EXPLORING INTELLIGENT MOBILITY

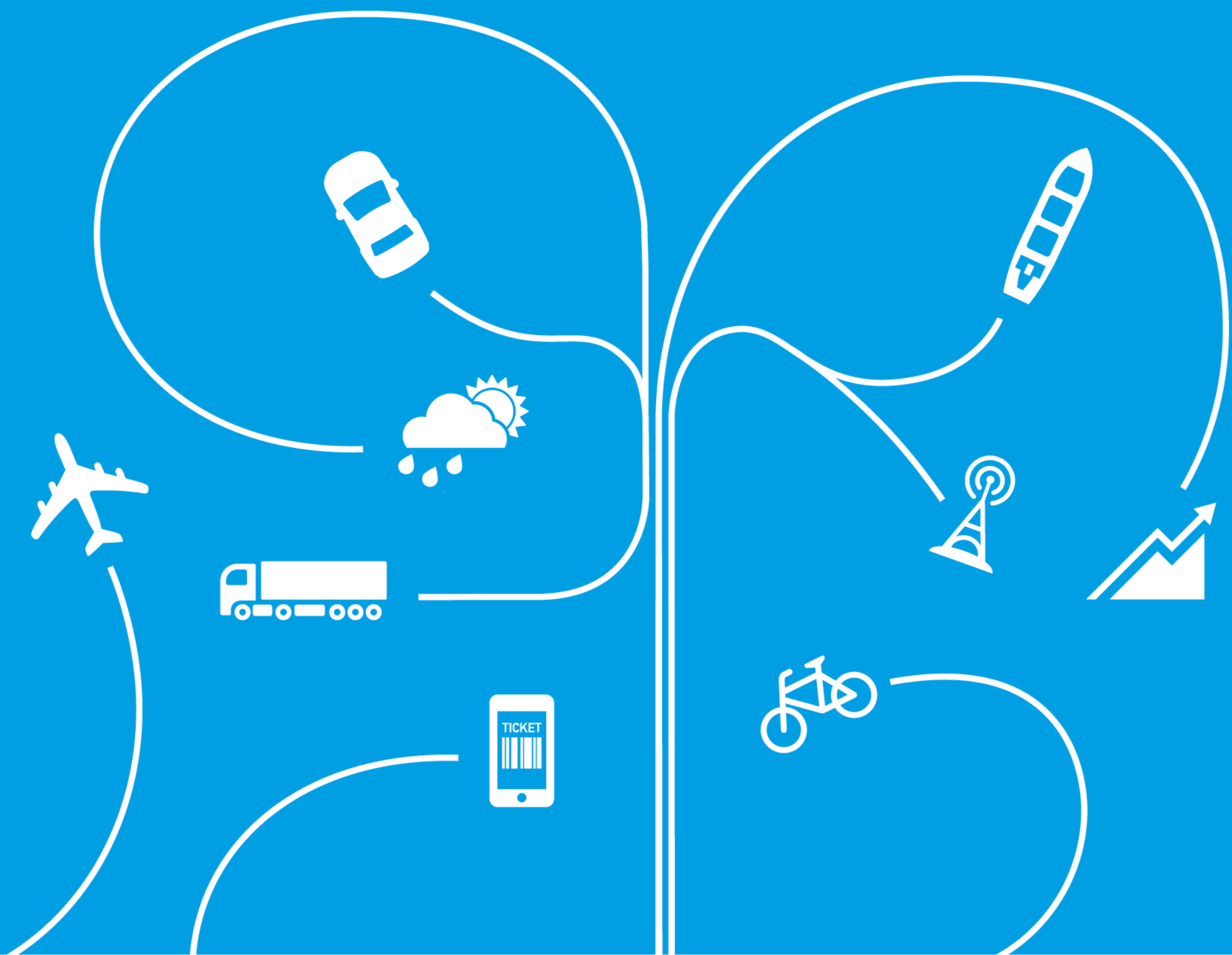
CATAPULT Transport Systems

Station Innovation 2

Work Package 7:

Connected and Automated Vehicle (CAV) Impact

March 2017



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Acronym List

ADAS	Advanced Driver Assistance System
APS	Assisted Parking System
ATO	Automated Train Operation
AV	Automated Vehicle
CAV	Connected and Automated Vehicle
C-ITS	Cooperative Intelligent Transport Systems
CV	Connected Vehicle
DfT	Department for Transport
ERTICO	European Road Transport Telematics Implementation Co-ordination Implementation
ERTMS	European Rail Train Management System
ERTRAC	European Road Transport Research Advisory Council
ETCS	European Train Control System
GDPR	General Data Protection Regulation
GRT	Group Rapid Transit
HGV	Heavy Goods vehicle
HMI	Human Machine Interface
ITS	Intelligent Transport System
OEM	Original Equipment Manufacturer
ORR	Office of Road and Rail
NR	Network Rail
PRT	Personalised rapid Transit
QoS	Quality of Service
ROC	Regional Operating Centre
SMMT	Society of Motor Manufacturers and Traders
TSC	Transport Systems Catapult
V2I	Vehicle to Infrastructure

1 Introduction

1.1 Overview

This report summarises the output from Work Package 7 (titled 'Autonomous and Connected Vehicles Impact'); a deliverable of the Station Innovation 2 project which has been undertaken by the Transport Systems Catapult (TSC) on behalf of the Department for Transport (DfT).

This work package considers how Connected and Automated Vehicles (CAVs) may develop over the next decade and how these could be integrated with future station designs and operations in order to provide an efficient interchange in a multi-modal transport system.

The report is structured as follows:

- Section 2 sets out the background to CAVs. The definition of CAVs is outlined and the landscape of research and deployment activities with respect to CAVs is discussed. Different types of CAVs are be considered as they would operate in different ways and address different segments of the travelling public market.
- Section 3 considers the potential timescales to CAV deployment and their uptake. This is based on a literature review of various expert opinion together with analysis of publicly available study outputs. It also maps these timescales against major rail schemes that include new station implementation.
- Section 4 presents an overview of the opportunities and implications for CAVs at railway stations.
- Section 5 provides analysis of practical opportunities and implications for four stations (used as case studies in the course of this work).
- Section 6 considers the implications and opportunities associated with fully automated trains.
- Section 7 considers current and projected passenger volumes and multi-modal traveller data for a particular case study station (in this case Milton Keynes Central) and to consider how this may change with various CAV deployment scenarios.
- Section 8 provides a summary of the report.

2 Background

2.1 Definitions

The term CAV can mean many different things. A vehicle might be automated to varying degrees, and / or connected to varying degrees. A broad definition of the two is as follows:

> **Connected Vehicles (CVs) (also can be known as Cooperative Intelligent Transport Systems (C-ITS)):** CVs refer to vehicles with increasing levels of connectivity which allows them to communicate with their surrounding environment (including the infrastructure and other vehicles). This could provide information to the driver about road, traffic, and weather conditions, and on routing options and enable a wide range of connectivity services. It could be argued that the term CV refers to a broader set of applications than C-ITS (including in car entertainment) so the two terms are not necessarily interchangeable but are closely related.
>
> **Automated Vehicles (AVs) (also known as autonomous, self-driving or driverless vehicles):** Vehicles with increasing levels of automation will use information from on-board sensors and systems to understand their location in relation to their environment and navigate through it with little or no human input for some, or all, of the journey. Road based vehicles are predominantly considered within this report.

Increasing numbers of vehicles are becoming connected, but it is worth bearing in mind that the majority of what are being referred to as AVs are not yet beyond the testing phase. There are some exceptions, such as partially automated passenger cars that enable automated highway driving under human supervision, or AVs (that are fully automated) that operate in segregated environments, such as the Heathrow Personalised Rapid Transit (PRT) system.

Combining connectivity and automation is desirable as AVs could use information from external sources to help inform decision making. This could, for example, involve instructions being sent from a control centre (with a human in the loop) to a vehicle, or it could be communications between a vehicle and a traffic signal controller. Connectivity could help automated vehicles to see beyond their sensors. Therefore connectivity and automation are often discussed together.

It is important to recognise that CAVs could be a disruptive presence in the transport sector. Professional drivers (e.g. taxis and bus drivers) could, at some point, be made redundant by the technology and many established industries, such as traditional public transport, insurance, vehicle repairs and maintenance may become obsolete or be forced to adapt to survive. In the same way that internet shopping is often cited as a reason for the decline in high street shops, the widespread introduction of AVs could have a number of consequences that at present are not immediately apparent.

The introduction of CAVs will be a complicated process, with many considerations. The challenges are not just technological, but there are also legal, environmental, economic, political and social considerations as depicted in Figure 1:

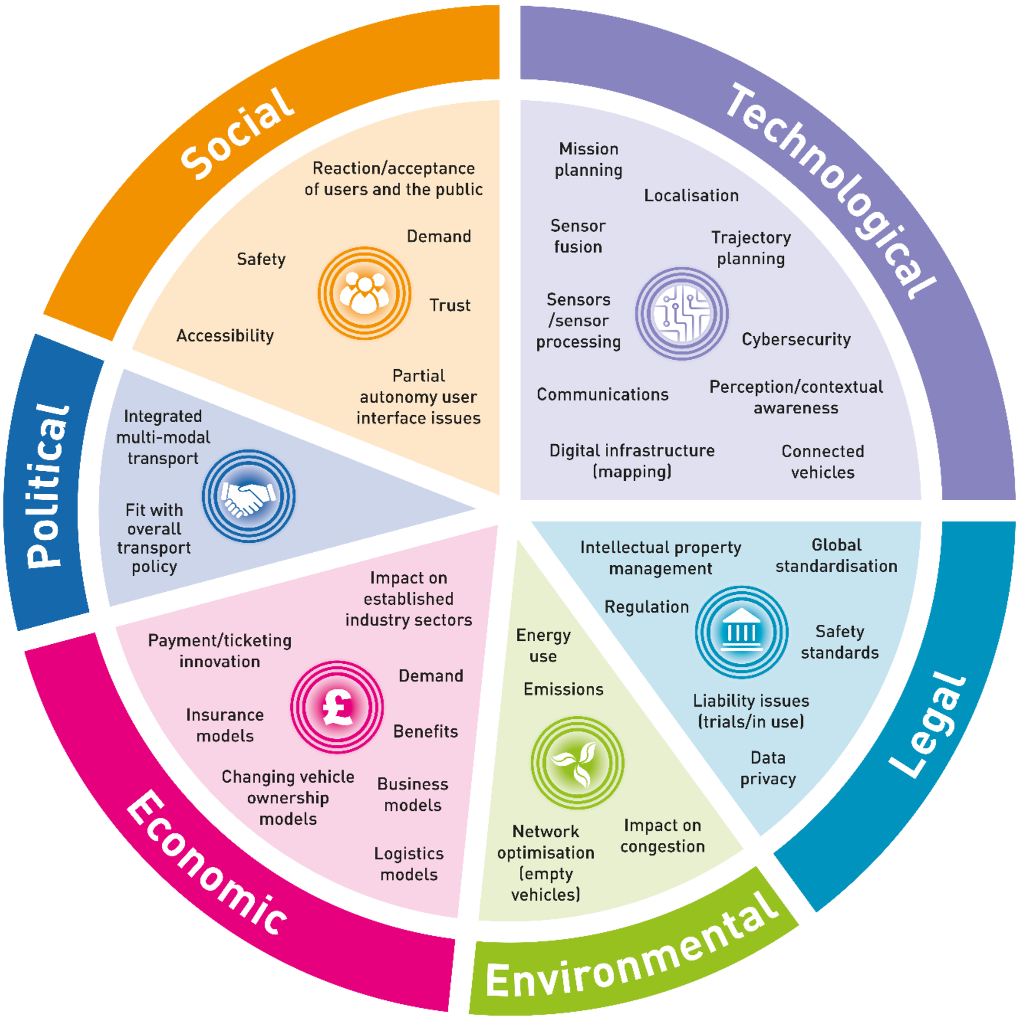


Figure 1: CAV Areas of Interest

2.2 Why CAVs?

The introduction of CAVs has been driven from several disparate sources. Some of the motivations for introducing CAVs are illustrated below in Figure 2:

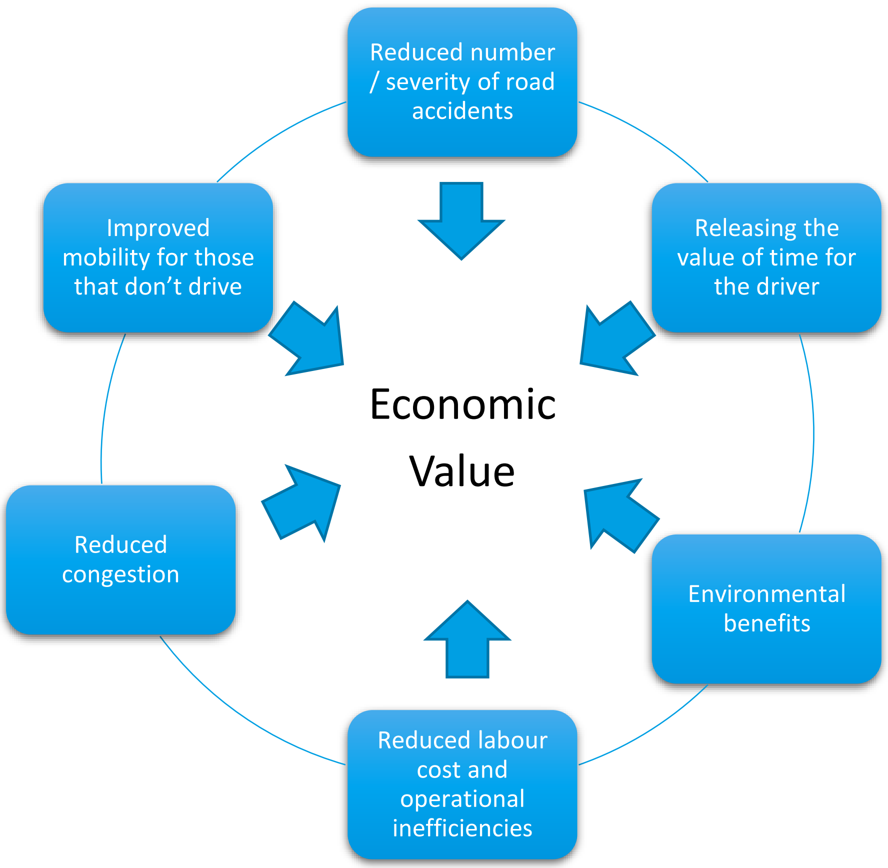


Figure 2: Motivations for CAV Introduction

Some of the above potential benefits are subject to debate and yet to be proven or quantified. There is little evidence yet that CAVs will actually lead to fewer road accidents, environmental benefits and reduced congestion, and there are indeed counter arguments that could suggest CAVs could lead to new induced demand and empty vehicle running that will lead to more vehicles miles travelled, not less. There are many issues concerning the interaction between existing road users and CAVs, so their introduction is unlikely to be a smooth transition. However, CAVs certainly have the potential to release driver time for other uses and improve mobility for those that don't drive, so these two aspects alone are sufficient reasons to be optimistic about their introduction.

2.3 CAV Use Cases

The term CAV can be used to describe many different types of technology, and it is helpful to classify these into a number of use cases. These might include:

- Privately Owned Passenger Vehicles with Advanced Driver Assistance Systems (ADAS) (SAE Levels 1-2);
- Privately Owned Passenger Vehicles with Connectivity;
- Highly Automated Privately Owned Passenger Vehicles (SAE Levels 3-5);
- Highly Automated Heavy Goods Vehicles (SAE Levels 3-5);
- Fully Automated Public Transport Vehicles (SAE Levels 4-5);
- Small fully automated delivery vehicles (could be footway based).

The SAE Levels of Automation referred to in the use cases above are detailed in Figure 3 below. The terminology used in the table is defined below the table for ease of reference.

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**

Figure 3: SAE Levels of Automation, SAE International / J3016

Definitions used in the above table include:

Dynamic driving task includes the operational (steering, braking, accelerating, monitoring the vehicle and roadway) and tactical (responding to events, determining when to change lanes, turn, use signals, etc.) aspects of the driving task, but not the strategic (determining destinations and waypoints) aspect of the driving task.

