Opportunities and challenges for automated vehicles in the Zuidvleugel

Clients:

Dhr. Lodewijk Lacroix

Dhr. Jan Ploeger

ZUIDVLEUGEL

Authors:

Prof.dr.ir. Bart van Arem
B.vanArem@TUDelft.nl

Dr.ir. Niels van Oort
N.vanOort@TUDelft.nl

Ir. Menno Yap

Dr. Bart Wiegmans

Dr.ir. Goncalo Homem de Almeida Correia

TU Delft
Delft University of Technology

January 2015

TU Delft
Delft University of Technology

Opportunities and challenges for automated vehicles in the Zuidvleugel

Abstract

Motivation

Since several years many developments regarding self-driving, automated vehicles (AVs) take place. Within the coming years it is expected that automated vehicles are becoming part of our transportation system. Therefore it's becoming more and more important for policy makers to get insights into the state-of-the-art developments around AVs, in order to foster applications of AVs which are promising from a societal point of view and to take these developments into consideration during the decision-making process.

Definition and function of automation

Automation in this study refers to the transport system including all of its components, such as vehicles, drivers, users, infrastructure, information systems and applications. The level in which the driver is still 'in the loop' is used in order to discriminate between the different levels of vehicle automation: driver assistance (level 1), partial automation (level 2), conditional automation (level 3) and high/full automation (level 4).

In this study, our aim is to analyze strengths, weaknesses, opportunities and threats related to different applications of automation for autonomous private vehicles, freight transport and handling, and public transport. The potential of different applications of AVs in the Zuidvleugel in this study is strictly considered from a societal perspective (demand driven), in which AVs have a societal contribution to answer challenges the Zuidvleugel will face the upcoming years. Each application of automation is analyzed based on its functional ability to contribute to more agglomeration power of the Randstad Zuidvleugel, which in turn can improve the position of the Randstad Zuidvleugel relative to other European metropolitan areas.

Conclusions

We can conclude that a variety of (developments of) applications of automation exist in the Netherlands and worldwide regarding autonomous vehicles, freight and public transportation. We see several opportunities for the Zuidvleugel to benefit from these developments. Some of them are relevant for the short term (4 years), whereas other developments need more time to may be applied. Below, the main findings are summarized.

Conclusions automation for autonomous vehicles

- On the short term, Intelligent Speed Assistance (ISA) systems, automated parking, and automated speed harmonization of vehicles in case of congestion or accidents, have potential to be tested and/or implemented.
- Given the current technological developments, legal and liability issues, the implementation of driver support or partial automated systems has most potential on the short term for private cars.
- Some scientist question whether a 100% fully automated vehicle in mixed traffic will be possible in the future, given the high complexity of the human driver task. On the other hand, technical developments are promising. Either way, it will take much time to achieve this final level. However, partly automated systems and/or limited mixture may be applied earlier.
- Humans are not that well suited for a task as supervisor of an automated system. One should be aware of these risks during the transition phase when a human driver should be able to intervene in an automated driving system in case of problems or difficulties.

Application	Strengths	Weaknesses	Opportunities	Threats	Possible applications Zuidvleugel
Intelligent Speed Assistance (ISA)	Traffic safety Less emissions Less fuel consumption	Longer travel times on low density roads	Implementation combined with cruise control facility in car	Driver acceptance	Urban roads with speed limit 30 km/h
Speed harmonization	Faster recovery from congestion Less congestion from 'kijkersfiles'	Investment costs Technology not applied yet	Less speed violations Higher safety	Increase share private car transport	(Pilot at) A20 between A13 and A16 (ring Rotterdam)

Automated parking	No parking time Less parking space	Investment costs	Better land use and shaping of scarce space in city centres	System unreliability Higher share private car	City center of Den Haag, Delft Locations to be investigated
Fully automated vehicles	Higher safety Environment	Technical and liability issues Less driving pleasure	Less congestion Better land use and city shaping	Overestimation of technical capabilities Uncoordinated legislation	Pilot in Zuidvleugel

Conclusions automation for freight transportation and handling

- Road transport and city distribution will contain the most innovations regarding automation and guidance in freight transport with success potential.
- The potential market for innovations is much larger for road freight transport (millions of trucks) as compared to rail or inland waterway transport (thousands of trains or barges).
- Financial resources at freight transport companies are much smaller than at passenger transport companies (such as car makers).
- Innovations in freight transportation often follow innovations which already take place in passenger transportation.
- Automation and guidance developments should lead to cost reductions or possibilities to increase sales in freight transport

Application	Strengths	Weaknesses	Opportunities	Threats	Possible applications Zuidvleugel
Automated truck platoons	Performance Cost efficiency Reliability Safety	Liability Implementation costs Hinder for private cars at on/off-ramp	Sustainability Replace truck drivers Less congestion	Competition from traditional road transport EU focus on intermodal transport	Between terminals Rotterdam Port Area Between flower auction Naaldwijk and Port Area Port - hinterland transportation A15
Automated city distribution	Efficient shipments Less labour costs	Technical issues Institutional issues	Scale enlargement	Electric vans and trucks Competition between modes	City centres of larger cities as Delft, Den Haag and Rotterdam

Conclusions automation for public transport

- High or full automation applications have on the short term only potential on separated infrastructure (like metro or light rail lines, or fully separated feeder services to main public transport lines), due to technical and institutional limitations.
- For urban tram and bus lines automation can function as driver support, thereby realizing a positive human-machine interaction. No high or full automation is expected there within 4 years.

Application	Strengths	Weaknesses	Opportunities	Threats	Possible applications Zuidvleugel
Automated metro and light rail lines	Capacity Punctuality Service quality Fleet size Operating costs	Investment costs Platform protection	Aging of drivers New innovation climate	Public acceptance Acceptance by unions/drivers Unreliability	Rotterdam metro network RandstadRail Den Haag Central – Zoetermeer / Rotterdam
Automated urban tram and bus lines	Punctuality Operating costs Service quality	Technical issues Institutional issues	Automation as driver assistance	Acceptance when machine failure occurs	-
Automation of feeder to main public transport	Improve door-to-door transport Flexibility Demand-driven	Separated infrastructure Investment costs	Areas with low PT supply level and high activity level	Demand overestimation Costs under-estimation Attitudes AV	Connection Meijersplein – Rotterdam-The Hague Airport
Automation with Personal Rapid Transit (PRT)	Improve door-to-door transport Walking time Waiting time	Technical issues Institutional issues Separated infrastructure	Internal transport	(Perception of) safety Costs	-

Recommendations for the Randstad Zuidvleugel

- It is recommended to form an alliance with involved stakeholders (like municipalities, HTM, RET, TU Delft, businesses) to investigate possibilities to start a pilot with automated vehicles as last mile transport connection between RandstadRail stop Meijersplein and Rotterdam-The Hague Airport, given the current limited public transport accessibility of the airport.
- An Intelligent Speed Assistance (ISA) system can improve traffic safety by informing, warning, intervening or overruling a car driver if he/she exceeds the local speed limit. This is especially relevant on urban roads (speed limits 30 km/h and 50 km/h), where car traffic heavily interacts with weaker traffic participants like cyclists and pedestrians. Therefore, for the Randstad Zuidvleugel it is recommended to support and facilitate a feasibility study to ISA systems and, possibly, the ISA implementation process. Most important here is facilitating the development of a central speed limit database, which is used as input for the ISA system as maximum speed at different locations and times. A gradual implementation process is recommended. By starting with urban roads with speed limit 30 km/h, with cars which are already equipped with cruise control, driver acceptance can be improved and starting costs can remain relatively limited.
- It is recommended to support a pilot or first implementation of automated speed harmonization on the heavily congested A20 highway between the A13 and A16, in cooperation with other involved stakeholders (e.g. Rijkswaterstaat, TNO, TU Delft).
- Formation of a freight coalition could be sought for by the Randstad Zuidvleugel for a first study into possibilities and feasibility of automation of (a platoon of) trucks on public roads, for example on the A15 highway or between mainport Rotterdam and greenport Westland. Here, the effect of truck platoons on hindrance for cars to/from on/off-ramps should be incorporated explicitly.
- For the Randstad Zuidvleugel, in cooperation with municipalities, transport authorities and public transport operators, it is recommended to investigate to which extent different levels of automation on the RandstadRail light rail connection between Den Haag and Zoetermeer / Rotterdam can reduce capacity problems on this track and against which costs.

Table of Contents

1 Introduction

1.1 Motivation

Since several years a lot of developments regarding self-driving, automated vehicles (AVs) take place. Different applications of AVs and pilots with AVs are starting in the Netherlands and worldwide. Within the coming years it is expected that automated vehicles are becoming part of our transportation system. Therefore it's becoming more and more important for policy makers to get insight in the state-of-the-art developments around AVs, in order to foster applications of AVs which are promising from a societal point of view and to take these developments into consideration during the decision-making process.

1.2 Policy goals

The potential of different applications of AVs in the Zuidvleugel in this study is strictly considered from a societal perspective (demand driven), in which AVs have a societal contribution to answer challenges the Zuidvleugel faces the upcoming years and to realize the following policy goals:

- More regional economic development and more agglomeration power of the Zuidvleugel.
- Higher quality of public realm.
- Better accessibility.
- Higher quality of transportation systems.
- More efficient and effective transportation systems.
- Higher safety of transportation systems.
- More sustainable transportation systems and higher quality of life.

1.3 Objective

The objective of this essay is to perform a first scan to state-of-the-art applications of AVs related to autonomous vehicles, freight transportation and public transportation. For different applications strengths and weaknesses are assessed. Also external opportunities and threats relevant for the realization of these applications are identified and discussed. Based on this SWOT analysis, we provide recommendations regarding promising applications of AVs in the Randstad Zuidvleugel area. Thereby, we focus on two different time horizons.

- We formulate conclusions about developments and applications of AVs which have potential to be realized within the next four years. This should lead to agreements between science and practice within the next year regarding these potential applications of AVs in the Zuidvleugel.
- We also provide more long term recommendations for more research to the feasibility of certain applications of AVs. This will give more insight in the potential of these applications being applied in the Zuidvleugel. For promising applications which require more research, we aim to line up with the four year SURF ('Smart Urban Regions of the Future') programme.

The list of applications of AVs as discussed in this essay should be considered as non-exhaustive, since such a large variety of AV applications exists, that it is not possible to mention them all within the scope of this project.

1.4 Research approach

Results of this essay are based on research performed by the Delft University of Technology, faculty of Transport & Planning. We obtained our results based on desk research and literature studies. Besides, we made use of interviews with important stakeholders in the field of automated transportation. Interviews were held with scientific experts, experts in the field and important parties responsible for (public) transportation in the Zuidvleugel.

1.5 Scope

In this essay we first discuss state-of-the-art applications of AVs in general. Then, we narrow down our scope to applications in the Randstad Zuidvleugel (Figure 1.1). Hereby, we focus on applications regarding autonomous car transportation, freight transportation and public transportation. In the end, we shortly mention promising combined applications from these three different fields.

1.6 Outline

The outline of this essay is as follows. In chapter 2 we define vehicle automation and its function, since this is crucial for a thorough understanding of automation in transportation. In chapter 3 applications of automation for autonomous car transportation are discussed. We discuss applications of automation in freight transport in chapter 4. Chapter 5 discusses AV applications related to public transport. In chapter 6 combinations of applications between car, freight and public transport are shortly mentioned. We finish with conclusions and recommendations for the Zuidvleugel regarding its role in facilitating research to / pilots of / implementation of promising AV concepts and applications.

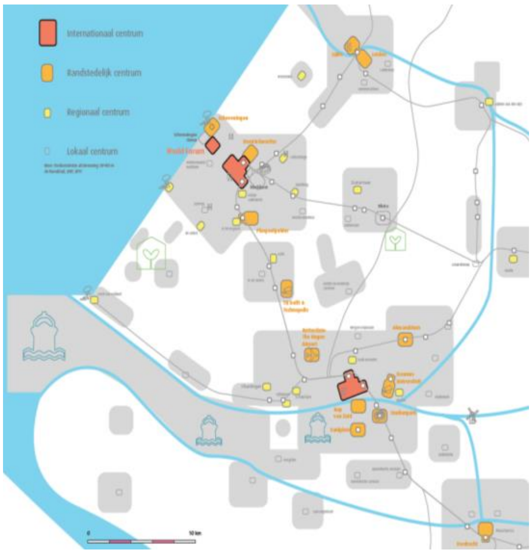

Figure 1.1. Randstad Zuidvleugel area (BSP 2011)

2 Definition and function of automation

2.1 Levels of automation

Automation in this study refers to the transport system including all of its components, such as vehicles, drivers, users, infrastructure, information systems and applications. The term automation is often used to define a process in which automation takes over control from the human. In this context, the level in which the driver is still ‘in the loop’ is used in order to discriminate between the different levels of vehicle automation. An often used definition of vehicle automation is the definition formulated by Gasser and Westhoff (2012) and SAE International (2014). Four different levels of automation are distinguished (Table 2.1), namely:

- Driver assistance (level 1)
- Partial automation (level 2)
- Conditional automation (level 3)
- High / full automation (level 4)

Table 2.1. Level of automation, applied to cars (SAE International 2014)

NHTSA level	SAE level	SAE name	SAE narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Backup performance of *dynamic driving task*	System capability (*driving modes*)
	***Human driver* monitors the driving environment**						
0	0	Non-Automated	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	1	Assisted	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	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	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	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**

In driver assistance, the driver permanently maintains either longitudinal control (speed choice, vehicle-following) or lateral control (lane/track keeping, merging, lane changing / switches, overtaking). The other tasks can be automated to a certain extent by an Advanced Driver Assistance (ADA) system. Partial automation entails the situation in which a system takes over both longitudinal and lateral control. The driver is required to permanently monitor the system and is required to take over control at any time. In the third level, conditional automation, the system takes over longitudinal and lateral control, but the driver is no longer required to permanently monitor the system. Nevertheless the driver must be prepared to respond adequately to a take-over request by the system. On the highest level there is high and full automation. In high automation, the system also takes over longitudinal and lateral control. However, in the case where a take-over request by the system is not carried out by the driver, the system will return to minimal risk condition by itself. In full automation the automated driving system performs all tasks under all conditions without requests to a human driver. Driving without humans on-board is only possible on this fourth level (Gasser and Westhoff 2012, SAE International 2014).

