When will autonomous transit be a reality?

A 2getthere white paper

Authors:
Robbert Lohmann Chief Operations Officer
Sjoerd van der Zwaan Chief Technology Officer

2getthere
A COMPANY OF ZF

2getthere, a ZF company
Proostwetering 26a
3543 AE Utrecht,
The Netherlands

www.2getthere.eu

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1. When will autonomous transit be a reality?

1.1 Introduction

Since the late 1990s, public interest and media attention in automated vehicles has escalated slowly as advancing technology has brought increased processing power, advanced sensoring, and smart networked systems to bear on the problem of creating fully autonomous cars. It seemed that technology was finally catching up with the futuristic sci-fi predictions of previous decades.

In the last eight years, the development of self-driving cars has been characterized by two opposing trends: firstly, roadmap announcements by major auto manufacturers and demonstrations [1] by technology companies, and secondly, actual automated solutions in everyday road use. They have both raised public interest and created an anticipation of fully self-driving vehicles being just over the horizon – or here already.

Conversely, after several years of intense hype, the same technology companies and automotive manufacturers have been changing their rhetoric to a more modest stance on what is feasible in the short and medium terms. Google, the pioneer of the driverless car stated in 2011, it would have driverless cars on the road in the next 5 years, if not, then certainly by the end of the decade. Chris Urmson said in March 2016; ‘How quickly can we get this into people’s hands? If you read the papers, you see maybe it’s three years, maybe it’s thirty years.’ [2]

This is certainly a different stance than Google had previously taken. Since then, Google has become Waymo and decided not to build its own vehicle, but to focus on supporting existing car manufacturers with technology instead. More recently, during CES in January 2017, Toyota re-set expectations by stating full autonomous self-driving cars would only be available in several decades [3].

1.2 Differing definitions: Autonomous or automatic?

In the debate on when automated vehicles will be ready, there is also a conceptual difference between automated and fully autonomous systems.
SAE International’s highest level of driving automation is Level 5, which refers

1. For an (incomplete) indication of cities featuring or preparing for demonstrations (or tests), please refer to: http://avsincities.bloomberg.org/global-atlas’
2. http://spectrum.ieee.org/cars-that-think/transportation/self-driving/google-selfdriving-car-will-be-ready-soon-for-some-in-decades-for-others
3. https://subtletv.com/baadPDT/Head_of_Toyota_Automation_Research_Says_Dont_Believe_the_Hype_It_Will_Be_Sever

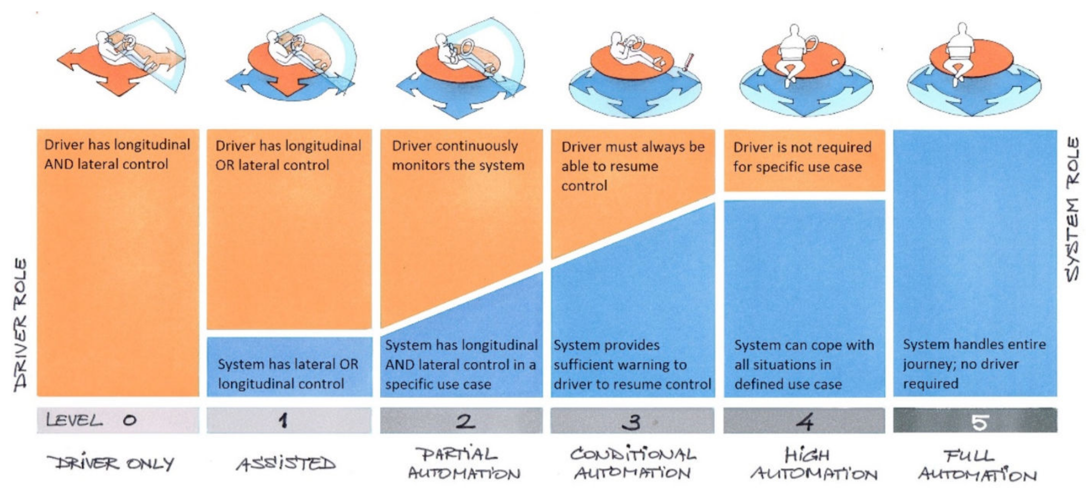
to “the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver”. This is what companies such as Waymo are aiming for with their autonomous vehicle projects.