Driving mode is a type of driving scenario with characteristic dynamic driving task requirements (e.g., expressway merging, high speed cruising, low speed traffic jam, closed-campus operations, etc.).

Request to intervene is notification by the automated driving system to a human driver that s/he should promptly begin or resume performance of the dynamic driving task.

The CAV use cases that are considered to have most impact on the design and operation of rail stations include ***'Highly Automated Privately Owned Passenger Vehicles'*** and ***'Fully Automated Public Transport Vehicles'***. These are discussed in more detail below.

2.4 Highly Automated Privately Owned Passenger Vehicles

Figure 4: Highly automated passenger vehicle (image: Volvo Cars)

It is anticipated that vehicles will be able to take full control of the driving task without the need for a human in the loop to act as the fall back or fail safe mechanism. This will probably be realised initially in the simpler driving environments such as motorways. For example, as part of Volvo's 'Drive Me' project, due for launch in 2017, there are plans to put 100 automated cars onto the highways around Gothenburg with members of the public encouraged to perform other tasks whilst being driven by the vehicle, and there are further plans to run trials around London.

The important distinction between vehicles available now which have some auto-driving capabilities, such as the Tesla Model S with Autopilot, and *highly* automated passenger vehicles is that with higher levels of automation the driver can perform other tasks whilst driving, and does not need to monitor the vehicle. The Tesla Autopilot feature expects drivers to be ready to take control at any time.

However, it is widely agreed that it will be some considerable time before an organisation is capable of producing a true level 5 vehicle - a vehicle that can operate without a human driver on all roadway types and in all environmental conditions in the same way that a human currently can - which is deemed safe and reliable. Potential timescales to deployment are discussed further in Section 3. However, we should not exclude the possibility of vehicles that can operate within certain geographic areas, such as a specific town or area, without the need for a human driver at all. Such a capability might enable the owner of a vehicle to permit others to use it, for example children or friends and relatives that need picking up – *"Wait there – I'll send my car to come and get you!"* It could also enable an owner to use their own vehicle to get to work, and then allow their vehicle to join an CAV car pool club, so it effectively can operate as a taxi during the day when not required by the owner and hence potentially generate income.

Another aspect that could be affected by advanced CAVs is the willingness of occupants to travel longer distances. The commute to work may become more attractive if the occupant can sleep, work or be entertained en-route, and as such they may be willing to commute further. This could create an economic benefit in that it permits a more mobile work force, with people willing to take jobs that they otherwise might not have considered.

People might also be prepared to travel further for leisure purposes. If it's possible to sleep all the way from London to Scotland, for example, people could be more willing to set off late on a Friday evening and arrive early Saturday morning, having slept in the car. It's possible that cars could become adapted to better accommodate sleeping and entertainment.

Further into the future, it's possible we could then start to see different vehicle shapes and sizes that become more like mobile living / working environments, and vehicle designs could begin to radically change.

The cost of highly automated privately owned vehicles may prove prohibitive for those on low incomes to afford them, at least initially. A study by Boston Consulting Group[1] suggests that a car with full self-driving capability may cost $10,000 USD extra by 2025. This additional cost is expected to decrease with time as the technology scales and the cost of hardware and software falls on a per vehicle basis. Therefore, privately owned CAVs may be purchased predominantly by those on higher incomes initially and over time might become more widely used.

Of particular relevance to railway station design is the potential for vehicles to park themselves, which is discussed further in Section 4.

2.5 Fully Automated Public Transport Vehicles

Within this scenario, a fully AV would collect passengers and transport them to their destination, providing a demand responsive service which is somewhere between that currently offered by a bus (passenger service vehicle), taxi or private hire vehicle. Users would not necessarily own the vehicle, instead there would be a fleet operator and vehicles might have a secure communications link to a control centre. It's possible that vehicles could be hailed using a smartphone app or via a piece of street infrastructure.

Using a system of shared CAVs, the vehicles could start to operate like a PRT / Group Rapid Transit (GRT) system. Vehicles could operate 24 hours per day, and could be demand responsive, so public transport vehicles could be waiting for their passengers, rather than the other way around. It is anticipated that this type of solution would first be enabled in low speed urban areas and for certain routes. Over time, the range of possible routes and destinations could grow.

This is the focus of testing for projects such as City Mobil 2, LUTZ Pathfinder and GATEway, as shown in Figure 5.

City Mobil 2 demonstrations, Europe | Lutz Pathfinder project, Milton Keynes | GATEway project, Greenwich

Figure 5: A range of smaller passenger carrying AVs

[1] https://www.bcgperspectives.com/content/articles/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles/?chapter=4#chapter4_section5

If a system were to be developed that could operate over a wide range of destinations across a geographical area, the advantages over other modes of transport could include the following:

Automated Public Transport Vehicle vs Private Car	• In some circumstances, AVs could offer greater convenience as a AV could drop passengers at their destination and remove the stress and cost associated with parking. This could be attractive for railway stations where parking is often a challenge. • Reduced stress and cost of vehicle ownership. • No need to learn to drive. • Potentially safer.
Automated Public Transport Vehicle vs Taxi / Private Hire	• Potentially significantly lower cost than conventional taxis or private hire vehicles due to the lack of the need to employ a driver. • Could offer personal space and avoiding the need to share the vehicle with a driver. • Potentially safer.
Automated Public Transport Vehicle vs Bus	• Could offer direct origin to destination travel and avoid the need to interchange. Bus travel is often not an option for many journeys. • Could offer personal space and avoiding the need to share the vehicle with other passengers. • Potentially improved ride quality.

Figure 6: Advantages of Fully Automated Public Transport Vehicles compared to other modes

In the short term, an automated public transport vehicle could complement the traditional bus network. Being demand responsive, they may be able to provide viable public transport to areas of low demand, or provide orbital routes around towns that are not typically catered for by the bus network.

For railway stations and for the railway network generally, automated public transport vehicles could make the using the train easier and more convenient by helping to reduce the 'last mile problem' of getting from the point of origin to the railway station and getting from the railway station to the final destination.

It's possible that, except for children under a certain age who would need to be accompanied by an adult, automated public transport services could be used by anyone. In terms of the trip to / from the railway station there would probably be modal shift from all traditional modes of travel, including private car, taxi / private hire, bus, walking and cycling. The proportions would depend on local issues and the automated public transport service vehicle that is provided. It could be particularly attractive to those who do not have access to a car. Some choose not to drive, others are physically unable to drive. Improving accessibility for those that do not or cannot drive is one of the key benefits of automated public transport vehicles.

3 Timescales to CAV Deployment and Uptake

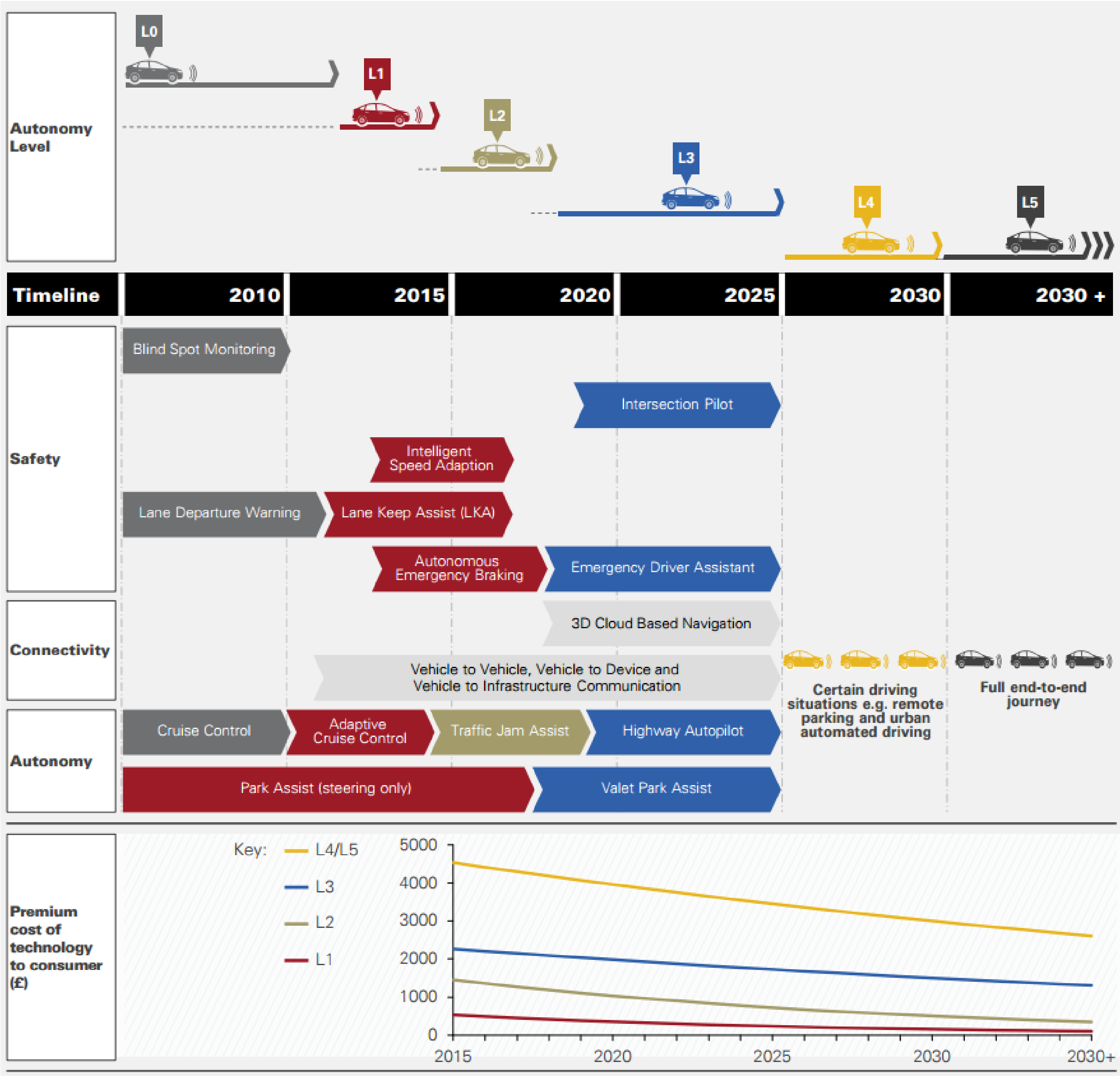
3.1 Introduction

It is useful for the purposes of infrastructure planning to have an indication of the potential timescales associated with CAVs. This section presents some relevant information to that effect. It discusses deployment timescale predictions made by prominent organisations, potential uptake of CAVs, and how CAV related timescales relate to timescales for planned railway station developments in the UK.

3.2 Technology Roadmaps

No one can be certain as to when fully AVs will be deployed on UK roads, and the rate at which their use will increase with time. Roadmaps for technology development and deployment have been produced by various organisations, which are a good starting point for attempting to answer this question. In March 2015, KPMG in conjunction with the SMMT published 'Connected and Autonomous Vehicles – The UK Economic Opportunity'[2]. The document included the following roadmap:

[2]http://www.smmt.co.uk/wp-content/uploads/sites/2/CRT036586F-Connected-and-Autonomous-Vehicles-%E2%80%93-The-UK-Economic-Opportu...1.pdf



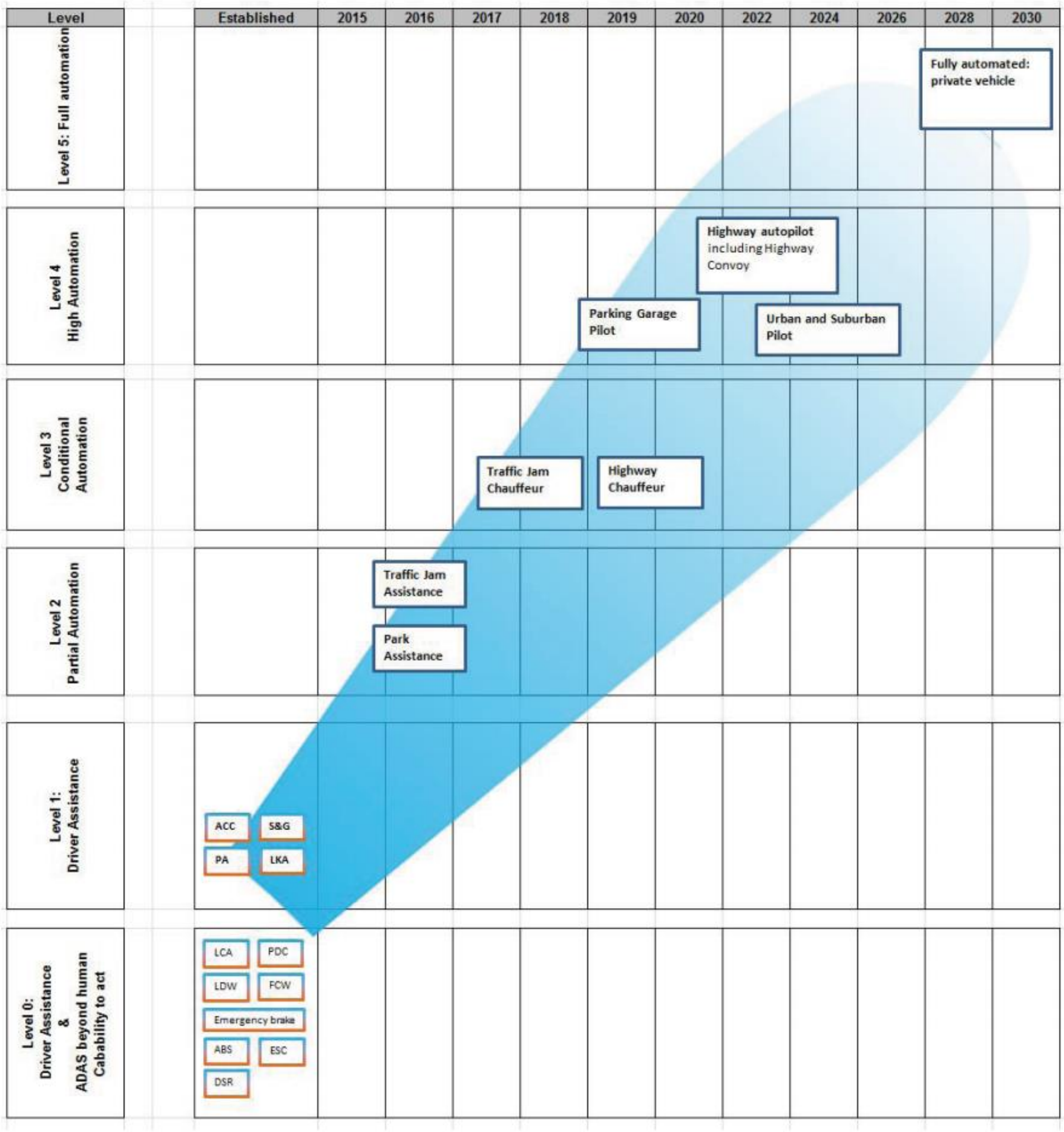
Source: KMPG, 2016

Figure 7: CAV technology road map

Therefore, this report suggests that remote parking and urban automated driving could be with us by 2030. Some question the assumption that the lower levels of automation will naturally evolve into the higher levels. Level 3 has a number of difficulties associated with sharing the driving task between the machine and the human, and some organisations such as Google and Ford are attempting to bypass Level 3 and jump straight to Level 4 or 5.

A report by European Road Transport Research Advisory Council (ERTRAC), titled 'Automated Driving Roadmap', was published in July 2015[3]. The following roadmap was produced for automation in privately owned passenger cars:

[3] http://www.ertrac.org/uploads/documentsearch/id38/ERTRAC_Automated-Driving-2015.pdf



Source: ERTRAC, 2015

Figure 8: The automated driving deployment path for passenger cars.

