Ricardo’s view on CAV and its implications, from Business models to Engineering challenges

CAV Meetup, Shanghai
April 2018
- Ricardo presentation
- Ricardo CAV white paper overview
- Ricardo’s activities in CAV
100 Years: Delivering excellence through innovation and technology

- A global, multi-industry, multi-discipline consultancy and niche manufacture of high-performance products
- The objective throughout our history has been to maximize efficiency and eliminate waste in everything we do
Megatrends driving focus for solutions:

- **Climate change**  
  (Emissions and waste)

- **Resource scarcity**  
  (Oil/water usage)

- **Urbanization**  
  (Transport, energy, efficiency)

- **Energy security**  
  (Renewables, bio-fuels)
... delivering integrated and optimized solutions for future critical infrastructures

Future **Transport** system, primarily electrified and automated with integrated personal and rapid transit connected to high-speed intercity links.

Future **Energy System** features centralized and distributed renewable sources via an intelligent network with storage and waste-heat utilization.

Future **Scarce Resource** use managed via a circular economy with zero waste and full re-use of critical materials to new products and/or energy and heat.
World-class professional engineers, consultants and scientists across a global footprint of facilities

250+ North America

1800+ UK

600+ Germany, Netherlands & Rest of the EU

250+ Asia & Rest of the World

Over 2900 staff worldwide
- Ricardo presentation
- **Ricardo CAV white paper overview**
- Ricardo’s activities in CAV
Future transport systems will become use-on-demand and automated solutions due to congestion, safety, connectivity & environmental pressures – Mobility as a Service (MaaS)

Why did we ever allow people to drive cars?

Why would you ever think of owning your own car?
High-automated or partially automated driving is part of the global megatrend towards smart and connected vehicles

Vehicle intelligence and networking

**Demand for comfort functions**
- Intelligent navigation
- Integrated infotainment functions (Cloud access)
- Networking with vehicle service facilities
- Automated driving function

**Prevent traffic congestion**
- Improved use of transport networks
- Reduce "unnecessary" trips and routes
- Self co-ordination of traffic (e.g. Platooning)

**Increased traffic safety**
- Automate mundane driving tasks
- Accident prevention (advanced braking and collision avoidance)
- Accident reduction

**Energy & emissions reduction**
- Optimisation of energy usage
- Predictive navigation / vehicle control with real-time data
- Advanced diagnostics and service functions

Source: Ricardo
Mobility as a Service systems will operate fleets of coordinated, connected Level 4 automated vehicles

Ownership cost per mile for different mobility solutions
TNC vehicle is a Transportation Network Company vehicle (for example self-driving taxi operated by Uber)

- On-demand & scheduled services, highly integrated with public transit to provide integrated multi-mode mobility
- Vehicles specifically designed for MaaS, with more comfort, safety and personal productivity during the journey with a high rate of utilisation
- Low cost MaaS leads to a reduction in private car ownership
Vehicle OEMs supply to mobility companies and fleets
- OEM transitions from B2C to B2B relationship
- Some OEMs creating their own mobility operators
B2B model could cause significant disruption to the industry

Could the Automotive industry move from B2C model to B2B

- Transition to operating similarly to airline or commercial vehicle industry?
- Mobility service operator specifies vehicle types, volumes, interior & exterior specification, comfort & infotainment features
- Reduced interest in vehicle styling or vehicle OEM brand
Freight transport will benefit from reduced costs and increased productivity

- 80% of European inland freight is by road
- Long distance freight haulage can receive significant benefits from platooning through improved fuel economy and elimination of rest stops

**Example Economic Opportunity for Line Haul Trucks**

- Multi-brand platooning planned in EU for 23MY
- Driver shortages in Japan is driving development of automated trucks and platooning
All vehicles in the platoon reduce fuel consumption

- Fuel consumption savings have been measured by numerous studies
  - 16% for following vehicles
  - 8% for lead vehicle
- Gains are maximised with short inter-vehicle distances
  - High level of automation
  - Low-latency connectivity
Future CAVs will be more complex than any other volume product

- Premium vehicles already contain ~100 networked ECUs, more than an Airbus A380
- Dramatic increase in number and complexity of Use Cases to handle
  - System functionality, safety-critical functionality, environmental conditions, types of objects to detect, interactions with other road users
**Functional Safety Analysis is More Complex**

