Automotive, the Future of Mobility

Rieck, F.G.; Machielsen, C.; van Duin, J.H.R.

Publication date
2017

Document Version
Final published version

Published in
Proceedings of EVS30 Symposium

EVS30 Symposium

Stuttgart, Germany, October 9 – 11, 2017

Automotive, the Future of Mobility

F.G. Rieck MSc[1], C. Machielse MSc[1], J.H.R van Duin MSc PhD[1, 2]

[1]*Research Centre Sustainable Port Cities, Rotterdam University of Applied Science, RDM Campus, Heijplaatstraat 23, 3089 JB Rotterdam, contact: f.g.rieck@hr.nl*
[2] *Faculty of Technology, Policy and Management. Delft University of Technology, Jaffalaan 5, 2628BX Delft, The Netherlands*

Executive summery

Will the Automotive era come to an end in the 21th century? Looking at today's environmental and economic challenges of the use of cars based on last century technology and listening to some trend watchers one could think so. Cars can be regarded, as an old school status product indeed, for which there is no use, no place, no money and no interest in our modern society. On de other hand, auto-mobility is still growing, both in developed as in developing countries. The current worldwide road travel by motorbikes, cars, trucks and busses will probably double to 80 trillion kilometers in 2050.

Facing comparable mobility growth in the Dutch Port City areas of Rotterdam, this paper describes the research of the Rotterdam University of Applied Science, following developments in automotive and providing first living lab experiments. In our vision, the traditional automotive values 'individual freedom and flexibility' and using new disruptive technologies, the automobile will very likely consolidate its position as preferred choice for mobility of persons and goods during the 21th century. To achieve that the sustainable disruptions: Electrification, Automation and Connectivity (sharing) must be adopted. Meanwhile one should focus on tempting goals, the Six Zero's; Zero Emission, Zero Energy, Zero Congestion, Zero Accident, Zero Empty and Zero Cost. These goals will guide us towards a new economy, sustainable ecology and more efficient use of time.

Keywords: Automotive, Logistics, Rotterdam, Electric Vehicle, Smart e-Mobility, Sustainability, Disruptive Technologies, Electrification, Automation, Connectivity, Sharing, Six Zero's, Zero Emission, Zero Energy, Zero Congestion, Zero Accident, Zero Empty, Zero Cost

1 Introduction

Many people believe that the 20th century was the heydays of automotive mobility. Evidently during this past century automotive as an industry and as a mean of transport was very dominant for prosperity and the way of life. The pioneering days of the automobile during the first half of the century up to the early sixties are regarded as the romantic age for classic motoring enthusiasts. At the end of the century automotive mobility became the number one and preferred mean of transport for persons and goods worldwide. Will this era come to an end in the 21th century? Looking at today's environmental and economic challenges in the use of cars based on last century technology and listening to some trend watchers one could think so. But auto-mobility is still growing. The current worldwide road travel by motorbikes, cars, trucks and busses will probably double to 80 trillion kilometers in 2050 [1]. And to be honest, there is generally no real alternative at the moment. The speed-bike could become an attractive alternative at the short distances personal transport and for freight in limited amounts trains and barges are already common alternatives. A more accurate question is will the automotive be still that dominant when the number of cars and trucks will drop dramatically because of more efficiency, autonomous driving and sharing developments. And what will happen as the automotive industry will not succeed in applying new (disruptive) technologies and other means of transport, will arise because they are more capable to absorb the new demands and technological possibilities?

The Dutch Port City area of Rotterdam is facing comparable mobility growth figures. Transport and logistics are the key factors for the regional economy. The fast majority of persons and freight is traveling respectively transported over the very well developed road infrastructure. About 60% of the regional business is related to this road transport [2]. The Port of Rotterdam is one of the European gateways to the world economy, and meanwhile making the Netherlands one of the leading distribution countries in Western Europe. Because of this, sustainability of mobility in logistics is a top priority for our regional and national economic development. With 60% reduction in 2025 compared to 2005, the local policy directive by the Rotterdam Climate Initiative has set the most ambitious goal for transport related CO_2 emission reduction in the Netherlands [3]. Moreover, to protect the health of its citizens, the clean air and low noise rules are now among the toughest in Europe. Continuing the current state could lead to a catastrophic situation for the economy, ecology and the citizens.

2 Electrification of Automotive

For the above-mentioned reasons the Rotterdam University of Applied Sciences started in 2009 together with the municipality and local companies the first practice-oriented research regarding the application of electric vehicles, which we already have on the roads at Rotterdam. This 'living lab' called eMobility-Lab has been rewarded with a SIA subsidy[1]. The goal was to provide education, government and business partners with new knowledge and practice based insights about crucial aspects: energy saving capabilities (including the recuperation through regenerative braking), best practices on safety measures and standards, total cost of ownership or operation, specific maintenance issues and not to forget user-satisfaction [4]. This research work was done on a variety of urban electric vehicles (EV's), like automated shuttles, garbage trucks, city busses, passenger cars, distribution vans and scooters. In some cases these EV's were prototypes or early production models, but most of them are still driving. A nice example is the e-Busz used by the public transport operator the RET [5]. All the above-mentioned aspects are researched from the very beginning of the deployment of the newly co-developed range extended electric city bus, from 2009 up to today. Empiric research through energy measurements of the unique e-Traction wheel motors led to design based research with the goal to optimize energy savings and cost efficiency, see figure 1 on page 3 [6]. Thanks to a study on electrical safety and the close co-operation with the Dutch road safety authority RDW, the e-Busz was the first electric city bus that was safe enough to be allowed on the Dutch roads in a commercial service [7]. Aspects like maintenance and driving instructions are developed and published in workshops and user manuals. Today the busses are fully monitored with advanced telematics, an on–line system from a start-up company Viriciti. The data is analyzed to find-out the best driving conditions for chauffeurs, and to define a fast charging strategy to make it possible to drive the whole service in zero emission electric vehicle (EV) mode.

