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SHared automation Operating models for Worldwide adoption

SHOW

Grant Agreement Number: 875530

Deliverable 12.5: Swedish CCAV demonstrators

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Legal Disclaimer

Executive Summary

The SHOW project aimed to support the migration towards effective and sustainable urban transport through technical solutions, business models and priority scenarios for impact assessment. This was achieved by deploying shared, connected, and electrified fleets of automated vehicles in coordinated Public Transport, Demand Responsive Transport, Mobility as a Service and Logistics as a Service operational chains in real-life urban pilots.

The goal of deliverable *D12.5: Swedish CCAV demonstrators* is to give a consolidated overview of the Swedish public pilots in SHOW. Full-scale pilots have been performed at two Swedish sites, in Linköping and Gothenburg between 2022 and 2023 (UC1.1; 1.2; 1.3; 1.6; 1.7; 3.4 at both pilot sites and UC3.1; 3.2 additionally in Linköping). Common events, knowledge exchange and experience building activities have been central to the success of the Swedish Site.

The main innovation of the Swedish Twin Site was intended to be a 5G control tower concept that could remote monitor and tele-operate a fleet of vehicles on both sites. This was enabled by 5G connections, and a traffic tower based on Drive Sweden Innovation Cloud open platform. Legal regulations and vehicle technology did however not allow for remote driving. Another central theme in the Swedish Twin Site was showing a multi actor business environment. Several Original Equipment Manufacturers and Public Transport Operators were involved in the Swedish site. This enabled good exchange of experiences and knowledge transfer.

Linköping and Gothenburg are located in the southern part of Sweden. Gothenburg at the west coast is the second biggest city in Sweden with 600,000 inhabitants. Linköping in the south-east is the fifth biggest city with a population of 167,000 inhabitants.

The Linköping site demonstrated a robust, safe, and reliable operation of fleet of three electrified automated vehicles. The route was 4.2 km long and had 13 stops. The site included both a mixed traffic with separate lanes for Vulnerable Road Users (VRUs) and shared spaces with VRUs. The speed limit is between 30 and 40 km/h; however, the ODD of the automated shuttles' speed was lower than 20 km/h. For Linköping, one Navya DL4 shuttle L4 and two EasyMile EZ10 Gen2 shuttles have been operated by Transdev Sweden AB for 23 months operation from February 2022 to December 2023. The shuttle service in Linköping was carried out as an interval-based supply with a start in morning and end at the end of the day. On weekdays the service ran from 08:00 until 18:00 CET, on weekends between 11:00-16:00 CET. Passengers were able to easily see on a digital map where the shuttles were, allowing seamless journey as they have been offering a "first mile - last mile" service to existing public transport. They could inform the shuttle through the app that they plan to go and from where, this information could also be send through pressing a button at the bus stops.

The most important goals for the large-scale pilots in Linköping were (1) to provide a service for all end users, including children with special needs, elderly, and other groups with specific travel needs, as well as (2) to test cooperation among multiple OEMs and multiple operators. In Linköping, the geographical context was also considered as important to evaluate how the mobility service and its technology fit into a real-life context. In particular, the University area was used to evaluate interaction between shuttles, pedestrians, and bicycles. The newly built residential area Vallastaden, built with sustainable smart city in mind, has relatively few parking spaces and is optimized for walking and cycling. The shuttles provided a first and last mile solution to the nearby trunk line. Besides commuters and residents in the area, a particular focus was on children <15 years old, with reduced mobility from a local

school and on elderly people > 66-90 years old, with reduced mobility from a retirement home in Vallastaden. Several activities have been conducted to understand their needs and wishes. The site collected the subjective views of the passengers, stakeholders and superusers (more frequent users). Linköping site has also applied relevant tools to collect and stream in real time all key data/Key Performance Indicators (KPIs) (i.e. vehicle position, speed, number of passengers, etc.) deriving from vehicle on-board equipment and from additional data sources (e.g. event diaries of safety drivers, i.e. on accidents). Subjective data has been collected using the project digital user acceptance surveys and interview guides. Data collected was used for various internal and public services (such as the digital map) whilst they have fed the project impact assessment and simulation analyses; key KPIs are visualised in the project public Dashboard (https://show-project.eu/show-dashboard/).

During the pilot period, February 2022 and December 2023, 10,938 passengers have been transported at Linköping site. The challenges provided the site with a greater understanding about the potential of AV operation, but also revealed the barriers today, such as that the technical development needs to continue. The operation revealed challenging situations and limitations of automated operation in real traffic environments and with the current infrastructure. During the pilots, the technical issues were solved, and the operation was adjusted over time by safety measures, updates, etc. Hard braking of the shuttles needed to be reduced since the service aimed at residents of a caregiving home and persons with special needs, e.g. a need to be able to predict and foresee what is going to happen next on board. The mounting of wheelchairs was not safe since no backrest exists in the automated shuttles and hence backward facing was not possible. The main cause of hard brakes was weather issues, which might be reduced with machine learning. In fact, the majority of the passengers were positive about the automated shuttle (AS) ride, it has been deemed important to attract more car users for which the ride is a positive experience. The driver role was variant in the shuttles, i.e. they needed to support both the shuttle operation and the passengers, especially children, the elderly, and people with disabilities such as the visually impaired. An increased focus is needed on how the vehicles should be able to interact with passengers on the shuttle, but also with those outside (pedestrians, cyclists, and other vehicle drivers). The shuttles can be a complement to public transport, such as feeder traffic to trunk lines. However, then there is a need for more automated vehicles (AVs) that also preferable run a bit faster than today. Focus should also be given to a more personalised booking using on demand functionality. The Linköping site installed call for service systems indicating passenger presence at bus stops (UC6.1). An on-demand booking system is planned to be launched in Linköping during the second half of 2024. In addition, the service might be complemented/ improved with strategies such as carpooling, parking management, micro mobility and other similar sustainable mobility paradigms. More effort should be put into perceived and actual safety for passengers of different categories. This needs to be solved before it is possible to remove the on-board safety operator and start to run on remote. The Linköping ecosystem continues with the AS service, currently with a focus on an on-demand solution for the users as part of the Ride the future initiative (https://ridethefuture.se/in-english/).

The Gothenburg pilot site was situated on the Chalmers university campus and represented a 2 km long route located on open public roads. The route had five stops, connecting public transport network, passing several interesting places (with restaurants, offices, Johanneberg Science Park entrance), the main library, a student residence, and a large parking lot. The traffic environment was urban and mixed traffic with car/bus traffic, cars, pedestrians, cyclists, and e-scooters, etc. The traffic density varied over the day, with rush hours in the morning, around lunch, and in the afternoon/evening. VRUs did not always have a dedicated lane / path along the AV route. For this pilot, two AS NavyaDL4 Arma ran along the route on Chalmers Campus Johanneberg in Gothenburg. The AS were integrated into the public transport network of Västtrafik in Gothenburg, as bus number 68.

The most important goals for the demo at Chalmers were (1) to provide a service for commuters to reach various areas of Chalmers University of Technology and (2) to demonstrate a safe and reliable operation of a fleet of electric automated vehicles for last/first mile service. Shuttles were operated since mid-October 2022 without passengers, and with passengers from February 2023 until June 2023. The dry run took more time than expected as there was a succession of issues connected to GNSS localisation on site, suspensions to replace etc. End-users were students, employees and visitors at Chalmers Campus and Johanneberg Science Park. At Gothenburg site, 1778 passengers have been transported in the final public operational phase, following the pre-demo phase, whereas the number of passengers varied over the time and during the day. Gothenburg pilot site, much like the Linköping site, also used a fleet management system (UC1.8) and the SHOW digital surveys to collect performance and subjective data and feed services, analyses and the SHOW Dashboard. Prior to anything else, data collected was utilised to produce actionable insights for Keolis (pilot site operator) to monitor the service performance (UC7.1; 7.2). The system was also integrated with the public transport operator in Gothenburg, regarding the timetables. Subjective data was collected including passengers and stakeholders.

Tests of early warning system VRU were successfully performed (UC1.3). The tests demonstrated technical feasibility of position-based warning systems where e.g. pedestrians were warned about approaching vehicles.

The large scale pilots showed that further technology development is needed. There are still many interventions necessary to enable a shuttle service, e.g. by adapting the infrastructure before setting up the service for passengers and during operations, such as manual driving due to obstacles on the shuttles route, including badly parked vehicles, snow piles and other weather difficulties. Thus, it was positive to have an operational team in place to work on site and in back office for diagnostic and fixing those issues iteratively during operation. Passengers were interested in this new mean of transportation. Yet, further business model development is needed to increase the understanding of the different demands/user needs. It is important to attract more passengers and user groups by improving communication about the transport option (by e.g. digital channels). Integrating shuttles in PTA system (as was done in Gothenburg) was a plus, together with real time data and other services for customers. Beyond SHOW project and level 3 shuttles operations, Keolis is currently working on developing projects and on-demand functionality in a test site in France.

The overall results from both pilot sites point to a technically feasible, although with at current date limited maturity, and appreciated concept. Several technical issues were dealt with during the course of the project, resulting in services that were in large parts perceived as useful and with potential for long-term use by the travellers. The overwhelming majority of the travellers were however individuals that would otherwise have walked or travelled by bicycle, strengthening the importance of achieving a sustainable modal shift that does not bring the opposite results and working more with complementing strategies. The shuttle service in Gothenburg was closed in June 2023 and no further operation is planned for.

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Abbreviation List

Abbreviation	Definition
API	Application Programming Interface
AS	Automated Shuttles
AV	Automated Vehicle
CCAV	Cooperative Connected Automated Vehicle
DMP	Data Management Portal
DRT	Demand Responsive Transport
HMI	Human Machine Interaction
KPI	Key Performance Indicator
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PT	Public Transport
PTA	Public Transport Authority
PTO	Public Transport Operator
TMC	Traffic Management Centre
UC	Use Case
VRU	Vulnerable road user
V2X	Vehicle to Everything

1 Introduction

1.1 Purpose and structure of the document

The goal of deliverable *D12.5: Swedish CCAV demonstrators* is to give a consolidated overview of the pilots performed at the Swedish Megasite. The document describes the two Swedish pilot sites Linköping and Gothenburg. The high level vision of the Mega Site is presented in Chapter 2 and the summary of operations taking place in that is provided in Chapter 3. Sites' detailed operations are described in Chapters 4 and 5 of the document respectively. Each Chapter, structured in the same way, summarises for each site the ecosystem, the fleet, infrastructure, services, use cases and target users. Further, it provides the reader with a description of the operations, data collections, and a selection of pilot operation key findings including key local pilot events, key challenges and impacts as well as lessons learned and a roadmap beyond SHOW towards replication. The document ends with a common conclusion of the Swedish Megasite (chapter 6).

1.2 Intended Audience

Deliverable 12.5: Swedish CCAV demonstrators is public and provides a consolidated overview of the large-scale pilot trials performed at the Swedish Megasite for people outside of the project consortium, aiming to share insights and lessons learned from the operations performed at the two Swedish pilot sites of SHOW.

1.3 Interrelations

Deliverable 12.5: Swedish CCAV demonstrators is related to the other pilot site deliverables to learn from and exchange the key findings of the different operations and use cases. Further, D12.5 builds upon *Deliverable 1.2: SHOW Use Cases*, which aimed to the identification and elaboration of the priority urban automated mobility Use Cases of the project, stakeholder interest and public acceptance. In *Deliverable 9.3: Pilot experimental plans, KPIs definition and impact assessment framework for final demonstration round* the common evaluation framework and the methodological approach for the final pilot evaluation are described. In Appendix I of D9.3 each site has described the experimental plans for the final pilot phase of SHOW.

Further discussion on this and other pilot sites deliverables follow in *Deliverable 12.9: Real life demonstrations pilot data collection and results consolidation* as well as in *Deliverable 13.5: SHOW impact assessment on user experience, awareness, and acceptance*, whereas, overall WP13 and WP10 Deliverables describe the impact assessment and simulation studies correspondingly that were fed by the Swedish (and all other pilot sites) results, insights and data collected.

2 High level vision of Swedish Twin Site and joint goals

The main innovation of the Swedish Twin Site was intended to be a 5G control tower concept that could remote monitor and tele-operate a fleet of vehicles on both sites. This was enabled by 5G connections, and a control tower based on Drive Sweden Innovation Cloud open platform. The long-term target was to prove a robust, safe and reliable operation of a fleet of electrical automated vehicle fleet with the 5G control tower that would enable removal of operator in the vehicle: a requirement for a commercial use of AVs in public transport.

Another central theme in the Swedish Twin Site was showing a multi actor business environment where different OEMs, public transport operators and service providers were to complement and combine operations in the same site.

The Swedish demos addressed the following Use Cases.

	UC	Comment
Automated traffic in real city environment	*1.1; 1.2; 1.3; 1.7*	Both sites ran vehicles/shuttles on public roads, offering public transport where none previously offered.
Connection to actual TMC and centralised teleoperation demo	*1.8*	Both sites delivered data to the Ericsson Traffic Tower and Show Dashboard. 5G was used in both pre pilot and full pilot.
Multi actor business environments demo	*2.1; 2.2; 2.4*	Sites included multiple PTOs and OEMs, offering insights to differences and needs of different organization structures.
Operational services in bus stops	*6.1*	Including e.g. on demand installations and information services
Enhanced services demo	*7.; 7.2*	Examples of user groups engaged in pilot: Elderly; Children; Disabled; Students; General public

3 Overview of pilot sites

The Linköping and Gothenburg sites were in the southern part of Sweden and performed pilots of shared automated passengers´ mobility in urban and peri-urban areas. Table 1 gives an overview of the duration of operation, the vehicles, use cases and involved passengers at each site. Estimated number of travellers were reached in one of the two sites. The Gothenburg site was limited due to more technical issues with vehicles and site, but also to find the 3rd vehicle than was foreseen.

Table 1: Overview of Swedish Mega Site contributing pilot sites during pilot phase.

Pilot site	Duration of operation	Leader	Vehicles	Use Cases (by ID and name)	Number of passengers transported in PUBLIC OPERATION
Linköping	23 months	VTI	2 EasyMile EZ10 Gen-2 1 Navya DL4 Arma	UC1.1 Automated passengers' mobility in Cities under normal traffic & environmental conditions UC1.2 Automated passengers' mobility in Cities under complex traffic & environmental conditions UC1.3 Interfacing non automated vehicles and travellers (including VRUs) UC1.6 Mixed traffic flows UC1.7 Connection to Operation Centre for tele-operation and remote supervision UC3.1 Self-learning Demand Response Passengers mobility UC3.2 Big data/AI based added value services for passengers' mobility UC3.4 Automated services at bus stops	10,938
Gothenburg	5 months	Keolis	2 NAVYA DL4 Arma	UC1.1 Automated passengers' mobility in Cities under normal traffic & environmental conditions UC1.2 Automated passengers' mobility in Cities under complex traffic & environmental conditions UC1.3 Interfacing non automated vehicles and travellers (including VRUs) UC1.6 Mixed traffic flows UC1.7 Connection to Operation Centre for tele-operation and remote supervision UC3.4 Automated services at bus stops	1778

4 Linköping Pilot site

4.1 The ecosystem

The Linköping site has had a local demo board consisting of eight members (Figure 1).

Figure 1: Linköping´s local ecosystem partnership

In addition, Veridict and Edeva was involved to provide specific solutions relevant for SHOW with regards to digital infrastructure. The Linköping Ecosystem is presented in the following table on a more operational level.

Table 2: Pilot site ecosystem at Linköping

Participating Entity	Internal to the Consortium (√)	External to the Consortium (√)	Role
VTI (The Swedish National Road and Transport Research Institute)	√		Site leader and responsible for the evaluation. Financial support of the shuttles, acting as depot, providing the workshop for service and installations. Owner of 1 shuttle.
Transdev Sweden	√		PT operator. Responsible for the daily operation with 8 shuttle safety operators. Financial support of the shuttles. Management and support for the daily operation. Owner of 2 shuttles.
Östgötatrafiken AB		√	PT provider. Responsible for the connection to PT. Financial support of the shuttles.
RISE (Research Institutes of Sweden)	√		Responsible for the digital infrastructure and solution including Dashboards, stream of data to DMP, visualisation of maps, rider information, etc.
LiU (Linköping University)		√	Hosting students, one of the key traveller groups also involved in land use issues. Financial support of the shuttles.
Linköping municipality		√	Owner of the ground in Vallastaden, responsible for communication issues, and infrastructure solutions like bus stops etc. Responsible for the maintenance and service at Vallastaden. Owner of the school and the retirement home with one of

Participating Entity	Internal to the Consortium (√)	External to the Consortium (√)	Role
			the key travelling groups. Financial support of shuttles.
Akademiska hus		√	Owner of the ground, responsible for maintenance and service at Campus.
Combitech	√		Responsible for the dashboard and the preparations towards a remote solution.

4.2 Operation setting

In Linköping pilot site, the geographical context is considered as important to evaluate how the mobility service and its technology fits into a real-life context. In particular, the University area (in the middle of the map (Figure 2) is used to evaluate interaction between shuttles, pedestrians, and bicycles).

Nearby the university there is a newly built residential area, Vallastaden, built with sustainable smart city in mind. It has relatively few parking spaces and is optimized for walking and cycling. In Vallastaden, there is also a school and a retirement home for elderly people. The closest PT bus stop is almost 300 meters away and the automated shuttles (AS) were aimed to provide a first and last mile solution to the nearby trunk line. To the west an industrial and business area is located, called Linköping Science Park or “Linköpings Silicon Valley” where tech companies are located with 1000 employers who are commuting daily. However, this area is not directly connected to the PT trunk line. People work here, people study and live here and need to be transported in between.

The route is approximately 4.2 km long with 13 bus stops which are both shared with PT and used only from AVs (Figure 3). The AV’s depot is located at VTI’ backyard, approximately 200 meters from the main automated line.

