Challenges and Opportunities in Connected Autonomous Vehicles

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Intelligent Vehicles Research Group

https://warwick.ac.uk/fac/sci/wmg/research/cav/

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IET The Institution of Engineering and Technology

Agenda

1. Background
2. Example Autonomous Vehicles
3. Challenges in Autonomous Driving
4. Achieving Autonomy
5. Cooperative Driving Opportunities and Use Cases
6. Development and Test Tools
7. Summary
8. Q&A

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WMG – Facts and Figures

- Established in 1980 by Professor Lord Bhattacharyya as Warwick Manufacturing Group to facilitate technology transfer and knowledge creation for Industry
- Over 800 staff in nine main buildings
- £105m income (2019)
- 40% of the entire University's research activity
- Effective relationships with over 500 companies
- 1,100 individuals from industry on part-time postgraduate and post experience education
- Over 1,200 full-time Master's students and 250 research students
- Teaching and research centres in Hong Kong, China, India, Singapore, Malaysia and Thailand
- Jaguar Land Rover, Tata Motors European Technical Centre and Tata Steel have re-located R&D in WMG buildings

National Automotive Innovation Centre

WMG Research

Research areas

Target sectors

Intelligent Vehicles Research Group

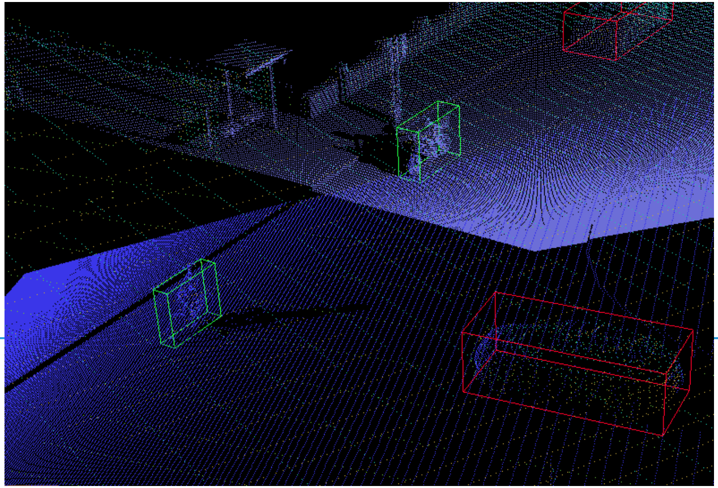
Prof Mehrdad Dianati & Prof Paul Jennings

Cooperative Intelligent Systems

Verification and Validation

Human Factors

Connectivity and Wireless Communication



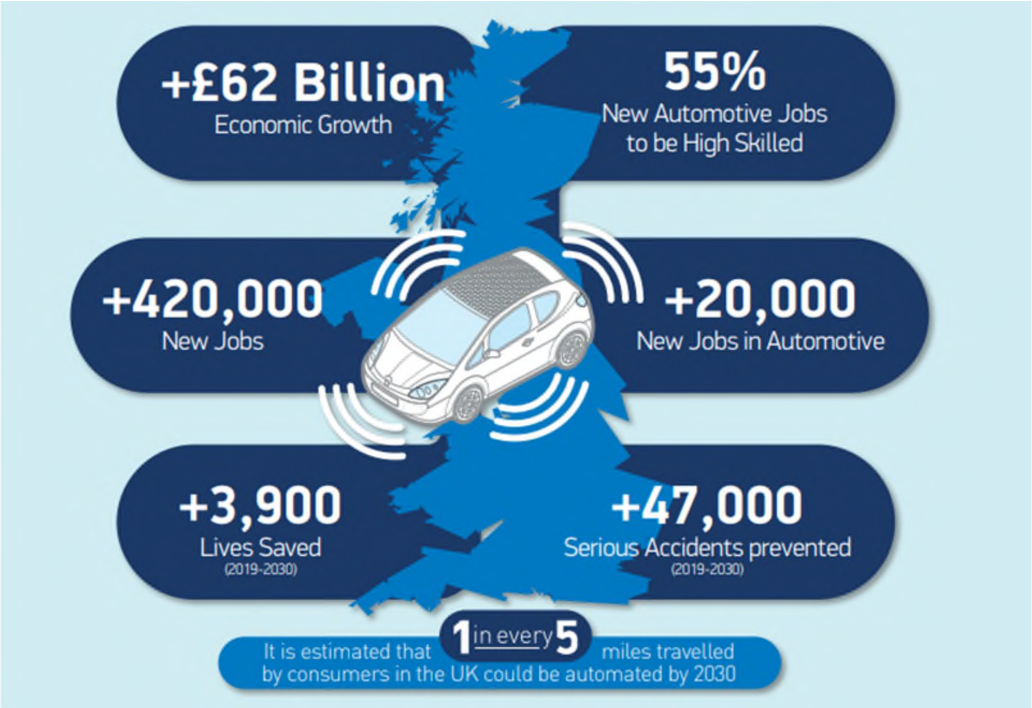
Background

Potential Benefits:

- Safer - 94% percent of accidents due to driver behaviour or error
- Less congestion
- Greater fuel efficiency
- Mobility for the less abled – greater independence
- More economically accessible
- More productivity – get there quicker and being productive on the move

https://bit.ly/3c9XilO

UK Impact



Potential Overall Impact of CAVs on the UK Economy by 2030
THE SOCIETY OF MOTOR MANUFACTURERS AND TRADERS LIMITED. CONNECTED AND AUTONOMOUS VEHICLES 2019 REPORT / WINNING THE GLOBAL RACE TO MARKET

The growth of the UK industry is limited by a number of factors :

- Skills shortages
- Ageing workforce
- Lack of efficiency, productivity, and innovation
- Narrow profit margins

