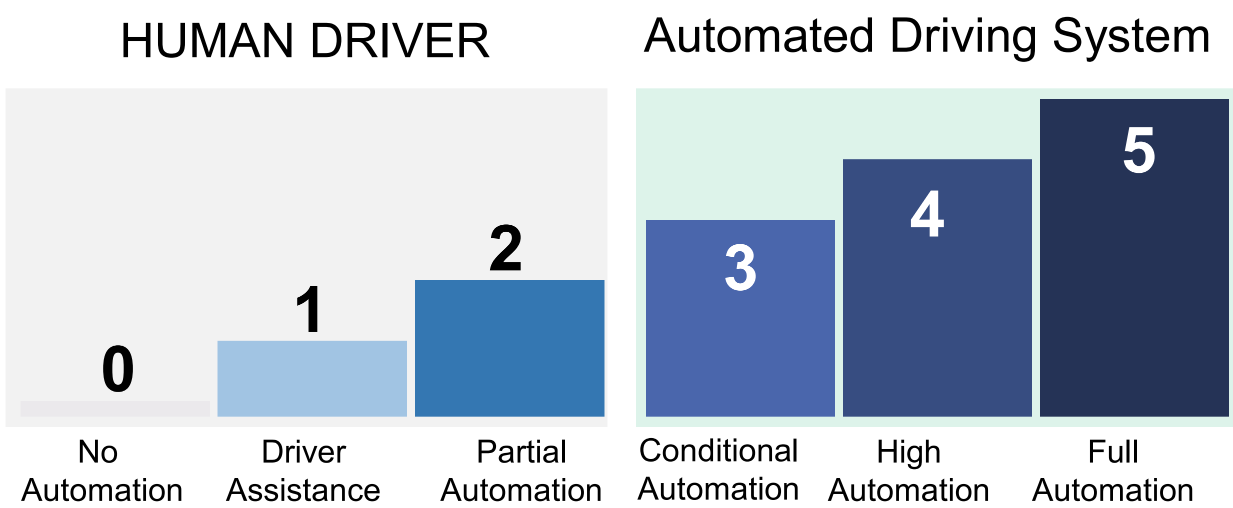
SURFACE VEHICLE STANDARD	J2735™	MAR2016
	Issued 2015-09 Revised 2016-03 Superseding J2735 JAN2016	
Dedicated Short Range Communications (DSRC) Message Set Dictionary		

- Message Frame
- Basic Safety Message
- Common Safety Request
- Emergency Vehicle Alert
- Intersection Collision Avoidance
- MapData
- NMEA corrections
- Personal Safety Message
- Probe Data Management
- Probe Vehicle Data
- Road Side Alert
- **RTCM corrections**
- Signa lPhase And Timing
- Signal Request Message
- Signal Status Message
- Traveler Information Message
- Test Message
- <Basicl nformation Message>

SAE J2735: MSG_RTCMcorrections

«**Use:** The RTCM Corrections message is used to encapsulate RTCM differential corrections for GPS and other radio navigation signals as defined by the RTCM (Radio Technical Commission For Maritime Services) special committee number 104 in its various standards. Here, in the work of DSRC, these messages are "wrapped" for transport on the DSRC media, and then can be re-constructed back into the final expected formats defined by the RTCM standard and used directly by various positioning systems to increase the absolute and relative accuracy estimates produced.»

SAFETY CRITICAL Requirements



KPI	Value
Position accuracy	**< 30 cm**
Speed accuracy	**?**
Trajectory handshake latency	<100 msec
Status message latency	<10 msec
Status message loss rate	$< 10^{-6}$
Status message rate	> 10 Hz

