WHITEPAPER

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The Real State of Play in Self-Driving Buses

By David Panter

Autonomous cars are currently getting a lot of media attention. So are self-driving buses. Media announcements routinely advise that the world's first self-driving bus is starting service in Singapore, Germany, Switzerland, China, Sweden or one of half a dozen other locations. It sounds exciting, but does the reality match the hype?

Self-driving buses hold the promise of lower costs, smoother rides and greater flexibility. They have the potential to change our commute even more radically than autonomous cars. With autonomous car technology continuing to evolve on many fronts, we are now seeing many of these technologies flow through to buses.

However, when we look at what is actually being delivered in self-driving buses, it becomes clear that we are still some way from being able to have a standard 12m bus arrive at a stop, load passengers, validate their tickets and then move on to the next stop – all without a driver to be seen. Why is this?

Let's look first at some bus-specific issues that need to be addressed, what manufacturers are offering and finally, where this is likely to go in the near future.

At all times, we should be aware that technology is a fickle tiger. Grabbing technology's tail will be exciting, but it may not give us the outcome we expect. Too early and you have a technological dead end like the *Apple Newton* on your hands. Too late and you are making horsewhips for automobiles.

BUS-SPECIFIC ISSUES

Buses, as any passenger will tell you, are different to cars. They present a number of challenges that autonomous car and trucks do not need to be concerned about.

Ticketing

Whether a self-driving bus is used for first/last mile transport or line haul, commuters will be expected to pay. The ticketing systems selected must support driver-free operation and the enforcement regime must back this up.

For ticketing systems that rely on ticket vending machines on and off the vehicle and large numbers of inspectors, this may just be a simple extension of current operations. For systems that use smartcards in a conventional Check-In-Check-Out (CICO) configuration, this becomes a lot more problematic as there is no driver to enforce the transaction.

Adding inspectors increases operational costs; with small passenger numbers and short travel times, it may be impractical to deploy ticket inspectors on a last mile route unless there is an identified issue. So how do we automatically identify fare evasion and send inspectors to the specific vehicle carrying those transgressors?

One solution is to avoid the question entirely. Passengers will need a ticket on the line haul service, so the first/last mile ticketing issue can be avoided by just including it in the line haul price. This is however a little simplistic because where driverless buses are used to deliver passengers to their door, there will be different distances involved. An additional feeder service may be needed for the higher level of service. In general, anything more sophisticated than a short feeder service will likely need alternate ways to charge the customer.

Interestingly, some of the current generation of shuttles can determine their own weight and thus can tell us tell if they are running empty. This type of solution may also be able to estimate passenger numbers based on weight differentials at stops, but because of the variety of individual passenger weights this can only ever be considered an approximation.

Given the simplicity of these shuttles, it is likely that a video-based passenger counter will be needed to count all passengers on board at any given time. These counters can be married to the ticketing system and used to validate whether there is a discrepancy between the number of passengers and tickets activated.

Advanced ticketing systems such as Trapeze's *Be-In-Be-Out (BIBO) solution* make the vehicle aware of when customers get on and off, charge for the distance travelled and make appropriate charges for transfers to and from other services. When linked to a passenger counting system, this has the potential to provide instant feedback when a ticket is not paid. Potentially, if there is no payment then the vehicle will not move, allowing for a form of automatic and peer group enforcement.

Depending on the privacy regulations of the region, video face matching could also be used to directly identify fare evaders and allow for precise follow-up action by inspectors.