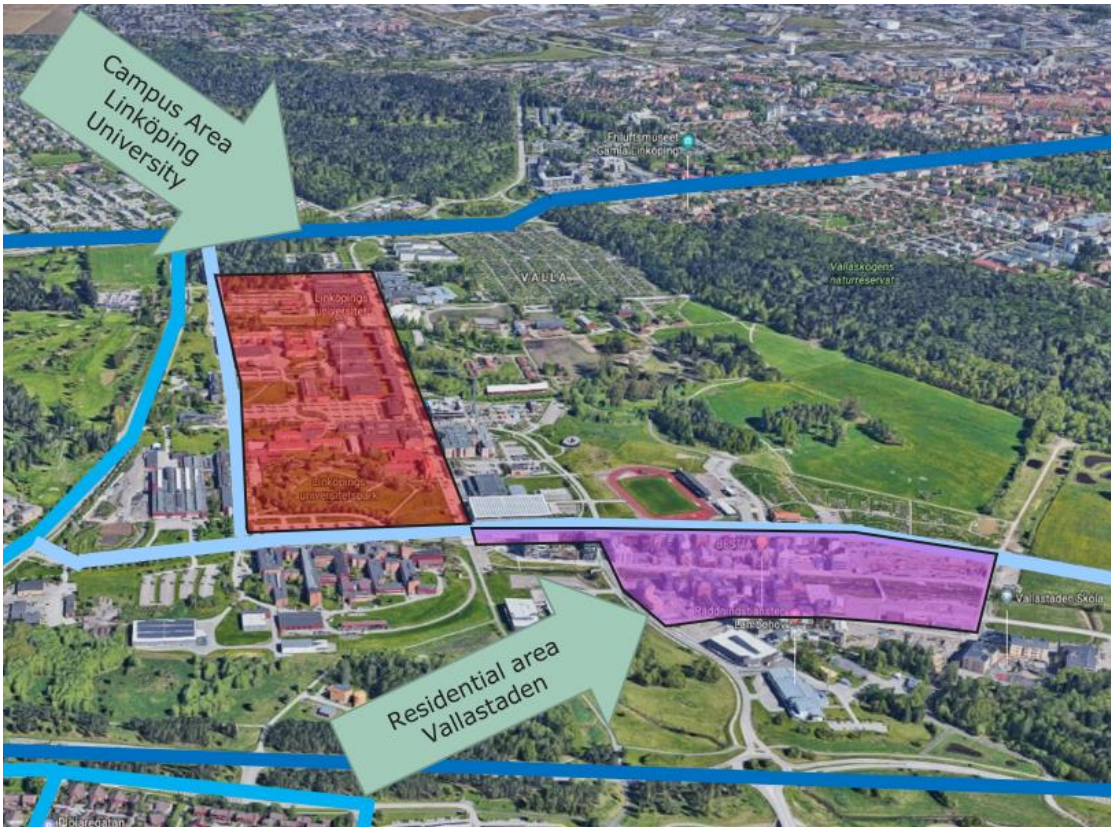

Figure 2: The geographical context in Linköping's Pilot site. The red area states the Campus and the purple area represents the Vallastaden residential area. The blue lines are illustrated as normal PT trunk lines

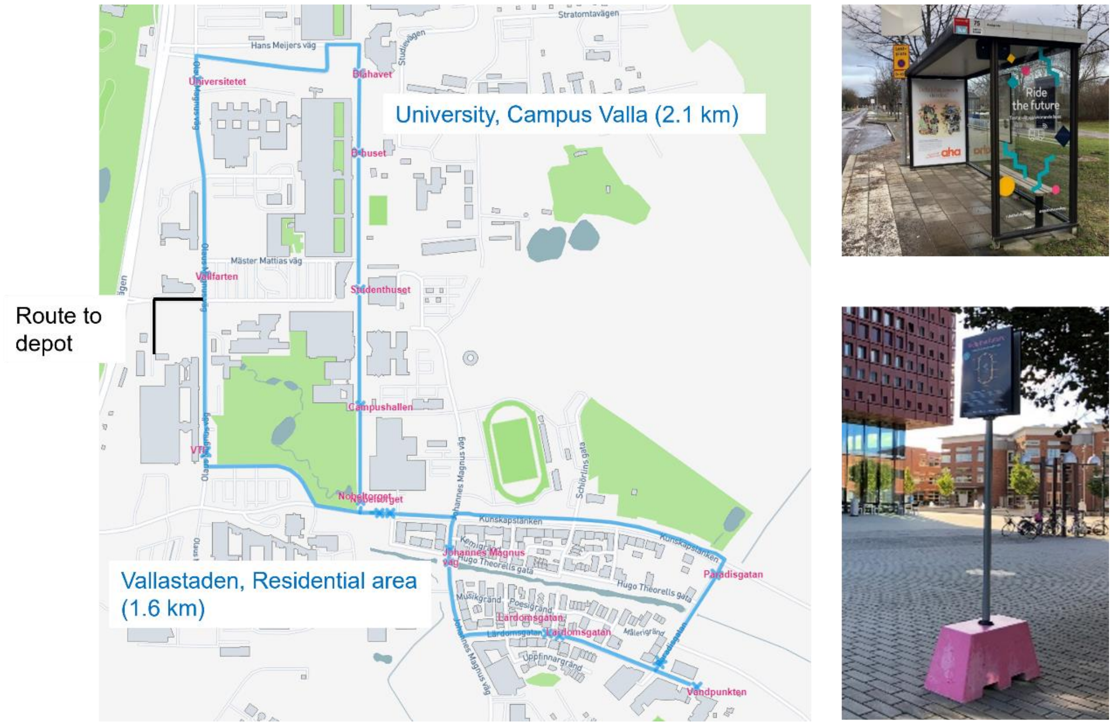

Figure 3: The driving path in detail, specifying length and bus stations as well as the representation of a merged AV and PTA bus stop and an explicit AV bus stop **(source photos: My Weidel/VTI)**

Weather conditions varied over the years being typical for the several seasons in southern Sweden with a combination of sun, rain, dry and snow conditions. The shuttles were equipped with winter tires during the winter season.

Varying weather conditions and related occurring problems (such as leaves, snowbanks, etc leading to e.g. hard braking) as well as the mix of road types deployed for the AVs mobility allowed to understand the potential but also revealed the barriers of the operation. The most demanding situation occurred when the campus was crowded with pedestrians and cyclist, as well as in Vallastaden during morning hours with lot of parents dropping off their children at school.

For more details about the conditions, see the following table:

Table 3: Road, traffic and weather conditions at site

Variable	Linköping
Weather	Temperatures varied between 25° C to -10° C
Sight conditions	Good. This is a requirement to have the capability to drive.
Road type	Urban roads with paths for pedestrians, shared space at Campus, dedicated PT designed road.
Road works	The Vallastaden part was under construction. Thanks to a good collaboration with the municipality, the understanding between the shuttles and the construction builders were good.
Incidents	Two safety operators fell due to unforeseen hard braking.
Traffic conditions	High density at mornings and evenings in general. At the Campus there were a lot of VRUs before start of the service during weekdays at 8:00 CET, at lunch 12-13:00 CET and at the end of the service, 16-18:00 CET) otherwise the area has more moderate volumes. On weekends the service was running between 11:00-16:00 CET with moderate volumes of VRUs in the area
Traffic composition	Depending on where on the route the shuttles are, it differs. The site is a combination of typical urban roads surrounding a Campus with mainly passenger cars to interact with (but also some zebra crossings), a dedicated area through Campus with high interactions with pedestrians and cyclists, and then a residential area with a lot of ordinary PT coming across a lot of interactions with buses and different type of cargo vehicles.
Traffic control	There is no physical traffic control that is digitalized. Real-time information was provided to travellers for AS and other buses positioning.
Area type	Most part around Campus and at Campus is in a typical peri-urban environment, the residential area was under construction and more city centre like.

4.3 Services and use cases

The most important goals for the large scale field trials in Linköping were the following:

- To provide a service for all users (end users), including children with special needs, elderly, other groups with specific travel needs, such as families
- To evaluate collaboration among multiple OEMs, PT providers and PT operators.

The Linköping site was in operation between February 2022 until December 2023. However, preparations and operation have been done stepwise on part of the route since mid-2021. Nine (9) safety drivers working for Transdev Sverige AB were responsible for the daily automated operation service.

The shuttle service was an interval-based supply running from morning to the end of the workday on weekdays (08-18:00 CET) and between 11-16:00 CET on weekends. Passengers were able to easily see where the shuttles are in real time, which enabled their seamless journey via the "first mile - last mile" service to existing public transport they offered.

A typical day of field trials for the site looked as follows (routine of operation).

> *The operation with the shuttles started at 8:00 CET in the morning, leaving the depot at VTI. The 3 shuttles were up running in parallel. During the day the safety drivers had a shift change with new drivers taking over after lunch and operated until 18:00 CET. On weekends, the service was operating between 11-16:00 CET.*
>
> *The shuttles were charged at lunchtime, however most often 2 were out driving while the third one was charged. In the end of the shift the shuttles were taken back to the depot in automated mode, cleaned, and charged.*
>
> *Throughout a day passengers got on-board along the route. Data was collected throughout the day and passengers were asked to fill in the acceptance survey as well as rating their satisfaction regarding the ride.*
>
> *The shuttles were operating in autonomous mode in varying degree depending on the season. As an example the last month during operation (December 2023) with the most demanding winter condition it went in automated mode more then 88% of the time. According to the Swedish regulation that applied at the start of operations, the Swedish Transport Agency's permit for experimental activities with self-driving vehicles requires a safety driver in or in the immediate vicinity of the vehicle.*

4.4 Site-specific test cases

In Linköping 8 use cases were covered, with the following site-specific test case descriptions:

First & last mile public transportation in normal conditions (responding to UC1.1 UC1.1[1])

Along the route there is a school for children with special needs and in the same building there is a residential for elderly people. The distance from this building to the PT trunk line is >300 meters and hence too long to walk. Thanks to the AV shuttle the children and elderly could access the PT. The shuttle service was connected to the PT trunk line.

First & last mile public transportation in complex conditions (responding to UC1.2[2])

The service operated with "extreme weather conditions" listed: snow and subzero temperatures during daytime operations.

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[1] UC1.1 Automated passengers' mobility in Cities under normal traffic & environmental conditions

[2] UC1.2 Automated passengers' mobility in Cities under complex traffic & environmental conditions

It snows in Linköping during the winter. Thanks to the AV service, passengers could easily and conveniently commute to/from their job/school/university with PT taking the shuttle for the first/last mile. Nevertheless, the operation was stopped when it snowed too much (impact on LiDARs, detecting snowflakes and thus braking), and when there was snow and ice on the road that may have impacted the behaviour of the shuttle: spinning wheels, etc.

Part of the route, in Vallastaden, does also interact with a main public transport prioritised road where the shuttles need to co-exist with faster and much larger busses.

First & last mile public transportation at shared space with VRU (responding to UC1.3[3])

The area at the Campus Core consists of a dedicated area for pedestrians and cyclists (Figure 4, right). The AV shuttles were integrated as an additional mobility solution and used to get to the existing PT bus stops, rental e-bikes or parking space in the outer boundaries of the area.

Figure 4: Shuttles operating in Vallastaden (left) and Linköping Campus (right) (source: My Weidel/VTI)

First & last mile public transportation in mixed traffic (responding to UC1.6[4])

In the area of Vallastaden (Figure 4, left) the operation was done on normal traffic road and integrated with passenger cars, buses and trucks using the same lanes. In addition, pedestrian/cycle crossing exists, sometimes with prioritisation for shuttles and sometimes not. The shuttle service was connected to the PT trunk line.

Linköping operational centre (responding to UC1.7[5])

Using the shuttle manufacturers proprietary APIs and operational dashboard for monitoring and the APIs for control (to initiate actions) and additional sensors, the shuttles connected to an operation centre via a monitoring dashboard solution. Initially the connection was only to monitor operation (and save data for further usage). In a second step simple “Stop Here” indication functions were added “Stop Here” buttons were mounted on all bus stops, see next section.

[3] UC1.3 Interfacing non automated vehicles and travellers (including VRUs)
[4] UC1.6 Mixed traffic flows
[5] UC1.7 Connection to Operation Centre for tele-operation and remote supervision

On-demand stop signal at bus stops (responding to UC3.4[6])

The shuttles intended to stop only when there is an actual demand. Using the shuttles control APIs, the shuttles only stopped when travellers wanted to get on or off board. A simple but integrated and connected “stop button” was placed along the route (Figure 5). The stop button placed at each shuttle bus stop was installed and connected through a LoraWAN network to our NiFi servers (developed by RISE) to the app showing positions of the shuttles to passengers (developed by Veridict), showing also to the shuttle operator if passengers were waiting at a specific stop. The work was hence connected to a simplified on-demand service. Inside the busses there was a STOP button so the passengers can indicate that they like to get off on the next stop.

Figure 5: Simple stop buttons placed at each bus signed bus stop, showing the shuttle operator if passengers are waiting at a specific stop (source: My Weidel/VTI)

When a button was pressed, a message was sent via the LoraWAN network to a central server. The passenger request could be seen on the local real time map and an SMS was sent out to the safety driver at duty, i.e. the working safety drivers were alerted that passengers were waiting at a specific bus stop. The route was still fixed though so this is not a true on-demand service.

[6] UC3.4 Automated services at bus stops

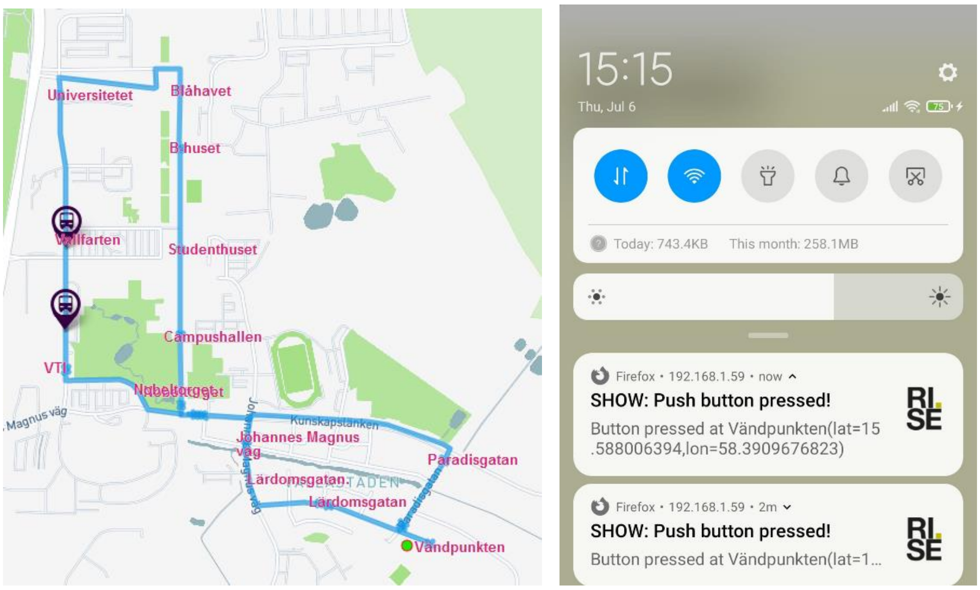

Figure 6**:** Passenger waiting at “Vändpunkten” and SMS notification when a passenger had pushed the “Stop Here” button.

Route optimisation based on passenger counting (responding to UC3.1[7])

Using historical travel data (such as number of travellers, boarding and disembarking per stop, date and time) a self-learning solution for route optimisation was used for suggesting number of shuttles per sub route, frequency and automatic stops along the routes.

Personalised route (on & off) suggestions (responding to UC3.2[8])

The purpose of this use case was to combine real-time city-wide public transport information, historical travel data and passenger information. Thus, it was possible to suggest the most optimal way of transport for all individual users of this service in terms of where and when to embark and disembark.

The system considers the users’ personal preferences and/or limitations e.g. special needs:

- Strategic: when to leave home/work/school to get to the shuttle that connects to PT, etc.
- Tactical: to know when and where to go and to get off the bus stop taking the passengers specific needs into consideration.

[7] UC3.1 Self-learning Demand Response Passengers mobility
[8] UC3.2 Big data/AI based added value services for passengers’ mobility

4.5 The fleet

The Linköping pilot site consisted of a total of 3 AV shuttles (2 EasyMile EZ10 Gen-2 and 1 Navya DL4 Arma, see also Figure 7).

Table 4: Fleet characteristics at site

Test/Use Case	**Deployed fleet characteristics**								
	Vehicle brand & model	**Vehicle type (shuttle, …)**	**SAE Level reached for the field trials [1-5]**	**TRL level reached for the field trials [1-9]**	**Summary of upgrades held during the project (in consistency with D7.2)**	**HMI and Hand-over strategies (in consistency with D7.2)**	**Maximum speed reached during the trials (km/h)** [9]	**Average speed during the trials (km/h)** [9]	**Maximum capacity of vehicle**
Same for all UCs: UC1.1; UC1.2; UC1.3; UC1.6; UC1.7; UC3.1; UC3.2; UC3.4:	EasyMile EZ10 Gen2-036	Shuttle	4	6	SW version Voyager 7 updated to SW Voyager 11	Vehicle normally runs in autonomous mode. When an event occurs, the vehicle requires handover to the safety driver. At complicated crossings with other traffic a yield by the	22	3.91	6 PAX (only seated allowed due to harsh braking)

[9] Due to contractual reasons no comparison between the vehicles were allowed. So, only the average values are presented.

Test/Use Case	Deployed fleet characteristics								
	Vehicle brand & model	**Vehicle type (shuttle, …)**	**SAE Level reached for the field trials [1-5]**	**TRL level reached for the field trials [1-9]**	**Summary of upgrades held during the project (in consistency with D7.2)**	**HMI and Hand-over strategies (in consistency with D7.2)**	**Maximum speed reached during the trials (km/h)** [9]	**Average speed during the trials (km/h)** [9]	**Maximum capacity of vehicle**
						driver is required.			
	EasyMile EZ10 Gen2-038	Shuttle	4	6	SW version Voyager 7 updated to SW Voyager 11	Vehicle normally runs in autonomous mode. When an event occurs, the vehicle requires handover to the safety driver. At complicated crossings with other traffic a yield by the driver is required.	22	3.91	6 PAX (only seated allowed due to harsh braking)
	Navya DL4 Arma	Shuttle	4	6	SW version 4.11.3 updated to SW 6.1.4	Vehicle normally runs in autonomous mode. When an event occurs, the vehicle	22	3.91	6 PAX (only seated allowed due to harsh breaking)

Test/Use Case	**Deployed fleet characteristics**								
	Vehicle brand & model	**Vehicle type (shuttle, …)**	**SAE Level reached for the field trials [1-5]**	**TRL level reached for the field trials [1-9]**	**Summary of upgrades held during the project (in consistency with D7.2)**	**HMI and Hand-over strategies (in consistency with D7.2)**	**Maximum speed reached during the trials (km/h)** [9]	**Average speed during the trials (km/h)** [9]	**Maximum capacity of vehicle**
						requires handover to the safety driver. At complicated crossings with other traffic a yield by the driver is required.			

Figure 7**: The three AV shuttles in Linköping. The middle shuttle is a Navya DL4 Arma, the two on the sides are EasyMile EZ10 Gen2 (source: My Weidel/VTI)**

The Navya and the EasyMile G2-036 have been used during the whole test period while the EasyMile G2-038 was introduced during 2022.

4.6 The infrastructure

The infrastructure consisted of two parts: Campus and Vallastaden. The first part of the Campus part was on public road with interactions with PT and other passenger cars, the second part was through the heart of the Linköping's University using the shared space with the path for cyclists as the road. The Vallastaden part was only on public road, passing through a construction area ending up at the school by Linköping's municipality and retirement home for people with cognitive disabilities. The route was extended during the final pilot and included a turn back loop through Paradisgatan making the route as two circles (see red markings in the map in Figure 3). The shuttles were stored, cleaned, and charged at a depot on VTI premises.

The shuttles had a large number of built-in sensors that record, among other things, speed, acceleration, compartment temperature and battery temperature. In addition to the sensors that were delivered with the shuttles, the Linköping partners themselves retrofitted an air quality sensor on the shuttle as well as an improved accelerometer and gyroscope (Edeva). Inside the compartment there were also two tablets. One was used for customer satisfaction research and the other for a system that records in real time where passengers get on and off the bus, a passenger counting dashboard (see further4.9).

In Linköping a solution has been developed to support travellers to know where the shuttles are in real time (Figure 8) and for them to send information to the safety operator that they want to take a ride (Figure 5).

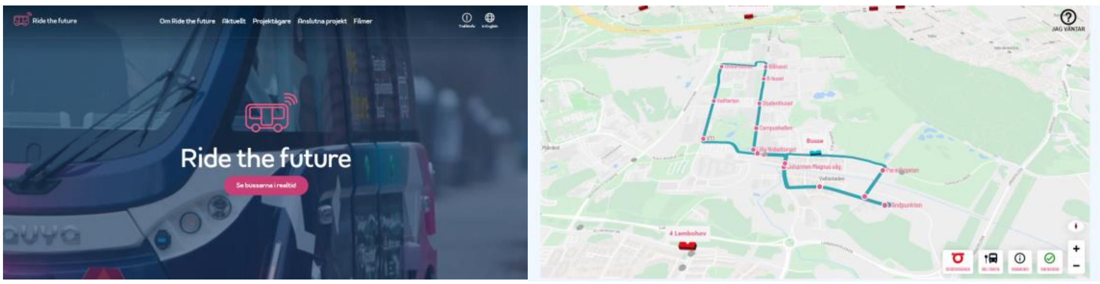

Figure 8: Homepage to access the real time map (left). The map contains blue buses for AVs and red for public transport (right) (source: https://ridethefuture.se/)

A digital map has been produced in which both the automated shuttles and regular public transport were shown in real time. Information on where to find this map was available at each bus stop as a QR code and furthermore there was a clickable link on the first page of the "Ride the Future" website (Figure 8).