2.2 Implications of automation

Different applications of automated vehicles on different automation levels also have different implications. Figure 2.1 visualizes the implications different applications of automated driving can have. Implications are larger (from travel/traffic implications in the inside only, to societal implications on the outside) in case a larger, ‘heavier’ application is implemented (ripple effect). Also, the higher the level of automation of an application, the larger the implications in general can be (Milakis et al. 2014).

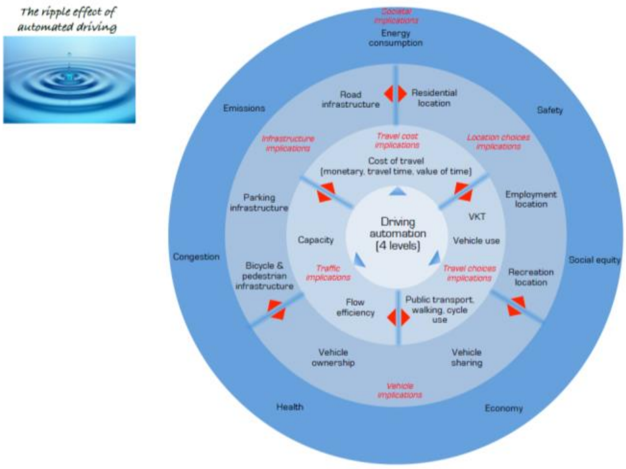

Figure 2.1. The ripple effect of automation: different levels of automation can have implications on different levels (Milakis et al. 2014)

2.3 Function of automation: automation as means to increase agglomeration power

The Randstad Zuidvleugel as metropolitan area competes with other European metropolitan areas for growth in prosperity and employment. The spatial components ‘agglomeration’/’urbanisation’, ‘accessibility’ and ‘quality of life’ can influence each other and influence the competitive position of the Zuidvleugel relative to other metropolitan areas (see Figure 2.2). However, despite its rich and polycentric structure, the Zuidvleugel area is currently not able to benefit from agglomeration advantages (Raspe et al. 2012; Manshanden et al. 2014; OECD 2014). To increase agglomeration power (defined as ‘the number of inhabitants, businesses and facilities which are connected in a fast and an easy way in an attractive environment’), it is necessary that urbanisation, accessibility and quality of life are better aligned with each other. This means that agglomeration growth and density should be increased at locations which have a good multimodal accessibility by car and public transport (for example: around stations Den Haag Laan van NOI and Rotterdam Alexander). The other way around, high quality (public) transport should be realized at highly urbanised locations (for example: business areas). When urbanisation and accessibility are better aligned, the Zuidvleugel can function as one daily urban system where borrowed size is used as means to increase agglomeration power.

By supplying multimodal connections, travellers can choose how they travel from A to B. Besides, when supplying good public transport connections between important areas with high densities of inhabitants, jobs and facilities, connections are also more sustainable. Both aspects (freedom of choice and sustainability) increase the quality of life. Figure 2.2 shows how better alignment of agglomeration/urbanisation, accessibility and quality of life can increase the competitiveness of the Zuidvleugel (Ram et al. 2014).

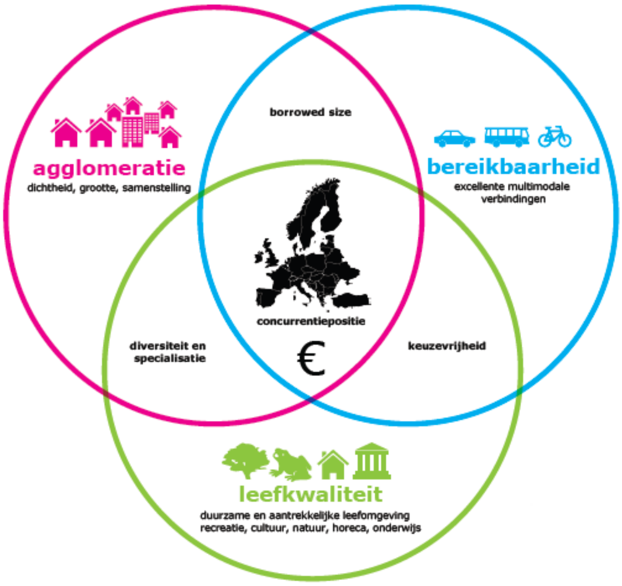

Figure 2.2. Spatial factors 'agglomeration', 'accessibility' and 'quality of life' can strengthen the competitiveness of the Zuidvleugel area (Ram et al. 2014)

Automated vehicles can contribute to the aim of increasing the agglomeration power and competitiveness of the Zuidvleugel area. Different applications of AVs can improve (multimodal) accessibility of important agglomerations in the Zuidvleugel. Thereby AVs can supply faster and more attractive connections and facilitate borrowed size between urbanized areas. AVs also have potential to improve the quality of life, by offering more freedom in mode choice and more sustainable ways of transportation. In general we can conclude that AV applications can have potential to better align urbanisation, accessibility and quality of life for certain locations in the Zuidvleugel. AVs thereby contribute to the policy goal of increasing agglomeration power and regional economic development, as formulated in chapter 1.2.

3 Automation for autonomous private vehicles

3.1 Conclusions automation for autonomous vehicles

Table 3.1. Summary SWOT analysis automation for autonomous vehicles

Application	Strengths	Weaknesses	Opportunities	Threats	Possible applications Zuidvleugel
Intelligent Speed Assistance (ISA)	Traffic safety Less emissions Less fuel consumption	Longer travel times on low density roads	Implementation combined with cruise control facility in car	Driver acceptance	Urban roads with speed limit 30 km/h
Speed harmonization	Faster recovery from congestion Less congestion from 'kijkersfiles'	Investment costs Technology not applied yet	Less speed violations Higher safety	Increase share private car transport	(Pilot at) A20 between A13 and A16 (ring Rotterdam)
Automated parking	No parking time Less parking space	Investment costs	Better land use and shaping of scarce space in city centres	System unreliability Higher share private car	City center of Den Haag, Delft Locations to be investigated
Fully automated vehicles	Higher safety Environment	Technical and liability issues Less driving pleasure	Less congestion Better land use and city shaping	Overestimation of technical capabilities Uncoordinated legislation	Pilot in Zuidvleugel

- Within the next 4 years, no substantial part of the cars will be driven fully automatically: current technological, legal and liability issues do now allow such operation.
- Some scientist question whether a 100% fully automated vehicle will be possible in the future, given the high complexity of the human driver task. Will an automated vehicle ever be able to anticipate on the risk that a child, playing near the street with a ball, will cross the street suddenly?
- Humans are not that well suited for a task as supervisor of an automated system. One should be aware of these risks during the transition phase when a human driver should be able to intervene in an automated driving system in case of problems or difficulties.
- The implementation of driver support or partial automated systems has most potential on the short term, within the next 4 years, for private cars.
- On the short term, Intelligent Speed Assistance (ISA), and automated speed harmonization of vehicles in case of congestion or accidents, have potential to be tested and/or implemented.
- A gradual implementation of ISA, starting with urban roads (speed limited to 30 km/h) is recommended.

3.2 Applications of automation for autonomous vehicles

3.2.1 Applications of task automation for autonomous vehicles on intermediate levels

Intelligent Speed Assistance (ISA)

Intelligent Speed Assistance (ISA) is a driver support application of automation (level 1). Different variants of ISA are possible (see Table 3.2). The ISA can function as informative system, which informs the driver if he/she exceeds the speed limit. It can also function as open, warning system. In case of exceedance of the speed limits, the system warns the driver by auditory and/or visual stimuli. The driver then decides whether to comply to the speed limits or not. ISA can also be applied as half-open system. In that case, a haptic throttle makes it harder for a driver to push the acceleration pedal in case of speed limit exceedance. However, the driver is still able to accelerate by pushing harder. In an automated, closed ISA system, it is not possible for the driver to accelerate in case the speed limit is exceeded (SWOV 2010).

Different implementation strategies are possible for ISA. It is possible to have a voluntary system, for which a driver can opt. It is also possible to implement a mandatory ISA system. This system can then be mandatory for certain driver groups (e.g. truck drivers, taxi drivers, other professional drivers, or drivers who have a history in offending speed limits), or for all drivers.

Table 3.2. Different ISA variants with different implementation strategies

Implementation strategy →	***Voluntary (self-selection driver)***	***Mandatory for driver segments***	***Mandatory for all drivers***
Level of support	Informative system		
	Warning (open) system		
	Intervening (half-open) system		
	Automated (closed) system		

The main goal of ISA is improving traffic safety, by (its aim of) preventing exceedance of the local maximum speed limit. Since speed is the most important cause of car accidents, ISA can play an important role in reducing the number of accidents. Depending on the type of ISA being implemented, a reduction in traffic fatalities between 18% and 59% is estimated in case of 100% penetration rate of ISA (SWOV 2010). Additional effects of ISA can be a small reduction in fuel consumption, lower emission levels and in busy traffic a more efficient handling of traffic flows, leading to lower travel times. On low density roads, ISA however increases travel times slightly, due to the lower average speed.

Speed harmonization application

There are also applications of automation levels lower than level 4 for autonomous vehicles. These applications function as driver assistance (level 1) or partial automation next to the driver (level 2). One of these applications is the coupling of automation with V2I (Vehicle-to-Infrastructure) communication. Such applications might reduce several negative effects that are today observed in the traffic system of the Netherlands and Randstad Zuidvleugel area, such as:

- Smoother recovery from heavy congestion by gradually accelerating the vehicles, by acting on their ACC (Adaptive Cruise Control).
- Avoid lower speeds in the opposite direction of a road where a traffic accident has happened (‘kijkersfile’), by acting on vehicles’ ACC (Adaptive Cruise Control) as well.

Figure 3.1. Connected vehicles

Currently, this technology is not applied in practice yet. However, there are large experiments taking place in some countries. That is the case with the Connected Vehicle Safety Pilot project being led by the Transportation Research Institute of the University of Michigan and financed by the USDOT. They had 300 connected vehicles to test V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) technology, a project that ended and 2013 and is being expanded (see for more information: *(http://www.mtc.umich.edu/vision/news-events/u-m-mobility-transformation-center-announces-founding-corporate-partners).* Among the systems being tested is the speed harmonization system:
“The Speed Harmonization application determines speed recommendations based on traffic conditions and weather information. The speed recommendations can be regulatory (e.g. variable speed limits) or advisory. The purpose of speed harmonization is to change traffic speed on links that approach areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that affect flow. Speed harmonization assists in maintaining flow, reducing unnecessary stops and starts, and maintaining consistent speeds. The application utilizes connected vehicle V2I communication to detect the precipitating roadway or congestion conditions that might necessitate speed harmonization, to generate the appropriate response plans and speed recommendation strategies for upstream traffic, and to broadcast such recommendations to the affected vehicles. The speed recommendations can be provided in-vehicle for connected vehicles or through roadside signage for non-connected vehicles” *(http://www.iteris.com/cvria/html/applications/app68.html#tab-3)*

Automation in parking

Another application of lower level automation in autonomous vehicles is more efficient parking by using smart phone parking where a car parks itself. This can be on street level or in garages. Less parking space is then needed because no space for entrance/leaving the vehicle is required. Besides, interactive systems can function as driver support, for example by providing drivers in-car information where parking spaces are available.

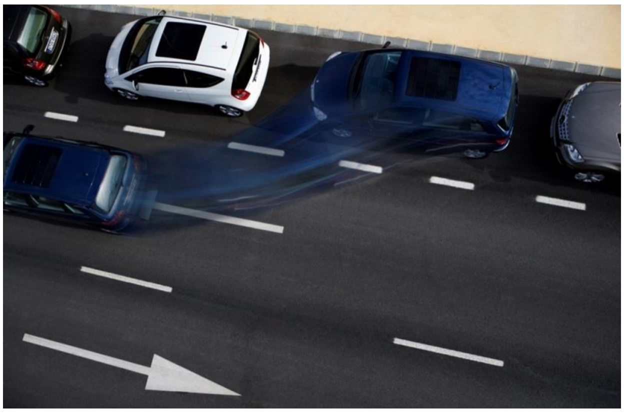

Figure 3.2. Automated parking

3.2.2 The fully automated vehicle as autonomous, private transport

Impact on traffic

Most of the studies that have been done on vehicle automation focus on vehicle technology to enable self-driving vehicles on our roads. The main concern is the interaction of automated vehicles (at every level of automation) and human driven vehicles in a stage of co-existence between both types.

The relationship between the different levels of vehicle automation and traffic flow efficiency is complex, as the effect of automation on traffic flow may be assumed to be dependent on many different factors. For example, besides the settings of the automated systems, the effects on traffic flow efficiency may be dependent on human factors, such as user acceptance and behavioral adaptation due to the changed role of the driver.