Security

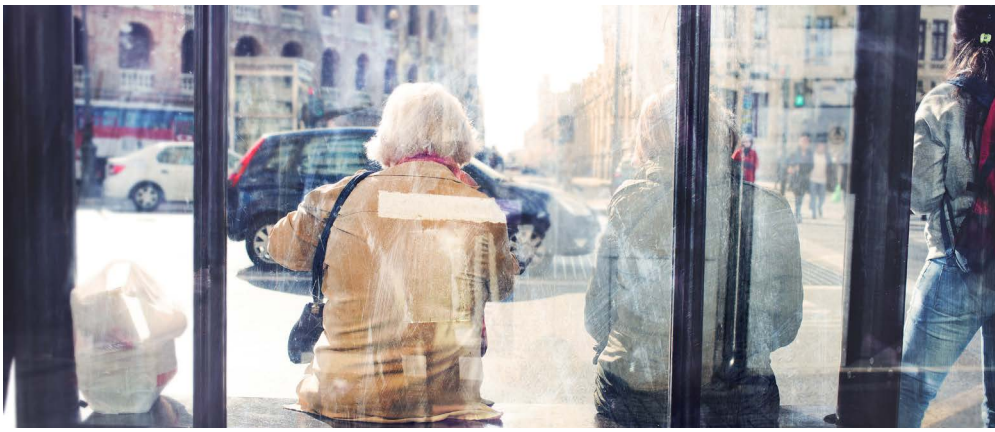
Safely getting passengers from point to point on time at a reasonable cost is the mantra of many transport authorities. The promise is that self-driving vehicles will be safer than manually-driven vehicles.

Certainly they will remove drivers from danger, preventing injury or even *death* as assaults on bus drivers rise in Australia[1,2] and around the world[3,4]. However, if a passenger has a problem (such as an elderly person having a fall), how will this be identified and addressed?

This calls for smarter video algorithms to identify and categorise non-standard activities and then send alerts to a central control system. This system must allow operators to look into the bus and coordinate a response. The control system should support operational overrides if necessary by directing the bus to pull over, open the doors and call emergency services.

Passenger pickup

Often, even on busy stops, there are no passengers waiting when the bus arrives. It is not desirable for a driverless bus to pull up at an empty stop, open its doors and allow some boarding time to elapse before continuing the journey. Passengers already on board do not want to needlessly stop and in an extremely hot or cold climate, the door opening frequently will reduce the comfort level inside the vehicle. This means that autonomous buses need the ability to sense passengers at a stop or



that an alternative sensing mechanism needs to be developed.

Route learning

Most self-driving vehicles use LIDAR and a host of other sensors to precisely locate themselves relative to their environment. Oliver Cameron's blog *An Introduction to LIDAR: The Key Self-Driving Car Sensor*[5] provides an easy-to-understand description of LIDAR operation. The use of this technology is both a strength and a weakness.

The current generation of driverless buses are shuttles that must be 'taught' the route. Essentially, this means they are driven over the route and the sensors take a 3D LIDAR snapshot of the route. When operating a service, the vehicle compares its current view to the snapshot and uses this to locate itself. A small side effect of this is that if there is a key change in the environment (such as a building being torn down or constructed, or even significant roadworks), the vehicle cannot get enough matches and is effectively lost.

The current response to this is the 'safety first' approach of having the vehicle stop and revert to manual operation. Fortunately, this is not a common event and it is likely that this will improve over time as the algorithms develop further.

The current autonomous bus trials use shuttle vehicles that allow a very narrow deviation from the planned path. This makes them pull up exactly at the stop. This is great for customers, particularly passengers with mobility impairments, but it limits their ability to veer off track to pass cars and trucks that might be parked wide. This may be fine in a dedicated right of way or an open campus, which is one reason why most trials are currently taking place in these environments, but on regular streets vehicles will recognise a problem and stop until a driver (on board or remote) takes over and navigates around the obstacle – hardly the driverless world we imagined. There is no doubt that developing *artificial intelligence (AI)* will remove this limitation, but for now this is a stumbling block.

An adjunct to this is that once an driverless bus can reliably get from A to B and pick up passengers, there is a need to determine just where A and B are. The vehicle's operations will need to be managed by a central system that can coordinate connecting services, allocate which buses will operate the first/last mile and ensure that the fleet is operating efficiently. This sort of connectivity is a key part of what the Swiss Transit Lab at *AMoTech* delivers.

Engine power

The first generation of autonomous buses are lightweight electric vehicles well suited to short operations

1 https://www.tmr.qld.gov.au/-/media/aboutus/rti/disclog/2014/13502759.pdf?la=en

2 *http://busexpress.com.au/assaults-bus-drivers-rising-union/*

3 Washington Metropolitan Area Transit Authority – Safety Management Inspection, Federal Transit Administration June 17, 2015

4 http://ottawacitizen.com/news/local-news/bus-union-renews-push-for-transpo-to-install-protective-shields-for-drivers

5 *https://news.voyage.auto/an-introduction-to-lidar-the-key-self-driving-car-sensor-a7e405590cff/*

in relatively flat terrain. They are designed to be a shuttle rather than a line haul bus. This design limits them to slopes with a gradient of less than 20%. Steeper gradients need more powerful motors and control systems.