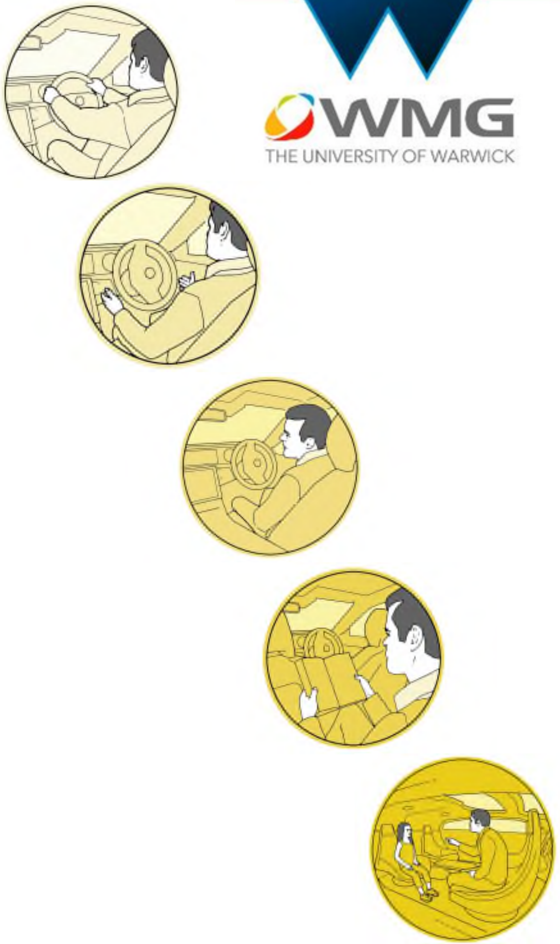
https://bit.ly/39TcamC

Levels of Autonomy

SAE INTERNATIONAL

SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/ acceleration support to the driver	These features provide steering AND brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions



Who is developing L4 and L5?

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ARGO AI

cruise

NVIDIA

MOBILEYE
An Intel Company

TESLA

WAYMO

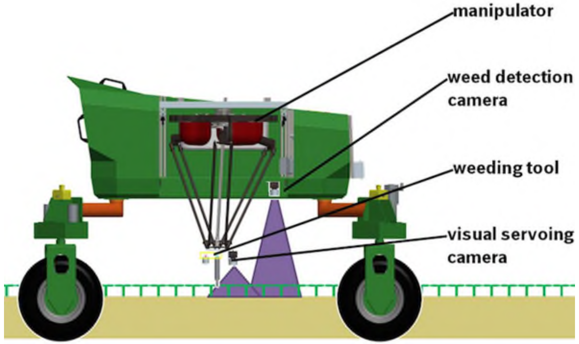
Uber

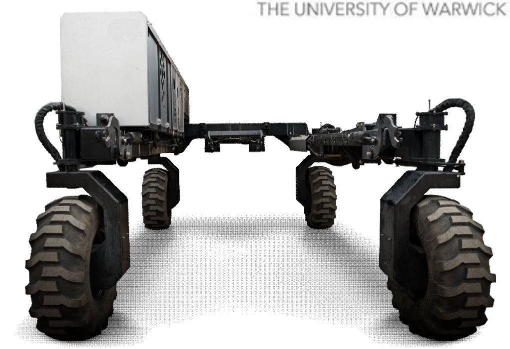
EXAMPLE AUTONOMOUS VEHICLES

Agriculture

Bosch Bonirob - Deepfield Robotics
Multipurpose Farm Robot/Weeding
(https://bit.ly/2v90Mo1)

- Weeding - saving 80% of chemical costs.
- Exchangeable application modules (tools)
- Can navigate autonomously along plant rows (e.g. dams) in the field
- Battery Powered
- Environmental sensors (e.g. Lidar), inertial sensors, wheel odometry and (optionally) GPS are mounted for row detection and navigation.
- Machine learning used to identify plant types





Dot (http://seedotrun.com/specs.php)

- Saving more than 20% on farm fuel, labour and equipment capital costs.
- Reducing your CO_2 emissions by 20%.
- Easily and economically rescaling your equipment to your future farm size. (Small and large farms becoming more efficient and profitable.)
- Reducing overlap while improving turning and filling efficiencies.

Mining

Komatsu Autonomous Haulage Trucks
(https://bit.ly/39ZqY3f)

In November 2018, the Komatsu Front Runner autonomous haulage system (AHS), moved more than two billion tonnes of surface material in the copper, iron ore, and oil sands industries.

CAT Autonomous Mining Trucks
https://bit.ly/38UGddw

- 2013, deployed the first six commercial autonomous trucks
- More than 130 autonomous haul trucks deployed across the world.
- In the process of hauling one billion tonnes, the autonomous trucks travelled nearly 35 million kilometers

On Campus

Singapore's Nanyang Technological University in 2013 (https://bit.ly/39VAoN9)

NAVYA: Salford-Manchester, Gothenburg, Michigan, and Adelaide (https://bit.ly/2PidgAA)

WMG, University of Warwick

On Road Vehicles

WAYMO

What is Common?

Specific operational design domain

- Road Types
- Speed range
- Weather

- Agreement with local authorities to operate

What are the Observed Benefits?

- Improved safety and working conditions
- Reduced costs and greater efficiency (more efficient fuel usage, more predictable wear)
- Lower emissions due to more efficient vehicle use
- Greater productivity
- Better profit margins - time and labor savings
- Addresses the skills shortage

The growth of the UK industry is limited by a number of factors :

- Skills shortages
- Ageing workforce
- Lack of efficiency, productivity, and innovation
- Narrow profit margins

Challenges in Autonomous Driving

Safety	Ethics/Legal	Market
• Sensor and system limitations (State-of-the-art) • Validation/testing • Security	• Legislation • Liability/Insurance • Privacy • Job Losses	• Supply chain • Desirability • Affordability • Business model (MaaS)

WHEN THINGS GO WRONG…

Uber

On Sunday, March 18, 2018, at 9:58 p.m. mountain standard time, an automated test vehicle, based on a modified 2017 Volvo XC90 sport utility vehicle (SUV), struck a pedestrian walking midblock across the northbound lanes of N. Mill Avenue in Tempe, Arizona.1 The SUV was operated by the Advanced Technologies Group (ATG) of **Uber Technologies**, Inc., which had modified the vehicle by installing a proprietary developmental automated driving system (ADS). The ADS was active at the time of the crash.

