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Towards safe and efficient shared-space oriented DRT Service – some insights with real case study in Linköping

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Abstract

With the expeditious development in technology autonomous vehicles (AVs) are going to become a part of our daily life. Their possible influences on current transportation systems and the needs of the future traffic systems with the introduction of AVs have been investigated extensively with use of traffic simulation tools. Apart from simulation studies more and more real-life demonstrations of AVs are carried out and real AV data becomes available. The latter one facilitates to further properly model AVs' driving behaviour in traffic simulation. Related impact evaluations can then be more representative and support policy and decision making. In this paper, real autonomous shuttle bus data is analysed to understand driving behaviour, to derive vehicle-related parameters for enhancing microscopic traffic simulation model, and to find out possible issues in real traffic environment.

Keywords

autonomous shuttles, demand responsive transport (DRT), shared space, microscopic simulation

Introduction

Within this decade the autonomous vehicle field has had fruitful development outcomes. Technology innovation continues to shape the overall AVs' development and redefine/enhance possible transport services in various aspects, i.e. safety, efficiency, comfort and security. This benefits not only road users travelling with private cars, but also those who use public transport services. Parallel to technology innovation many demonstrations have been either carried out, in progress or in planning in different national and international projects for functional verification and validation as well as service demonstration in different daily scenarios. One of the current undergoing large demonstration projects is the European project SHOW (Shared automation Operating models for Worldwide adoption) [1]. Within this project, demonstrations will take place in 20 cities in Europe with more than 70 AVs and the focus is put on the enhancement of public transport with AVs.

Currently, AVs in the public transport area mainly appears in form of shuttle bus or robo-taxi. The former one is with a small capacity (maximum 15 people) and low travel speed (up to 25 km/h), and the later one is an autonomous car, mostly operated for a ridesharing company, with a maximum travel speed varying generally between 50 and 70 km/h in general. Both of them can be good means as a supplement for regular public passenger transport to extend public transport network coverage and area accessibility, and enhance overall service quality accordingly. Respective application condition mainly results from current technical development status, traffic situation and legislation limitation. The current service arts, provided by autonomous shuttle busses, can be either (1) demand-responsive stops, (2) fixed stops or a mix of (1) and (2), where route is fixed. Most use cases can already be conducted in public road environment [2, 3]. In comparison with that, the respective application in real shared space is quite limited due to challenges from higher dynamic interactions between an autonomous shuttle bus, bikes and pedestrians. Moreover, the demonstration scale with the aspect of the number of deployed autonomous shuttle busses is also still limited. In most of the cases 1-2 shuttles are deployed at a test site for a certain operation period. Therefore, microscopic traffic simulation is still an important instrument to find out possible issues during operation and the influence of autonomous shuttle buses and robo-taxi exploitation with different penetration rates and operation plans as well as at different scales and traffic demands.

In this paper, autonomous vehicle data, collected from a test site with shared space, parking activities and normal road, is analysed for getting more insights about autonomous shuttle bus's operation situation and possible raised issues during driving. After introducing the test site, the analysis result are presented. Based on the analysis result and the other collected infrastructure data, a basic simulation environment is set up and illustrated in this paper. Conclusion and discussion are given at the end of this paper.

Test site Linköping

The test site Linköping is a part of the Swedish twin mega pilot in the European project SHOW, and is also a part of several other projects, such as ELIN [4]. This test site locates in the Linköping University (LiU) area, where not only the university but also schools, day-care centers and residential apartments/houses exist. According to the demonstration phases, this test site can be further divided into two parts. The first part is the campus area, and the respective demonstration has begun in late 2019. The second part is in a residential area with local businesses and the respective demonstration activities are under planning. The aim of the demonstration in the project SHOW is to show how autonomous shuttle buses can (1) improve user experience for all involved users and (2) provide a robust first/last mile solution to public transportation. An overview of the test site is illustrated in Figure 1. Currently, one EasyMile shuttle bus with SAE level 4 and a capacity of 12 passengers is running clockwise in the campus area and serve at 8 pre-defined bus stops. In the second phase this shuttle will also run in the residential area together with an additional Navya shuttle bus later on. The planned Navya shuttle will be SAE level 4 and have a capacity of 14 passengers. The allowed maximum speed on the operation route is 14 km/h at the present time. The service period is basically from 8 to 18 on weekdays and from 10 to 17 on weekends, and may be subject to change due to circumstances such as demand, changes in regulations or research experiments involving the shuttle.