Manufacturers have these more powerful vehicles available, but at extra cost. It is thus important that operators be clear about how they intend to use these shuttles before making a purchase, or they will find themselves constrained.

Legislation

There is a lot of legislation developing around driverless vehicles, with many cities and states allowing road trials of vehicles with varying degrees of autonomy. Most legislation focusses on defining responsibilities in the event that something goes wrong. Recent deaths in both Tesla and Uber trials have put this under sharp focus and caused some governments to reconsider their approach. There are already *some suggesting* that it is better to wait and see rather than risk getting it wrong.

Technology is not waiting and there are already a host of smaller legislative changes needed. For instance, most of the new shuttles built by Navya, EasyMile, LocalMotors and 2getthere are bidirectional. How does this affect laws that define tail lights, headlights or the location of the registration plate? When operating on the road, self-driving vehicles need to be licensed and these legal issues need to be resolved. *Trapeze recently completed this process* with their Trapizio shuttle in Switzerland, so we know it can be done.

Customer acceptance

Logically, a Level 5 autonomous bus should be safer than one driven by a normal driver. However, logic often has little to do with customers' perceptions. Passengers and other road users ideally want proof of safety and this is hard to come by.

Many of the trials around the world go some way towards showing riders that these vehicles are safe and easy to use. The result of exposure via trials is generally positive, such as that experienced in Taiwan[6]: after taking the test ride, 22-year-old Wang Tsung-wei said, "The autonomous vehicle wasn't as terrifying as I had imagined."

Customer acceptance of driverless buses has a precedence with driverless trains. These can be seen around the world, including the world's longest driverless train system in Dubai[7] and on a smaller scale at many airports where they connect terminals quickly and safely. Passengers might express concern before the first trip, but quickly accept the concept and even move to the front of the train for an up close and personal experience of the route.

Australia is now getting on board, with the rail safety regulator approving their use. In June 2018, Rio Tinto hauled 28,000 tonnes of iron ore in the Pilbara region of Western Australia on an autonomous freight train for the first time[8]. The first *autonomous trains on Sydney metro services* are also under test. These trains are smooth, fast and demonstrate precise stopping alignment.

Compared to buses however, these are running on a dedicated track, separated from other vehicles and pedestrians and stopping at every station. Trains need to be aware of fewer environmental variables and have a much smaller response set to manage.

The good news is that, like driverless trains, travel on self-driving buses is safe and in fact pretty boring. They arrive without fuss, boarding is simple, they pull out and, subject to some limitations, they travel to the next stop without issues. Once passengers take a trip and find nothing to see, they move on to considering this a regular part of their commute.

The current generation of self-driving shuttles is a bit like toddlers learning to walk. They are a little nervous with their movement and at times a little slow and jerky. Safety of passengers and pedestrians is paramount and this means that if

6 *http://focustaiwan.tw/news/aftr/201708240005.aspx*

7 *https://www.railway-technology.com/projects/dubai-metro/*

8 *https://www.smartrailworld.com/rio-tinto-inaugural-journey-worlds-largest-and-longest-robot*

anything gets in the way, the vehicle will stop.
However, just like toddlers, they are learning and getting better all the time. Many use AI in their algorithms and it will not be long before they mature and can smoothly and confidently travel the route.

WHAT ARE VEHICLE MANUFACTURERS DOING?

With all these additional demands on self-driving buses, it is no surprise that their development is not as mature as the self-driving car. However, things are improving. There are multiple trials underway around the globe and some vehicles are now operating on the open street. But, whilst an internet search will yield lots of stories about self-driving buses **about** to deliver services, there are all too few examples where this actually happening. It would seem that Karl Iagnemma, CEO of Nutonomy, was right when he said, "Technology developers are coming to appreciate that the last 1 percent is harder than the first 99 percent". The early hype means that now we are at risk of having passengers and bus companies enter Aarian Marshal's *trough of disillusionment* – the emotional gap between the excitement of the technology promise and the final delivery.