Looking at Figure 7 and Figure 8 together, both indicate that auto-valet parking will be with us between 2018 and 2025 (in Figure 7 it is referred to as 'Valet Park Assist' and in Figure 8 as 'Parking Garage Pilot'). KPMG suggested that remote parking could be implemented by 2030. This is assumed to mean a vehicle that can drive itself some distance along the public highway prior to parking itself.

Urban and suburban pilot is predicted to arrive around 2025, although it is assumed that a human driver might be needed for when the vehicle reaches the edge of its operational envelope, for example the edge of the geographically constrained area within which it can drive itself, or if environmental conditions require a handover to the human driver (such as heavy rain).

The same report included a road map for automated driving deployment in 'urban environment systems', which corresponds to the description in this report of automated public transport vehicles:

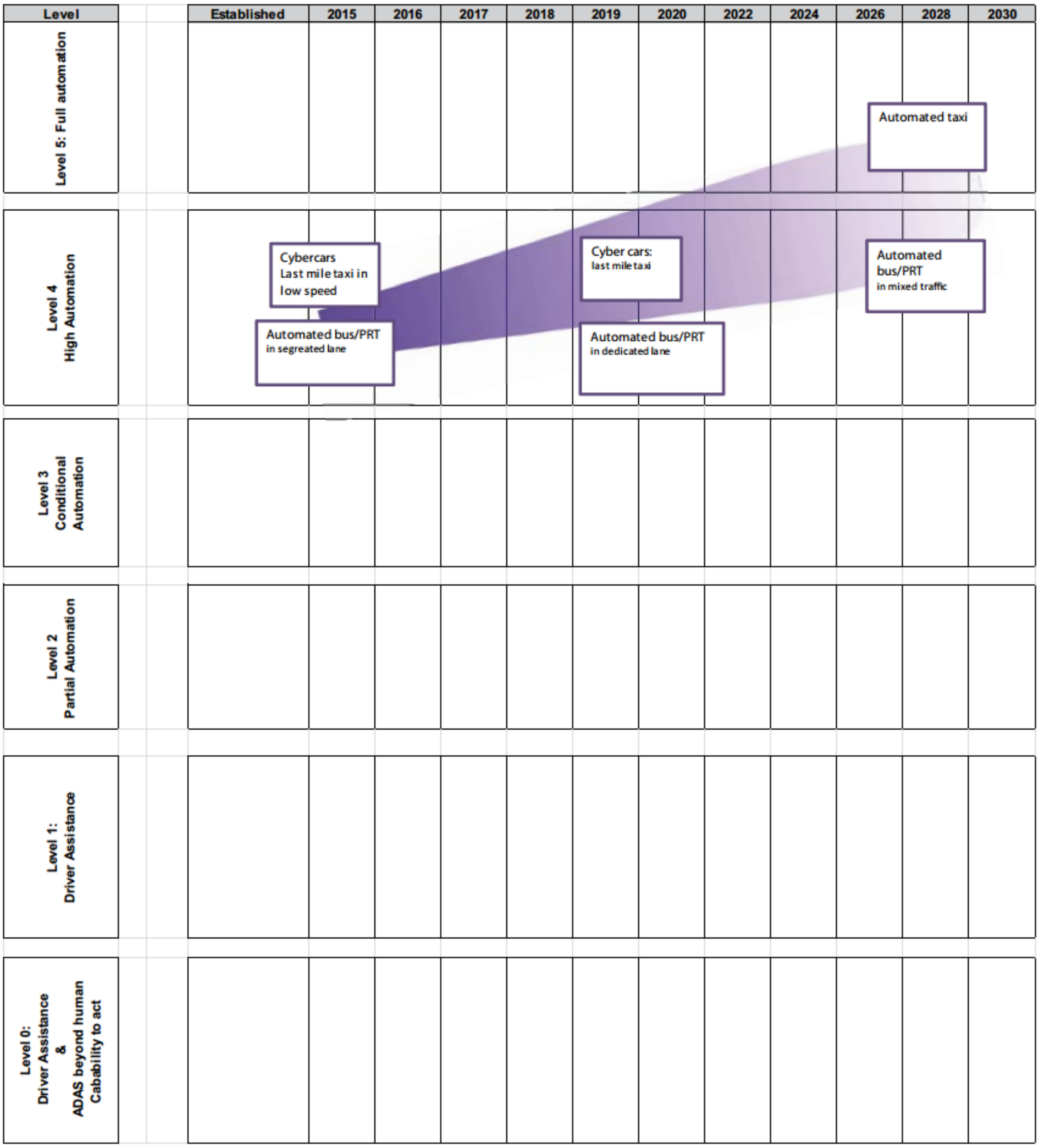


Figure 9: The automated driving deployment path for urban environment systems

Figure 9 indicates that automated taxis and buses, which can operate in mixed traffic, could be arriving from around 2026 onwards.

TSC View:

The above timescales for the arrival of privately owned vehicles that can park themselves and automated public transport vehicles that can operate in mixed traffic may be realistic to describe the first deployments of certain systems in certain areas. However, much will depend on the complexities of local contexts, and it should not be assumed that because a system is deployed somewhere it will immediately make sense to deploy it everywhere. What is perhaps more interesting is the potential uptake and adoption rates of technology rather than first deployments.

3.3 Stakeholder Comments

It is useful to compare the above roadmaps to some of the claims being made by the key technology developers:

3.3.1 Ford

"Ford today announces its intent to have a high-volume, fully autonomous SAE level 4-capable vehicle in commercial operation in 2021 in a ride-hailing or ride-sharing service." [4]

Ford Website, August 2016

This supports the view that automated public transport vehicles will be capable of operating in some environments by 2026, if not sooner.

3.3.2 Google (now Waymo)

"If you read the papers you're going to see that it's maybe 3 years, maybe 30 years. I think honestly that it's a bit of both. Firstly, this technology is almost certainly going to come out incrementally. Secondly, when it does come out we are going to want it to be better than human drivers. We can do a really good job of modelling how good our self-driving car is, but it's actually really difficult to understand how good people are."[5]

Chris Urmson, Director, Self-Driving Cars, Google, March 2016

Google have been at the forefront of technology development and have tested vehicles on public roads more extensively than other organisations, as evidenced by their Self Driving Car reports[6]. They state that they have now driven 2 million miles in self-driving mode:

"Since we started at Google in 2009, we've accumulated the equivalent of over 300 years of human driving experience, largely on city streets. That's on top of 1 billion simulated miles we drove just in 2016".

Much of their testing has been focussed on certain US states and it may not be straightforward to transfer that technology to other geographic areas, which could be why Chris Urmson made reference to the technology coming out incrementally. It should be noted that the self-driving car division of Google has now been renamed 'Waymo', and operates as a separate company under the Alphabet group.

3.3.3 BMW

"In 2018, we will launch a BMW i8 Roadster. This will be followed in 2021 by the BMW i NEXT, our new innovation driver, with autonomous driving, digital connectivity, intelligent lightweight design, a totally new interior and ultimately bringing the next generation of electro-mobility to the road."

[4] https://media.ford.com/content/fordmedia/fna/us/en/news/2016/08/16/ford-targets-fully-autonomous-vehicle-for-ride-sharing-in-2021.html
[5] https://www.youtube.com/watch?v=Uj-rK8V-rik
[6] https://waymo.com/

"People often ask me, when will we be driving autonomously? My answer is: We already can. A BMW test vehicle autonomously completed a lap of the Hockenheimring racetrack back in 2006. In 2011, a BMW drove on the A9 autobahn from Munich towards Nuremberg – without any driver intervention. It will be a while before these cars reach series maturity – also because the proper legal framework for customers and manufacturers has not yet been decided.

Our goal is already clearly-defined - to be Number ONE in autonomous driving. However, with us, the customer always decides – because Sheer Driving Pleasure also means: freedom to choose. When do I hand over control? When do I drive myself? Autonomous driving depends on highly accurate real-time maps and data. In 2015, we paved the way for this when we joined with partner companies to acquire map service HERE from Nokia."[7]

Harald Krüger, Chairman of the Board of Management of BMW AG, May 2016

The German car makers certainly shouldn't be underestimated in their capabilities with regard to automated driving, and BMW, Daimler, Audi, Volkswagen and others are heavily invested in this area. An important project to monitor is the PEGASUS research project[8], which many of the German car makers are involved in. The project is looking at requirements for AVs and how safety and reliability can be proven.

3.3.4 Tesla

"We're going to end up with complete autonomy, and I think we will have complete autonomy in approximately two years." That doesn't mean city streets will be overflowing with driverless Tesla vehicles by 2018 (coincidentally, the company's Model 3 should be on roads by then). Musk expects regulators will lag behind the technology. He predicts it will take an additional year for regulators to determine that it's safe and to go through an approval process. In some jurisdictions, it may take five years or more, he says.

Musk adds an important caveat—one that raises the standard of what it means to achieve full autonomy. "When I say level 4, I mean level 4 autonomy with the probability of an accident is less than that of person," he says.[9]

Elon Musk, co-founder, CEO and product architect, Tesla Motors, December 2015

"It's going to be common for cars to become autonomous a lot faster than people think," Musk said. "I think that seven or eight years from now, half of all cars produced will be fully autonomous, and it would be viewed as odd if it wasn't in a car."[10]

Elon Musk, co-founder, CEO and product architect, Tesla Motors, May 2016

Tesla have certainly been a disruptive force in this area. In releasing their 'Autopilot' feature, which combines lane keeping technology with adaptive cruise control (which maintains the gap to the vehicle ahead), they have pushed the boundaries, although representatives from other car makers have suggested that they could have done this but were concerned about driver misuse of the system. However, the vast amount of data that Tesla has now gathered from the significant number of Autopilot users could give them an advantage[11]. This would support the view that self-driving and self-parking privately owned passenger vehicles could arrive by 2026.

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[7] https://www.press.bmwgroup.com/global/article/detail/T0260006EN/statement-harald-krueger-chairman-of-the-board-of-management-of-bmw-ag-96th-annual-general-meeting-of-bmw-ag-at-olympiahalle-in-munich-on-12-may-2016

[8] http://www.pegasus-projekt.info/en/about-PEGASUS

[9] http://fortune.com/2015/12/21/elon-musk-interview/

[10] https://www.theguardian.com/environment/2016/may/05/elon-musk-we-need-a-revolt-against-the-fossil-fuel-industry

[11] https://electrek.co/2016/11/13/tesla-autopilot-billion-miles-data-self-driving-program/

3.3.5 Volvo Cars

"Real customers will get behind the wheel of self-driving cars for the first time in 2017 as part of the Drive Me program. After that I expect things to move relatively slowly – self-driving cars won't be on sale until, say, after 2020. The reason is that we will have to prove that the self-driving car is safe in the environment in which it is used. There will be huge efforts to verify that the Drive Me cars are safe in Gothenburg traffic, but that doesn't mean that you could take the same car and it will be safe in London. There may be exceptional situations there that the car has never encountered. You have to perform verification activities wherever customers will drive the car because there are big variations in infrastructure, weather conditions and driving behaviours across the world." [12]

Erik Coelingh, Senior Technical Leader for Safety and Driver Support Technologies, Volvo Cars

Volvo could be one of the first to reach market for privately owned vehicles that are capable of fully automated highway driving, based on the intentions of the DriveMe programme.

3.3.6 Nissan

"If it's a question of being autonomous on one lane on a highway or maybe changing lanes, then yes this is 2016, 2017. You're talking about autonomous driving in a city, with crossroads or the car making decisions in complicated situations, then frankly I don't think it's going to be ready before 2020," [13]

Carlos Ghosn, CEO, Renault-Nissan Alliance, January 2016

3.3.7 Overly optimistic predictions?

It should also be acknowledged whilst the above organisations are investing heavily in the development of AVs, not many in the list above are explicitly anticipating fully AVs to be available imminently (as sometimes suggested by the media), and there are limited predictions regarding the geographic coverage to which vehicles might be capable of operating in over time. There is an incentive amongst car companies and technology developers to seek to appear to be at the forefront so as to justify research budgets and send a positive message to shareholders and the wider public, which might influence the claims of CEOs and marketing departments, although it is interesting that this is not how automotive Original Equipment Manufacturers (OEMs) normally operate. They don't normally say that technology X will be available in Y years, but normally keep everything secret until, or just before, launch. Perhaps on the more pessimistic end of the scale, the following quote is interesting:

"Consider the significance of the different timelines associated with this. Presently people are making decisions based on an unrealistically fast timeline for the development of the technology. What would the implications be if the timeline was a lot slower than you think it is? In what way would your decisions be different?

In terms of pods picking you up and taking you anywhere? What if that were 2075 for that?"

Dr Steven Shladover, UC Berkeley, June 2015

With the pace of development in this field the above predictions by the OEMs, whilst optimistic, are not outside of the realm of possibility. However, removing the need of the driver to supervise the system and to make the system responsible for handling all emergency situations is a huge step which may not be an easy barrier to overcome. Alongside the technical barriers, there are those associated with cost, public acceptance, insurance and liability, connectivity and regulations. This makes timescales for first deployment uncertain.

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[12] http://www.volvocars.com/intl/about/our-innovation-brands/intellisafe/intellisafe-autopilot/this-is-autopilot/coelingh-interview

[13] http://www.digitaltrends.com/cars/nissans-ghosn-cautious-on-self-driving-cars-news-quotes/

3.4 Potential Uptake

Uptake of technology is even more difficult to predict than first deployment. One study which has attempted to answer this question is a paper[14] submitted to the 2016 European Transport Conference by Serbjeet Kohli of Steer Davies Gleave and Luis Willumsen of Kineo Mobility Analytics & Willumsen Advisory Services. The study involved a 'Delphi poll' of 45 transport and traffic modelling experts from around the world, all of which has at least 10 years of experience post studies, and average experience was 23 years. The results were included as follows:

	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
	World		US & Canada		Western Europe		Latin America		Australasia		R o W	
1. Year AVs will be available	**2023**	2.9	**2021**	2.0	**2025**	2.7	**2026**	0.6	**2024**	1.8	**2025**	3.6
2a. AVs will be 10% of the car fleet	**2032**	7.0	**2028**	5.1	**2033**	5.7	**2039**	14.4	**2032**	2.1	**2029**	4.2
2b. AVs will be 20% of the car fleet	**2037**	8.5	**2033**	6.2	**2039**	8.0	**2045**	17.1	**2037**	2.1	**2035**	6.0
3. Premium to be paid for an AV	**$6,677**	$3,816	**$5,111**	$3,361	**$7,000**	$3,338	**$7,000**	$2,449	**$5,600**	$2,881	**$9,800**	$5,263
4. Percentage of AVs owned %	**42**	29	**45**	29	**33**	21	**56**	39	**47**	32	**37**	36
5. Ratio AV_price/Uber_price	**0.9**	0.3	**0.7**	0.3	**0.9**	0.3	**1.0**	0.1	**0.9**	0.1	**1.3**	0.5
6a. Ratio Freeway Lane Capacity @ 10%AV	**1.0**	0.1	**1.1**	0.1	**1.0**	0.1	**1.0**	0.1	**1.0**	0.0	**1.0**	0.1
6b. Ratio Freeway Lane Capacity @ 20%AV	**1.1**	0.1	**1.2**	0.2	**1.1**	0.1	**1.0**	0.2	**1.1**	0.0	**1.0**	0.2
7a. Ratio Urban Lane Capacity @ 10%AV	**1.0**	0.1	**1.1**	0.1	**1.0**	0.1	**1.0**	0.1	**1.0**	0.0	**0.9**	0.2
7b. Ratio Urban Lane Capacity @ 20%	**1.0**	0.2	**1.1**	0.1	**1.1**	0.1	**1.0**	0.2	**1.0**	0.0	**0.9**	0.2
8a. Ratio AV Owners VKT/Car owner	**1.1**	0.3	**1.1**	0.1	**1.2**	0.1	**1.0**	0.2	**1.1**	0.1	**1.0**	0.4
8b. Additional percentage of AV_VKT	**12**	17	**9**	6	**10**	14	**3**	5	**19**	21	**26**	36
8c. Ratio AV Renter VKT/Car owner	**0.9**	0.3	**0.9**	0.2	**0.9**	0.4	**0.8**	0.4	**1.0**	0.0	**0.9**	0.2
8d. Additional percentage of AV_VKT	**13**	10	**18**	11	**13**	10	**6**	10	**12**	6	**11**	13
9a. Ratio of Bus demand @10% Avs	**0.9**	0.2	**0.7**	0.4	**1.0**	0.1	**1.0**	0.0	**1.0**	0.0	**1.0**	0.0
9b. Ratio of Bus demand @ 20% Avs	**0.9**	0.2	**0.7**	0.3	**0.9**	0.1	**1.0**	0.0	**0.9**	0.1	**1.0**	0.1
10a. Ratio of Fixed Track PT demand @10%	**0.9**	0.3	**0.8**	0.4	**0.9**	0.3	**1.0**	0.0	**1.0**	0.0	**1.0**	0.0
10b. Ratio of Fixed Track PT demand @20%	**0.9**	0.2	**0.9**	0.3	**0.9**	0.3	**1.0**	0.0	**0.9**	0.1	**1.0**	0.0
11a. Journey to Work: ratio AV_VTTS	**0.9**	0.2	**0.8**	0.2	**0.9**	0.3	**0.8**	0.2	**0.8**	0.1	**1.0**	0.2
11b. Journeys during work: ratio AV_VTTS	**0.9**	0.2	**0.9**	0.2	**0.9**	0.3	**0.9**	0.3	**0.8**	0.1	**1.0**	0.1
11c. Other journeys: ratio AV_VTTS	**0.9**	0.3	**0.8**	0.2	**1.0**	0.4	**0.9**	0.1	**0.8**	0.2	**1.0**	0.1
12a. Journey to Work ratio Social AV_VTTS	**0.9**	0.2	**0.9**	0.3	**1.0**	0.2	**0.9**	0.2	**0.9**	0.1	**1.0**	0.1
12b. Journeys during work: ratio Social AV_VTTS	**0.9**	0.2	**0.9**	0.2	**0.9**	0.2	**0.8**	0.3	**0.9**	0.1	**0.9**	0.1
12c. Other journeys: ratio Social AV_VTTS	**0.9**	0.1	**0.9**	0.2	**0.9**	0.1	**0.9**	0.2	**0.9**	0.1	**1.0**	0.1