4.7 Passengers

Type of end-users in Linköping were commuters and residents in the area. A particular focus was on children <15 years old, with reduced mobility and on elderly people > 66-90 years old, with reduced mobility. Several activities have been conducted already during the preparation and the pre-demo phase to understand the user group in focus (children and elderly) needs and wishes. On-board studies took place with children during normal conditions and more demanding situations (i.e. adverse weather conditions) – see Figure 9.

Figure 9: User engagement in Linköping with children - screenshots of paintings, elderly and blind persons with guide dogs (source: Anna Anund/VTI)

A local study on user acceptance and attitude from 2022, aimed at the public, showed that almost everyone who chose to travel with the automated shuttles otherwise walks or cycles [2]. Around 24% of those who answered would have taken the car otherwise.

Numerous dry runs have been performed during day-to-day operation by mapping and gathering preliminary user and technical input to develop and streamline the Linköping pilot site further before real-life pilot began. The pre-demo phase for Linköping was run between November - December 2021, after the realisation of then verification and validation procedure. In Linköping, there was an approach followed in conducting an as short as possible pre-demo pilot phase so that the site would proceed fast to the open to the public pilot phase (which it did). In total four videos have been created to show and inform VRUs and other road users on what to expect in relation to the automated vehicle’s behaviour (https://ridethefuture.se/filmer/).

4.8 Total number of passengers

During the pilot period, February 2022 to December 2023, 10,938 passenger rides have been recorded (in addition to the 401 passenger rides recorded during the pre-pilot period in November and December 2021; in total 17,000 passengers rides were recorded since 2020 until now). The passengers were mainly students at Campus, employees at Campus and visitors to the area. However, the safety operators at Transdev were very active inviting people to come on board and join the ride. There was a barrier to get people on again after the restrictions from Covid and when the shuttles have been running for technical test, but without passengers. The number of passengers varied from day to day (Figure 10; Figure 11). During the summer break in 2022 and 2023, the shuttles were not operating (mid-July – mid August) as it was the case in adverse weather conditions and when extraordinary technical issues arose.

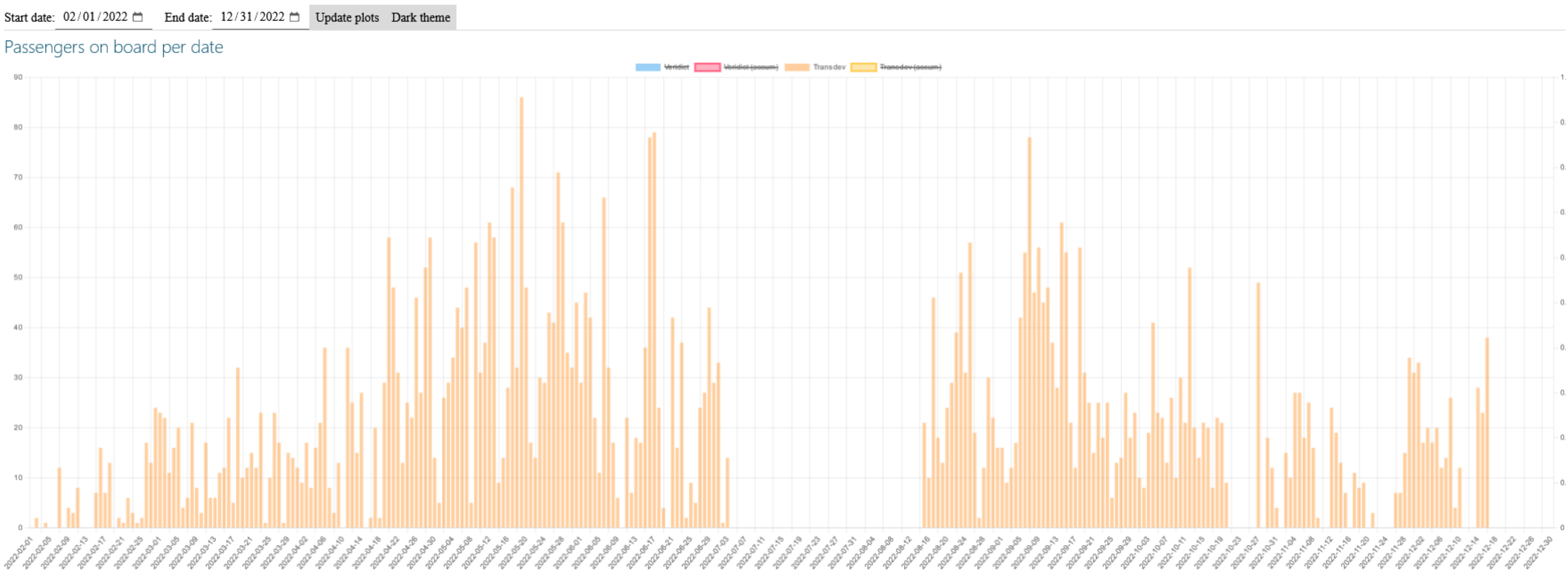

Figure 10: Number of passengers per day during the pilot period February 2022 – December 2022 (source: RISE)

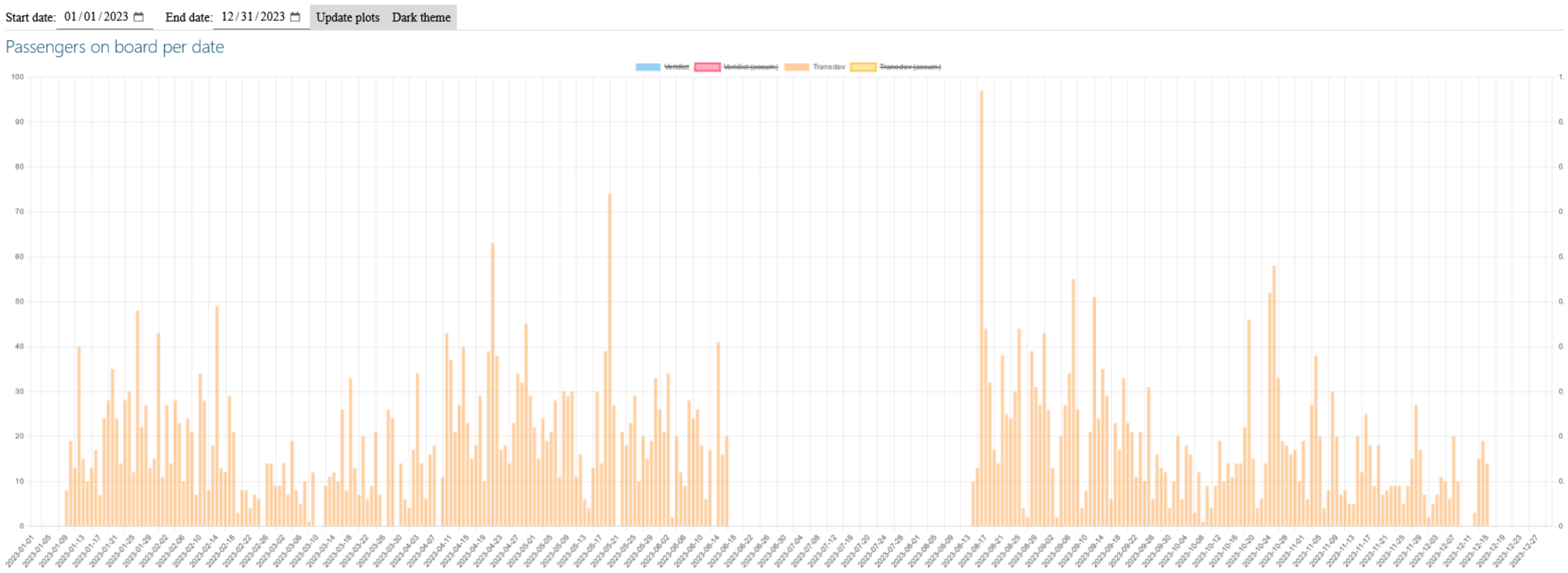

Figure 11: Number of passengers per day during the pilot period January 2023 – December 2023 (source: RISE)

The number of passengers stepping on/off per bus stop during the whole pilot period can be seen in Figure 12:

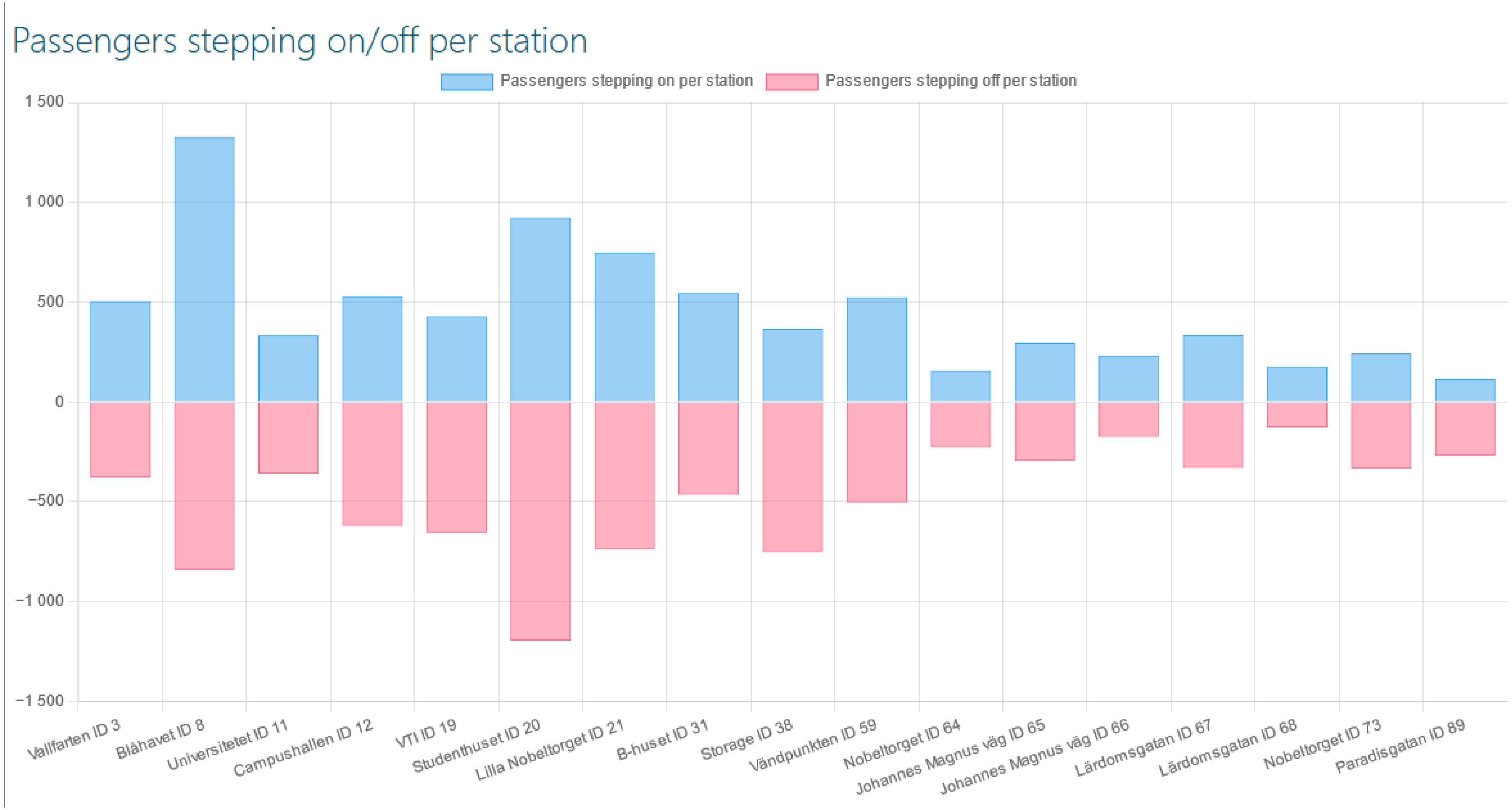

Figure 12: Passengers stepping on/off per station from February 1 2022 to December 31 2023 (source: RISE)

The number of passengers varied during the week with most passengers in the middle of the week (Figure 13) and during the middle of the day, between 11 am and 2 pm (Figure 14).

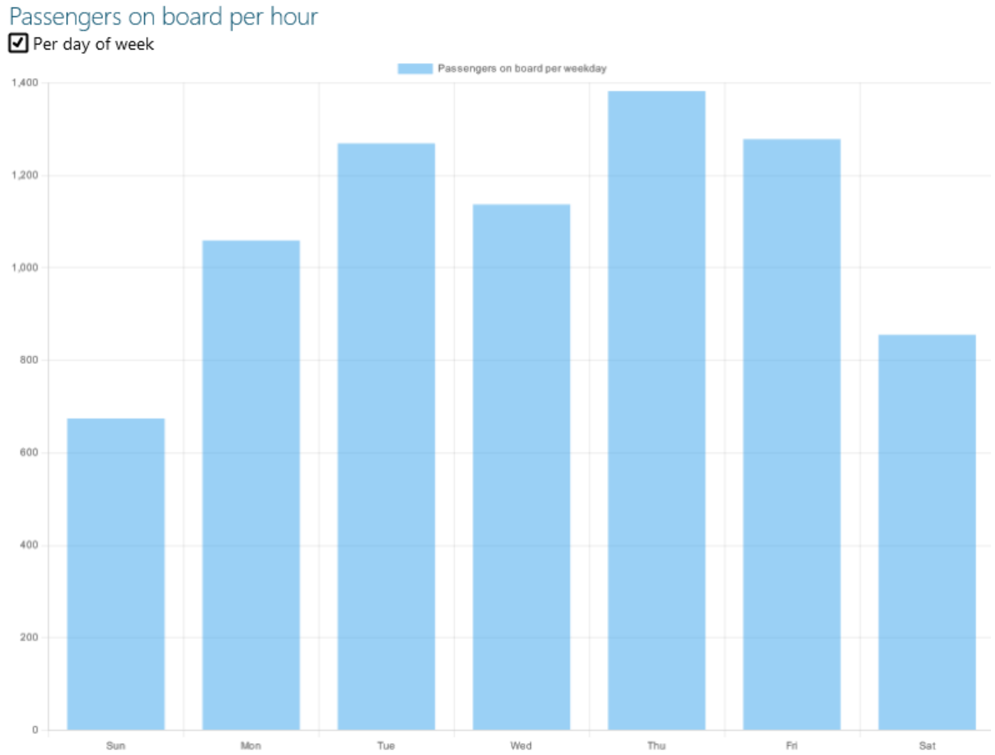

Figure 13: Passengers per weekday during the pilot 2022-2023 (source: RISE)

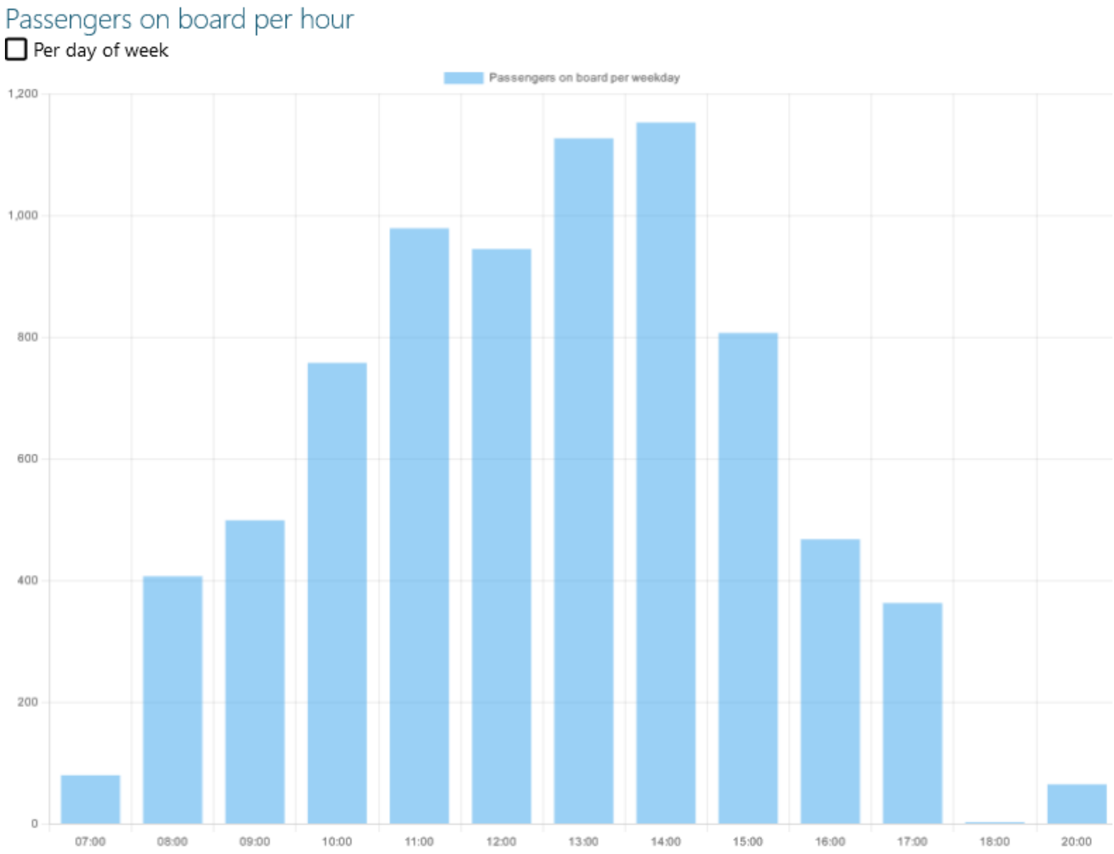

Figure 14: Passengers on board per hour (source: RISE)

4.9 Data collection

Linköping site has applied relevant tools to collect and stream in real time all key data/KPIs (i.e. vehicle position, speed, number of passengers, etc.). Those have been logged in the project DMP, used in some cases to feed other KPIs and in the context of impact assessment and simulation studies, and also visualised in the project Dashboard. The site had also additional data sources (i.e. event diaries of safety drivers on accidents, etc.) that have been used for complementing some KPIs, while environmental data like CO_2, dust particles, and weather data have been collected using a sensor from EDEVA. This was also used to get higher resolution of data to make it possible to calculate additional KPIs like Jerk. The sensor was partly finaced by SHOW, but mostly by VTI as in-kind.

A data collection system called NiFi (https://nifi.apache.org/) was used for collection of data (Figure 15). Nifi is an open-source project within The Apache software Foundation. It is developed to easily manage many heterogeneous data sources simultaneously. The NiFi system continuously downloads data from several of the mounted sensors and from the various subsystems. In several cases, the subsystems have their own data management systems with databases at the subcontractors. Nifi provides support for easily retrieving data via the various APIs (Application Programming Interface) that the subcontractors provide. When the data was downloaded, it was saved in a central database at RISE in Linköping and made available for various research projects.