[1] SIA is a Dutch institute with a specific focus on Universities of Applied Sciences

In 2012, 100 years after electric vehicles dominated the car market for short period of time and 30 years after the first ‘Californian’ revival, automotive e-Mobility started booming again. The Netherlands is now together with California, Norway, and China a frontrunner in the electrification of road transport. From a historical viewpoint this can been seen as the realization of the idea of the Dutch Professor Sibrandus Stratingh (1785-1841), who made in 1835 a first working battery powered scale model that can be regarded as the forerunner of the electric vehicle, see figure 2.

Full-electric city bus (e-Busz)		Base case	Conventional city bus	
Unit	Total costs	Price difference	Total costs	Unit
Costs per functional unit	€785.275,63	€95.369,51	€880.645,13	Costs per functional unit

Figure 1: Functional Unit Cost of e-Busz [6]

Figure 2: First scale model Electric Vehicle

We are still finding new way’s to electrify road transport. Different electric urban-distribution trucks are now in the testing phase in Rotterdam and other cities. Large heavy trucks transporting freight are usually diesel-powered tractors towing a trailer on which the load is transported. Battery electric trucks for the long haul transport are not very feasible in the short term, because of the enormous driving range that is required. In the long term, hydrogen-electric trucks like the recently shown Nicola One prototype can offer a solution [8]. For the shorter term we are researching the feasibility of an active e-trailer concept [9]. It will have two electric direct-drive motors on one of the rear axles of the trailer, along with a battery pack to store the energy. The active e-trailer will be able to provide extra propulsion and regeneration of brake energy for the whole combination. Acting as a plug-in hybrid, the combination saves fuel by peak shaving the load of the diesel engine and if needed can drive the last miles in zero emission EV mode.

Based on our research and laboratory tests it can be concluded that electrification is the technical master key for all forms of automotive mobility in terms of emissions reduction, energy efficiency and cost saving. Meanwhile, developments in renewable electric energy production will be come proven technologies as well, which will lead to an integral future proof solution for e-Mobility, see figure 3 and 4 [10]

Figure 3: EV testing at the RDM Campus laboratory

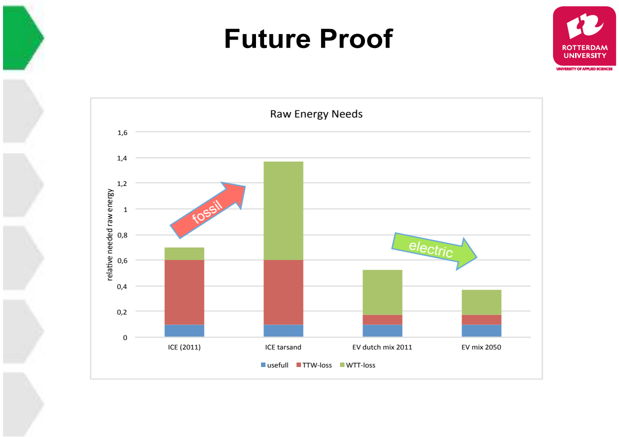


Figure 4: Energy efficiency e-Mobility in the Netherlands [10]

2.1 The step to Smart e-Mobility

The eMobility-Lab research led to crucial changes in the content of our education Automotive Engineering but also to a new multi-disciplinary approach together involving other Technical, Logistics and Economic faculties in our and at other Universities. From a technical viewpoint, the understanding grew that there is strong synergy and synchronization between electrification and digitization of vehicle technology. Together, this formed the basis for Smart e-Mobility. Like Diarmuid O'Connell of Tesla said 'EV's are the step-up function to rolling computers' [11]. For electric vehicles the step to automated driving capabilities or even self driving autonomous vehicles is relatively small.

The electric Rivium Parkshuttle, which is already in operation since 2002, is a good example, see figure 5. It was the first vehicle researched in eMobility-Lab and is still revolutionary, because it drives zero emission electric and fully automatically without a driver [12]. From 2015 a research project of HAN Universities of Applied Science was joined, addressing Intelligent Truck Applications in Logistics [13]. This project is mainly focused on the application of full electric AGV's and automated electric trucks in the Port of Rotterdam, see figure 6. More recent in 2016, we have joined the Surf STAD (Spatial and Transport impacts of Automated Driving) a research project started by the Delft University [14]. In this research we study existing and emerging Demonstrators and Cases of Autonomous Driving in and around cities [15].

Figure 5: Automated Electric Rivium Parkshuttles [12]

Figure 6: Automated Electric AGV's APM Terminal [13]

3 Adopting sustainable disruptions

Tony Seba, Professor Entrepreneurship, Disruption and Clean Energy at Stanford University, is one of the first scientist who puts an automotive vision of sustainable disruptions forward. He points out that major disruptive transitions, electrification, renewable solar energy, automation and the sharing economy will completely change the face of the automotive industry in the coming decade. His conclusion, due to total electrification and a renewable electric energy society, we will be able to move in a post fossil energy age. Additional developments such as automation and sharing economy will contribute to the development that we will only need 1/3 of the vehicles for the same mobility needs [16].

Our Research Centre Port Cities at the Rotterdam University of Applied Science also takes multi level sustainable disruptions as the starting point for big transitions. In the program Moving@Rotterdam three Research Professors are joining forces and research together, sharing their disciplines regarding Smart Logistics, Future Mobility and Sustainable Transition. Based on our practical know-how of the fruitful crossover between the disruptive technologies 'electrification, automation and connectivity' we support the view of Seba. Technically it's already possible and also politics and regulation are more and more demanding for a sustainable change. We believe that based on the 'traditional' automotive values of individual freedom and flexibility and thanks to disruptive technologies the automobile can consolidate its position as preferred choice for mobility of persons and goods if it positively develops in a sustainable way during the 21th century. This both in terms of ecology and economy, and also for the Netherlands as indicated in the Automotive Disruption Rader by Ronald Berger [17]. However, we strongly believe that next to technology the 'willingness to chance' is by far the strongest factor in this transition. In other words, the social part of the innovation process of new disruptive technologies. This calls for a closer look at the underpinning desirable targets of our will to change to sustainable automotive mobility. That's why we defined Six Zero's, as targets that are hard to refuse and must be absorbed by the Automotive industry.