- Driver not available to take over
  - Driver unavailable within required time
  - No driver controls in vehicle
  - No one in vehicle
- Functional safety (ISO 26262) assumes driver is present as a last resort
  - Bespoke extensions to ISO 26262 required to develop CAV systems
    - No driver
    - Human factors – deliberate malicious actions, misinterpretation
- Fail safe → Fail operational
  - Increased redundancy
  - Increased verification & validation
- Entire integrated system must be analysed – not just the vehicle
Emergence of Cybersecurity Threats

- Cybersecurity: exploitation of vulnerabilities in the system to affect or access:
  - System operation / control of host vehicle or other vehicles / systems
    - Safety critical
  - Could affect individual vehicle, or whole fleet / integrated system

- Cybersecurity development processes not as mature as for functional safety
  - SAE J3061, ISO 21434

- Similarities between functional safety (ISO 26262) and cybersecurity (J3061) processes but also important differences
  - Past knowledge of faults vs. anticipating future actions of attackers (future sources of information, future tools)
  - Incident detection, tracking, response process continues beyond SOP (Start Of Production)
  - Include manufacturing, servicing, updates
The cyber attack surface is complex and covers many layers
Many of these are outside an OEM’s direct control

Layer 1
Electronic Control Unit (microcontroller and hardware)

Layer 2
Individual Local Network (CAN, flexray…)

Layer 3
Whole vehicle Network inc. gateways

Layer 4
Interfaces

Layer 5
GSM / Infrastructure / DSRC / ITS-G5 / GPS

Layer 6
Backend servers & mobile devices

Layer 7
Engineering Development (inside job)

Layer 8
Supply Chain

Layer 9
Manufacturing

Layer 10
Service Environment & 3rd party service suppliers

Data Flow

Product Development

Post Sales

Uncontrollable environment – additional end-end solutions may be required to overcome weaknesses here

Uncontrollable environment – additional end-end solutions may be required to overcome weaknesses here
Development Cycle – Increased Emphasis on Field Monitoring

From concept to implementation and release

“System” definition

Risk & Threat Assessment

Functional Safety & Security Design

Technical Safety & Security Design

HW & SW Design

HW & SW Development

HW & SW Int. Testing

System Int. Testing

Vehicle Int. Testing

Safety & Security Validation

Field Monitoring

Safety
- Identify new scenarios
- Detect new error conditions

Cybersecurity
- Detect & respond to new threats
- Update software
How safe is safe enough?

- Safer than a human driver
  - 2x, 5x, 10x?
- Mileage-based?
  - Fatality every ~0.5bn miles so need to test 5bn miles?
  - Are they relevant miles?
- Scenario based approach
  - Compile database of relevant scenarios, including common & rare / unusual scenarios
  - Mainly virtual testing, with some physical testing
    - Waymo 2017 statistics: 2 million physical miles, 2.5 billion virtual miles
- Challenges
  - How to handle millions of test scenarios
  - How to handle, process & understand results from millions of simulations

Source: Reported road casualties in Great Britain: main results 2015, Department for Transport, September 2016. Graph shows 2014 data

Passenger car: 1.8 fatalities per billion passenger miles
Cloud-based virtual testing, verification & validation will be required throughout the development process.

Scenario generation:
- Vehicle test data
- Parameter ranges - Environmental conditions, other road users
- Variant generation
- Concrete scenario generation
- Scenario classification
- Scenario database
- Domain Experts (Use cases, Standards, Legislation, etc.)

Simulation:
- Simulation environment
- Fault injection

Performance attribute evaluation:
- Simple pass/fail performance targets
- Automated evaluation
- Complex subjective performance targets
- Manual evaluation
- New test case generation

Test case generation:
- Increasing amounts of data to manage
- Cloud-based virtual testing, verification & validation will be required throughout the development process.
- Ricardo introduction
- Ricardo CAV white paper overview
- Ricardo’s activities in CAV
Ricardo CAV Capability Summary

Pre-Concept | Concept | Development | Pre-Production | Post Launch

Functional Safety | Independent Safety & Cybersecurity Assurance | Cybersecurity | Vehicle control & Connected cooperative control | Energy management