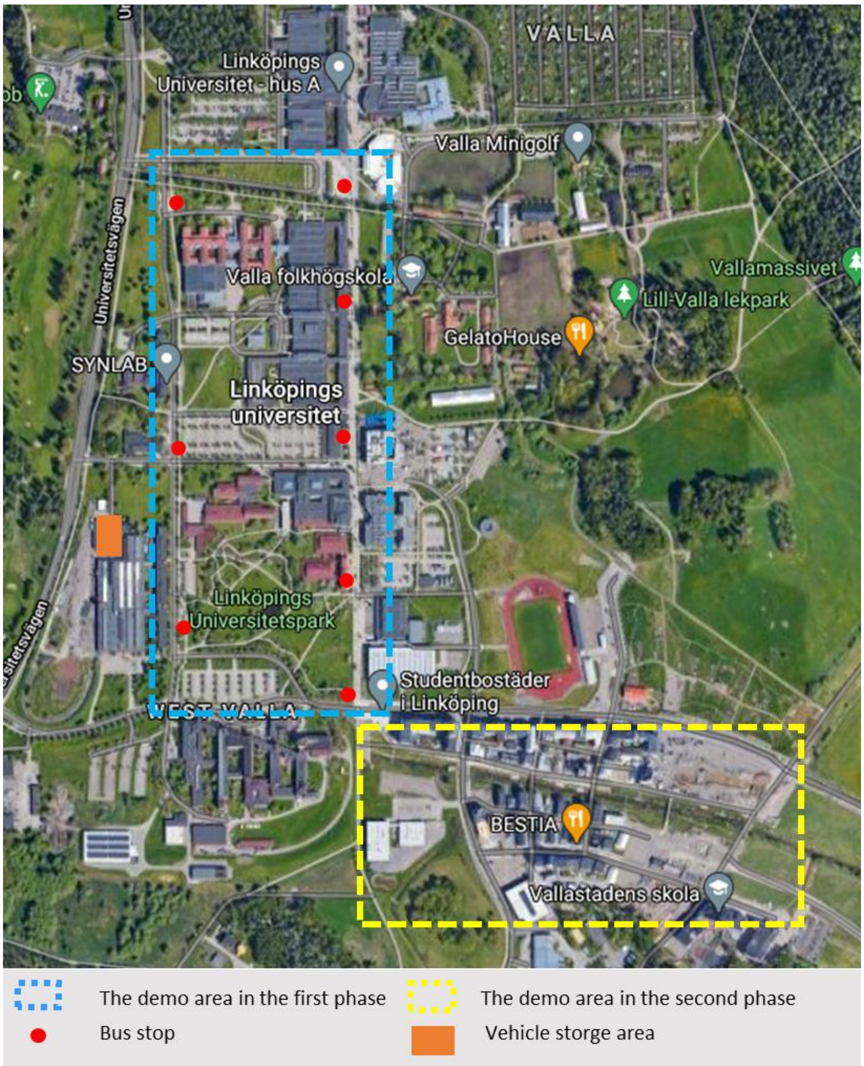


Figure 1 Overview of the demonstration areas at the test site in Linköping (map source: Google Maps).

The current demonstration track covers not only normal public roads, but also shared space, and can be categorized into four sub-stretches with different characteristics:

(1) Eastern road stretch: shared space corridor with a bi-directional and non-divided bike path (one shared lane for both directions) in the center of the road, and non-separated pedestrian paths on both sides. The shuttle bus shares the lane with bikes and has interactions with bikes and pedestrians. Moreover, the shuttle bus serves at five bus stops in this corridor.