Figure 10: Extract from 'Traffic Forecasting and Autonomous Vehicles'[14]

The results show that on average, the group felt that AVs (defined in the paper as highly automated – Level 4/5):

- will be available by 2023;
- will by 2032 comprise 10% of the car fleet;
- will by 2037 comprise 20% of the car fleet.
- 42% of AV's will be privately owned, with 58% available as public transport vehicles, although it is interesting that the respondents from Western Europe thought that the proportion privately owned would be significantly lower (33%).

It should be noted that the high levels of standard deviation in relation to the above answers show that views were wide ranging, and reflects the uncertainty.

3.5 Mapping against planned railway station developments

Based on the information presented above, privately owned vehicles that can drive and park themselves could be available by the late 2020's, and could start to become used in significant numbers into the 2030's. The consequences of these technologies on different types of railway stations is discussed in Section 4. Whilst the findings of this report could be relevant to railway station operators, it could be particularly useful for those currently involved in designing new stations or upgrades to existing ones. There are stations planned for implementation within the relevant timescales of emerging AV technology and could take on board some of the suggestions.

[14] http://www.steerdaviesgleave.com/sites/default/files/elfinder/Traffic-forecasting-and-automated-vehicles-Kohli-Willumsen.pdf

Network Rail owns more than 2,500 railway stations, and manages 19 of them directly (which tend to be the largest stations). Management and operation of the remaining stations is carried out by Train Operating Companies, and the franchise schedule going forward to 2024 has been published by the Department for Transport.[15]

3.5.1 East West Rail

East West Rail includes the 'Western Section', which involves the upgrade and reconstruction of existing and mothballed section of the lines linking Bedford and Bicester, and Milton Keynes and Princes Risborough. It includes various station works at Winslow, Bletchley, Ridgmont, Monks Risborough, Aylesbury Vale Parkway, Little Kimble, Bedford Midland and Woburn Sands. Services are due to start operating in 2019. This could be some years before widescale CAV usage is expected, but it may be wise to 'future-proof' station design and ensure that the layout is adaptable for CAV use in the future.

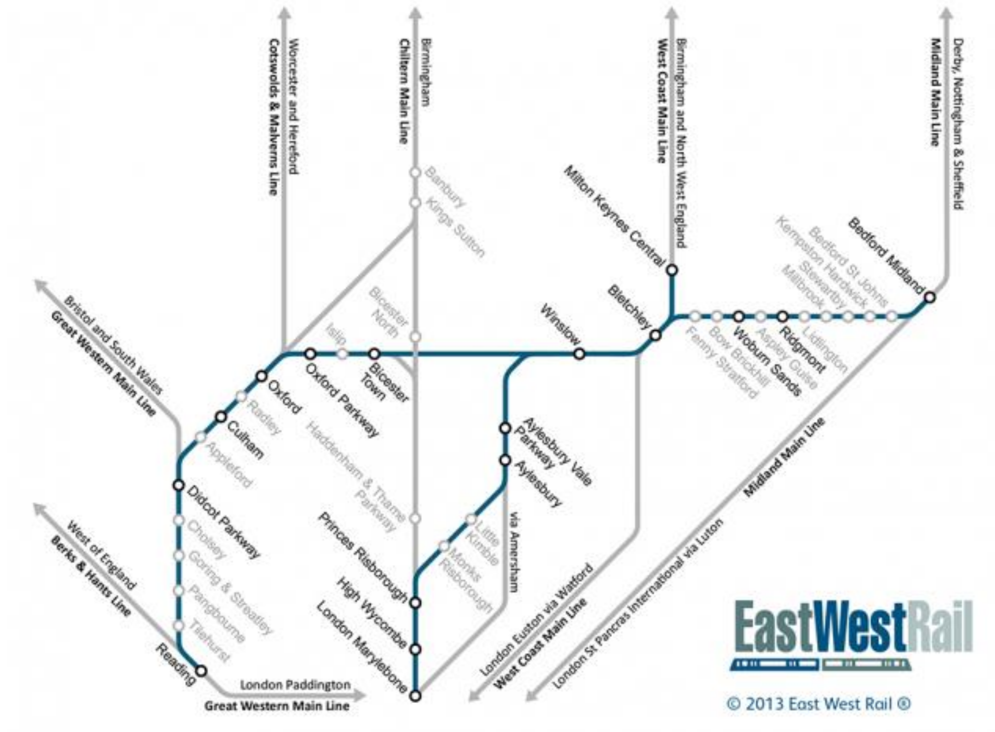


Figure 11: East West Rail proposals. Source: http://www.eastwestrail.org.uk/train-services/

3.5.2 Crossrail

Crossrail involves significant works on new stations and upgrades to existing stations, as detailed in Figure 12.

[15] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/574792/december-2016-rail-franchise-schedule.pdf

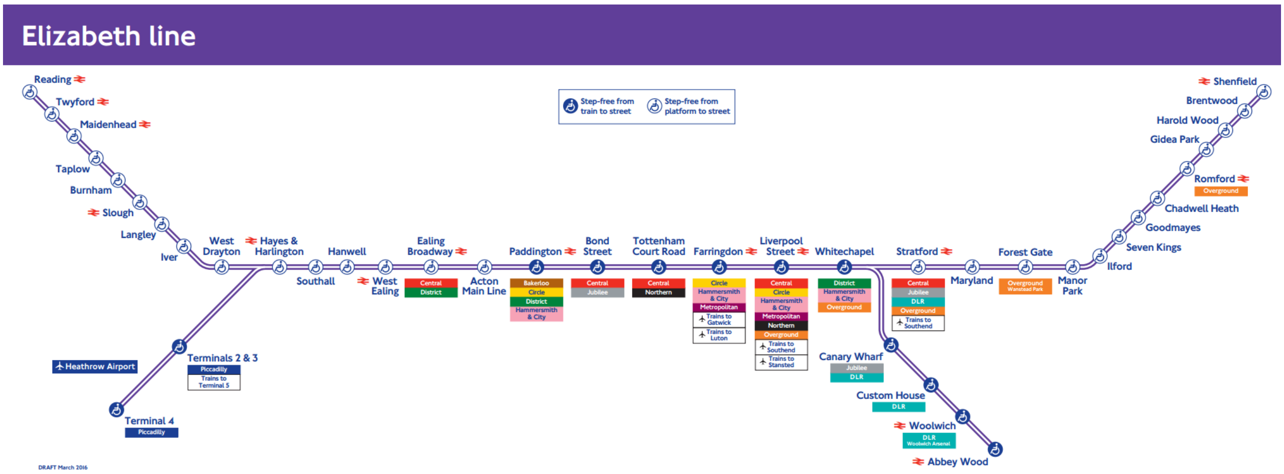


Figure 12: Crossrail Route. Source: http://www.crossrail.co.uk/route/maps/route-map

However, according the January 2017 quarterly update, phased services are due to commence within 2017, and it is stated that:

> *"Architectural fit-out will continue at all our new stations, bringing to life the distinct character of each. At the same time, the major station overhauls and upgrades on the outer western and eastern ends of the route will gain pace together with public space improvement works at 40 sites along the railway."*

The above indicates that the project has moved beyond the design stage and is towards the end of the construction phase, although there may still be scope to influence design of station forecourts, which will be the critical area of operation for AVs. As discussed later in this report, this may be more important at the smaller stations outside of London.

3.5.3 High Speed 2

The high-level timescales for HS2 are as follows:

2024-2026	Commissioning and testing for phase 1
2026	Phase 1 (London-Birmingham) of HS2 opens to passenger services
2026-2033	Phase 2 construction period (starts and ends at different times and at different points along the route)
2033	Phase 2 (Birmingham-Leeds/Manchester) of HS2 opens to passenger services

Table 1: HS2 Timescales

These timescales directly correspond to those for deployment of AVs therefore there is an opportunity to ensure stations being designed for HS2 are future-proofed for integration with AVs.

4 Implications and Opportunities for Railway Stations - Overview

4.1 Overview

This sections discusses implications and opportunities of highly automated vehicles. The two CAV applications which are considered most relevant are:

- Auto-valet parking for privately owned vehicles
- Drop off / Pick up for Automated Public Transport Vehicles

The above two concepts are discussed in more detail below. Four 'case study' stations are investigated In section 5 to consider how real world stations could be adapted to respond to this emerging technology.

4.2 Vehicles with auto-valet parking

The idea of 'autonomous valet parking' has been discussed for many years, and several car companies have demonstrated systems which show a CAV capable of searching for, detecting and manoeuvring into a parking space with no human intervention. This creates exciting opportunities both for the user and for the infrastructure provider. Firstly, for the user, this would enable a driver to park somewhere close to the entrance of a car park in a designated vehicle drop off area and continue directly to their destination without incurring the time and stress of parking their car. The car could be subsequently summoned to a collection area. This could be attractive for railway station car parks, where those parking are often in a hurry to catch their train and could do without the inconvenience and/or stress of searching for a parking space.

Railway stations are typically places where demand for car parking exceeds supply. For railway station car park providers there could be an opportunity to significantly increase car parking provision within a given land area. In theory, empty CAVs could park themselves very efficiently without the need for human occupants to open the doors. This alone could enable 20% more spaces to be provided within a car park. Taking it one step further, CAVs could block each other in and let each other out when necessary. A study by Audi suggested 2.5 times the number of vehicles could fit into a car park using this method compared to human-controlled vehicles[16].

[16] http://audi-urban-future-initiative.com/blog/piloted-parking-future-mobility

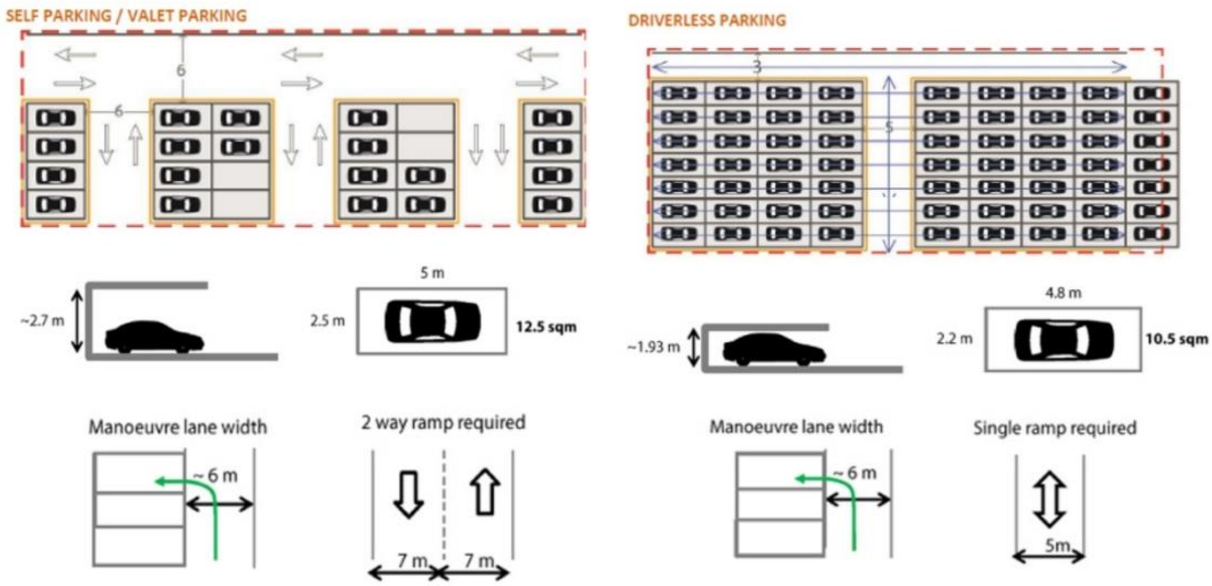


Figure 13: Conventional parking layout (left) vs possible CAV parking layout (right) [Source: http://audi-urban-future-initiative.com/blog/piloted-parking-future-mobility]

Figure 14 below has been captured from a video which simulates how CAVs could park themselves in a highly efficient manner. The concept illustrated is that each vehicle can be blocked in by up to two other vehicles. If a blocked in vehicle needs to exit, the vehicles will move out of the way to allow passage.

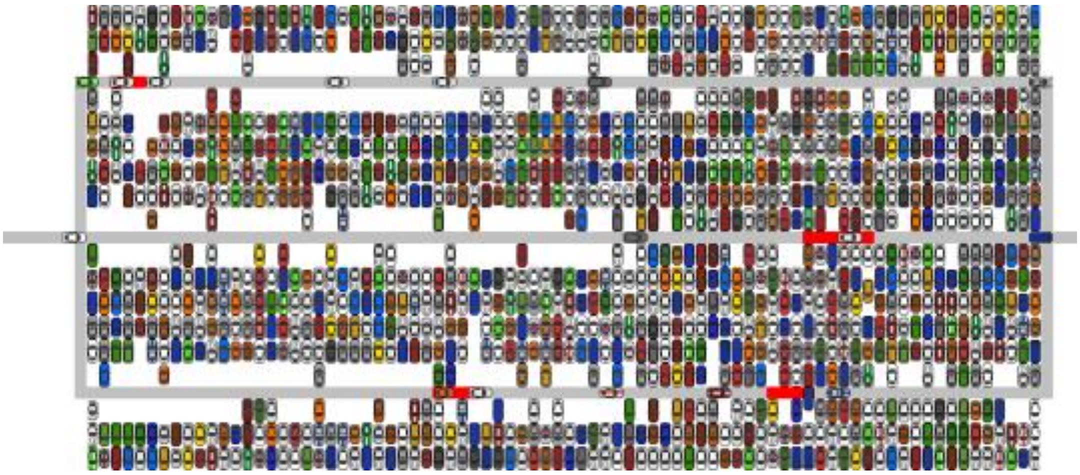


Figure 14: Potential layout of CAV carpark, achieving high parking density [Source: http://www.v-charge.eu/?p=1169. Video can be viewed at https://www.youtube.com/watch?v=pCzI-l8tsPY]

Enabling vehicles to manoeuvre as directed by the car parking system could be challenging. Some form of remote control access will need to be granted to the car park operator. Safe guards would also be needed in the event that a vehicle does not respond, and how to retrieve any vehicles that may be blocked.