Figure 1. (Left) Location of the crash on northbound Mill Avenue, showing the paths of the pedestrian in orange and of the Uber test vehicle in green. (Right) Postcrash view of the Uber test vehicle, showing damage to the right front side.

https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=62978&CFID=2951047&CFTOKEN=433700b0892cd668-640F9CEA-D954-5E42-4EBD48460CC5D731
https://www.ntsb.gov/investigations/AccidentReports/Reports/HWY18MH010-prelim.pdf

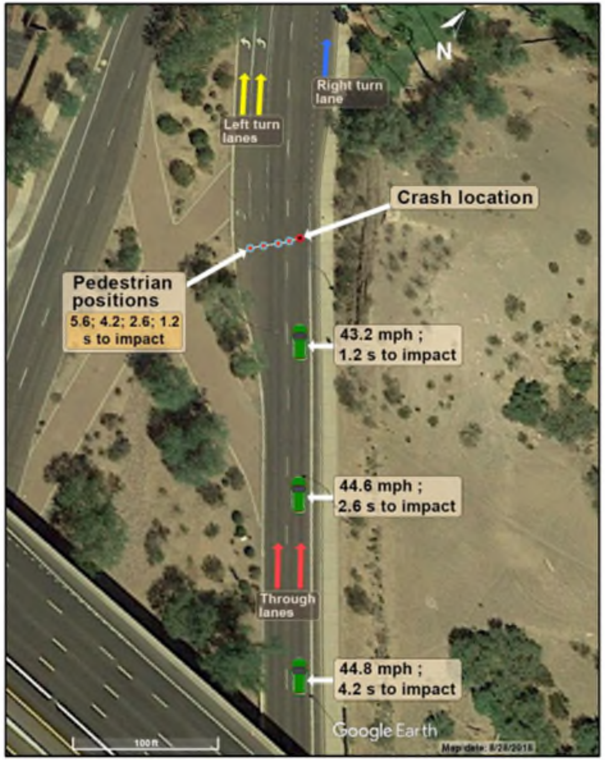


Figure 1. Aerial view of crash location showing path of pedestrian as she attempted to cross N. Mill Avenue and movement and speed of SUV at three points before impact. Pedestrian's path shows her position from initial detection (5.6 seconds before impact) until impact; SUV's position is shown at corresponding times beginning 4.2 seconds before impact. (Source: Adapted from Google Earth)

Probable Cause

- …failure of the vehicle operator to monitor the driving environment and the operation of the automated driving system because she was visually distracted throughout the trip by her personal cell phone.

Contributing factors

- inadequate safety risk assessment procedures
- ineffective oversight of vehicle operators
- lack of adequate mechanisms for addressing operators' automation complacency—all a consequence of its inadequate safety culture.

Further contributing factors

- the impaired pedestrian's crossing of N. Mill Avenue outside a crosswalk
- the Arizona Department of Transportation's insufficient oversight of automated vehicle testing

Achieving Autonomy

We envision three architectures to achieve full autonomy (SAE5):

Decentralised	• Vehicles are independent units responsible for sensing the environment and finding an optimal trajectory.
Centralised	• Infrastructure centralises sensing and decision making; vehicles only follow the control actions.
Hybrid	• Vehicles and Infrastructure share information to enhance perception and decision making.

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Decentralised: Vehicles as independent units

- All sensors, data processing and decision making happens on board the vehicle.
- Currently the most used architecture.
- No communication required with external infrastructure/agents.
- The vehicle is not vulnerable to communication signal loss.
- All vehicles must be equipped with a full sensor suite.

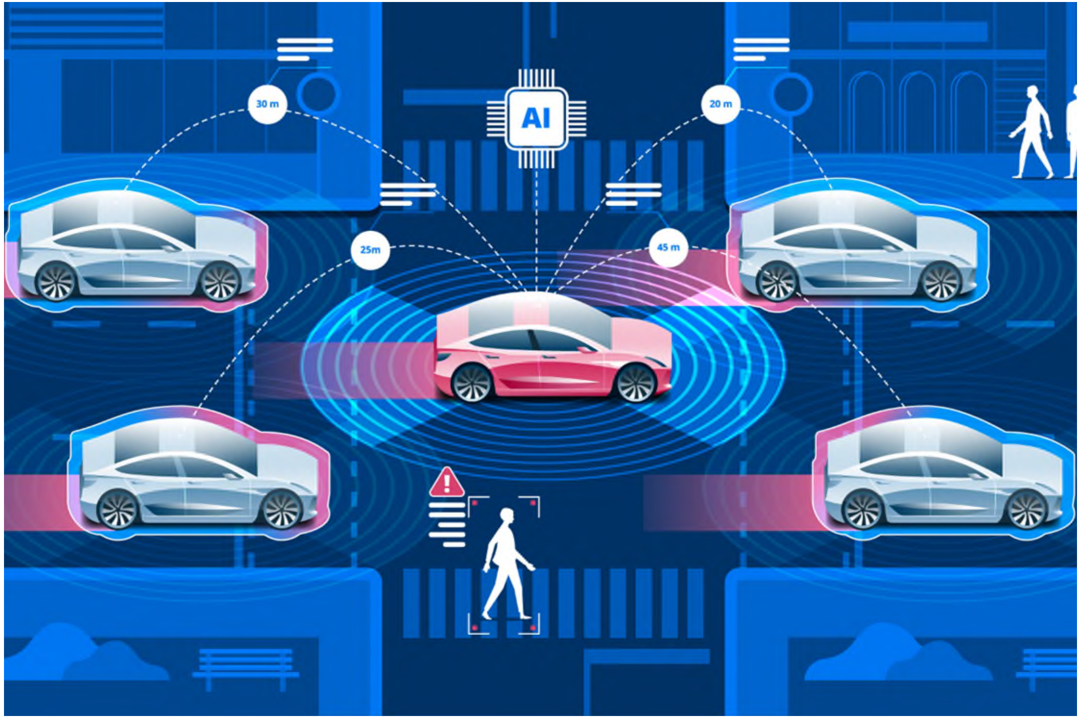
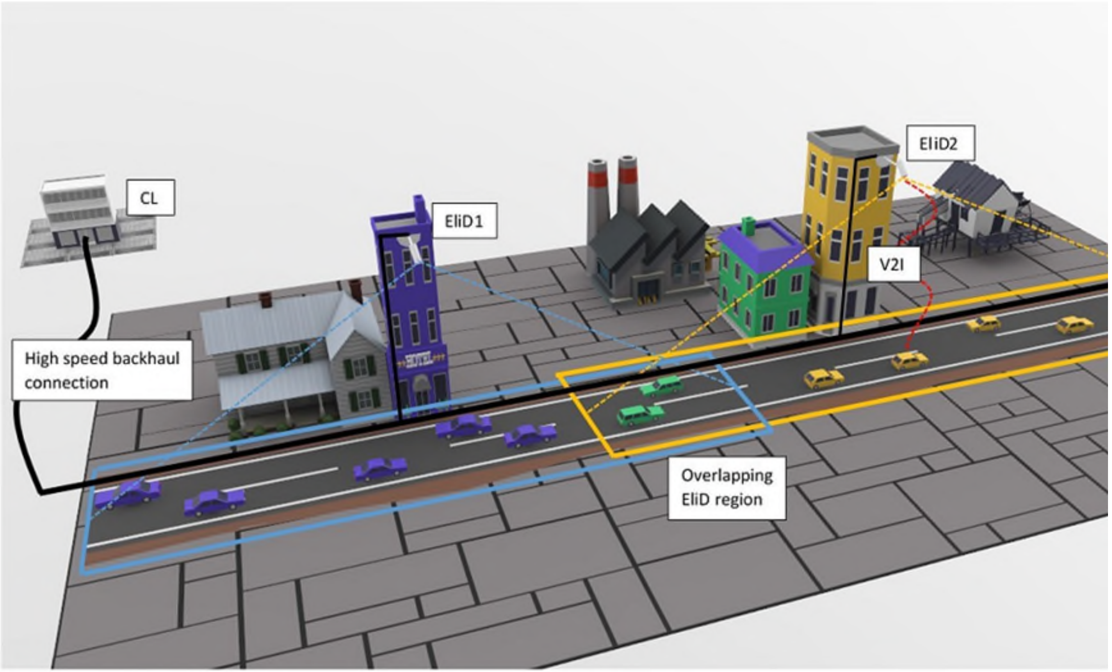


