



Regulations required: safety drives autonomous vehicles market.

A 2getthere white paper

Authors:

Robbert Lohmann Chief Operations Officer

Sjoerd van der Zwaan Chief Technology Officer

2get³there

2getthere B.V.
Proostwetering 26a
3543 AE Utrecht,
The Netherlands

www.2getthere.eu

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Executive summary:

Many vehicles today already possess advanced driver assistance mechanisms. The prospect of increasing the automation levels of vehicles raises complex questions concerning accountability and liability when accidents occur. While the universal, full automation of vehicles is expected to result in enhanced safety for all traffic participants, the foreseeable future will hold a mix of fully autonomous, partially automated, and manually driven vehicles. The sober reality is that autonomous vehicles - often presented by the industry as a panacea - may not necessarily contribute to smarter cities, and that their relative safety levels may not be competitive with present-day public transport. To develop autonomous vehicles in a way that supports cities that are truly safer, cleaner, and less congested - in short, a place you would want to live in - will require strong regulations, in addition to a significant focus on shared mobility.

We will not get there overnight. Serious hurdles remain before autonomous vehicles will be able to drive in mixed traffic and all-weather conditions safely. The key drivers of autonomous vehicle advancement are RAMS: reliability, availability, maintainability and safety. When you take into account complex urban situations featuring multimodal traffic, at-grade intersections and unpredictable human behavior, it is obvious that defining standards and achieving a safety target acceptable to society is not straightforward. Therefore, manufacturers of autonomous vehicles (AVs) and systems should step away from inflated claims of level-5 safety and focus on improving performance in semi-controlled, reduced-complexity environments first.

To truly achieve smarter cities, AVs should set ambitious safety targets and their development should go hand in hand with the promotion of shared mobility. The public debate on these issues cannot be perennially suspended to avoid inconveniencing what is perceived to be a multi-billion industry in the making. Regulators must set safety requirements, introduce clear liability laws, and establish certification processes that are in line with public expectations - even if this means deflating the expectations of a currently exuberant industry. Meanwhile, independent assessments of design and operations safety cases could serve as an intermediate step, allowing the industry to learn and develop, without having to wait for tomorrow's regulations.



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1. The market for Autonomous Vehicles

1.1 Becoming more autonomous: from level 2 to level 4

Nowadays many cars already incorporate well established advanced driver assistance functions, which include ESP, ABS and navigation systems. Examples of more recent and advanced systems are ACC, CACC, automated lane keeping and AEB where the car detects an obstacle in its pathway. These systems assist the driver in controlling the car and allow them to respond better to any given situation. Ultimately, by law, the driver is still responsible for driving the vehicle: he should be able to drive safely even when these systems are off (SAE level 2). This is why the systems featured on a Tesla, now inappropriately termed ‘autopilot’, are actually purely advanced driver assistance systems.

The questions as to the driver’s responsibilities must also be considered and codified. An analogy can be made with regard to the autopilot systems on an aircraft. In the 2009 crash of Air France flight 447 from Rio de Janeiro to Paris, the pilots were unable to recover control of an Airbus A330 after the autopilot gave out as a result of a sensor failure. Who is responsible for the accident in this kind of scenario – the aircraft manufacturer or the pilot? In the end, the accident investigation concluded that the fault was with the pilots, as even when flying on autopilot, a person must retain responsibility for the safety of the aircraft– autopilot in this sense being a ‘pilot assistance system’. With automated cars, the situation is similar but perhaps even more fraught with complications. If the control system of an autonomous car decides that any given situation is too complicated to handle and surrenders control to a human, the driver/steward may have very little time to react. A lot of things can happen in 8 seconds, and a vehicle travelling at 100 km/h will cover 250 m in this time. If the driver is reading a book, napping or otherwise unfocused, it seems unlikely that he or she would have any chance of regaining control of the vehicle in such an event. In the case of a steering failure, the vehicle will actually be in an uncontrollable situation in less than 1 second.