In addition, since no driver may be present, any car park operator intending on allowing CAVs with no occupants into their car park would need to establish an automatic electronic payment method. This could be done via number plate recognition, an electronic tag, or Vehicle to Infrastructure (V2I) communication.

The ISO Standard ISO/DIS 16787, "Intelligent Transport Systems — Assisted Parking System (APS) - Performance requirements and test procedures", has been drafted, although this mainly covers the driver assistance function of the vehicle taking lateral control to guide the vehicle into a parallel parking space. Further standards will be required to cover the type of application that manages the whole parking process without driver input, and standardisation will be important to enable different vehicle systems to communicate with infrastructure. Extensive trials would be needed to help develop standards and regulations.

A future vision for car park design can be seen in a drawing published by US architect firm Arrowstreet, reproduced below in Figure 15. The top level of the carpark is for use by CAVs (since it is the furthest away), with the remaining levels still used for conventional parking.

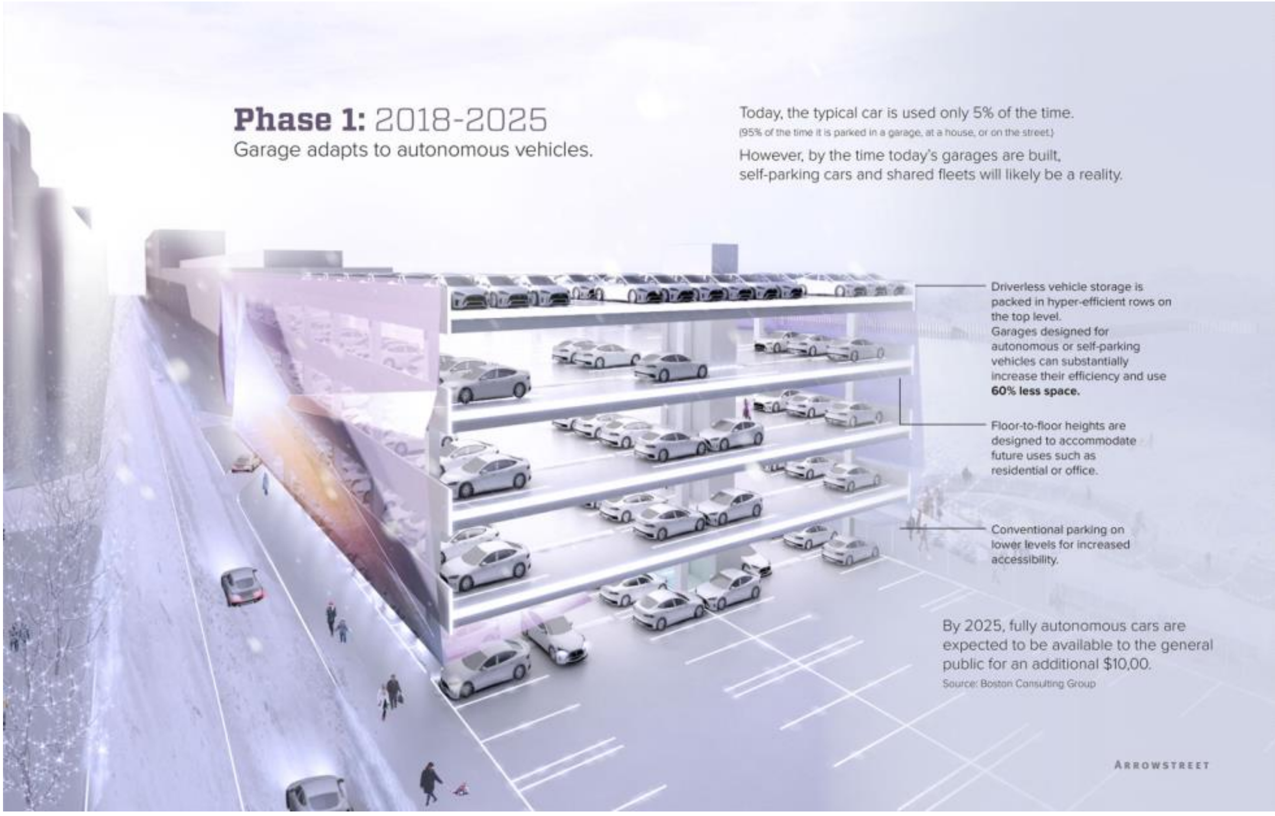


Figure 15: An example of a segregated area of the carpark for use by CAVs [Source: http://www.arrowstreet.com/portfolio/autonomous-vehicles/]

To compliment CAV-compliant parking areas, valet pick-up/drop-off areas will need to be considered. This is a designated area where people can drop-off and collect their CAVs. They must be designed with safety in mind and with sufficient capacity to allow for peak use. It may be that a small area is required initially which can be expanded in the future as uptake of CAVs increases. Figure 16 below shows an example of a valet parking area and how a charging system may work within a carpark. A small number of electric charging spaces are provided and owners can move their cars in and out as required.

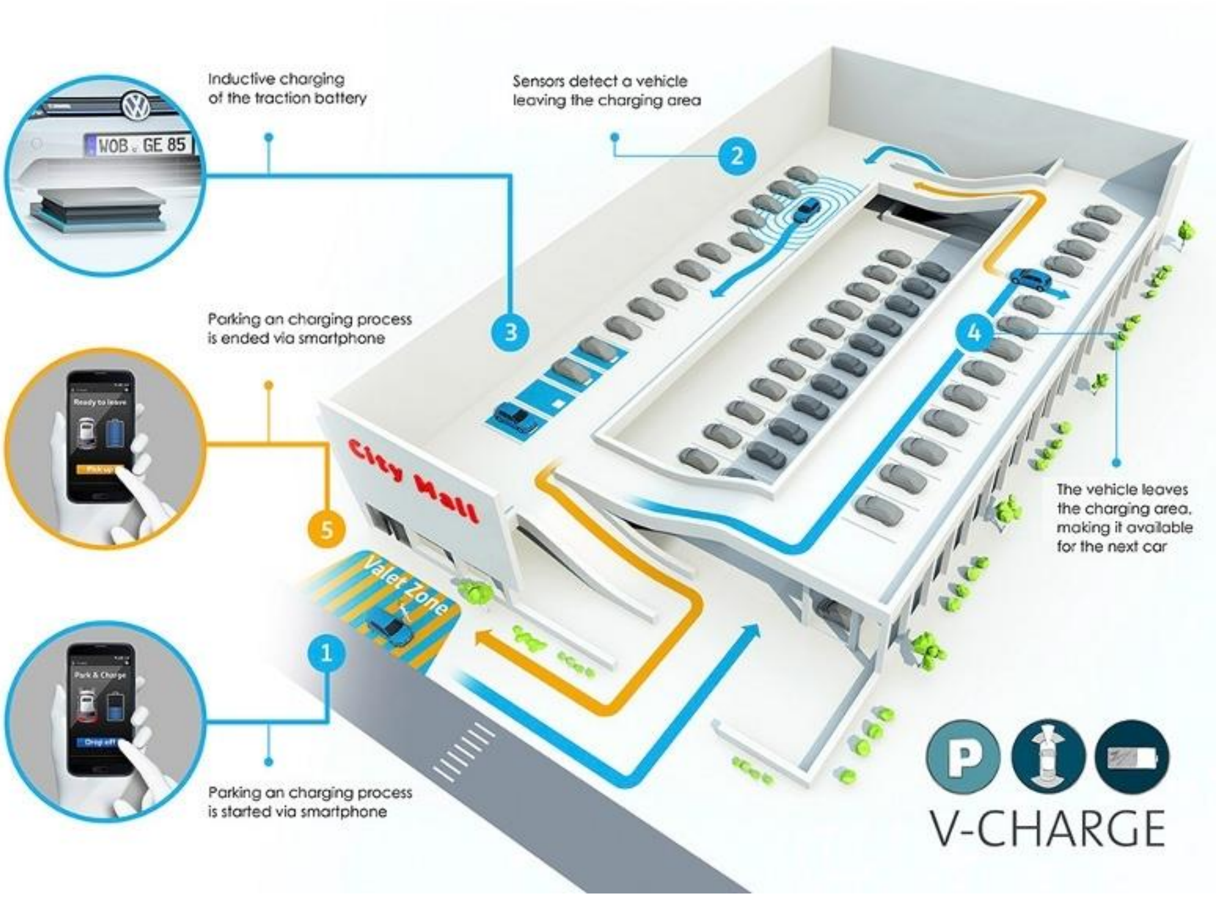


Figure 16: Carpark showing use of a 'Valet Zone' and charging areas [Source: http://www.volkswagenag.com/content/vwcorp/info_center/en/news/2015/07/charge.html]

4.3 Automated Public Transport Vehicles

As discussed in Section 2, automated public transport vehicles could become an important part of public transport systems of the future. The real benefit for both the customer and the operator is that they can be demand responsive without the cost and operational limitations associated with human drivers. The overall number of vehicles within the public transport fleet is no longer limited to the number of drivers that are available, and could substantially increase, with the result that vehicles are always available, waiting for passengers, and passengers do not need to wait for vehicles.

Such vehicles could offer affordable public transport to areas that are not well served by conventional public transport, such as sparsely populated areas. They could encourage lower private car ownership and usage, which could impact positively on congestion and parking demand issues.

For railway stations the main aspect for consideration is pick up and drop off facilities for such vehicles. In the early years, these vehicles will need to co-exist with traditional forms of public transport road vehicles, such as buses, taxis and private hire vehicles. There is already competition for road space around railway stations, and there may be opposition to relocating conventional modes of transport to create pick up and drop off areas for AVs.

An additional challenge is that, at least in the early years of deployment, AVs will probably operate more effectively in simplistic operating environments, and are not well suited to complex environments where there are a large number of different road users, ad-hoc parking, complicated crossing points and junctions, etc.

Many of the new types of vehicle being considered use electric powertrains and as such it might be beneficial to incorporate inductive charging into the waiting areas for such vehicles, as already happens for manually driven buses in Milton Keynes.[17]

Ultimately, planners could become more ambitious. We could consider solutions for small vehicles that transport people directly onto the station platforms, which could be of use for people with disabilities, and consider how the infrastructure needs to adapt for this change. We could consider new grade separated roadways for new vehicle types that avoid the congested station surroundings.

The next section considers four case study stations to look at the practical implications and opportunities for real-world railway stations of various size and type.

[17] http://www.arup.com/news/2014_01_january/09_january_worlds_most_demanding_electric_bus_route_launched

5 Implications and Opportunities for Railway Stations – Case Studies

5.1 Introduction

In this section a selection of existing railway stations are considered to explore whether CAVs could play a role in their operation in the future.

The following stations were considered, which represent a range of different station sizes, categories, and typical characteristics.

Station	Annual entry and exits*	Number of Platforms	DfT Station Category	Station Type (based on DfT category)	Local Authority	Managed by
London Paddington	36.54 million	14	A	National Hub	City of Westminster	Network Rail
Milton Keynes Central	6.836 million	7	B	Regional Interchange	Borough of Milton Keynes	London Midland
Hitchin	3.199 million	2	C2	Important Feeder	District of North Herefordshire	Great Northern
Aylesbury	1.158 million	3	D	Medium staffed	District of Aylesbury Vale	Chiltern Railways

*Based on 2015/16 figures

Table 2: Case Study Station Characteristics

5.2 London Paddington

London Paddington is a central London railway terminus and major transport hub within a relatively constrained area of Inner London. As illustrated in *Table 2*, the station experiences high passenger throughput, with in excess of 36 million entries / exits per year, and provides 14 platforms. The station is the London terminus of the Great Western Main Line. The London Underground station provides connections to the Bakerloo, Circle, District and Hammersmith and City Lines.

The station experiences heavy inbound London traffic during the morning peak and outbound during the PM peak. The overall layout of the station environment is shown below:

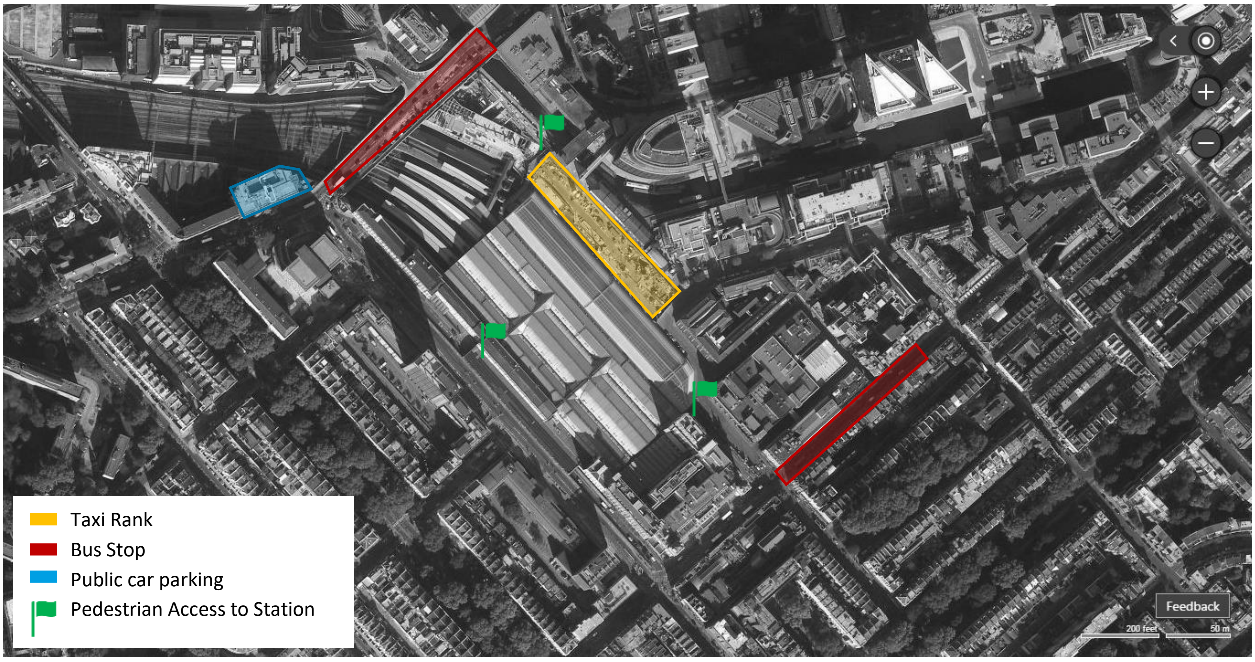


Figure 17: Paddington Station environment

The station is bordered by the Paddington Basin canal to the north east and Westway to the north west, and there is a mix of business and residential properties around the station in what is a built up urban area. Paddington is also one station along the currently under construction Crossrail route, and the following image illustrates the plans for the station, and the level of land use constraint within the local area:

Figure 18: Paddington Station Crossrail Plans (Source: http://www.crossrail.co.uk)

5.2.1 Auto-Valet Parking

It is considered unnecessary to consider the prospect of auto-valet parking at a station like Paddington for two reasons. Firstly, there is limited local parking which could be used for CAVs, and secondly a very low proportion of travellers would consider driving to and parking at Paddington. It is more likely to be used as an interchange between public transport, for example between mainline rail services and the London Underground or bus services. It might be possible to construct new car parks that could be used for auto-valet parking, but this is probably undesirable as it would encourage car trips into an already congested Central London area.

5.2.2 Automated Public Transport Vehicles

Deploying automated public transport vehicles around Paddington Station will probably be a challenge technically for many years due to the environmental complexity. The sheer volume of buses, private hire vehicles, taxis, pedestrians and cyclists competing for limited road space and the ad-hoc nature of private vehicles dropping off and collecting passengers presents significant challenges.