The following is a non-exhausting list of conclusions that have been reached in several research projects and experiments on the topic:

- The presence of semi-automatic vehicles (lower than the 4thlevel) with vehicle following capability in mixed traffic improves air pollution levels and fuel savings during transients caused by rapid acceleration maneuvers (Bose and Ioannou 1999).
- Semi-automated vehicles with vehicle following capability in mixed traffic smooth traffic flows by filtering the response of rapidly accelerating lead vehicles (Bose and Ioannou 1999).
- For each 1% more vehicles equipped with ACC (Adaptive Cruise Control: level 1 automation) there is an increase of the road capacities by about 0.3% (Kesting et al. 2010).
- ACC with V2V (Vehicle-to-Vehicle) communication improves further the traffic flow stability and efficiency (van Arem et al. 2006).
- There may be negative behavioral effects on unequipped, non-automated vehicles by mixing them with vehicles equipped with ACC (Gouy et al 2014).
- V2V communication allows the formation of platoons on highways, which leads to more capacity and safety (Halle and Chaib-draa 2005).
- Despite the apparent potential for disastrous accidents, autonomous intersection management is likely to improve driver safety considerably (Dresner and Stone 2008).
- V2V technology in a fully automated vehicle allows managing an intersection in a more efficient way (Alonso et al. 2011).
- In not very busy intersections V2V communication for managing its crossing can outperform stop signs: vehicles spend less time waiting and consume less fuel (VanMiddlesworth et al. 2008).
- Infrastructure sensors may provide through V2I (Vehicle-to-Infrastructure) communication a reduction on on-board vehicle sensors and at the same time improved performance of the vehicles driving (Rebsamen et al. 2012).

Impact on the mobility system

There are scant studies regarding the impact of level 4 automated vehicles in the global mobility system of cities and regions. There are however reports that tentatively enumerate the expected effects on the transportation system. These have been done by transport research experts based on their experience and results of studying transport demand and supply.

Bierstedt et al. (2014) state that there are “potentially dramatic changes to the transportation planning and engineering profession” because of AVs. They refer to some of the factors that will influence the automated vehicles adoption and typical use, hence the degree with which it will affect the total number of vehicle kilometers travelled by car. In that list, besides the instrumental characteristics of the new vehicles such as speed and safety, they refer that the “quality of service offered by alternative modes of travel, which will vary by urban setting” will play a role on that indicator, clearly acknowledging the importance of competition between modes and assuming that at least in the medium-run autonomous vehicles will co-exist with other modes.

Changes are expected on the value of travel time inside an automated private vehicle compared to a normal one, since now travelers will be able to use that time in more productive activities. However there is no particular study on quantifying these changes yet, hence it is impossible to compare both modes from that point of view. An exploratory study by Yap and Correia (2015) however indicates that the value of time in automated vehicles is not expected to decrease directly. In this study, travelers indicate an even higher value of time, which can possibly explained by some uncertainty, stress or distrust to the AV during the trip.

SWOT analysis of adopting autonomous private driving

Different strengths of adopting autonomous driving are identified:

- Provide accessibility to non-drivers: either young or old people, as well as physically impaired.
- Energy savings, hence less direct or indirect pollutant emissions.
- Potential to decrease the number of road accidents.
- Potential to decrease the number of parking spaces needed, freeing space for other more productive land uses (especially in areas where space is scarce, like city centers).

Also, different weaknesses of the automated driving capabilities are mentioned:

- Costs: today technology demands the installation of vehicle systems or/and infrastructure systems that are still expensive.
- Despite its potential, current technology does not lead to road capacity increase yet.
- Most of the countries do not have legislation that allows the use of autonomous vehicles on non-dedicated infrastructure. This is the reality in the Netherlands today.
- Liability in case of an accident: who should be responsible in case of a crash?
- Electronic security: there may be hacking of the vehicle management system.
- Privacy: who controls the data that is being generated and transferred between the vehicles and between the vehicle and the infrastructure?
- Limited wireless/telecom bandwidth availability for V2V and V2I communication.
- Risks in the vehicle-to-human taking over process in a partial, conditional or highly AV.
- Automation takes-off the pleasure to drive (supported by Yap and Goncalo 2015).

Opportunities of autonomous driving

- The automated driving will provide the opportunity to change the shape of our cities, mainly by allowing the municipalities to manage their territories in a more efficient way by better allocating land to more productive activities.
- Potential to increase road capacity (shorter headways) and thereby reduce congestion.

Threats of autonomous driving:

- Uncertainty on deployment staging.
- Technology investments needed for supporting the use of the automated vehicle may not be possible due to lack of funds.
- Private or public transport? The doubt may delay the use of vehicle automation at its full potential.
- Legislation changes may take more time than expected, thereby hindering the roll-up of the technology.
- The development of different regulations in different regions of the country. If there is no top-down coordination from the national government, or if regional authorities do not work together or communicate with each other when developing regulations, there is a risk that different, non-compatible regulations emerge in different countries or in different parts of the country like the Netherlands (Van Arem 2014).
- Limited budget in the Netherlands for innovation.
- Overestimation of technology capabilities, which may hinder the full adoption of automation.

3.2.3 The fully automated vehicle as a door-to-door ubiquitous shared transport mode

Impact on the mobility system

With level 4 automation comes the possibility of moving away from the vehicle ownership model to one more similar to cell phones with a subscription. This may help decrease the time that a vehicle is in the hands of the owners (Bierstedt et al. 2014), hence accelerating fleet renewal. This can be helped by the growth of car-sharing systems, which is already leading to a decrease on vehicle ownership in some countries like the USA.

Shared vehicle systems are quite relevant for the discussion on the effect of autonomous vehicles in future cities. Many researchers and practitioners foresee that having vehicles with level 4 automation means that these vehicles can be used in practice as an ubiquitous transit system that provides trips for lower costs compared to taxis (no driver needed). It is a sort of car-sharing system where the vehicle does not have to be picked-up at a specific point: the vehicle can be called, pick-up the client, and drop him off at any point. In truth a door-to-door transit system constituted by private vehicles has been a reality for many decades with the classic taxi systems, at least since people could call to ask for one at their door step. Some innovations in respect to the use of information to better manage and upgrade these systems are taking place, such as allowing for more than one service to be attended by the same taxi and handling the requests by cell phone. This is called a taxi sharing system, which benefits from optimized routing and clients matching done at a central dispatching level. Uber, a ridesharing web-based service that hires private drivers and their cars (UberX/UberPop) to supply transportation services, has recently launched the UberPool, by which a person may request a car that is already transporting someone.

Figure 3.3. Example Uber-app

These systems have been tested using simulation and results show that they are able to satisfy a great part of travelling demand in an urban area (Martinez et al. 2014). Automation can only make these systems cheaper and more flexible. Fagnant and Kockelman (2014) used the same methodology to study the implications of having a fleet of autonomous vehicles in a city for serving part of its mobility needs. They took the current car-sharing usual modal share, 3.5% of the trips, and tested different operational scenarios in their own agent-based model of a “mid-sized city, perhaps the size of Austin”. They concluded that each automated vehicle would be able to replace eleven conventional ones, but could incur in 10% more travelling to reach the next traveler in line to be picked-up (Fagnant and Kockelman 2014). Spieser et al. (2014) had the same objective. However, in their case they tested the substitution of all vehicles for automated ones for the city of Singapore. They aimed at finding the minimum fleet size for a minimum quality of service to be provided to the clients (waiting time and vehicle availability), where they concluded that with 1/3 of the total number of passenger vehicles currently in operation it would be possible to meet the total personal mobility needs of the entire population. Brownwell and Kornhauser (2013) used travel demand for the state of New Jersey and they reached the conclusion that the Smart Para-Transit model – one of the business models for a collective car-sharing system – appears to be economically viable, requiring a fleet size between 1.6 and 2.8 million 6-passenger vehicles (which is substantially lower than the current fleet size) to meet the state’s travel demand in its entirety, at a cost to consumers of $16.30 to $23.50 per person per day. Zhang and Pavone (2014) studied the replacement of the taxi demand in Manhattan for a fleet of automated vehicles, concluding that 8,000 vehicles would be enough to satisfy the existent demand (roughly 60% of the existing fleet).

When a demand-responsive shared transport system would be fully implemented on the long term, this can also have major consequences for the traditional public transport networks as we are familiar with nowadays. The exact effects are difficult to predict. However, one scenario could be that such demand-responsive system replaces a part of the current public transport lines, especially if more than one person can use such AV simultaneously. Probably especially feeder lines with lower occupancy rates and low cost coverage, requiring a relatively large governmental contribution, would be replaced by such door-to-door system. It is likely that especially the busiest public transport lines, connecting the most important activity areas within an agglomeration as the Randstad Zuidvleugel (regional train lines; metro lines), will co-exist with such shared transport system. Replacing such busy, high capacity public transport connection, which bundles many trips together, by demand-responsive, low capacity, door-to-door transport would require an enormous fleet size of AVs, which seems not likely nor desired. In that case, also the role of (regional) governments as transport authority is likely to change. It is expected that subsidies from governments are less needed for these remaining busy public transport axes. Therefore, the need for governmental intervention in public transport operation is likely to decrease. Governments as transport authority should however still formulate and guard minimum requirements for public transport operation, like safeguarding public transport accessibility for disabled people.

SWOT analysis of an ubiquitous shared transport system

Different strengths of an ubiquitous car-sharing system can be identified:

- Each vehicle is used more efficiently, since currently private cars are parked for about 80-90% of the time, and therefore used in a non-efficient way. This leads to smaller fleet sizes.
- Mobility costs reduction. A cost reduction can especially be realized if, besides sharing the time of different people with 1 vehicle, people will also share the space in a ridesharing mode.

Also some weaknesses of such system can be mentioned:

- New vehicle models needed to cope with the greater usage intensity of each vehicle, which can reduce average life span of the vehicles compared to privately owned cars.
- There will always be a waiting time for the vehicle, as little as it may be.

Opportunities when implementing such car-sharing system can be:

- Save money by scrapping classic transport systems that are currently being underused.
- Transform mobility into a service and as such make it more efficient and tailored to everyone's needs.
- Possibility of introducing much faster new cleaner vehicle technologies.

Threats for the implementation of a collective car-sharing system are:

- Opposition by traditional transport modes, especially if a certain mode has a powerful organization (such as the taxi branch).
- If the economy improves there will be probably a switch to private cars again, thereby delaying the public fleets deployment.
- No expectation of technology regarding automated operation of such a system being ready in the next 20 years.

3.3 Recommendations for the Zuidvleugel

Based on the SWOT analyses performed for different applications of automation in autonomous vehicles, we describe locations in the Zuidvleugel where promising applications might be applied. We also formulate recommendations for the Randstad Zuidvleugel how to participate.

Intelligent Speed Assistance (ISA):

- The implementation of ISA as separate module in cars is expensive. However, since currently more and more cars are equipped with cruise control, it should be aimed for to implement ISA as part of this already existing cruise control system. This can fasten the implementation process and reduce implementation costs.
- It is important to consider driver acceptance of an ISA system. Research indicates that acceptance will decrease, when the level of control of the ISA system increases. An advisory system is more widely accepted than a closed system. There is also more acceptance for a voluntary implementation strategy, compared to a mandatory strategy. However, here is a risk of a self-selection bias: drivers who need ISA the most, are least willing to use it (SWOV 2010). This can decrease the effectiveness of ISA. An interesting implementation strategy can therefore be to apply different approaches for different driver segments. A mandatory, closed ISA system can be thought of for drivers who have a history in exceeding speed limits, comparable with the mandatory construction of a so-called 'alcohol lock' in cars of drivers who did exceed drinking limits. Molin and van den Bos (2014) show that acceptance of a mandatory ISA system for speed offenders is high by drivers in general. For professional drivers, an informative or (half-)open system might be suitable.
- For the Zuidvleugel it can be interesting to support the application of ISA for local roads, where a speed limit of 30 km/h holds. Currently, it is tried to reduce drivers' speed on these roads by physical obstacles, like road bumps, which requires substantial investments. It is recommended to support a feasibility study to the implementation of ISA for these lower speed urban roads, where costs of adjusting urban space can be compared to implementation costs of ISA. Next to potential savings in adjusting urban space, this also reduces the complexity to determine the dynamic ISA speed limit, since this speed is hardly dependent on traffic flows on these roads and therefore mostly stable. AVV (2001) and Wiethoff (2003) also indicate that

ISA acceptance is largest for urban roads with 30- and 50- km/h speed limits, which can ease the implementation process.

- For the Zuidvleugel it is important to stimulate a feasibility study to ISA on urban roads, and afterwards to stimulate the implementation process. Most important hereby is facilitating the development of a central speed limit database, which is used as input for the ISA system as maximum speed at different locations and times (SWOV 2010). A gradual implementation process is recommended. By starting with urban roads with speed limit 30 km/h, with cars which are already equipped with cruise control, acceptance can be improved and starting costs can remain relatively limited. Carsten (2005) indicates that a positive benefit-cost ratio can be expected on the long term when implementing ISA. In this way, the Zuidvleugel can contribute to speed up the implementation process. Also (investing in) a narrow cooperation between governments and the project group which implements the system is recommended. An ISA pilot held in a neighborhood in Tilburg shows that such good cooperation contributed to the success of the pilot (AVV 2001).

Speed harmonization:

- The region can position itself on the first place of transport innovation on automation by supporting a pilot or first implementation of this application. An example of a road link where this could be applied is the A20 highway between the A13 and A16, which suffers from both structural and incidental congestion. The link is a bottleneck for people entering Rotterdam city and its port, and for those travelling North-South and going eastern towards Germany.