By contrast, automated transport systems are designed to perform in predetermined ways under specific circumstances. This requires a much lower level of systems intelligence, which has made safe and efficient operation possible for the last few decades. Automated People Mover systems, typically on their own dedicated guideway, are a feature of major airports around the world and are even seen in urban applications. [4]

1.3 Driverless Transit Arena

Currently, there are various companies pursuing autonomous transit, coming from different industry backgrounds.

Firstly, major auto manufacturers such as Ford, BMW and Volvo have been making claims that autonomous cars will be a reality in 2020 (Business Insider, 07 April 2016). This is completely within the realm of possibility – if one defines autonomous driving as highway traffic that is moving in the same direction, with no cross traffic, traffic lights, intersections, pedestrians or other such complexities to deal with. The highway is a relatively uncomplicated environment, but speeds are high, meaning split second decisions will need to be taken at high speeds and real dilemmas come into account: like having to assess the options between multiple crash situations. Secondly, numerous technology and software companies are focusing on the actual



4. A good description of the distinction between automated and autonomous, as well as driverless and self-driving is provided by David Levinson (https://transportist.org/2017/06/29/on-the-differences-between-autonomous-automated-self-driving-and-driverless-cars/)

autonomous vehicles and developing the technology needed for them to function in uncontrolled inner city traffic environments. These include renowned tech-giants Waymo and Uber, as well as numerous start-up companies such as Nutonomy, Easymile, Navya and LocalMotors.

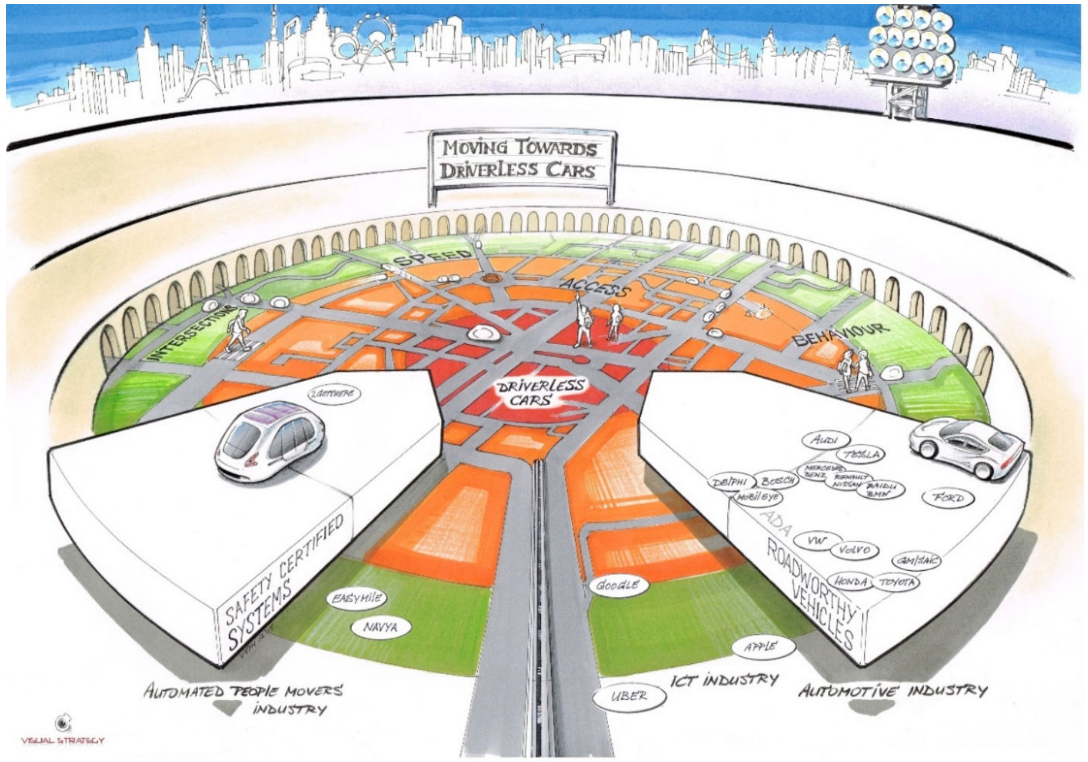
However, the self-driving car didn't start with Google or Tesla[5] and automated transit isn't new. Developers of automated transit systems have been around for many years and can be found at major airports and cities around the world. Typically, these are rail-guided, with non-rail guided systems in service since 1997 in the Netherlands (Parking Hopper at Schiphol Airport). The oldest system of this type is the ParkShuttle in the city of Capelle aan den IJssel in the Netherlands, which was introduced in 1999 and replaced by a 2nd generation system in 2006. To date, it is still the only automated system operational in the world that operates at grade, featuring at grade intersections, without having a steward or safety driver on-board.

