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Exploring the use of automated vehicles as last mile connection of train trips through an agent-based simulation model: An application to Delft, Netherlands

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A B S T R A C T

The last mile in a public transport trip is known to bring a large disutility for passengers, because the conventional transport modes for this stage of the trip can, in many cases, be rather slow, inflexible and not provide a seamless experience to passengers. Fully automated vehicles (AVs), that is, those which do not need a driver, could act as a first mile/last mile connection to mass public transport modes. In this paper, we study a system that we call Automated Last-Mile Transport (ALMT), which consists of a fleet of small, fully automated, electric vehicles to improve the last mile performance of a trip done in a train. An agent-based simulation model was proposed for the ALMT whereby a dispatching algorithm distributes travel requests amongst the available vehicles using a FIFO sequence and selects a vehicle based on a set of specified control conditions (e.g. travel time to reach a requesting passenger). The model was applied to the case-study of the connection between the train station Delft Zuid and the Technological Innovation Campus (Delft, The Netherlands) in order to test the methodology and understand the performance of the system in function of several operational parameters and demand scenarios. The most important conclusion from the baseline scenario was that the ALMT system was only able to compete with the walking mode and that additional measures were needed to increase the performance of the ALMT system in order to be competitive with cycling. Relocating empty vehicles or allowing pre-booking of vehicles led to a significant reduction in average waiting time, whilst allowing passengers to drive at a higher speed led to a large reduction in average travel time, whilst simultaneously reducing system capacity as energy use is increased.

Introduction

The last mile in a public transport trip is known to bring a large disutility for passengers, as the conventional transport modes for this stage of the trip can, in many cases, be rather slow, inflexible and are not able to provide a seamless experience to the passengers. Wang and Odini (2012) indicate that the last mile is one of the main deterrents in public transport in

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order to be competitive with the car. Multiple new transport concepts (e.g. bicycle sharing systems, carsharing programs) have been proposed to solve the last mile problem (Correia and Antunes, 2012; Jorge and Correia, 2013). However, passengers still face limitations when using these transport alternatives such as slow speed, weather conditions or high costs.

Personal Rapid Transit (PRT) is one of the transport concepts which could reduce the disutility for the last mile as it aspires to be on-demand and provide a direct service with a short waiting time by operating small vehicles on a separate network (Schweizer and Fabian, 2005). Nevertheless, due to the fixed infrastructure, the accessibility of the service area is depending on the network density. The main drawbacks of conventional PRT systems are believed to be the visual intrusion of the guideway and the high investment costs (Andreasson, 2011). Vuchic (1996) even states that the PRT concept is a combination of two incompatible systems: small vehicles vs. high transport volumes. Mueller and Sgouridis (2011) concluded that a PRT system could be made more viable if it would be integrated with light rail or metro lines, such that it encourages multimodal transport, and decrease the disutility on the last mile by providing fast transport from or to a transit hub.

Nowadays tests with highly automated vehicles (AVs) are taking place all over the world, as for example with the Google Car and Uber. However as automation technology is still far from full penetration, van Arem et al. (2015) indicate that probably the most promising short-term application of AVs for public transport purposes is on improving the door-to-door performance, by providing the last mile of a trip. They state that the most viable application areas to start this system are, for example, university campus areas, because densities are high but still with scattered demand patterns and with the possibility of driving the vehicle with higher safety inside the campus.

Fully automated vehicles (SAE-level 5), that is, those which do not need a driver, are in essence independent of special infrastructure and could, therefore, operate on any available infrastructure. Therefore, AVs are able to solve one of the main limitations of conventional PRT systems. AVs could further develop the PRT concept and improve the last mile accessibility in a public transport trip. The greatest advantage of this system compared to PRT systems is a major reduction in infrastructure costs. Comparing the AVs with the classic bus systems, these have great operational cost reduction as they do not need a driver and they can be demand responsive.

The system proposed and studied in this research will be designated as Automated Last Mile Transport (ALMT) system. The objective of this system is to improve the last mile performance in a public transport trip such that a door to door experience can be delivered to a passenger (Liang et al., 2016). The ALMT system is characterized as being a feeder service for conventional public transport operated by AVs. We consider this main part of a trip still being performed by high capacity conventional public transport (e.g. train or metro) as they are able to operate with a higher efficiency and with an economy of scale as indicated by van Arem et al. (2015). The advantages of this combination strategy between high capacity (main part of the trip) and low capacity demand responsive (egress mode) has been studied by Mageean and Nelson (2003) who concluded that due to financial and scheduling reasons, Demand Responsive Transport (DRT) services are not suitable for a dominant mode of transport but should be regarded as a supplier of the main mode of transport.

The system that we will study is constituted by small, fully electric AVs. Vehicle batteries are recharged in a central depot or at an intermediate stop in the network. Booking of the vehicles occurs via a smartphone application or a push button at a stop, after which the vehicle is dispatched to pick-up the requesting passenger and bring him/her to the required destination. After the arrival, the vehicle awaits further orders until a new request arises.

In this research, we aim to assess the potential of the ALMT system in providing the suggested improvements to the last mile in a public transport trip with train as main mode. This is done by assessing the system performance under different scenarios in terms of network structure, demand patterns, and vehicle behaviour. Nevertheless, we must note that no demand model was used to relate the operational parameters and the total demand for these intermodal trips. For a study on the main trade-offs between several modes used as last mile transport of train trips, including both socio-demographic variables, mode specific attributes and attitudes, the study of Yap et al. (2016) provides interesting findings of a survey applied to the same case-study that we use in this paper.

The assessment of different operational and demand scenarios has been done through agent-based modelling (ABM). Many different simulation models of PRT systems and shared automated systems have been proposed in the literature, for example (Mueller and Sgouridis, 2011; Fagnant and Kockelman, 2015; PRT, 2015; Martinez et al., 2014, 2016). However, none of those simulation models consider the last mile of a public transport trip, by incorporating full integration with train or metro (Correia et al., 2015).

The definition of agent-based simulation model used in this work is the one by Bonabeau (2002): "In agent-based modeling (ABM), a system is modelled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviours appropriate for the system they represent—for example, producing, consuming, or selling." This means that we are not considering other more complex components of the agents as memory and learning, focusing more on the decision-making and spatial interaction. The main advantage of ABM is the convenience in defining the behaviour of the system components up to a high level of detail by means of state charts. Statecharts allow the model designer to easily adapt the behaviour such that many variations can be simulated.

As a case-study for the model application we used the connection between the train station of Delft Zuid (The Netherlands) and the university campus of the Delft University of Technology because currently, no public transport exists in this connection, hence this could improve the last mile performance of people arriving at the campus. The distance between the train station and the passengers' destinations is on average 1.8 km and therefore should allow for efficient PRT operation