Automated parking:

- Especially in the (historic) city centers of Den Haag and Delft this can be an opportunity, since space is scarce over there and has a high value. In the near future parking lots could be created where only automated vehicles would be allowed to park. In Den Haag, currently there is one automated parking garage in operation, and one is being constructed at the moment. For the Zuidvleugel it can be relevant to investigate, in cooperation with municipalities, where such system might be an option.

Fully automated autonomous driving:

- Within the next 4 years, no substantial part of the cars will be driven fully automatically. This is because current technology and current legislation do not allow such operation.
- The deployment staging of vehicle automation is still a question mark. In general, a distinction can be made between two different approaches (Van Arem and Tsao 1997): a geographical approach or functional approach. In the geographical approach, the implementation of most (if not all) aspects of the highest level of automation (i.e., full automation) will take place in one step, while the geographical areas of implementation expand gradually. This will mean that the region of South Holland may want to position itself as one of the regions where this is going to happen. The functional approach however is based on the assumption that the functionality of fully automated vehicles cannot be realized suddenly and hence intermediate steps must be identified and optimized. An intermediate step towards full automation can be defined as any discernible increment whose realization may encounter considerable difficulties. Reality has shown already that the functional approach best represents the current development towards full automation. The different levels of automation as described in chapter 2.1 can be viewed as intermediate steps towards full automation. However, it is also possible to make a more detailed roadmap towards full automation for which the region should prepare.
- On the long term, a higher share of automated vehicles might be expected. Predicting the share of privately owned automated vehicles in the fleet is an important research topic in science. A group of members of the IEEE stated that the share in 2040 will most probably reach 75% of the fleet (http://www.ieee.org/about/news/2012/5september_2_2012.html). The Victoria Transport Policy Institute tried to answer the same question using deployment cycles, cost and adoption rates of other automotive technologies to conclude that a 50% adoption will be the most likely scenario for 2050 and that a 75% figure will only be possible by 2060. Bierstedt et al. (2014) find the latest a most probable scenario. However, they refer that benefits such as a lower accident rate may diminish with time.
  However, other scientists warn for too much optimism about the possibilities of automated vehicles (Hagenzieker 2014; Van der Bijl 2014). They mention risks especially in the phase of partial and conditional automation, where the human driver functions as supervisor of the automated system. From a psychological point of view, this role does not suit that well with

human characteristics, leading to distractions from this safety task. In such partial or conditional automation, it means that the human driver does not have to take action during the largest part of the trip. However, only during the most difficult, dangerous part of the trip, where automation cannot handle the situation anymore, the distracted driver suddenly needs to intervene directly and adequately. This is not without risks. In the airline industry, many pilot tasks have been automated the last decades. The crash of the Air France flight (AF447) from Rio de Janeiro to Paris can mainly be attributed to the inability of the pilots to take over the auto-pilot on a difficult part of the flight in an adequate manner. Also the cognitive complexity of the driving task (e.g. anticipatory behavior) leads to questions whether a 100% fully automated vehicle will be possible. Will an automated vehicle ever be able to anticipate on the risk that a child, playing near the street with a ball, will cross the street suddenly? (Van der Bijl 2014).

- However, the Randstad Zuidvleugel can contribute to pilots with fully automated vehicles. The Zuidvleugel has a tradition in different AV pilots and applications (e.g. demonstration N11; AV at port terminals; Parkshuttle; Connected Cruise Control A20) (Van Arem 2014). This contributes to the innovative climate of the Randstad and can contribute to reducing problems regarding road congestion and safety on the longer term. It must however be noted that – although the testing of AVs is allowed within current legislation (e.g. pilot AV on the A10 highway) – the exact requirements for AV testing are not that well specified. More research in this topic is therefore recommended.

An ubiquitous shared transport system:

- The realization of an ubiquitous automated car sharing system is not expected within the next decades, because this requires large technological, institutional and societal transitions.
- Although at this moment there is no technology that allows for such system to exist, nevertheless the first flexible web-based shared-ride services are coming up, with services such as Uberpool. These services lead to not only the sharing of the vehicle's time, but also its space. This will bring double efficiency while being a more flexible door-to-door mode of transport. The region can position itself as a pioneer in supporting the entrance in the market of this type of service which is not allowed in the Netherlands yet. These systems will most likely be the precursors of the future automated shared systems. In this way, the Randstad Zuidvleugel can pave the institutional road for an automated ubiquitous shared transport system.

In general, for the short term it is recommended to the Zuidvleugel to focus on facilitating the implementation process of applications where driving tasks are only partly automated. Given the current technological developments, legal and liability issues, the implementation of driver support or partial automated systems has most potential on the short term for private cars. Figure 3.4 supports this recommendation, by indicating the estimated first deployment times of different levels of automation for autonomous cars (Shladover 2015).

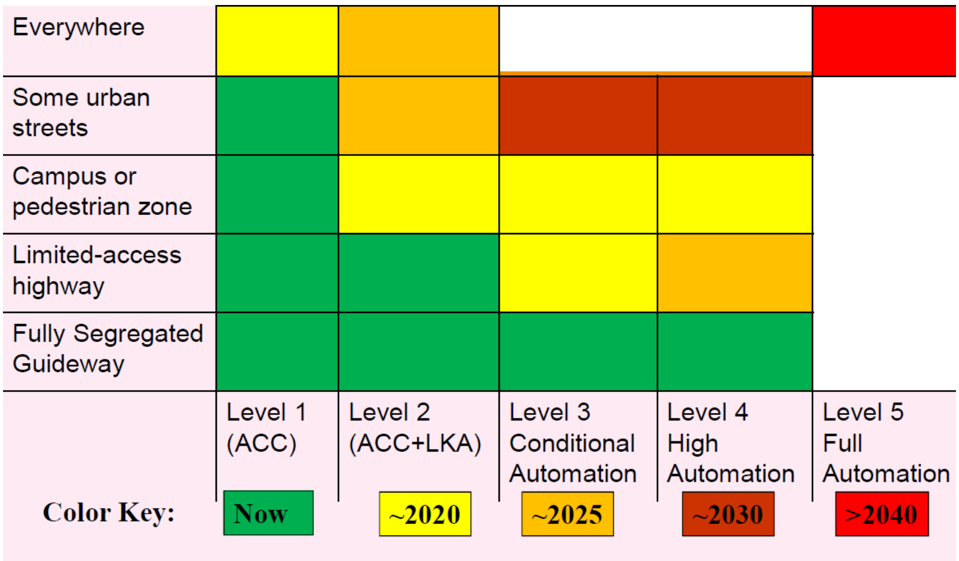

Figure 3.4. Estimated first deployment times for different levels of automation (Shladover 2015)

4 Automation and guidance in freight transport and handling

4.1 Conclusions automation in freight transport and handling

- Road transport and city distribution will contain the most innovations regarding automation and guidance in freight transport with success potential.
- The potential market for innovations is much larger for road freight transport (millions of trucks) as compared to rail or inland waterway transport (thousands of trains or barges).
- Financial resources at freight transport companies are much smaller than at passenger transport companies (such as car makers).
- Innovations in freight transportation often follow innovations which already take place in passenger transportation.
- Automation and guidance developments should lead to cost reductions or possibilities to increase sales in freight transport

Table 4.1. Summary SWOT analysis automation in freight transportation

Application	Strengths	Weaknesses	Opportunities	Threats	Possible applications Zuidvleugel
Automated truck platoons	Performance Cost efficiency Reliability Safety	Liability Implementation costs Hinder for private cars at on/off-ramp	Sustainability Replace truck drivers Less congestion	Competition from traditional road transport EU focus on intermodal transport	Between terminals Rotterdam Port Area Between flower auction Naaldwijk and Port Area Port - hinterland transportation A15
Automated city distribution	Efficient shipments Less labour costs	Technical issues Institutional issues	Scale enlargement	Electric vans and trucks Competition between modes	City centres of larger cities as Delft, Den Haag and Rotterdam

4.2 Applications of automation in freight transportation

In freight transport, both transport by different modes (rail, inland waterway, road) and terminal handling are important areas for automation (see 1-4). Two special cases are formed by complete new transport systems: fully automated, capsule oriented, underground, dedicated lanes (see 5) and city distribution in city centres (see 6):

1. Road transport and logistics (different forms of automation and guidance).
2. Inland waterway transport (different forms of automation and guidance).
3. Rail transport (different forms of automation and guidance).
4. Terminal handling (different forms of automation and guidance).
5. Complete new freight transport systems (fully automated, capsule oriented, underground, dedicated lane) (Wiegmans et al. 2010).
6. City distribution (different forms of automation and guidance).

For each of the six categories given above, several innovations and/or projects are identified over the past 10-20 years on a global scale (for a complete overview see appendix A). Out of these innovations a selection is made based upon three criteria that indicate success potential of these innovations:

1. Innovation should lead to cost reduction or sales increase in freight transport.
2. Innovation builds upon experiences gained in passenger transport (e.g. automated truck developments follow developments in automated vehicles for person transport).
3. Innovation should reduce the impacts of large problems related to freight transport (such as congestion and limited sustainability).

These three criteria indicate that category 1 (road and logistics) and 6 (city distribution) will contain the most innovations in freight transport (automation and guidance) with success potential. Innovations in rail and inland waterway do often not lead to cost reductions or sales increases. Furthermore, experiences gained in passenger transportation are often first used to test them in road freight transportation because of the 'closer' connection between road passenger and road freight transport. In addition, the potential market for innovations is much larger for road freight transport (millions of trucks) as compared to rail or inland waterway transport (thousands of trains or barges). Finally, the most urgent problems in freight transport are linked to road freight transport and to city distribution (congestion, non-sustainability).

In Table 4.2 below, for each of the six innovation categories, segments are presented that consist of different example innovations which can be found in appendix A. In the main text, a SWOT analysis is presented for the category of road transport and logistics and for city distribution.

Table 4.2. Examples of automation and/or guidance innovations in freight transport

Innovation	Automation	Guidance vehicle?	Guidance load unit?
Road transport and logistics	Trucks	Truck – truck (platoon) Truck - infrastructure	IT systems in port areas
Inland waterway transport		IT systems	Distrivaart IT systems
Rail transport	Locomotive	IT systems	IT systems
Terminal handling	Complete terminals Trailers on train Horizontal Vertical	AGVs for terminal transport	
Complete new freight transport systems	ULS (Underground Logistic System)		
City distribution			Parcel delivery Van delivery

4.2.1 Automation of trucks

The automation and guidance of trucks takes place at different levels: 1. at terminals, 2. between terminals in port areas, and 3. on highways.

1. Automatic guided vehicles (AGVs) were first used indoors in factories to transport pallets or roll-cages. In the 1990s, larger outdoor AGVs for containers were developed and taken into operation at European Container Terminals (ECT) in Rotterdam and later at the Altenwerder container terminal in Hamburg. AGVs are mostly used for short to medium distances (several kilometres) and operate at low to medium speeds (1-5 m/s). AGVs were also considered for automated underground transport systems in the Netherlands (called ULS/OLS – Underground Logistic System / Ondergronds Logistiek Systeem) and for inter-terminal transport connecting the different automated terminals of ECT in the port of Rotterdam and the Rail Service Centre (RSC).

2. Although not (yet) automated, developments in Multi-Trailer Systems (MTS) could also be of interest. MTS systems have been in use for many years within the port area. Some trials also proved the technical feasibility of automated MTS, where one automated guided vehicle (AGV) pulled a set of five trailers. Preliminary studies show that using manned MTS systems on the roads at night could help reduce the congestion problem, and could save up to 30 percent on transport equipment costs and up to 75 percent in labour costs. However, one of the main concerns of using MTSs on public roads is the safety of other road users.

3. Most innovations in road transport consist of small gradual improvements (e.g. adaptive cruise control). However, there are also developments towards (fully-) automated trucks (without a driver). Automated trucks can be used to transport semi-trailers with containers or swap bodies and can cover long distances at relatively high speeds (comparable with conventional trucks). A considerable advantage of an automated truck is the labour cost savings. But, so far, no automated trucks are in operation. Several projects have been focusing on designing and testing automated trucks: i) EU-project Chauffeur (1996-1998, Daimler Chrysler); ii) Dual Mode Truck (PWRI, Japan); iii) ACTIPOT (METRANS, USA); iv) Combiroad (1994-1998, Hollandia, Terberg and Traxis); v) PATH (University of California, USA); 6; European project SARTRE; (Safe Road Trains for the Environment, since 2009); and 7) Energy ITS backed by Japanese government and Japanese universities, since 2007). *Combiroad* was a concept for an automated road transport system, developed in order to accommodate as shuttle between large container terminals and the hinterland terminals. The system enabled the automated driving on adapted 'secured' infrastructure, but with a driver it could also be used as a traditional truck in order to do the pre- and end-haulage. The concept was developed by Hollandia and DHV. The advantages for potential users were however too limited and insufficient attention has been paid to finance and market distortion.

A SWOT analysis is performed for the application of an automated truck platoon (Figure 4.1). The strengths of the truck platoon could be: superior performance as compared to trucks outside platoons, cost efficiency by saving fuel and driver cost, higher reliability and safety through the central and controlled driving. Weaknesses of the truck platoon could be: responsibility and liability issues in case of accidents and other problems that might occur, high cost of the new system to be implemented, lack of manufacturing efficiency when the new system is introduced, and the concept of truck platoons is already quite old and fits into past innovation failures (why would it be successful?). Besides, a platoon of trucks might have negative effects on private cars at on /off-ramps. It is unknown to which extent such platoon on the right lane can hinder a private car which wants to take an off-ramp or drives on an on-ramp. Opportunities that truck platoons might offer are: it could replace truck drivers if the trucks following could be implemented without a truck driver, sustainability might increase by more fuel efficient driving (5-10%: Knight 2014), it could reduce congestion (Minderhoud 1999, Minderhoud and Hansen 2002, Minderhoud 2011). Threats for truck platoons could be: accidents and liability issues could limit its potential, governance (in Europe) favouring intermodal transport, traditional road transport could lower its prices to drive the initiative out of the market.