(2) Western road stretch: bi-directional street (one lane in each direction with narrowed reversible lane at three road sections) with separated bike and pedestrian paths on both street sides. The shuttle bus interacts with conventional vehicles in road sections and interact with pedestrians and bikes at unsignalized intersections. In this stretch, there are three bus stops for regular busses and the shuttle bus.

(3) Southern road stretch: bi-directional street (one lane in each direction) with two intersections connected to a car park. The shuttle bus interacts with conventional vehicles coming from or going to the car park.

(4) Northern road stretch: one-way street (1-lane) with roadside parking and separated pedestrian paths.

The shuttle bus interacts with conventional vehicles and vehicles doing parking activities.

With the involvement of various road characters and road users the respective driving data of the shuttle bus and surrounding data, if available, can be good sources for enhancing simulation model.

Data analysis

The used vehicle data set covers the period from September 1, 2020 to November 7, 2020. Besides of the timestamps, speeds and geo-coordinates other information, such as vehicle control mode, door situation and supervision mode, is also available. This information can help to further understand more driving situations during operation. Invalid data and data collected during the off-duty periods are filtered out before analysing the data. Moreover, there are four data entries every second, and the first data entry of each second is used for second-based analysis. The focus here is to examine the parameters related to modelling the shuttle bus in traffic simulation and the driving situations for finding out existing and potential issues.

Speed

Figure 2 shows the distribution of speeds, grouped by the driving modes, per operation day. Some negative values appear, which mean that the shuttle bus drives backwards. It is clear to see that such behaviour occurs mainly during the manual driving mode. Moreover, the vehicle runs slower at the manual driving mode than at the automatic driving mode. The maximum speed is 3.58 m/s (12.88 km/h), which corresponds to the allowed maximum speed (14 km/h).

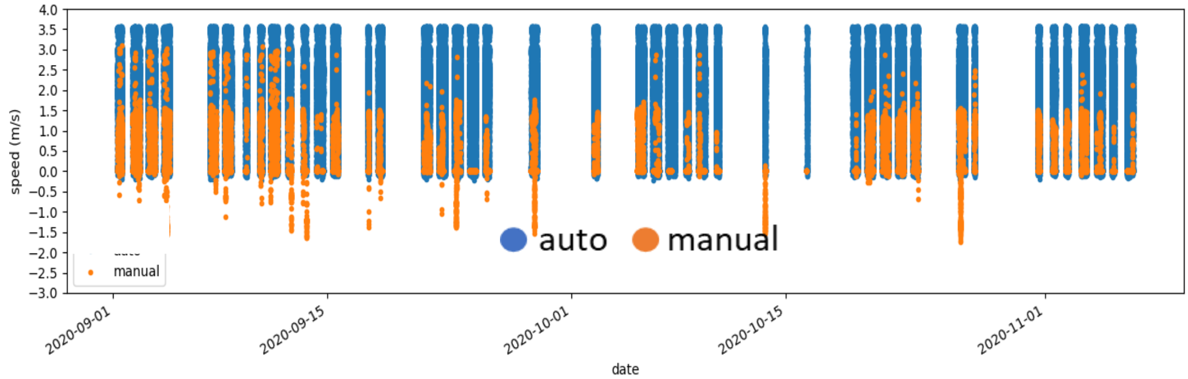
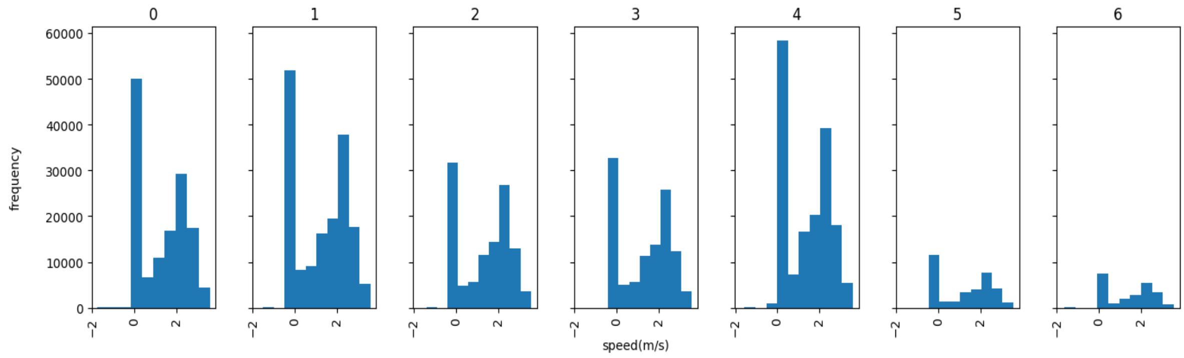