All these companies, with their varied backgrounds, are moving towards automated transportation. Where some are at Level 2 automation e.g. Tesla, most are currently at Level 3 automation e.g. Waymo, NuTonomy, Uber, Easymile (Driverless, 10 April 2017). The only system worldwide that is at Level 4 automation is the previously discussed ParkShuttle transit systems. This application is viewed as a transport system, rather than individual vehicles providing transportation.

2. From Automated to Autonomous Vehicles

We have often been asked what the difference is between automated and autonomous vehicles. Automated vehicles are featured Automated People Mover (APM) systems around the world, predominantly at airports. The basic technology is largely the same, so is there a difference between the two concepts?

5. http://inhabitat.com/the-self-driving-car-didnt-start-with-google-or-tesla/



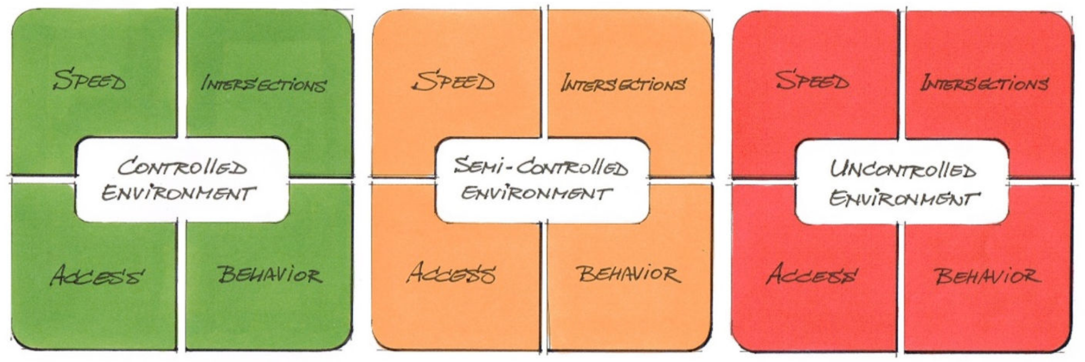
2.1 From Controlled to Uncontrolled Environments

For APMs it is possible to fully design and control the operating environment of the vehicle. Familiar solutions of this type include automated vehicles moving passengers between airport terminals, amongst others. In a fully controlled environment, it is relatively easy to provide high passenger throughput while retaining the highest levels of safety.

By contrast, autonomous cars operating in uncontrolled environments face completely different engineering and system design challenges. This is the arena in which companies such as Waymo are positioning themselves with their autonomous vehicle projects.

One of the most important factors in being able to deploy actual, operational, real world autonomous vehicle solutions within some reasonable future timeframe is in understanding the transition between controlled and uncontrolled environments. Realistically, working solutions in the upcoming years will start with the former and will gradually, over time, progress towards the latter.

A noticeable trend at the time of writing this paper, is that large companies that have previously made very ambitious predictions about the adoption rates of their autonomous vehicle solutions have refocused their efforts on concepts with some degree of control over the vehicle's environment.



In considering the difference between controlled, semi-controlled and uncontrolled environments, four key areas need to be addressed:

Speed. How fast is the vehicle moving and other vehicles in its vicinity? At lower speeds everything is always easier, especially when nearing intersections.