3.1 The Six Zero's

The Automotive industry is used to working with 'zero' goals, 'Zero Defect' being the most famous. Although this seemed unreachable in the short term, through continues improvement like the Kaizen and Six Sigma the goal works well in the long term. This was the most important message in the book 'The machine that changed the world'[2] [18]. And helped the car industry to develop the widely adopted efficient near faultless 'Lean Production' at the end of the 20th century. The same principle should be adopted for sustainable mobility in the 21th century. Figure 7 shows the relation between technology disruptions (electrification, automation and connectivity) and the Six Zero's (zero emission, zero energy, zero congestion, zero accidents, zero empty and zero cost).

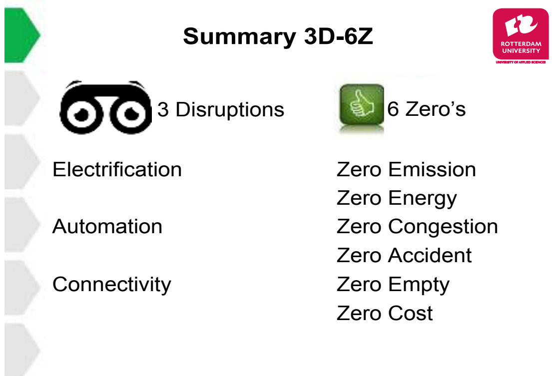


Figure 7: Three technology disruptions and the Six Zero's

To begin with, we should answer the question, given the possibilities do we want to reach the zero goals in a foreseeable timeframe or not? If the answers are positive, automotive can indeed be the future of mobility.

- Zero Emission: Why should we still accept air pollution, climate change and noise produced by our automotive mobility, while we can do without by using electric vehicles?
- Zero Energy: Why should we still spill energy or risk the depletion of fossil energy recourses by our automotive mobility, while we can drive far more efficiently on renewable electricity?
- Zero Congestion: Why would we still want to get stuck in traffic jams, while using automated or autonomous cars, trucks and busses can avoid or by-pass them?
- Zero Accident: Why should we still want or risk accidents or road fatalities due to unsafe driving and lack of control by human drivers while automated or autonomous vehicles will be much safer?
- Zero Empty: Why should we still accept that cars on average are utilized on 25% of the passenger space and trucks are on average 50% filled with freight, while connecting them with a electronic travel data exchange via internet of things could use them to full capacity?
- Zero Cost: Why would we still want to pay for owning our own vehicle and spending a lot of money on vehicles that are more parked than moving, while connecting and sharing them, using big data and Internet of Things vehicles can cover their own cost?

To explore the above-mentioned Six Zero's they will be put in perspective to the current developments.

[2] One can question if the Tesla Model S is now the machine that changes the world

3.2 Zero Emission

CO_2 emissions are everywhere; for most biological and chemical processes they are unavoidable. In the 35 OECD counties, energy accounts for two-thirds of total 'man-made' greenhouse gas emissions and 80% of CO_2 [19]. Motor vehicles are dependent on oil, because it is now there main energy source. As a consequence of burning fossil-oil, road transport directly account for about 20% of the CO_2 emissions in Europe [20]. Apart from, the possible climate change risk by CO_2 in the atmosphere, toxic tailpipe emissions and traffic noise are an increasing thread for the air quality and livability of our urban areas. Currently, trucks, cars, vans and busses are, in that order, the big polluters when it comes to NO_x, see figure 8 [21] in the Dutch cities. And road traffic also significantly contributes to soot particle emissions increasing the risk of long diseases. According to the World Health Organization more people die from poor outdoor air quality, which is significantly caused by road traffic, than from road accidents [22].

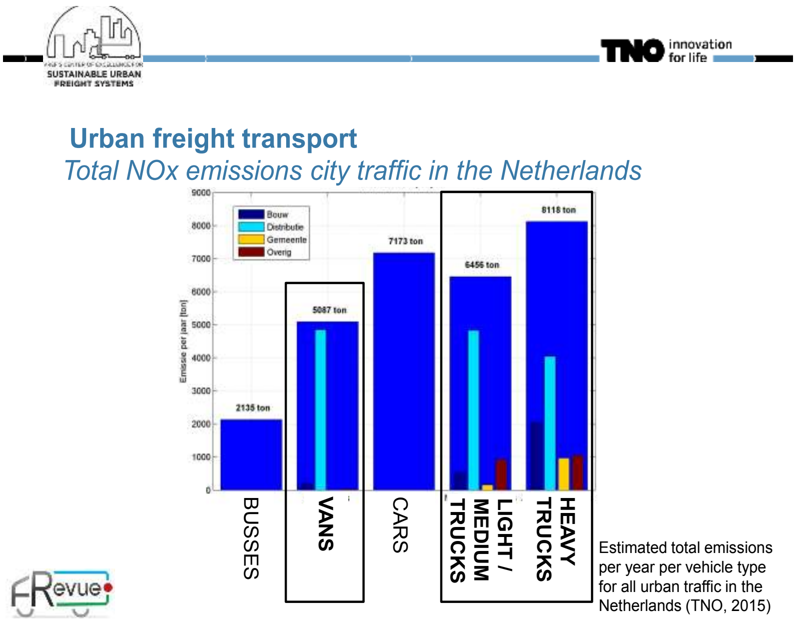


Figure 8: NO_x emissions from trucks, cars vans and busses [21]

Emissions from vehicle propulsion are avoidable. Trains, trams and metro's are already electrified decades ago and in the early years, cars where electric too. In 1914, 2,4% of the Dutch car fleet was battery electric but after initial success lagged behind in electrification for practical reasons [23]. The range was too limited and the batteries where to big, heavy and expensive, while oil was far more energy dense and cheap. Thanks to improved electronics, batteries and fast charging technologies, a 500 km range per charge and fast charging within an hour are now becoming the standard for modern Battery Electric Vehicles (BEV's).

Tailpipe emission and engine noise of BEV's are zero, which has an immediate positive effect on local air quality and livability. Depending on the energy source also emissions in the energy supply and manufacturing chain can be ultra low or even zero. In contrast to some popular opinions, even the worst case environmental impact with an EV driven on electricity from hard coal is already better than the current internal combustion powered car, see figure 9 on page 7 [24]. The study also shows that the total environmental impact (including materials) is four times lower when driving on renewable energy. In the Netherlands all public charging stations offer electricity from renewable energy sources like water- and wind-power. In the Lombok district of the city of Utrecht, electricity from photovoltaic solar panels on the roofs is via a smart grid used to power EV's. So these energy chains are completely emission free already. Electric cars are more and more seen as storage capacity (e/g as battery or hydrogen tank) for the fluctuating renewable energy and are in that respect helping the transition to sustainable energy.