Figure 2 Speed distribution per operation day

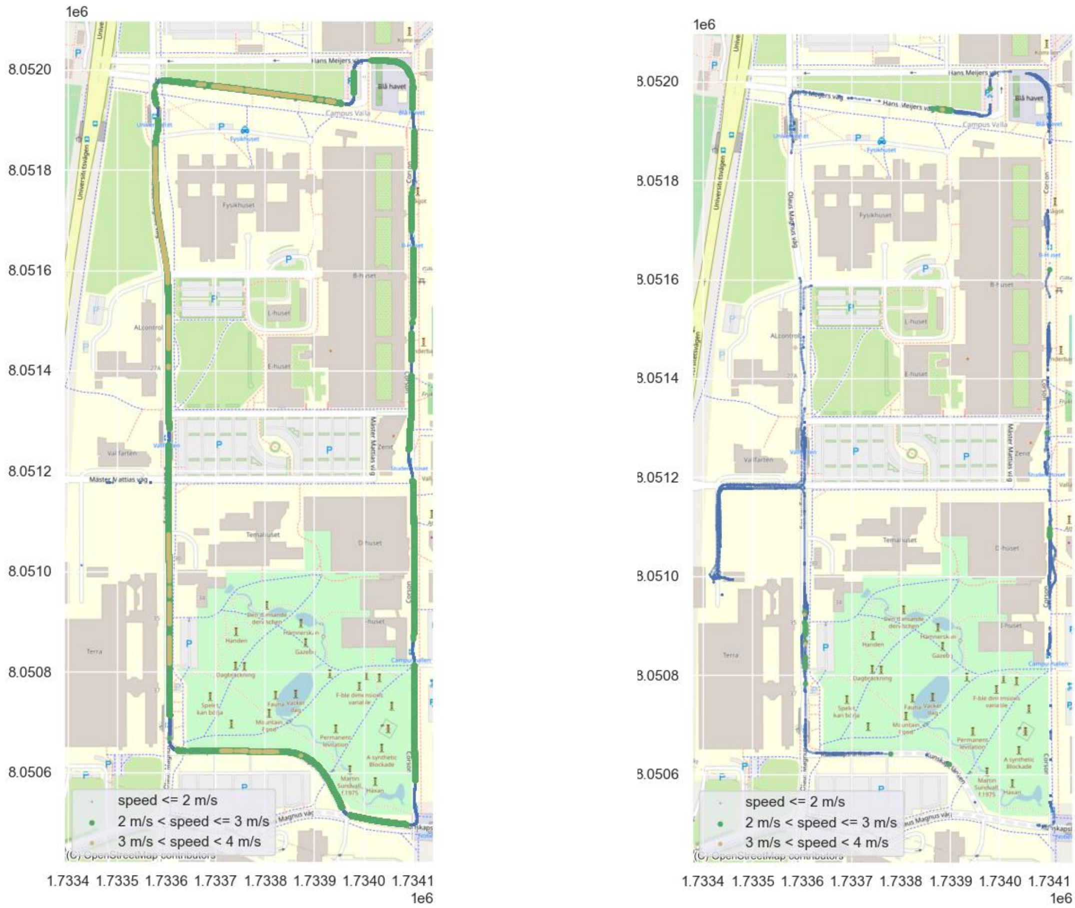
In Figure 3, it indicates that most speeds are between 0 and 2.5 m/s. Only a few of speeds are larger than 3 m/s. The daily speed patterns are generally similar to each other, where there are more speed values very close to or equivalent to zero on Mondays, Tuesdays and Fridays. It may implicate that more interactions between shuttle bus and other road users raise on these days than on Wednesdays and Thursdays given that the daily operation plan is the same in the week.



