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Impact of Automated Highway Autopilot on the Average Network Travel Times and Total Distance Travelled

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Abstract

Allowing Level 4 Automated Vehicles (AVs) to drive on highways could potentially have an impact on the road network performance. Although it might probably take a while before AVs are on the road, National Road Authorities (NRAs) are already concerned about understanding what changes would be required on their current infrastructure to make it ready for AVs. In this study, we simulate part of the highway network in the Netherlands, the region of Rotterdam The Hague, to investigate the impact of AVs on the network performance in terms of network travel times and distances travelled. Results allow us to conclude that 50% AVs (Level 4) result in an increase in distance travelled on highways but a decrease in the total network travel times and corresponding delays.

Keywords: autonomous vehicles; highway autopilot; OmniTRANS; NRA

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Acronyms

ACC	Adaptive Cruise Control
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CEDR	Conference of European Directors of Roads
NRA	National Road Authority
VOTT	Value of Travel Time

1. Introduction

The research presented in this paper is the result of initial work done in the scope of the MANTRA project which is an acronym for "Making full use of Automation for National Transport and Road Authorities – NRA Core Business". This is a project that responds to the question posed by CEDR Automation Call 2017 Topic A: How will automation change the core business of NRA's? In this paper we focus on the impact of highway autopilot on the highway network performance and on what could NRA's expect if they allow AVs on the roads in terms of network usage (average delay, average trip travel time). Can they expect added vehicle kilometers by automated vehicles (AVs) traveling between different cities on a highway?

1.1. Highway autopilot

According to ERTRAC (2017), the highway autopilot, including highway convoy, provides automated driving up to 130 km/h on highways, or roads similar to highways, from the entrance to exit, on all lanes, including overtaking and lane change. The driver must deliberately activate the system but does not have to monitor the system constantly. The driver can at non-critical times override or switch off the system. There are no requests from the system to the driver to take over when the system is in normal operation area (i.e. on the highway). Depending on the deployment of cooperative systems, ad-hoc convoys could also be created if Vehicle-to-Vehicle communication is available.

1.2. Impact mechanisms

The variety of impacts and impacts mechanisms of connected and automated driving, and the related key performance indicators (KPIs) regarding connected automated driving impacts on mobility and travel behavior, driver behavior and traffic flow, traffic safety, user acceptance, energy and environment were comprehensively defined by the Trilateral WG and CARTRE (2018). For the MANTRA work we have selected the most relevant KPIs. The following sub-sections present the main findings of the review of the literature on the selected KPIs regarding the topic of this paper which are network effects on interurban roads.

1.2.1. Road capacity

The capacity of a road highly influences the network performance. The capacity of a highway is highly related to the time headway settings of simulated AVs. Users of ACC tend to keep a larger headway than manually driven vehicles. In accordance with this finding, Bierstedt et al. (2014) concluded that non-connected AVs would indeed degrade highway capacity due to the safety-conscious programming of ACC equipped vehicles. Their simulation suggests that capacity benefits will only occur if 75% of the fleet mix consists of AVs – leading to traffic flow benefits of 25-35%.

On the other hand, connectivity brings a lot of benefits. Headways decrease, resulting in an increase in capacity on highways. Shladover et al. (2013) studied the impact of connected vehicles for different market penetration rates using microsimulation. They used time gaps as chosen by drivers during a field test with automated vehicles. Increasing market penetration of CACC leads to an increased road capacity – up to 3970 vehicles/hour/lane for a 100% CACC scenario compared to a capacity of 2200 vehicles/hour/lane in the base scenario.

1.2.2. Value of Travel Time

Despite recent research efforts, it is fair to say that current understanding regarding how travellers will experience AVs is still limited. Although many researchers expect that the Value of Travel Time (VOTT) will decrease as a result of automated driving, to the best of our knowledge only few studies have started to investigate the impacts of AVs on the VOTT. Milakis et al. (2017) surveyed several experts who have concluded the reductions of travel time to be in the interval of 15% to 30%, however, this was not based on specific behavioral studies. Childress et al. (2015) assume, like others do in other studies, that there is a reduction of VOTT which they associate with the difference between high-quality rail and the private car. Contrary to general expectations, Yap et al. (2016) found that people are willing to pay more (rather than less) to reduce their travel time in an AV as compared to a normal car however this is when the vehicle would be used as a last mile connection of public transport. The mainstream theory is still that the VOTT should decrease due to opportunities to improve productivity while driving (Fagnant and Kockelman, 2015; Krueger et al., 2016; Scheltes and Correia, 2017; van den Berg and Verhoef, 2016). In a recent study the authors found that the VOTT is most likely going to reduce when associated to the possibility of working when compared to leisure as the latter may be more attractive to be performed in other places, and the work in a vehicle can cut work time at the office, which can later be used for having leisure at home (Correia et al., 2019).

