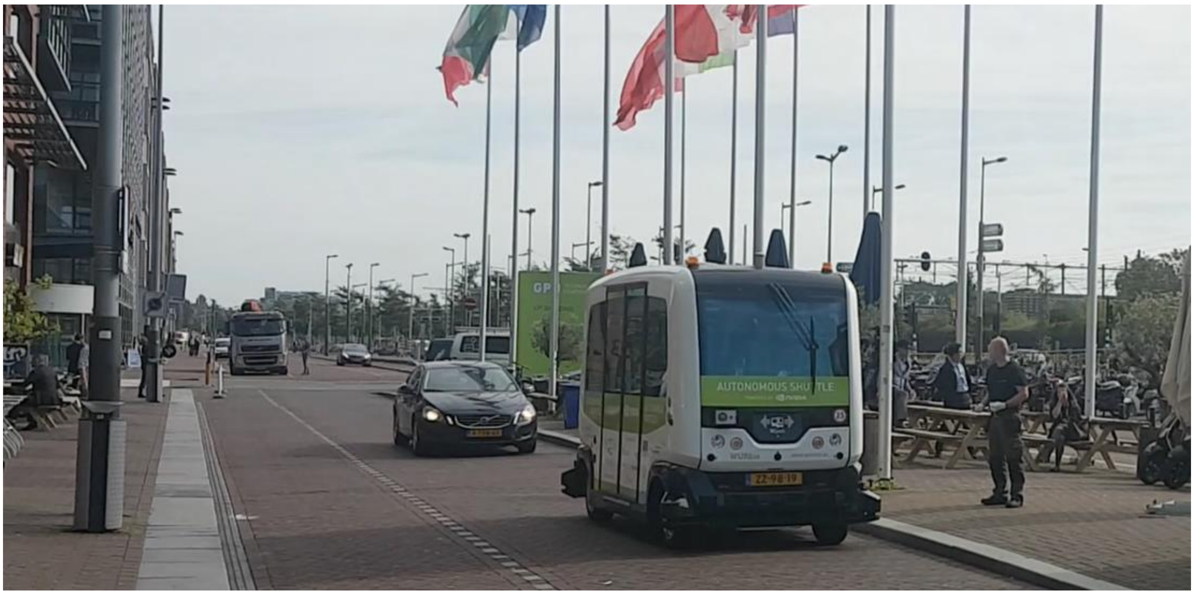
Automated Shuttles on public roads: Lessons learned



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This paper addresses Lessons Learned by the WEpods project in The Netherlands on:

- technology aspects including mapping, positioning and cyber security
- institutional, legal and governance frameworks; liability
- evaluation and validation frameworks; FOTs; certification and reliability
- applications (e.g. fully automated vehicles, ion for public transport, etc.)
- behavioral aspects and human factors; user acceptance

WEpods is a project of:

provincie Gelderland
TU Delft
RCS ROBOT CARE SYSTEMS
spring innovation management

1 - Abstract
Automated shuttles on a private track were introduced in the Netherlands 20 years ago. And they run ever since. But what about taking them to public roads? Can it be done? What technology is needed? How to get a legal road permission? And how do people react?
In January 2016 the WEpods project introduced two automated shuttle vehicles on the roads of the Wageningen University Campus and 8 km onwards to the railway station in the city of Ede. We ran the vehicles on public roads from the very first tests. In June 2016 we got permission to transport passengers. We learned a lot about what problems to solve and how people react: passengers, other road users and .. the neighbors. This paper gives the overview of lessons learned.
The WEpods project was successfully completed in March 2017 and is being continued in the Interregional Automated Transport (I-AT) project that will run up to December 2019.