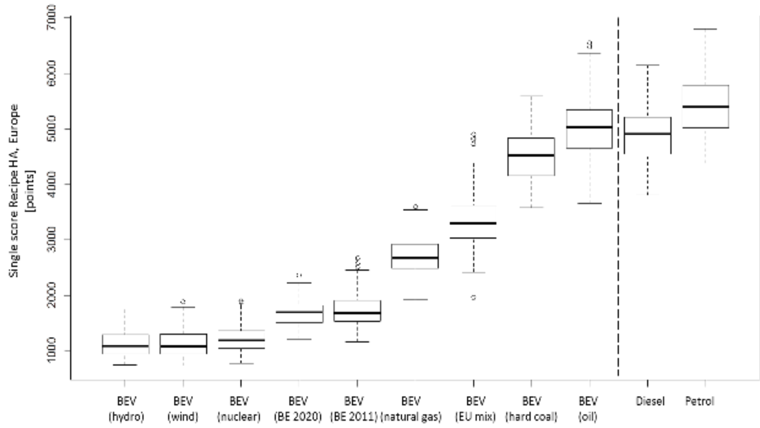


Figure 9: Influence of the electricity mix on single (eco) score Recipe [24]

And last but not least, constant noise emission from traffic is an increasing problem in our city's, causing 60.000 citizens of Rotterdam health problems. Measurements in practice show that EV's in city's are on average 10 dB or three times less noisy [25]

Today we are not able to drive emission free everywhere or for all road transport. However, some inner cities, mountain villages and islands have already banned emitting vehicles. Electrification of all vehicles free the way to total emission free road transportation, in due time. In the near future all road vehicles can be electrified and can use renewable electricity from sun, wind and water. Than there will be no negative emissions effect on climate, air and health anymore. Zero Emission or not, do we have the choice?

3.3 Zero Energy

Moving around requires energy, that's a law of physics. However some forms of movement do not need a thermodynamic process, they use the energy that's available for free in nature, like birds climbing on warm air or boats sailing in the wind. If fact, nature provides them energy (in-directly) from the sun.

The Internal Combustion Engine (ICE) uses a reciprocal thermodynamic process by burning fuel like petrol or diesel. The big advantages of these fuels are that they are fluid and very energy dense. The big energetic disadvantage is that the burning process is very inefficient due to thermal losses caused to necessary cooling and unavoidable tale pipe emissions. In ideal laboratory conditions, a not equipped ICE can reach 40% efficiency in its so-called sweet spot. This means that only two-fifths of the energy content in the fuel is transferred to useful mechanical power. In practice, with variable speed and load and the engine fully equipped, this is even significantly less. This power system, which is used for over a century in our cars, is in fact a better heater than an engine. The efficiency of an electric traction motor is much higher, for the motor itself an efficiency of 85% is feasible at all loads and speeds. Including inverter, battery and charger losses, the practical efficiency is still around 70%. The above comparison is the so-called Tank to Wheel (for the ICE) with Plug to Wheel (for the EV). This is in the vehicle, but of course the origin and transportation of the fuel and electricity matters too. A more realistic and fair way, is to access the total energy chain from (energy) Well to (car) Wheel.

For fuel, this chain will start with the winning of oil from the well. In the pioneer days, the oil erupted from the wells, only the drilling needed energy. But the time of easy oil is over, water injection, deep see drilling, tar sands and fracking are nowadays needed to meet our oil demand. This is not for free, one barrel of tar sand oil needs the equivalent one-third barrel of oil to get it out of the sand (by steam). The so-called Energy Return on (Energy) Invested (EROI) dropped in this case from a traditional 25:1 to less than 3:1 [26]. Transporting the oil, refining it to petrol, diesel or LPG and finally the fuel distribution takes a significant amount of energy too. An increasing energy use in the fossil chain, especially happening at the source, decreases the Well to Wheel efficiency in the future, as seen in figure 4 on page 3 [10].

Electricity is not practical available from one direct well, it should be generated from different energy sources, like fossil coal and gas or energy from water, wind and solar. Modern electricity utilities, which are using coal and gas, have an energy efficiency of between 40 and 60%. Hydropower plants, wind farms and solar parks do not need additional energy, so they do not add any los to the energy chain. After the generation, the electricity has to be transported over a high, mid and low voltage infrastructure, which do lower the Well (Source) to Wheel efficiency of EV's. In general, electricity from the grid does not come from one source but in a mix. The current development is that this mix gets more and more electricity from renewable sources, which increases the Well to Wheel efficiency in the future, see figure 4 on page 3 [10].

If we compare different literature studies on Well to Wheel efficiency, it becomes clear that even the worst-case efficiency for an EV with electricity from coal-fired utilities is still equal or better than the ICE, see figure 10 [10]. Even after more than a century development, throwing about 85% of the energy out of the window is unfortunately a fact for ICE technology. However, EV's running on electricity from renewable energy, and the majority does by contract or from decentralized renewable energy, are on average three times more efficient than the car using the good old combustion technology.

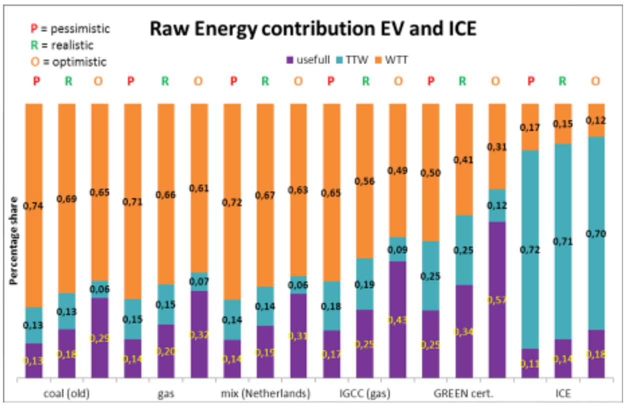


Figure 10: Well to Wheel comparison EV and ICE [10]

Figure 11: The Stella, winner Solar Challenge [28]

A striking example of using free available energy is the planned project of the Hedgehog™ System at the central station of Apeldoorn [27]. Waste brake-energy of the incoming trains is stored in batteries and used to fast-charge the electric city busses. And there is more, students of the Technical University of Eindhoven designed for the Solar Challenge, the price winning 'Stella', a lightweight passenger car with photovoltaic cells on the roof, see figure 11. On average this car is energy positive, it generates more energy than its uses for driving [28]. If students can do this, is Zero Energy than not the way we should move in the near future?