1.2.3. Share of car & public transport

Mode choice depends on many factors including: trip distance and travel time, trip motive, available transport alternatives and travel costs. It is complex to assess mode choice before new alternatives are introduced into the market which is the case with AVs. Many times what researchers have available are stated preference surveys whereby people state what they would do if they were before a certain situation. Several of these experiments have been done in the recent years and they help to understand the impact of connected automated driving on the shares of car and public transport demand (Ashkrof et al., 2019; Correia et al., 2019; Yap et al., 2015, 2016).

Vehicle automation may come in essentially two forms: private cars or public transport systems. Researchers and practitioners have been discussing the pros and cons of both uses of vehicle automation and certainly the future can be a mix of both uses. Regarding the latter there are already many pilot systems under operation in Europe and the United States with pod like buses (Alessandrini, 2017; Alessandrini et al., 2015). In the Netherlands a level 4 system running in its own segregate path, the Parkshuttle bus connection, has been in operation for two decades now.

With usage of vehicle automation as public transport it is foreseen that with the cheaper operation costs (no drivers needed) and flexibility to operate the system (vehicles can be sent anywhere at any time to other areas of operation) it will be possible to offer a better quality of service to the populations (Winter et al., 2018, 2016). This can be done with smaller vehicles (cars in car-sharing systems) (Liang et al., 2018) or buses (in a more traditional public transport approach). These systems are expected to be used essentially in urbanized regions and one of the most useful usages will be as last/first mile transport. For long distance intercity transport still high capacity public transport systems such as rail continue to be seen as the best option to transport many people in the most sustainable way. The role of robotaxis in connecting different cities thus using the highway network is difficult to assess as this will represent a management challenge: moving vehicles from one city to another may represent great vehicle stock imbalance which will lead to a high price to be paid by the passengers. These robotaxis can be driven in any optimal way desired by their operators but there could also be the case of, if imposed by law, a specific behaviour being imposed by public authorities for a certain part of the network.

Private cars in the future can be fully automated under all operational design domains (level 5 automation) and in that case we are talking about vehicles that can become almost like private living rooms where people would be able to have leisure time or even work. This can shift demand toward private cars, if prices are competitive, with the difference that with an improved experience people are willing to stay longer in their vehicles which can add to the traffic congestion as an occupant does not have an incentive to change his/her behaviour. The driving behaviour of the vehicle can be controlled in terms of route and also lower level control (motion) which can be beneficial to the road operators, however it is not clear what type of control will be possible to centralize or to give to the vehicle itself. In a very futuristic scenario with only AVs, the control over those vehicles could be perfectly centralized to achieve what is called the system optimal equilibrium whereby travel time/costs are minimized.

In summary it is at this point impossible to estimate the demand that both modes of transport will have (private or public) since it is depending greatly on what the technology will allow to do in a car, the price of the vehicles, shared mobility market take- up (Nieuwenhuijsen et al., 2018) and whatever policies authorities will implement in the future to achieve desired outcome on the mobility system: locally and on a national level (Milakis et al., 2016).

1.2.4. Total kilometers travelled

The distances that will be travelled as automation penetrates the vehicle fleet will depend naturally on the type of usage of these vehicles: public transport or private transport. It is argued that private automation will be associated with longer distances because with a lower value of travel time (Correia et al., 2019) the disutility of traveling will be lower for the same travel distance (Wadud et al., 2016).

That change of utility on the short term may mean longer routes but also more time spent on congestion as passengers will not feel their time inside the vehicle (Correia et al., 2015; de Almeida Correia and van Arem, 2016; Milakis et al., 2016). On the longer term a lower disutility of traveling may mean a willingness to move farther away from work locations (typically in the city center) which will then lead to longer commuter distance trips which will then be difficult to avoid once the spatial structure of urbanized regions is allowed to change (Correia et al., 2016; Wadud et al., 2016).