There are no obvious areas of road space that could be easily allocated for automated shuttle pick up and drop off, without displacing other modes of transport. This could be politically sensitive. Paddington could be an example where a more radical solution to accommodate CAVs might be necessary, such as an elevated road way which is segregated from the complex urban environment below.

However, there is a question over whether the benefits of automated public transport vehicles in an area such as Paddington, where there are so many existing transport options available, would justify the cost. It may be preferable to focus on encouraging and managing existing modes of transport, including walking and cycling.

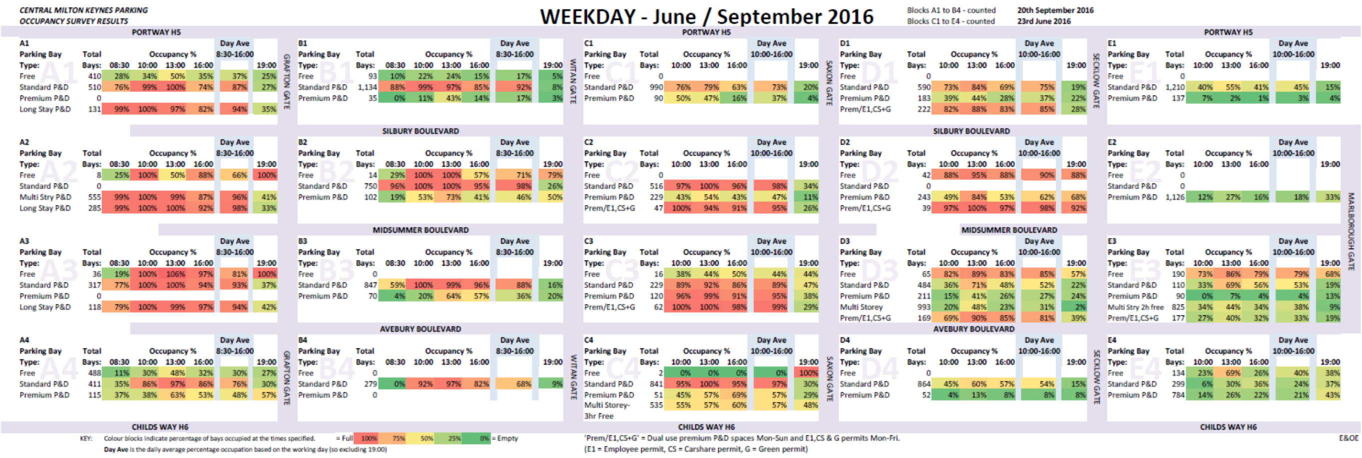
5.3 Milton Keynes Central

Milton Keynes Central is located on the West Coast Mainline and provides direct connections to London Euston and Birmingham New Street. The following aerial image illustrates the general layout, although the taxi, bus and public drop off areas have been reconfigured since this photograph was taken.

Figure 19: Milton Keynes Station (Station Square – prior to recent reconfiguration)

5.3.1 Auto-Valet Parking

Milton Keynes Central railway station is located at the western end of the two square kilometres that comprise Central Milton Keynes. Central Milton Keynes has over 20,000 car parking spaces. However, spaces around the western end, near to the station, are in high demand especially mid-morning during the working day. The following parking occupancy diagram for Central Milton Keynes was published by Milton Keynes Council:



CENTRAL MILTON KEYNES PARKING
OCCUPANCY SURVEY RESULTS

WEEKDAY - June / September 2016

Blocks A1 to B4 - counted 20th September 2016
Blocks C1 to E4 - counted 23rd June 2016

PORTWAY H5

A1

Parking Bay Type:	Total Bays:	08:30	10:00	13:00	16:00	Day Ave 8:30-16:00	19:00
Free	410	28%	34%	50%	35%	37%	25%
Standard P&D	510	76%	99%	100%	74%	87%	27%
Premium P&D	0						
Long Stay P&D	131	99%	100%	97%	82%	94%	35%

B1

Parking Bay Type:	Total Bays:	08:30	10:00	13:00	16:00	Day Ave 8:30-16:00	19:00
Free	93	10%	22%	24%	15%	17%	5%
Standard P&D	1,134	88%	99%	97%	85%	92%	8%
Premium P&D	35	0%	11%	43%	14%	17%	3%

C1

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	0					
Standard P&D	990	76%	79%	63%	73%	20%
Premium P&D	90	50%	47%	16%	37%	4%

D1

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	0					
Standard P&D	590	73%	84%	69%	75%	19%
Premium P&D	183	39%	44%	28%	37%	22%
Prem/E1,CS+G	222	82%	88%	83%	85%	28%

E1

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	0					
Standard P&D	1,210	40%	55%	41%	45%	15%
Premium P&D	137	7%	2%	1%	3%	4%

SILBURY BOULEVARD

A2

Parking Bay Type:	Total Bays:	08:30	10:00	13:00	16:00	Day Ave 8:30-16:00	19:00
Free	8	25%	100%	50%	88%	66%	100%
Standard P&D	0						
Multi Stry P&D	555	99%	100%	99%	87%	96%	41%
Long Stay P&D	285	99%	100%	100%	92%	98%	33%

B2

Parking Bay Type:	Total Bays:	08:30	10:00	13:00	16:00	Day Ave 8:30-16:00	19:00
Free	14	29%	100%	100%	57%	71%	79%
Standard P&D	750	96%	100%	100%	95%	98%	26%
Premium P&D	102	19%	53%	73%	41%	46%	50%

C2

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	0					
Standard P&D	516	97%	100%	96%	98%	34%
Premium P&D	229	43%	54%	43%	47%	11%
Prem/E1,CS+G	47	100%	94%	91%	95%	26%

D2

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	42	88%	95%	88%	90%	88%
Standard P&D	0					
Premium P&D	243	49%	84%	53%	62%	68%
Prem/E1,CS+G	39	97%	100%	97%	98%	92%

E2

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	0					
Standard P&D	0					
Premium P&D	1,126	12%	27%	16%	18%	33%

MIDSUMMER BOULEVARD

A3

Parking Bay Type:	Total Bays:	08:30	10:00	13:00	16:00	Day Ave 8:30-16:00	19:00
Free	36	19%	100%	106%	97%	81%	100%
Standard P&D	317	77%	100%	100%	94%	93%	37%
Premium P&D	0						
Long Stay P&D	118	79%	100%	99%	97%	94%	42%

B3

Parking Bay Type:	Total Bays:	08:30	10:00	13:00	16:00	Day Ave 8:30-16:00	19:00
Free	0						
Standard P&D	847	59%	100%	99%	96%	88%	16%
Premium P&D	70	4%	20%	64%	57%	36%	20%

C3

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	16	38%	44%	50%	44%	44%
Standard P&D	229	89%	92%	86%	89%	47%
Premium P&D	120	96%	99%	91%	95%	38%
Prem/E1,CS+G	62	100%	100%	98%	99%	29%

D3

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	65	82%	89%	83%	85%	57%
Standard P&D	484	36%	71%	48%	52%	22%
Premium P&D	211	15%	41%	26%	27%	24%
Multi Storey	993	20%	48%	23%	31%	2%
Prem/E1,CS+G	169	69%	90%	85%	81%	39%

E3

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	190	73%	86%	79%	79%	68%
Standard P&D	110	33%	69%	56%	53%	19%
Premium P&D	90	0%	7%	4%	4%	13%
Multi Stry 2h free	825	34%	44%	34%	38%	9%
Prem/E1,CS+G	177	27%	40%	32%	33%	19%

AVEBURY BOULEVARD

A4

Parking Bay Type:	Total Bays:	08:30	10:00	13:00	16:00	Day Ave 8:30-16:00	19:00
Free	488	11%	30%	48%	32%	30%	27%
Standard P&D	411	35%	86%	97%	86%	76%	30%
Premium P&D	115	37%	38%	63%	53%	48%	57%

B4

Parking Bay Type:	Total Bays:	08:30	10:00	13:00	16:00	Day Ave 8:30-16:00	19:00
Free	0						
Standard P&D	279	0%	92%	97%	82%	68%	9%
Premium P&D	0						

C4

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	2	0%	0%	0%	0%	100%
Standard P&D	841	95%	100%	95%	97%	30%
Premium P&D	51	45%	57%	69%	57%	29%
Multi Storey-3hr Free	535	55%	57%	60%	57%	48%

D4

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	0					
Standard P&D	864	45%	60%	57%	54%	15%
Premium P&D	52	4%	13%	8%	8%	8%

E4

Parking Bay Type:	Total Bays:	10:00	13:00	16:00	Day Ave 10:00-16:00	19:00
Free	134	23%	69%	26%	40%	38%
Standard P&D	299	6%	30%	36%	24%	37%
Premium P&D	784	14%	26%	22%	21%	43%

CHILDS WAY H6

KEY: Colour blocks indicate percentage of bays occupied at the times specified. = Full 100% 75% 50% 25% 0% = Empty
Day Ave is the daily average percentage occupation based on the working day (so excluding 19:00)

'Prem/E1,CS+G' = Dual use premium P&D spaces Mon-Sun and E1,CS & G permits Mon-Fri.
(E1 = Employee permit, CS = Carshare permit, G = Green permit)

E&OE

Figure 20: Central Milton Keynes Parking Occupancy (source: Milton Keynes Council)

Milton Keynes Central rail station is located at the western end of Midsummer Boulevard, between the areas A2 and A3 as shown on the diagram. It is clear that parking demand is high in this area, which reflects the fact that many people seek to park near to the station to take the train or near to a number of commercial premises in this area.

With auto-valet parking, it could be possible for drivers to alight their vehicles at the station, and for their vehicle to drive itself empty to an area of lower parking demand. For example, according to Figure 20, area B1 to the north of Central Milton Keynes does not generally reach capacity (or at least it didn't during the above survey period). Such a route is illustrated below:

Figure 21: Potential Auto-Valet Parking Route from Milton Keynes Central to area of Lower Parking Demand

CAVs could then park themselves in a space efficient manner within the designated CAV parking area (i.e. closer together than at present, and even blocking each other in). At the appropriate time the owner could summon the vehicle to drive empty along the reverse of the above route, and a waiting area could be designed near to the drop off point. This would require the reallocation of existing parking spaces to use for auto-valet parking pick up / drop off, but it could free up a larger number of spaces near to the railway station as more drivers make use of this facility.

There is, however, a negative impact from the above idea in that the empty trip from the station to the parking area is a new trip that wouldn't otherwise have been on the network if the driver had parked at the station, or chosen to travel by another mode of transport to avoid the stress of parking. This new trip could contribute to local congestion at peak times. This would need to be investigated as part of a wider modelling exercise. It is possible that many drivers are circulating local roads looking for car parking spaces, and the situation could be improved with such a scheme.

5.3.2 Automated Public Transport Vehicles

It is clear that Milton Keynes Central does not suffer the same space constraints as a railway station in a built-up area, such as London Paddington. There is considerably more public space to the front of the station and it would be possible to reconfigure the layout to accommodate automated public transport vehicles separately from other forms of public transport and private vehicles if deemed necessary. As part of the LUTZ Pathfinder project, a small two-seat AV used the pedestrian areas of Station Square and surrounding underpasses to demonstrate the technology. This has lead into a much larger programme called 'UK Autodrive' which is aiming to deploy 40 public transport vehicles, and to move towards a system that provides a useful public transport service to members of the public.

Figure 22: 'Driverless Pods' have already been demonstrated within pedestrian areas around Milton Keynes Central as part of the LUTZ pathfinder project.

It is therefore considered that Milton Keynes Central is suitable for trialling and ultimately deploying automated public transport vehicles. The greater challenge is how the vehicles travel from there to the surrounding residential and commercial areas.

5.4 Hitchin

Hitchin Railway Station is located approximately 1.6km north east of Hitchin Town Centre. It is on the East Coast Main Line, linking to London Kings Cross to the south and Peterborough, Cambridge and King's Lynn to the north. The layout of the station is shown below:

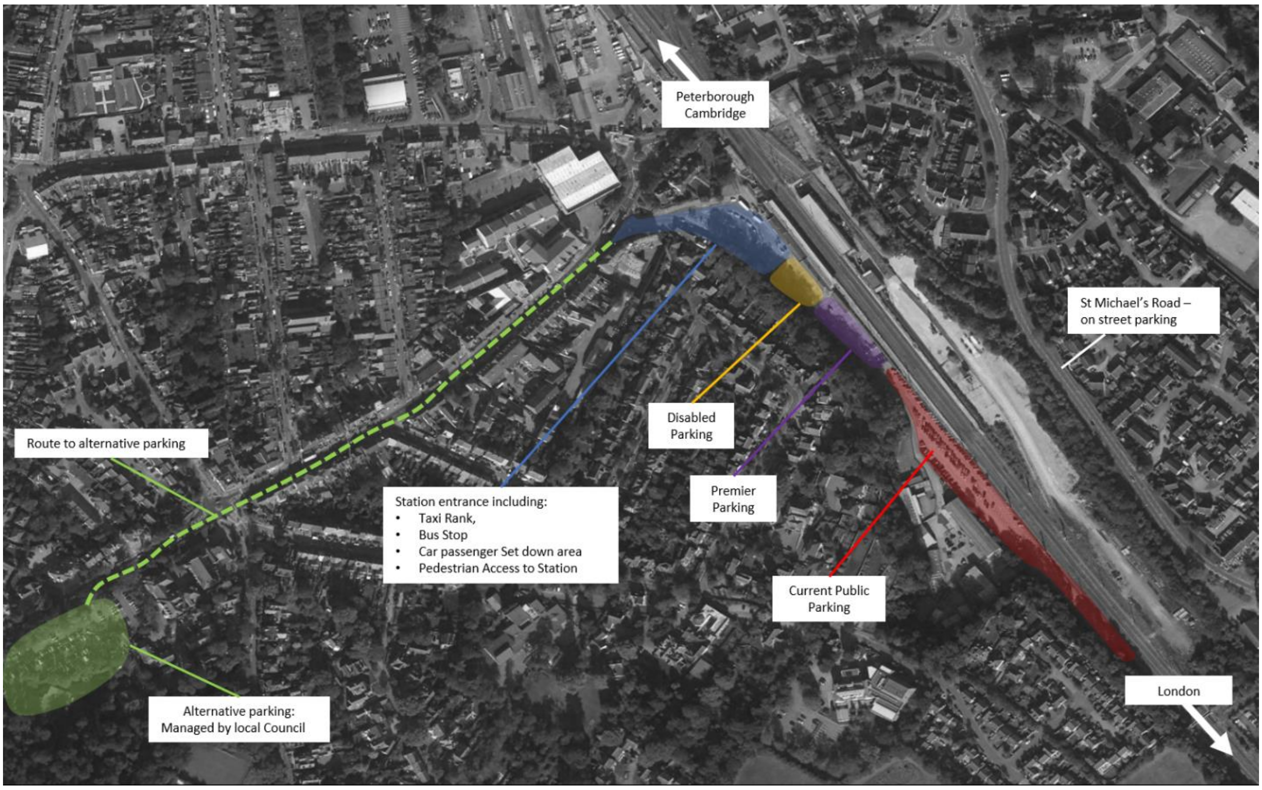


Figure 23: Hitchin Railway Station layout

The area of official station car parking is shown on red on the plan. The car park is quite long walk from the station entrance, and demand often exceeds supply, which means drivers can drive to the end of the car park to find no space available (a problem that could be solved with variable message signage and car park sensors). They then have limited options, which includes driving to the council managed Woodside car park, shown in green. This is a 10 minute walk from the station entrance. Another option is to head towards St Michael's Road, which is located to the east of the railway line, and park on street. There is no pedestrian route from St Michael's Road through to the station without walking around the road network, so it is a walk of around 10 minutes. A further option if heading south is to continue by car to Stevenage station, a drive of around 11km which can take up to 30 minutes at peak times.