Figure 4.1. Platoon of automated trucks (Knight 2014)

4.2.2 Automation of city distribution

Automation and guidance in city distribution is of a relatively limited level as compared to automated driving in cars (or trucks). In general, city distribution refers to the final leg in a business to consumer (B2C) delivery service whereby the consignment is delivered to the recipient, either at the recipient's home or at a collection point (see also Figure 4.2 below).

Different network types exist to organize city distribution. First, in ‘traditional’ city distribution networks the products are transported by transport companies from the manufacturer to the distribution center owned by the online retailer. From this distribution center the online orders are delivered to the customer by using a dedicated parcel delivery company (UPS, PostNL etc.). An alternative city distribution network type is ‘van delivery’. An online retailer can choose to deliver the goods directly to the customer with their own delivery van (or van fleet). Two recent developments are important in city distribution: 1. urban consolidation centers and 2. pick-up points. An *urban consolidation center (UCC)* is a logistics depot that is situated on the outskirts of the city area it serves, from which it bundles freight deliveries for that area for (a) certain type(s) of goods flows and which enables efficiency gains through a more optimal organization of long-haul & short-haul (‘last-mile’) transport. The UCC operator sorts and consolidates the loads from a number of logistics companies and delivers them, often using environmentally friendly vehicles (e.g electric vans with solar power panels). A *pick-up point* is a small location where the online retailer delivers the packages for customers in a certain region and the costumers can pick up their package themselves at this location. Pick-up points are generally located in easily accessible/central locations (e.g. supermarkets) to improve accessibility of the customer.

Strengths of city distribution could be: shipments into city centres can be made more efficient; city distribution leads to less emissions; city distribution might also result in less trucks in the city centre (and thus more safety); city distribution might offer cost savings to its customers. Weaknesses of city distribution might be: so far it proves difficult to realize city distribution in a profitable way;

subsidies appear to be needed; optimal city distribution might benefit from 1 supplier, but in general, more suppliers might be expected. Opportunities of city distribution might be found in scale enlargement (connecting more areas such as Delft, Den Haag and Rotterdam). Threats for city distribution are competition between different alternatives leading to less cost savings and less efficiency; and vans and trucks all being electrified leading to decreasing pressure for consolidation of packages through city distribution models into city centres.

Besides these more general characteristics of city distribution, automation of city distribution can also be characterized. An additional strength of automation of city distribution is the savings of labour costs. Additional weaknesses are the current technological and institutional limitations. For regular passenger road traffic it is technically not possible yet to apply fully automated vehicles in mixed traffic. For (small) vans it is expected that these technical limitations are at least as relevant as for passenger road transport. Also, AVs in mixed traffic are not allowed yet within current legislation in the Netherlands. Therefore, automation of city distribution is not something which can be realized within the next few years. However, preparations can be made to pave the road for such application on the more long term.

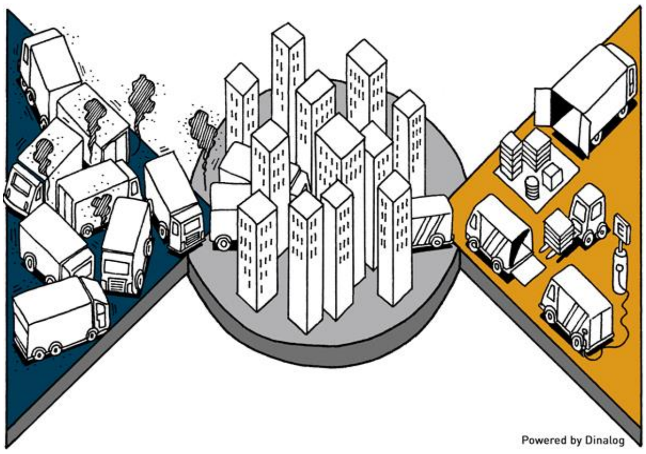

Figure 4.2. City distribution (http://www.dinalog.nl/en/projects/r_d_projects/4c4d__city_distribution/)

The reader is referred to appendix A for a description of different applications of automation in freight transportation systems.

4.3 Recommendations for the Zuidvleugel

Based on the SWOT analyses performed for different applications of automation in freight transport, we describe locations in the Zuidvleugel where promising applications might be applied. We also formulate recommendations for the Zuidvleugel how to participate.

4.3.1 Recommendations regarding automated truck platoons in the Zuidvleugel

In the Zuidvleugel of the Randstad area, three cases can be observed where truck automation and guidance might play a role: 1. between terminals in the Rotterdam Port Area; 2. between the flower auction Naaldwijk and the port area (or between Aalsmeer and Naaldwijk); and 3. hinterland transportation via the A15 highway in truck platoons.

Currently, automation of trucks is only applied on terminal area of the Port of Rotterdam. Because of the private infrastructure and because of already gained experiences with AVs, these terminals are promising locations for new applications. When these applications are sufficiently developed and tested, it is expected that these automation concepts will move outwards from the terminal areas towards hinterland applications. Especially the A15 highway is an important road for the application of automated truck platoons, given the current congestion levels and high share of trucks. Automated truck platoons also have potential as a 'greenport – mainport' connection between the Westland (e.g. flower auction Naaldwijk) and the Port of Rotterdam. Currently, perishable goods from the Westland (like fruit, vegetables, flowers) are mainly transported via Schiphol Airport by aircraft, given the high time value of these goods. However, special containers are currently becoming available which are able to keep those goods in better condition during transport. Therefore, the expectation is that transport of these perishable goods will partly shift from Schiphol Airport to the mainport Rotterdam, since the time value of these goods decreases (Van Arem 2014). This can be an opportunity for applications of automated truck platoons between the Westland and the Port of Rotterdam. For the part of the flowers from the Westland which will still be transported via Schiphol, application of automated truck platoons between the Westland and Aalsmeer can also be interesting.

The timeline for an application of a form of 'an automated truck' on Dutch motorways could be envisioned in the medium term (10 years from now). Automated cars are tested now and if successful, this could be transferred to trucks as well. However, with automated trucks, new challenges will arise that must be solved. In the next five years, a close connection with developments in automated cars could be developed. Furthermore, a freight coalition of the willing could be sought for by the Zuidvleugel and a first study into possibilities and feasibility could be done. Here, the effect of truck platoons on hindrance for cars to/from on/off-ramps should be incorporated explicitly.

4.3.2 Recommendations regarding automated city distribution in the Zuidvleugel

In the Zuidvleugel area, especially the larger cities such as Delft, Den Haag, and Rotterdam might offer opportunities for the introduction or growth of city distribution models. Also cooperation between those three large urban areas might offer opportunities to further increase the efficiency and sustainability of city distribution. Delft already knows the initiative 'Tailored Distribution Delft', where a number of partners cooperate to make shipments to Delft more efficient and greener (Livinglabs Delft 2014). In Den Haag and Rotterdam, currently city distribution appears to be less in focus of authorities, as no operational initiatives could be identified (by desk research). The automation and guidance in city distribution is more concentrated in intelligent software than in automated vehicles. Participating in such an initiative might be interesting for the Zuidvleugel in order to investigate or extent this topic further for the Randstad Zuidvleugel, or to increase attention / awareness of municipalities to this topic.

City distribution is an issue where a short term (1-5 years) could be envisaged. Important conditions in city distribution are a 'pressing sustainability' problem in the city centre and the willingness of a municipality (or a combination of municipalities, such as Delft, Den Haag and Rotterdam) to financially contribute for a longer period of time (maybe even infinite) to the city distribution initiative. For the municipality the trade-off is a financial contribution to the urban consolidation centre in exchange for more sustainability.

5. Automation in public transportation

5.1 Conclusions automation in public transportation

- High or full automation applications have on the short term only potential on separated infrastructure (like metro or light rail lines), due to technical and institutional limitations.
- For urban tram and bus lines automation can function as driver support, thereby realizing a positive human-machine interaction. No high or full automation is expected on the short term.
- It is interesting to form a coalition of stakeholders to investigate possibilities for a pilot for an automated transport connection between RandstadRail stop Meijersplein and Rotterdam-The Hague Airport.

Table 5.1. Summary SWOT analysis automation in public transportation

Application	Strengths	Weaknesses	Opportunities	Threats	Possible applications Zuidvleugel
Automated metro and light rail lines	Capacity Punctuality Service quality Fleet size Operating costs	Investment costs Platform protection	Aging of drivers New innovation climate	Public acceptance Acceptance by unions/drivers Unreliability	Rotterdam metro network RandstadRail Den Haag Central – Zoetermeer / Rotterdam
Automated urban tram and bus lines	Punctuality Operating costs Service quality	Technical issues Institutional issues	Automation as driver assistance	Acceptance when machine failure occurs	-
Automation of feeder to main public transport	Improve door-to-door transport Flexibility Demand-driven	Separated infrastructure Investment costs	Areas with low PT supply level and high activity level	Demand overestimation Costs under-estimation Attitudes AV	Connection Meijersplein – Rotterdam-The Hague Airport
Automation with Personal Rapid Transit (PRT)	Improve door-to-door transport Walking time Waiting time	Technical issues Institutional issues Separated infrastructure	Internal transport	(Perception of) safety Costs	-

5.2 Applications of automation in public transport

5.2.1 Automation of main public transport lines

Automation of metro lines

Automated metro operation is the new standard for new metro lines almost everywhere in Western Europe and south-east Asia (for example the Meteor in Paris, the Docklands in London, the VAL in Lille, Singapore, Dubai). Since metros have 100% segregated infrastructure without any interaction with other traffic, automation is no problem from a technical perspective. Recently, even transformation of an old manual operated metro line to driverless operation is performed in Paris. Here, the oldest and busiest metro line 1 is currently operating automatically, while during the transformation process metro operations were hardly disturbed (TrackTalk 2014). In London, there are now plans to transform manual operated metro lines to automated operations as well. In case the deep Tube lines would be automated, probably there still has to be a driver on board for emergency evacuations, just like the Jubilee, Victoria and Central line now (high automation level) (Begg 2014). However, in the undisturbed situation this driver could provide information and service to passengers.

There are different strengths of automated metro operation. Automated metros can have shorter headways, since acceleration and braking profile are determined and executed in an optimal way. For the transformed metro line 1 in Paris, the minimum headway decreased from 105 to 85 seconds after automation, meaning that the capacity increased by 24% from 34 to 42 metros per hour per direction. Besides, fewer vehicles are required on high frequency routes. For Paris, the required fleet size decreased from 52 to 49 (TrackTalk 2014). Also, because of the optimal calculated speed profile, punctuality and reliability increase. When a driver is not necessary anymore, or only required for emergency situations, this driver can provide better service to passengers by giving information, helping passengers and contributing to the perceived safety by ‘showing your face’. Also, for driverless metro operation there is a high flexibility to adjust supply to peaks in demand. If it is busier than expected on a certain route, extra metros can be put into service by one ‘push on the button’. Currently, additional metro services need to be planned weeks ahead because of personnel scheduling complexity.

Weaknesses are mainly related to the costs of constructing an automated metro line. Especially when a manual operated metro lines is being transformed to automated operation, there can be substantial costs for adjusting the vehicles and signaling system. Often, there are also costs related to platform adjustment (platform doors), although this protection is not applied to all automated metro or light rail systems (SkyTrain Vancouver; Copenhagen: Figure 5.1). There can be parts of the line which are hard to transform, since originally the possibility of automation was not considered. For example, in Paris there were a few stations located in a curve, where it is hard to apply platform doors in a safe way.

Figure 5.1. Automated metro in Copenhagen without platform doors (http://metroautomation.org/wp-content/uploads/2012/12/25-Copenhaguen-Train-General_view.jpg)

Opportunities are related to aging in western societies, as in the Netherlands. This means that the percentage of older workers is relatively high at public transport operators. For example, more than 50% of the tram drivers of HTM (the urban public transport operator of Den Haag) are 55 years or older (Tros and Rodrigo 2014). Given the expected retirement of many of these workers, there are opportunities to automate parts of the network the upcoming years smoothly. Another opportunity is that the innovation climate for public transport operators increases again. Last years, many public transport operators were confronted with budget cuts and discussions about liberalization of the public transport market. This uncertainty did not stimulate an innovative climate for operators regarding investments relevant for the longer term (e.g. the next 20-30 years).

Three possible threats can be expected when automating metro lines. First, it can be questioned whether there will be public acceptance when a metro is driven automatically. Since automated metros are applied in many cities worldwide, based on experiences from these cities it can be concluded that passengers accept this from a safety point of view. However, it might be important to show the public what they get 'in return' for this automation. Emphasis on the higher quality of public transport which can be achieved (higher frequencies, punctuality and reliability) is important, in order to prevent a public perception that driverless operation is only a matter of cost-cutting (Tros and Rodrigo 2014). Also the level of automation can be of importance here. For public acceptance it can make a difference whether there is a 'high automation level' (where a driver is still on board for emergencies) or a 'full automation level' (with no driver on board at all) (see Table 1.1). For example, even in aircraft a high automation level is widely accepted by the public. However, full automation without pilots in the cabin would probably not be accepted by passengers.