Keywords: Automated shuttles, mixed traffic, lessons learned

2 - Introduction / About WEpods

The Province of Gelderland wants to gain knowledge about the potential of automated driving for future use in public transport in urban and regional areas. They asked the Technical University of Delft to create Proof of Concept; a project to show it can be done and to serve as a knowledge generator about what problems to solve and how, with equal emphasis on public acceptance, technology and on integration in the environment. The project was not burdened with requirements on transport capacity, minimum trip time or uptime, but the Province was strict on budget and especially on delivery time: 1,5 year to get it done.
The project has a national and international significance of being a first application of fully automated shuttles on public roads and the first to apply for an official governmental waiver. All stakeholders were aware that the high level of innovation involved a high level of uncertainty. New questions would present themselves and we would have to find answers along the way. However the goal was clear and the spirit was high. TU Delft gathered a core group for a pre-study and asked Spring Innovation Management to run it. All stakeholders were involved from the start, including relevant authorities. The project became a true triple helix cooperation; that proved to be crucial to its success.

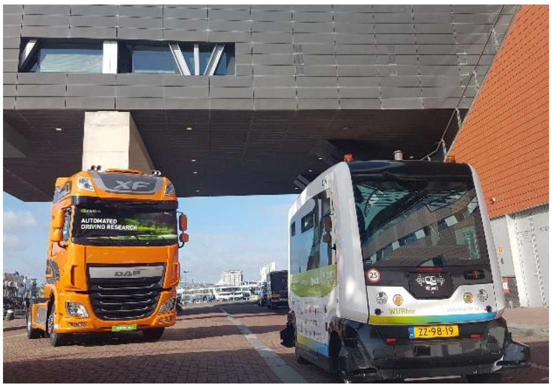
The consortium consisted of:
- TU-Delft – contract partner - Robotics group of the Mechanical Engineering Department and two groups of Civil Engineering & Geosciences: Geoscience & Remote Sensing and Transport & Planning.
- Robot Care Systems – system integration, navigation and sensor fusion
- Spring innovation management – project management and non vehicle tasks.
- Connekt – communication
- Mapscape – HAD map engineering

The project also involved a number of suppliers, local authorities and regional education institutes.

The WEpods project started in March 2015 and bought two Easymile EZ10 vehicles, equipped for automated driving in secluded areas. WEpods equipped them with additional systems to be able to handle the complexity of driving on public roads in mixed traffic. Parallel engineering resulted in two vehicles instrumented and ready to hit the roads. The vehicles were licensed and in January 2016 the Dutch Minister Melanie Schulz van Haegen officially launched the test phase. In June the vehicles acquired permission to transport passengers on the Wageningen Campus and in December they were able to navigate automatically from the Campus to the railway station in the neighboring city of Ede; a stretch of 8km through housing areas and rural landscape, including crossings and traffic lights, meeting cars, trucks, cyclists, pedestrian and even horses.
As from 2017 the project evolved into the new I-AT project, financed by the Interreg programme, that will take it to end of 2019 to develop two additional sites in Germany in NordRhein Westfalen; on Weeze airport and on a cross border connection between the cities of Aachen (D) and Vaals (NL).

The project took as prerequisite to use the infrastructure as it is and not to require instrumentation of the road for navigation. Neither do the vehicles use road lineage, since that is not generally available on local streets. As exception to the rule of 'no infra changes', the project required busy crossings to be equipped with traffic lights using WIFI-P for communication with the WEpod vehicles. For reasons of safety the maximum driving speed in this first development phase was set at 25 km/hr. Hence the route the WEpods follow in Wageningen and Ede was selected on a maximum speed of 30 km/hr for minimal speed difference between WEpods and other road users.

The vehicles run under human supervision of an operator in the control room. He is able to check the status of the vehicles at all times. He has three on board camera's to oversee the front rear and the interior of the vehicles and intercoms to talk with passengers and people outside. He is alerted when a vehicle encounters a problem and his task is to help solving it. He is not facilitated to control the vehicles, since that would involve too high risks, but he has a number of relatively simple subroutines that he can order the vehicle to execute. The operator is an inherent part of the system. His task is however largely taken over by the steward on board. The steward is a temporary element in the system needed for safety in the early stage of gaining experience, and proved to be a legal necessity since automated driving in the Netherlands and most European countries still requires a driver on board until liability is allowed to be assigned otherwise.