Image from Smart Cities World

Centralised: Infrastructure sensing and decision making

- All sensing, data processing and decision making happens in the infrastructure.
- Joint optimal trajectory for all users.
- Vehicles only follow control actions.
- Requires stable communication link required. Link failure could result in dangerous situations.
- Infrastructure is required for all driving areas. Vehicles only require cheaper short-range collision avoidance sensors.
- Who is responsible for setting the infrastructure? Liability? Business model?



N. Jayaweera, N. Rajatheva, and M. Latva-aho, “Autonomous Driving without a Burden: View from Outside with Elevated LiDAR,”.

Hybrid solution: shared sensing; vehicles responsible for ultimate decision making and control

- Infrastructure share information with vehicles (raw/processed sensor data).
- Vehicles may use this information to make optimal trajectory/control decisions.
- A failure in the communication link is less likely to cause hazardous incidents than the previous case.
- Infrastructure is more likely to be deployed in dense traffic areas.
- Vehicles still require advanced sensors for regions where infrastructure is inexistent.
- Emerging technology with test sites in NYC, Tampa and Wyoming.

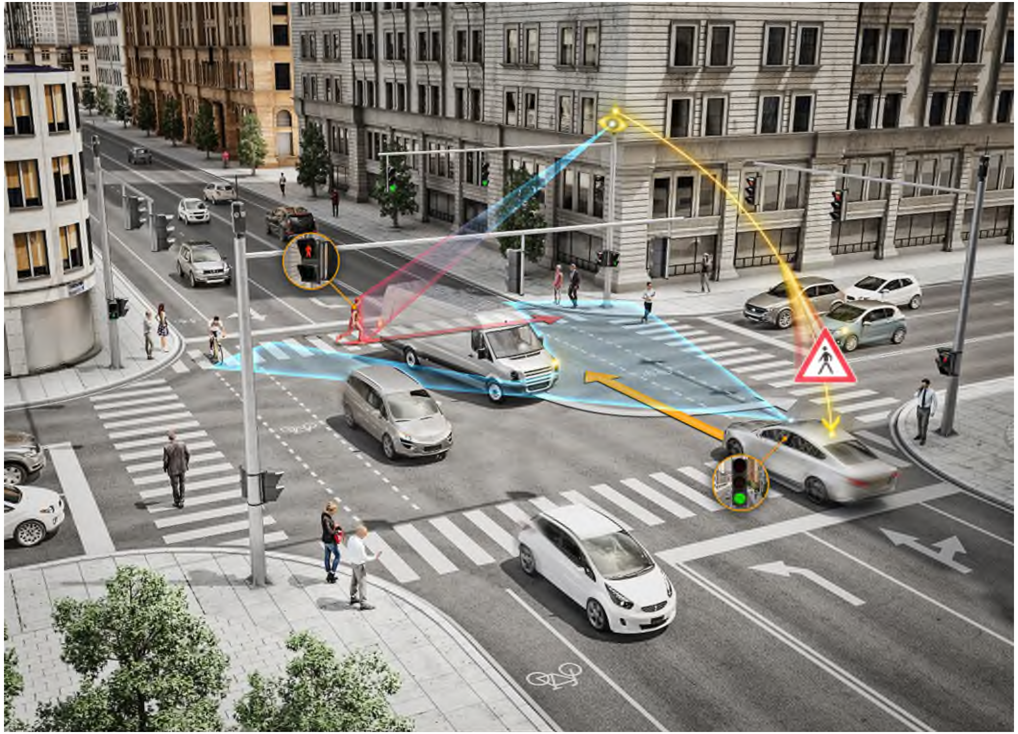


Image from Car-IT.com

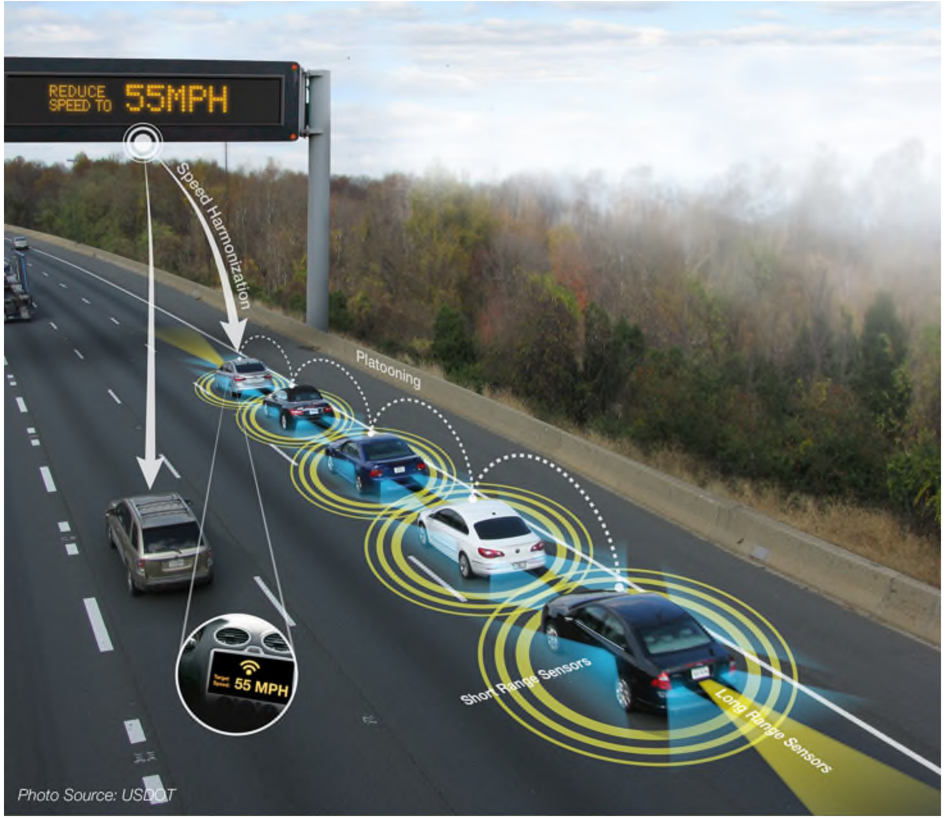
https://www.cvp.nyc/project-scope

COOPERATIVE DRIVING OPPORTUNITIES AND USE CASES:

Platooning, Cooperative Motion Planning and Cooperative Perception

Platooning

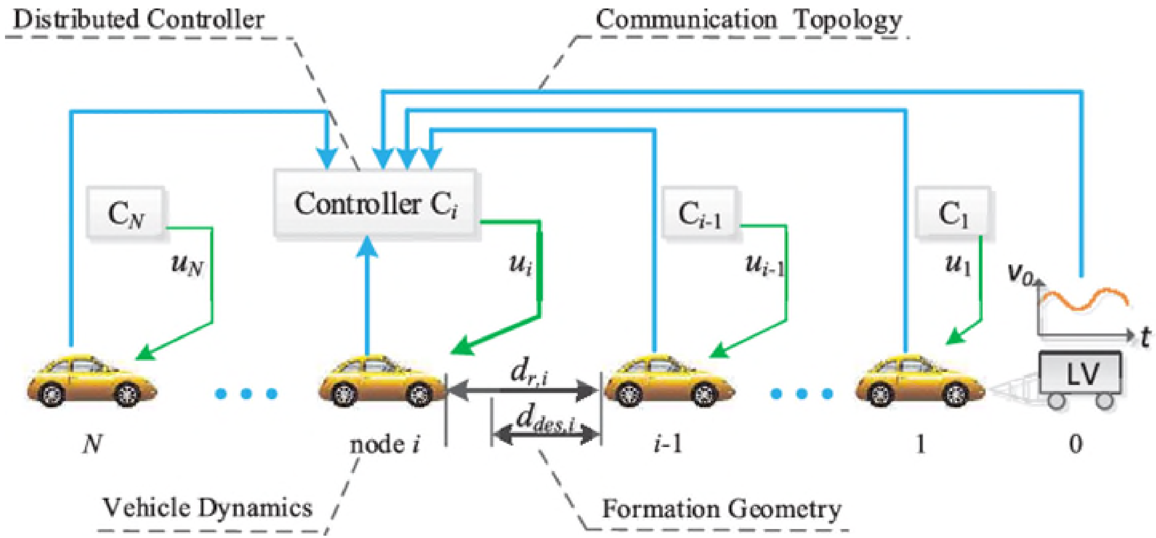
- A platoon is formed by a group of vehicles travelling closely together, safely at high speeds.
- The platoon increases the vehicles' aerodynamic performance and reduces fuel consumption (between 10-17% depending on position and separation) [1].
- Platooning also increases the capacity of the road, as the vehicles travel closer together.