The station environment provides access to buses, taxis and private vehicles as shown below:

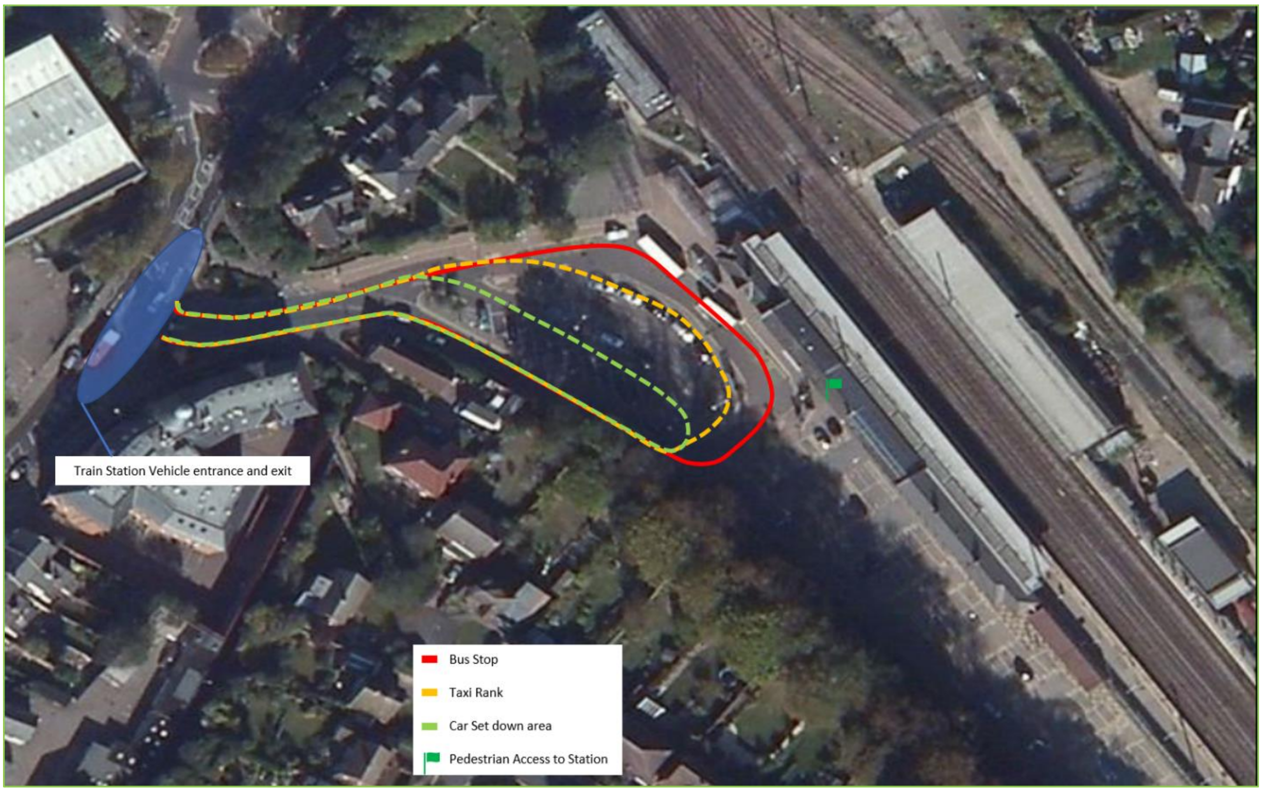


Figure 24: Hitchin Railway Station – local surroundings

5.4.1 Auto-Valet Parking

The issues around parking were described previously, and there might be potential for CAVs to play a role in alleviating pressure on car parking. It may be possible for drivers to alight at the station entrance using the set down area and for the car to continue empty along the route shown in green on Figure 23 to park in Woodside Car Park. The occupancy of this car park has not been investigated, and the technical feasibility of the route for a fully automated vehicle would require detailed investigation.

If the empty vehicle were to be summoned by the driver to return to the car park the vehicle will need to wait for the owner to arrive (especially if the driver demands the vehicle early to ensure it is waiting for them). It's possible that space is reallocated to an 'auto-valet parking collection point', but there are questions over why this should be prioritised over other demands for the space from taxis, buses and disabled parking, and this would be a politically sensitive issue. In this case, it is probably preferable that the driver walks to the car park to collect the vehicle, or some of the station car park spaces could be reallocated for this purpose.

A second idea is to take steps to introduce new car parking, which could be utilised in a highly efficient manor by CAV's. If a new car park could be constructed it could be offered exclusively for use by CAVs with the ability to park in a highly efficient manor, as described in Section 4.

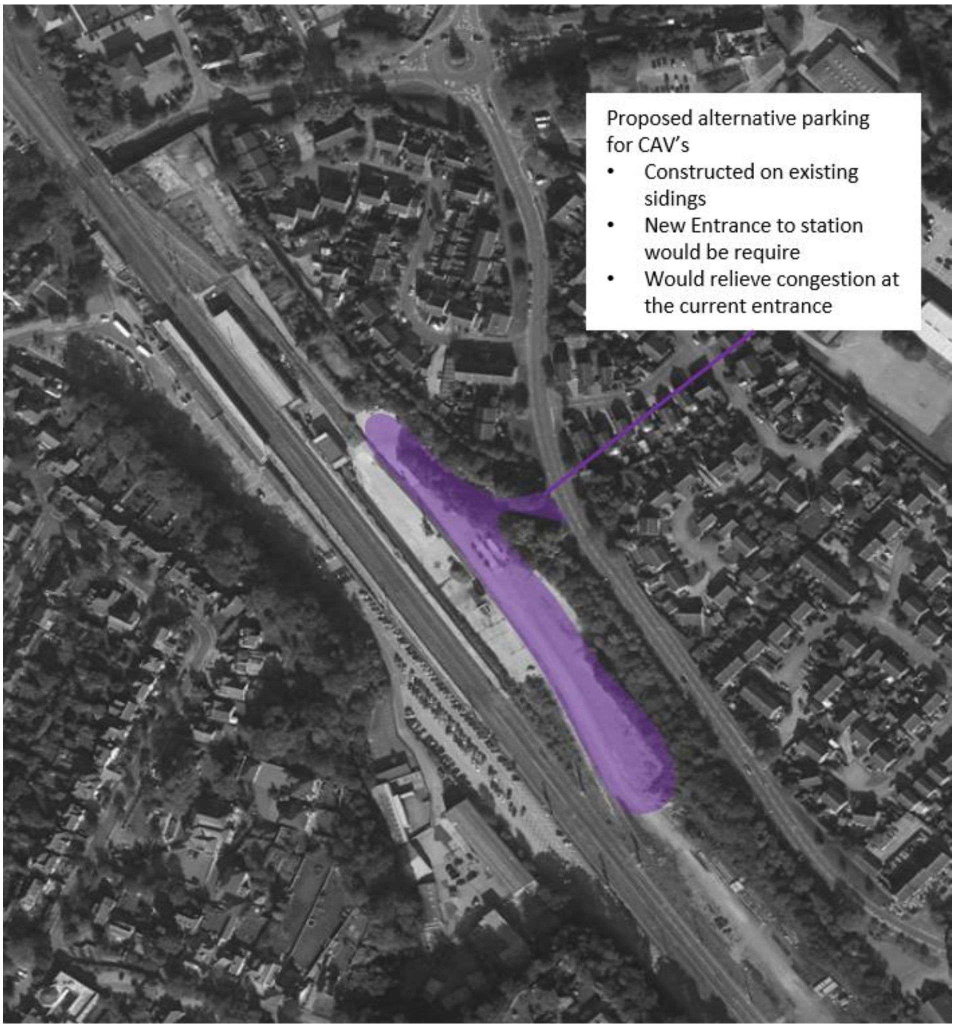


Figure 25: Potential for New CAV Car Park at Hitchin Station

There have been no investigations into the feasibility of such a car park, but this has been included to highlight the advantages of inserting a new piece of infrastructure that could be used in a more efficient way by CAVs.

5.4.2 Automated Public Transport Vehicles

As for many railway stations, the area near the main station entrance is busy and there are competing demands of buses, taxis and private cars, all of which are setting down and collecting passengers. This is combined with large numbers of pedestrians and cyclists in the area. This is amongst the most complicated type of environment for an AV to attempt to handle.

It may be necessary to provide an automated public transport vehicle with its own pick up / drop off area, which is slightly further from the main station entrance. It may be possible (if not unpopular with some) that the 'Premier Parking' is repositioned slightly further from the station entrance, and this space is reallocated for automated public transport vehicle pick up / drop off. Alternatively, a small number of the public set down spaces could be reallocated and designed into a loop for this new public transport option.

5.5 Aylesbury

Aylesbury is the penultimate stop on the London to Aylesbury Line from London Marylebone via Amersham. A branch line from Princess Risborough on the Chiltern Main Line terminates at Aylesbury. Work is currently underway to continue the line to Winslow, Bletchley and Milton Keynes as part of a East-West rail link.

The layout of the station is shown as follows:

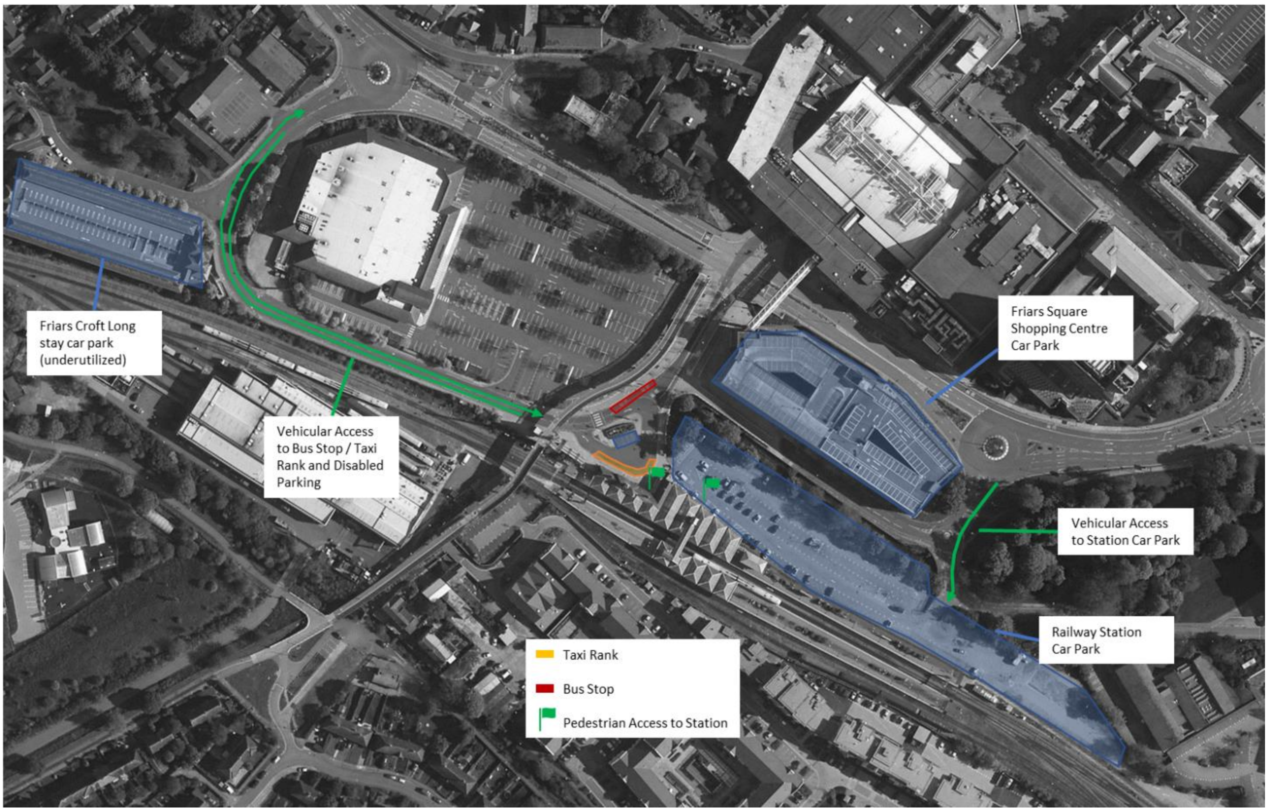


Figure 26: Aylesbury Station Environment

As can be seen in *Figure 26*, there are a number of parking options within the local area. The closest car park is the official railway station car park immediately to the north. Further north is Friars Square shopping centre car park, which is more expensive for parking over long periods and tends to be used more by short stay shoppers. To the west is Friars Croft car park, which offers low cost all day parking, but is a three minute walk to the railway station entrance. The large car park in the centre of the image is for customers of the Morrisons supermarket.

The taxi rank is located within a small turning area directly outside the western entrance to the station, and a bus stop is located slightly further north along the bus only through route to the bus station under Friars Square shopping centre further north.

5.5.1 Auto-Valet Parking

There could be an opportunity to consider auto-valet parking as part of the station environment. Friars Croft car park is often underutilised, and is a short walk from the station entrance. Therefore, drivers could park their vehicles outside of the western station entrance, and the car could drive and park itself on the top floor of Friars Croft car park. CAVs could then park in a space efficient manner within the designated CAV parking area.

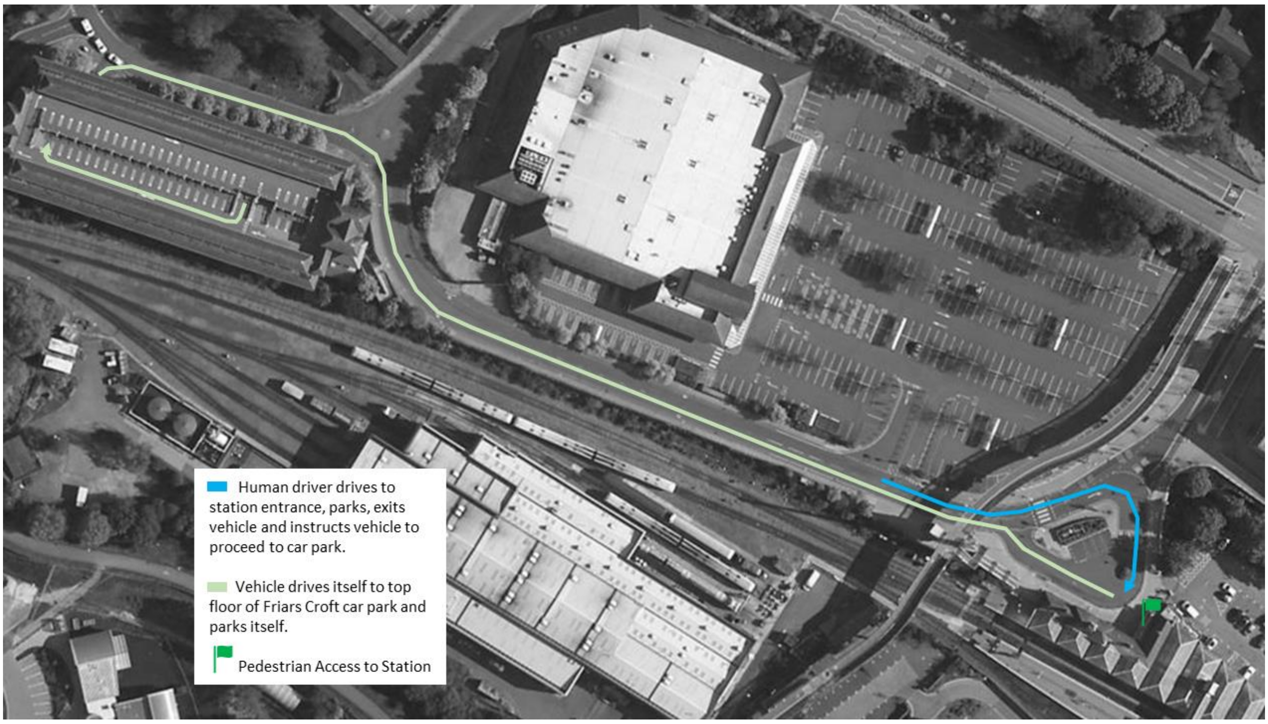


Figure 27: Potential Auto-Valet Park Vehicle Drop off arrangements

The above drop off procedure could be workable without change to existing infrastructure. The road between the station entrance is relatively simple from an AV perspective. There is no on-street parking, no pedestrian crossing points and relative light levels of vehicular, pedestrian and cyclist traffic.