A positive relation with the public is vital for innovation with such an societal impact as automated driving. The project regards communication to the outside world as an important prerequisite for success. This is radiated by the name; WE stands for Wageningen and Ede, but also for 'we = you and us'. Next to normal PR to interest groups and visitors, the communication was geared to people living along the track and to other road users. The vehicles are dressed to make other road users aware of their different nature. They are equipped with ticker tapes front and rear that can carry messages to inform and alert others. Since automated vehicles carry the risk of an unexpected stop, the default message on the ticker tapes is 'automated vehicle; keep distance'.

3 - Main challenges

The project team set out to master to following main challenges.

- *Navigation*
  This is the challenge is to make the vehicle neatly follow the road in the middle of its lane and taking corners in a way that is comfortable to the passengers and safe for other traffic. This requires very precise localization, a very accurate and complete map and the development of a path planner that defines the actual line on the map (street) the vehicle will follow.
- *Handling other traffic*
  This is the second and even more complex task. The vehicles are equipped with multiple environmental sensors. Being a research driven project the number of sensors was not scrutinized. The best available sensors of different physical principles were installed. The vehicle has a base (low level) sensor system built with SIL2 certified single layer laser scanners. An intelligent high level safety system was added to be able to handle more complex traffic scenario's needed to drive in mixed traffic. This system consists of advanced multilayer lasers, radars and camera's, including data processing units with deep learning capabilities. All sensors are arranged for a 360^{o} view.
- *Human factors*
  Equally important but of a very different nature is the challenge to promote a positive public attitude Automated vehicles, in this early stage, are inherently vulnerable for inappropriate actions of users: road users, neighbors, hackers a.s.o. Hence the project invited residents to information meetings at the start, discussed with them, maintained an active information policy through the website and local media and, later, invited everybody for test rides.

- *Legal permit*
  WEpods was the first project to use the new regulation for automated driving vehicles that were just launched by the Dutch Government at the time (2014). The regulation was an open framework nobody had yet filled in and it was not specified how to do so. All stakeholders were involved and committed to make this happen, make it safe and learn a lot: learning by doing.
  The project team presented an approach to use the regulation that was approved by the national road authorities (RDW). It was not easy for either side, but we found a way and the mutual effort to adapt built a fine cooperation.

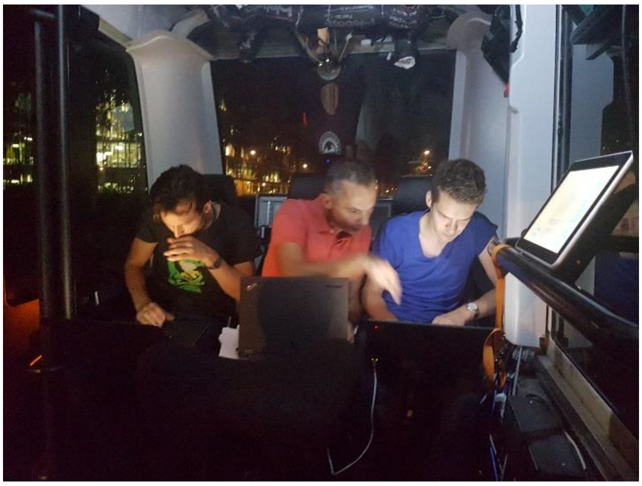
4 - Lessons learned / Results

During its development phase the project team was confronted with problems of all kinds. We thought it would be difficult, but it proved more difficult than we thought. That was Lesson nr 1. The team had to master problems we would never have dreamt of: technical, organizational, legislative, juridical as well as related to cooperation and PR. Partners were not only challenged on professional skills, but also on creativity and leniency to jointly find answers to questions not dealt with before.

4.1 - Technology,

The complexity of automated driving technology is such that lessons learned are many and varied. Highlights are mentioned below.

