

Introduction of Autonomous Buses for Swedish Airports



Project within: FFI Accelerate the transition to sustainable road transport.

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FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which about €40 is governmental funding.

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Summary

Arlandastad (Airport City Stockholm) is Sweden's first airport city that is currently being built between Uppsala and Arlanda Airport. This new city is poised to play a crucial role in Sweden's economic growth. Plans are in place to create jobs for 50,000 people, and the companies that establish themselves here will be close to Sweden's two fastest-growing regions, Stockholm, and Uppsala. As the city becomes more populated, mobility needs are expected to increase. Since public transportation is limited in the area, it is likely that private car usage will rise. Transport already accounts for over 30% of emissions in Sweden, and autonomous buses have long been considered a safe, efficient, and sustainable alternative for passenger transportation. That is why this pre-study explores how to harness automation, digitalization, and electrification to provide new mobility services with full-sized autonomous buses.

This pre-study highlights the potential impact of a new mobility service utilizing full-sized autonomous buses traveling between Arlanda Airport and Arlandastad (Airport City). This use case has been examined because it offers a unique operational design domain (ODD) for testing multiple full-sized autonomous buses and has been selected to prepare for a pilot study as a follow-up project. The project has determined that a successful pilot study has significant potential to lead to the introduction of new services with full-sized autonomous buses in the near future.

Sammanfattning på svenska

Arlandastad (Airport City Stockholm) är Sveriges första flygplatsstad som håller på att byggas mellan Uppsala och Arlanda flygplats. Denna nya stad kommer att ha en betydande roll i Sveriges ekonomiska tillväxt. Det finns planer på att skapa 50 000 nya arbetstillfällen, och de företag som etablerar sig på Arlandastad kommer att vara nära de två snabbast växande regionerna i Sverige, Stockholm och Uppsala. När staden blir mer befolkad förväntas också mobilitetsbehoven öka markant. Eftersom kollektivtrafiken är begränsad i området är det sannolikt att resenärerna kommer att välja att köra sina egna bilar till området. Transporter står redan för mer än 30 % av utsläppen i Sverige, och autonoma bussar har länge varit ett övervägt alternativ för säker, effektiv och hållbar passagerartransport. Därför utforskar denna förstudie hur man kan utnyttja automation, digitalisering och elektrifiering för att erbjuda nya mobilitetstjänster med fullskaliga autonoma bussar.

Förstudien belyser den potentiella påverkan av en ny mobilitetstjänst som använder fullskaliga autonoma bussar som pendlar mellan Arlanda flygplats och Arlandastad (Airport City). Detta användningsfall har valts eftersom det möjliggör en unik operativ designmöjlighet (ODD) för att testa flera fullskaliga autonoma bussar och har identifierats som ett lämpligt alternativ för en pilotstudie som en fortsättning på projektet. Projektet har kommit fram till att en pilotstudie som bedöms ha potential att resultera i införandet av nya tjänster med fullskaliga autonoma bussar inom en snar framtid.

Background

Arlandastad (Airport City Stockholm) is Sweden's first airport city being built between Uppsala and Arlanda airport. This new city will play a crucial role in the economic growth of the Stockholm region and Sweden. New jobs are planned here for 50,000 people and the companies that establish themselves there will be connected to Sweden's two fastest-growing regions Stockholm and Uppsala. Arlanda Stad Group, which is developing the city with their partners, have estimated that as the city becomes populated, mobility needs are expected to rise at a rapid pace. As public transport is limited in the area, visitors are most likely to drive cars to get there. Transport already represents more than 30% of the emissions in Sweden¹, and as air traffic is recovering from the pandemic, both flights and the airport are transforming to become fossil-free. Ground transport, both the one connecting the airport to the cities and the ones within the airport, need to catch up with the rapid development of autonomous vehicles and accommodate future air traffic with emission-free solutions. Autonomous buses have long been under consideration for safe, efficient, and emission-free passenger transport. That is why this project is looking at how to leverage automation, digitalization, and electrification to provide new mobility services that are fossil-free, safe, equal, and efficient using full-sized autonomous buses. Autonomous buses will be used to create a new mobility service to link Arlanda airport and Arlandastad.