Virtual Testing, Verification & Validation | Requirements, Architecture & Integration | Demonstrator / Concept vehicle builds | Electronics & Software | Technology / Market studies
Functional Safety for CAV

Overview

- Ricardo strong experience in functional safety (FuSa) engineering for a wide range of applications e.g. for automotive and rail using standards IEC 61508, ISO 26262 and EN5012x.
- Ricardo experience in both designing & developing safety critical systems as well as consultancy to advise new CAV suppliers what they need to do for functional safety.
- Ricardo actively involved in development of safety related standards including MISRA and ISO 26262.
- Functional Safety for CAV brings new challenges as new architectures required for fail safe/fail operational and existing standards not ready yet for driver out of the loop.
- Ricardo database of FuSa processes, template, prompt-lists and wide experience of OEM/supplier approaches/projects.

Research interests

- Safety critical engineering
- System of Systems approach to CAV safety
- Advanced V&V techniques for high ASIL systems
- FuSa tools and processes
- Extension of existing standards to support CAV development
- New CAV E/E architectures

Selected Projects

- Confidential – Safety manager and safety support for high volume ASIL D system for passenger car.
- Confidential – FuSa support to HGV Platooning supplier.
- Confidential – FuSa support for automated warehouse parcel tug.

Capabilities

- Full lifecycle FuSa engineering activities
- Hazard Analysis & Risk Assessment
- CAV Functional Safety Concept
- Safety Analysis (FTA, FHA, FMEA, etc.)
- Gap Analysis / Process development
- Design Review & Audit
- Confirmation Reviews / Safety Assessment
Independent Safety & Cybersecurity Assurance for CAV

Overview

- Ricardo long experience of Independent Safety Assurance for the Rail Industry
- Including safety assurance for Personal Rapid Transport (PRT)/Group Rapid Transport (GRT)
- Capability extended to safety assurance for Connected / Automated Vehicles
- Approach developed combining rail standards (EN5012x) with automotive standards (ISO 26262)
- Safety assurance team brought together from broad range of Ricardo experts covering e.g. safety, electronics, software, infrastructure, HMI, CAV, rail, automotive to provide required depth of experience
- Extending assurance service to include cybersecurity

Research Interests

- CAV Independent Safety & Cybersecurity Assurance
- Extension of safety and cybersecurity standards for CAV
- CAV safety certification
- Extension of capability/service to new forms of mobility, e.g. Connected Automated Personal Transport (CAPT)

Selected Projects

- **Brussels airport driverless bus** – support for tendering process & safety assessment
- **WEpods driverless pod** – safety management & assessment
- **Masdar PRT** – independent safety assurance for Abu Dhabi driverless PRT
Cybersecurity for CAV

Overview

- Ricardo long experience in developing automotive ECUs and supporting OEMs with development
- Existing threats incl. via infotainment, over the air updates (OTA), eCall and smartphones
- Increasing interest in cyber security especially for CAVs due to the additional threats from mobile comms/wireless comms and potential for taking over driver assistance / automated vehicle control functionalities
- Cybersecurity requires collaboration with other industry cyber experts and combined approach for development lifecycles similar to safety lifecycles
- Ricardo collaboration with Roke Manor Research to develop solutions that will make automated and connected transport robust against cyber attack

Research interests

- Development of new tools, processes and assurance schemes for cyber security
- Development of testing & evaluation + cyberengineering services

Selected Projects

- 5StarS – aiming to develop a 5-star type consumer rating framework for automotive cyber security

Capabilities

CAV cyber security development
ECU security
Cybersecurity Assurance (under development)
Supporting tools & Processes (under development)
Vehicle control & connected cooperative control for CAV

Overview

- **Vehicle control**
  - Development of control algorithms for longitudinal and lateral motion control
  - Application of lidar / radar /camera to non automotive applications
  - Sensor fusion
- **Platooning Control Models & Simulation (PCAMS)**
  - White box control algorithms for longitudinal & lateral control vehicle control, LV & FV platoon control logic
  - Simulation environment to support desktop development
- **Connected vehicle**
  - Definition of V2V messaging for HGV platooning
  - Integration of connected technologies incl. V2P/wireless charging/wi-power technologies
- **Collaboration with partners for higher automation levels to provide complete prototype through advanced engineering service**