So the question is, should the ultimate accountability rest with the driver – or the system manufacturer? And if a human is still required to be in charge of the car at all times (even if they are now called a ‘steward’ instead of a ‘driver’), will he actually feel and act responsibly knowing there is so much technology integrated into the vehicle?¹ Evidence shows that it is human nature to assume

1. <http://www.latimes.com/business/autos/la-fi-hy-tesla-autopilot-20180125-story.html>

one can ‘safely drop the ball’ in such a scenario. Recent research shows that the assistance systems are good enough for people to rely on them, but that the trust is actually misplaced². The assistance systems do improve safety in the sense that they are more likely to see an event faster than a human, who has a longer ‘delay’ between registering the actual event and taking appropriate action. The result in some cases, is that the vehicles with the advanced driver assistance systems might be rear-ended more often⁵ as they brake quicker (and perhaps harder) than a human driver typically would or could⁴.

For now, accountability can still be addressed by exported requirements on the operator of the vehicle. Both Tesla and Volvo⁵ acknowledge that their systems might not react appropriately when a stationary object is detected directly in front of the vehicle in lane-switching situations. This issue is directly related to avoiding ‘false-positives’: the risk of detecting an obstacle that is not there. Consequently, the vehicle risks needlessly grinding to a halt, creating an unsafe situation and hindering the normal flow of traffic. Where the responsibility and accountability is currently addressed by putting the onus on the driver to be aware of the situation at all time, and appropriately intervene in every circumstance, this justification will no longer be valid when autonomous cars eventually achieve SAE level 4.

1.2 Where to introduce automation first?

Only once all cars are autonomous, will their full potential be reached. Until that time, such advantages will only be achieved in autonomous-only zones. In mixed environments, autonomous cars are unlikely to change much, since the roads will still be congested due to the current behaviours of human drivers. Likewise, if people switch to autonomous cars at the expense of public transport, cities may be filled with autonomous vehicles with far less total capacity than buses or trains. These higher occupancy vehicles will immediately provide benefits to their operating environments in lowering the density of traffic, thus easing the complexity and the likelihood of incidents. Any solution that doesn’t increase the average occupancy and/or the number of people that can be transported per hour is not a solution for a Smart City.

The mistake made by many is that they exclusively focus on the user experience of the person in the car⁶. This is a logical emphasis for a car manufacturer; but not for a city. We should prioritize the user experience of citizens and communities over that of transportation in the narrow sense. Where passengers might be comfortable in autonomous vehicles, communities are most likely impacted

2. <https://www.theguardian.com/technology/2018/jan/24/self-driving-cars-dangerous-period-false-security>
3. <https://www.theinquirer.net/inquirer/news/2457521/google-self-driving-car-rear-ended-by-human-driven-vehicle>
4. <https://techcrunch.com.cdn.ampproject.org/c/s/techcrunch.com/2018/02/01/we-were-in-an-accident-during-an-automated-driving-tech-demo/amp/>
5. <https://www.wired.com/story/tesla-autopilot-why-crash-radar/>
6. <https://techcrunch.com/2017/12/27/with-autonomous-vehicles-its-not-about-the-journey-its-about-the-destination/>



negatively by the creation of more, faster and longer traffic jams and more inhospitable, crowded, city streets. That's not a Smart City but a dumb city.

The solution is a 'soup of various sized vehicles' providing mobility and connecting the various attractors within the city, with the ultimate goal of freeing up the shared public space on the street for more human uses. The transit ingredients of the soup are smart mass transit (the 'thick' lines), small vehicles (electric bikes and scooters for individualized trips) and shared Autonomous Vehicles which fill in the gaps. In the end, smart cities aren't just about improving transportation, but about improving cities and the experience of living in them.