Purpose, research questions and method

This project aims to map the prerequisites for the introduction of autonomous buses from a system innovation perspective, investigate the feasibility, and attract additional partners to prepare for a larger pilot study for a case connecting Arlanda airport to Arlandastad.

Through a state-of-the-art analysis, consortium building, and pilot planning for full-sized autonomous busses, the project will answer the following questions:

- What are the latest developments in autonomous buses since the year 2020?
- What is the potential integration solution and business cases of the chosen route?
- What are the latest developments in safety validation and verification for autonomous vehicles such as processes, frameworks, and standards?
- How feasible is the chosen route from the safety perspective?
- What are the stakeholders who need to be involved in accelerating the introduction of autonomous buses?

To achieve the project's goal of establishing a knowledge base for a demonstration the of full-sized autonomous buses to the meet transportation needs regarding connecting Arlanda Airport to Arlandastad, the project stakeholders have undertaken a series of activities.

The work has encompassed both collaborative project activities and activities tailored to the specific needs of the individual partners. This section will provide an overview of all the activities.

¹ <https://www.naturvardsverket.se/data-och-statistik/klimat/vaxthusgaser-utslapp-fran-inrikes-transporter/>

Initially, the joint activities centered around establishing the project's framework with respect to the respective system dimension and gathering valuable insights through interviews with external stakeholders who possessed experience in operating full-scale autonomous buses, even though they were not directly involved in our project.

Subsequently, the focus shifted towards sharing experiences derived from the work conducted during the spring and commencing the analysis of the results obtained. This led to discussions about the distinctive and common aspects of this use case and how we intended to proceed with the insights gained.

Throughout the project's duration, we conducted internal project meetings. The frequency of these meetings varied depending on the need for coordination and sharing information. For instance, we held project meetings every two weeks consistently throughout the entire project timeline.

We also engaged in interviews and meetings with external parties beyond our project group, including:

- Swedavia, the owner of Arlanda Airport, who granted us permission to operate on their land and has allocated 100 hours to assist us if we initiate a pilot.
- Sigtuna municipality, the owner of land along part of the route, which dedicated a staff member to work part-time (15% of full-time) in the event of a pilot project.
- Volvo and Scania, both vehicle manufacturers.
- The Swedish Transport Agency, the regulatory authority responsible for granting permissions for experimental activities involving autonomous vehicles.
- Fusion Processing, a company currently running a pilot project with full-scale autonomous buses in Scotland.
- Quality Hotel, Connect Hotel, and Scandic Hotel, all of which operate in Arlandastad and expressed interest in potentially paying for a service using autonomous buses to transport their customers from Arlanda Airport.
- Scandinavian XPO, which hosts between 80-100 events per year at Arlandastad and is actively seeking transportation solutions.
- Kolumbus AS, currently running a pilot with autonomous buses in Stavanger where we did a site visit.
- Adastec, visiting R&D office and operation center. Also visit test track at Bilsim Vadisi, Turkey's largest industry park.

The interviews and meetings served a dual purpose: to share preliminary project findings and to collect fresh perspectives aligning with the project's goals. Consequently, the project not only facilitated the dissemination of new knowledge regarding full-scale autonomous buses but also laid the groundwork for examining location-specific insights pertaining to the selected route.

Our conclusions are founded on the interviews we conducted with external stakeholders who are not part of the project consortium, as well as on the state-of-the-art research and the site assessment that has been conducted. These findings were then analyzed in alignment with the overarching goals of the project, which encompass behavior, technology, infrastructure, policy, and business models.

Objective

The project aimed to conduct a feasibility study for the introduction of autonomous buses related to Arlanda airport and simultaneously establish a consortium for a potential pilot study and service introduction. The project has achieved this through the following project objectives:

- Delivering a knowledge foundation from a system innovation perspective with deep analysis of all five system dimensions².
- Choosing a use case for a demonstration project and creating a safety case that explains what is needed to permit automated vehicle trials and testing on Swedish roads.
- Establish a consortium for a continuing pilot project that will enable the commercial introduction of full-sized autonomous buses that are accepted by users and society and are economically viable.