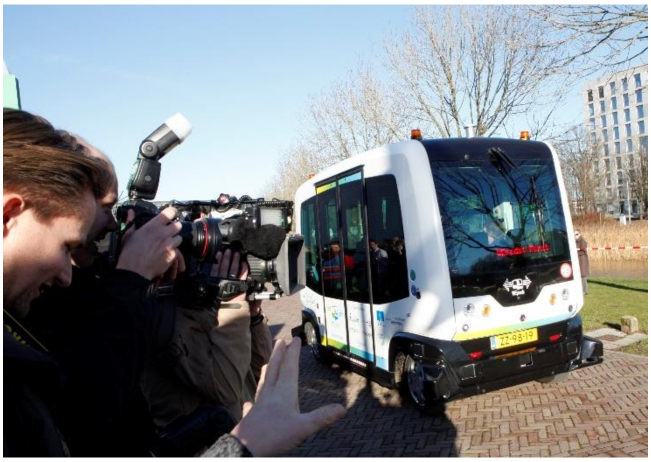
- *Localization by D-GPS-RTK is not enough.*
  We achieved an accuracy of +/- 5 cm in optimal circumstances (RTK-fix). But we learned soon that the system was prone to disturbances that reduce the accuracy to levels unfit for securely following a road. Especially high buildings and the foliage of broad tree crowns caused problems. And the track in Ede/Wageningen is lined with such trees. Consequently the project decided to add a laser based system (Ibeo Lux multilayer lasers) for positioning relative to the road side. This dual architecture resulted in two position measurements that were fused by integrating the RTK position into the Ibeo system. It proves reliable. Further redundancy by line following is under evaluation.
- *No existing maps are accurate enough.*
  Normal digital maps showed large discrepancies with reality. The best maps could be obtained from the municipal land registry, but even they were not sufficient. Consequently the project decided to make own maps. This was facilitated by the adoption of the laser positioning system, using the SLAM (Simultaneous Localization And Mapping) approach. The map was combined with the track: the exact line of movement on the map with a nominal speed for each segment. Also the locations for switching on/off the side indicators are geo-referenced in this system.
- *Building a system on SIL2 certified components doesn't work in traffic.*
  Being allowed to test on public roads required to prove the system safe before it was even tested. This contradiction was bridged with a two-fold approach using a proven laser based detection system built of SIL2 certified components, pairing reliability to very limited programming possibilities, and developing an additional intelligent sensor system with advanced data processing.
  The low level system allows to define a trigger zone ahead of the vehicle and reacts on all objects detected in this zone with an emergency stop. Normal behaviour in traffic however requires following objects in an earlier stage and taking account of their speed and direction before initiating a proportionate brake action. An overtaking vehicle that would merge-in close in front would trigger an unwelcome stop. Since this event is more likely and critical on busy road sections, we anticipated the need to manually take over speed control. Hence we developed the semi-automated driving mode meaning that the vehicle navigates autonomously, but the steward (see below) controls speed. In addition this feature proved very practical in testing new maps.



- *Most problems are in the interfaces*
  The modules that make up the system were developed by various partners. Interfaces were clearly defined in interface descriptions agreed between the involved companies. Modules were first tested in simulation, including their interfaces, before they were installed in the vehicle for integration testing. Even so, the multitude of problems encountered during testing could largely be traced back to interface issues. Testing in real life brings about variances that could not be thought of before. Reality proves unruly. Such problems are of a complicated nature, not only because of the technical difficulty, but also because of the question which side of the interface, that translates to 'which partner,' should do the necessary modifications.

--------------------------- *At boundaries of innovation you have to solve problems yourselves.* ---------------------------

4.2 - Testing on public roads
When developing new drive systems to be used on Public Roads the well-known procedure is to test it first in isolation before hitting the road. Also the final test for certification is done on secluded test grounds. For automatic shuttle systems this is not adequate since the roads the vehicle(s) will drive on is an inherent part of the system itself. The approval is restricted to the roads the vehicles will drive on and is not granted on a general basis, like in the case of other road vehicles. In today's relatively early stages of deployment the system is developed to cope with known traffic situations in the particular zone it will be used in, and the system performance is not verified for situations elsewhere. Also the infrastructure may be (locally) adapted or instrumented. This implies that the final test to obtain a waiver has to be done on the track itself and hence the vehicle does not yet have the waiver when it is doing preparation testing for this final test and the certification test itself. WEpods asked the Dutch Road Authorities to be allowed to test on Public Roads right from the start. That was new, but since everything else in the approval procedure was too, this was more an item on the list than a road block.