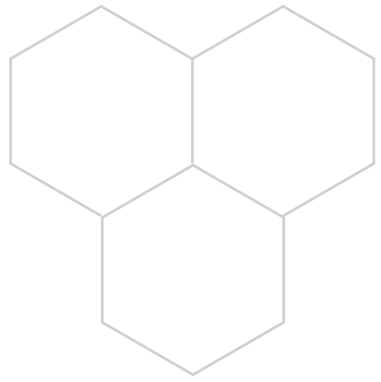
People travelling in automated cars may be safer than in manually driven vehicles, but not necessarily safer than they would be on trams, trains or buses. All of these exhibit significantly enhanced safety levels per passenger kilometer travelled relative to cars. If at a future date more people decide to travel in automated cars, instead of taking public transport, the overall number of traffic fatalities might not decrease significantly – especially when taking into account the impact an increased amount of cars on the surroundings. Hence, the natural starting point to autonomous transportation will always be automating public transit, with it setting the safety target society should expect from autonomous cars as well.

1.3 Autonomous Driving 101

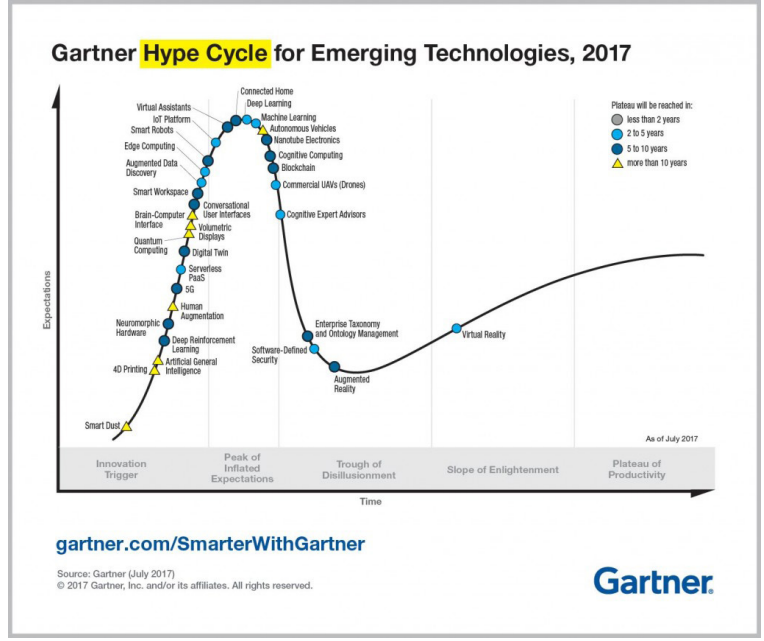
In the public discussion and industry debate on the future of mobility, the concept of automated, shared, or electric are often happily confused. The automated car doesn't reduce the number of cars on the road - ride-sharing does. The automated car won't make the city more sustainable, only electrically powered cars from a sustainable power source will. And yes, automation can improve traffic safety immediately for people that were previously driving themselves; however, autonomous cars will need to be at least 10 times safer to match the current safety levels of public transport systems⁷.

The industry almost presents autonomous cars as a cure-all. Major car manufacturers and tech-companies contribute to this craze through capability claims and grandiose marketing statements, all hoping to establish themselves as the market leader. Start-ups are popping up, joining in, hiring the brightest young minds available, and being taken over for eye-popping amounts. The main beneficiary of all this hype, is the valuation of the perceived innovation and market leaders.

7. <http://www.apta.com/mediacenter/pressreleases/2016/Pages/Hidden-Traffic-Safety-Solution.aspx>



The hype is working for suppliers, as state, regional and local authorities are trying to benefit from it at the same time. Autonomous vehicles are seen as an attractive new industry, offering new jobs, new high-income residents and a sparkly new "modern" image. Authorities are competing to attract their share of an estimated \$7 trillion industry, by requesting demonstrations, and in some cases funding them through subsidies, tax exemptions and/or new legislation. It is a win/win situation, as both the authorities and suppliers seek to bolster their perceived status as leaders in the field.