ELECTRONIC HORIZON

Vehicles and Road users

- Position, speed
- acceleration
- direction (heading)
- Yaw rate

Static obstacles

- Position

Infrastructure

- **High Accuracy Digital map**

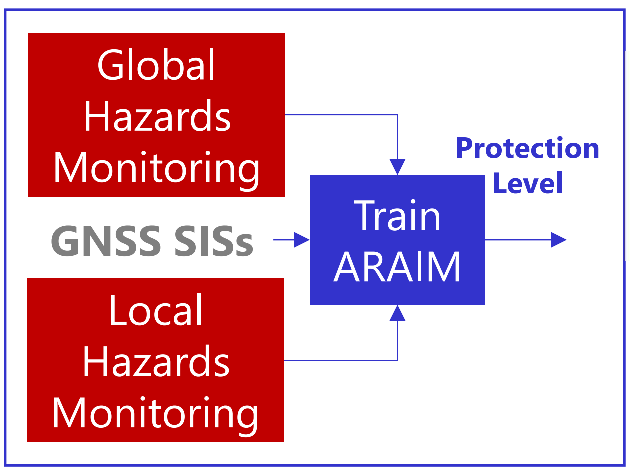
From other sources

- traffic
- weather information

AUTOMOTIVE Reference Architecture

1. Based on Road Environment **MODELLING**
2. **Candidate solution(s) Architecture derived from Rail (RHINOS)**
    - Integrity Monitoring and Augmentation System Reference **Architecture**
    - On Board System Reference **Architecture**
    - **Local** hazards detection and effects mitigation,