Note: 0: Mondays; 1: Tuesdays; 2: Wednesdays; 3: Thursdays; 4: Fridays; 5: Saturdays; 6: Sundays

Figure 3 Speed histogram per weekday

To help to further understand the speed variation, the operating speed are plotted along the operation route according to the respective geo-coordinates. Figure 4 (a) shows clearly that the shuttle bus at the automatic driving mode can run with higher speeds (between 3 and 4 m/s) in the western, southern and northern road stretches, i.e. the road stretches (2), (3) and (4) defined in the Section Test site Linköping, but not in the eastern road stretch, where the shared space exists. Furthermore, speed lower than 2 m/s occurs mostly at curves, next to bus stops and in the shared space corridor. When at the manual driving mode, most speed values are lower than 2 m/s (see Figure 4 (b)) which is due to restrictions on maximum possible speed in manual mode.



(a) at automatic driving mode (b) at manual driving mode

Figure 4 Speed distribution along the route

Acceleration

Generally speaking, comfortable acceleration for autonomous shuttles is between -1 and 1 m/s^2 with the consideration of passengers on board [5, 6], especially for unbelted or standing passengers. When acceleration is out of this range, it implicates that unexpected conflicts with other road users raise during operation. Here, acceleration values are derived from the speed values and the respective timestamps in the applied data set. Figure 5 and Figure 6 display the distribution of the accelerations, grouped by the driving mode, per operation day and the acceleration histogram per weekday respectively. In most of the cases, the acceleration values are within the comfortable acceleration range. When at the manual driving mode, the acceleration range is mostly from -1 to 1 m/s^2 and, in some few cases, the acceleration values are between -2 and -1.5 m/s^2. The acceleration spectrum becomes wider, i.e. between -3.5 and 0.98, when the shuttle bus runs at the automatic mode. The number of the cases with a deceleration rate larger than 3 m/s^2 are very few, while there are some more cases with an acceleration between -3 and -1 m/s^2. The respective reason can be better investigated if data collected from the respective surrounding environment is also available.

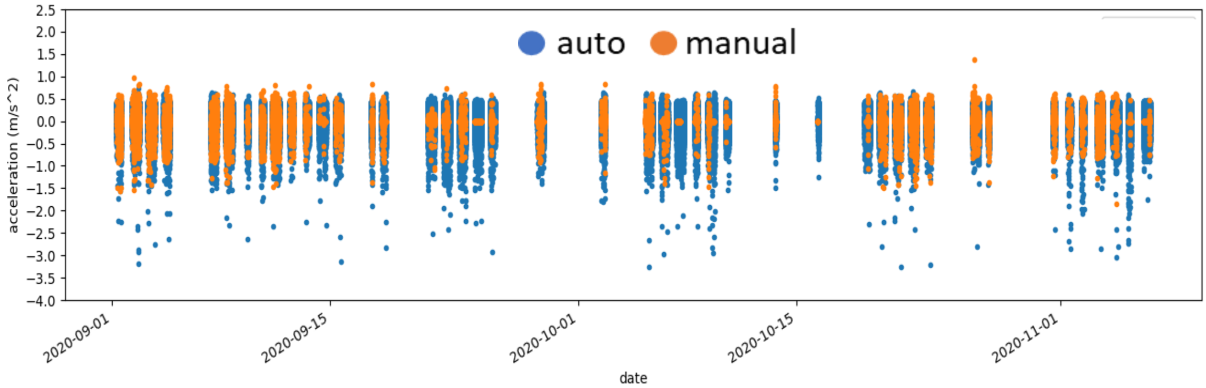
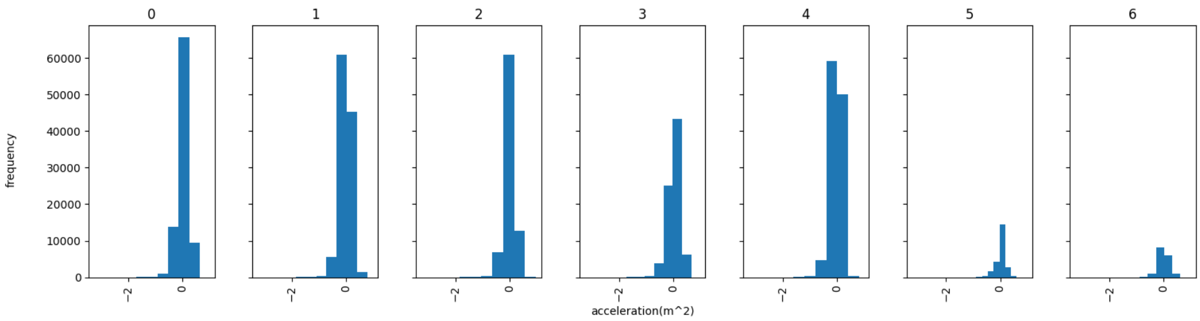