What have we learned?

- *Testing on public road is possible in a safe way.*
  This is a comprehensive statement in retrospect of 1,5 year of testing. We can't prove its validity beyond our own experience, but we have no reason to believe it will change in the next years. As long as we keep on taking the appropriate precautions. It does not mean nothing will happen. The goal is, with proper precautions, to keep the effects to levels as would have been encountered on a secluded test track.
- *Select your circumstances and anticipate traffic.*
  This is precaution nr1. Don't test on busy roads and avoid busy hours. Example: when we decided to do a combined test of three new control modules, we planned it on an evening knowing the Campus roads would be deserted. We found the roads behind our building to be very quiet and declared them to be our test track. Nr2: all new functionality was to be tested there first and all unfinished test-software to be replaced by a validated version when wrapping up a test day.
  Nr3: during testing the steward keeps a close watch on the road and stops the vehicle in anticipation of approaching road users. At first this included stopping in advance for all approaching and overtaking vehicles. Although this was a tedious work procedure, we kept this rule until we had enough evidence and confidence that the navigation systems were reliable enough not to take an unexpected departure when another vehicle would be passing us.
- *Always have 2 people during testing and 1 finger on the red button*
  The role of the steward is to take responsibility for safety on board. During driving his only task is to take care of traffic. He may not be distracted. When doing tests another person, the test- engineer, has to be on board to concentrate on the testing. These roles are clearly identified and never mixed. Stewards are required to have a (car) driving license and receive a special training from our chief engineer before their

names are added to the official stewards register held by the RDW road authority. Others are not allowed to 'drive' a WEpod.

- *Communication to traffic is very important*
  An observant reader may have already concluded that we must have made quite a few stops on the road. We did. This, and the low speed we were driving at, regularly resulted in one or more other vehicles queuing up behind the WEpod. In such circumstances the ticker tapes we had installed proved to be very useful; warning others to keep distance. In addition the steward regularly waved other drivers along, to let them know they could pass safely.

----------------------- *Speed seems higher and trees seem closer in an automated vehicle.* ------------------------------

4.3 - Public reaction

It has been mentioned already that the project is very observant of public reactions. Public attitude is considered a gate to success. Not only can adverse public behaviour create risks in traffic or hinder the vehicle, the project received high media attention from the start and a mishappening on the street could adversely affect the deployment of automated driving in general. The conventional communications task of the project was extended to 'PR and Neighbourhood'. Local information sessions were held, residents were informed with mailings, the website was frequently updated with project news, and press and residents were invited for test drives. Experience highlights are:

- *Positive attitude: public, authorities, companies, press.*
  Automated driving in general enjoys a lively and favourable public attitude. It is also a media favourite and press is prevailingly positive. This is as remarkable as helpful. Remarkable because automated driving implies major societal changes and such subjects are often regarded as a risk, especially if they are technology driven and imply handing over autonomy to machines. However automated driving is seen as intriguing, by grannies as well as true technoheads. Maybe this is because automated driving strives to solve societal issues on road safety, congestion and the environment.
  The positive public attention is very helpful indeed. Plans for automated driving in housing areas would probably fail if neighbours would start to protest or hinder the vehicles. On the road other road users may be slowed down by a laggard moving shuttle and called to show patience. And they generally do, as long as we keep away from traffic arteries.
- *Pedestrians*
  Pedestrians are one of the most frequent road users to meet in residential areas as well as one of the most unpredictable. A car is destined to follow the road. Pedestrians could virtually do anything and are, in The Netherlands, often not very obedient to traffic rules. Such behaviour is to expected and not a new 'lesson learned'. However the most frequently seen reaction of pedestrians is of a different nature: taking out their smartphone for a photo shoot.
- *Bikers*
  Bikers are a very frequent and relatively unpredictable category of road users too. In the very early stages of testing on the road the vehicles drove 8 km/hr and we saw bikers pass the vehicle on both left and right side. Since the vehicle drives in the middle of the lane it often leaves enough space for passing along the right side. Although initially this enervated the steward it proved pretty harmless behaviour. Largest risk form bikers is that they tend to merge in close after overtaking, which triggers the low level sensors and produces a stop. Since we raised the vehicle speed overtaking bikers has become less of an issue.