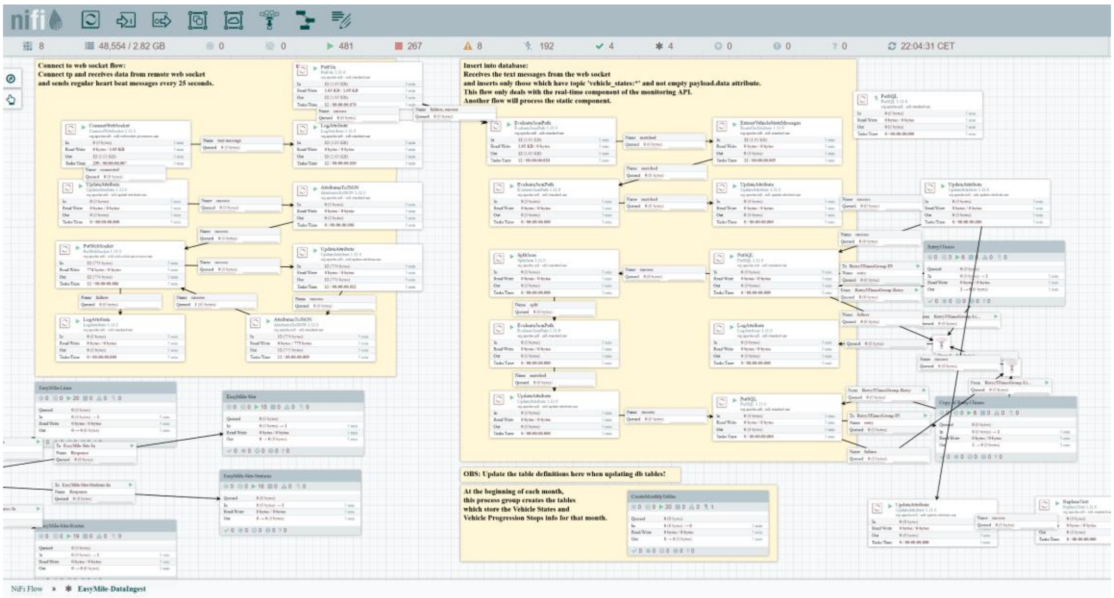

Figure 15: Screen shoot of the Nifi data collection flow for the Linköping site (source: RISE)

As mentioned, the collected data was then distributed to other system such as the SHOW DMP and more local tools as site dashboard maps and analysis tools, such as for passenger counting (Figure 10) and accelerometer data (Figure 16).

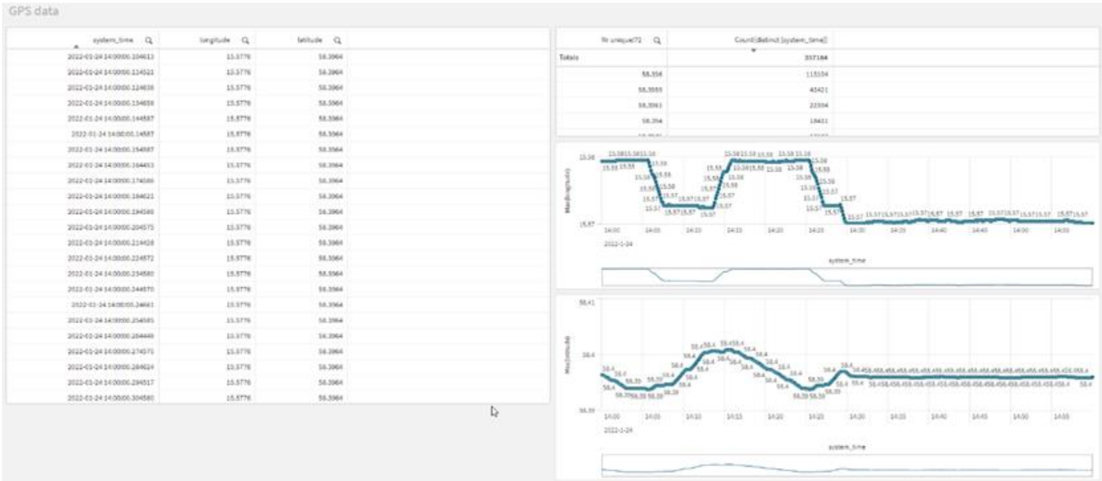

Figure 16: Examples from the local data analyses toolbox: high resolution GPS coordinates vs gyro and accelerometer data (source: RISE)

Based on the data provided from the available API coming from the shuttles it was clear that the resolution, especially for the acceleration, was too low. An extra system with accelerometers were installed in all three shuttles with a possibility to have data about x,y and z accelerations with a frequency of >50 Hz, to be able to calculate jerk (Figure 17).

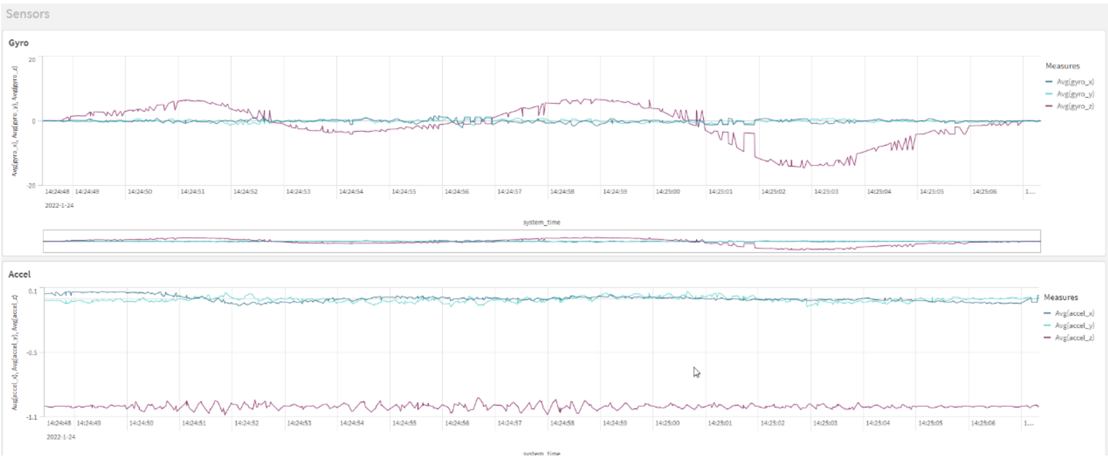

Figure 17: EDEVA system for 50 Hz measures of accelerations Linköping (source: RISE)

The collected data was then used for various internal and public services. Examples of the public services that used collected data were a dashboard developed by RISE and one by Veridict:

- Passenger counting dashboard (https://elin.linkoping-ri.se/dashboard)
- Real time map to show where the shuttles are (https://map.ridethefuture.se/)

To collect daily events for further analysis a solution for the bus drivers was developed by Transdev Sweden (see further in 4.10.3).

The site collected further the subjective views of the passengers, stakeholders and superusers (more frequent users). For the acceptance survey, the respondents were asked to use a QR pointing at the survey implemented in the survey tool Netigate. In total 150 respondents filled in the acceptance survey. The one question about satisfaction was implemented on a touch screen using five smiles from happy to not happy (Figure 18). One screen was implemented in each AV. For this survey 2212 answers were collected. The interaction survey, asking about experiences when encountering an automated vehicle (shuttle, car or delivery robot), had 96 responses. Feedback from 7 safety drivers was collected too.

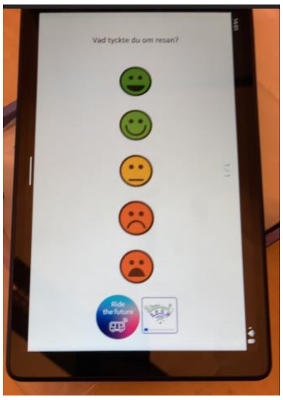

Figure 18: Touch screen for satisfaction reporting - Linköping

Interviews with stakeholders took place at the end of 2023. Three different stakeholders were interviewed using the prepared interview guide presented in D9.3. The received information was summarised and uploaded using the Netigate tool of SHOW. Analysis of subjective results follows in *D13.5: SHOW impact assessment on user experience, awareness and acceptance*, whereas key performance results follow in D12.9: Real life pilot data collection and results consolidation.

To collect data from experienced users, Linköping pilot worked with so-called superusers: a group of 10 persons recruited to travel at least 10 times/rides each. They were asked to indicate their experiences with the shuttles related to e.g. comfort, speed, safety, efficiency and accessibility (c.f. 4.10.4). The superusers study showed a potential for changing travel habits. Several of the students stated that they have changed their travel habits during the trip, yet from walking and cycling towards taking the shuttle busses. In the future, pedestrians/cyclists are not the target group the project aims at, in the long-term corresponding studies should be carried out with car drivers.

In SHOW, the overall impact assessment is conducted over two stages. The first being the stakeholder assessment through a MAMCA workshop. The second is quantitative assessment of the measured KPIs and further aggregation using the results of said MAMCA workshop. To validate this method, a pilot workshop was conducted at the Linkoping pilot site, after completion of the pre-demo phase, to test the methodology with stakeholders and improve the content and process. Due to the unavailability of all the measured KPIs, the second part of the overall impact assessment could not be conducted yet. More details on the MAMCA workshop in Linköping can be found in D9.3.

4.10 Pilot operation key findings

4.10.1 Key findings per Use Case

High level findings per Use Case		
Use Cases	Overall qualitative performance score (1-3[10])	Justification
UC1.1: Automated passengers/cargo mobility in Cities under normal traffic & environmental conditions *Linköping specific: First & last mile public transportation in normal conditions*	3	The operation worked fine, and we had more than 10,000 passengers during the final pilot phase. Satisfaction was scored high and also acceptance.
UC1.2: Automated passengers/cargo mobility in Cities under complex traffic & environmental conditions *Linköping specific: Operation during cold weather and snow and in complex infrastructure like 4-way crossings.*	2	The operation worked fine in 4-way crossings, but we have had major problems to find routines for days with heavy snow. Extra maintenance was ordered to remove snowbanks further from the shoulders to make the operation smooth. The ODD set a limit to run below – 10 degrees. We ran according to that, and it worked perfectly fine. Such days we needed to charge the vehicles during lunchtime.
UC1.3: Interfacing non automated vehicles and travellers (including VRUs) *Linköping specific: First & last mile public transportation at shared space with VRU*	3	The operation ran through a shared space area. No crash or severe incident were reported. Satisfaction and acceptance were high. Through parallel HMI projects and student projects we found that there was a need for a standard, preferable multimodal, to make it more clear for actors that interact with the shuttle what its intention is and what to expect from it and hence how they were expected to act close to the shuttles.

[10] 1 [Low] – 2 [Medium] – 3 [High]; success qualitative score, considering all aspects (technical, user acceptance).

High level findings per Use Case		
Use Cases	Overall qualitative performance score (1-3[10])	Justification
UC1.6: Mixed traffic flows *Linköping specific: First & last mile public transportation in mixed traffic*	3	The operation ran in mixed traffic with PT and other vehicles. No crash or incident happened. The speed of the shuttle was slow. This was seen as both good and bad. The good thing is that it will not attract those that can walk or cycle by them self, the bad thing is that it will not be attractive enough for car drivers. Another good thing is that if hard breaking happened the effect of it was not serious. The driver onboard could support and explain why it ran slow. This was very positive during the operation.
UC1.7: Connection to Operation Centre for tele-operation and remote supervision *Linköping specific: Linköping operational Dashboard*	1	Legal barriers existed – and there was no way to test this in real life setting. The local dashboard with a real time map and simple control function was set up, orders were sent but no action in real time could happen due to legal barriers.
UC3.1: Self-learning Demand Response Passengers/Cargo mobility *Linköping specific: On-demand stop signal integrated in the web application with real time data on bus position.*	2	Drivers continuously stored number of passengers getting on and off at bus stops. This was continuously used for the planning of the operation. A first light version was developed that made it possible to inform the drivers (book) through the webpage that a passenger wanted to go. This was however not a customer promise. In the future, the next generation of on-demand has been planned and from the 15th of August 2024 on-demand using Padam solution will be kicked off in Linköping.
UC3.2 Big data/AI based added value services for passengers' mobility *Linköping specific: Personalised route (on & off) suggestions*	2	It was demonstrated how to combine real-time city-wide public transport information, historical travel data and passenger information as an added value service. By this, we could suggest the most optimal way of transport for all individual users of this service in terms of where and when to embark and disembark. The

High level findings per Use Case		
Use Cases	Overall qualitative performance score (1-3[10])	Justification
		system was able to consider the users' personal preferences and/or limitations e.g. special needs.
UC3.4: Automated services at bus stops *Linköping specific: On-demand stop signal at bus stops*	3	Stop buttons at bus stops were integrated both as hardware and software. The function was aimed to support persons without mobiles (hence without access to the webpage for booking). It worked fine from a technical perspective.

4.10.2 Key challenges and mitigations outcomes

The key challenges have been identified below. They often provide the site with a greater understanding about the potential of AV operation, but also reveals the barriers as of today.

Table 5: Key challenges at Linköping pilot site

Challenge	**Type** (Operational, Technical, Business, Other)	**Mitigation**	**Mitigation outcome**
Certain weather conditions and their implications (such as leaves, snowbanks, etc.) can cause problems related to hard braking.	Technical, Operational	Shuttles were equipped with safety belts for the passengers and a safety arm as a support for the safety driver. Good maintenance can help to reduce this, as well as updates. But the system is designed to quickly reduce speed when obstacles occur, to avoid accidents.	Safety belts for passengers and safety arm for shuttle safety driver reduced the effects of hard braking. Perceived safety also increased. Hard braking has been reduced by updates, and a shift using the engine instead of using the brakes when braking made it smoother. Still further technical/ safety improvement is needed.
The infrastructure along the route had to be adapted.	Technical	LiDAR markers, GNSS mast was installed for local mapping.	After several additional LiDAR markers and a dedicated GNSS mast was installed, the vehicle positioning performance was satisfactory
Navigation and positioning errors	Technical	Additional LiDAR markers and a GNNS mast was installed together with updates to vehicle software.	Thanks to updates, the errors have significantly decreased from 2020 to 2023. Deviations and hard braking have improved and adjusted over time, but the system is both oversensitive

Challenge	**Type** (Operational, Technical, Business, Other)	**Mitigation**	**Mitigation outcome**
			and can miss out objects.
Mix of road type	Operational	Adapting the shuttles behaviour and driver training to different conditions.	A significant reduction of hard braking was achieved and it provided the involved persons at the site with a greater understanding about the potential of AV operation.
Peak hours and campus crowded with pedestrians and cyclists.	Operational	Cameras to be used as mirrors were installed in the cabins (inside the shuttles) to help the safety drivers. Instruction movies were developed and spread at Campus.	The solution did not solve the problem fully. Further technical improvement needed.
Almost everyone who chose to travel with the automated shuttles otherwise walks or cycles. Only a few of them would have taken their car.	Business/ Impact (modal shift), Other	Visits at schools, University and public local events to promote usage of shuttles.	Introduce a service fee and attract more car owners. Service was free of charge which might have attracted more people walking by.

4.10.3 Key incidents and impacts

At Linköping site, an event reporting tool was used by the safety-drivers to describe and classify events occurring when driving the vehicle. Information is provided through a smartphone app (Figure 19), which included fields such as event date, event type, vehicle, location, cause of event, description, person injury, vehicle damage, third party damage and light/road/weather conditions. This reporting system was not generated automatically from the vehicle but from the human (safety driver) that accompanies and controls the shuttle, which is a Swedish law requirement.

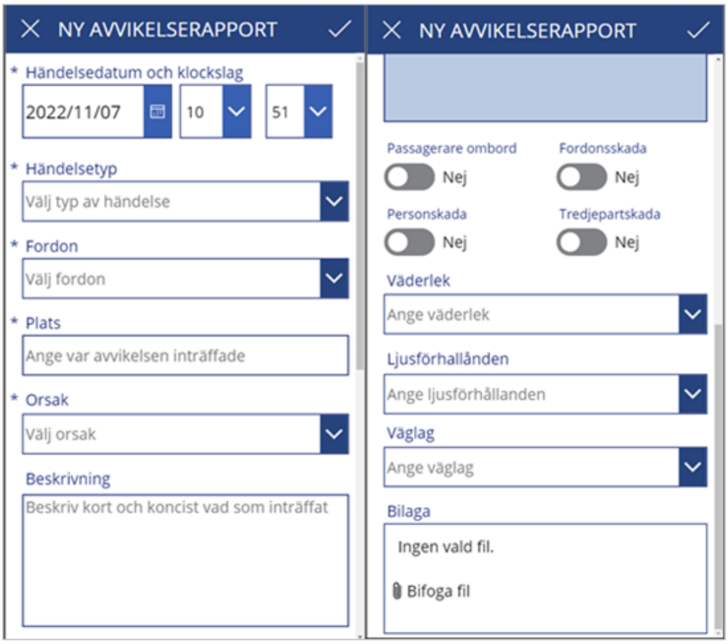

Figure 19: Dashboard of the event reporting system within the vehicle

The following description of events is based on data from a designated test period from January 2020 to November 2022, containing a total record count of 1071, and during this period a total mileage of 25,889 km has been driven (corresponds to 9131 laps on the shuttle route). In the first year of SHOW public pilot phase (2022), the total distance driven with the three vehicles were 11,562 km with a total of 226 events reported. The Navya and the EasyMile G2-036 have been used during the whole test period while the EasyMile G2-038 was introduced during 2022. The distance driven has increased during the test period, and at the same time, the number of reported incidents has decreased. For the event type recorded, under 2022 there is a mix of event types such as vehicle causing the event, traffic or other, which indicates a need for more detailed information. At the same time, it can be difficult to document cause and effect, e.g. a software error could cause a hard brake, and a hard brake could cause software error.

During the public pilot phase, several difficulties were faced on site:

- Use of emergency button

In one case the shuttle started to run and the driver was left behind by the vehicle. The driver could stop the vehicle by pushing the emergency door opening button. Two cases were VRUs were not noticed by the vehicle sensors: a cyclist approaching the vehicle at high speed and a pedestrian. The LIDAR sensor system of the vehicles in general tends to be extremely sensitive. In one case the emergency stop was initiated manually.

Information on the activation of the emergency break came from the (manually written) description field only. The vehicle will most probably not have any recording of the event since the pedestrian/cyclist was not "seen". It is important that this information gets the right priority – a manual emergency stop is not possible without a safety driver.

- Hard brakes due to weather issues such as leaves and dust particles:

The hard brakes, mostly caused by leaves and dust particles, have caused some safety related issues. For example, a brake was damaged, the fire extinguisher became loose/got damaged and a passenger fell off its seat, as a result of hard braking. Hard brakes were also commonly related to branches and uncut grass along the route. During winter, hard brakes occurred due to snow on the ground and in the air.

The system is designed to quickly reduce speed when obstacles occur, to avoid accidents. The note descriptions in most cases do not distinguish the stop severity, i.e., if a soft stop or a hard brake occurs. Due to this being a subjective matter, all described hard brakes and stops have been assigned the same category.

The commonly occurring hard brakes lead to a question of need for seat belts and soft padded surface materials. For the pilot phase, the chairs have been replaced and were equipped with three-point belts and padded seats with higher friction.

- Cancelled trips:

Cancellations were related to service and s/w updates taken. Many software related notes refer to the same software update causing various or repeated errors. Trips being cancelled due to weather has been also occurring, due to snow, on the ground or in the air. Fog and heavy rain are also mentioned.

- Overall performance:

Examples reported on the overall performance refer often to errors caused by navigation/software/hardware, where the vehicle for example loses its GPS signal and stops or where the vehicle goes off-route. Both navigation and positioning errors have decreased from 2020 to 2022.

S/w updates have been implemented during the test period, both in the navigation system and the LIDAR detection, leading to a significant reduction of these types of events. Also, the total number of event notes has decreased over the test period, and put in relation to the increased mileage, the number of events is one per 34 km in 2021 and one per 80 km in 2022. There is a difference between the type of vehicle (Easymile and Navya) regarding the number of event notes per vehicle.

4.10.4 The passengers´ point of view

In general, it can be stated that most users involved in the various studies are positive about the automated shuttles and traveling with them. An average user perceives above all that it is fun/cool to travel with a vehicle as such. However, there are different conditions for the users that are important to take into account in the future development of the service.

The superusers (a group of 10 persons recruited to travel at least 10 times/ rides each) indicated predominantly positive responses to the comfort, speed, and accessibility. The hard braking was felt to have a negative effect on comfort. It was unclear to some participants how long it takes before the shuttle arrives, even though you can see where it is in the app (Figure 8). This, together with the lack of a timetable, lowered the rating on accessibility. Efficiency was rated slightly less positive as the shuttle was perceived as slow and as it was going in one direction only. The involvement of superusers provided a good understanding of what persons that use them frequently see as important achievements.