Self-driving buses look to be developing in three ways:

- Existing bus manufacturers will incrementally develop and roll out their own technology.
- Disruptive vendors will enter the market.
- Car manufacturers will turn their autonomous vehicles into larger passenger movers.

Existing Manufacturers

Mercedes-Benz

The Mercedes-Benz *Future Bus with CityPilot* is a 12m bus with a top speed of 70km/h on the open road. It is able to recognise obstacles and pedestrians on the road, comes to a precise halt at bus stops with less than 10cm between the bus and the curb, moves off automatically and communicates with traffic light systems. Not yet fully autonomous, this bus technology is steadily advancing and was demonstrated in 2016, running in bus-only lanes from Amsterdam's Schiphol airport to Haarlem, a city just outside Amsterdam.

The Future Bus has demonstrated the technology potential and possible applications in public transport. Actual production use is more conservative, with Andreas Mink from Daimler Buses saying, "An implementation into series products will happen system-by-system / step-by-step." Dates have not yet been announced.

Volvo

Volvo[9] are adopting an incremental approach to driverless buses, starting with areas that they feel deliver the greatest value. They are leveraging off the work they have done with trucks and many features are included or available on Volvo buses today. Each of these represent a step towards an autonomous future, with each technology applied being a key factor in achieving overall autonomy. Features available today on the Volvo Euro 6 coach range include: Emergency

- Volvo Dynamic Steering
- Collision Warning and Braking
- Lane Keeping Support
- Adaptive Cruise Control

In January 2018, Volvo Buses and Singapore's Nanyang Technological University (NTU) signed a cooperation agreement on a research and development program for autonomous electric buses. Volvo and NTU will build an autonomous driving solution on Volvo's platform, which will be Volvo's first autonomous application in public transportation. The basis of the program is two all-electric 12m Volvo 7900 buses, of the same type that Volvo Buses already delivers today.

IVECO

IVECO bus and Paris transport operator Régie Autonome des Transports Parisiens (RATP) recently demonstrated how autonomous operations could enter bus operations early without needing to address many of the passenger issues.

They have *run a depot-only trial* [10]

9 Volvo Australia statement 29 April 2018.

10 *https://www.busnews.com.au/industry-news/1805/french-underground-autonomous-bus-test-a-european-first*

where the bus powers up in autonomous mode, exits its depot parking space and approaches the depot exit. The driver then gets on board and begins their shift. At the end of the shift, the driver leaves the bus at the depot entrance and the vehicle parks itself in the spot assigned by the automatic fleet management system. This allows for more efficient parking.

Haylion Technologies

Alphaba run 4 self-driving passenger buses in China. The buses are built by Haylion and have a designed speed of 40km/h. Equipped with LIDAR sensors, cameras and GPS antennae, they are bigger than most new shuttles and are said[11] to automatically avoid hitting pedestrians, vehicles and barriers, safely change lanes and stop at designated sites. Dongfeng Xiangyang Touring Car Co announced that a 6.7m-long, 25-passenger self-driving bus is about to enter service in Shenzhen, Guangdong Province[12]. These buses still have drivers in a safety role.

Scania

Building on their self-driving truck technology, Scania have a self-driving city bus. To date, this has only operated on Scania's test track, but it represents a step towards Scania's view of a fully autonomous public transport system. Schedules are fed into the planning system, which automatically generates on-time departures. The bus will stop for embarking and disembarking passengers along the way in completing its route before making another on-time departure.

Car Manufacturers

Most car manufacturers have some form of autonomous vehicle project at various stages of development.

For instance, *Volvo's 2016 XC90 SUV* shows a range of technologies being incrementally applied as versions roll out. *Uber has announced plans to replace human drivers with robotic ones*. Tesla continues to upgrade the autopilot feature of its customers' existing cars (although even this is not yet fully autonomous). *Waymo* is currently leading the world in AI for vehicle control[13]. However, they are still addressing real-world problems that range from detecting a *700kg moose in Sweden* to avoiding suicidal kangaroos in Australia.

It is therefore not surprising that few of these manufacturers are talking about autonomous buses.