- *Cars*
  The most remarkable experience with cars is that they generally show good patience; better than expected. Although patience certainly is not the default reaction in the normally hectic Dutch traffic, drivers do show a certain degree of self-control not to squeeze themselves past the vehicle. This forgiving attitude is probably inspired by the different presence (shape, ticker tapes, stickering) of the WEpod that

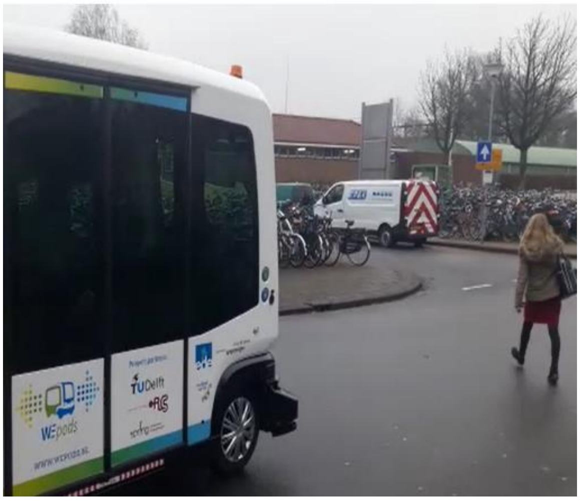
makes clear it is an automated vehicle. The vehicles invoke the sympathy and complacency of meeting a horse driven carriage, combined with the interest of seeing something special. We do take precautions and help by signalling, but remain thankful. There are exceptions, most caused by professional drivers, understandably pressed by delivery schedules.

- *Biggest risks*
  Risks can be categorised in risks originating from the automated vehicle itself and those from other road users. Biggest risks in both categories are related to braking.
  The biggest risk related to the automated vehicles themselves is that they may produce an unexpected brake action. If caused by the low level sensor system this is an emergency stop, if caused by false positives from the high level sensor system this will most likely be a comfort brake action. It is undesirable in both cases. Counter measures taken are the low speed of the vehicle, the selected roads they drive on and the warning on the ticker tapes to keep adequate distance to the vehicle. Filtering false positives is a top priority in development.
  The biggest risk presented by other road users comes from the belief some people seem to have that robots can do anything. Knowing that the vehicle stops automatically for objects in front some people see no objection in jumping in front of the vehicle to test it all out. It does not happen often, but it causes a fright and is difficult to anticipate. The vehicle mechatronics indeed react quicker than a human could, but the vehicle uses conventional brakes and still has a normal brake distance.
- *Neighbours*
  Reactions from residents are both positive and observant. We have had one adverse reaction with a 'Not In My Back Yard' nature that dissolved when we made the author aware that the vehicles would not drive through his street. The many other reactions we received evidenced some level of pride and excitement that this innovative system would use their street as test ground. The schools we pass were specifically addressed, but did not show any anxiety.
  We started testing at the Wageningen university campus and it was not until when we started to drive to the station in Ede that we received mails from residents about alleged strange behaviour of the vehicles. These were merely written out of curiosity than as a complaint. So far the number is such that we can react personally to provide clarifications.

-- *Automated driving makes you feel more relaxed.* --

4.4 - Getting a waiver

The Dutch Ministry of Transport and the Environment developed the policy to promote automated driving. This policy materialized in the publication of the regulation to allow automated driving vehicles on the Dutch roads. The regulation encourages pilot projects in all levels of automated driving to apply for a waiver from regular legislation, offering a framework for a tailor made procedure. The WEpods team was the first to apply for a pilot with fully automated driving vehicles. The procedure to follow and requirements to meet had yet to be filled in. This involved the Ministry, the National road authority (RDW), the National research institute for road safety research, SWOW, and the municipalities of Wageningen and Ede. All stakeholders had the intention to make it work; backed up by the active support of our Minister.

