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Construction Research and Innovation

ISSN: 2045-0249 (Print) 2475-6822 (Online) Journal homepage: http://www.tandfonline.com/loi/tcri20

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To cite this article: David Smith (2017) Robocar versus the Pod: A commentary on the state of play in the race for autonomous vehicle commercialisation, Construction Research and Innovation, 8:2, 60-65, DOI: 10.1080/20450249.2017.1337849

To link to this article: https://doi.org/10.1080/20450249.2017.1337849

CONSTRUCTION RESEARCH AND INNOVATION, 2017
VOL. 8, NO. 2, 60–65
https://doi.org/10.1080/20450249.2017.1337849

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David Smith

Two very different visions of the future of autonomous vehicles are emerging. In one camp are automobile manufacturers questing for "driverless cars", hyper-intelligent and all-seeing machines that promise to make car ownership sublime. In the other camp are state actors interested in more modest vehicles – pods – that could change the paradigm of urban public transport. The UK is investing millions of pounds to incubate the latter, and a consortium led by US multinational engineer Aecom was recently given £4.2 million to conduct trials of a "pods-on-demand" service in London. In interviews with CRI, consortium members outline what they see as the advantages of the pod approach, including an emphasis on connectivity over the ruggedly individualistic focus on autonomous artificial intelligence. Challenges include how the built environment can adjust to such a new paradigm, and cyber security. This article surveys the terrain of autonomous vehicle development from the perspective of this race to commercialisation.

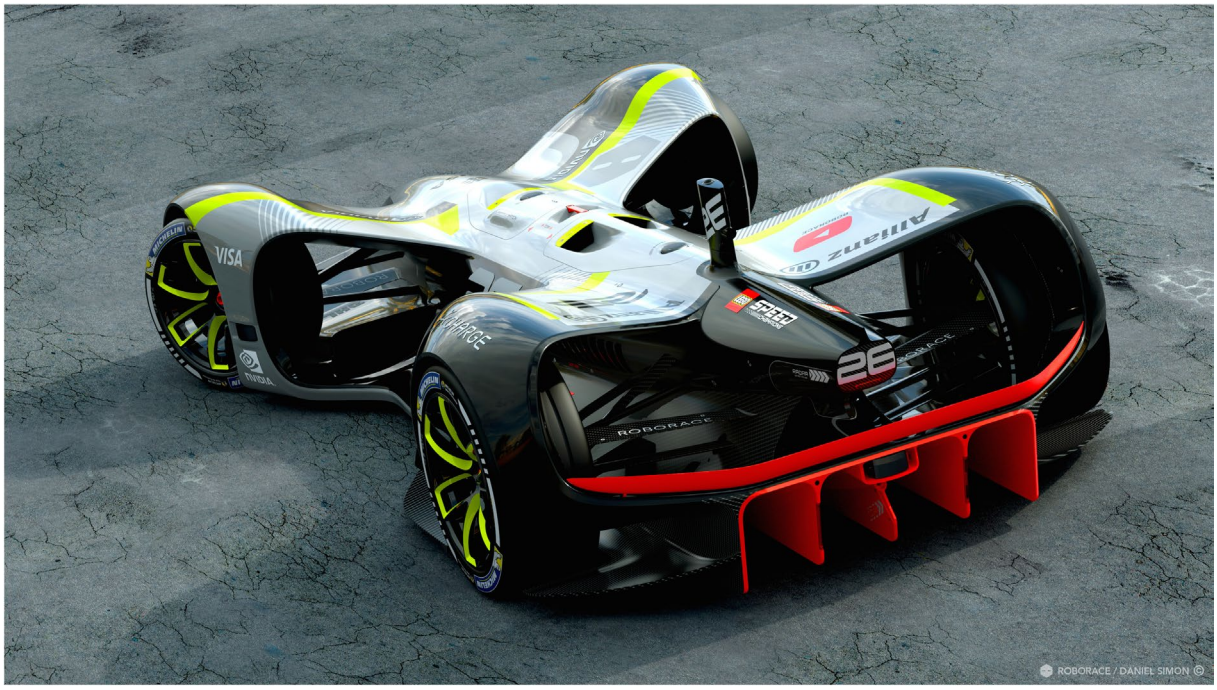

Figure 1. The Robocar, a fully-autonomous race car, completed a 1.9km circuit in Paris in May this year (© Roborace/Daniel Simon).