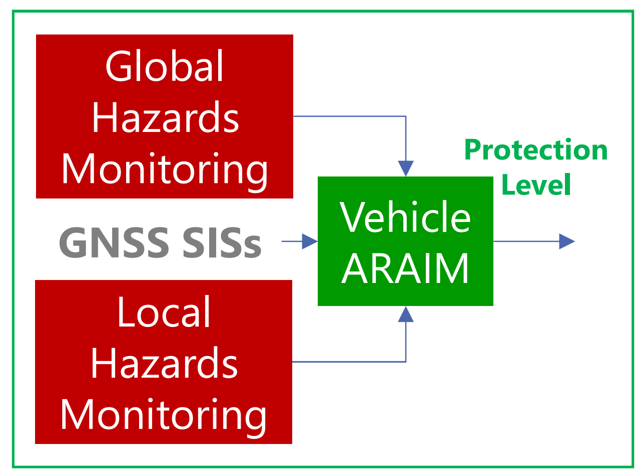
RAIL



HORIZON 2020

RHINOS

AUTOMOTIVE



AUTOMOTIVE Reference Architecture

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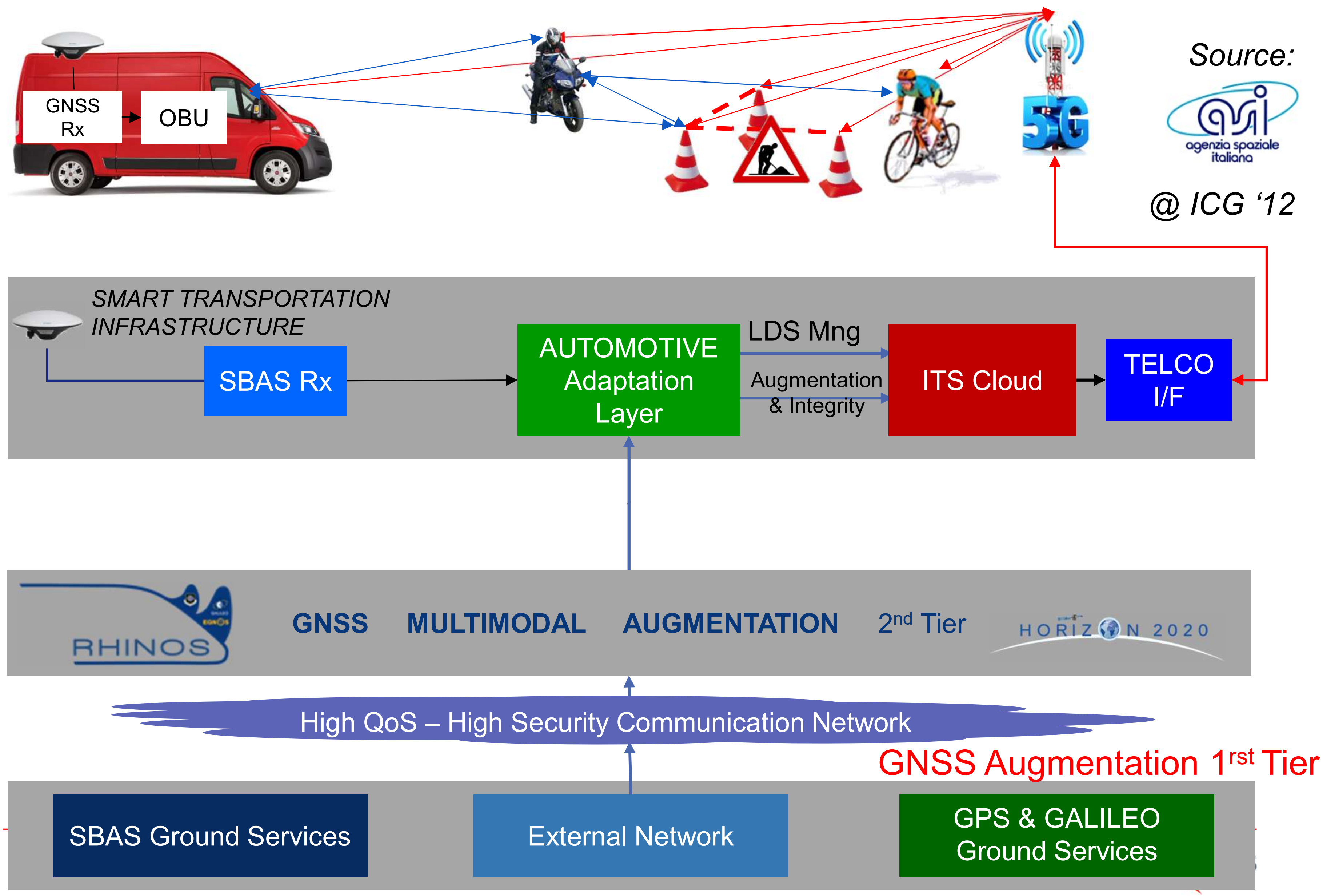
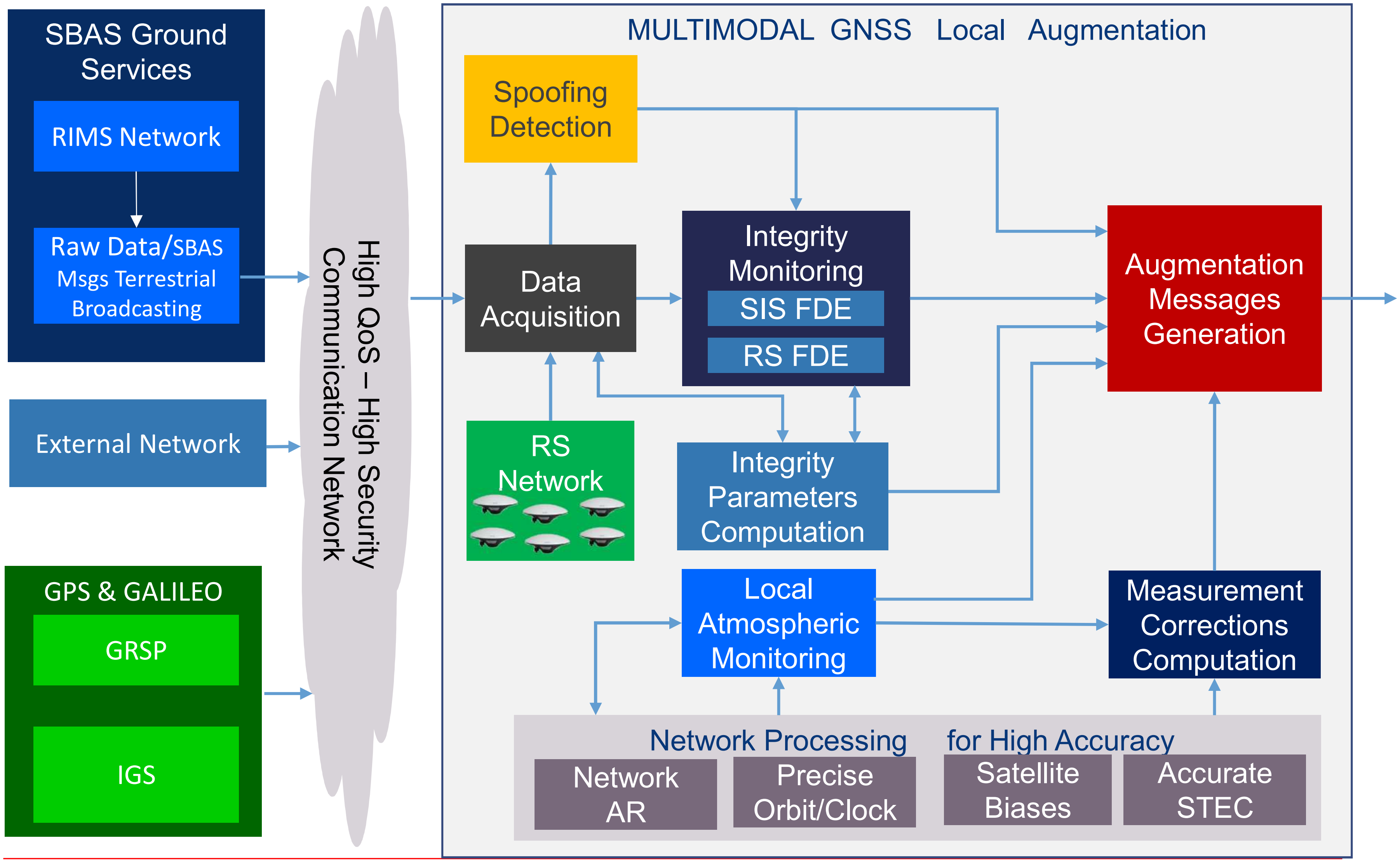
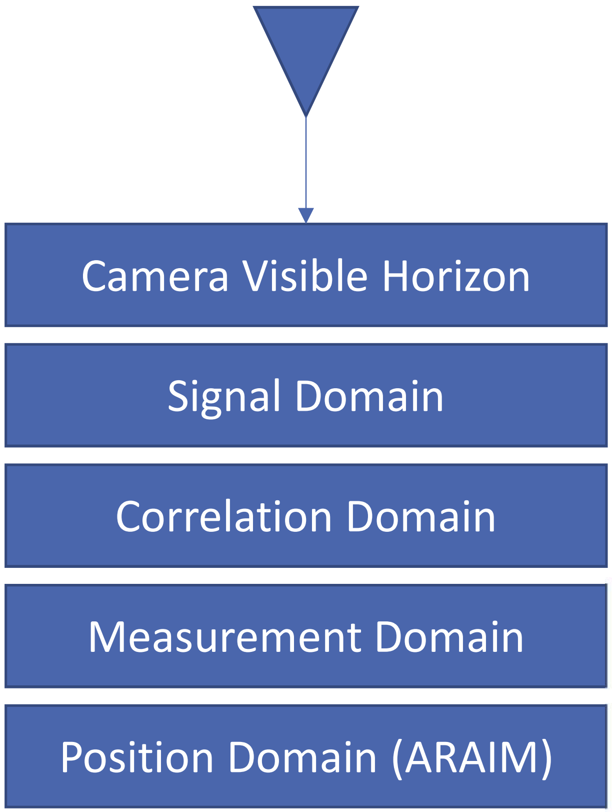