Results and deliverables

State-of the-art

Public Transportation is an integral part of any Smart City and Urban infrastructure. In 2018, in the US alone, riders took 9.9 billion trips on public transport services. Over the last 20 years, ridership has grown 21% - a higher growth rate than the population growth. However, many transport systems in the US and worldwide are antiquated. It is proven that investment in public transportation systems drives economic growth. In the US alone, public transport is estimated to be 10x safer than a car journey. Providing clean, modern, socially inclusive 24x7 services across a wider coverage area can increase demand, further improve safety, and drive broad economic returns to businesses and communities. This is only feasible with lowered labor costs and improvements in the bus and the infrastructure to deliver these economic advantages. Automated buses radically reduce labor costs and the market for automated vehicles has an increasing maturity and will experience rapid technological development.

Increasing automation in road vehicles has the potential to revolutionize urban mobility. Predicted benefits of automated vehicles include significantly improved road safety, along with better productivity, mobility, and environmental outcomes. To achieve these outcomes, it is crucial that automated vehicles are trialed to demonstrate the capability of the technology. Industry and governments must assess automated vehicles against real-world challenges, including interactions with other road users and road environments. Trials will also increase awareness and understanding among the public – the users and beneficiaries of this mobility revolution. Due to existing legal barriers, vehicles cannot legally operate in a conditionally or highly automated driving mode on public roads. Organizations seeking to run automated vehicle trials will require state and territory road transport agencies to provide permits or exemptions from these legislative obligations. This could include permits or exemptions from obligations in the road rules or other road transport legislation.

² <https://www.vinnova.se/m/hallbar-systemforandring/>

Globally, a few pilot projects are ongoing related to full-sized autonomous buses, as summarized below.

First and Only Automated Bus Deployment in the USA

This is a pilot is done by Michigan State University, Karsan, ADASTEC, Michigan Economic Development Corporation at the campus of Michigan State University (MSU). The operation deployed a Karsan electric autonomous bus approved by the NHTSA (National Highway Traffic Safety Administration). The pilot route is 3.3 miles long, with 7 controlled (V2I integrated traffic lights) intersections, bicycle lanes, crosswalks, and two uncontrolled left turns, as shown in Figure 1. The bus operated Monday through Friday between 8:30 a.m. and 3:30 p.m., making a total of 40 roundtrips per week. Since April 2022, the bus has transported over 1000 students and faculty across campus. The operation was a revenue service, took place on public roads, and transported students from a commuter parking lot (Commuter Lot 89) to the MSU Auditorium. The bus was operating at an average speed of 15 mph when it was first deployed. In 2020, the speed was increased to 20 mph. Interior surveillance cameras and required signals of the automated platform are recorded and reported periodically to NHTSA. Automated vehicle tests in the USA can be tracked with the "Test Tracking Tool," which allows online monitoring within the "AV-Test Initiative" established under NHTSA. ADASTEC is a member of the AV-Test Initiative and is the only company that tests automated public transportation buses in this context.