Intersections. Does the vehicle need to contend with cross traffic, other cars or Vulnerable Road Users (VRUs)? Are the intersections on a grade? Is the traffic in them regulated, and if so, how much control is there over the traffic flow?

Access. Is the vehicle segregated in its own separate lane or pathway, or does it need to share the lane with other vehicles? How likely is it that there will be people or vehicles in the lane that are not supposed to be there? What other vehicles does the autonomous system need to share its lane with? Sharing part of the street infrastructure with a human-driven bus is much easier than with random traffic and pedestrians.

Behaviour. How much control is there over how people use and interact with the system? Human nature dictates that people will always be disobedient and ignore traffic signals. Who are the users? Compared to a public city environment, it is much easier to run an autonomous transport system on private premises where employees and visitors are educated on how to use the system and can be expected to follow instructions.

Differences in these four areas denote a continuous scale from fully controlled to uncontrolled environments. At one end of the scale is a people mover system operating on private premises along its own track or pathway. At the other, a fully autonomous driverless vehicle navigating busy city streets amongst other traffic. In this sense, car manufacturers and tech-giants talking about autonomous cars being deployed in the upcoming years (2020 - 2025) are talking about highways. An environment where all vehicles travel at approximately the same speed, have no at grade intersections, with access restricted to cars and behaviour being relatively similar. It is basically a semi-controlled environment and certainly a far cry from a city centre where cars, buses, bikes and pedestrians driven by different nationalities and personalities mix-and-match, creating an uncontrolled environment: which is much less predictable and more complex.

2.2 Stand-alone or system-managed?

As already discussed, automated cars are completely within the realm of possibility if one defines autonomous driving as highway traffic that is moving in the same direction, with no cross traffic, traffic lights, intersections, pedestrians or other complexities to deal with.

The real challenge for fully autonomous driving, though, is to be able to operate both at high speeds and in complex environments, like city centres. Urban city environments feature relatively low speeds, but complexity is high as they need to deal with vulnerable road users and individuals or drivers that do not obey traffic rules or signs. Dariu Gravila of Delft University of Technology puts it candidly: to navigate the urban streets robocars need to learn to think like humans (reference to https://www.wired.com/story/self-driving-cars-freezing-robot-problem/).

Even though several companies have unveiled research prototypes and/or actual production models of autonomous road vehicles or last-mile shuttles, these vehicles are not yet suitable for uncontrolled environments, as they require a human steward on board to be responsible for vehicle and passenger safety. This is understandable, as the complexity of inner cities and the criss-cross traffic movements are daunting. Often companies providing level 3 demonstrations argue that the steward is only present as regulations still require one, even though their software is level 4 or 5 capable. However, even when regulations would be in place, there is no assurance that any of the companies have the experience, knowledge and expertise to demonstrate that their software and processes are certified and their developed product can meet the required safety target. With the safety target being a question mark on its own: just as safe as a car? Or safer? Twice as safe? Or just as safe as public transit (a factor 10 at least, depending on the country considered)?

The only way to guarantee safety for now, is by means of a safety driver or alternatively a steward with an emergency button, while operating at a reduced speed. The CityMobil2 EU-research program, where demonstrations were given in European cities, concluded that due to the low speeds required to ensure safety, dedicated lanes would be the preferable operating environment to provide an acceptable service level to passengers (European Commission Horizon 2020, 19 February 2015).

Most developers are approaching the problem of automated transport from the standpoint of building standalone vehicles that solve all the issues within the car itself. This overlooks the possibility of modifying the environment the vehicle operates in, or introducing way-side infrastructure, signalling and/or supervisory systems to manage the vehicles and their interactions with each other and their surroundings.

Building safe and efficient autonomous vehicle systems is already possible with today's technology; however, to succeed, the approach must encompass the system as a whole, including the vehicles, their supervisory systems and infrastructure. All three of these areas must be addressed to deliver safety levels that are acceptable to society.

3. Moving towards automated transportation

3.1 Proving Technology and Standards

Another difference between Automated People Mover Systems and Autonomous Vehicles is that the latter can't be considered fully proven, with experimentation and testing still ongoing. There certainly aren't set standards, or even guidelines in place yet. The result is that the projects realized today are demonstrations rather than applications, which can show the capabilities of the technology, but not the system reliability and availability needed for deployment in daily operations for public usage.