Motoring history was made on May 20, 2017 when a self-driving race car completed a 1.9km circuit in front of crowds at Les Invalides in Paris, all by itself. Dubbed "Robocar", it was developed by a team pulled together by the London-based high-tech investment fund Kinetik in its bid to launch a new type of motor sport – Roborace – in which driverless cars go head-to-head in a clash of speed and artificial intelligence (AI). Robocar was designed by the automotive futurist Daniel Simon, creator of vehicles for Hollywood sci-fi blockbusters. With four, 300kW motors, its developers say it can reach speeds of 200mph. In the driver's seat is a supercomputer from graphic chip-maker Nvidia. Its Drive PX2 "brain", processes inputs from five lidar sensors (light detection and ranging), two radars, 18 ultrasonic sensors, two optical speed sensors, six AI cameras, and a

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global navigation satellite (GNS) positioning system. So powerful is this brain that it can crunch data at a rate of 24 trillion AI functions per second, Kinetik says.

On the day, though, observers had to settle for imagining all this thrilling potency because, with so much to learn on its maiden circuit, Robocar crept along the route "slowly and tentatively", "like a teenager on their first lesson", as an eye witness from *The Telegraph* put it on 28 May. Nevertheless, capturing global attention with its promise of speed and superhuman smarts, Robocar is intended as the aspirational ideal of the driverless future of the automobile. "This needs to be the superhero of self-driving cars," designer Daniel Simon said at Robocar's unveiling two months earlier in Barcelona, adding it would be "an ambassador for this amazing rise of artificial intelligence."

Robocar represents one of two divergent streams in the development of "connected and autonomous vehicles", or CAVs, and it tends to get the lion's share of media attention as major car makers like Jaguar Land Rover, Nissan, Audi, and electric vehicle-maker Tesla get drawn into the race to produce driverless, or self-driving cars. The hype is not surprising. These manufacturers have deep pockets to publicise their efforts, and they fire our imaginations with a future of road travel that looks a lot like today, only much better. In this vision we own cars that look like normal cars but which are self-taught and all-seeing, driving us around more safely than we can ourselves, freeing us to prepare for meetings, to sleep, or to day-dream.

The second stream is mundane by comparison. It envisages poky little "pods" that pootle along unassumingly at 15mph, cleanly and efficiently getting people from A to B in close urban environments. Though less glamorous, this stream envisages a much more profound shift in what cars "mean". It allows the possibility of an end to private car ownership, with its associated problems of traffic, pollution and the need to reserve vast swathes of the urban realm for parking. Many now dream of stepping onto the street and summoning a pod with a phone. The pod detaches itself from the stream of circulating CAVs and lets you in. Instructions and payment are handled instantly also by phone. In quieter periods, surplus pods take themselves to out-of-town depots to be cleaned, maintained, and to wait for a resumption of demand.

For some time now analysts and corporate visionaries have been dreaming up potential business models for "MaaS" (mobility as a service) or "TaaS" (transport as a service). A pioneer is Finland, whose government submitted a bill on May 24 this year to prepare the ground for a new, open, digitalised market for mobility provision in the country. The "Act on Transport Services", says the transport ministry on its website, creates the preconditions for opening the public transport market to new players who are able, with a variety of different vehicle types, to get people around more efficiently. Such preconditions include the interoperability of information systems. Many see CAVS, and pods specifically, as an obvious answer to this challenge. Singapore, for instance: in 2014 its government set up a Committee on Autonomous Road Transport to devise a way forward, seeing CAVS as key to making the city state more liveable and sustainable.

So a kind of race to commercialise is underway between Robocar, or the stream it represents, and the humble pod. Many back the pod, partly because of its potential to ease some of the most intractable problems facing cities, and partly because there may be money in it. One such backer is the UK government. Hoping to incubate a new industry to catch what it sees as a gathering, a global wave, it has made £35 million available to industry consortia who come up with good R&D proposals for developing CAV technology and applications.

Dipping most recently into this pot of cash is a consortium of 20 organisations led by US multinational engineer, Aecom. This group, called CAPRI[1], successfully bid for £4.2 million in order to run trials for a "pods-on-demand" (POD) type of service, culminating in tests "in the wild" at London's Queen Elizabeth Olympic Park. In interviews with CRI, consortium members outlined what they see as the advantages of the pod direction of travel. These include an emphasis on connectivity, whereby the CAVS are in constant touch with other vehicles and transport infrastructure, over the ruggedly individualistic focus on autonomous AI, so celebrated in Robocar. (A misplaced faith in this AI may have led to the death last year of an early user.) Revenue streams from a pod-based MaaS and TaaS business models are another advantage. Challenges, of course, remain, including how the built environment needs to adjust to accommodate pods, and security, both cyber and physical, will be a tough nut to crack.