So, let's burst the bubble. Or at least deflate it a little.

The demonstrations with autonomous vehicles to date do not meet the level 5 criteria (fully autonomous in all driving situations). Frankly, any person or company now claiming level 5 autonomy should at least be required to go back to school, or alternatively locked up. The demonstrations aren't even level 4 (fully autonomous within the operational design domain) yet. As they have the safety driver or steward on-board, with an active role in ensuring the safety of operations, the demonstrations are widely considered to be level 3 applications.

But there are two exceptions: Waymo's cars in Chandler, Arizona and 2getthere's ParkShuttle in Capelle aan den IJssel, the Netherlands. The exceptions show a different approach towards achieving mixed traffic autonomy without steward. Where the Waymo vehicle operates in normal mixed traffic, it is phasing out the person in the car. Initially from behind the steering wheel (originally), to the back seat (currently) and out of the vehicle (ultimately). 2getthere has been operating

a driverless vehicle, without steward, since 1997, phasing in mixed traffic: from a dedicated road (originally), to a dedicated road with at grade intersections (currently) and mixed traffic (ultimately).

Keeping this in mind, it is important for us as a society to move away from the idea that fully autonomous vehicles will arrive overnight. In simplified terms, any automated vehicle needs to solve three challenges: where am I? (localization), where should I go? (path planning) and how to get there safely? (control and safety).

2. Safety as a driver

Questions of safety are usually the first to come to mind when thinking about self-driving cars. Since we humans are not always great or consistent in our driving, there is no question that automation is safer – or is it?

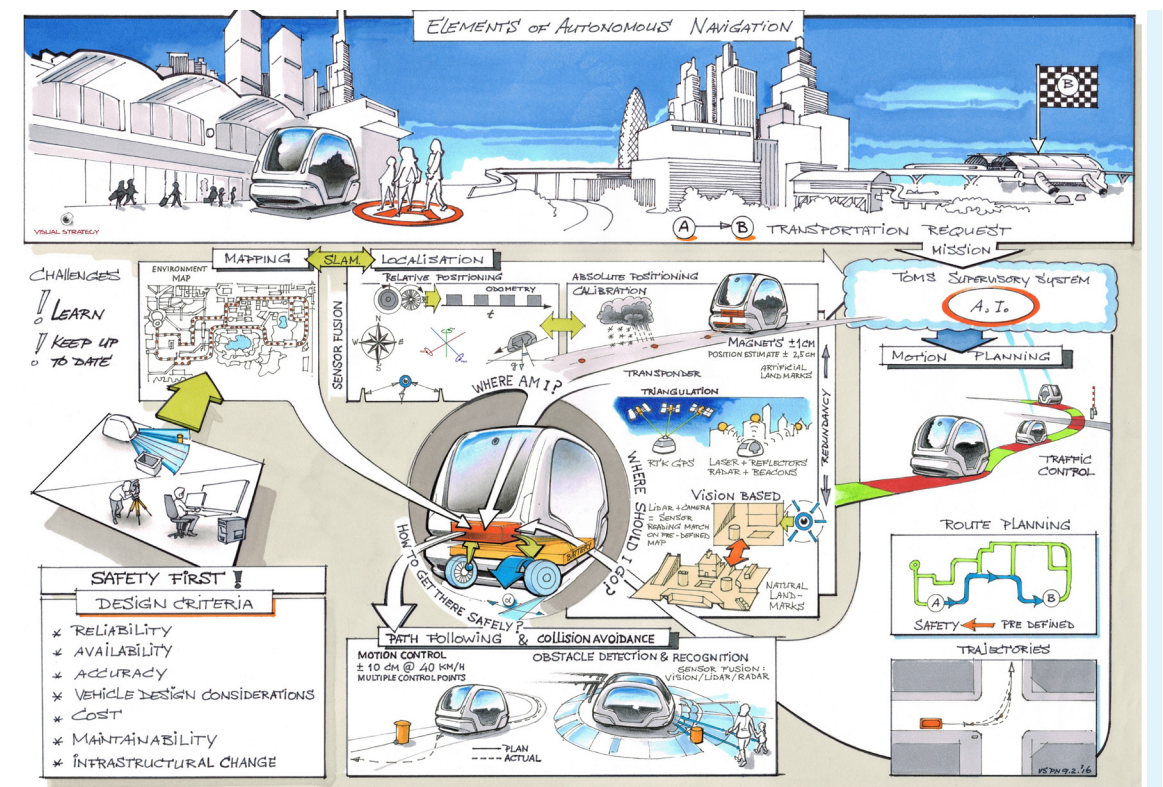
The difficulty in building autonomous cars is not to provide the ability to drive automatically – it is the ability to be able to react to everything, in a repeatable, safe and predictable manner. It is not about making a single automated car safer – it is about reducing the total number of incidents, accidents, injuries and casualties across all journeys.