Other researchers argue that there could be an inverse movement back to living in city centres as these become more attractive due to the reallocation of public space from parking to other more attractive uses such as wider sidewalks or parks (Hollestelle, 2017). What effect will dominate the other is still to be seen and again it depends on what technology will allow to do inside an AV as well as human preferences of traveling and living.

Regarding public transport the risk is more focused on the empty kilometres that may be generated by shared vehicle systems (Martinez et al., 2014). Results in the literature point for the need of fewer vehicles to satisfy the same demand once vehicles become level 4 or level 5 and start to be incorporated in taxi and Uber-like systems (Fagnant et al., 2015; International Transport Forum, 2015), however the other side of the coin is the need to relocate such vehicles as they move to pick-up clients in other parts of the network (Jorge et al., 2014; Martínez et al., 2017). Current Uber systems are already creating more traffic congestion due to the added empty kilometres but also to the added demand of people who used to use public transport and who find it much more comfortable now to just request for a ride (Growth et al., 2017; Schaller, 2018).

2. Methodology

The impacts of highway autopilot on average network travel times and distances travelled, are simulated using a complete network of part of the Netherlands. The region comprises the cities of Rotterdam, The Hague and Delft.

2.1. Network

We perform simulations using macro simulation software OmniTRANS 8.0.16 of DAT.Mobility which is the most widespread software used for transport demand modeling in the Netherlands. We use traffic model "V-MRDH 2.2" featuring Metropolitan region Rotterdam – The Hague (The Netherlands) as a basis (see Fig. 1). We

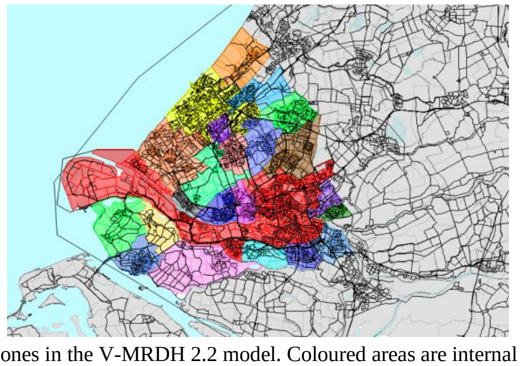

Fig. 1 Overview of zones in the V-MRDH 2.2 model. Coloured areas are internal zones, grey areas are external zones.

perform simulations given the demand and network modifications as predicted for the year 2040. The model consists of 3 time periods for an average working day: morning peak (7-9am), afternoon peak (4-6pm) and the rest of the day.

2.2. Modelling highway autopilot

The MANTRA project (2019) defined several penetration rates for different automation types, based on market introduction predictions and fleet renewal statistics. For the highway autopilot a vehicle-km penetration rate of 47.2% is expected in 2040-high. This scenario assumes the acceleration of automated driving via financial incentives such as reduced taxation or via regulatory actions, for instance by mandating automated driving in specific conditions. According to the veh-km penetration rate, we assume that approximately 50% of the vehicles in the simulation network is an AV. According to Shladover et al. (2013) this implies an 8% increase of highway capacity. For simplicity reasons, the highway links in the network are adjusted according to this increase in capacity instead of the addition of a new mode (AV) with respective parameters.

We did not simulate any additional trips other than those incorporated by the V-MRDH2.2 traffic model. It is expected that the introduction of AVs on highways alone (Level 4) will not lead to new trips by elderly or disabled people, since only part of the trip can be performed automated. Additionally, increased travels due to reduced Value of Travel Time (VOTT), (e.g. due to working during a trip) or shifts from public transport to AV are still too uncertain therefore we prefer not to guess at this stage.

3. Results

We applied the automation functions of highway autopilot on the V-MRDH 2.2 network.

3.1. Total distance

Due to the introduction of AVs on highways, a slight shift of 1% from other roads to highways can be noticed, as can be seen in Fig 2. This generally implies driving a bit longer route. Accordingly, the total vehicle-kms driven in the network during the afternoon peak (about 9 million kilometers) increases with 0.438%.