Second, a threat can be that drivers and unions do not accept the replacement of human jobs for automation. It is important to be careful that support of drivers is not lost, because they lose their jobs. Experiences in other parts of the world however show that there are possibilities to mitigate this threat. In Paris for example, all metro drivers of the transformed line 1 were able to work as service worker with hold of salary, thereby reducing resistance from drivers. Only for new service workers a more modest salary was applied (TrackTalk 2014). In Barcelona, this threat has even been turned into an opportunity (Van Arem 2014). There, a policy was applied that a new job was offered to all old drivers, where they partly had to work as service worker, partly as dispatcher and partly as controller in the vehicles. In that way, the original job of driving has been turned into a more varying and challenging job, which was supported by the drivers and unions. Besides, transparency to drivers about the quality objectives of automation is important. In Paris, even some young drivers supported the transition to automation after the necessity of it from a passenger perspective was explained to them (TrackTalk 2014). A stepwise transition towards automation, partly following the aging pattern within a company, can also contribute to more acceptance from drivers.

A third threat might be the system reliability. There are examples in the Netherlands where automated systems sometimes react 'too safe', leading to hindrance for travelers, like the newly opened Coentunnel, the A73 tunnel and the Schiphol train tunnel. It is important that the frequency of 'false alarms' remains limited, to prevent that the public loses trust and acceptance.

Automation of light rail lines

Automation of (parts of) light rail lines is also a possible application of automation. Here, we only focus on automation of the parts of a light rail line where there is segregated infrastructure without interaction with other traffic. When considering the automation of light rail lines, in general the same strengths, weaknesses, opportunities and threats hold as for automation of metro lines. In the Netherlands, light rail services are usually operated with a high frequency. Although passenger volume is often not as large as in metro lines, benefits from more capacity, higher flexibility and enhanced punctuality and reliability can also be achieved for light rail systems. Both metro and light rail systems are operated on segregated infrastructure, but metro infrastructure is always elevated or in tunnels. Light rail infrastructure is often built at grade level. This means that it can be necessary to realize more track protection also *between* stops, compared to metro systems, to prevent the possibility that people cross the tracks on non-allowed places. Compared to metro systems, such extra protection might lead to additional costs.

Automation of urban tram lines

Another application of automation in public transport can be the automation of urban tram lines. Strengths are a higher punctuality and reliability, and savings because of reduced labor-costs.

Two important weaknesses are identified. First, currently the technology of automated driving within mixed traffic is not sufficiently developed yet. Currently, uncertainty exists how to create a fail-safe system within the urban areas. For example, what happens if a sensor is blocked by a leaf during autumn? It is even argued that full automation within mixed traffic is not possible. This is because of the complexity of the cognitive driving task. A human driver can for example anticipate on possibly upcoming dangerous situations based on his or her experience. It is questionable whether a machine can ever realize the same cognitive performance as required for driving within mixed traffic (Van der Bijl 2014). Second, if it would be possible to design a fail-safe automated system, it is questionable if speeds would not become very low in busy areas like a city center or pedestrian areas. We can conclude that a high or full level of automation in urban tram lines is not expected in the near future.

An opportunity for urban tram lines can be the application of automation as driver assistance. Automation can support the driver with a faster and more efficient boarding regime, thereby increasing punctuality. The driver is then still responsible for driving the vehicle through the traffic. In this manner, a positive human-machine interaction can be realized. This is more in line with the current role of automation in urban public transport. For example, currently HTM drivers get information about their punctuality on a 15-seconds detail level (Van Oort and Van Nes 2009). Then drivers can respond to this information.

An important threat is that human failure is more accepted by public than failure of automation. When a tram or bus driver gets sick unexpectedly during driving, this can of course lead to passengers getting hurt or even killed. However, to a certain extent the public realizes that there is a very small probability that such thing can happen. On the contrary, if an automated tram would hurt or kill someone, probably no one will accept this. This means that there is a substantial risk regarding public acceptance: if one accident happens, the implementation of automation will be delayed for years (Tros and Rodrigo 2014).

Automation of bus lines

A high or full level of automation of bus services within mixed traffic is not expected in the short and medium term future. Compared to urban tram lines, the driving task of a bus driver is even more complex because of both longitudinal and lateral control. Also, capacity benefits are expected to be less than for tram lines, because bus lines are often operated at lower frequencies. On the other hand, for bus services costs of the driver contribute more to the total operation costs compared to tram or light rail services. This means that from a cost-cutting perspective, automation of bus services has a relatively high potential.

In literature opinions about automation of bus services differ. Although it is mostly agreed on that high or full automation is not expected the next years, some expect that this can happen on the long term (Maartens 2014). Some expect that partial automation can be applied to bus services as well, for example to support bus parking at stops. However, history shows that even driver support for parking at bus stops was a failure for the Phileas busses in Eindhoven: this application has not really been used (Van der Bijl 2014). May (2009) shows in a simulation study that using automated busses on major routes between suburbs and city centers, or between a major facility (like an airport) and the city center had a negative cost-benefit ratio for cities like Trontheim, Vienna, Tyne and Wear and Madrid. We therefore conclude that the role of automation in bus services is uncertain: if there is some role for automation, only a limited role is expected.

5.2.2 Automation of feeders to main public transport lines

Automation in the area of public transportation can also be applied to transport which functions as feeder to busy, main public transport lines. This feeder function can have two different types of applications. First, such automated feeder transport can be applied in rural, low density areas where cost coverage of conventional public transport is low. Second, such feeder can be a connection between a public transport station or stop and an area with a high activity-density which is not directly located near a public transport stop (like a business area, shopping mall or airport). As mentioned above, a high or full automation level is not expected in mixed traffic operations within several years. The second application has as advantage that the route is more fixed: there is one public transport stop and one area with a high activity-density. This enables the use of dedicated infrastructure without losing too much of its flexibility, at least until technology is more developed. For the first application, destinations are more dispersed over a larger area. Using dedicated infrastructure is then not straight forward and leads to high costs and/or loss of flexibility of the system. Therefore, the second type of application has more potential to be realized the upcoming years. Especially in an area like the Randstad Zuidvleugel with a high density, this second applications seems to have more potential.

Strengths of automated feeder transport to/from important public transport lines are mainly related to improving door-to-door (D2D) transport, thereby increasing the attractiveness of the total multimodal chain. Also cost cuttings can be realized if this feeder / last mile transport is operated driverless.

May (2009) shows in a simulation study that such a new feeder system is not financially feasible in cities with a high public transport patronage, good public transport quality and relatively low fares (like Vienna). In areas with higher public transport fares and in areas with relatively low public transport quality, such feeder service by AVs or PRT (Personal Rapid Transit) systems to conventional high speed or high quality PT can be promising. Van Arem (2014) also indicates the potential of such feeder systems in areas with limited public transport supply, and also with no extreme public transport demand (else, economies of scales can often be realized with a conventional bus or rail system). From an institutional perspective, it is currently only allowed to operate fully automated vehicles on totally separated infrastructure. Applications can for example be found in Singapore, Tokyo and Rennes. This means that within current regulation, automated vehicles as access/egress between a main PT stop and area with a high activity-density have most potential to be realized.

Two threats hereby are demand overestimation and costs underestimation. First, in many studies demand for AVs as feeder for public transport is overestimated, since the transfer between AV and conventional public transport is not mentioned explicitly to respondents. This means that the disutility gained from waiting time, walking time and transfers tends to be underestimated in these studies (Thompson and Brooks 2010). O'Toole (2014) therefore mentions that especially in non-congested areas the competitive advantage of such last mile automated transport remains limited. A recent study to the role of AVs as last mile transport, where the total door-to-door (D2D) trip including its transfers is incorporated explicitly in the survey, also shows a lower potential than when these transfers are not incorporated in the survey (Yap and Correia 2015). Second, it should be realized that investment costs of an automated feeder service which requires 100% separated infrastructure are high. History also shows that such ideas failed because of costs, like the plan to connect the train station of Eindhoven and the university campus by AVs (Van der Bijl 2014). For a feeder system from an area with a high activity-density to a public transport stop on its own it is hard to get a financial sound business case. However, when such system is incorporated in a total business case of such an area (like the business case of a business area or airport), there can be potential from a financial point of view (Van der Bijl 2014). A third threat is underestimation of psychological factors, like attitudes of travelers against AVs. Recent research shows that attitudinal factors, like trust in AVs and reliability of AVs, belong to the most important aspects influencing AV demand. Therefore, sufficient attention should be paid to make sure that these attitudinal aspects are not an issue for users. Else AV demand can be overestimated substantially, despite its instrumental characteristics like travel time and cost.

5.2.3 Automation by Personal Rapid Transit (PRT) systems

Different applications of using an automated Personal Rapid Transit (PRT) system are investigated in literature. The idea of PRT systems is that they can compensate for the negative properties of conventional public transport, since PRT systems can provide door-to-door (D2D) transport, are demand-driven and flexible (compared to supply-driven, scheduled, stop-to-stop transport of conventional public transport). This shows that PRT systems in theory have potential to supply transport with less waiting times and walking times compared to conventional transport. Different applications are shortly discussed.

Janse and Ockhuijsen (2014) mention the benefits of demand-driven fully automated PRT. The disadvantage however is that integration of these PRT systems in mixed traffic is currently not possible (technical problems) and not allowed within current regulation (institutional problems). For implementation on the short term, dedicated infrastructure is required. The use of dedicated infrastructure does however not fit with the principle of delivering flexible door-to-door transport. This means that the role of PRT in supplying a full door-to-door trip will remain limited the upcoming years.

May (2009) mentions the application of PRT to connect inner city facilities. An issue related to inner city transport is the high pedestrian crowding levels. In order to design a fail-safe system, it is expected that operational speed will be very low.

Another application of PRT is the replacement of conventional public transport at moments with low demand in time and space. For example, one could think of replacing conventional public transport on a quiet bus line during evening hours by PRT. Three threats can however be distinguished (Tros and Rodrigo 2014). It is questionable whether many small vehicles will be cheaper than a few conventional busses. When providing door-to-door transport with PRT vehicles with a capacity of 4-6 persons, it is likely that a quite high number of vehicles is required in order to reduce waiting times. Second, the perception of safety by passengers especially during evening hours can be a threat. Traveling in an almost-empty tram or bus during evening hours is usually experienced as inconvenient already. However, when a passenger has to travel in a driverless, small vehicle, the (perception of) safety is likely to decrease in such way that demand might decrease as well. Third, public transport operators mention the relevance of supplying public transport with a comparable quality level. For passenger perception it might be strange if only during evening hours one part of a line is very modern with automated transport, whereas passengers have to use an 'old bus' later in that same trip or during other periods of the day.

At last, PRT systems can be applied for internal transport in buildings or areas, like internal transport between campus buildings, hospital buildings, airport terminals or within a shopping mall. Successful examples can already be found at London Heathrow airport, where terminals are connected by PRT (Figure 5.2), and in Masdar (Abu Dabi), for internal transport in a large shopping mall (2getthere 2014). Also for these cases, the PRT is part of a larger business case (Van der Bijl 2014).

Figure 5.2. PRT system in use at Heathrow Airport (http://www.arup.com/Projects/Heathrow_Personal_Rapid_Transit_PRT.aspx)

5.3 Recommendations for the Zuidvleugel

Based on the SWOT analyses performed for different applications of automation in public transport, we describe locations in the Zuidvleugel where promising applications might be applied. We also formulate recommendations for the Zuidvleugel how to participate.

Automation of metro lines:

- Applications of automated metro are mainly relevant for the busiest metro tracks in Rotterdam. Here, capacity problems are most dominant, indicating that automation has potential to reduce these problems. Automation then can improve accessibility and better align urbanized regions and accessibility by facilitating borrowed size.
- Some metros in Rotterdam are currently already able to change track at the terminal station automatically, without driver. Although we are not familiar with details, it is interesting to investigate whether automated driving would technically be possible in current Rotterdam metros. For example, the new M5 metros in Amsterdam can technically drive either with or without driver.
- In case of automation of this metro system, high or full automation would be the most relevant level given its fully segregated infrastructure.

Automation of light rail lines:

- Currently, most capacity problems are on the RandstadRail light rail track between Den Haag Laan van NOI and Leidschenveen, where both the HTM and RET light rail services are operated. Currently it is not possible to increase the frequency here because of capacity limitations, although the current demand would justify a further increase in frequency.
- These capacity problems can be a trigger for regional governments, transport authorities and public transport operators to investigate how automation could improve this capacity and against which costs.
- For automation on the RandstadRail line, it is recommended to consider only on the track between Den Haag Central Station and Zoetermeer / Rotterdam, since there is a fully separated track without interactions with other traffic.
- If automation can be feasible here, a stepwise approach is recommended. One could start with a pilot where a driver is still within the vehicle for emergencies (high automation), or even in the cabin (partial or conditional automation).

Automation of urban tram or bus lines:

- Given the technical, institutional and societal issues and uncertainties regarding automation within urban areas with mixed traffic, no recommendations are provided to investigate in (more research regarding) these applications the next years.

Automation of feeders to main public transport lines:

- Given current institutional limitations it is recommended to focus on applications where feeders connect a public transport stop with an area with a high activity-density. An currently existing example is the ParkShuttle between public transport / Park&Ride station Kralingse Zoom and business area Rivium (Figure 5.3).
- Within the Zuidvleugel, the connection between RandstadRail stations Meijersplein and Rotterdam-The Hague Airport can be interesting. Currently, public transport supply to this airport is limited. Given the short distance (1.5-2.0km) between airport and RandstadRail stop in relatively rural area, the realization of dedicated infrastructure can be feasible from a financial and spatial perspective. By this connection, an attractive and fast connection to the RandstadRail to both Den Haag and Rotterdam can be provided. In this way, urbanization and agglomeration are better aligned, which can increase agglomeration power.
- It is therefore recommended to form an alliance with involved stakeholders (like municipalities, HTM, RET, TU Delft, businesses around the airport) to investigate possibilities of AVs on this route. An institutional opportunity hereby is enthusiasm of amongst others HTM and the TU Delft to join in such alliance. A pilot can be an interesting option here.