2.1 Safety as part of RAMS

Ultimately, operations approval and the user experience are the key drivers for the advancement of autonomous vehicles. Setting (authorities) and meeting (suppliers) RAMS requirements should be the basis of operations approval. RAMS is the acronym of essential elements for autonomous vehicles:

- **Reliability** is a product's or system's ability to perform a specific function and can be broken up into two parts, design reliability or operational reliability.
- **Availability** is the ability of a system to be kept in a fully functioning state.
- **Maintainability** is determined by the ease with which the product or system can be repaired or maintained.
- **Safety** is the requirement not to harm people, the environment, or any other assets during a system's life cycle.

For the passengers, this will ensure safe and reliable transportation. On the supply side, implementing RAMS, meeting the requirements and achieving operations approval will identify the companies complying with the rules and regulations from those that are unable to do so. On the demand side, this focus will put an emphasis on permanent projects with proper budgets for RAMS



engineering. The operations approval of applications using autonomous vehicles is possible today for controlled (geofenced) environments, but not yet for 'uncontrolled' environments. To get there, we'll either need to drive billions of miles on public roads or move to 'semi-controlled' environments first.

The vehicles being tested on public roads today are yet to be certified as the legislation is still being developed. They (still) lack any proven availability and reliability in a broad range of scenarios and weather circumstances. Autonomous vehicles operating in city centers have absolutely no control over the factors determining the complexity of automating systems: speed, intersections, access and behaviour. Cars, bikes and pedestrians move at different speeds, drivers have different habits and skill levels, and all these parties have to navigate their way across at-grade intersections. Demonstrating RAMS with so many different scenarios is a daunting task, if not near on impossible. One is forced to question whether or not it is appropriate to allow systems to be tested in public space. Limiting the number of possible scenarios is a simple, but essential first step to introducing automation.

Semi-controlled environments provide a degree of control over the complexity of different factors. A semi-controlled environment, is an environment where the unpredictability is significantly decreased, allowing for simpler and more deterministic



decision-making. Basically, this is comparable with cars driving automatically on a highway or interstate, where all vehicles are heading in the same direction at approximately the same speed without being confronted with cross traffic or traffic lights. It is highly desirable to start with the easiest scenarios to get right.

Automated People Movers at airports have been around and certified for ages, as there is complete control over the four factors: demonstrating RAMS is more straightforward, when operating on a dedicated, grade separated infrastructure (deterministic circumstances). To achieve tangible results in the short term, the focus should be on establishing a certification process – or at least a method of assessing the safety of the system before allowing it to enter the public realm – and a sound, economically viable business case would be useful. This focus will push suppliers to address real transit issues and authorities to set RAMS requirements, resulting in permanent applications serving their daily users more effectively.

In other words: let's improve our cities today before it all gets out of hand.