3.4 Zero Congestion

In most urban area's congestions are a daily given. A well-known example of human driving behavior in dense traffic is the shock wave effect causing unnecessary phantom traffic jams [29]. Towards zero congestion means that we should have a system of shared automated or autonomous vehicles (SAV) that intelligently communicates with the other vehicles and the road to avoid congestion and collision. The SAV system can operate as a taxi service on demand; the SAV system could provide low-cost service to travelers and possibly replace the need for personal vehicles. Like the Rivium Parkshuttle, which offers a reliable and cost effective service at SAE level 4[3], see figure 5 on page 4. These future driverless taxis or so-called POD's will operate as a taxi service on demand and can avoid congestion due to the ability to optimize their routes. Meanwhile they pick up other passengers to share the same ride with minimal increases in travel time and costs. Obviously, it is reasonable to expect that SAVs will operate in areas with high passenger/freight loads.

3 SAE has standardized safety levels for automated vehicles; level 4 is driverless in restricted environment

Previous studies [30, 31, 32, 33] assuming the fact at all travelers use SAVs, found that each SAV could service multiple travelers, reducing the number of vehicles needed in the whole SAV fleet. Although 100% SAV use is unlikely to occur in the near future, previous results suggest great potential benefits when SAVs become viable. Strategies such as preemptive relocation of SAVs for expected demand [31] or dynamic ride sharing [32] are additional options for improving service. Dynamic ride sharing is a system that uses one SAV to service multiple traveler trips simultaneously to reduce the SAV fleet size, vehicle miles traveled and operating costs.

Levina et al. [34] showed in 2017 that the addition of a dynamic ride sharing was highly effective at reducing congestion by combining traveler trips. They illustrated this effect in their experiments on the downtown Austin network consisting: 171 zones, 546 intersections, 1247 links, and 62,836 trips over two hours in the morning peak. Their study showed that ride sharing had the best travel times when the number of SAVs was small (2000 SAVs providing service to 62,836 travelers), and these travel times were comparable or even better than the personal vehicle scenarios. They proofed that with effective routing heuristics and the right fleet size, SAVs could replace personal vehicles as Paratransit or individual taxis.

One could argue that users may be less willing to share vehicles, or require higher economic compensation, if this causes low reliability of mobility compared to their own vehicle. Companies or public ownership could severely underestimate the operating costs if they do not consider congestion. It is therefore critical that future work on SAVs have a realistic understanding of the congestion avoidance potential. Still we are aware that there might be situations in which congestion cannot be avoided. We are confident that the SAVs with dynamic ride sharing are the answer for the future to avoid congestion as much as possible.

Is it like to happen on a short term? Yes and no. For the handling and distribution of containers between port terminals in the ‘Maasvlakte’ 1 & 2, the construction of the Container Exchange Route (CER) has started and is put into operation in 2019. The improved connectivity between different terminals will not only lower the harbor residence time for the containers, but will also reduce costs and reliably. At the start of the CER in 2019 an estimated 500,000 containers per year will be transported. The Port Authority assumes and provides for growth to ultimately 1,200,000 containers per year by 2030. It was decided to layout the CER as a separate, closed track of 14 kilometers. However, due to strong demands of the labor union the transport will not be conducted with autonomous vehicles straight from the start, but will be ready for it. They have required that the transport will be manned for the first five years. After five years this requirement will expire and opens the way for a congestion free SAE level 4 container transport [35].

3.5 Zero Accident

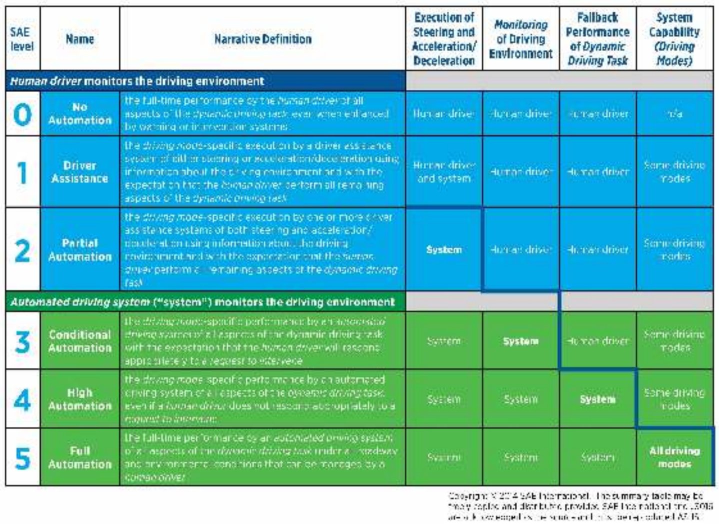
Although humans can be amazing good drivers, driving failure is a main cause of road accidents. The NHTSA mentions the human failure is in 94% the critical reason [36]. An more in-depth Dutch research regarding single vehicle crashes indicates that on average 66% can be directly accounted to not enough alertness of the driver (a/o distraction, speeding, drinking and fatigue) compared to only 7% is caused by technical failure of the car (mainly tires) [37]. For the rest, weather and road conditions played a role. However, also here the human drivers reaction and anticipation can be seen as a crucial factor.

Unfortunately during the last two years the number of road accidents are rising again, most probably due to distraction by the use of smart-phones. In the short term it’s hard to prove that automated driving is a solution for better road safety [38]. But given the above figures it’s likely. Although Tesla claims that after activation of their Advanced Driver Assist System (wrongly called Autopilot), the number of car accidents of the Model S dropped with about 40%, still one fatal crash was world news. After investigation of the NHTSA the driver seemed to have ignored repeated warnings. Also with Google Car, the number of accidents was relatively small and in all cases due to ‘human’ failure.