Automation with PRT:

- For internal transport between the parking places and the terminal of Rotterdam-The Hague Airport, a PRT system might be an alternative. A comparable system has been applied to Schiphol Airport in the past.

Figure 5.3. ParkShuttle PRT system between Kralingse Zoom and business area Rivium (http://www.cybercars.org/c-ParkShuttle2-Rivium.html)

6. Combined applications of automation

In chapters 3-5, applications of automation for autonomous private vehicles, freight transportation and public transportation are discussed. There are also combined applications of automation, which influence two of these sectors simultaneously. In this chapter we shortly address some of these combined applications. A more extensive investigation to these combined applications is however recommended.

Example combined application of freight and public transportation: CargoTram

In Dresden and in Zurich, CargoTrams are operated which transport certain freight products (car components of VolksWagen in Dresden; glass, electronics and waste in Zurich) (Figure 6.1). Also for Amsterdam there were plans to use a CargoTram for city distribution, in order to replace some trucks in the inner city. This can improve the sustainability of transport, and therefore the quality of life in a certain area. The CargoTram project in Amsterdam was however not realized because of financial problems. These examples however show that automation can also play a role in these combined applications. When partial or a higher level of automation would be applied on urban tram lines on the longer term, is can be worthwhile to consider these freight applications as well, next to applications to public transport for passengers.

Figure 6.1. VolksWagen CargoTram Dresden (http://www.billiger-autofahren24.de/tag/dresden/)

Example combined application of freight and public transportation: town luggage check-in

In Hong Kong and Dubai it is currently possible for airline passengers to check-in their luggage in the city center between 90 minutes and 24 hours before flight departure, a so-called 'town luggage check-in'. Luggage in then transported autonomously to the airport, so that passengers do not have to worry about their luggage in the trip to the airport. For improving the attractiveness of the trip to/from Rotterdam-The Hague Airport, the Zuidvleugel can consider such approach as well. Trip attractiveness increases by improving the last mile transport to the airport, for example by the operation of an automated Personal Rapid Transit (PRT) system between RandstadRail stop Meijersplein and the terminal, but also because passengers do not have to carry their luggage in this trip (Derksen et al. 2014). Such combined, integral approach has potential to increase agglomeration power of the Zuidvleugel, by really improving airport accessibility. Besides, it can be investigated if a certain level of automation can play a role for the luggage transport between town and airport.

Example combined application of person and freight transportation: PRT and FRT

Next to the Personal Rapid Transit (PRT) vehicles, also developments regarding Freight Rapid Transit (FRT) vehicles take place. 2getthere has for example developed a fully automated flatbed freight vehicle, which can be used to transport containers for general cargo, waste or perishable goods up to a load of 2 EURO-pallets (2getthere 2014). It is also indicated that PRT and FRT vehicles can be operated together in mixed operation on the same network, as long as driving characteristics (speed, acceleration and deceleration) are similar. For internal transport, like transport within a shopping mall, , or between different buildings of a hospital, FRT systems and PRT systems could be used simultaneously. This can be interesting since, next to person transport, freight transport is usually an important aspect when considering hospitals or large shopping malls.

7. Conclusions and recommendations

We can conclude that a variety of (developments of) applications of automation exist in the Netherlands and worldwide regarding autonomous vehicles, freight and public transportation. In our study, our aim is to analyze strengths, weaknesses, opportunities and threats related to different applications, in order to get insight in applications which have potential to be implemented in the Randstad Zuidvleugel. In our analysis, we considered these applications strictly from a demand-driven perspective: each application is analyzed based on its functional ability to contribute to more agglomeration power of the Randstad Zuidvleugel, which in turn can improve the competitive position of the Randstad Zuidvleugel relative to other European metropolitan areas.

Based on our study, we provide different recommendations to the Randstad Zuidvleugel regarding its contribution in these developments.

Automated last mile transport to/from Rotterdam-The Hague Airport:

- The accessibility of Rotterdam-The Hague Airport by especially public transport is currently suboptimal. For this airport, the current (public) transport accessibility is not in line with the level of urbanization/activities around the airport and the important regional function of the airport. This means that improving accessibility of the airport can increase agglomeration power and the competitive position of the Randstad Zuidvleugel.
- It is therefore recommended to use the connection to/from the airport as pilot where innovative concepts of automation are tested. This leads to new insights in characteristics, strengths and improvements of automated transport systems. It also contributes to the innovative character of the region and can lead to better accessibility of the airport. Given our analyses, we recommend to focus on the last mile transport connection between RandstadRail station Meijersplein and the airport terminal for this pilot.
- It is therefore recommended to the Randstad Zuidvleugel to form an alliance with involved stakeholders (like municipalities, HTM, RET, TU Delft, businesses around the airport) to investigate possibilities of automated vehicles as pilot on this route.
- Optional, luggage transport to/from the airport can also be considered in this pilot, for example by integrating a (partly automated) town luggage check-in system in the experiment.

Intelligent Speed Assistance (ISA) on urban roads:

- One of the most important policy goals of (regional) governments is improving safety of transportation. Reducing accidents on urban roads, especially on roads with a speed limit up to 30 km/h or 50 km/h where car traffic heavily interacts with weaker traffic participants like cyclists and pedestrians, is one of the most important objectives of governments.
- Intelligent Speed Assistance (ISA) systems are a means to improve traffic safety by informing, warning, intervening or overruling a car driver if he/she exceeds the local speed limit. Therefore it is recommended to the Zuidvleugel to support and stimulate a feasibility study to the implementation of ISA on urban roads. This can give insight in the effects of such system on traffic safety and allows comparison of implementation costs of ISA with costs of currently taken speed-reducing measures on 30 km/h roads, like physical barriers as road bumps.
- In case of positive results of the feasibility study, it is recommended to the Zuidvleugel to stimulate the ISA implementation process. Most important here is facilitating the development of a central speed limit database, which is used as input for the ISA system as maximum speed at different locations and times. A gradual implementation process is recommended. By starting with urban roads with speed limit 30 km/h, with cars which are already equipped with cruise control, driver acceptance can be improved and starting costs can remain relatively limited.
- Before and during the implementation process, a narrow and continuous cooperation between governments and the project group which implements the ISA system is recommended.

Automation on the A20 highway:

- The A20 highway around Rotterdam (especially between the A13 and A16) suffers from heavy congestion, which is caused by structural causes (traffic demand exceeds the available capacity) and by non-structural causes, like accidents or 'kijkersfiles' on the road opposite to the road where the accident took place. Congestion on the A20 leads to reduced accessibility of the region for both persons and freight (to/from the Port of Rotterdam), and reduces the level of sustainability. All aspects reduce the competitive position of the Randstad Zuidvleugel.
- Speed harmonization generates appropriate response plans and speed changes / recommendations for traffic, in order to smooth the traffic flow in case of traffic congestion, bottlenecks or incidents. We therefore recommend to investigate how automated speed harmonization (Vehicle-to-Infrastructure) can reduce congestion levels.
- The Randstad Zuidvleugel can position itself on the first place of transport innovation on automation by supporting a pilot or first implementation of automated speed harmonization on the A20, in cooperation with other involved stakeholders (e.g. Rijkswaterstaat, TNO, TU Delft).

Automation of truck platoons between Mainport and Greenport:

- Automated freight transport currently occurs only on dedicated terminal areas of the Port of Rotterdam. However, congestion levels on the A15 highway as main road connection to the port can reduce the competitive position of the port and the region as a whole. Therefore, it can be interesting for the Zuidvleugel to contribute to a pilot or study to investigate whether this automated freight transport can move ‘landward’ from the terminals to the public roads, e.g. between mainport Rotterdam and Greenport Westland.
- Application of a form of a (partly/highly/fully) automated truck, or platoon of trucks, on Dutch motorways could be envisioned in the medium term (10 years from now) and might contribute to solving congestion issues. Although automated cars are tested now, with automated trucks new challenges will arise that must be solved.
- For the Randstad Zuidvleugel it is therefore recommended to develop a close connection with developments in automated private cars the next years. Furthermore, a freight coalition of the willing could be sought for by the Randstad Zuidvleugel and a first study into possibilities and feasibility of automation of (a platoon of) trucks could be done. Here, the effect of truck platoons on hindrance for cars to/from on/off-ramps should be incorporated explicitly.

Automation of metro and light rail systems in the Randstad Zuidvleugel:

- The RandstadRail light rail connection Den Haag – Leidschenveen – Zoetermeer / Rotterdam suffers from capacity problems currently.
- These capacity problems can be a trigger for the Randstad Zuidvleugel, in cooperation with municipalities, transport authorities and public transport operators, to investigate how automation could improve this capacity and against which costs (infrastructure/vehicles).
- If automation can be a feasible solution, a pilot could be started on this route where a driver is still within the cabin or vehicle for emergencies.

References

2getthere. (2014). *Applications Personal Rapid Transit.* http://www.2getthere.eu/ Consulted November 25th, 2014.

Alonso, J., Milanés, V., Pérez, J., Onieva, E., González, C. and De Pedro, T. (2011). Autonomous vehicle control systems for safe crossroads. *Transportation Research Part C, 19(6),* 1095-1110.

AVV. (2001). *Eindrapportage praktijkproef Intelligente Snelheidsaanpassing.* Rijkswaterstaat, Adviesdienst Verkeer en Vervoer. Rotterdam, the Netherlands.

Begg, D. (2014). A 2050 Vision for London: what are the implications of driverless transport. London: Clear Channel.

Bierstedt, J., Gooze, A., Gray, C., Peterman, J. Raykin, L. and Walters, J. (2014). *Effects of next-generation vehicles on travel demand and highway capacity.* Unpublished.

Bose, A. and Ioannou, P. (1999). Analysis of traffic flow with mixed manual and semi-automated vehicles. *Proceedings of the 1999 American Control Conference*, pp. 2173-2177, San Diego, June 1999.

Brownell, C. and Kornhauser, A. (2013). A driverless alternative: fleet size and cost requirements for a statewide autonomous taxi network in New Jersey. *Transportation Research Record (in press)*.

Bureau Stedelijke Planning. (2011). *Toekomstvisie afstemming OV-RO in de Randstad. Onderzoeksrapportage.* Bureau Stedelijke Planning: Gouda, the Netherlands.

Carsten, O. (2005). *PROSPER Results: Benefits and Costs.* PROSPER Seminar: Brussels, Belgium.

Dekker, A. (2014). Zelfrijdende auto deelt tik uit aan het ov. *OV Magazine.*

Derksen, R., Kandel, H., Korving, W. and Karrenbeld, B.J. (2014). *Verkennende studie naar OV-bereikbaarheid van Rotterdam The Hague Airport.* RebelGroup: Rotterdam, the Netherlands.

Dresner, K. and Stone, P. (2008). A Multiagent Approach to Autonomous Intersection Management. *Journal of Artificial Intelligence Research, 31,* 591-656.

Fagnant, D.J., Kockelman, K.M. (2015). Dynamic ride-sharing and optimal fleet sizing for a system of shared autonomous vehicles. *Transportation Research Record, 2015, in press.*

Gasser, T.M. and Westhoff, D. (2012). BASt-study: Definitions of Automation and Legal Issues in Germany. *Transportation Research Board*, Road Vehicle Automation Workshop, July 25th, 2012.

Gouy, M., Wiedemann, K., Stevens, A., Brunett, G. and Reed, N. (2014). Driving next to automated vehicle platoons: How do short time headways influence non-platoon drivers' longitudinal control? *Transportation Research Part F, 27B,* pp. 264-273.

Hagenzieker, M. (2014). Er heerst te veel optimisme over zelfrijdende auto's. *Delta TU Delft.*

Hallé, S. and Chaib-draa, B. (2005). A collaborative driving system based on multiagent modelling and simulations. *Transportation Research Part C, 13(4),* 320-345.

Janse, J., Okhuiijsen, M. (2014). Toekomst stedelijk ov is aan fully automated vehicles. *OV Magazine.*

Kesting, A., Treiber, M. and Helbing, D. (2010). Enhanced intelligent driver model to access the impact of driving strategies on traffic capacity. *Phil.Trans.R.Soc.A.*, 368(1928), pp.4585-4605.

Knight, W. (2014). *Good Computer: Automated System Lets Trucks Convoy as One.* Technology Review, http://www.technologyreview.com/news/527476/10-4-good-computer-automated-system-lets-trucks-convoy-as-one/. May 28th, 2014.

Krumm, P. (2014). Personal communication. December 1st, 2014.

Livinglabs Delft. (2014). *Urban distribution. Cutting costs by shared urban distribution.* http://livinglabdelft.com/en/proeftuin/cutting-costs-by-shared-urban-distribution/27

Maartens, M. (2014). Ook bussen rijden straks zelf. *OV Magazine.*

Manshanden, W., Bouman-Eijs, A., Koops, O., Fischer, N., Chahim, M. and Rietveld, E. (2014). *De Top 20 van Europese grootstedelijke regio's 1995-2012; Randstad Holland in international perspectief.* Delft, the Netherlands: TNO.