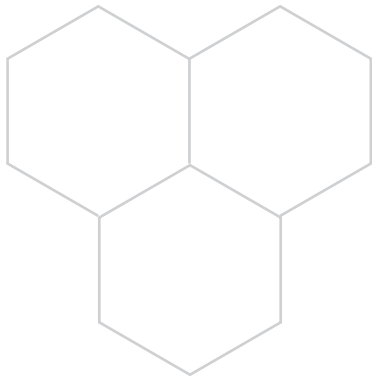
2.2 Setting a safety target

When having to set a safety target for autonomous vehicles, the comparison to the current level of safety is an easy starting point – and often used.

In several widely published cases, failures of the automated driver features have led to accidents, as the system has failed to respond appropriately to surrounding traffic. In spite of these accidents, autonomous vehicles have so far averaged a safety record 1.5 times better than traditional cars, operated by a human⁸. Even though accidents or even fatalities caused by failures of autonomous vehicles systems are difficult to accept on an intuitive and human level, the record is a valid argument for autonomous vehicles. However, is 1.5 times safer, safe enough?

Many societies have different philosophies on this subject; even within Europe. The French are familiar with the philosophy of GAME (globalement au moins équivalent), where the system must be at least as safe as the one it is replacing. In the UK the principle of ALARP (as low as reasonably practicable) is applied, which acknowledges the cost effectiveness of safety measures as well as acceptance of society. In Germany, they have yet another principle called MEM (minimum endogenous mortality) which allows a maximum contribution to mortality by technology relative to the minimum mortality by natural causes over all age groups.

8. <https://qz.com/721510/a-tesla-was-involved-in-a-fatal-crash-while-in-autopilot-mode/>



So what should be the factor? 1? Some talk about a factor of 2, others a factor of 10. Research in the Netherlands⁹ indicates that in the eye of the general public, technical failure fatalities weigh as much as 4 human error fatalities. Between deliberate misuse fatalities and human error fatalities this is a factor of 5.5. With this knowledge in hand, should we aim at a factor 5.5? The essential thing to understand is that the required safety level of automated vehicles will be the level society demands.

The table¹⁰ by Great Britain's Department of Transport below expresses the number of micromorts (a unit of risk defined as one-in-a-million chance of death) a passenger experiences per 1,000 kilometres.

Mode of transport	Micromorts/ thousand kilometres	Kilometres/ micromort
Air	Close to 0	A lot
Rail	0.3	3,333
Water	0.2	5,000
Bus/ Coach	0.3	3,333
Car	2.7	370
Van	0.9	1,111
Motorcycle	111	9
Pedal cycle	34	29
Pedestrian	44	23

Based on the table above, it can be concluded that there is a factor of 9 difference, between a car and a bus. An autonomous car would therefore have to be nine times safer than a regular car to avoid exposing a passenger, previously traveling by bus, to the same levels of safety. It should be noted that autonomous cars might have an impact on improving the safety of pedestrians: for this the improvement of the safety of each car on its surroundings should be researched against the consequences of the increased amount of vehicles travelling in a city.

To make the largest impact in improving safety for both passengers and the surroundings, while improving liveability, the number of vehicles operational within a city should be decreased alongside automation being introduced. The safety target set for all autonomous vehicles, whether cars or public transit, should at least be equal to the current level of safety provided by buses. This requirement sets a high bar for the AV industry - one that could slow down what everybody believes to be a multi-billion industry in the making – an

9. Thesis Bart Overakker, The Social Acceptance of Automated Driving Systems: Safety Aspects, <https://repository.tudelft.nl/islandora/object/uuid:31159f82-e33d-4124-a5a2-2b605974870e/datastream/OBJ/download>
10. Taken from: <https://understandinguncertainty.org/node/243>



industry that every country, state and city is fighting to host in order to create employment, income and be seen as a city of the future. The prime example is how the states of Michigan, Florida and Arizona immediately stepped up after California announced it was unprepared to work with Uber, as Uber wasn't willing to share information about its program as required¹¹.

