Deploying Level 4 Shared Automated Vehicle Services on ODD-compliant Subnetworks: a Multimodal Analysis

Lotte Notelaers*[1], Chris M.J. Tampère[2]

[1]PhD candidate, KU Leuven Institute for Mobility (CIB), KU Leuven, Belgium

[2]Professor, KU Leuven Institute for Mobility (CIB), KU Leuven, Belgium

SHORT SUMMARY

This abstract reports on a case study in which a station-based shared automated vehicle (SAV) service would be deployed in Leuven, Belgium. The vehicles are assumed to operate on a level 4 of automation and are restricted to drive on a subnetwork compliant with the operational design domain (ODD). The scenario is evaluated using a multimodal equilibrium assignment model in which the SAV market share is assumed dependent on its level-of-service (LOS) and competition with other modes. The model uses a macroscopic modelling approach based on the traditional 4-step transport model. However, it is integrated with a microscopic modelling approach to properly model the SAV service supply. Results suggest that, in the scenario considered, the new service would serve a market share of 21.0% of which most customers are former car users and passengers. Further, vehicle-hours-travelled (VHT) and vehicle-kilometers-travelled (VKT) increase by 23.6% and 1.7%, respectively.

Keywords: autonomous vehicles, mobility on-demand, multi-modal transportation, ODD, SAE level 4, shared mobility

1. INTRODUCTION

In recent years, autonomous vehicles have become a trending topic in industry as well as in research. It is recognized as having the potential to fundamentally disrupt the transportation system of today, e.g., positively impact congestion, and give more autonomy to people with medical or age-related mobility constraints (Harper et al., 2016). Besides these unique opportunities, there are rising concerns about disadvantageous effects as well. Assuming the value of travel time (VTT) will go down, people may start travelling more, undoing congestion reduction, energy savings and environmental benefits (Sprei, 2018). Moreover, this new travel mode might take people away from the more sustainable modes, such as public transport (PT), biking and walking.

Therefore, a much-debated question is *how* the introduction of this technology into our mobility system will and/or should happen. To gain insights into this, scientific progress should be made on three fronts. First, methodologically, transport modelling tools should be elaborated to include these types of services. Secondly, empirical research should shed light on which attributes of the services are valued how much by which customers, and on the service supply characteristics in various settings. Thirdly, insights into context-appropriate designs (which type of service to deploy in which spatial and mobility context) should be gained. This research contributes to the third front by bringing certain aspects of realism into the scenario modelled.

The designed scenario explores the introduction of an SAV service in Leuven. It reckons that SAVs will coexist and compete with the already existing modes when they will get introduced. Further we assume that first, (S)AVs will operate on automation level 4 and require a controlled environment compliant with the ODD. In this study, only a limited ODD-compliant subnetwork (shared with conventional vehicles) connects the SAV service points, so that SAV routing options are limited. This is in contrast with previous scenarios explored in literature that assume all-round SAVs (level 5) serving all demand as if no private cars exist anymore (Martinez and Viegas, 2017; Zhang, Guhathakurta, and Khalil, 2018). Further, this study is the first in a Flemish context. It is of relevance as impacts are shown to differ between regions (Kröger, Kuhnimhof, and Trommer, 2019).

To enable the adequate modelling of this type of scenario, this study also differs from similar studies from a methodological perspective. Firstly, whereas the majority of research assume all, or a fixed number of trips to be served by SAVs (Martinez and Viegas, 2017; Fagnant and Kockelman, 2018; Zhang, Guhathakurta, and Khalil, 2018; Shen, Zhang, and Zhao, 2018), here a multimodal demand model is integrated. Further, most case studies assume travel times to be (S)AV-flow independent (Fagnant and Kockelman, 2018; Martinez and Viegas, 2017; Zhang, Guhathakurta, and Khalil, 2018; Shen, Zhang, & Zhao, 2018). However, as this study considers AVs of level 4 in a mixed traffic situation, travel times of regular cars might be seriously impacted. Therefore, the supply-side of the developed model incorporates a static traffic assignment in which private vehicles and SAVs route according to a deterministic user equilibrium (DUE) and travel times are assumed car and SAV flow dependent. SAVs are assumed to consume more capacity than regular vehicles because of their initial cautious behaviour.