[1] McAuliffe, B., Lammert, M., Lu, X. Y., Shladover, S., Surcel, M. D., & Kailas, A. (2018). *Influences on energy savings of heavy trucks using cooperative adaptive cruise control* (No. 2018-01-1181). SAE Technical Paper.

Platooning

- Each vehicle requires a controller that takes all vehicles' position and the Lead Vehicle (LV) velocity to control for the inter-vehicle distance.
- The control mechanism is in place to guarantee a minimum inter-vehicle distance, which is required for the safety of the platoon.
- The cooperative aspect emerges from the communication link to establish the platoon and the vehicle's position signals.



Zheng, Yang & Li, Shengbo & Li, Keqiang & Ren, Wei. (2016). Platooning of Connected Vehicles With Undirected Topologies: Robustness Analysis and Distributed H-infinity Controller Synthesis. IEEE Transactions on Intelligent Transportation Systems.

Cooperative Motion Planning

- Motion planning requires estimating the next state of objects in the scene and finding a safe path that does not intersect other objects and adheres to traffic rules and to the vehicle dynamics constraints.
- Estimating the next state of vehicles can be challenging in practice. Cooperative motion planning allows vehicles to agree on a motion plan, which reduces the likelihood of accidents.

Image from car-2-car.org

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Video from Parallel Studio

Cooperative Perception

- Autonomous vehicles require a perception module to understand the environment and agents around the vehicle; *i.e.* detecting objects, the road and traffic signs.
- Understanding the environment from a single point of view is prone to occlusion and limited field-of-view.
- When cars share their sensor data or detected object list, it is possible to create redundancy and increase safety, especially in complex environments.