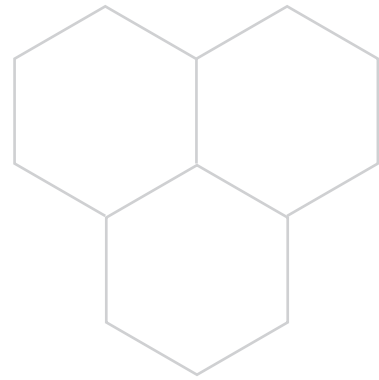
These and other related questions constitute an important public debate that still needs to be held. At the moment, rather than defining specific safety level requirements for automated vehicles, regulators and decision-making organizations remain hesitant to do so and are perhaps intentionally lowering their demands in order to accommodate technical development in the field.

2.3 Achieving the safety target

Vehicle manufacturers – whether automated or traditional – must manage a complex balance of contradictory values. On one hand, commercially operated companies aim to minimize their research and development, production and manufacturing costs while meeting the safety requirements placed upon them by regulators. On the other hand, manufacturers retain an ethical responsibility to provide their passengers with the highest safety level that is reasonably possible. Over time, and given sufficient passenger volumes, fatalities will inevitably occur with any system – but everyone wants to avoid them.

Ultimately, the manufacturer is always fully responsible for its product, but the evaluation of such situations remains a demanding task, especially when it concerns features not yet addressed by current regulations. Who can – and will – sign off on the safety of the design, engineering, production and operations? Or the control measures captured in highly complex control software? How can systems be evaluated and tested to achieve sufficiently low failure rates? If multiple suppliers and system providers work together on a system, how can the accountability of the entire supply chain be assessed by independent third parties?

A lot of these questions can be answered by looking at other domains (rail, aerospace, medical) with a much longer pedigree of RAMS demonstration and certification and applying these to autonomous transit as well. The interesting question though is: which practices are directly applicable and what is fundamentally different about autonomous driving that makes it so hard to define regulations and processes on one hand and find technological solutions on the other hand? One thing that stands out is there appears to be no other industry that has a SAE level 5 equivalent (i.e. absolutely no human intervention needed) for such a large and complex set of use cases. If you know one, drop us a line immediately.



Society holds vehicle manufacturers to certain safety targets, and consequently manufacturers must demonstrate that their products meet or exceed these targets. For automated cars setting realistic safety targets to which suppliers can deliver, the process of approval/certification, which standards to follow and what stakeholders to involve are still very much a work in progress, which causes difficulties for those considering autonomous transit solutions now. Autonomous vehicles often operate in a mixed environment, where the number of scenarios that can be encountered are practically infinite: people tend to find new ways to deviate from the expected behaviour on an almost daily basis. For this reason, many of the companies developing autonomous vehicles argue that they should be allowed to test their vehicles in similar uncontrolled settings. This deviates from common practice in other domains, by first gathering data in an open loop with the different scenarios, verifying and validating them in simulation and only then run tests in real-life environments. With the first two steps currently the differentiator between industries, as autonomous vehicles can only be tested on the open roads in cities with safety drivers or stewards present.

Demonstrations without safety stewards, can be conducted in test environments set up to replicate an actual city with a variety of scenarios. While this has the advantage that normal people aren't unwittingly subjected to an AV experiment, the drawback for developers is that there is no “normal” behaviour in an artificial context. This requires gathering of data in an open loop, which could then be used to simulate over and over again. The exact same amount of scenarios would be tested, but without an active, untested autonomous system running to gather the data (as is happening now). It should be noted that even when doing this, people will always find new, unique and sometimes stupid ways to create new scenarios. A straightforward way to address this issue is to move towards semi-controlled environments first, where the number of possible scenarios can be restricted.