2. METHODOLOGY

The case study of Leuven is visualized in Figure 1. The level 4 SAVs are restricted to drive on the ODD-compliant links indicated in blue, whereas conventional cars can use all roads. These blue links are part of the subnetwork which is chosen based on Claes (2020). Claes (2020) investigated the automated driving suitability of the roads in Leuven for level 4 AVs. Due to this restriction on certain roads, the service is no regular door-to-door service but station-based, in which passengers are picked up and dropped off at specific locations in the network, visualized in red in Figure 1. Further, it is a ride-sharing service in which multiple passengers may share the vehicle simultaneously. It is chosen to deploy the SAV service in 15 zones (green in Figure 1) with the highest demand that have a pick-up and drop-off point within a range of 500 meters.

Model

The developed model starts from a combined mode choice and assignment model which is further extended to enable the integration with the tour planning module, responsible for modelling the SAV service. These three components form the main building blocks.

Cascetta (2009) expressed this multimodal equilibrium assignment as a two-level problem and formulated a solution approach, called the external cycle approach. The procedure used in this study is based on that approach as it expresses the mutual dependency between the generalized transportation costs and demand externally to the one between link flows and travel time costs.

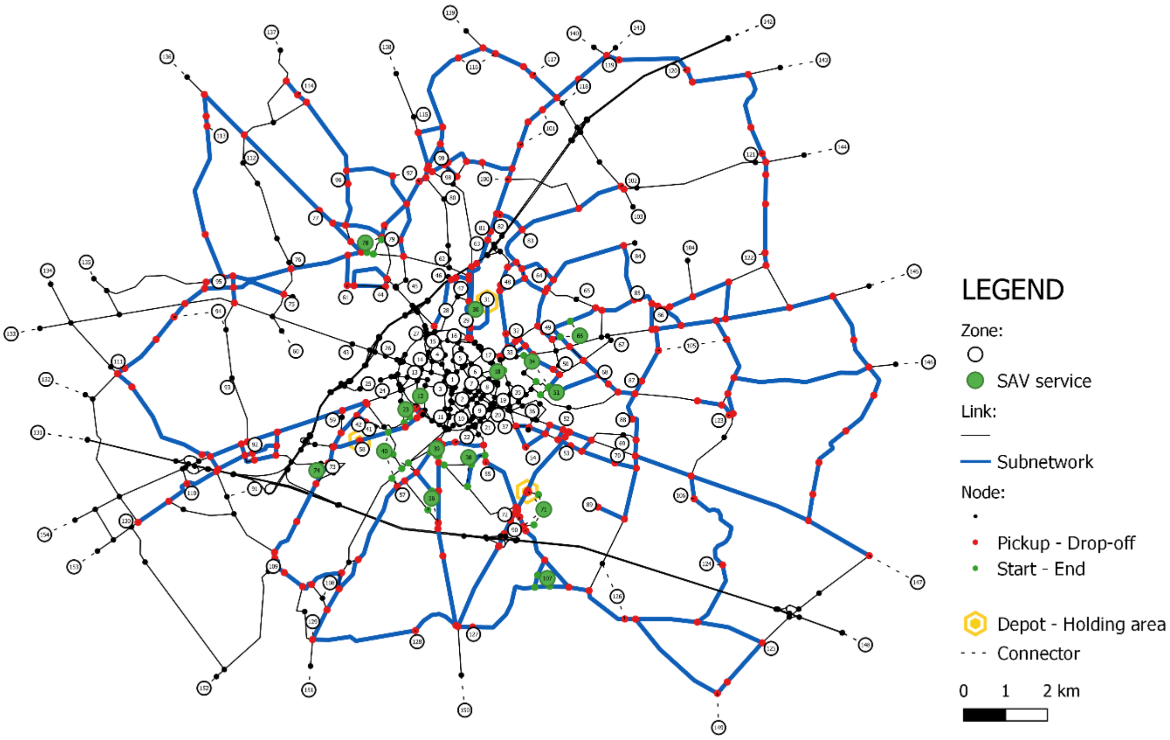

Figure 1: Subnetwork for vehicle automation

The **mode choice model** is a Multinomial Logit (MNL) model derived from the Provincial Traffic Model 3.7.1 (PVM 3.7.1), developed by the Flemish Department of *Mobiliteit en Openbare Werken* (MOW) (De Coster, Verlinden, and Van Houwe, 2018). The available alternatives are car, car passenger, PT, bike, and foot. The new mode of transport, the SAV service, should be added to the MNL model.