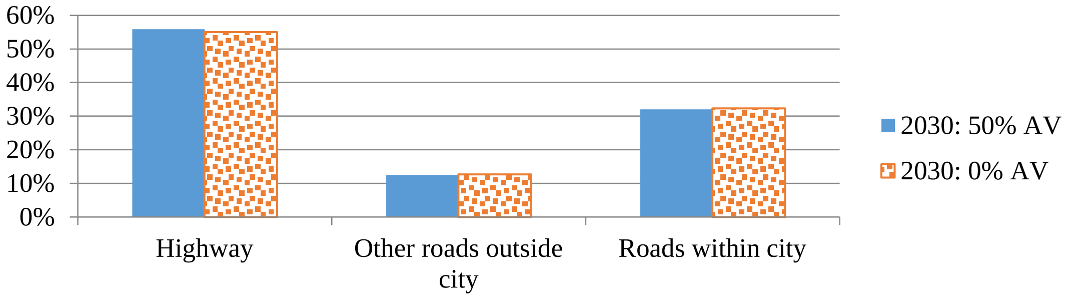

Fig. 2 Vehicle-km per road type in the afternoon peak, relative to the 0% AV scenario

3.2. Total travel time

Although the total distance travelled increases, the total travel time decreases due to the increased capacity of highways. For example, the total travel time in the morning peak reduces from 44978185 (0% AV) to 44933673 hours (50%): a reduction of 44512 hours or 0.1%. It should be noted that 54% of the travel time is spent on other roads than highways. Additionally, not on all highways congestion appears. Therefore, it is more useful to look into the changes in delay after introduction of AVs.

3.3. Delay

The introduction of AVs on the highways leads to a decrease of 15-22% of delay on the highways as can be seen in Fig 3. Delays are computed by comparing the driven travel times to the free flow travel times. In absolute numbers, this means a decrease from 9233 to 7639 hours during the morning peak. Also other road types slightly benefit from the introduction of AVs, mostly due to traffic shifting toward highways.

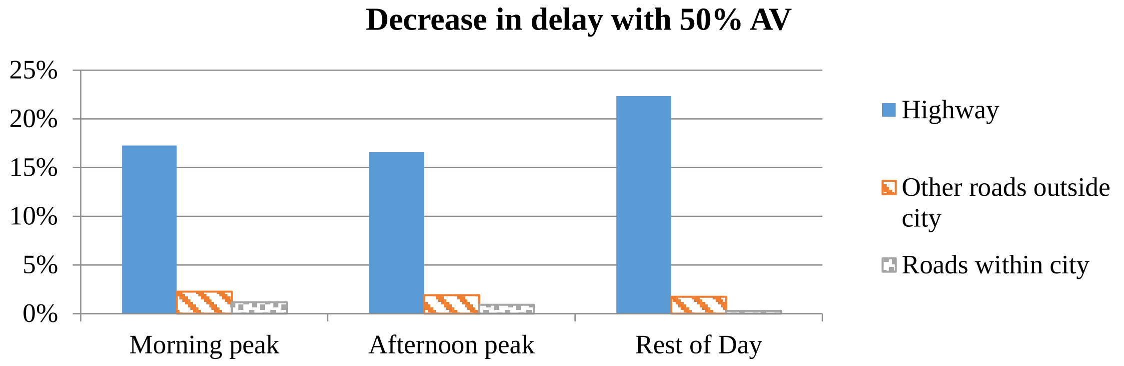

Fig. 3 Average delays with 50% AV, split per time period and road type

4. Conclusions

In this paper, we investigated the impacts of highway autopilot including highway convoy on the performance of freeway traffic. We performed numerous macroscopic simulations with the OmniTRANS software. We simulated part of the network of the Netherlands, including the cities of Rotterdam and The Hague.

The results of the macro simulation with 50% AVs show a shift from local roads toward highways, leading to an increase in vehicle-kms driven and a decrease in total travel time and delay (15-20%) due to the added road capacity. However, in this way it is assumed that every highway is occupied by 50% AVs, which might not necessarily be the case. A better implementation might be introducing a completely new mode where an AV is modelled as a vehicle with a lower PCU-value.

In general, NRAs should take notice that allowing AVs on the highway most likely leads to increased traffic volumes on the highway. However, due to better traffic flow caused by AVs (increase in capacity), this will not result in additional traffic delays – assuming that AVs are connected.

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References

Alessandrini, A., 2017. Automated road vehicles and transport systems, in: Intelligent Transport Systems (ITS): Past, Present and Future Directions. pp. 315–330.