2.4 Towards Certification and Shake Out

Certification of these systems will depend on regulators creating sensible requirements that define safety level that society is comfortable with. However, just because a system is certified doesn't mean a manufacturer – or driver – can lean back and take it easy. One never knows what one doesn't yet know, and the real world will continue to surprise us. It's a manufacturers responsibility to adhere to the standard set by authorities, as well as ensure the continuous improvement of the system based on the on-going learnings of both its own and other autonomous vehicles.

11. https://motherboard.vice.com/en_us/article/d7nnqa/uber-doesnt-want-to-share-self-driving-car-crash-data-with-the-dmv



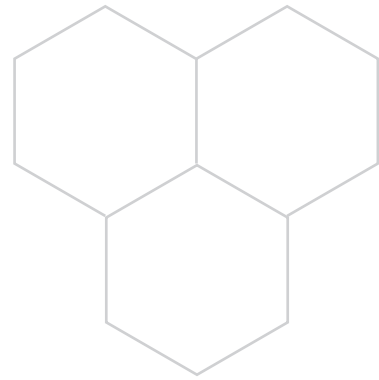
In many countries, governments are taking steps to address these concerns, often by introducing laws that lay the responsibility for the safety of autonomous vehicles unequivocally with the manufacturers. Manufacturers will have to prove conclusively that their solutions are safe enough – whatever that is defined to be.

In a limited number of locations, operations of autonomous vehicles are now being allowed even in the absence of any well-defined safety requirements. In Arizona, where the laws regulating autonomous tests were first practically non-existent, regulation requiring proper registration and automatic stopping in case of failure of the vehicle have been introduced only when questions were raised with regards to who was liable, which highlighted the lack of regulation¹². California is similarly lenient towards autonomous vehicle testing, not requiring any type of safety case or the associated evidence, nor does it have to be assessed independently. This is a dangerous precedence, that could damage the whole industry.

The irony is, that the leniency in both of these states is in stark contrast with other automated transit services. The airports in Phoenix, Los Angeles, San Francisco and Oakland all feature automated people mover systems that are compliant to stringent regulations, with extensive hazard analysis as part of the required safety cases, which have been independently assessed and reviewed. As such, it is now possible that once passengers disembark the well-regulated automated people mover system onto the streets, they could be injured by an unregulated autonomous car. Perhaps the lyrics to Alanis Morissette's 'Isn't it Ironic' should be updated to reflect 'Mr Play it Safe, was afraid to drive'?

Setting and meeting the requirements and the need to achieve certification, will create a shake-out of the market in the process – on both the supply and the demand side. Suppliers shying away from requirements and the need to meet them, will not be able to transition from temporary demonstrations to permanent applications. It will reduce the supply side to those who are actually capable of providing a system in line with the expectations of society. On the demand side it will ensure a focus on permanent applications, due to the increased costs of projects as a result of having to achieve certification. No more demonstrations, real life applications solving a transit problem with a viable business case.

In the end, a framework such as ISO26262 might develop into the standard engineering process requirement to validate, verify and ultimately approve the operations and safety of autonomous vehicles. But ISO26262 is only part of the puzzle. It addresses functional safety (i.e. hardware and software developed to



minimize catastrophic risks caused by a functional failure) but does not address any design flaws in algorithms. This is covered by standards/approaches like SOTIF (safety of the intended function) which ensures the correct behaviour of the system in each scenario is captured/defined. With SOTIF expected to be part of the new release of ISO26262 in late 2018, definition of correct behaviour will not be trivial and remain highly subjective. Any OEM should adapt a safety first principle to stay on the safe side.

In absence of certification, operations approval through independent assessment of a design safety case and an operations safety case, is an intermediate step allowing the industry to move forward with safe and reliable deployments. In line with Orlando Pescetti conclusion in 1603 'Il meglio è nemico del bene' (perfect is the enemy of the good), this will allow us to progress with today's requirements without having to wait for tomorrow's regulations.

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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.

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