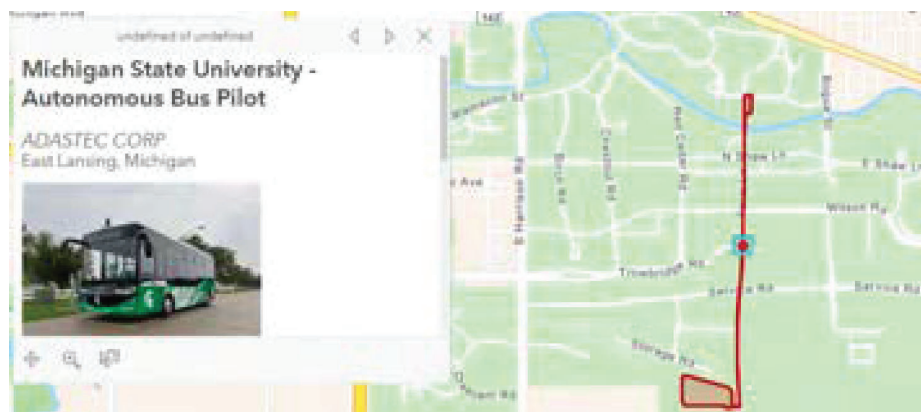


Figure 1 Autonomous bus in MSU campus

First Automated Bus Deployment in Europe

This joint project by Vy, Kolumbus, ADASTEC, Applied Autonomy and Karsan is conducted in the city center of Stavanger, Norway since 2019. It is the first-ever autonomous and electric bus that is fully integrated into the public transit system in Stavanger. The bus is certified by TÜV NORD and approved by the Norwegian road authorities. The pilot route is 1.6 miles in length and takes place on public roads shown in Figure 2. The route includes five bus stops, four roundabouts, and twelve crosswalks and goes alongside the harbor. Every day, a minimum of one cruise ship arrives, letting out 1000+ tourists who visit the city by using Karsan's bus automated by ADASTEC. To accommodate the demand, the bus operates 7 hours daily from 1:00 - 7:30 pm, making a total of 14 roundtrips per day. Thus far, the bus has transported over 9000 passengers. ADASTEC reports and uploads different types of data to the central cloud, which is shared with

various authorities. During the Stavanger operation, the autonomous driving average speed is approximately 15 km/h, and the maximum speed is 40 km/h due to traffic and road conditions.



Figure 2 Autonomous bus in Stavanger

Automated Bus Deployment in Scotland

This is a joint project by Fusion Processing Ltd., Stagecoach PLC, Alexander Dennis Ltd., Transport Scotland, Napier University and Bristol Robotics Lab. Operations have been running since May the 15th 2023 by Stagecoach PLC with 5 autonomous busses who run on a 14-mile route from the Ferrytoll Park and Ride in Fife, across the Forth Road Bridge Public Transport Corridor, to Edinburgh Park. The weekly capacity is up to 10,000 passengers.



Figure 3 Autonomous busses in Scotland

Industrial Zone Deployment in Romania

This is a collaboration by Karsan, ADASTEC, BSCI on deploying the first-ever autonomous bus in Ploiesti Romania. The operation has been approved by Romanian Road Transport Authority (ARR) and runs on a 1.1-mile route in a technology park. The deployment takes place in open traffic and includes pedestrian paths. The project originally started as a technology project. It was completed in 2021 and is now actively used in demonstrations.

In Sweden, there are no active full-sized autonomous busses since the investigation done by the Swedish Transport Administration in 2020. Conversations have been initialized with the Swedish OEMs including Volvo busses and Scania busses, and the dialogs are ongoing.

The chosen route – Connecting Arlanda Airport to Arlandastad

During the project we have conducted extensive site assessment for the chosen route between Arlanda airport and Arlandastad. In this section we begin by describing the chosen route, followed by a description of the base vehicle. We then describe the autonomous driving system we aim to use in a potential pilot, followed by the operation design and finally the site assessment.

The selected route for the project connects Arlanda Airport to Arlandastad (Airport city, as shown in Figure 4 below) spans approximately 15 kilometers. Along this route, there are two designated bus stops strategically located to serve passengers. The speed limits on this route varies, ranging between 50 to 70 kilometers per hour. Notably, the route experiences low traffic, providing favorable conditions for autonomous bus operations. Moreover, a significant portion of the route (approximately 8.5 kilometers) covers through a forested area.