No car is an island

Predictions of when we'll see true CAVs of any kind on our roads vary wildly, from three years to decades. McKinsey (Heineke et al. 2017) a business consultancy, states confidently that we won't see fully autonomous vehicles available in the next 10 years. It says car manufacturers need to put "dramatically more effort" into solving many of the technical challenges, including dealing with weather, like snow, that obscures visual prompts, and negotiating the driving patterns of both human drivers and other CAVs. "Development timelines have stalled given the complexity and research-oriented nature of the problems," McKinsey said. What impressed

[1]The award was announced in April 2017. CAPRI stands for "Connected & Autonomous POD on-Road Implementation". The consortium comprises Aecom, AXA, Burges Salmon, Conigital, dynniq, ESP Group, Fusion Processing, Heathrow, Loughborough University, NEXOR, Queen Elizabeth Olympic Park, South Gloucestershire Council, Transport Simulation Systems, University of Warwick, University of Bristol, thingful, TVS, University of the West of England, Westfield and YTL.

the UK government about the CAPRI bid, however, was its argument that pods could be up and running on British roads well ahead of driverless cars.

One of the CAPRI companies is Thingful, an Internet of Things (IoT) data search and interoperability services company, which is leading on the connectivity aspects of the project. Its chief operations officer, Moeen Khawaja, says media distort the picture by focusing on the glamour of self-driving cars, while the socio-economic drivers of pods are deeper and more urgent. Pods, he argues, have huge commercial potential to help people with restricted mobility, such as the more than 30 million blind people and five million wheelchair users in Europe. "If you have an Uber style app you can make a strong mobility case for the elderly and disabled," he says.

But there is another reason why pods could end up in service ahead of autonomous cars, according to Khawaja. He says most car manufacturers are neglecting the importance of connectivity among CAVs and between CAVs and their environment. The thrust of self-driving car development is the ability of the vehicle's own "brain" to make sense of and learn about its surroundings using data from cameras, lidar, radar and ultra-sound. As exciting as these developments are, Khawaja worries that the near infinite combinations of phenomena in the physical world may be too much for AI. Connectivity, the argument goes, allows CAVs to speak to each other and "cooperate". But Khawaja says car makers are afraid to embrace open connectivity. "They worry that tech players like Google would eat them alive if they let them into the operating systems and they would be relegated to making parts," he said.

The problem with marginalising connectivity is that it reduces the amount of information available to the vehicle as it attempts to understand its environment. It forces the AI to attempt to discern a vast array of objects and behaviours. Will it know what a tandem bike is? How an old man behaves on an electric scooter will differ from how a child behaves on a bike. There's always the danger that the AI system encounters a situation it's never seen before, especially in the chaotic road environments of rapidly growing cities in developing countries like India.

The perils of early over-reliance on AI were made apparent in May last year when one of Tesla's cars, a Model S, which is equipped with Tesla's branded Autopilot self-driving system, crashed into a truck at 74mph, killing the human occupant, Joshua Brown, on a state highway in Florida. The car ran straight into the side of the truck at an uncontrolled intersection. "Neither Autopilot nor the driver noticed the white side of the tractor trailer against a brightly lit sky, so the brake was not applied," Tesla wrote on its website after the accident. Eight months after the crash, no doubt to the relief of Tesla chief executive Elon Musk, federal auto-safety regulators said they had found no defects in the car's self-driving system. They decided that Brown had been to blame because he had not been paying attention: the last recorded driver action was Brown increasing the cruise control speed to 74 mph less than two minutes prior to impact.

Figure 2. And the pod: RDM's Lutz Pathfinder pod, used for initial trials in Milton Keynes, which ended last year (Credit: RDM Group).

It is important to note that Tesla does not claim Autopilot is a fully functioning self-driving system. Instead, Tesla says, it is "an assist feature that requires you to keep your hands on the steering wheel at all times" and, further, that it is "still in a public beta phase before it can be enabled". If the system detects no hands, the car slows. This is why the US National Highway Traffic Safety Administration found no fault with Autopilot. It said Autopilot had proved adept at preventing Tesla's cars from rear-ending other vehicles, but situations involving cross traffic – such as in the Florida crash – were "beyond the performance capabilities of the system".

Data driven

The accident can be seen to confirm the conclusions of the 2017 McKinsey report on automotive cars – that autonomous technology is not close to being ready for every unexpected occurrence on the roads. But Khawaja says there are also lessons about the value of connectivity for autonomous vehicles. He says that if the Tesla car had been connected to the transport infrastructure around it, including other vehicles, it could have received a "cooperative message" from the truck letting it know what it was doing. "The car would have slowed down. It would not have had to rely only on the machine learning algorithm for information," he said.