In the aviation business, automation is completely accepted with a proven and high safety rate. And in Rotterdam practice, the 15 years old Rivium Parkshuttle, after some minor accidents in the early pilot phase, turns out to be accident prove. And in markets where recently full automation has been introduced, like on container terminals as APM terminal located on the 'Maasvlakte' 2 of the Port of Rotterdam, no accidents haven taken place. Please find figures 4 and 5 on page 4.

In the Netherlands a start has been made with the project Talking Traffic [39]. A required part of the overall communication system between car and environment. With this project real time data between different users of the traffic infrastructure is shared. The aim of this project is that, in the near future, every driver or car will be connected and able to make use of real-time travel information and driving support via a dashboard screen, navigation system or automatically.

On the route from SAE level 1 (driver-assist, partial automation) to level 4&5 (diver-less, automation) it will be a challenge to give the driver a meaningful task, see figure 12. Maybe the most fundamental questions about zero accident is not if the technology will be accurate enough, but if the user or driver will accept that he or she is not fully in charge anymore. To realize this shift a psychological and behavioral approach must be a serious part of the system. Already now, people are more willing to accept advice form navigation systems like TomTom than from the way finding and instructions signs along the roadside. This fact, maybe, will make the desirable roadmap to zero accident more hopeful.



SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 12: Levels of Automation (SAE, 2014)

Figure 13: Picture of empty container trucking

3.6 Zero Empty

Do we value the privacy of our own car so much, that we love to drive alone? More likely there is another reason that on average less than 1.2 persons are sitting in a 5-seat passenger car. Commercial vehicles, which are meant for transporting goods are driving about 50% without cargo. As you can see in the picture (figure 13, above) for some 'empty container trucking' is a business in the Rotterdam Port area. Zero empty trips are a good strive to gain efficiency and reduce congestion on our roads. Collaborative connectivity is the key to success. A clear example of successful collaboration in transport logistics is the P&G–Tupperware case. The case uses inter-modal transport but is still relevant as the line of thought for matching is similar. In 2014 Muylaert & Stofferis [40] showed in their study that the overall process shows a significant reduction in costs and emissions, and meanwhile the load factor strongly increases, although some parts of the process have increased costs. The following results are obtained:

- 17% cost reduction;
- Capacity utilization increased from 55% to 85%. Based on volume and weight;
- Over 200 tons CO_2 reduction;

Muylaert & Stofferis [40] conclude that there are matching criteria that are important to realize performance gain. When destinations and goods of the shipments are matched and the companies do not compete, the result is reduced costs and increased capacity utilization for both companies, even for a simple line haul matching.

Crucial element in the collaboration is the willingness to share. Sometimes, confidential information and the acceptance of new business models are needed to share all cost gains among the joining partners. In practice several initiatives can be found as starters who provide software technology to match freight demand to empty truck capacities. For example Quicargo works with an app and links the supply and demand of multiple transport companies. They focus on b2b and domestic transport by offering an End-To-End solution arranging the financial settlement, monitor payment and insurance. Currently a lot of existing platforms can be found in practice such as FreightUber, Cheapcargo, Tri-Vizor, Destitrans or Airhunters. Therefore it is quite realistic that in the near future the goal of zero empty will be closely met. Imbalance in freight demands cannot be avoided and therefore will always cause inefficiency in transport.

Connected Vehicles, could easily communicate the free seats or space. So hitchhikers or commuters can find a lift on demand. The French start-up BlaBlaCar does already provide this service already via mobile telephone. Though Internet of Things cargo could automatically search for empty container trucks. In fact, the Port of Rotterdam already started Rotterdam Logistics Lab to develop these kinds of sharing services anticipating on intelligent vehicles. Will it be the cargo that finds the vehicle for a trip, in the near future?

3.7 Zero Cost

In his latest book the American advisor Jeremy Rifkin explained that we are entering an age with zero marginal costs [41]. Marginal cost is the term that refers to the increase in total production costs resulting from producing one additional unit of the item. Zero marginal cost describes a situation where an additional unit can be produced without any increase in the total cost of production. For example, an update of new software for an electric autonomous car can be noticed as zero marginal cost because once developed it can be distributed remotely to every car without any extra cost.

We prefer to speak about zero cost instead of zero marginal cost because by the implementation of new technologies also other examples of cost reduction will occur. For instance, electric vehicles are in fact very simple vehicles and will be cheaper in Total Cost of Ownership once reached economics of scale, due to less complicated production, low energy use and much less maintenance. Real mass-production of dedicated EV's, batteries and other electric traction components is expected to start around 2020. This will finally bring prices down, to a level competitive or lower than ICE cars [42]. Also the cost of maintenance will be low because of minimal moving parts. And when a system of more intensively driving cars is reached cars will sooner be replaced by newer cars having state of the art technology (e.g. electricity efficient, lighter materials and likely also less safety constructions because of the reduction of accidents).

Eventually the price per barrel oil will rise but for batteries the price will decline. Within a few years already, a reduction will take place by almost 80% per usable kilowatt-hour [43]. Besides of these costs, electric cars are much more energy efficient, resulting in an impressive reduction of mobility cost. EV's can, as written in chapter 3.3, be energy positive or storage. They may earn money by storing energy delivering energy to the smart grid (V2G) or remote homes.

Not only at the level of the car there will be significant reduction of cost, but also at the different infrastructures around the car. For example, there will be less parking lots and parking garages when a system of car sharing and (partly) self-driving cars has succeeded. Cost reductions are also expected when organizational systems as Mobility as a Service (MaaS) are fully implemented. Not longer the supply of existing lines and vehicles will dominate the way people can make use of de network, but the demand of a person will be the central starting point. These will cause a shift from owning to using cars and other means of transportations that are offered by the MaaS-system. Knowing that most of the cars nowadays are standing still in front of livings (80%) or offices (16%) and just 4% is really driving around, because of MaaS there will be an enormous decline of stationary cars and eventually also of a smaller total number of cars. By upcoming mobility systems, another fundamental change will occur. A reduction of the fix costs will taken place and instead of that the variable cost may grow but on the average the cost will be much lower because of a better and more efficient use of the smaller number of available cars.