Martinez, L.M., Correia, G.H.A., Viegas, J.M. (2014). An agent-based simulation model to assess the impacts of introduction a shared-taxi system: an application to Lisbon (Portugal). *Journal of Advanced Transportation,* doi: 10.1002/atr.1283*.*

May, A.D., Muir, H., Shepherd, S., Jeffery, D. and Levin, T. (2009). An assessment of city-wide applications of new automated transport technologies.

Milakis, D., Van Arem, B. and Van Wee, G.P. (2014; work in progress). *Implications of automated driving.* Delft, the Netherlands: Delft Infrastructures and Mobility Initiative.

Minderhoud, M. (2011). Simulation study after the impact of trucks on passenger car travel time and motorway capacity. In *International Conference on Traffic and Transportation Engineering* (ICTTE). Dubai, UAE.

Minderhoud, M.M. (1999). *Supported driving: Impacts on motorway traffic flow*. T99/4, July 1999, TRAIL Thesis Series, Delft University of Technology.

Minderhoud, M., & Hansen, I. (2002). Preliminary Assessment of Platoon-driving with Automated Trucks. International Congress on Freight Transport Automation and Multimodality. Delft, the Netherlands.

Molin, E.J.E. and Van den Bos, G. (2014). Car drivers' preferences for ISA policy measures. *European Journal of Transport and Infrastructure Research, 14(2),* pp. 143-158.

Muir, H., Jeffery, D., May, A.D., Tripodi, A., Shepherd, S. and Vaa, Torgeir (2009). Assessing the contribution and feasibility of a citywide personal rapid transit system. *Transportation Research Record, 2009,* 163-170.

O' Toole, R. (2014). Policy Implications of Autonomous Vehicles. Washington DC: CATO Institute.

OECD. (2014). *OECD Territorial Reviews: Netherlands 2014,* OECD Publishing. *http://dx.doi.org/1.1787/9789264209527-en.*

Ram, M., Faver, M. and Gerretsen, P. (2014). *Duurzame Verstedelijking & Agglomeratiekracht*. Vereniging Deltametropool Rotterdam i.s.m. College van Rijksadviseurs: Rotterdam, the Netherlands.

Raspe, O., Weterings, A. and Thissen, M. (2012). *De internationale concurrentiepositie van de topsectoren.* Den Haag, the Netherlands: PBL Netherlands Environmental Assessment Agency.

Rebsamen, B., Bandyopadhyay, T., Wongpiromsarn, T., Kim, S., Chong, Z.J., Qin, B. Ang, M.H., Frazzoli, E. and Rus, D. (2012). Utilizing the infrastructure to assist autonomous vehicles in a mobility on demand context. *TENCON 2012 – 2012 IEEE Region 10 Conference,* pp. 1-5, Cebu, Philippines, 19-22 November 2012.

SAE International. (2014). Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. SAE International, rapport SAE J 3016.

Shladover, S.E. (2015). Automation Deployment Paths. Limiting Automation Functionality or Geographic Scope. *TRB Annual Meeting 2015 Session 564:* USA, Washington.

Spieser, K., Treleaven, K., Zhang, R., Frazzoli, E., Morton, D. and Pavone, M. (2014). *Towards a Systematic Approach to the Design and Evaluation of Automated Mobility-on-Demand Systems: A Case Study in Singapore.* Springer: Massachusetts Institute of Technology.

SWOV. (2010). *SWOV Fact Sheet. Intelligent Speed Assistance (ISA).* Leidschendam: the Netherlands.

Thompson, M.K. and Brooks, A.G. (2010). Considerations for the design of automated urban transportation systems. *The Twenty-Third KKCNN Symposium on Civil Engineering, November 2010, Taipei.*

TrackTalk. (2014). Automation of metro lines – sharing key success factors to enhance performance. *TrackTalk – Automation of metros lines issue,* 1-12.

Tros, P. and Rodrigo, H. (2014). Personal communication. November 27th, 2014.

VanMiddlesworth, M., Dresner, K. and Stone, P. (2008). Replacing the Stop Sign: Unmanaged Intersection Control for Autonomous Vehicles. *AAMAS Workshop on Agents in Traffic and Transportation,* pp. 94-101, Estoril, Portugal, May 2008.

Van Arem, B. (2014). Personal communication. November 24th, 2014.

Van Arem, B., Van Driel, C.J.G.and Visser, R. (2006). The impacts of cooperative adaptive cruise control on traffic flow characteristics. *IEEE transactions on intelligent transportation system,7(4),* pp. 429-436.

Van der Bijl, R. (2014). Personal communication. November 18th, 2014.

Van der Bijl, R. (2014). Robots doen ov nog geen concurrentie aan. *OV Magazine.*

Van Oort, N. and Van Nes, R. (2009). Control of public transport operations to improve reliability: theory and practice. *Transportation Research Record,* No. 2112, pp.70-76.

Wiegmans, B.W., Visser, J., Konings, R. and Pielage, B.J.A. (2010). Review of underground logistic systems in the Netherlands: an ex-post evaluation of barriers, enablers and spin-offs. *European Transport, 45,* 34-49.

Wiethoff, M. (2003). *Technologieën voor snelheidsbeheersing.* R-2003-12. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam, the Netherlands.

Yap, M.D. and Correia, G.H.A. (2015; in press). *User preferences for automated vehicles as last mile transport for public transport trips.*

Zhang, R. and Pavone, R. (2014). *Control of Robotic Mobility-on-Demand Systems: A Queuing-Theoretical Perspective.* arXiv:1409.6775.

Appendix A Applications of automation in freight transport

This appendix shows an overview of different applications of automation in freight transportation including a short description: see Table A.1.

Table A.1. Applications of automation in freight transportation

1. Road and Logistics	
Automation	There are developments towards (fully-) automated trucks (without a driver). Automated trucks can be used to transport semi-trailers with containers or swap bodies and can cover long distances at relatively high speeds (comparable with conventional trucks).
Guidance	
Data Hub for Intermodal Transport	Vos Logistics, a third party logistics service provider, implemented an inter-organizational information system (IOS) in the Netherlands for the transport of maritime containers between a hinterland terminal in Veendam (northern part of the Netherlands) and the port of Rotterdam.
Integrated solutions	Usually these solutions originate from software companies that integrate several logistics aspects (carrier instructions, equipment repair and lease invoices, freight bills, load tender transactions, dispatch, rating, billing, management & financial reporting, tracking & tracing, driver management & pay, equipment maintenance, sales, statistics) into one solution.
Freight Information Highway (FIH)	Given the number and diversity of participants involved in modern supply chains, ensuring the flow of full and accurate information is a significant challenge. The FIH aims to utilize a mix of open source message sets and Internet communications software to permit the flow of freight information between modes (i.e., marine, truck, and rail).
www.vrachtuitwisseling.com(freight exchange website)	This website is an alliance of most sea container road transport companies. The alliance safeguards the individual and collective interests of companies operating in the road sea container transport market.
Identity cards for haulers	The port of Felixstowe has introduced the 'Road Hauler Identity System (RHIDES)'. The card enables better safety and more stringent control of accessing trucks.
Freight Information Real-time System for Transport (FIRST)	The terminals comprising the Port of New York and New Jersey (PONY/NJ) are severely restricted in terms of landside access. FIRST is an Internet-based "one-stop-shop" for freight and port information premised on a network of sources for real-time freight and port-related data.
Port Infolink: PCS Port of Rotterdam	In Rotterdam, around 2,500 different companies work together to move and transport the containers which enter or exit the port. Port Infolink is a private company which is completely owned by the Rotterdam Port Authority. The PCS services support the import and export processes, communication between organizations in the market, and communication with governmental organizations.
Dakosy: PCS (Port Community System) Port of Hamburg	Hamburg is connected with its hinterland by four different transport modalities: road, rail, inland shipping over the river Elbe, and coastal shipping to primarily the Scandinavian countries and Eastern Europe. Dakosy is an independent organization with a strong position in the port of Hamburg. The goal of this PCS is to improve the transportation process by improving the associated flow of information.
Appointment System for trucks at the Ports of Los Angeles and Long Beach	Both the ports of LA/LB are operated by their respective cities under trust from the state of California. The appointment system is a Web-based system that collects data from ocean carriers and marine terminals. These data are then used to provide services for a fee to the marine terminals, ocean carriers, trucking companies, and port community.

2. Inland Waterway Transport	
Automation	
Rollerbarge	Rollerbarge is a terminal concept for the horizontal handling of containers to and from barges by a platform. A container pack of (8 to 24 units) is placed on a hydraulic platform that forms part of the barge.
Guidance	
Extended Gate Model ECT	To benefit from the relationship between terminal (i.e. quay crane) productivity and stack fill rate and dwell time, ECT is developing the so-called extended gate concept. The key to this concept is the possibility to send large volumes of containers from the deep-sea terminal to inland terminals immediately after arrival on the deep sea ship.
Distrivaart	Distrivaartis a project that tried to develop a national network in the Netherlands to transport palletized goods with barges between distribution centers and supermarkets.
Management Information System Container Inland Waterway Transport, MIS-Cobiva	The system is based on tracking and tracing of barges by GPS. The position of the vessel is sent to the MIS-Cobiva-system on shore by GPRS. The owner/commissioner of the barge can see in his application among others the barge location, its direction and at what speed it travels.
www.bargelink.com	Bargelink is the marketplace for European inland shipping. Shippers, transport operators, logistics service providers, expeditors, and private persons here find their transport partners.
MokumMariteam (vracht door de gracht: freight through the canals)	MokumMariteam is a project that aims to realize a collection- and distribution network for freight transport in the city center of Amsterdam.
ICT to improve IWW transport	Better communication systems may enable more efficient and flexible operations. On a European level, the River Information System is the most important initiative in this field. RIS contains information on loading and unloading planning, locks planning management, customs formalities and water police.
Synchronizing Barge Plans	Barges that need to pick up containers at various terminals in the port of Rotterdam often suffer delays, long waiting times, and unreliable plans. A system has been developed that makes efficient and realistic barge rotation plans in such a way that companies do not lose control and do not need to be transparent.
3. Rail Transport	
Automation	
Automated rail-guided systems	Well known operational automated rail guided systems are the driverless metro type of systems in e.g. the USA, Japan, France and the UK. Automated train systems (ATS) for freight, based on traditional rail have been developed mainly in Germany. The *SelbsttätigesSignalgeführtesTriebfahreug* (SST) is an unmanned train that was tested in 1994.
Self-driven container wagons	Container wagons propelled by a linear motor on a track for individual transport on short distances in the port, at shunting yards and on container terminals.
Guidance	
CargoSprinter	The CargoSprinter is a short train for the transport of a limited number of containers. It is also called 'truck on rails'.
Tracking and tracing	Tracking and tracing comes in several alternatives. One is the identification system for wagons and load units.
RFID systems	Radio frequency transmission is to be seen as waves moving through the air. For radio frequency transmission, a transmitter and a receiver are needed. Especially, RFID systems seem to be suitable for rail freight logistics control. The RFID system comprises of four elements: tags, antennas, readers and application software.
Global Positioning System	Global Positioning System (GPS) used in conjunction with communication links and computers can provide the backbone for

	systems tailored to applications for train and locomotive and/or wagon tracking and tracing. GPS provides coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity and time.
4. Terminal handling	
Automation of terminal handling	
Compact Terminal Tuchschmid	The next criteria were used when designing the Compactterminal: simple procedures, minimal container handling with short travel distances, no need for adapters for rolling stock and containers, use whenever possible existing proven individual components,low operating costs.
NoellMegahub	An example of a new-generation terminal is the NoellMegahub. In general, the infrastructure of a new-generation terminal consists of a storage area for the temporary stacking of load units, a track area where trains are served and a transport system that moves load units from one crane to another.
Cargobeamer	Cargobeameris a system that aims to handle trailers automatically and transship them onto and from rail. The Cargobeamer consists of existing components (such as standard semi-trailer, swap bodies, containers, the European wide rail network) and new components (such as innovative transshipment, new rail wagons for railways-based transportation of semi-trailers, and an internet-based customer service infrastructure for the information, booking, coordination, tracking and clearing of the transportation services).
Cargospeed (Schwopple train)	Cargospeedis a rail based system which core is formed by a railcar with a liftablewellfloor with a trailer on it. Cargospeed is a road to rail system that both supports Roll-On / Roll-Off and Lift-On / Lift-Off operations at the terminals.
Abroll Container Transport System: (ACTS)	ACTS is a system of transporting (exchangeable) containers in rail-road transportation. In ACTS, container handling is possible without the use of special devices in container terminals (such as cranes, reach stackers, etc.).
Guidance of vehicle or load unit at the terminal	
Automated Guided Vehicles	Automated guided vehicles arrange for the transport of containers between quay and stack yard (and vice versa), including the management and navigation software to control the AGV fleet.
Multi Trailer Systems	The concept consists of a number of trailers coupled behind each other to form a trailer train pulled by a heavy duty terminal tractor. The principle of the Multi Trailer System (MTS) concept is the accurate steering system which allows that every trailer in the train follows exactly the same track as the terminal tractor.
5. Capsule-oriented systems	
Automation and guidance	
Capsule systems	Capsule systems are mostly used to carry relatively smaller goods, such as valuables or post, within banks or offices. The systems are mostly pneumatic systems, using air to push the capsules through the tubes.
Underground Logistics Systems (ULS)	Underground freight transport deals with automated transport of general cargo by vehicles moving through an underground tunnel network. Because fundamental changes in the organisation of sending and receiving actors are necessary, underground freight transport in the Netherlands is also called underground logistic systems (ULS).
6. City Distribution	
Automation and guidance	
City distribution	City distribution refers to the final leg in a business to consumer (B2C) delivery service whereby the consignment is delivered to the recipient, either at the recipient's home or at a collection point.