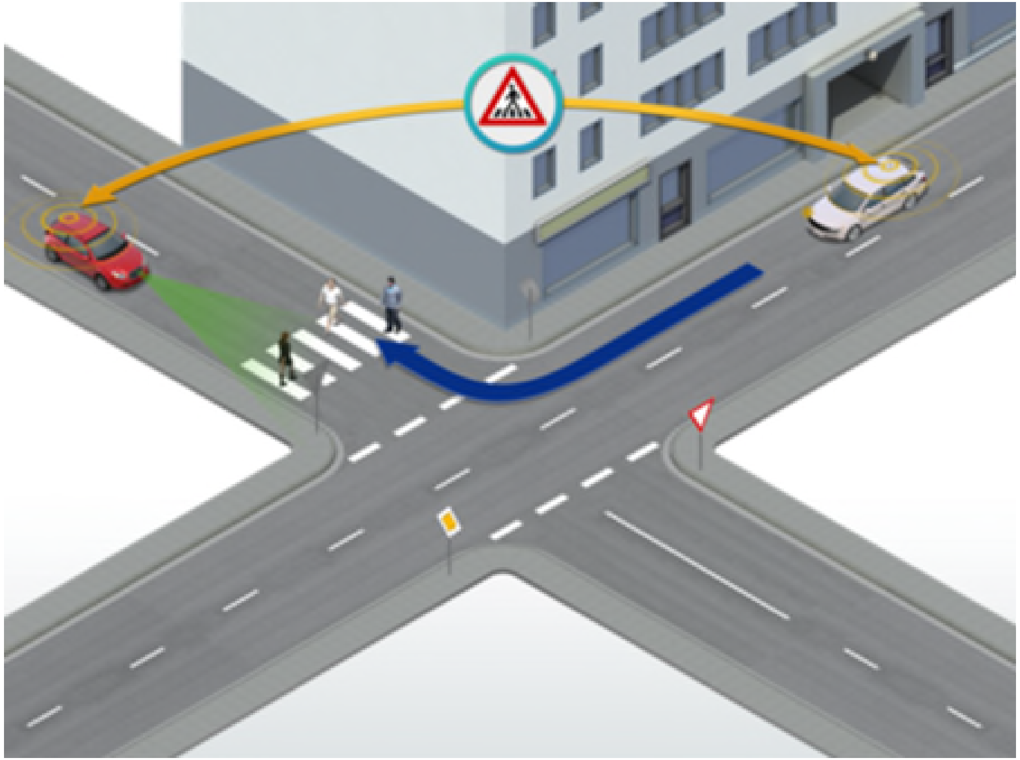
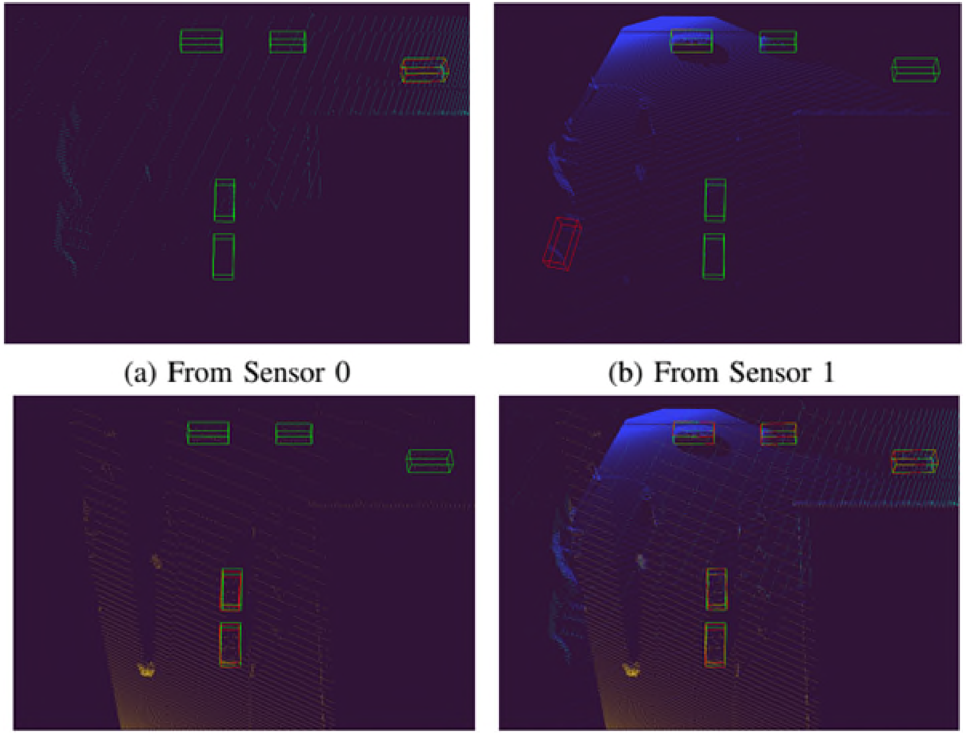


Image from car-2-car.org

Cooperative Perception

- Boxes in green represent the ground-truth objects, while the ones in red represent the boxes detected by the system.



(a) From Sensor 0 (b) From Sensor 1

(c) From Sensor 5 (d) Early Fusion from sensor set (0,1,5)

E. Arnold, M. Dianati and R. de Temple. Cooperative Perception for 3D Object Detection in Driving Scenarios using Infrastructure Sensors. Preprint, December 2019.

Cooperative Driving Benefits

Efficiency	Safety	Reliability
• Energy (platooning, motion planning) • Road capacity (platooning) • Optimal trajectory (motion planning)	• Increased perception horizon reduces risk of accidents • Platooning reduces hard-breaks which could cause accidents	• Sensor Redundancy • Computational Redundancy