Research interests

- Resilient control architecture
- Human-like behavior
- Movement prediction
- Machine learning

Selected Projects

- **SARTRE** – Full design & demo of 5 veh platoon on public highway
- **Confidential** – Designed, developed and implemented a full autonomy actuation system for a small electric vehicle
- **Confidential** – Automated Vehicle using DSRC Communication
Energy management & Prognostics for CAV

Overview

- How to optimise energy usage for a CAV or fleet of CAVs.
- Ricardo has many years experience of developing optimal and predictive control strategies for automotive powertrains and vehicle including optimal control, model predictive control & reference governors.
- Electronic horizon control algorithms
  - E-horizon problem can formulated as an optimal control or predictive control problem and solved online
  - Typical Ricardo project involves modelling, optimisation, control, development to production processes, vehicle integration
- Research interests
  - Machine learning techniques using Big Data for vehicle prognostics for improved servicing & maintenance
  - Optimisation at vehicle, fleet, grid level
  - EV range optimisation
  - Electronic horizon
  - Real-time, cooperative optimisation

Capabilities

Energy management
Optimal & Predictive control algorithms
E-horizon algorithms
Machine Learning for Big Data Prognostics
Modelling & Simulation
Vehicle integration

Selected Projects

- Footlite – eco-driving vehicle demonstrator
- Sentience – predictive Powertrain control
- Confidential – Platooning Control Strategies and Simulation for Asian Truck OEM
Virtual Testing, Verification & Validation for CAV

Overview
- Ricardo long experience of verification & validation, testing and simulation
- Extra challenges with CAV require new approaches to modelling & V&V for functionality, safety, security, new ADAS/V2X simulation tools becoming popular such as PreScan/VTG
- Platooning Control Models & Simulation (PCAMS) Simulation environment (based on Trucksim)
- Advanced techniques for safety critical verification
  - Simulink Design Verifier (SLDV)
  - MBAT and PICASSOS formal methods research projects

Research interests
- System development
- Verification & validation
- Performance evaluation
- Test case generation
- Agent Based Modelling

Selected Projects
- **MBAT** – Model Based Analysis & Test
- **PICASSOS** – Proving Integrity of Complex Automotive Systems of Systems
- **Confidential** – agent based modelling for real world CAV modelling

Capabilities

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Selected Projects

| MBAT – Model Based Analysis & Test |
| PICASSOS – Proving Integrity of Complex Automotive Systems of Systems |
| Confidential – agent based modelling for real world CAV modelling |
Overview

- Full vehicle systems design and development capability
- Systems Engineering
  - Requirements, specifications, process optimization, design, testing, prototypes, validation, SOP support
  - Concept Definition
  - Architecture & Layout
  - Performance / Simulation
  - Functional Safety
  - DV / PV Testing & Validation
- Systems Integration & Packaging
  - Sensors
  - Controllers
  - Actuation HW
- Demonstrators & Development Vehicles
- Project Management & Delivery

Research interests

- Fault tolerant/fail operation architectures

Selected Projects

- TaxiBot – complete system design for steer-by-wire aircraft tractor
- Confidential – concept study for large L4 automated industrial vehicle
Demonstrator / Concept Vehicle Builds for CAV

Overview

- Customer need for demo / concept vehicles driven by range of needs from wanting to have a vehicle to showcase some new CAV technology to wanting to develop a proof of concept or prototype vehicle.
- Ricardo wide experience in range of vehicle demo builds and draws on Ricardo strengths including vehicle, electronic, harnessing and control software.
- Size of projects vary widely from simple integration of component to extensive vehicle conversion and development.
- CAV demos
  - System requirements/vehicle selection
  - System design/architecture
  - Sensor selection/integration
  - Safety approach appropriate to demo
  - CAN and other network discovery, performance and integration
  - Driver-by-wire actuator selection/integration
  - V2V WifiP/mobile communications
  - Vehicle Control

Selected Projects

- **Drivewise III** – steer by wire safety demonstrator
- **Confidential** – proof of concept demonstrator for automated train coupling system using automotive lidar + radar sensors
- **Confidential** – DSRC V2V demonstrator for ITS World Congress
Electronics / Software for CAV