For users with special needs, such as difficulties to walk longer distances, the shuttles make it possible to reach more destination points in the area and the PT trunk lines. It was highlighted that it was easier to travel with the shuttle because they are smaller, have few passengers, that it is more comfortable and safer. Here, too, it was highlighted that hard braking can be a problem, especially for the elderly. They were also positive about using the shuttles in the future. A prerequisite, however, is that you can plan your trip, e.g. by booking or having a timetable at the bus stops.

Results from the focus groups with school children indicate that automated shuttles can act as a safe means of transport for children to get around the city on their own. One aspect that contributed to the children's feeling of safety was that there was a driver on the shuttle who could do other things than driving the shuttle, such as answering the children's questions if they felt unsafe. The low speed of the shuttle was another factor that contributed to perceived safety, according to the children. The children mentioned that hard braking can make the journey feel unsafe. However, the prompt braking of the shuttle at the slightest obstacle was something that made them feel confident that the shuttle would not collide with anything.

4.10.5 The safety drivers´ point of view

An operation with this kind of automated vehicle requires a safety driver on board according to the regulations for experimental activities with self-driving vehicles in Sweden. The idea is that the driver should be able to quickly react if something is going wrong.

When asking the drivers how they experienced their work as a safety driver they mentioned that it was a good experience on board (based on SHOW survey). The lowest value was linked to on how one experienced the robustness of the vehicles. The drivers were also asked how they generally experience working as a safety driver and all answered very or fairly positive.

Hard braking was perceived as a serious problem for the passengers and the safety drivers. Anything that contributes to smoother braking can be expected to reduce the risk of falling. During the project, demands towards the vehicle suppliers have led to software updates with improvements in form of more balanced brake functionality as a result, but more work is required in this area. For safety reasons, a safety arm was installed (Figure 20). Also, the location of information surfaces is not optimal from a driver's perspective.

Figure 20: Safety arm for incidents' avoidance - Linköping (source: My Weidel/VTI)

Another aspect mentioned by the safety drivers was the need to ensure that it works to board all types of passengers and that all safety drivers must be able to help those who are going to ride. According to the drivers, this is a prerequisite before everyone can be allowed to use the shuttle.

The safety drivers have different tasks during a work shift compared to when driving a conventional bus. They have more contact with passengers and often help people who find it difficult to travel alone. From a mechanical perspective, the shuttle is easy to handle. However, it does not have a steering wheel but a joystick for manual control. Normally, the driver should not have to intervene, but it happens regularly that one needs to take over and resolve a stop. The increased skill and competence that the drivers need to have applies to the vehicle's various IT systems, settings, and maintenance.

4.10.6 The other road users´ point of view

Certain difficulties have been identified both on the regular roads and on the Campus (shared bicycle and pedestrian path). It is common that there are abrupt stops. It is not perceived as comfortable/safe for the people inside the shuttle, but risky situations can also arise outside the shuttle when other road users must react to the hard braking, because the bus stops for a few seconds and can become an obstacle for other vehicles/road users.

Easymile and Navya use different types of sounds in different types of situations, something that needs to be developed in the future to find a standard that is easy to understand. Light and sound warnings given by the shuttle are considered to come too late for the hard braking, it leaves no time to prepare for neither by the surroundings nor by the people in the shuttle.

In normal cases, road users interact through different types of communication in a smooth way, but it becomes more difficult with an automated shuttle that has a fixed route, and limited ability to communicate with the environment. It is unclear whether current warnings have any effect or whether they contribute to keep more distance.

Other vehicle traffic has also expressed that the vehicles are an obstacle. The vehicle's speed is largely lower than most other vehicles. Speed difference between vehicles is not desirable and in the long term it should be avoided.

4.10.7 The stakeholders´ point of view

When the decision was made to plan for a mobility solution with automated shuttles, it was a joint decision by eight partners with different interests. Together, the business was established with the aim of contributing to an understanding of what automated electrified vehicles can be expected to contribute in a modern dense city. The stakeholder´s motivation to extend the route for the operational operation to Vallastaden was to provide first- and last-mile to public transport, so that students, residents, and their relatives do not need a car to get to and from home and activities.

Our living lab started with vehicles that drove around with closed doors during the pandemic, opening up and welcoming travellers after a long period of operation has been a challenge and we have set aside time and resources to welcome travellers. It has also been important to scale up to three vehicles in operation. However, technical problems like failing vehicle components e.g. LiDAR sensors, on-board computer, combined with long delivery time for spare parts have limited the number of days with three vehicles in operation. The technical maturity of the vehicles has affected the ability to evaluate user aspects, but to a lesser extent than we anticipated. Many of the respondents have nevertheless been able to disregard this and value what the mobility solution can contribute, something that has been positive for our living lab.

Changing behaviour is not only about offering more mobility options, but it is also about limiting and making car use more selective. In this project, we have only offered a new mobility solution, which has likely contributed to a lower passenger base than if restrictions on cars had been introduced. Changing travellers' behaviour is not easy and it is often emphasized that a multidisciplinary approach is required to solve these types of challenges, something that is a starting point in the work with Linköping's ecosystem.

4.11 Key local pilot events

It has been clear from the beginning that travelers feel familiar with new transport solutions like this. A great deal of work has been put into involving and engaging those who live and work in the area the vehicles are circulating. We have deemed it important to provide the opportunity to physically get to know the vehicles and to be able to talk to safety drivers and researchers about the shuttles, their purpose and what they can and cannot do. User awareness and engagement has taken place in several different ways and only a few of them are described below.

What: Linköping University event

Who: organized by VTI

When: April 2022

Objective: Give students and employees of the university the possibility to get to know the vehicle and to engage more people to travel with the automated shuttles.

Outcome: Interest in automated services raised. Recruitment of so-called superusers to get more long-term feedback from passengers.

Figure 21: University campus event (source: Anna Anund/VTI)

Figure 22: 10-rides tickets as used by the superusers (source: VTI)

What: Public showcase of automated shuttles at the town party in Linköping

Who: shuttle presentation organized by VTI

When: August 2022

Objective: Give visitors the possibility to get to know the vehicle, answer questions and collect feedback from potential users.

Outcome: Interest in and knowledge on automated services raised especially with regards to where the shuttles run, how they work and whether you can ride along.

Figure 23: Vehicle shown at the centre of Linköping during the town party (source: Anna Anund/VTI)

What: Children and elderly visiting school, leisure centre & nursing home

Who: organized by VTI

When: under 2021 and 2022

Objective: Several visits at for example the school and leisure center in Vallastaden and at a nursing home to inform and talk about the self-driving shuttles operating in the area. Get to know the vehicle, answer questions and collect feedback from specific groups of users.

Outcome: Children aged 8–10 years old and their parents had the chance to get to know the shuttle and to get answers to their questions. Get knowledge on the infrastructure needs from residents and visitors to a nursing home to take measures fulfilling the needs and design recommendations.

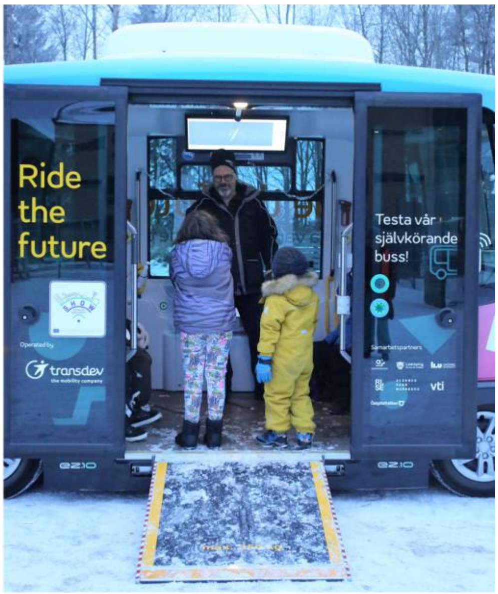

Figure 24: Kids visiting the shuttle (source: My Weidel/VTI)

4.12 Lessons learned & Recommendations

Technical:

- The technical development needs to continue: The operation today leads to challenging situations and limitations in real traffic environments and with the current infrastructure.
- Improve hard braking: extra problematic for fragile elderly and persons with a need to be able to predict what is going to happen next on board. The main cause of hard brakes are simple and repeated weather issues. The properties of leaves and dust particles must be possible to distinguish from those of pedestrians and real obstacles by machine learning and to be totally filtered out.
- Develop towards a technology that is easier to integrate into existing infrastructure, physical as well as digital, with lower requirements for adaptations and maintenance.
- Make sure there is a standard of the use of sound and visual information for the other road users: Persons with hearing problems do not know if the AV is

close behind or is about to stop, and blind persons do not understand what the sound is aimed to solve.
- Events describing activation of emergency brake might be hidden by the fact that this is information comes from the (manually written) event recording only, e.g., where the LiDAR sensors did not register a pedestrian/cyclist but the safety driver. The vehicle will most probably not have any recording of the event, since the pedestrian/cyclist was not “seen”.
- A “black box” function in the vehicle system could be used to recall detailed information after a critical event which is of large importance.

Operational:

- The majority of the users were positive about the shuttle ride, but it is important to attract more car users/drivers to achieve a change in mobility paradigm.
- The mounting of wheelchairs is not safe since no backrest exists and hence backward facing is not possible.
- The drivers support both the shuttle and the passengers, especially children, the elderly and people with disabilities, such as the visually and mobility impaired. Overall, the driver role is different: they have to support persons with disabilities to get on / off, they need to inform when to get off/on, they are considered as the link to a safe/secure ride. In order to remove the safety operator there is a need for clear standardisation on how to solve the topic the drivers need to handle. This includes standards for sound and light internally and externally, but also what is needed to make sure that persons with mobility impairments can access by them self, here both slop of ramps and mounting inside need to be included.
- An increased focus is needed on the development of how the vehicles should be able to communicate with passengers on the shuttle, but also with those who interact with the shuttle outside (pedestrians, cyclists and other vehicle drivers). For people outside the shuttle, it can be about reinforcing messages about the shuttle's intentions and confirming which objects the shuttle has identified and is acting on. For example by visualizing the “safety bubble” with help of light, or by a combination of light and sound provide feedback to VRUs that are too close to the shuttle causing hard brakings as an example.
- Real-time visualization of where the shuttles are located is popular, but further development is required to be able to easily find the map and to get information about when the shuttle is coming and when it will arrive at the traveller’s intended destination (on demand functionality).
- For event detection, the distinction between a normal and an emergency brake is rather hard to make. There is a risk that the driver gets used to a rough vehicle behaviour and either lets emergencies pass unnoticed or overreacts when the patience runs out.

Business:

- The shuttles can be a complement to public transport, such as feeder traffic to trunk lines if we have more vehicles and if they run a bit faster. Focus should also be given to complementing strategies such as carpooling, parking management, micro mobility, etc.
- Frequent and systematic maintenance and mitigation of possible disturbances along the route needs to be included in the cost estimate. This includes disturbances caused by snow during the winter to prevent snow or plow banks being perceived as objects that cause braking/stop and grass/bushes and trees in the spring/summer period.
- We need to understand more about what the actual costs really are, which can be done only through scaling full passenger services.

- The assessment from the studies we have done shows that the driver's presence in the shuttle during operation is central as the technical maturity of the vehicles is still not sufficient for e.g. fully driverless remote operation [2].
- Willingness to pay (based on a small-scale study): when we asked what passengers are prepared to pay in relation to today's cost of a public transport ticket, the usual answer was less than today's price (65%), but 33% felt they were willing to pay the same price. Only 2% answered that they were willing to pay more [2]. Still, more analytical answers are following in D13.5.
- It is important to attract more car owners. Almost everyone who chose to travel with the automated shuttles otherwise walks or cycles [2].

Other:

- Testing different vehicle types allowed to draw further conclusions. For operators and safety drivers it would be important to further address: standardisation, better access to the vehicles and adaption to public transport needs.
- Long-term partnerships as in Linköping give us the opportunity to practically and concretely evaluate and test new mobility solutions, but also get a deeper understanding of the future driver role within the concept of mobility and autonomation. The collaboration allows us to look forward and learn together.
- Focus has been on vehicle performance, such as solving brake behaviour, positioning, signage, etc. More effort should be put into perceived and actual safety and comfort for passengers of different categories.
- The commonly occurring hard brakes lead to a question of need for seat belts and soft padded surface materials. These topics open for a wider discussion about seat design and materials, and about how to communicate safety by design.
- The area of safety involves many other perspectives such as gender equality, since technology and infrastructure are often developed by men. Can we observe any difference between men/women safety drivers or passengers or other road users? First insight follows in D13.5.

4.13 Roadmap beyond SHOW and replicability

The operations along the route in Linköping are continuing. The test site seen as a living lab and named Ride the future (https://ridethefuture.se/). Based on lessons learned from SHOW and other research projects and in order to define and stake out the path for the service´s future development, a workshop was held in May 2023 with all local project partners (see Figure 1). The purpose of the workshop was primarily to discuss three possible areas of development: On demand, Remote and Service development in existing operations.

On demand in this context means that public transport is flexible based on the user's geographical and temporal needs. The participants in the workshop suggested that booking trips in an on-demand solution should be done digitally in an app, including such as booking/cancelling of a trip, trip confirmation and waiting time. It was also discussed that there are different degrees of on demand. A service similar to a taxi service, where you can pre-book a trip, would increase reliability and give passengers the opportunity to plan their trip. With this, however, some of the flexibility disappears in comparison to a more flexible system in which one would be able to book the journey physically at the stop (via a button/display) and not having to choose a destination in advance. To make journeys more time (and cost)-efficient, automatic stops at each bus stop should be avoided, the routes should be flexible, and the shuttle can run in both directions. Further advantages of an on-demand solution were seen when it comes to flexible boarding/disembarking at digital shuttle stops, increased sustainability of the service as the operation can thus become more resource efficient and would attract more user groups. A procurement for an on-demand solution in Linköping is ongoing.

Remote means that the shuttle is monitored, and any interventions take place from a place other than in the vehicle. With remote, the intention is that several buses (2-5) are controlled by one person ("control tower"). The driver's role has then shifted to operational traffic controller with a video connection to the bus for support for example. With regard to a development towards a driverless operation, the participants concluded that the shuttles would need to be rebuilt, as well as that permission and the installation of camera equipment on the shuttles will be required. However, it is important to bear in mind that there are people who may need physical assistance on the shuttle and that remote operation can feel less secure. As advantages the participants named that the operation can be more resource effective, increasing service availability during more times and on more routes for example. To test driverless operation (function and acceptance), small robotic goods vehicles could be connected to Ride the future as a first step.

During the workshop, the participants came up with many different proposals for service development. The proposed development options ranged from including transport of goods (e.g. deliveries from various stores and restaurants, package deliveries) or even being connected to small, automated delivery vans. Another suggestion was that there should be stops that are adjacent to destination points in Linköping, that the shuttle can function as a meeting room on wheels or as a monitoring tool to increase security in the area. The participants also discussed that the speed should be increased on the routes where it is possible and that there should be individually tailored information in the bus. It is important to develop the service to find new/better business models. It is the basis for creating a sustainable business model and an opportunity to increase both service and revenue. Increased services generally provide increased accessibility, and different proposed development directions are good for different groups and for attracting new passenger groups. However, the participants agreed that it should not be too many services as this is often perceived as messy or complicated. Rather being innovative and creating services that meet a need and provide added value. Conducting further surveys can be a way to get answers to what the citizens want. The participants believed that Ride the future can act as an ambassador for the whole of public transport, thus improving its public image.

5 Gothenburg Pilot site

5.1 The ecosystem

The ecosystem consists of partners that are internal and external to the SHOW consortium, as follows.

Table 6: Pilot site ecosystem at Gothenburg

Participating Entity	Internal to the Consortium (√)	External to the Consortium (√)	Role
Keolis Sverige AB	√		PTO – Operator of pilot operations
RISE AB (Research Institutes of Sweden)	√		Mega Site leader, user acceptance data collection, dashboard development.
Ericsson AB	√		Leading the work on connecting the service to Control Tower and Ericsson Innovation Cloud (5G infrastructure and VRU).
Navya	√		OEM – The shuttles are manufactured by Navya.
Gothenburg Traffic Office		√	Local authority for trial permission, involved in the Site Acceptance Test (SAT): written agreement from the local authority to ride on open roads.
Autofleet		√	Provider of the Fleet Management System: dashboard to monitor shuttles online, through the Navya API and smartphone app for the safety drivers to count the passengers and report problems and operational forms.
Hugo AB		√	Developer of shipping robots that are tested in several international locations.
Västtrafik		√	Public Transport Authority Västra Götaland is responsible for all public transport within the Västra Götaland region including

Participating Entity	Internal to the Consortium (√)	External to the Consortium (√)	Role
			Gothenburg and is Sweden's second largest public transport company.

The automated shuttle service was integrated into Västtrafik's public transport, which ran as bus line 68 (Figure 25).

Figure 25: Line 68 displayed on shuttles in Chalmers (source: Maxime Le Guern/Keolis)

5.2 Operation setting

The shuttle service was operating at Chalmers campus in Gothenburg, a Swedish university that focuses on research and education in technology, natural sciences, architecture, shipping, and administrative areas. Chalmers is located on two campuses in the city of Gothenburg: Johanneberg south of the city center (Figure 26, right), and Lindholmen in the middle of the vast Norra Älvstranden (north of the river).

Figure 26: Aerial image and location of the Johanneberg Chalmers demo area in Gothenburg/Sweden (source: google maps/open street map, accessed on 12/06/22)

Campus Johanneberg (Figure 27; Figure 28) is an urban campus near the city centre. On the campus you will find the student union building, the main library, cafes, laboratories, lecture halls, several engineering programs, student housing, etc.

Figure 27: View of Chalmers university entrance, from Göteborg Chalmers tram station (source: Google maps, accessed on 12/06/22)

The campus is surrounded by green areas in the west and south, but is also relatively densely built-up, with possibilities for expansion in the eastern part of the area that can be implemented in the longer term.

Figure 28: Shuttles in operation at Chalmers University (source: Cilli Sobiech/RISE)

The traffic environment is urban with cars, truck traffic, pedestrians, cyclists, and e-scooters. Traffic density also varies throughout the day, with peak times in the morning, around lunchtime and in the afternoon/evening. There is also traffic by commercial campus vehicles, including tractors, trucks, or small electric cars (Figure 29).

Figure 29: Shuttles with University traffic, after Sven Hultins Plats, direction south (source: Maxime Le Guern/Keolis)

For this pilot, two automated shuttles ran along the route on Chalmers Campus Johanneberg in Gothenburg (Figure 30). The route was a total of approximately 2 km long with five stops, connecting Västtrafik public transport network from the Göteborg Chalmers tram stop to the library, passing several interesting places such as Sven Hultins Plats (with restaurants, offices, Johanneberg Science Park entrance), the main library, a student residence and a large parking lot.