Figure 5 Acceleration distribution per operation day



Note: 0: on Mondays; 1: on Tuesdays; 2: on Wednesdays; 3: on Thursdays; 4: on Fridays; 5: on Saturdays; 6: on Sundays

Figure 6 Acceleration histogram per weekday

When observing the acceleration distribution along the route in Figure 7 it is clear that most of the uncomfortable decelerations (> 1 m/s^2), indicated in yellow, orange and red, occur in the shared space corridor, where direct interactions between the shuttle bus, bikes and, sometimes, pedestrians happen.

Furthermore, uncomfortable deceleration is often found in the northern road stretch with roadside parking and in the upper part of the western road stretch. In the last part, deceleration rates larger than 3 m/s^2 have raised in few cases.

Manuel and automatic driving modes

In most of the cases, the shuttle bus runs at the automatic driving mode. The application of the driving modes along the route are further examined to figure out at which places manual driving mode is often activated and with which kind of door mode, either “closed” or “opened”. Figure 8 shows that manual driving occurs often at curves, in the middle of the shared space corridor and in the eastern and southern road stretch, or at the entrance or exit of a car park is located. In these areas, the door mode value is sometimes “opened” not only at bus stops but also between stops. Many factors, such as weather and unexpected events, may affect the driving mode. In addition, it shows that only manual driving mode is used between the storage area and the intersection connected to the western road stretch of the operation route. It can be seen as preparation stage.