DEVELOPMENT AND TEST TOOLS

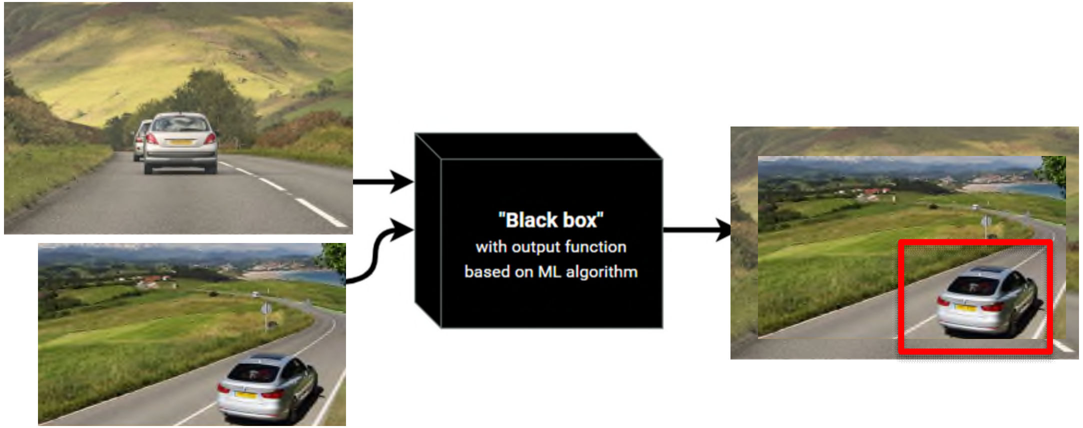
Development and Testing Tools

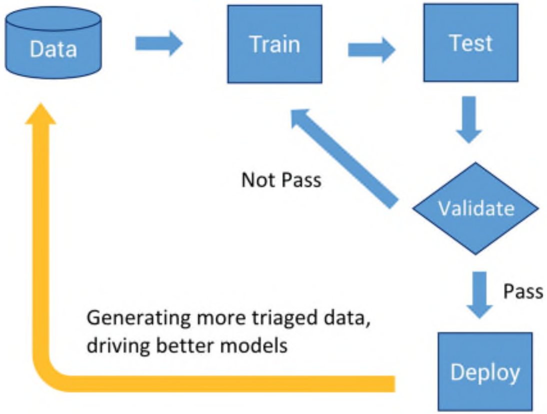
Modelling and Simulation

Controlled Environments

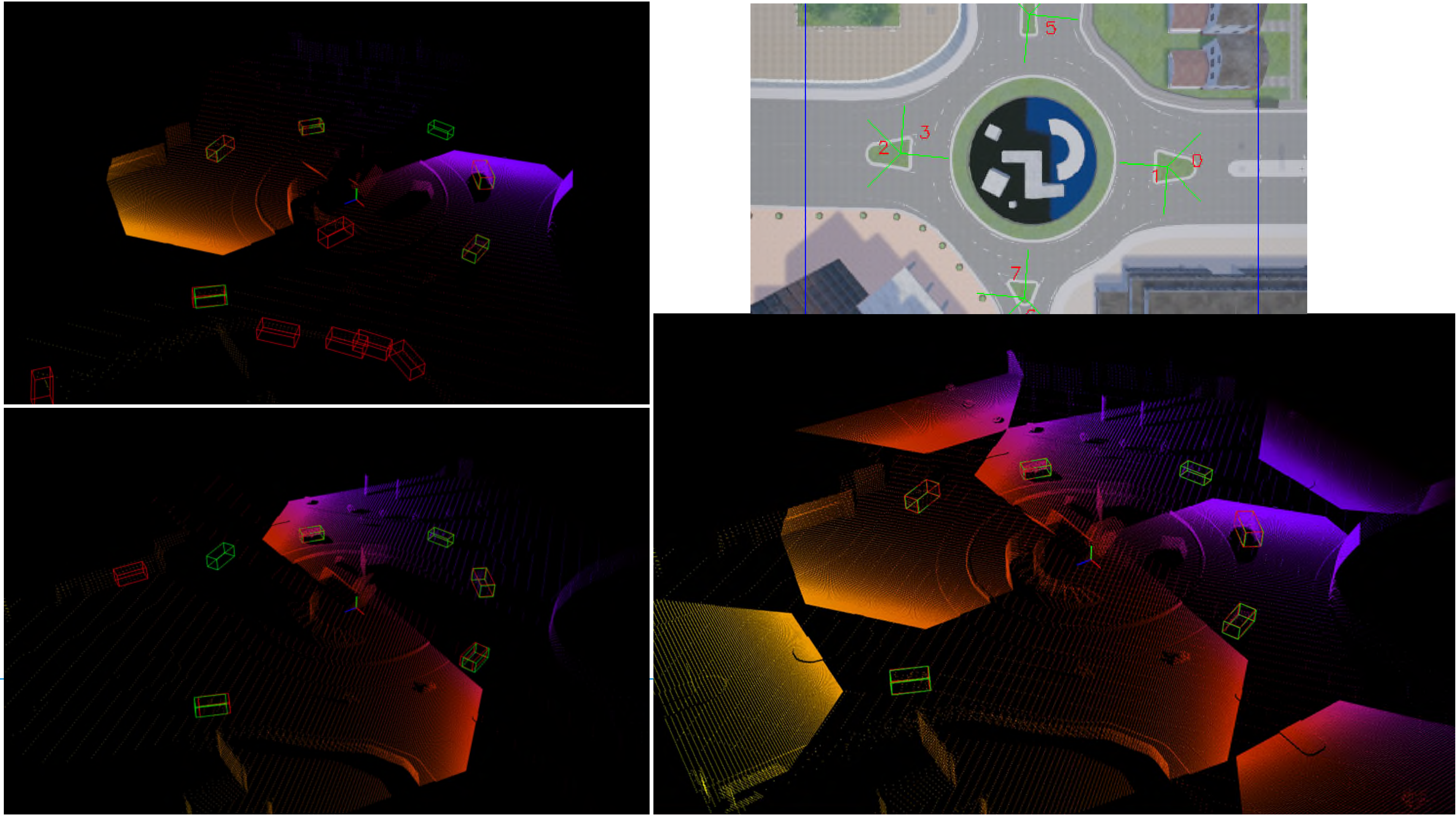
Public Environments

Example – Development and Test of Perception Algorithms

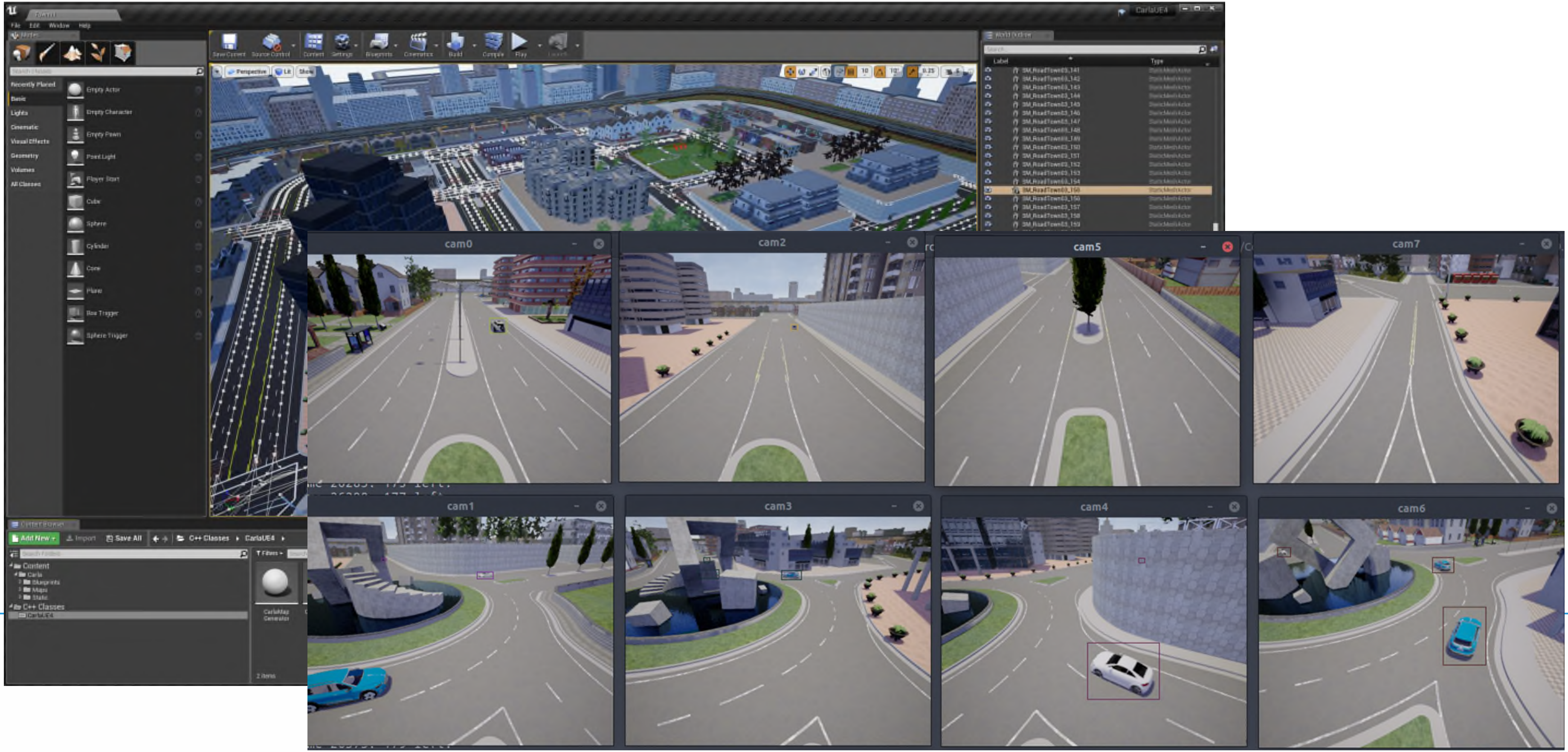




- When available, real sensor data is preferred for training perception models.
- Validation: simulation allows to consider edge-cases that are dangerous/difficult to reproduce on a test track.
- Controllability: replaying simulated/real sensor data is key to quickly verify impacts of changes in the model.


5
3
2
0
1
7

Example – Design and Instrumentation of Infrastructure Cameras



Example – Design and Instrumentation of Infrastructure Cameras

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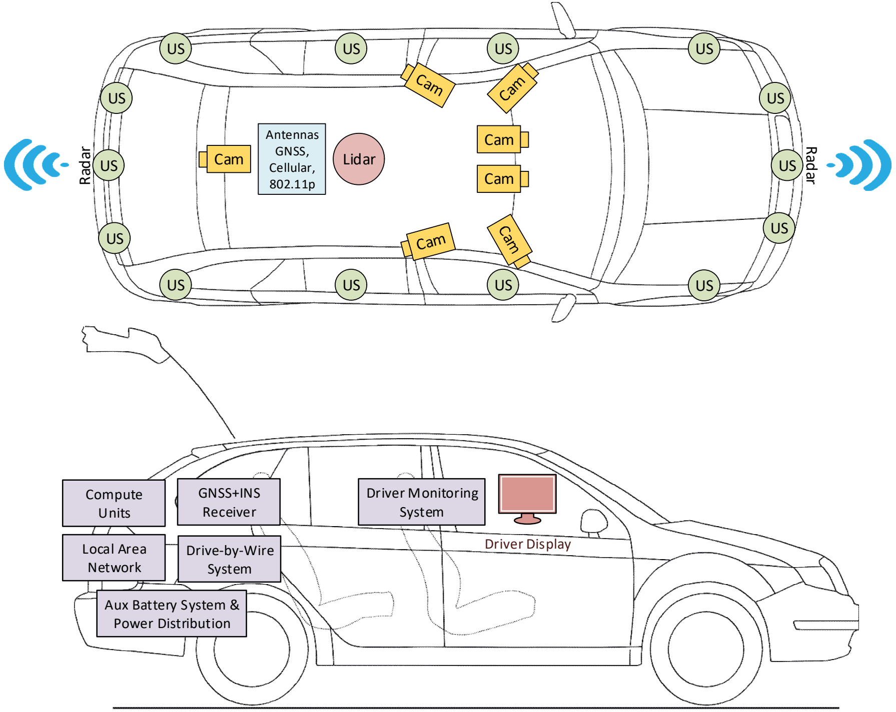
Example - Test Vehicle & Proving Ground



MIDLANDS FUTURE MOBILITY

Midlands Future Mobility (MFM) offer services from initial virtual development, to real-world trials and market deployment.