One notable exception is Volkswagen, who are leveraging off their work in autonomous cars. VW has confirmed that they will bring to production their Level 5 autonomous shuttle SEDRIC[14], which could be used as a small school bus or shuttle. For now, this product is still in the trial stages.

Disruptive Technology Vendors

There are a growing number of new vehicle vendors that seek to disrupt the industry by offering small electric shuttles. These vendors, amongst others, include *EasyMile*, *Navya*, *2getthere*, *LocalMotors* with their Olli, *Auro* and *Ohmio* from New Zealand.

These shuttles form the basis of most of the *trials currently underway*. These vendors are innovative and fill the gap in size between cars and buses. This innovation leads to some interesting business opportunities, which we explored in *a recent whitepaper on bus operations in the autonomous world*. However, there are still some issues that need to be worked through, from the open-sided approach of *Ohmio* (which may not win over customers in the rain or extremes of heat and cold) to low-powered engines that preclude the use of these shuttles on anything but flat ground.

Regardless of the vendor, integration with the transportation control system is a vital part of making the most of these disruptive offerings. There is some integration already happening with the successful *AMoTech integration of a Navya shuttle with the Trapeze AVLCS*

11 *http://www.chinadaily.com.cn/hkedition/2017-12/20/content_35339175.htm*

12 *http://www.chinadaily.com.cn/china/2017-12/04/content_35190702.htm*

13 *https://www.theverge.com/2018/5/9/17307156/google-waymo-driverless-cars-deep-learning-neural-net-interview*

14 *https://techcrunch.com/2018/03/13/volkswagens-self-driving-electric-sedric-concept-is-heading-to-production/*

in Switzerland, but more research is needed.

WHERE TO FROM HERE?

None of the issues raised here are insurmountable and there is nothing to say that they will not be addressed in the near future. We can be sure that advances in autonomous cars and trucks will flow through to buses over the next 2 – 3 years and during that time, many of these issues will be sorted. What is clear is that transport authorities and bus operators are getting ready for the day when these driverless buses will be available. The existing shuttles will continue to improve and will soon be viable vehicles. They will, however, face competition from large-capacity autonomous cars used as rideshares.

The sunk investment in a full fleet of buses means that we are not likely to see instant widespread use. Rather, there will be a period of adaptation as operators look at how to make the most of their fleet control systems to manage self-driving buses. Initially this may be in first/last mile services, and then in perhaps 5 years we might see some line haul use trialled. Once public confidence has been gained, it will be on for young and old and the autonomous fleet will be rolled out over the following 15 years as existing assets come up for replacement.

CONCLUSION

The press about autonomous vehicle development is exciting and we are starting to see these vehicles on the roads right now. However, getting caught up in the hype could lead

to consumer disillusionment. For buses in particular, there are several issues that must be addressed above those required to autonomously drive a car from point to point. These include ticketing, passenger identification, on-board security and user confidence.

The initial flush of trials is encouraging. They help authorities understand some of these issues and let the public come to realise that, done properly, autonomous buses do not represent a risky approach to travel. These trials are mostly led by disruptive, newer entrants in bus manufacturing offering electric shuttles of varying capacity. These currently fall short of customer expectations, do not have the level of autonomy people are expecting and are limited in speed and flexibility.

Traditional bus manufacturers are more conservative and tend to follow an incremental approach to delivering features. They are still some years away from delivering driverless buses as an off-the-shelf product.

Change is coming and the next few years will transformational for passengers. There will be more and more self-driving shuttles on the roads and they will quickly form a vital part of an extended public transportation network. However, there are still issues to be worked through and public acceptance to be gained. It is important to maintain momentum and set expectations with customers, bus operators and public transport authorities alike.

So – get on board the shuttle, but just don't expect to see a full-size bus rolling up at your stop without a driver in the next year or two.

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If you have questions about autonomous vehicle and control centre integration, or would like someone from Trapeze to provide consultation on your organisation's options for intelligent transport solutions, please contact ***info@trapezegroup.com.au***

Trapeze Group works with public transport organisations and their communities to develop and deliver smarter, more effective public transport solutions. For more than 25 years we have been Here for the Journey, evolving with our customers around the world to helping them move people from point A to Z, and everywhere in between.

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