Overview
- Customer need for customer electronics / software to glue together various new technologies / fill the gaps between supplier offered components / bridge the interfaces
- Services typically offered as part of demo or prototype vehicle project
- Ricardo wide experience in custom electronics and software design as well as use of rapid prototyping ECUs such as Ricardo rCube2, or dSpace MicroAutoBox
- Example services:
  - Porting of software to Automated Driving ECU for research to production migration path
  - AD controller selection
  - Custom gateway ECUs to interface to conventional powertrain components
  - Custom hardware & software design
  - Software of glue/low-level software
  - Supply/use of rapid prototyping ECU
  - Low volume hardware manufacturing & supply

Research interests
- Safety critical software

Capabilities
- System requirements and definition
- Functional safety analysis
- Control strategy development
- Electronic circuit, layout and PCB schematic design
- Mechanical enclosure design and thermal analysis
- Rapid prototyping
- Design validation and production validation
- Full design to production support

Selected Projects
- Confidential – supply of rapid prototyping controller & software for automated train coupling system demo
- Sentience – rapid prototyping controller, custom interface box & software for eHorizon demo vehicle

rCube2 RPC
Technology / Market Studies for CAV

Overview

- Ricardo provides range of services to help customers with their CAV technology strategy and development
- Technology strategy
  - Road-mapping
  - Market analysis/technology trends
  - Technology assessment
  - Access to Ricardo knowledge, market analysis and expert opinion
- Technology Feasibility
  - Scenario modelling
  - Performance, cost & risk trade-offs
  - Define technology mix
- Technology demonstration
- Technical Support Agreements (TSA)
  - for Q&A / small support projects
- Ricardo Automated Vehicle Update
  - Quarterly publication of ADAS/AV abstracts and opinion

Capabilities

- Technology strategy
- Technical Support Agreements (TSA)
- Ricardo “Automated Vehicles Update”
- Advanced technology development
- Technology Feasibility
- Technology Demonstration

Selected Projects

- Confidential – ADAS strategy for bus manufacturer
- Confidential – future ADAS technology study for Asian truck OEM
Project Examples – CAV Engineering
Ricardo has extensive experience in combining innovative business solutions with large scale project delivery to enable significant and accelerated strategic change

Cooperative control platooning project
- Lead vehicle driven by trained professional driver, following vehicles have automated driving
- €6.4M EU co-funded FP7 project, seven partners
- Ricardo responsible for: Project lead & coordination, safety analysis based on IEC61508/26262, platoon control system incl. longitudinal and lateral control strategies
- Successful platoon demonstration on public roads

Safety management and assurance for “WEpods”
- First driverless vehicles on public road in the Netherlands
- Safety management & assurance support including:
  - Writing the Safety Plan & Safety Case
  - Helping the project team ‘do the right thing’ - Hazard identification sessions, Reviews of specifications & Use Cases, Gathering and Writing safety evidence
  - Performing FMEA

Steel mill slab yard automation
- Client using customer built slab carriers to transport 20t steel slabs from continuous casting machines to slab sorting fields & various processing facilities
- Client looking to replace ageing vehicles with newly designed automated vehicles which will operate in a new automated slab yard environment
- Ricardo proposal to develop new slab carrier vehicles and slab carrier automation

Production L3 Highway Pilot Support
- OEM developing L3 highway pilot system for passenger car mass production.
- Sensor fusion system being developed by EU supplier
- Ricardo support to ensure quality of supplier development focusing on R&D + development phase
- Ricardo supporting software, hardware, diagnostics, comms, functional safety & ECU mech design.

Aircraft Towing Tug Development
- Pilot controlled aircraft tug to allow aircraft ground movement without engines
- Mechanical and electronic control systems design and development
- Autonomous steering and steer-by-wire systems
- Vehicle build, validation and sign off to aerospace standard
- Production launch support

TTI Platooning Demonstrator Project
- US federal government looking to develop platooning demonstrator to explore technology and benefits
- Consortium consists of partners incl. OEM, EPAS supplier, V2x DSRC supplier
- Sensor fusion supplier unit consists of integrated radar, camera, brakes and safety controller
- Ricardo responsible for platoon control system integration incl. demonstration