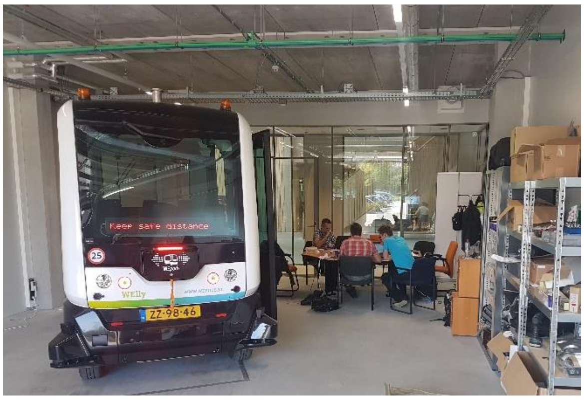


Lessons learned:

- *Automated vehicle don't fit a current vehicle category*
  This is lesson number 1. Road authorities are used to apply clear rules that have been well documented in extensive public libraries. These rules start with the selecting of the proper vehicle category. Automated shuttles are so different that they don't fit any existing category. Trying to squeeze them in resulted in a pile of exceptions and a list of discussions on inapplicable requirements. This became a true roadblock,

because granting a license plate is directly linked to a vehicle category. The solution came from using an 'unusual vehicle category' for rolling machines that sometimes need to use the road.

- *EMC was a big issue*
  In the early phases of the approval process the prevailing focus of road authorities was on conventional vehicle requirements like brakes and lighting. This shifted, but EMC requirements remained as being relevant for mechatronics and robotics. The issue here is that EMC requirement are very hard to fulfil in a vehicle under development, since small changes on wiring and shielding influence the result. Such changes were made all the time. The project improved the vehicle to the level of 99% fulfilment and then concluded that the last step was to be done after all hardware was fixed and frozen



- *Steward on board*
  The project first planned the Steward as a functional need for safety. In the many discussions with authorities about the waiver it soon became clear that from a juridical point of view the Steward was regarded mandatory to fulfil the liability role of the driver. An operator on distance or an on-board computer were, in The Netherlands, not regarded as appropriate substitutes. This has changed. The Ministry recently published proposed legislation to allow tests with automated driving vehicles without anybody on board. This is very new and can be traced is still the situation today, but the thinking has started to change and it can be stated that the WEpods project made an important contribution to these advancing insights within the Ministry.
- *Certification is a process not a test*
  Applicants are supposed to know the content certification/homologation requirements and to have validated their cars accordingly. Hence approval is organized as an end test. Software based systems however are ill fit to be validated this way and for the innovative WEpods system such standardized tests were not available in the first place. The traditional approach fell short. The development process had to be part of the final judgement. The approval was to be based on a Safety dossier rather than a test result. Validation became a process over time rather than a verification moment. This requires a change of mindset and innovation in work methods. It also challenges road authority officials to dive into new technology to understand difficulties, possibilities and risks.
- *Developing regulation is different from executing regulation.*
  The project necessarily challenged existing rules that were not applicable to the kind of vehicle at stake. This clashed with road authority specialists who have been trained to bending applicants to rules rather than the other way around. The project was assigned to be handled by another department targeted to develop rules rather than keep them. This was done in joint discussion and with full respects of all stakeholders; a joint achievement and a major milestone.
- *Coordination by the National body.*
  There are many road authorities involved in the project: national, provincial, 2x municipal and the university. The National road authority took the coordination. The other stakeholders were kept well informed and connected. This worked very well. *The cooperation between project and road authorities is super.*

------------ *It wasn't easy but we managed and reached a fruitful mutual understanding and respect.* ------------

5 - Discussion

The above are highlights of the lessons learned. Contemplating these and other experiences during one year of test driving we can distil some deeper insights to fuel further thoughts and discussion.
Automated Shuttle services ..:

- *.. provide the missing link in the public transport chain*
  They already do so driving on a secluded track. The question is when they will be ready to pick up this role, driving on public roads. Today's pilots will evolve into mature systems that will meet all operational

and business requirement of automated transport. Automated shuttles will provide the on demand individual transport on local networked tracks. Once installed (invested) they can do so on a 24/7 basis, also in 'low demand' periods, bringing Public Transport to new service levels.