The CAPRI pod project has emphasised connectivity more than any other pod project to date, says Lee Street, Aecom's Director and Head of Technology Europe. Street says other pod projects have taken the approach favoured by most of the car manufacturers to automation, focusing on developing lidar, radar and cameras to create 3D images of where they're going. But what these vehicles can do is relatively unsophisticated. They are able to follow white lines and evade obstacles, but they're not truly intelligent and they behave "robotically", he says.

They can't re-route if they perceive a hazard and they are confined to designated pathways. Unlike conventional drivers they can't decide to drive more aggressively in heavy traffic, or more meekly in the countryside. The aim for the CAPRI pods is to make them more flexible and adaptable so they don't need to stick to pre-defined pathways, Street says.

Thingful is probing connected data flows for CAPRI. This means equipping them to communicate with the public infrastructure around them, which could include everything from public transport systems and weather stations, to parking meters and municipal rented bikes. The pods themselves will produce more data about speeds, passenger numbers, the location of stops, and other vehicles on the road. Thingful will work with its consortium partner Dynniq, the Dutch transport infrastructure giant, to create a "connector" for the cooperative messaging system. Khawaja says his research will be guided by the EU's policy programme to create a common connectivity corridor across the EU called "Cooperative-Intelligent Transport System (C-ITS)". This policy programme recommends a common communication standard (802.11p wireless) and common data messaging framework to enable data sharing between vehicles and infrastructure, also referred to as V2X. Even when the UK leaves the EU, the policy programme will still be relevant, he says, as the UK Government has signed up to the protocols.

"For CAPRI, we'll be studying the cooperative messaging from pod to pod, but also between pods and fixed infrastructure and between pods and the traffic infrastructure management system," he said. "Questions will include can the pod make sense of the weather sensors around it? Can it find out about parking meters and parking notifications and make use of that information? Can it share that information with other parties such as Transport for London?"

Losing interest in cars

Starting later this year, CAPRI will run four separate trials on the pods, which are designed by Westfield Sportscars. The trials will progressively ramp up the "difficulty" for the pods. The first will be on private land at Filton Airfield, near Bristol. The second will test a public mobility service in a shopping centre car park to assess performance in busy pedestrian areas. The final two trials will be at the Queen Elizabeth Olympic Park, a large estate that includes retail, recreation, residential and business centres. CAPRI will test the pods on a network of roads with the service interacting with traffic control systems. If they succeed in making the pods work, Aecom's Lee Street hopes to be able to commercialise the concept.

The goal is to create commercial services catering for the last mile or two of a person's journey. Early applications might be relevant to business parks, airports and event centres. One idea is to test the pods as a MaaS application. The biggest advantage of the concept is its social inclusivity, Street says. "When people can't afford a car, or they're too young, or elderly and lacking confidence, they could have shared use of it and wouldn't need to own a vehicle," he said. Initially, such a concept would not require the entire network to be autonomous. The pods could be the first autonomous vehicles to be integrated; driverless cars could join them when they are ready.

Street's view is supported by a number of optimistic forecasters. A San Franciso thinktank, RethinkX, predicts (Arbib and Seba, 2017) that by 2030, within 10 years of regulatory approval of CAVs, 95% of US passenger miles traveled will be through on-demand autonomous electric vehicles owned by fleets, not individuals. The drivers for this shift to MaaS/TaaS will be financial. Using TaaS, the average US family would save more than US$5,600 per year in transportation costs, equivalent to a wage raise of 10%. Pre-TaaS platform providers like Uber, Lyft and Didi are already engaged, and others will join this high-speed race, predicts RethinkX. Fleets will transition to autonomous electric vehicles with far lower maintenance, energy, finance and insurance costs. "As a result, transport-as-a-service (TaaS) will offer vastly lower-cost transport alternatives — four to ten times cheaper per mile than buying a new car and two to four times cheaper than operating an existing vehicle in 2021," state Arbib and Seba.

A PwC report (Viereckl et al. 2016) on connected vehicles also supports the idea that urban residents in Western markets are losing interest in owning their own cars. The trend is exacerbated by the desire to move to urban areas. "Cars simply aren't a requirement, and public transport and ride-sharing apps can easily fulfil their needs", especially, perhaps, for Millennials, the authors said.