Automated People Mover Systems conversely are well regulated, with several established standards in place, governed by local rules and regulations. Typically, the Design Safety Case and Operational Safety Case, in which the supplier and the operator provide evidence that the system can meet the safety target set, are evaluated by an independent safety assessor, who also witnesses the system passing all the tests during the testing and commissioning period.

The testing of an automated people mover system is relatively straightforward in comparison to automated cars: as the vehicles operate in a controlled area, the number of scenarios that can be encountered is restricted. Autonomous vehicles operate in a mixed environment, where the number of scenarios that can be encountered is practically infinite, as people tend to find new ways to deviate from expected behaviour on a daily basis. For this reason, many of the companies developing autonomous vehicles argue that they should be allowed to test their vehicles in real-life, on real roads. The various systems currently being tested in cities, Uber in Pittsburgh, Nutonomy in Boston and Singapore, Waymo in Arizona and California, require safety drivers, as the state of the technology isn't considered mature.

The associated regulations should be strict, as shown by the example of an Uber-car driving through a red light, and therefore jeopardizing unwary bystanders (Fortune, 26 February 2017). People in these cities haven't consented to being part of an environment where an automated car is operating on their streets, without being independently assessed or proven to meet any safety standards. Safety drivers in the vehicles are important to help prevent anything serious from happening, at the same time it should be questioned whether it is ethically responsible to test a car that hasn't met any safety standard in an environment where people haven't consented to being part of that particular test.

For this reason, testing environments are being set up that allow for an actual city to be replicated and different scenarios to be tested. These testing environments give us the advantage that the general public aren't unknowingly subjected to being part of a test environment, the drawback for developers is that within an artificial city there is no normal behaviour. The scenarios being tested are limited by the imagination of the testers, leaving the question open whether what works in an artificial city really represents what happens in actual cities. A straightforward way to address the dilemma is by moving towards semi-controlled environments, where the number of possible scenarios is controlled, allowing them to be tested in an artificial city, before allowing the cars on the public roads.

3.2 Autonomous vehicles - from demonstrations to applications

The focus on the business case and the financial viability is essential to make the step from demonstration to application, with actual day-to-day operations and passengers.

When discussing the current situation and possible future of autonomous vehicles, it is imperative to make a clear conceptual difference between applications, trials and demonstrations. The former are systems that have been delivered and put into productive use. The latter are conceived to provide the public with an image of what autonomous vehicles can achieve in the future. Trials are mainly used for experimenting, gaining experience, validating technologies and finally for the gathering and sharing of data. It should be noted though, that trials can lead to false data. Users are aware they are not using a 'normal' mode of transportation and hence do not exhibit their normal behaviour.

At the time of writing, demonstrations outnumber applications by a significant margin.[6] With demonstrations, autonomous vehicles are set up to operate in high-profile areas for a limited time-period. The "wow factor" from these demonstrations is intended to raise interest, engage decision makers, and make stakeholders receptive to introducing such systems into their cities. Ultimately these demonstration is intended to support the case for making the funds available to realize permanent applications.

The requirements for demonstrations and applications are very different. Availability rates of 80% may be perfectly acceptable in demonstrations, but a fully operational application will be expected to be available and running at least 99% of the time.

Typically, demonstrations are executed within a restricted timeframe and on a low budget. Therefore demonstrations are typically simplified, and constrained to an environment where the full complexity of the final solution is avoided. The result being that people will have high expectations of what they will see in an automated vehicle system. Unfortunately, they will almost always be disappointed, as the demonstrations still feature stewards on-board and operate at very low speeds (up to 15mph only). This is not surprising, as the demonstration system is not fully representative of what the final operational solution would be.

Permanent autonomous transport systems can typically be expected to significantly lower operational costs but will require higher initial investments compared to traditional solutions. The return on investment will be realized only after several years, which means that the vehicles will need to be engineered for extended service lives. A planned 20-year vehicle life cycle is normal for a transport system, but is completely different from a PR-driven demo system based on vehicles and sensory technology that is still at the research and development stage.