It may be more problematic for the vehicle to drive empty back to the entrance of the station to collect the owner. The route back to the station entrance includes a zebra crossing, which may be challenging for an AV to interpret correctly. The vehicle will also need to wait for the owner to arrive (especially if the driver demands the vehicle early to ensure it is waiting for them). It's possible that space is reallocated to an 'auto-valet parking collection point', but there are questions over why this should be prioritised over other demands for the space from taxis, buses and disabled parking, and this would be a politically sensitive issue. In this case, it is probably preferable that the driver walks to the car park to collect the vehicle.

5.5.2 Automated Public Transport Vehicles

It may be more straightforward than at many stations to allocate an area for AV pick up / drop off. Aylesbury benefits from the northbound bus only link immediately north of the station. This accommodates a bus stop, but it may be possible to reallocate the carriageway, footways and bicycle lane to accommodate an AV stop in this area.

5.6 Summary

In summary, this section has demonstrated that there are different potential opportunities and issues with the introduction of AVs associated with each type of station. However, some general themes include:

- There is first a need to consider whether AVs are a desirable solution for transporting people to and from railway stations of various types. For example, at London Paddington it could be argued that there are sufficient public transport options already available, and with road space at a premium encouraging parking around the station might be undesirable.
- Auto-valet parking could help to relocate parking from areas of high parking demand to areas of low demand. The 'outbound' movement from the station to the car park might be simpler to implement than the 'inbound' movement as the latter would require the provision of a waiting area for the vehicles near to the station entrance, which would often be difficult to provide without compromising other road users or public transport modes.
- There is potential of auto-valet parking to increase supply of parking with vehicles parking more efficiently and hence making better use of existing car parks. It is recommended that real-world trials of this technology continue as this could be particularly beneficial at railway stations where demand often exceeds supply.
- Until the technology is more mature and intelligent, automated public transport vehicles will need dedicated pick-up and drop off areas. This could be difficult to provide close to the station entrance without compromising other road users or public transport modes. There may be difficult choices ahead about how to allocate space around station entrances, and this should be discussed in the planning of any future station designs.

6 Implications for Railway Stations – Fully Automated Trains

6.1 Overview

This section first outlines the background to fully automated trains. The prospects for amendments to railway station design are then discussed.

6.2 Background to Automated Trains

A fully automated train service running on the UK rail network is a number of years away. Network Rail (NR), as part of the Digital Railways program, plan to start upgrading the current UK's signalling system to European Rail Train Management System (ERTMS). The upgrade to ERTMS includes European Train Control System (ETCS) and Automated Train Operation (ATO).

Mid last year, Digital Railway changed the deployment model, instead of deploying by route, ETCS will be deployed within congested areas by overlaying ETCS onto the existing signalling system, with the aim to solve the capacity pinch points on the UK rail network.

This change indicates that a UK wide rollout for fully automated train service is possibly 25 years away[18] due to:

1. The existing train stock will need to be retrofitted with ETCS kit.
2. The trains are generally not owned by the train operating companies running them. This is where the fragmentation of the franchising model sometimes leads to a disincentive to train operators to modify the trains. Train owners may also not want to update the trains due to cost.

The train life cycle is approximately 25 years. New trains being introduced to the network are ERTMS compliant, therefore there is an assumption that ERTMS cannot be operated until the last of the old rolling stock is replaced, or completely reconditioned. It's possible that certain routes are ERTMS enabled sooner but other routes, which still use older trains, will not be able to for some time.

Some within the rail industry question the possible deployment of a fully automated train service on a complex mainline rail system. Currently on the mainline railways in the UK there is very little automation. There are two pilot projects for ETCS operation, with the first intended introduction proposed to be the new Thameslink connection through London (north to south). The aim is to provide a direct link from north to south and increase the number of trains per hour to 24.

From studies in the past, and as cited in the IET report[19], the London Underground's Victoria line is fully automated during peak hours. Without this automation, the Victoria line could not achieve the headway or throughput required. But the London Underground differs from the mainline system in that it is considered a closed system, and interaction with other rail traffic is minimal, if non-existent, therefore creating a fully segregated environment. Within this Metro style environment, automation process and moving to autonomous control has been possible.

The challenge with mainline rail systems is the integration of the different elements required, numerous vehicle types, infrastructure conditions and the distances between access points, to name a few. These major challenges need to be clearly understood before moving to fully autonomous trains. The European approach to ERTMS is the

[18] https://www.networkrail.co.uk/our-railway-upgrade-plan/digital-railway/

[19] The complexities of automating a mainline railway is also discussed in an IET report "Automated Vehicles: Cross-modal learning in autonomy" http://www.theiet.org/factfiles/transport/auto-trans.cfm

corridor approach, which creates a semi segregated system for main line train services. This is the general approach for HS2 in the UK.

This could be one reason why automation of mainline rail could be seen as falling behind other domains such as aviation, automotive and marine, especially considering rail has fully segregated corridors on which to operate.

Over the last few year, NR has been re-signalling parts of the network, and integrating hundreds of local signal boxes into twelve Regional Operating Centre's (ROC's). This program will remove the last remaining manually controlled signals, enabling the digitisation and thus automation of the signalling system from local signal boxes into the ROC.

6.3 Integration of Train Services with CAV's

Once the transition to a digitised (real-time) signalling system is complete, which will enable tracking of train movements with great accuracy, there could be an opportunity for CAV's to link into and coordinate service provision with train arrivals. For example, a message could be sent to inform the fleet of automated public transport vehicles that the train arrival is imminent, and an appropriate number of automated public transport vehicles could arrive shortly before the train arrives. However, most of the country already has access to "near" real time train movement information, therefore this approach is not necessarily dependent on real-time signalling.

6.4 Station Design and Layout for Fully Automated Trains

Automated trains are expected to have limited impact on station layout and design. The same general infrastructure, such as platform lengths and station layouts, are expected to function for automated trains as for manually controlled trains.

7 Potential Modal Shift to CAVs

This section considers passenger volumes and multi-modal traveller data for the main case study station (Milton Keynes Central), to consider how this may change with various CAV deployment scenarios.

A study completed in 2009[20] estimated the mode share of people travelling to Milton Keynes Central based on 498 face to face and 98 online interviews in 2008, mode share was calculated based on the respondent's stated main mode of travel to/from the station, where main mode was defined as the mode used for the greatest distance of the journey as determined by the respondent. The results were as follows:

Walk	Cycle	Car – drive alone	Park & Ride	Car Share	Car – drop off	Train	Taxi	Motorbike	Bus / Coach / Tram	Other
20.1%	3.3%	8.0%	0.0%	2.2%	26.1%	0.5%	14.0%	0.0%	25.8%	0.0%

Table 3: Modal Share of people travelling to Milton Keynes Central (source: Rail Delivery Group, 2009)

It is estimated by the Office of Rail and Road (ORR) that the following number of users entered and exited Milton Keynes Central station within the financial year from April 2015 until March 2016:

Entries Full	Entries Reduced	Entries Season	Entries Total	Exits Full	Exits Reduced	Exits Season	Exits Total	1516 Entries & Exits
601,219	1,698,302	1,118,264	3,417,785	601,219	1,698,302	1,118,264	3,417,785	6,835,570

Key:

Entries_Season	Estimated entries made to the station using a season ticket
Entries_Total	Estimated total number of entries made to the station
Exits_Full	Estimated exits made from the station using a full price ticket
Exits_Reduced	Estimated exits made from the station using a reduced price ticket
Exits_Season	Estimated exits made from the station using a season ticket
Exits_Total	Estimated total number of exits made from the station
1516 Entries & Exits	Estimated total number of entries and exits made at the station in 2015-16

Table 4: Annual Entries / Exits to Milton Keynes Central (source: ORR, 2016)

Assuming there is no material difference between weekday travel and weekend / bank holiday travel (clearly an incorrect assumption, but probably inconsequential for the purposes for this exercise), then the annual and daily travel to and from Milton Keynes Central can be estimated as follows:

[20] http://www.raildeliverygroup.com/files/Publications/archive/2009_station_travel_plans_report.pdf

	Walk	Cycle	Car – drive alone	Car Share	Car – drop off	Train	Taxi	Bus / Coach / Tram	Total
Annual travel (Based on modal share x total entries)	686975	112787	273423	75191	892042	17089	478490	881789	3417785
Daily travel	1882	309	749	206	2444	47	1311	2416	9364

Table 5: Estimate of Annual and Daily Trips to Milton Keynes Central

A report from the National Rail Travel Survey published in 2010[21] suggests that *"the majority of rail travel occurred in two daily peaks. 36 per cent of journeys started between 6.30am and 10am and 36 per cent started between 4pm and 8pm".* Assuming the above factor applies to Milton Keynes Central, we can estimate peak period and peak hour modal shift:

Table 6: Estimate of Peak Hour Trips to Milton Keynes Central

	Walk	Cycle	Car – drive alone	Car Share	Car – drop off	Train	Taxi	Bus / Coach / Tram	Total
Peak period (6:30 – 10am)	678	111	270	74	880	17	472	870	3371
Hourly (assuming flat profile within peak period)	194	32	77	21	251	5	135	248	963

Table 7: Estimate of Peak Hour Trips to Milton Keynes Central

The above numbers may be inaccurate due to the assumptions made, but probably provide reasonable approximate estimates. They suggest that in the order of 200-300 people might be arriving by bus at Milton Keynes Central during peak periods, and less than 100 are arriving by car.

If we were to assume that by 2025 25% of vehicle owners have a vehicle that can park itself, this shows that there might be around 20 cars per hour at peak times that could make use of auto-valet parking.

Demand for automated public transport services is difficult to estimate, as the extent of the service available in the future as well as the journey time and journey time reliability from various urban areas, is unknown. However, it has the potential to extract trips from all other modes of transport. If it is assumed that 10% of trips are made by this mode by 2025, then this would equate to around 100 people per hour arriving using this mode of transport.

As discussed in Section 2, automated public transport vehicles currently in development tend to be much smaller than traditional buses, accommodating somewhere between 2 to 8 passengers. If the average occupancy of these vehicles were 4 passengers, then this would mean 25 vehicles per hour arriving into the station environment, or approximately 1 vehicle every 2 minutes.

In reality, demand would fluctuate rather than following a flat profile as AVs arrive either ad hoc or to correspond to the timetables of particular trains.

[21] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/73094/national-rail-travel-survey-overview-report.pdf

8 Summary / Conclusions

This report summarises work package 7; a deliverable of the Station Innovation 2 project which has been undertaken by the TSC on behalf of the Department for Transport DfT.

This work package considers how CAVs might develop over the next decade and how these could be integrated with station design and operation in order to provide an efficient interchange in a multi-modal transport system.

This report has examined various CAV use cases. It is predicted that two use cases would be of most relevance to railway station design:

- Automated valet parking
- Automated public transport vehicles

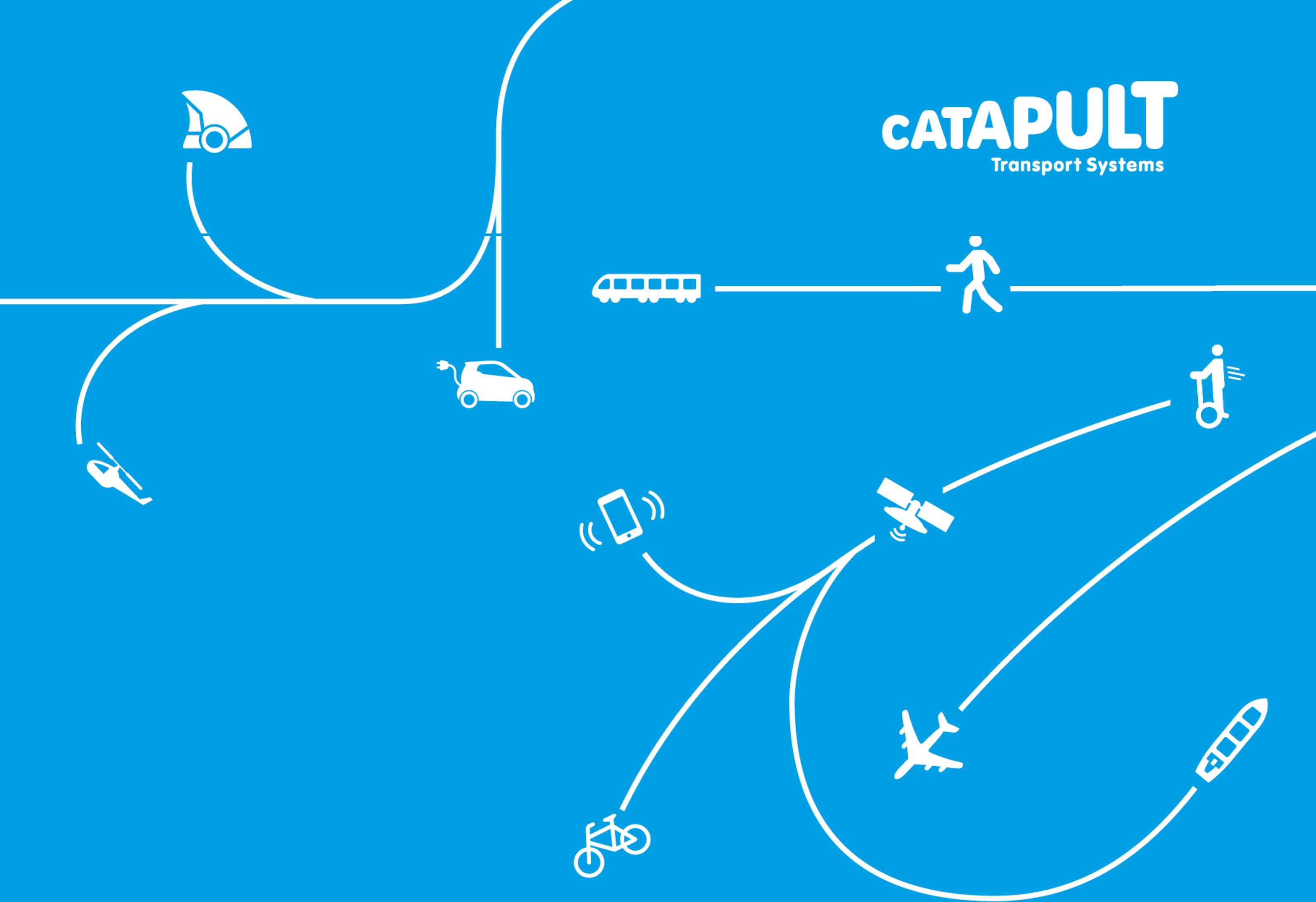
Auto-valet parking could help to relocate parking from areas of high parking demand to areas of low demand. The 'outbound' movement from the station to the car park might be simpler to implement than the 'inbound' movement as the latter would require the provision of a waiting area for the vehicles near to the station entrance, which would often be difficult to provide without compromising other road users or public transport modes.

There is potential of auto-valet parking to increase supply of parking with vehicles parking more efficiently. It is recommended that real-world trials of this technology continue as this could be particularly beneficial at railway stations where demand often exceeds supply.

Generally, until the technology is more mature and intelligent, automated public transport vehicles will need dedicated pick-up and drop off areas. This could be difficult to provide close to the station entrance without compromising other road users or public transport modes. In the early years, these vehicles will need to co-exist with traditional forms of public transport road vehicles, such as buses, taxis and private hire vehicles. There is already competition for road space around railway stations, and there may be opposition to relocating conventional modes of transport to create pick up and drop off areas for AVs. There may be difficult choices ahead about how to allocate space around station entrances, and this should be discussed in the planning of any future station designs.

There is first a need to consider whether AVs are a desirable solution for transporting people to or from and single railway station. For example, at London Paddington it could be argued that there are sufficient public transport options already available, and with road space at a premium encouraging parking around the station might be undesirable.

The report also discussed the background to fully automated trains, which are expected to have limited impact on station layout and design. The same general infrastructure, such as platform lengths and station layouts, are expected to function for automated trains as for manually controlled trains.



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