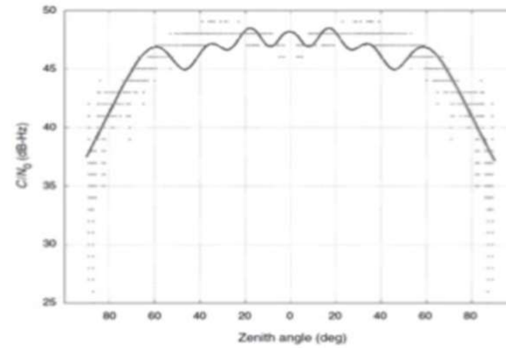
Reference GNSS Local Augmentation Architecture

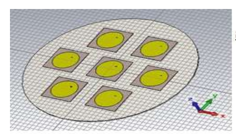


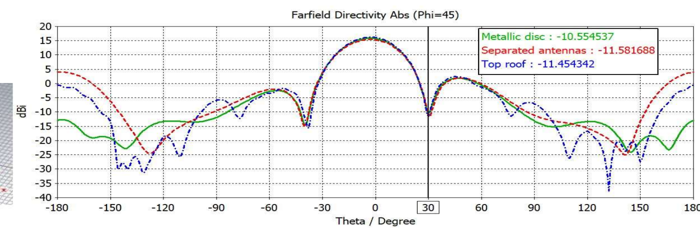
OBU: PVT Solution + ARAIM

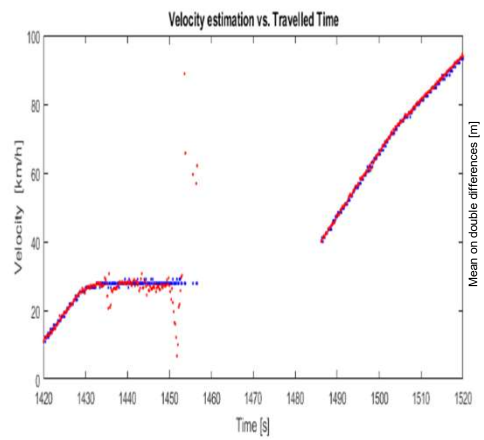


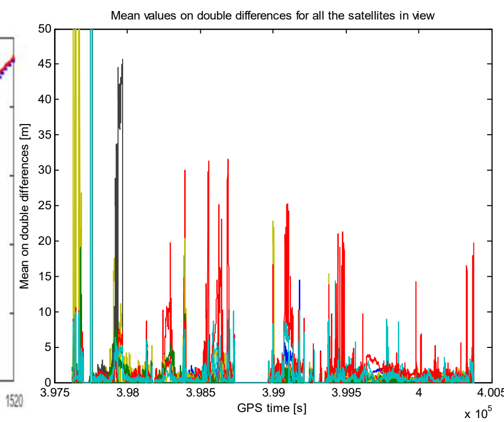
Source: Prof. Per Enge



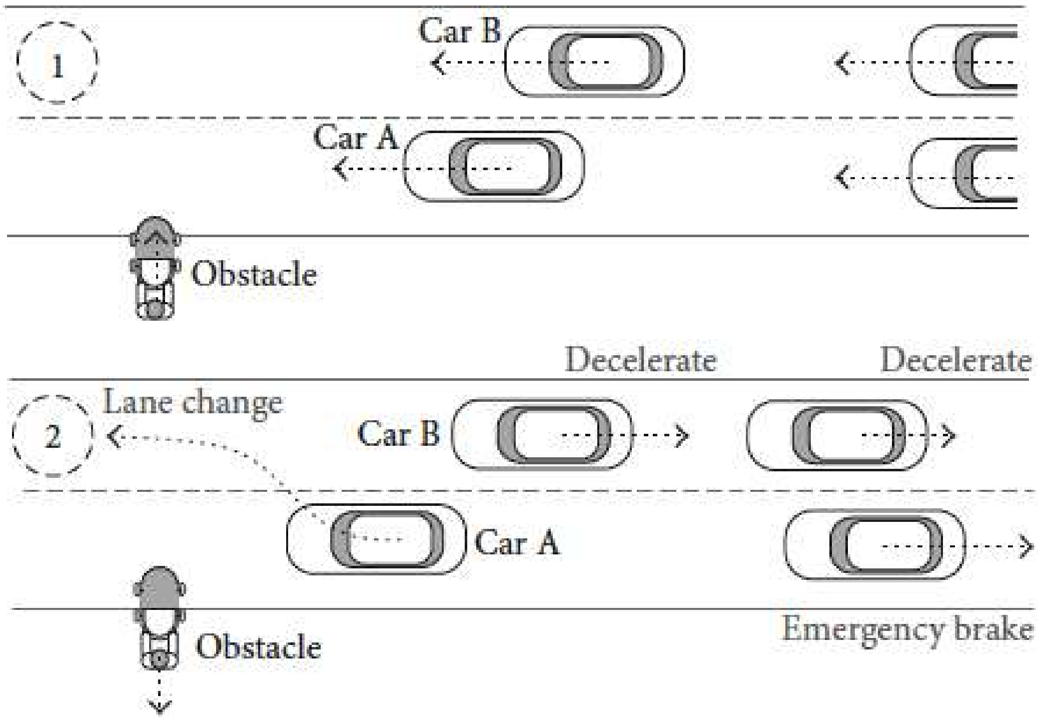








Thank you for your attention


1
Car B
Car A
Obstacle
Decelerate
Decelerate
2
Lane change
Car B
Car A
Obstacle
Emergency brake

AUTOMOTIVE Reference Architecture

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