It should be noted that there is a considerable difference between demonstrations and trials. Where demonstrations are intended to convince decision makers to invest in an application, trials have a research objective. Trials can run for years

6. All of the tests mentioned at http://avsincities.bloomberg.org/global-atlas are demonstrations of capabilities, with the exception of the Rivium ParkShuttle at Capelle aan den IJssel (near Rotterdam in the Netherlands) and the planned system at Zaventem Airport in Belgium.

and are used by companies such as Waymo, Uber and Nutonomy to gather data, gain experience and validate new technology. They are working to prove the viability of technology first, before deploying the technology in actual applications and carrying members of the general public.

A focus on high-profile demonstrations is a natural strategy for start-up companies pursuing further investment rounds and showcasing their capability for innovation, it does not however necessarily promote the long-term adoption of autonomous vehicle solutions and improvement of the accessibility and liveability of cities. To move to the future, we need to look less to demonstrations and more to trials and especially field-proven automated vehicle applications that have the possibility to be delivered – today.

4. Conclusions

4.1 Conclusions

- Despite roadmap announcements and demonstrations by major auto manufacturers and technology companies, most companies involved in autonomous driving have been quietly repositioning themselves with a more modest stance regarding what is feasible in the short and medium term.

- There is a conceptual difference between automated and fully autonomous systems. The latter refers to "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". By contrast, automated transport systems are designed to perform in predetermined ways under certain constrained circumstances.

- At this time, major auto manufacturers and technology companies are focused on the actual autonomous vehicles and developing the technology that is needed for them to function in uncontrolled inner city traffic environments. This overlooks the possibility of modifying the environment the vehicle operates in, or introducing some type of wayside infrastructure, signalling and/or supervisory system to manage the vehicles and their interactions with each other and their surroundings.

- Know-how regarding wayside infrastructure, signalling and/or supervisory systems is the intellectual property of developers of automated transit systems, not of major auto manufacturers and technology companies.

- In order to succeed, major auto manufacturers and technology companies must embrace the system as a whole, from the actual vehicles to their supervisory systems and infrastructure. All three of these areas must be addressed to deliver safety levels that are acceptable to society.

- A sensible and practical pathway for developing autonomous vehicle systems is therefore to start with semi-controlled environments and gradually expand to less-controlled ones. A semi-controlled scenario would be an autonomous vehicle sharing a bus lane with human-driven buses. In this scenario, speed and behaviour can be fully controlled, as human drivers can be trained to respond appropriately to the automated vehicles.

- Other, even less controlled solutions could include automated vehicles on university campuses with full control over speed and some behaviours, but no control over intersections and access. Or, airport airside operations in which speed and access can be defined with precision, as behaviour can be influenced through staff training, but interactions with taxiing aircraft and ground vehicles represent uncontrolled elements.

To secure a working future for autonomous systems we must shift from high profile demonstrations in contrived situations, to focusing on financially viable applications that can gradually move from a controlled to a semi-controlled environment. In due time the experience gathered through extensive technology trials will result in the application being realized in a less controlled environment, most likely at a forward looking city focused on the long term, such as the city of Capelle aan den IJssel in the Netherlands.