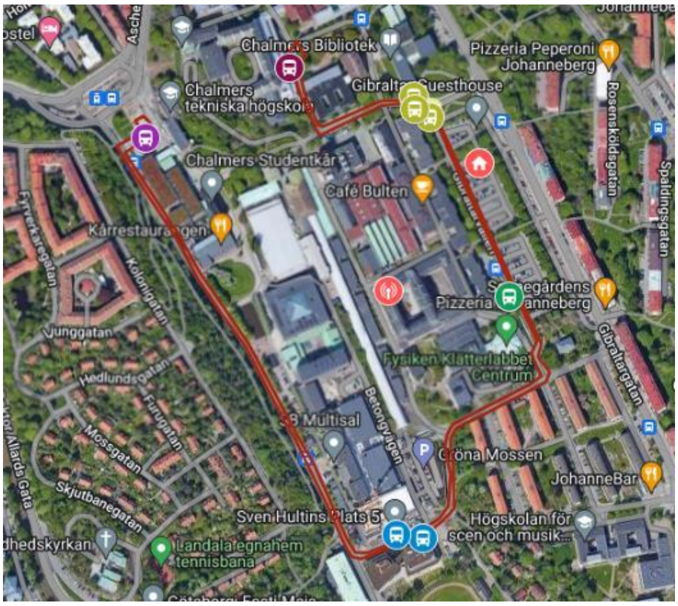

Figure 30: The route of the shared shuttles (source: Google maps)

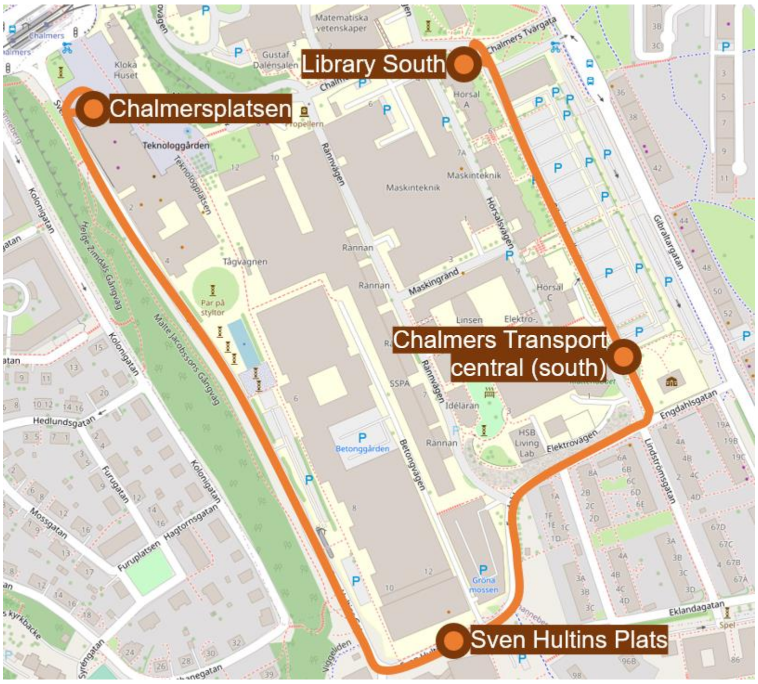

Figure 31: Simplified version of the route and the four stations (five considering Sven Hultins Plats as two stations, one each direction) (source: OpenStreetMap / Maxime Le Guern/Keolis)

A simplified version of the route has been chosen (Figure 31):

- Chalmersplatsen is on asphalt in a meeting square, with the walkway between the tram/bus station and Chalmers University entrance. There are also some cars and many bicycles, a city bike station, and a e-scooter station. The shuttle stops at its station and turns in the square, with priority for pedestrians, heading south along Sven Hultins Gata.
- The area between Chalmersplatsen and Sven Hultins Plats (Sven Hultins Gata) is composed of trees and vegetation on the east side and buildings and the other side. On this stretch, there are several pedestrian crossings with bottlenecks and speed bumps to make cars decrease. At Sven Hultins Plats stations (both south and north) are surrounded by newer buildings with offices and restaurants.
- Between Sven Hultins Plats and Chalmers Transport Central runs a slope, curved, surrounded by vegetation and some stones. After the hill there is an intersection with a small shop. Direction Library South, there is a left turn that must be validated by safety drivers. On the other hand, it is also a right turn that must be validated by the safety driver.
- Between Chalmers Transport Central and Library South there is a parking lot with many pedestrian crossings and parking exits. Shuttles go a little slower and cannot pass. Safety drivers must avoid crossing each other on this stretch.
- Finally, at Library South, like Chalmersplatsen, shuttles turn there (Figure 32). There is vegetation and almost no building.

Parking and charging were included in the safety drivers' shifts. It was part of the work description of the safety drivers.

There have been no major software updates during the pilot period. Maintenance was organized locally. The shuttle was cleaned every day, inside and outside. All LiDARs and sensors were carefully cleaned every day to prevent deterioration.

Figure 32: Turnover at Library South (source: Safety Driver Marika/Keolis)

Further conditions are described in the table below:

Table 7: Road, traffic, and weather conditions at site

Variable Name	**Gothenburg**
Weather	Severe winter and wind conditions with rain/snow/sleet/ hail/foggy between January and March 2023, with temperatures below -10° C. During winter period sun rises at 09 am and sets at 03.30 pm. Heavy rain and extensive, deep puddles can irritate the shuttles, further small fragments such as snowflakes or leaves. Snow: make shuttles detect obstacles (snow pile…)
Sight conditions	Restricted conditions due to rain, snow, fog in January - April 2023. Impact on LiDARs Restricted conditions also due to glare from the sun, when in lower position in winter.
Road type	Urban roads with different speed limits on route, max 30 km/h. Number of intersections on route: in total 5 with priority to the right (without counting parking exits between Chalmers Transport Central and Library South) No of roundabouts: 0 No traffic lights on route: 0 No dedicated lanes for shuttles, mixed traffic roads only Almost 20 pedestrian crossings, 3 one of them with bottlenecks to reduce speed of cars. Many parking exits (at least 13) Shuttles are integrated to the to the public transport system of Gothenburg, as bus line nr 68. Many e-scooters and city bikes are available for first/last mile transport in the area.
Road works	Road works (planned/ unplanned) and construction works on buildings ongoing as the whole area is re-shaping: new modular building, fences during carnival, punctual construction works. Punctual delivery trucks and Chalmers University commercial vehicles, on shuttles path.

Variable Name	Gothenburg
Incidents	Punctual delivery trucks and Chalmers University commercial vehicles, on shuttles path. Major changes at close-by buildings or construction sites, such as scaffolding or equipment lying around can irritate the shuttles. Heavy rain and extensive, deep puddles can irritate the shuttles.
Traffic conditions	The traffic density varies across the area and across the day, with rush hours in the morning, around lunch and in the afternoon/evening. The events on the campus influence the traffic. More people at the end of the year with carnival, end of exams etc.
Traffic composition	Mixture of cars, delivery vans /trucks, site vehicles, busses, bicycles, mopeds, e-scooters. There are also some tractors.
Traffic control	-
Area type	Campus Johanneberg is a densely built urban campus near the city centre.

5.3 Services and use cases

The most important goals for the demo at Chalmers were the following:

- To provide a service for commuters to reach Chalmers University of Technology in Johanneberg's various areas, from the tram station to the library through buildings such as restaurants and offices.
- Demonstrate safe and reliable operation of a fleet of electric automated vehicles for last/first mile service with traffic tower and possibility of cooperation with delivery robots.

The commissioning took place in October 2022. Shuttles were operated since mid-October 2022 with few passengers in the context of dry run of the final public service on days when operations were possible, and with a regular schedule and passengers from February 2023 until June 2023. The dry run took more time than expected as the shuttles were not authorized by Keolis and Navya to take passengers. Indeed, there was a succession of issues: trouble with GNSS localisation on site, hard drive disk to replace, suspensions to replace etc.

The automated shuttles were integrated into the public transport network of Västtrafik in Gothenburg, as bus number 68. The shuttle had designated bus stops, where basic information about the route and the project was displayed (Figure 33).

Figure 33: Shuttle stop at Chalmers transport south with a LiDAR marker (white rectangle) and at Chalmersplatsen without LiDAR marker (source: Keolis)

The system was moreover integrated with Västtrafik systems, PTO/Gothenburg, regarding the public transport timetables (Figure 34).

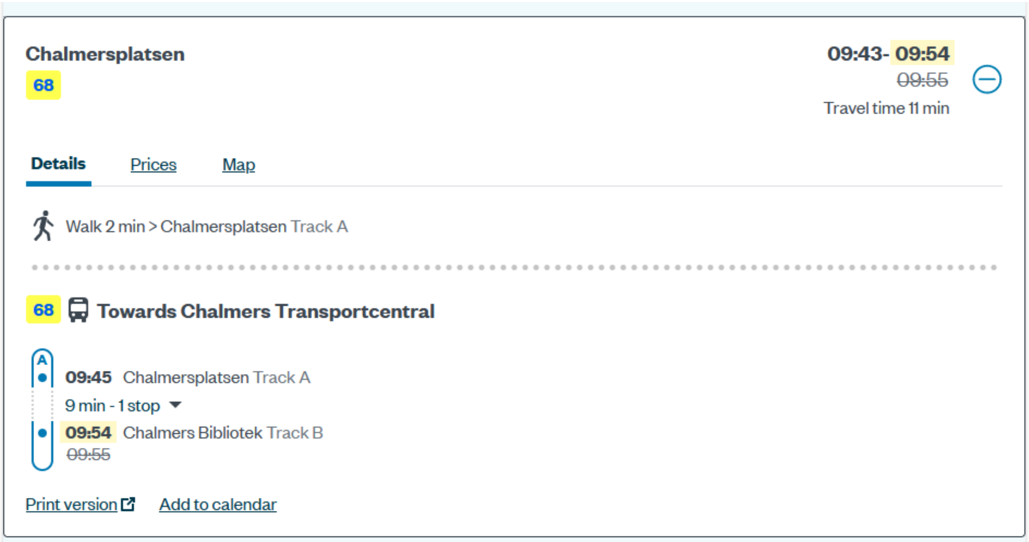

Figure 34: Shuttle departure and trip planning in the PT application from Västtrafik in Gothenburg (source: vasttrafik.se, accessed on 30/05/23)

A typical day of field trials for the site looked as follows (routine of operation).

> *During a normal test day, the operation with the shuttles is running between 07:00 to 17:00 CET on weekdays. The shuttles are parked and charged in a garage at night. The garage is a temporary isolated tent.*
>
> *The shuttles are operating in autonomous mode on the route with max speed of 20km/h. Speed limit in the area is 30km/h, which is a city environment with a normal/smooth traffic context between Chalmersplatsen and Sven Hultins Gata, i.e. without any traffic or other environmental complexity (UC1.1). It is not known how much of the operation that was possible to run in automated mode.*
>
> *Between Sven Hultins Gata and Library South the shuttles operate within a more complex traffic context (e.g. intersections, slopes, parking lot exits). Complex environmental conditions such as extreme winter and wind conditions with rain/snow/sleet/ hail/foggy with temperatures below -10° C. Due to delivery trucks and site vehicles time-restricted capacity of passage for shuttles can occur (UC 1.2).*
>
> *The shuttles are operating in mixed traffic on real roads together with other cars, trucks, cycles and e-scooters, crossing streets and (pedestrian) crossings on its way, either with prioritization for the shuttle or not. The traffic density varies across day, with rush hours in the morning, around lunch and in the afternoon/ evening (UC 1.6).*
>
> *Under operation in mixed traffic, the shuttles ring a bell to warn other road users, stop at pedestrian crossings/crossings, overtake and/or wait for free passage. It can happen on the way that the shuttles brake abruptly (UC 1.6).*
>
> *At the five bus stops, passengers enter or leave the vehicles. Assistance systems help the vehicle at the bus stops (UC 3.4). Vehicle data is used by the fleet management system in real time (UC1.7).*

The test case UC1.3 with regards to VRUs was tested at specific sections of the route and has been performed successfully at least 15 times; organised with personnel from Keolis and Ericsson as follows (more details in planning can be found in D9.3): The objects included in this UC are the automated shuttles operated by Keolis and a VRU sensor integrated in a reflective vest. By means of the digital infrastructure, as described in section 5.6 and SHOW Dashboard real-time processing to trigger actions/events is enabled based on location/heading of reporting objects, such as the VRU, delivery robots, and passenger vehicles.

In addition, a demonstration event with automated delivery robots took place in close collaboration with a national project. This was not a part of the evaluation.

5.4 Site-specific test cases

First/last mile PT at Chalmers (corresponding to UC1.1[11])

Near the Chalmersplatsen tram stop, the AV begins its ran along Sven Hultins Gata towards Library South station. To get closer to their offices/classrooms or a restaurant, many travellers took the shuttle connection from the tram station at Chalmersplatsen. After making a U-turn in front of the university entrance and a left turn to go on Sven

[11] UC1.1 Automated passengers' mobility in Cities under normal traffic & environmental conditions

Hultins Gata (stop sign, the safety driver validated the left turn), the shuttle ran on a 500 m straight road, without important complex features (roundabout, priority to the right or left, V2X infrastructure). Nevertheless, there were crosswalks with bottleneck sections, with a sign on the left and one on the right of the crosswalk, to make road users slow down. There was also a speed bump. Autofleet Fleet Management System allowed us to track speed on this section (Figure 35).

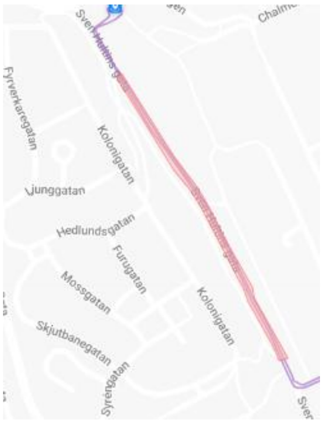

Figure 35: Speed sections on Autofleet (source: Keolis)

First/last mile PT at Chalmers under complex environmental conditions (corresponding to UC1.2[12])

The service operated with "extreme weather conditions" listed: snow and subzero temperatures during daytime operations. It can snow in Gothenburg during the winter. Thanks to the AV service, passengers could easily and conveniently commute to/from their job with PT taking the shuttle for the first/last mile. Nevertheless, the operation was stopped when it snowed too much (impact on LiDARs, detecting snowflakes and thus braking), and when there was snow and ice on the road that may have impacted the behaviour of the shuttle: spinning wheels, etc.

UC1.3 Shuttle connecting to other passengers/VRUs at Chalmers (corresponding to UC1.3[13])

The shuttles could connect to other passengers in the surroundings of the vehicles, as on the route VRUs might be. When the shuttle was approaching, 15 to 20m, in this test case a yellow vest started flashing on selected passengers in the Chalmers area (students at technology college) connected via public 5G mobile network (Telia). The test case UC1.3 with regards to VRUs was tested at specific sections of the route and has been performed successfully at least 15 times.

First/last mile PT at Chalmers in mixed traffic (corresponding to UC1.6[14])

At the pilot site the shuttles were operating in mixed traffic on real roads together with other cars, trucks, busses, cycles, and e-scooters, crossing streets, bicycle lanes and (pedestrian) crossings on its way, either with prioritization for the shuttle or not. At four points on the route, it was mandatory for the safety driver to validate the “GO” of the

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[12] UC1.2 Automated passengers’ mobility in Cities under complex traffic & environmental conditions

[13] UC1.3 Interfacing non automated vehicles and travellers (including VRUs)

[14] UC1.6 Mixed traffic flows

vehicle by verifying the environment. It has been set by both Navya and Keolis and validated by the authorities. Indeed, at those intersections, it was too complex for the shuttle to take a safe decision: there is a dead angle on the priority area (vegetation blocking the view on a left priority area). Under operation in mixed traffic, the shuttles trigged a bell to warn other road users, stop at pedestrian crossings/crossings, overtake and/or wait for free passage. It could happen on the way that the shuttles brake abruptly. The safety driver needed to make passengers aware of this before riding.

Connection to Autofleet fleet management system (corresponding to UC1.7[15])

A fleet management system was used. Realtime vehicle data from Navya's API are collected and aggregated by the Autofleet's platform to produce actionable insights for Keolis (as an operator) to monitor the service performance. Real-time data collected from the installed 5G devices were published into SHOW Dashboard, enabling real time visualization of vehicle data and real time alerts. The AVs were successfully connected Autofleet Fleet management System via Navya API (Figure 36).

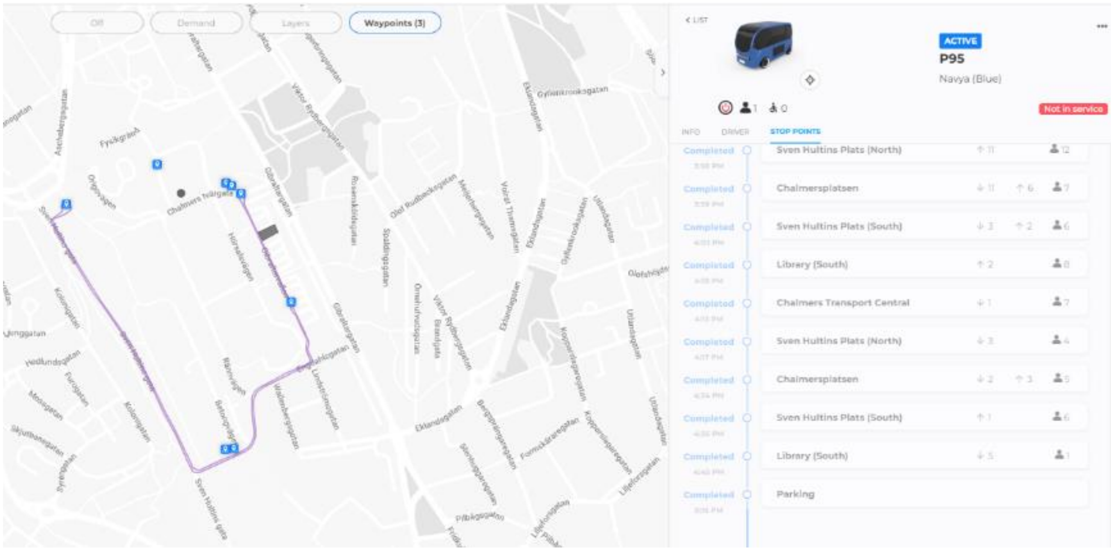

Figure 36: Autofleet dashboard (source: Autofleet)

Supervision and Keolis Team could in real time see the shuttles, as well as some KPI as such as battery, speed, mode (auto/manual), next station, name of safety driver, number of passengers, quality of GNSS reception, etc.

The tool alerted supervision if there was for instance (Figure 37):

- Long Stop at a station (more than 2minutes)
- Severe brake
- Manual mode initiated

[15] UC1.7 Connection to Operation Centre for tele-operation and remote supervision

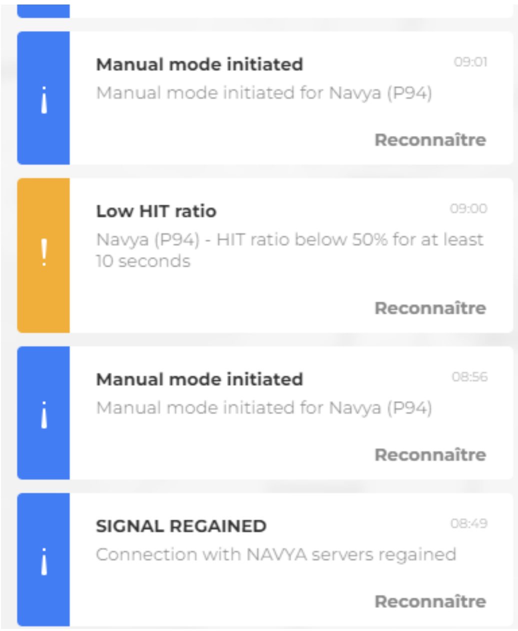

Figure 37: Examples of alerts (source: Autofleet)

Automated driving functions at bus stop (corresponding to UC3.4[16])

Assistance systems would help the vehicle at the bus stops. Navya vehicles/API had a functionality that assisted to get back on the road. Yet, for UC3.4 the potential of automated functions at bus stops would rather been valuable for specific user groups, which were not included at this stage. There was a seamless/parallel assessment of test cases along the route for UC1.1, UC1.2, UC1.6 and UC3.4 at the bus stops. The trials were conducted in the context of current operational lines and with a frequent service. Shuttles used for the SHOW project has moreover enabled tests of interaction with shipping robots. Focus has been on both the practical mechanical interaction between self-driving vehicles and delivery robots, and via Ericsson, a digital platform implemented for the communication between vehicle and robot tackling the "Rendezvous" optimization problem.

Figure 38: Demonstration in spring 2023: AV interaction with a delivery robot.