Testing times

An awareness of the changing nature of transportation is behind the thinking on several other pod projects being funded by the UK Government. This year, in Greenwich, London, the GATEway electric shuttle vehicles will carry up to six people at a time at 12mph. The shuttles will run on dedicated lanes and the aim is to connect residential locations, commercial areas and transport hubs using a zero-emission, low noise transport system.

Meanwhile, in Milton Keynes, the RDM Group, a tier one supplier of car computers, is trialling 40 of its Pod Zeros later this year as part of the UK Autodrive project, which has received £19.2 million from Innovate UK for a three-year project to integrate CAVs into urban environments. The Pod Zeros are connected to each other, but, unlike the CAPRI pods, not to ambient traffic infrastructure. Their creators argue that further levels of connectivity are not essential for short journeys at low speeds.

RDM entered the pod market three years ago with the Lutz Pathfinder. It was successfully trialled on the pathways, underpasses and shopping areas of Milton Keynes last year. But this year's trials are on a whole new level, according to Miles Garner, an RDM Group spokesman. The Lutz Pathfinders had steering wheels and drivers to take over if something went wrong. The trials were carefully controlled and members of the public were not involved. But the Level 5 automation Pod Zeros have no steering wheels and no one to take control. Members of the public will be invited to hop in and provide feedback on the experience. There is a strong commercial angle to the interiors. Video screens can play adverts, information videos, or simply show the view outside. RDM's CEO David Keene says the company has already received more than £15 million in orders for pods from around the world, from smart cities, to golf courses, and he says the potential market is "worth billions".

RDM has opened up offices in Texas and Adelaide, judging there to be strong interest in CAVs in the US and Australia, and Garner says RDM is in talks with local governments in these countries about deploying pods in new eco-towns under construction. He says planners are contemplating building dedicated low speed transport lanes for electric shuttles that run alongside pedestrian walkways. There are further projects underway to integrate RDM pods into large malls in the Middle East. The advertising possibilities in such a context are strong, he says. "Passengers can be shown ads on screens, such as 'special offer on drinks at Costa Coffee on the right'. They can hop on and off," he said.

Vulnerable to hacking

Although the risk of a fatal collision at 15mph is low, cyber security is a major concern. "It's vital to protect the pods, and it's important for the Government because it has wider repercussions for all connected vehicles," said Professor Carsten Maple, Professor of Cyber Systems Engineering at the University of Warwick, who is in charge of cyber security for the CAPRI project.

Maple says only a handful of British universities are studying cyber security and he is frequently asked to get involved in consortia projects. But he decided to work on CAPRI because it will allow him to research defences to both electronic and physical attacks. Electronic attacks could be made on the AI systems that communicate data to the cloud, or in the cloud itself, while physical attacks could target the sensors and actuators that allow the pod to understand its environment – by, for instance, training a laser light on the machine vision system. "If the pod is blinded because the sensors are not working we have to make sure it is failsafe and doesn't run someone over," he said. "There are also methods of using small jammers to stop radar working and disabling the ultrasound."

Riddled with software and connected wirelessly to the internet, cars are already vulnerable to cyber attack. He

Figure 3. Aecom's Lee Street in a CAPRI-branded pod, to begin testing this year (Credit: Aecom).

pointed to the 2015 experiment, reported by the magazine *Wired* (July 21, 2015), in which computer researchers used a laptop to seize control of a Jeep Cherokee miles away, cutting the brakes and transmission at the flick of a switch, while it was driving. The pair used a bug in the car's entertainment system, which was connected to the internet, to tunnel into the car's internal network. A few days after the article appeared in *Wired*, Fiat Chrysler issued a safety recall affecting 1.4 million vehicles in the US.

Even more relevant to the safety of the CAPRI pods were experiments carried out in 2016 by researchers from China's Zhejiang University, the University of Carolina and Chinese security firm Qihoo 360 (Chen Yan, 2016). The researchers found ways of attacking many of the typical sensors on self-driving Tesla and Audi models. For example, they jammed the cars' ultrasound system by drowning it with a loud enough burst of ultrasound. Rather than assuming there was an object out in front, both cars acted like there was no obstacle for half a kilometre and crashed into a person (albeit at slow speed) standing in front of the jammer. The researchers also built a machine to interfere with the radar system and effectively made another car disappear from the Tesla car's view. In the case of the CAPRI pods, it may be possible for the data gathered from the connected elements to provide information that overrides what the radar, or ultrasound systems, are telling the vehicle. This is one subject for study.

In the end, security is one of the most important elements in winning public trust, according to Lee Street. "One of the hardest things to crack is public acceptance that the pods can be used in a commercial manner which is why we are focusing hard on making the environment safe for the pods," he said.

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