Alessandrini, A., Campagna, A., Site, P.D., Filippi, F., Persia, L., 2015. Automated Vehicles and the Rethinking of Mobility and Cities. Transp. Res. Procedia 5, 145–160. https://doi.org/10.1016/J.TRPRO.2015.01.002

Ashkrof, P., Homem de Almeida Correia, G., Cats, O., van Arem, B., 2019. Impact of Automated Vehicles on Travel Mode Preference for Different Trip Purposes and Distances. Transp. Res. Rec. J. Transp. Res. Board 036119811984103. https://doi.org/10.1177/0361198119841032

Bierstedt, Jane, Aaron Gooze, Chris Gray, Josh Peterman, Leon Raykin, and Jerry Walters, 2014. Effects of next-generation vehicles on travel demand and highway capacity. FP Think Working Group, 10-11.

Boston Consulting Group, 2016. Impactanalyse zelfrijdende voertuigen.

CARTRE, 2018. D5.3 Societal impacts of automated driving.

Childress, S., Nichols, B., Charlton, B., Coe, S., 2015. Using an Activity-Based Model to Explore the Potential Impacts of Automated Vehicles. Transp. Res. Rec. J. Transp. Res. Board 2493, 99–106. https://doi.org/10.3141/2493-11

Correia, G., Milakis, D., Arem, B. van, Hoogendoorn, R., 2015. Vehicle automation for improving transport system performance: conceptual analysis, methods and impacts, in: Bliemer, M. (Ed.), Handbook on Transport and Urban Planning in the Developed World.

Correia, G., Milakis, D., van Arem, B., Hoogendoorn, R., 2016. Vehicle automation and transport system performance, in: Bliemer, M., Mulley, C., Moutou, C. (Eds.), Handbook on Transport and Urban Planning in the Developed World. EE Elgar, Cheltenham, UK, pp. 498–516. https://doi.org/10.4337/9781783471393

Correia, G.H. de A., Looff, E., van Cranenburgh, S., Snelder, M., van Arem, B., 2019. On the impact of vehicle automation on the value of travel time while performing work and leisure activities in a car: Theoretical insights and results from a stated preference survey. Transp. Res. Part A Policy Pract. 119, 359–382. https://doi.org/10.1016/j.tra.2018.11.016

de Almeida Correia, G.H., van Arem, B., 2016. Solving the User Optimum Privately Owned Automated Vehicles Assignment Problem (UO-POAVAP): A model to explore the impacts of self-driving vehicles on urban mobility. Transp. Res. Part B Methodol. 87, 64–88.

ERTRAC, 2017. Automated Driving Roadmap. Version 7.0, Date: 29/05/2017. ERTRAC Working Group “Connectivity and Automated Driving“. 54 p. http://www.ertrac.org/uploads/images/ERTRAC_Automated_Driving_2017.pdf

Fagnant, D.J., Kockelman, K., 2015. Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. Transp. Res. Part A Policy Pract. 77, 167–181. https://doi.org/10.1016/j.tra.2015.04.003

Fagnant, D.J., Kockelman, K.M., Bansal, P., 2015. Operations of Shared Autonomous Vehicle Fleet for Austin, Texas, Market. Transp. Res. Rec. J. Transp. Res. Board 2536, 98–106. https://doi.org/10.3141/2536-12

Growth, T., Services, A.R., City, N.Y., 2017. Unsustainable? The Growth of App-Based Ride Services and Traffic, Travel and the Future of New York City.

Hollestelle, M., 2017. Automated Driving: Driving Urban Development? Delft University of Technology.

International Transport Forum, 2015. Urban mobility system upgrade: How shared self-driving cars could change city traffic.

Jorge, D., Correia, G.H.A., Barnhart, C., 2014. Comparing optimal relocation operations with simulated relocation policies in one-way carsharing systems. IEEE Trans. Intell. Transp. Syst. 15. https://doi.org/10.1109/TITS.2014.2304358

Krueger, R., Rashidi, T.H., Rose, J.M., 2016. Preferences for shared autonomous vehicles. Transp. Res. Part C Emerg. Technol. 69, 343–355. https://doi.org/10.1016/j.trc.2016.06.015

Liang, X., de Almeida Correia, G.H., van Arem, B., 2018. Applying a Model for Trip Assignment and Dynamic Routing of Automated Taxis with Congestion: System Performance in the City of Delft, The Netherlands. Transp. Res. Rec. 1–11. https://doi.org/10.1177/0361198118758048

MANTRA, 2019. Deliverable 2.1: Vehicle fleet penetrations and ODD coverage of NRA-relevant automation functions up to 2040.