[16] UC3.4 Automated services at bus stops

A demo day was held on May 23, 2023, with lectures and a demonstration of the

shipping robot fully autonomous) and on-board driving at AV (

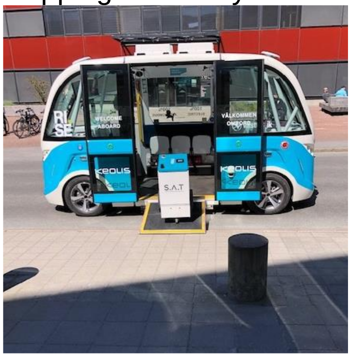

Figure 38).

5.5 The fleet

For the large scale pilot trials, two NAVYA automated shuttles were driving along the route connecting the public transport network of Västtrafik with other parts on the Chalmers Campus to improve first/last mile access in the area. The shuttles turned at the end of the route and headed back to the public transport station.

Homologation of a third vehicle was late due to immature OEM especially regarding risk analysis. Self-driving delivery robots were however used without need for such homologation.

Table 8: Fleet characteristics at site

Test/Use Case	**Deployed fleet characteristics**								
	Vehicle brand & model	**Vehicle type (shuttle, …)**	**SAE Level reached for the field trials [1-5]**	**TRL level reached for the field trials [1-9]**	**Summary of upgrades held during the project (in consistency with D7.2)**	**HMI and Hand-over strategies (in consistency with D7.2)**	**Maximum speed reached during the trials (km/h)**	**Average speed during the trials (km/h)**	**Maximum capacity of vehicle**
UC 1.1, 1.2, 1.3, 1.6, 1.7, 3.4	Navya Arma	Shuttle	3 / 4	6 - 7	Public 5G network for VRU use case	Vehicles normally run in autonomous mode. When an event occurs, the vehicle requires handover to	16 km/h	6.87 km/h (running + stops, which means when shuttles is at 0 km/h at stop	All passengers need to be seated: there are only 8 passengers allowed in each shuttle,

Test/Use Case	**Deployed fleet characteristics**								
	Vehicle brand & model	**Vehicle type (shuttle, …)**	**SAE Level reached for the field trials [1-5]**	**TRL level reached for the field trials [1-9]**	**Summary of upgrades held during the project (in consistency with D7.2)**	**HMI and Hand-over strategies (in consistency with D7.2)**	**Maximum speed reached during the trials (km/h)**	**Average speed during the trials (km/h)**	**Maximum capacity of vehicle**
						the safety driver. At 4 specific points, including 1 specific crossroad, it is mandatory for the safety driver to take over the vehicle, verify the environment and start the vehicle again. It is located at STOP signs. Parking area: shuttle will not		signs for instance)	plus safety driver

Test/Use Case	Deployed fleet characteristics								
	Vehicle brand & model	**Vehicle type (shuttle, …)**	**SAE Level reached for the field trials [1-5]**	**TRL level reached for the field trials [1-9]**	**Summary of upgrades held during the project (in consistency with D7.2)**	**HMI and Hand-over strategies (in consistency with D7.2)**	**Maximum speed reached during the trials (km/h)**	**Average speed during the trials (km/h)**	**Maximum capacity of vehicle**
						cross each other in autonomous mode. Manual mode is necessary.			

5.6 The infrastructure

The shuttles were stored and charged in a temporary garage, a tent, on the parking lot. Even if the garage is temporary, it is isolated. Contrary to pre-demo at Lindholmen where very cold temperatures negatively affected batteries' autonomy and their charging, there were less similar issues at Chalmers.

There is only a GNSS Navya base on site, to give accurate and precise GPS data to the shuttles (Figure 39).

Figure 39: Route of the shuttle at Chalmers with position of the GNSS base and garage (tent)

For the VRU tests, a 5G modem was used on the shuttles, using the public 5G network.

Geofences and VRU detection at pilot site:

For the VRU field trials, static geofences were set-up at the Chalmers site. They represented areas where a pre-defined set of real-time rules applied, e.g. reduced speed, no-entry, emission-free zone etc. Static geofence could be applied around construction work areas, accident area, etc.

When an event was triggered, notifications were sent to both vehicle and VRU sensor device. When the objects were entering and/or leaving the static geofence areas on the route, these notifications were presented as alert messages in both the shuttles and the SHOW Dashboard. For the VRU they were represented as audio-visual notifications with flashing LED lights in front and back on safety vest as well as audio in earphones.

For the field trials, also dynamic geofences were created around dynamic objects, and follow the object's movements. In this case, dynamic geofences were created as a polygon in the front of the vehicles and a disk centred around VRUs (Figure 40).

Once a vehicle and a VRU dynamic geofences overlap on the route, notifications were sent to respective connected sensors. Presented as notification message for the safety driver and audio-visual notification at VRU´s vest as well as in the SHOW Dashboard. SHOW Dashboard[17], an application within the Ericsson Innovation Cloud, in addition to visualizing vehicle location and network information at that specific location, also included real-time processing logic to trigger actions based on location/heading of reporting objects (Figure 41, Figure 44).

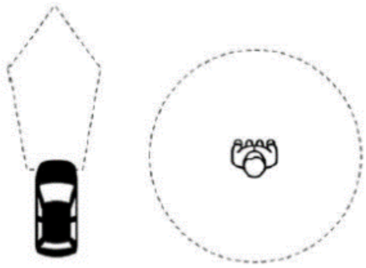

Figure 40: Sensing and logic (source: Ericsson)

- Dynamic geofences based on
  - Position
  - Heading/bearing
  - Speed
- Logic to detect:
  - When objects get close to each other
  - If maintained speed and direction may cause incident
  - When geofences overlap
- Notification messages sent to "engaged" objects over MQTT messaging protocol (Message Queuing Telemetry Transport)
- Warning visualization
  - Flashing lights, sound warnings and/or tactile feedback
  - Warning symbol and arrow to approaching object on vehicle display or equivalent (Figure 41)

[17] Please note that this refers to the previous and not last version of the Dashboard that has been redeveloped by CERTH.

Figure 41: Notifications for VRU Ericsson project (source: Ericsson/ Maxime le Guern/Keolis)

For UC1.3 the tests were performed using Telia public 4G/5G network and for the VRU demonstrator we used the following set-up:

- For User Equipment (UE) we used a Sony Xperia 1 IV with a mobile app that was continuously sending GNSS (global navigation satellite system) position data to a backend system over MQTT (Message Queuing Telemetry Transport) communication protocol.
- A Python based backend- and logic system consisting of an MQTT broker system (a backend system that coordinates messages between different clients) with following functions:
  1. Receiving positioning data from pedestrians and vehicles and placing them on a virtual map.
  2. A logic system creating geo-fence areas around pedestrians and vehicles, calculating distances and risk of interception and sending out warning messages over MQTT.
  3. A Grafana-based panel with map, objects, device position details and notification information.
- Receivers to act when warning messages are received.
  - for pedestrians - a Raspberry PI with I/O board to make LED lights flash on safety vests (Figure 42)
  - for vehicles – Android tablets showing warning symbol and arrow pointing towards the vulnerable road user

Figure 42: Yellow flashing led vest and shuttle (source: Keolis)

Figure 43: VRU testing. Lights on vest informing and drawing attention to that the automated shuttle is approaching.

The VRU field trials were set-up and demonstrated at the Chalmers site (Figure 43, Figure 44):

Interface to non-automated vehicles and travelers (including VRU)

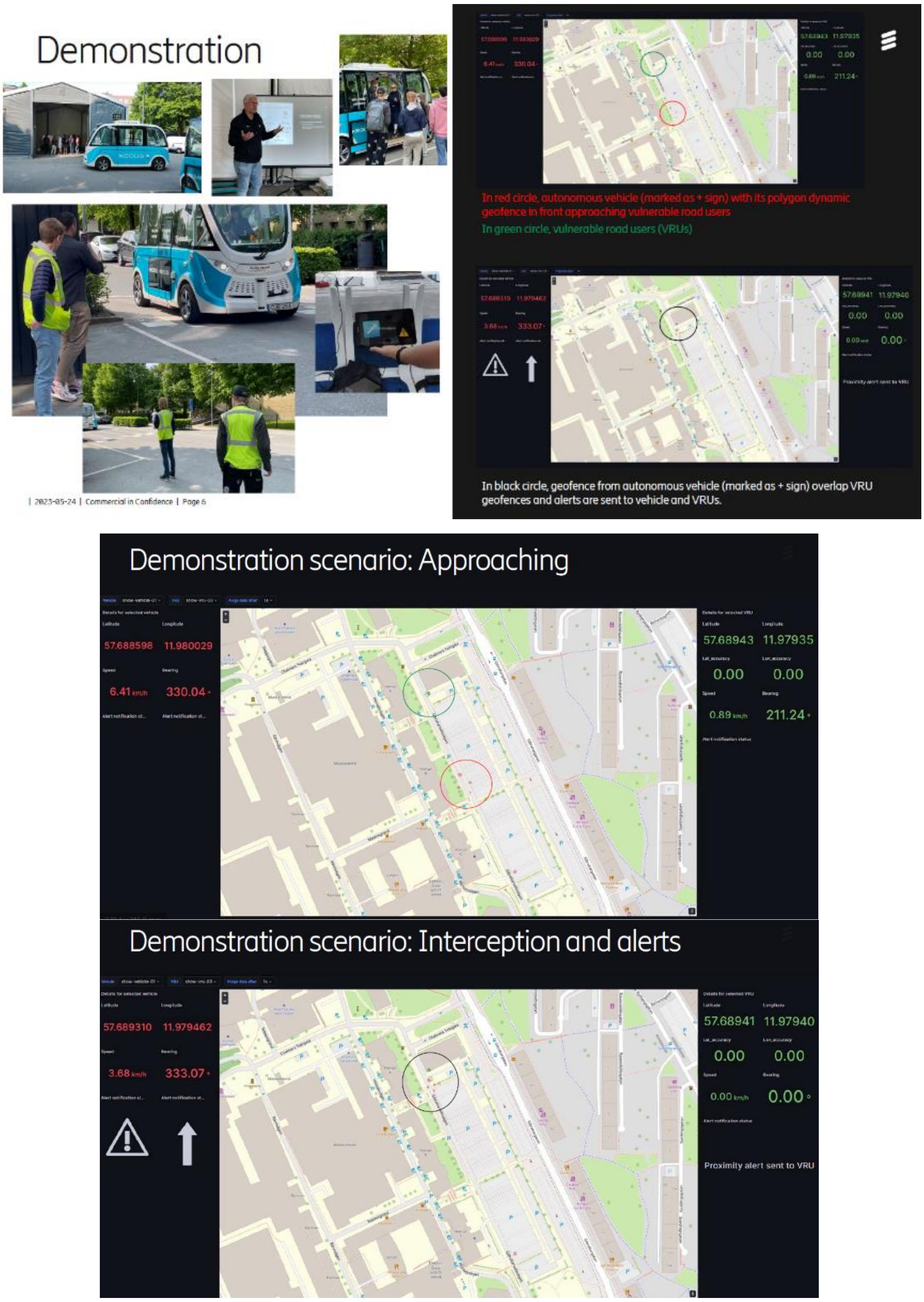

Figure 44: VRU test alerts (source: Ericsson)

5.7 Passengers

End-users were students, employees and visitors at Chalmers Campus and Johanneberg Science Park.

Signs were installed at bus stops in Chalmers, announcing automated shuttles were running in the area (Figure 47). Students were equipped with yellow vests that would start flashing when the shuttles were approaching (Figure 45).

People in the offices and the restaurant could see the shuttles running daily. And finally, a lot of students were passing by and saw the shuttle. In the end there were frequent users of the shuttles, taking it on daily basis or just punctually when it was at the station they were (typically the tram station).

Figure 45: Shuttles with passengers on boarding at Chalmersplatsen (source: Cilli Sobiech/RISE)

The most used station was Chalmersplatsen (Figure 49), which made sense as it is located between the tram station and the entrance of university, where an important flow of students and workers pass by. Also, the shuttles tended to stay longer there, since it is a good spot to regulate shuttles and wait for potential passengers from trams and buses at the station.

We also could notice that total passengers boarded was increasing over time:

- People are got used of the shuttles (schedule, route, stations…) and used it more.
- Weather was clearly improving in May and in June, with no snow and warm weather: people were more outside.
- There were more events during the month of May on the Campus: demo, carnival, etc.
- One of our main safety drivers was daily scheduled on the shuttles and retain passengers by talking to them (create passenger loyalty), inviting pedestrians to hop on, especially if they had not tested the services (Figure 46).

Figure 46: The shuttle waiting at bus stop Library South (source: Cilli Sobiech/RISE)

Figure 47: Passenger information at the shuttle stops (source: Cilli Sobiech/RISE)

5.8 Total number of passengers and freight deliveries

During February 2023 and June 2023, 1778 passenger rides have been conducted. The number of passengers varied over the time (igure 48) and from station to station (Figure 49). Demonstration of combination of passenger vehicles and two delivery robots of different models were enabled by SHOW. This took place at one demonstration event (c.f. 5.11). Hence, no SHOW related data for evaluation exists.

Passengers and stakeholders in the loop

Number of passengers transported during final public phase: 1778.
We were transporting passengers on a regular base starting February 27th of 2023 to June 12th of 2023. From October 2022 only few days allowed to have passengers onboard due to testing and technical problems.

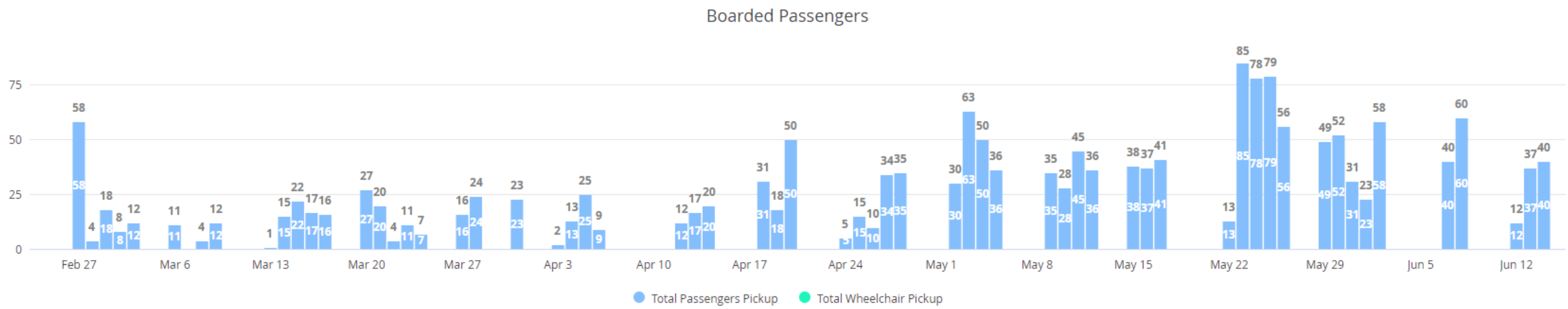

Figure 48 – Number of passengers boarded per day (source: Autofleet)

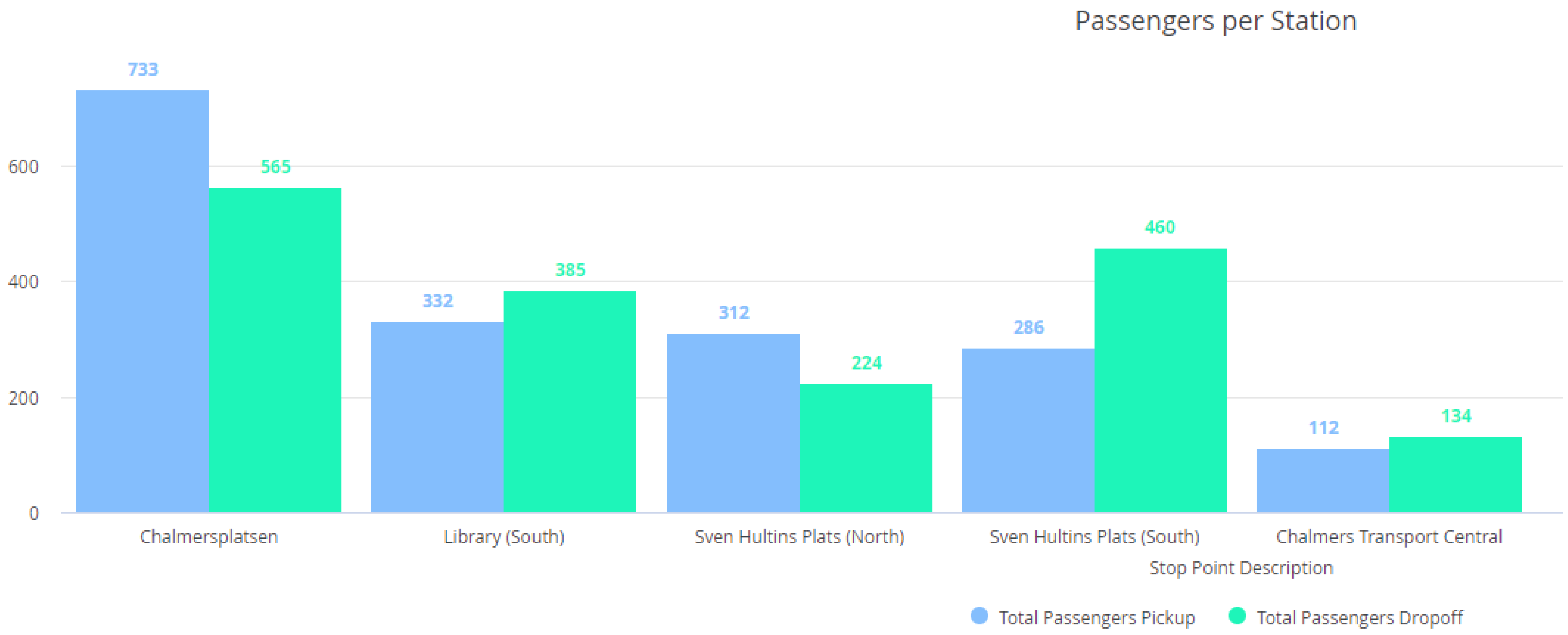

Figure 49 – Total boarded/Unboarded passengers per station (source: Autofleet)

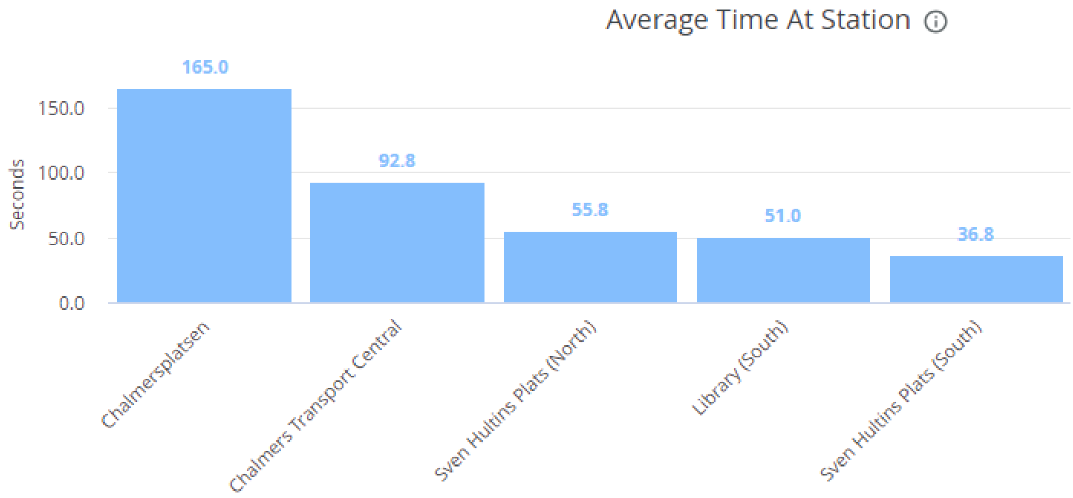

Figure 50 – Average time at station (source: Autofleet)

5.9 Data collection

Dashboard at demo site:

Gothenburg site used two dashboards serving different purposes:

- Autofleet solution (https://www.autofleet.io/) for its fleet management system
- SHOW Dashboard (https://demo.innovationcloud.ericsson.net/show-project/view/dashboard/Goteborg) site view for visualizing project KPIs.