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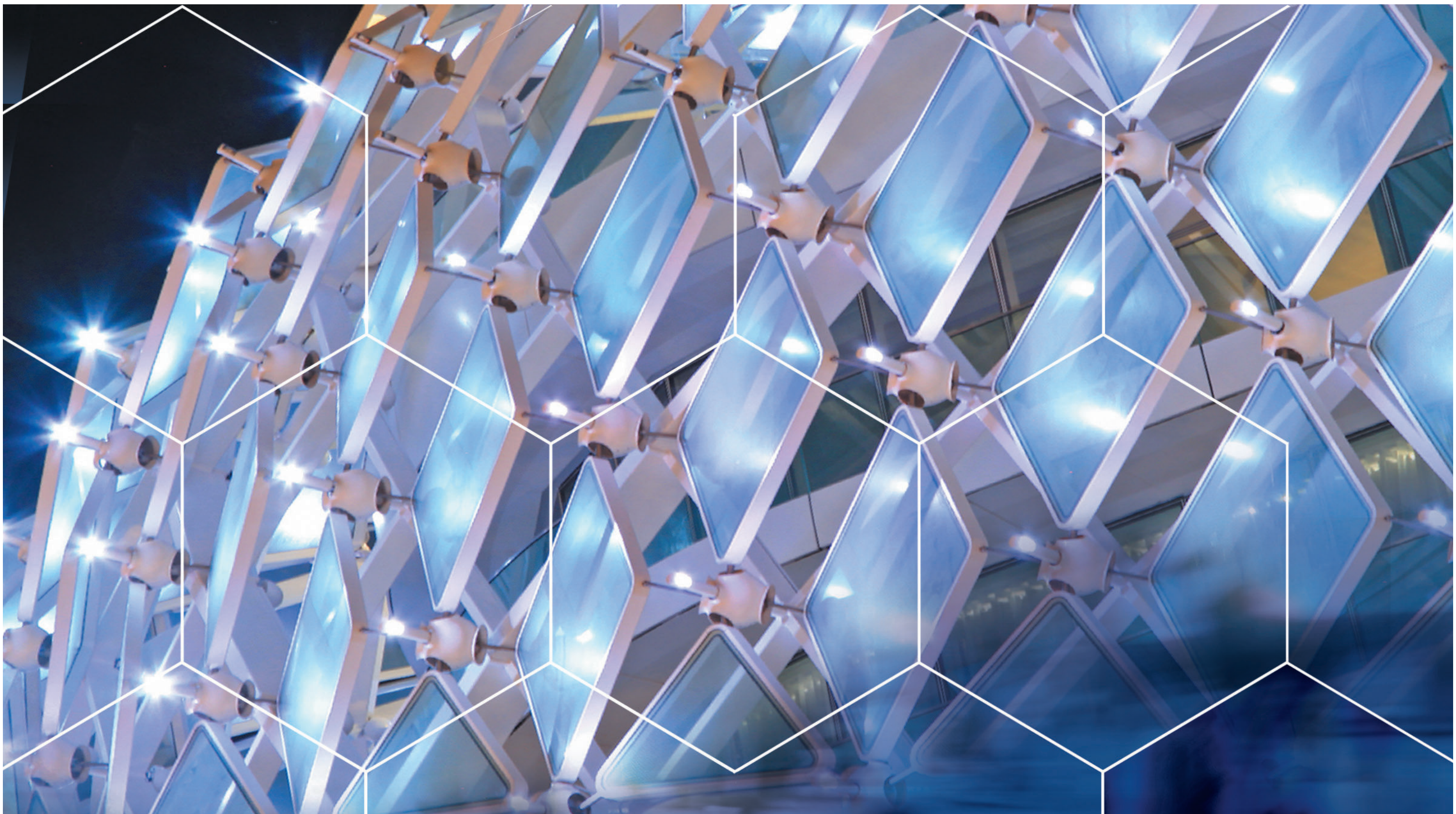

About the authors

Sjoerd van der Zwaan (Chief Technology Officer) and **Robbert Lohmann** (Chief Operations Officer) are part of the management team of 2getthere, a company developing, marketing and delivering automated transit systems since 1997. The systems are based on 30+ years of technological development and experience with automated vehicles in various demanding environments – ranging from factories, to ports and urban developments.

The views and arguments presented in this paper are based on their experience delivering automated vehicle systems at several locations around the world. However, these views are solely those of the authors, and may differ from those of other companies and experts operating in the field.

2getthere (HQ)
Proostwetering 26a
3543 AE UTRECHT
The Netherlands
T: +31 (0)30 2383570
F: +31 (0)30 2383571
E: info@2getthere.eu

2getthere Middle East
a joint-venture with United Technical Services LLC
Plot No. 3E, Sector MN-3 Musaffah
P.O.Box: 277 Abu Dhabi, UAE
T: +971 2 6171000
F: +971 2 5538853
I: www.uts.ae

2getthere Asia
a joint venture with SMRT Services Pte Ltd
2 Tanjong Katong Road
#09-01 Tower 3 Paya Lebar Quarter
Singapore 437161
T: +65 65548723
E: enquiry@2getthere-asia.com.sg