Martínez, L.M., Correia, G.H. de A., Moura, F., Mendes Lopes, M., 2017. Insights into carsharing demand dynamics: Outputs of an agent-based model application to Lisbon, Portugal. Int. J. Sustain. Transp. 11, 148–159. https://doi.org/10.1080/15568318.2016.1226997

Martinez, L.M., Correia, G.H.A., Viegas, J.M., 2014. An agent-based simulation model to assess the impacts of introducing a shared-taxi system: an application to Lisbon (Portugal). J. Adv. Transp. 49, 475–495. https://doi.org/10.1002/atr.1283

Milakis, D., Snelder, M., Arem, B. van, Wee, B. van, Correia, G., 2016. Development and transport implications of automated vehicles in the Netherlands: scenarios for 2030 and 2050. Eur. J. Transp. Infrastruct. Res. 17, 63–85.

Milakis, D., Snelder, M., Van Arem, B., Van Wee, B., De Almeida Correia, G.H., 2017. Development and transport implications of automated vehicles in the Netherlands: Scenarios for 2030 and 2050. Eur. J. Transp. Infrastruct. Res. 17, 63–85.

Nieuwenhuijsen, J., Correia, G.H. de A., Milakis, D., van Arem, B., van Daalen, E., 2018. Towards a quantitative method to analyze the long-term innovation diffusion of automated vehicles technology using system dynamics. Transp. Res. Part C Emerg. Technol. 86, 300–327. https://doi.org/10.1016/j.trc.2017.11.016

Schaller, B., 2018. The New Automobility : Lyft , Uber and the Future of American Cities.

Scheltes, A., Correia, G.H.D.A., 2017. Exploring the use of automated vehicles as last mile connection of train trips through an agent-based simulation model. Int. J. Transp. Sci. Technol. 6, 28–41. https://doi.org/10.1016/j.ijtst.2017.05.004

Shladover, S., Su, D., & Lu, X.-Y., 2013. Impacts of Cooperative Adaptive Cruise Control on Freeway Traffic Flow. Transportation Research Record: Journal of the Transportation Research Board, 2324(September 2015), 63-70.

Snelder, M., Wilmink, I., van der Gun, J., Bergveld, H.J., Hoseini, P., van Arem, B., 2019. Mobility Impacts of Automated Driving and Shared Mobility: Explorative Model and Case Study of the Province of North-Holland. Proceedings of the Transport Research Board 98th Annual Meeting. Transportation Research Board.

van den Berg, V.A.C., Verhoef, E.T., 2016. Autonomous cars and dynamic bottleneck congestion: The effects on capacity, value of time and preference heterogeneity. Transp. Res. Part B Methodol. 94, 43–60. https://doi.org/10.1016/j.trb.2016.08.018

Wadud, Z., MacKenzie, D., Leiby, P., 2016. Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. Transp. Res. Part A Policy Pract. 86, 1–18. https://doi.org/10.1016/j.tra.2015.12.001

Winter, K., Cats, O., Correia, G., van Arem, B., 2018. Performance analysis and fleet requirements of automated demand-responsive transport systems as an urban public transport service. Int. J. Transp. Sci. Technol. 7, 151–167. https://doi.org/10.1016/J.IJTST.2018.04.004

Winter, K., Cats, O., Correia, G.H. de A., van Arem, B., 2016. Designing an Automated Demand-Responsive Transport System. Transp. Res. Rec. J. Transp. Res. Board 2542, 75–83. https://doi.org/10.3141/2542-09

Yap, M., Correia, G.H. de A., Arem, B. Van, 2015. Valuation of travel attributes for using automated vehicles as egress transport of multimodal train trips, in: 18th Meeting of the Euro Working Group in Transportation (EWGT).

Yap, M.D., Correia, G., van Arem, B., 2016. Preferences of travellers for using automated vehicles as last mile public transport of multimodal train trips. Transp. Res. Part A Policy Pract. 94, 1–16. https://doi.org/10.1016/j.tra.2016.09.003