- *… need a permission instead of a waiver*
  It is a major step forward that we can operate automated shuttles on public roads based on an exception to current legislation. However the Future requires not to regard and handle them as an exception. For true deployment, dedicated legislation on a European level is needed. That may well determine the development speed of automated driving. Hopeful is that European Ministers of Transport have endorsed the joint ambition to have a framework for legislation in place in 2019[1]. The Dutch Government already reacted with new legislative proposals.
- *.. will improve quality of life*
  Automated shuttles are an asset to the environment they drive in. They move around quietly, calmly, gently, predictable and considerate. They add a friendly, sympathetic and unwinding touch to local traffic.
- *.. will put lawyers out of job*
  A vehicle without a driver is (was) unthinkable to experts in traffic related jurisdiction. Who to address liability to? In fact automated driving will make their life much easier. Automated vehicles log their driving and sensor data. The cause of accident will be undeniably, easily and quickly be determined by reading the logs.
- *.. will revalue the importance of traffic rules*
  Automated vehicles follow pre-specified logic. Humans not always do. It happens regularly that people do not keep to traffic rules. This can cause traffic risks, but can also be needed to solve roadblocks. To what extend is a driver liable for solving a risk created by others? When is it 'permitted' to temporarily ignore a rule in order to reduce a risk or keep traffic going? This is an ethical issue to be addressed.

6 - Conclusion / Further learning

This was Learning Chapter 1. There is much more to be done, experienced and learned. 'Learning by Doing'; the Dutch adagium. Prioritised areas for doing and learning are:

- Sensor performance
  Sensor hardware will improve while costs will come down. However most progress is needed in the area of advanced data processing. One essential issue is very reliable and faultless filtering of sensor data to exclude false positives and false negatives. Improved and more diverse classification will facilitate more precise path prediction. We are still a long way from the level of human anticipation, interpretation and

[1] Declaration of Amsterdam, 14 april 2016

adaptability in traffic. Deep learning (artificial intelligence) is a very practical and promising tool to make progress, but proving the reliability and level of the results remains an issue.

- Handling more complex traffic scenario’s
  The same issues as in object detection play a role here: the variety of traffic situations is infinite. Here shuttle systems have an advantage that can put them into a leading role in development; they drive only in a defined area. These sites each have their specific traffic variety. They can be selected on specific scenario’s to be tested. The challenge is to make well considered steps on the roadmap to full deployment of automated driving.

Eventually the robustness and ‘driving skills’ that future developments deliver, will enable to drive the vehicles empty. This is the ultimate goal of automated shuttle development. It needs discussion on hardware architecture, system performance and many engineering hours, but it will be reached. Not immediately ‘in all circumstances’ and ‘on all roads’, but in selected circumstances and selected roads at first.

------------------------ *The ultimate goal of automated shuttle systems is to drive empty* -------------------------- 😉

7 - Acknowledgements

All the above Lessons are Learned from running this very exciting project. WE did this together with the many parties that contributed to WEpods. Thanks goes to all. I name the most relevant for the lessons listed:

Project Customer:	Province of Gelderland
Project Partners:	Technical University of Delft
	Robot Care Systems
Authorities:	Ministry of Infrastructure and the Environment
	Rijksdienst Wegverkeer
	Municipality of Ede
	Municipality of Wageningen
Others	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid
	Hogeschool Arnhem Nijmegen
	University of Wageningen
	Sogeti B.V.
	Easymile S.A.
	Ibeo A.S.
	Nvidia
	Ricardo
	Technolution