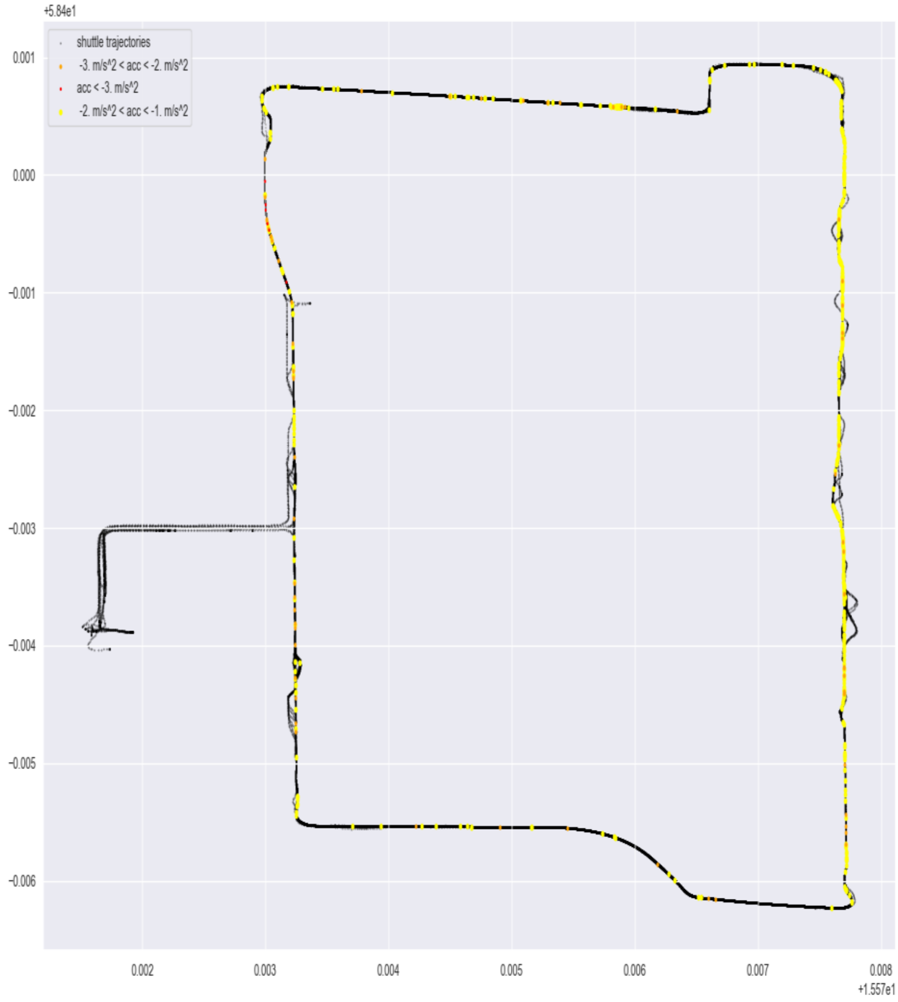


Figure 7 Acceleration distribution along the route

Figure 8 The distribution of driving modes along the route

Simulation set-up

According to the above-mentioned data analysis, the available shuttle bus technical data and the collected traffic infrastructure data a microscopic simulation environment has been established in SUMO [5]. This simulation network is based on OpenStreetMap. The respective parking facilities, the shared space where bikes and the shuttle bus share the bike path and bus stops are considered in the simulation. The built simulation network corresponds to the campus layout plan, as illustrated in Figure 9. This simulation environment will be used as a base for model enhancement and scenario assessment.