Realtime vehicle data from Navya's API were collected and aggregated by the Autofleet's platform to produce actionable insights for Keolis (as an operator) to monitor the service performance.

The system was also integrated with Västtrafik systems, PTO/Gothenburg, regarding the public transport timetables.

KPI data were extracted and imported into SHOW SMDP, and then visualized in the respective KPI screens of SHOW Dashboard. Real-time data collected from the installed 5G devices were published into SHOW Dashboard, enabling real time visualization of vehicle data and real time alerts.

Data was collected to monitor safety on board:

- Safety drivers were always in contact with the control tower thanks to the 5G communication system
- The shuttle monitors all events. These events were analysed to prepare for any emergency event.
- In case of any security-altering event, an alert popped up on the safety driver's screen to switch to manual mode
- Passengers on board were reported by the safety driver. Processes were developed to answer to any passenger incident on board
- Temperature inside and outside (depending on the weather, this might indicate a necessary service interruption)

Furthermore, to monitor traffic efficiency:

- Distance travelled with / without travellers
- Total fleet distance
- Average speed / Average commercial speed

- Max speed for each shuttle everyday
- Number of rotations (laps)
- Distance travelled in autonomous mode vs manual mode
- Number of manual modes initiated
- Battery level for each shuttle
- Passing frequency is measured at each station (regularity)
- Number of passengers boardings & drop-offs at each station
- Time spent at each station

In total 130 respondents filled in the Netigate acceptance survey. The question about satisfaction was answered with a touch screen using five smileys, as in Linköping (Figure 18: Touch screen for satisfaction reporting - LinköpingFigure 18). For this survey 1231 answers were collected. Feedback from three safety drivers and four stakeholders was collected too.

5.10 Pilot operation key findings

5.10.1 Key findings per Use Case

High level findings per Use Case		
Use Cases	Overall qualitative performance score (1-3[18])	Justification
UC1.1/1.2: Automated passengers/cargo mobility in Cities under normal/complex traffic & environmental conditions *Gothenburg specific: First/last mile PT at Chalmers*	2	Technical difficulties with keeping vehicles running. Satisfaction was scored high and also acceptance. Overtaking traffic sometimes halted operation by cutting in to close in front. Some problems to find routines for days with heavy precipitation. Extra maintenance was ordered to mow grass, remove leaves and snow.
UC1.3: Interfacing non automated vehicles and travellers (including VRUs) *Gothenburg specific: UC1.3 Shuttle connecting to other passengers/VRUs at Chalmers*	2	UC1.3 was tested at specific sections of the route and has been performed successfully >15 times. The shuttles could connect to other passengers in the surroundings of the vehicles and warn VRUs visually (yellow vest started flashing on selected passengers in the Chalmers area) via public 5G mobile network (Telia). No haptic warning was tested.
UC1.7: Connection to Operation Centre for tele-operation and remote supervision*Gothenburg specific: Connection to Autofleet fleet management system*	2	The AVs were successfully connected to Autofleet Fleet management System via Navya API. It produced actionable insights for Keolis (as an operator) to monitor the service performance (such as vehicle data and real time alerts). Real time information was transferred over 5G which enabled limited remote supervision. Legal barriers existed for remote operation – and there was no way to test tele-operation in real life setting.

[18] 1 [Low] – 2 [Medium] – 3 [High]; success qualitative score, considering all aspects (technical, user acceptance).

5.10.2 Key challenges and mitigation outcome

The following challenges could provide future sites with a greater understanding about the potential of AV operation, but also reveals the barriers as of today.

Table 9: Key challenges at Gothenburg pilot site

Challenge	**Type** (Operational, Technical, Business, Other)	**Mitigation**	**Mitigation outcome**
Technical knowledge on how to operate in winter conditions	Technical	Training and problem handling by the safety drivers Service cancellations	Technical understanding on how winter and wind conditions affect the performance; heating while charging etc. Mostly ending up with a greater understanding of guidelines for maintenance during snow conditions.
Hit Ratio (= quality of the perception of the shuttle, taking in account the GPS, the lidars, the odometry) was not displayed correctly on the dashboard in one vehicle	Technical	Software update(s)	One shuttle was unable to operate until the software issue was solved.
Technical knowledge on interface with vulnerable road users	Operational	Training and problem handling by the safety drivers	Technical development and education, training, etc. No clear results were achieved.
A site responsible at the property area, would have helped a lot, some of the delay was due to difficulty finding the responsible person	Operational	Establishing local partnerships	Smooth operation

Challenge	**Type** (Operational, Technical, Business, Other)	**Mitigation**	**Mitigation outcome**
Working in close cooperation with all partners is essential for a smooth operation and permission process	Business, Other	Establishing local partnerships	Smooth operation and permit process
In Sweden, the homologation process was to be run in parallel with 2 different entities, the local traffic office, and the Swedish Transport Agency (STA), unless you want to prolong the process	Other	Run the homologation process in parallel	Good communication with authorities
Homologation of third vehicle, was late due to immature OEM especially regarding risk analysis (during homologation process)	Other	Early & iterative involvement of the OEM documentation in the homologation process	Knowledge on how to ensure maturity of the technology by providing a profound risk assessment and risk handling for AVs
Technical innovation may happen faster than policy/legislation development	Other	Raising awareness for these challenges	Awareness of the gap has increased
Delivery robot cooperation with shuttles	Other	Raising awareness for these challenges	Awareness of the gap has increased

5.10.3 Key incidents and impacts

Realtime vehicle data from Navya's API were collected and aggregated by the Autofleet's platform to produce actionable insights for Keolis as an operator to monitor the service performance, such as vehicle data and real time alerts.

One collision occurred with one of the shuttles: The shuttle detected an obstacle (vehicle parked incorrectly). The operator had switched to manual mode to overcome the obstacle and when launched to auto mode, a vehicle overtook and hit the shuttle.

No physical damage for the operator occurred, from the first observations made, only an impact on the bodywork was apparent. The incident occurred at the parking area near Chalmers Transport Central. The shuttle went back to the garage until logs were analysed and authorization to drive again was given from Navya.

The following pictures show impacts that have been reported by the safety drivers manually:

During the commercial phase, we faced several difficulties on site which we illustrate here exemplarily in the following figures:

Figure 51: Temporary fences being detected as obstacle in priority area (pedestrian crossing area, source: Keolis)

Figure 52: New modular buildings (student housing) developed after commissioning (source: Keolis)

Figure 53: Cars parked at bus stop or on shuttle route (source: Keolis)

Figure 54: Vehicles blocking the way (source: Keolis)

Severe winter and wind conditions with rain/snow/sleet/hail/foggy in February - June 2023, with temperatures below -10° C could affect performance. Very cold temperatures negatively affect batteries' autonomy and their charging. During winter, the isolated tent allowed to keep the shuttle at a correct temperature.

Heavy rain and extensive, deep puddles can irritate the shuttles during operation, further small fragments such as snowflakes or leaves. The shuttle was cleaned every day, inside and outside. All LiDARs and sensors were carefully cleaned every day to prevent deterioration.

As there were several snow episodes in March, operations were not possible. Indeed, driving in complex environmental conditions can be considered as out of the Navya Operation Design Domain and shuttle behaviour could be not the one expected: frequent braking, path exits etc. For safety and legal reasons, we are allowing to drive with snow/ice on the road for instance.

Also, bellow -10°C, the shuttles were not allowed to be turned on as the LiDARs (Velodyne) could be mechanically impacted.

Figure 55: Snow remaining being detected as obstacle, after March snow drop (source: Keolis)

Figure 56: Snow (operations had to be stopped temporarily)

Figure 57: LiDAR markers were put down by strong winds (source: Keolis)

These difficulties were usually overcome:

- Without consequences for operation (no impact on auto mode), such as the modular building.
- With temporary manual driving to overtake cars and trucks that are poorly parked or parked at bus stops. Some preventive measures have been taken, such as erasing the parking lot in front of Chalmers Transport Central Syd station.

- By stopping operations: snow on the road is usually outside the Operational Design Domain (ODD) and it is not safe to operate the shuttle.

5.10.4 The passengers' point of view

- Users gave positive rating for safety, travel comfort and reliability.
  - These results were found for both young and elderly passengers.
- Some criticism was received for low transport speeds.
- Digital channels for improving communication of project and attracting more passengers were appreciated. Example of such was in the inclusion of the shuttle service in the PTA travel planner.

Further detailed insight follows in D13.5.

5.10.5 The safety drivers' point of view

- The safety drivers experienced themselves to have fulfilled an important role technically and towards the passengers.
- Their technical knowledge on how to operate in winter conditions was essential.
- They worked with different user groups and needs (e.g. those that do not use public transport usually) and adapted the services accordingly.

Safety drivers were always in contact with the control tower thanks to the 5G communication system. The shuttle monitored all events. These events were analysed to prepare for any emergency event. In case of any security-altering event, an alert popped up on the safety driver's screen to switch to manual mode. Passengers on board are reported by the safety driver. Processes were developed to answer to any passenger incident on board.

Further detailed insight follows in D13.5.

5.10.6 The other road users' point of view

Violations of the traffic rules by other road users happened on a regular basis, this could be related to the reduced speed of operation in comparison to e.g. other motor vehicles and/or related to human error/misbehaviour.

Due to delivery trucks and site vehicles, time-restricted capacity of passage for shuttles could occur as well as during rush hours. Hard braking could also occur due to overtaking by e.g., cars or bicycles that were coming to close to the AV which brakes abruptly to prevent collision.

5.10.7 The stakeholders' point of view

- Business models and further technology development is needed.
- Working in close cooperation with all partners is essential for a smooth operation and permit process.
- Furthermore, how to interact with delivery robots is of relevance to some stakeholders. Solution exists digitally but also purely mechanical should be investigated further.

Stakeholders named the importance of a business model, especially for integrating such a service as first/last mile solution into a PT system. One stakeholder pointed out that the tests are important, but that it needs a combination of different factors to successfully integrate AV shuttles in the future PT system: a technical development boost regarding the shuttles, including the digital infrastructure, business model development and reliability of the service for the end users. Currently, also the permit process can be time-consuming and a prompt coordination with local traffic authorities can help to enable good service.

Furthermore, the importance of projects such as SHOW was pointed out by one stakeholder where knowledge is generated at different sites and with different test cases that can be shared. Stakeholders see the importance of combining trials with simulations and digital infrastructure/telecommunication with knowledge about user behaviour/acceptance.

Further detailed insight follows in D1.3.

5.11 Key local pilot events

A couple of key local pilot events are described further below:

What: Test riding for elderly, public transport users & focus group

Who: organized by RISE, Keolis & City of Gothenburg

When: 27th of February 2023

Objective: Understand the needs of elderly in public transport of tomorrow

Outcome: We had focus group discussions before and after the group tried the automated shuttles. In principle, the group thought that this type of public service (first-last mile from/to transport hubs) was useful and convenient. Yet, without a safety driver onboard, many mentioned would make them feel uncomfortable.


Göteborgs Stad

Kalendarium för Göteborgs Stad

Tillbaka till kalendariet

Framtiden är nu - självkörande skyttlar på Chalmers Campus Johanneberg

Bild: RISE

Datum:
Måndag 27 februari

Tid:
12:30–14:30

Kostnad:
Gratis

Självkörande fordon, hur fungerar det egentligen?
I februari gör vi en utflykt till Chalmers Campus Johanneberg för att få lyssna på hur det går för projektet med självkörande skyttlar där bland annat Chalmers, Keolis och forskningsinstitutet RISE samarbetar. Vi får möjlighet att åka med skyttlarna och dela med oss av våra tankar kring upplevelsen, vi får också bidra till projektets utveckling genom att besvara några enkla frågor i en enkät på plats.

Figure 58: Invitation for elderly focus groups to test the automated shuttles on 27 February, announced in the Gothenburg City calendar (accessed on 10/02/2023)

Figure 59: Focus groups and test riding with elderly people from Gothenburg (source: Tor Skoglund/RISE)

What: Public showcase of automated shuttles and delivery robot at Chalmers University of Technology/Johanneberg Science Park 23rd of May 2023

Who: organized by Johanneberg Science Park, Keolis & Berge

When: 23rd of May 2023

Objective: Demonstrate and present results of shuttle-robot interactions

Outcome: The aim of these tests was to better understand and test cooperation of connected vehicles for combined passenger-freight transport.

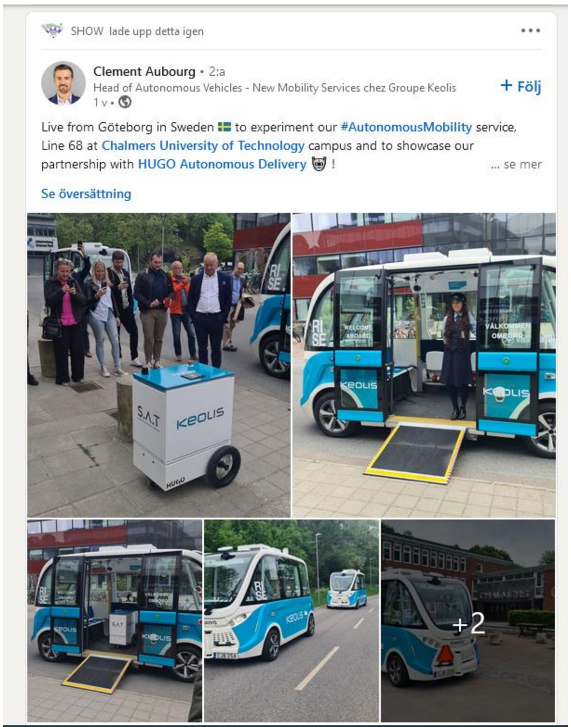

Figure 60: Social media article on the event 23rd of May 2023 (posted by Keolis)

Figure 61: Presentation of the SHOW shuttle service pilot by Keolis (source: Cilli Sobiech/RISE)

During the period September 2022 to May 2023, several attempts have been made with interaction AV and shipping robots. Furthermore, a brainstorming about how the vehicle should "hitchhike" with the self-driving vehicle has been carried out and a solution could be with some form of electromagnetic solution where the vehicle rolls attached to the AV.

What: Exchange with and visits from Parque de innovation/Buenos Aires, University of Tokyo and Netherlands/City of Helmond

When: Between October 2022 and November 2023

Objective: Exchange experiences and test

Outcome: Exchange of lessons learned and plans on further potential and cooperation.

Figure 62: Exchanging experiences with University of Tokyo (source: Cilli Sobiech/RISE)

Figure 63: Study visit by Parque de innovation, Buenos Aires/Brasil (source: Johanneberg Science Park)

5.12 Lessons learned & Recommendations

Technical

- Further technology development is needed for a smooth and safe ride in higher speeds.
- Ensure maturity of the technology by providing a profound risk assessment and risk handling for AVs.
- Many interventions to do on both shuttles in order to start the service and boarding passengers were necessary (such as technical repairs, software updates, solving GNSS issues).
- It was good to have an operational team in place to work on site and in back office (Keolis and Navya) for diagnostic and fixing those issues.

Operational

- Preparation of the route, such as cutting overhanging trees and further clearance of the shuttles track beforehand enables a smooth operation.
- Changes at close-by buildings or construction sites, such as scaffolding or equipment lying around can irritate the shuttles.
- Data collection procedures should be simplified for the sake of all stakeholders involved. Stakeholders involved in SHOW are not always represented by IT engineers. The procedures need to be adapted so that all partners understand precisely what is expected from them. For instance, it should not be taken for granted that all partners will we able to connect to an API all by themselves, as this requires time and very specific skills. Dedicated time and help should be provided by e.g. data collection WP leaders.
- Having local maintenance and spare parts to speed up operations and gain on the availability rate of shuttles.
- Weather difficulties that make the shuttles not running in snow and heavy rains.

- If no safety driver on board, passenger information must be crystal clear to welcome passengers, and communicate safety messages. A particular attention must be paid to vulnerable passengers or those with disabilities.

Business

- Passengers on campus were numerous and interested in this new mean of transportation.
- Business model development is needed increasing the understanding of the different demands/user needs.
- Manual interventions necessary by the safety operator often due to obstacles on the shuttles route, including badly parked vehicles and snow piles.

Other

- Ensure flexibility of the trials for technology development
- Legislation may prevent to experiment further with particular use cases (e.g. on remote operation).
- Attracting more passengers and user groups by digital channels by improving communication of the project is vital.
- The passenger pilots paved the way to other research on, for example, interaction and integration with delivery robot systems.
- Integrating shuttles in PTA system is a plus, with real time data, as shuttles cannot be reliable every time (no service when it snows, Estimated Time Arrivals must often be recalculated etc.).

5.13 Roadmap beyond SHOW and replicability

Beyond SHOW project shuttle operations (more globally), Keolis is currently working on developing projects in a test site in France (Châteauroux), including developing new safety and operational processes, new roles and new missions for our employees. There is also a focus on acceptability and how to welcome passengers in a means of transportation with no driver.

The test site allowed Keolis to train employees, and test the processes in real conditions, to challenge and improve them. The test site is also a sport area, thus there are opportunities to board passengers during competitions and do pilots.

Moreover, Keolis is testing on-demand automated transportation on this site, to optimize the consumption of shuttles and avoid empty trips.

Finally, all those tests and run will allow Keolis to offer efficient services in the future.

6 Conclusions

The large-scale field trials at the Swedish Twin Site of SHOW were successful overall and offered the possibility to study effects of the medium and, to the possible extent, long-term use of novel automated transport technology in real city environment as well as its role in the overall transport system. A large public interest was noted, whilst the pilots enabled and paved the way to further adaptations and development beyond the scope of the SHOW project.

The Swedish Twin Site fulfilled to:

- provide a robust, safe and reliable operation of a fleet of electrical automated vehicle fleet which enabled understanding of challenges and possibilities;
- offer understanding user experience with special focus on passengers with special needs;
- integrate and connect multi brand vehicles to a common service, complementing existing PT.

The project also enabled development of solutions for combining automated shuttles and delivery robot services.

The two pilot sites encountered several technical challenges, most often related to immature vehicle technology. Furthermore, the implementation of the 5G control tower concept at both sites faced challenges due to technical (e.g. limited access to the shuttles´ APIs), organizational (e.g. partner engagement) and legal difficulties. The level of technological maturity as demonstrated at the sites did not allow a removal of the safety operator yet, which is a requirement for a commercial use of AVs in PT.

In total, over 20,000 people were over an extend period of time transported with automated shuttles (including the pre-demo phase; see Deliverable 11.3). Several workshops with experts, stakeholders, and public (youths, children, and elderly) were held. From collaboration and work with users and stakeholders, it became apparent that further work needs to be done in relation to the business model(s) and to make the service attractive/accessible to certain user groups.

The SHOW pilot platforms enabled moreover other initiatives such as interaction studies with VRUs, part of which has been also initiated in SHOW. Future work will focus on technology with even higher autonomy levels and on-demand functionality. The pilot sites allowed to see possibilities and to identify challenges that are needed to further work with. Often the focus has been on vehicle performance, such as solving brake behavior, positioning, etc., yet more effort should be put into safety, behavior, and complementing strategies so that a full, inclusive, cost-efficient and of high-quality mobility service is provided.

Further analysis of data collected (for this and all SHOW pilot sites) are following in *Deliverable 12.9: Real life demonstrations pilot data collection and results consolidation* and in *Deliverable 13.5: SHOW impact assessment on user experience, awareness, and acceptance*, while stakeholder analysis is to be found in *D1.3: Stakeholder & travellers needs evolution through Pilots.*

References

[1] SHOW (2024). D9.3 Pilot experimental plans, KPIs definition & impact assessment framework for final demonstration round. Revised. Deliverable of the Horizon-2020 SHOW project, Grant Agreement No. 875530.

[2] VTI 2023: Autonoma elektrifierade bussar. VTI rapport 1177.