And MaaS but also less dedicated and advanced systems (e/g Car2Go or SnappCar) will influence the way public transport will be organized. Certainly unprofitable bus- and maybe also train lines will be liquidated and replaced by shared (autonomous driving) cars. Moreover, the need of second cars will decline because one can order any type of vehicle on demand.

An abstract way of cost-reduction will be the way we price time. Time will become less expensive because in driverless autonomous cars ‘drivers’ could productively use commuting time. So, time may become less scarcity. This kind of costs is hardly taken in account in the way we calculate the costs of mobility. This is not correct, especially when we can imagine that the car could become the extension of the office, living room or meeting place. As a Chinese car company stated, the car gave us freedom of travel, now it will give is freedom of time. And time is money.

Concluding discussion

There are plenty possibilities to positively adopt the disrupted technologies. At the end the number of vehicles we need for our mobility might drop, but the quality and economics of use will increase. The automobile, might loose some dominance, but will stay the most flexible way of transport. It will adapt in a sustainable way and form the basis of a more demand driven need for mobility. Competition of other modalities will stay and might increase. On the other hand, the car may evaluate from family cars towards more personal dedicated micro cars & trucks [44] and they may even go airborne. First signs of this trans-formation are already visible in cities and urban areas. Thanks to the three technology disruptions, the development awareness is high, see figure 14. Although the disruptions are not completely synchronous they more or less coincide and reinforce each other, see figure 15. This means that it is now the time to make a fundamental change for the better, by focusing on the Six Zero’s regarding: emissions, energy, congestion, accidents, empty and cost. And then, to our opinion the Future of Mobility will be Automotive.

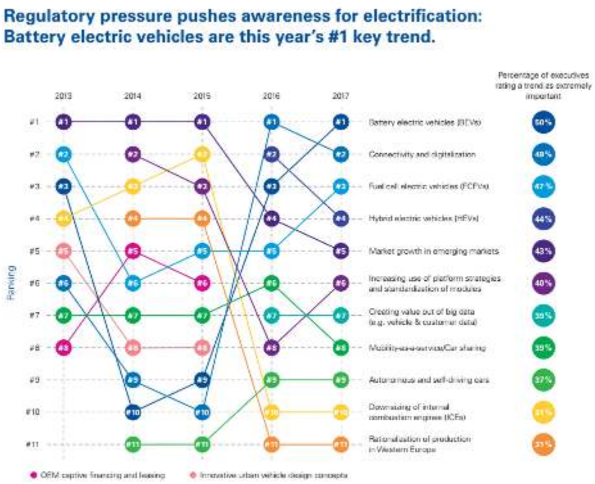


Figure 14: KPMG Global Automotive Excecutive Survey 2017

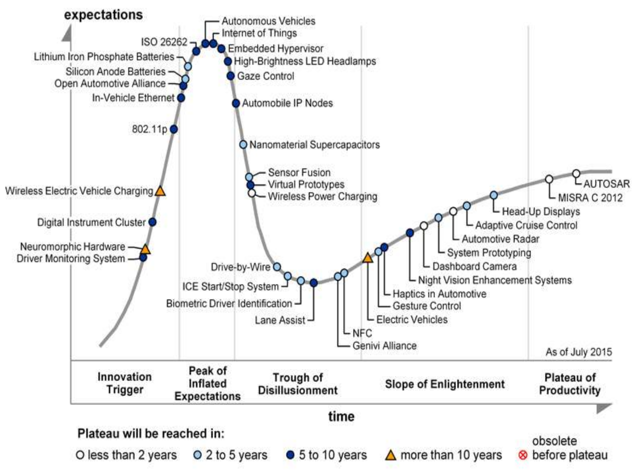


Figure 15: Gartner Hype Cycle Automotive 2015

Acknowledgments

We would like to thank all research partners, colleagues and students for the contribution to the groundbreaking projects that led to the research results, knowledge and this paper.