Due to the lack of useful stated choice data, assumptions on the parameters for the SAV utility function are made based on two approaches. First, attributes and coefficients are derived from the PVM 3.7.1 model as there are similarities between the car and PT modes and the SAV system. Secondly, assumptions are based on dedicated research reported in the literature (Alonso-González et al., 2020; Alonso-González et al., 2021; Carmen, 2019; Compostella et al., 2020; Kang et al., 2021; Krueger, Rashidi, and Rose, 2016; Lavieri and Bhat, 2019; Shaheen and Caicedo, 2021). Because of space limitation in this abstract, only the used papers are referenced, and no further explanation is given.

The **assignment model** includes a static DUE assignment of cars and SAVs on the network. Link travel times are modelled by volume delay functions following a standard BPR formulation. To model the presumably cautious behavior of early level 4 AVs, a PCU factor of 1.2 is taken into account (USTUTT, 2018). A PCU factor higher than 1.0 indicates that an AV takes more capacity than a conventional car and hence, results in higher travel times.

The **tour planning module** covers the modelling of SAV demand and supply interactions. As the quality of the SAV service is highly determined by the accessibility of the pickup and drop-off locations and the experienced detour factors for picking up other passengers, a microscopic modelling approach is preferred. For this, two procedures available in Visum are used (PTV group, 2021).

The *Generate trip requests* procedure available in Visum disaggregates the zone-based origin-destination (OD) SAV demand resulting from the mode choice model into trip requests with a specific start and end location within the origin and destination zones as well as a time window in which the person wants to be transported. Next, the dispatching of the individual SAVs to serve the sampled trip requests is performed by the *Tour planning* procedure available in Visum. These two steps are repeated multiple times such that average expected values regarding the SAV flows and provided LOS can be derived which can be used in the assignment and mode choice model that operate on an aggregate level.

3. RESULTS AND DISCUSSION

The developed multimodal equilibrium assignment model allows quantifying changing travelers' mode choices (Table 1) and the impacts of level 4 SAVs on regular traffic.

Table 1 shows that the new service reaches a market share of 21% in zones where this service is available. One notices the car and car passenger modes have become significantly less attractive. This is in contrast with most other research that finds that this type of service will attract most users from the more sustainable modes, such as PT (Vosooghi et al., 2019). An important reason explaining this is that the impact of the level 4 SAVs on travel times (see further) decreases the utility of the car modes (impact on PT, biking and walking travel times is ignored).

Table 1: Modal split

Scenario	OD pairs	Car	Car passenger	Public Transport	Bike	Walk	SAV
Reference	served[1]	48.5%	14.7%	13.6%	18.3%	4.9%	0.0%
Subnetwork	served[1]	38.0%	9.9%	11.6%	15.4%	4.3%	21.0%

[1] See service zones in Figure 1.

Concerning VHT, there is an increase of 23.6%. There is a significant impact on conventional car traffic. For the OD pairs served by SAVs, the average travel time by car increased by 52.3%. For the other OD pairs, the average travel time in the network increased by 21.4%. Total VKT increased by 1.7%. This overall increase in VKT is the result of the SAV service being less efficient in terms of kilometers driven per passenger (8.29 km/pass.) than regular traffic (4.03 km/pass.) because of empty trips between service and less direct routes over the subnetwork.

4. CONCLUSIONS

This study explored the impacts of the deployment of a level 4 station-based SAV service in the city of Leuven. The level 4 SAVs were restricted to drive on only a subpart of the network that was compliant with the ODD. The developed simulation framework included a mode choice model, allowing it to account for changing travelers' mode choices while assessing the impacts of the introduction of this new service. This, in combination with a traffic assignment model, enabled to determine the impact on regular traffic, in terms of VHT and VKT, as well. Results revealed that, in contrast with other literature, the SAV service can compete with private cars without cannibalizing the more sustainable modes such as PT, biking and walking when congestion levels increase, and it is made sure PT is not affected by that.

ACKNOWLEDGMENT

The authors like to thank Paul Ortmann, Mohammad Ali Arman, and Gaurav Malik of KU Leuven for their advice and guidance throughout the research process. Moreover, PTV is acknowledged for providing the traffic planning software VISUM with the tour planning procedure.

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