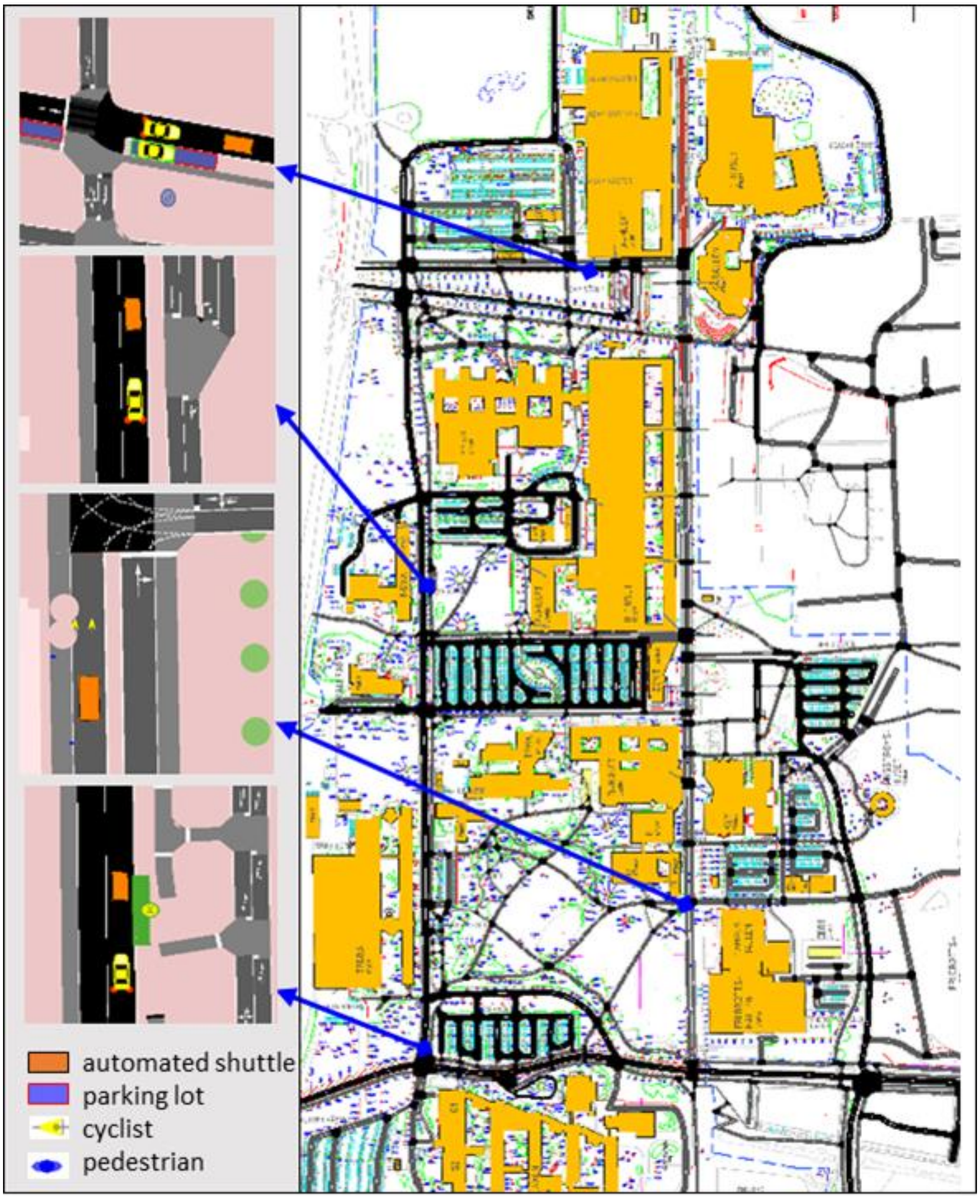


Figure 9 Simulation network built with SUMO (background map source: Akademiska Hus)

Conclusion and discussion

With the readiness of today's technology, the influence of autonomous vehicles can be evaluated not only by traffic simulation tools, but also with real-life demonstrations, which covers various traffic conditions. Real AV data becomes available accordingly. However, the current demonstration scale at most test sites is still quite limited in general. AVs' impact at city or regional level cannot be derived directly from demonstration. Traffic simulation can help to overcome this limitation and provide quantitative evaluation results for supporting policy and decision making. With real AV data simulation model can be further enhanced to closely reflect the reality and existing and potential issues during operation can be examined and possibly found out.

The test site Linköping consists of various traffic elements, i.e. shared space, (roadside) parking, and narrowed reversible lane, and it makes the whole demonstration rich. In this paper, 10-week data from the test site Linköping is analysed to derive the speed and acceleration characters of the shuttle bus on the operation route. The result shows that, in most of the cases, the shuttle bus runs comfortably. The average speed is under the allowed maximum speed (14 km/h) all the time. Speed in the shared space corridor is under 3 m/s (10 km/h) steadily, while higher speeds (> 3 m/s) appear in the other 3 road stretches of the route. This is understandable due to more interactions between shuttle bus, bikes and, sometimes, pedestrians. Moreover, in most cases, the shuttle also runs within the comfortable acceleration range. Uncomfortable decelerations (> 1 m/s^2) occur on all road stretches of the route, and most of them are in the shared space corridor. When looking at driving modes, it is revealed that the shuttle bus runs automatically in most of the time. When at the manual driving mode, it often happens in the shared space corridor, the road sections related to parking activities and the western road stretch with narrowed reversible lane. One of the possible reasons is that some objects block the virtual track, which the shuttle bus follows. Thus, manual driving mode is activated for overtaking objects and guiding the shuttle bus back to its track.

Although this demonstration has been running since the beginning of 2020, the involved road users are quite limited due to COVID-19. The demonstration at the test site Linköping continues to go on and will be executed at least until 2023. More shuttle bus data will be available. Once road users take the shuttle bus as part of the daily life, higher running smoothness and higher degree of complete automation of the shuttle bus is expectable. If data related to vehicles, pedestrian and bikes in the surrounding environment could be also available, deeper insights about the driving situations can be obtained. This also helps to figure out the issues, which the shuttle bus deals with and faces.

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