References

[1] J. Dulac, Global Transport Outlook 2050, International Energy Agency, 2014
[2] Port Vision 2030, Port of Rotterdam, 2011
[3] L. Verheij, Nulmeting RCI, Uitstoot CO_2 Rotterdam, RCI, 2005
[4] F. Rieck, SIA Raak PRO-1-248, Inhoudelijke eindrapportage eMobility-Lab, Hogeschool Rotterdam, 2014
[5] F. Rieck, Technisch verslag pilotproject openbaar vervoer per bus in de regio Rotterdam, NEMS, 2013
[6] J. vd. Velde and F. Rieck, Insight in actual operational costs of Electric Transport, Rotterdam University of Applied Science, EVS27 paper and poster, 2013-10
[7] Verkenning elektrisch rijden, Part 1: Technologische onzekerheden en uitdagingen rondom elektrisch rijden in Nederland, chapter 2.5 Veiligheid en Milieu, Dutch-INCERT, 2010
[8] Nicola One, Motor Company, https://nikolamotor.com/, accessed on 2017-02-14
[9] S. Boonstra, F. Rieck and G, Ebbers, Analysis of a fictive active e-trailer, Rotterdam University of Applied Science and e-Traction, EVS30, to be published 2017
[10] H. Righolt and F. Rieck, Energy chain and efficiency in urban traffic for ICE and EV, Rotterdam University of Applied Science, EVS27 paper and poster, 2013-10
[11] D. O'Connell, Tesla, Keynote speech presentation at Nordic EV Summit, Drammen, Norway, 2017-02-07
[12] S. v. Sterkenburg, E. Rietveld, F. Rieck, B. Veenhuizen and H. Bosma, Analysis of regenerative braking efficiency - A case study of two electric vehicles operating in the Rotterdam area, HAN & Rotterdam University, VPPC paper, USA, 2011
[13] B. Veenhuizen, "INTRALOG - Intelligent Truck Applications in Logistics", HAN University of Applied Sciences, 2014
[14] B. v. Aram, STAD: Spatial and Transport Impacts of Automated Driving Project proposal, NWO Sustainable Urban regions of the Future (SURF), Technical University Delft, 2015
[15] R. Boersma, B v. Arem and F. Rieck, Application of Driverless Electric Automated Shuttles for Public Transport in Villages: the case of Appelscha, Technical University Delft and Rotterdam University of Applied Science, EVS30, to be published 2017
[16] T. Seba, Clean disruption of energy & transportation, ISBN 9780692210536, 2014
[17] Automotive Disruption Radar, Roland Berger GmbH, 2017
[18] J. Womack, D. Jones & D. Roos, The machine that changed the world, Free Press, ISBN 9780743299794, 1990-04-09
[19] OECD/International Energy Agency, CO_2 emissions from fuel combustion Highlights, 2016
[20] European Commission Climate Action, Road transport: Reducing CO2 emissions from vehicles, https://ec.europa.eu/clima/policies/transport/vehicles_en, accessed on 2017-06-21
[21] Estimated total emissions per year per vehicle type for all urban traffic in the Netherlands, TNO, 2015
[22] M. Krzyzanowski, B. Kuna-Dibbert and J. Schneider, Health effects of transport-related air pollution, World Health Organization (WHO), 2016
[23] J. Wouters, De elektrische auto, Pepijn B.V Uitgeverij, ISBN 9789078709220, 2013-0617
[24] M. Messagie, F-S Boureima, T. Coosemans, C. Macharis and J. v. Mierlo, A Range-Based Vehicle Life Cycle Assessment Incorporating Variability in the Environmental Assessment of Different Vehicle Technologies and Fuels. Energies, Vrije Universiteit Brussel, 2014
[25] Gemeente Rotterdam, Rotterdam test elektrisch rijden, Proeftuin RVO, report and presentation, 2013
[26] J. Hughes, Drill, Baby, Drill, can unconventional fuels usher in a new era of energy abundance? Post Carbon Institute, 2013-02
[27] Hedgehog Applications, http://www.hedgehogapplications.nl/en/project-apeldoorn/systeemuitleg/, accessed on 2017-07-04

[28] M. Steinbuch, Disruptions, Technical University Eindhoven, Presentation Avere E-Mobility Conference (AEC), 2016

[29] Shockwave traffic jams recreated for first time, https://www.youtube.com/watch?v=Suugn-p5C1M, New Scientist 2008, accessed on 2017-07-04

[30] L. Burns, W. Jordan, and B. Scarborough, Transforming Personal Mobility. Earth Island Institute, Columbia University, 2013

[31] D. Fagnant, and K. Kockelman, The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. Transportation Research Part C: Emerging Technologies 40, 1–13, 2014

[32] D. Fagnant, and K. Kockelman. Dynamic ride-sharing and fleet sizing for a system of shared autonomous vehicles in Austin, Texas. Transportation, 1–16, 2016

[33] D. Fagnant, K. Kockelman and P. Bansal. Operations of a shared autonomous vehicle fleet for the Austin, Texas market. Transportation Research Record 2536, 98-10. 2015

[34] M. Levina, K. Kockelmanb, S. Boylesb and T Lib. A general framework for modeling shared autonomous vehicles with dynamic network-loading and dynamic ride-sharing application. Systems 64, 373–383, 2017

[35] A. Spruijt, R. v. Duin and F. Rieck, Intralog: Towards an autonomous system for handling inter-terminal container transport. Rotterdam University of Applied Science and Technical University Delft, Proceedings EVS30, to be published 2017

[36] S. Singh, Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey. (Report No. DOT HS 812 115). Washington, DC: National Highway Traffic Safety Administration, 2015-02

[37] R. Davidse, Run-off-road crashes in the Province of Zeeland: characteristics and possible solutions, SWOV, 2011

[38] N. Kalra, S. Paddock, How Many Miles of Driving Would It Take to Demonstrate Autonomous Vehicle Reliability? Rand Corporation, 2016

[39] https://www.partnershiptalkingtraffic.com/, accessed on 2017-07-07

[40] K. Muylaert and L. Stofferis, co3-project. [Online] Available at: http://www.co3-project.eu/wo3/wp-content/uploads/2011/12/CO3-conference-Koen-PG-BIC-20140528.pdf, 2014

[41] J. Rifkin, The Zero Marginal Cost Society, The Internet of Things, the Collaborative Commons, and the Eclipse of Capitalism, Palgrave Macmillan Ltd, 2014

[42] UBS consumer survey EV's, 2017

[43] Bloomberg new energy finance, special: electric vehicles, Electric vehicles – it's not just about the car, 2016-08-22

[44] R. Hogt, J. Warmerdam and S. Balm, Designing Light Electric Vehicles for urban freight transport, Rotterdam and Amsterdam University of Applied Science, EVS30, to be published 2017

Authors

	Frank Rieck is Research Professor Future Mobility at the Research Centre Sustainable Port Cities of the Rotterdam University of Applied Science. Educated as Mechanical Engineer and Industrial Designer. Has a background in various innovation, marketing and management functions in the Automotive Industry. Is currently, responsible for the research & innovation regarding Future Mobility. And is chairman of Dutch-INCERT a national network of knowledge centres regarding eMobility and is representing the Netherlands as vice president of EU organization AVERE.
	Kees Machielse is Research Professor Sustainable Transition and Future of the Port at the Research Centre Sustainable Port Cities of the Rotterdam University of Applied Science. Educated as Town and regional planner. Has a background in innovation, regional economics, urban planning, logistics, transition management and scenario planning, both as researcher, policy maker and as manager. Besides his appointment as research Professor, he also has his own consultancy company Sinik bv.
	Ron van Duin is Research Professor Port & City Logistics at the Rotterdam University of Applied Sciences and assistant professor at the department Engineering Systems and Services at Delft University of Technology. He completed his master study Econometrics at the Erasmus University Rotterdam (1988). He received his Doctorate in Technology, Policy and Management from Delft University of Technology (2012). As a researcher he has worked on numerous studies concerning, (city) logistics, (intermodal) freight transport, infrastructure, ports, and terminals. His main interests are in research in sustainability, efficiencies, cost and quality impacts of new technologies in freight transport and logistics.