300-mile network of roads

Continuous connectivity

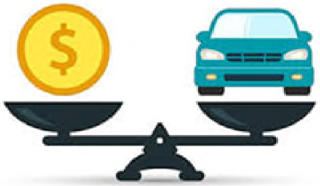
Diverse road environments

Smart monitoring

https://midlandsfuturemobility.co.uk/

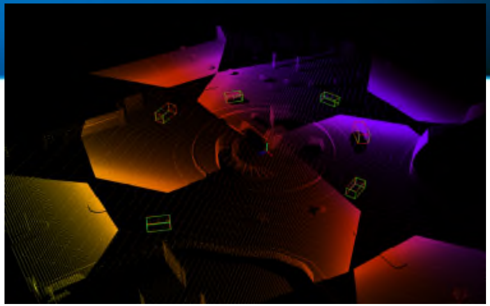
Summary - Challenges in Autonomous Driving

Safety	Ethics/Legal	Market
• Sensor and system limitations (State-of-the-art) • Validation/testing • Security	• Legislation • Liability/Insurance • Privacy • Job Losses	• Supply chain • Desirability • Affordability • Business model (MaaS)



Summary

- Autonomous driving technology has the potential to substantially improve traffic efficiency and safety.
- Cooperation among driving agents and infrastructure can address some of the challenges in achieving autonomy.
- Test and validation across the spectrum (from virtual, to test tracks to public roads) are needed to ensure safety and reliability of the vehicles and traffic agents.
- The quick progress of research and industry efforts suggests that L5 autonomy is possible. Achieving it in a safe and reliable manner is the challenge!



Questions?

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