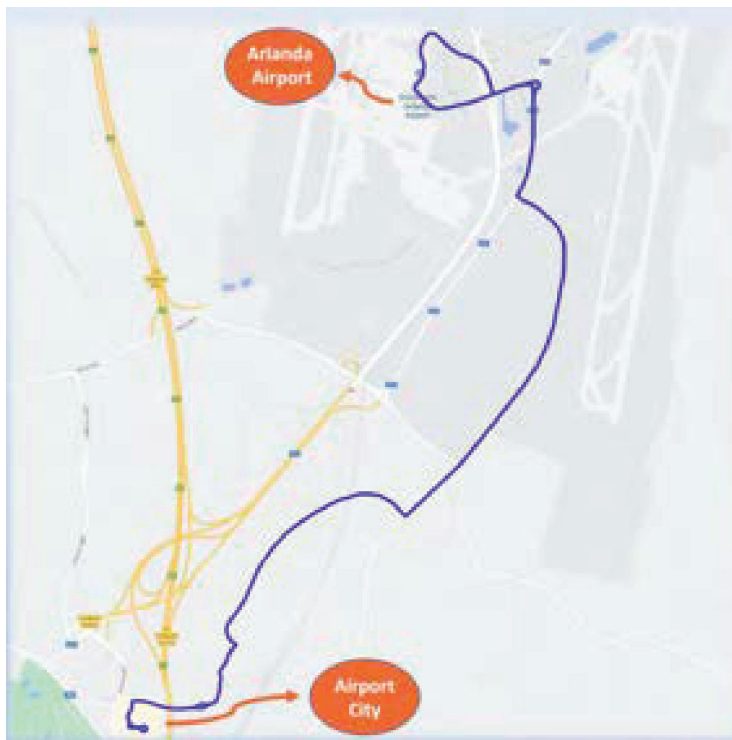


Figure 4, The chosen route

Base Vehicle

The pre-study has explored the potential use of the Autonomous e-ATAK bus for an upcoming pilot project. The Autonomous e-ATAK aligns with the requirements of public transportation and serves as an efficient and modern public transport vehicle. It has been specifically designed for public transportation needs, with carefully selected and engineered components, making the

Autonomous e-ATAK a highly efficient vehicle. It boasts a low-floor platform, an ECAS system, panoramic views, comfortable seating, and a range of equipment options, including Wi-Fi and a camera surveillance system.

The Autonomous e-ATAK is a modern, comfortable, and secure public transportation vehicle that includes features such as a high passenger capacity, a wheelchair-accessible low-floor design, front independent suspensions, and an electric engine that delivers optimal efficiency and produces zero emissions.



Figure 5 the e-ATAK vehicle used in Stavanger

The vehicle largely complies with the applicable EU and UN ECE regulations as stated in Table 1:

| | |
|---|-------------------------------|
| Approval of Motor Vehicles and Trailers | Directive No. 2007/46/EC |
| Permissible sound level | UNECE Regulation No. 51 |
| Rear underrun protective devices (RUPDs) and their installation; rear underrun protection (RUP) | UNECE Regulation No. 58 |
| Space for mounting and fixing rear registration plates | Regulation (EU) No. 1003/2010 |
| Steering equipment | UNECE Regulation No. 79 |
| Audible warning devices and signals | UNECE Regulation No. 28 |
| Devices for indirect vision and their installation | UNECE Regulation No. 46 |
| Braking of vehicles and trailers | UNECE Regulation No. 13 |
| Electromagnetic compatibility | UNECE Regulation No. 10 |
| Seats, their anchorages and any head restraints | UNECE Regulation No. 17 |
| Vehicle access and manoeuvrability (reverse gear) | Regulation (EU) No. 130/2012 |
| Speedometer equipment including its installation | UNECE Regulation No. 39 |
| Manufacturer's statutory plate and vehicle identification number | Regulation (EU) No. 19/2011 |
| Safety-belt anchorages, Isofix anchorages systems and Isofix top tether anchorages | UNECE Regulation No. 14 |
| Installation of lighting and light-signalling devices on vehicles | UNECE Regulation No. 48 |
| Towing device | Regulation (EU) No. 1005/2010 |
| Safety-belts, restraint systems, child restraint systems and Isofix child restraint systems | UNECE Regulation No. 16 |
| Location and identification of hand controls, tell-tales and indicators | UNECE Regulation No. 121 |
| Heating systems | UNECE Regulation No. 122 |

| | |
|---|-------------------------------|
| Safety glazing materials and their installation on vehicles | UNECE Regulation No. 43 |
| Installation of tyres | Regulation (EU) No. 458/2011 |
| Speed limitation of vehicles | UNECE Regulation No. 89 |
| Masses and dimensions | Regulation (EU) No. 1230/2012 |
| M2 and M3 vehicles | UNECE Regulation No. 107 |
| Vehicle with regard to specific requirements for the electric power train | UNECE Regulation No. 100 |

Table 1 Regulations that the vehicle complies with

The Automated Driving System (flowride.ai)

The project has explored utilizing the flowride.ai system as the automated driving system for a potential pilot project. ADASTEC's automated driving system, flowride.ai delivers an advanced Level 4 automation platform for full-size commercial vehicles currently available. The main target of flowride.ai is its implementation and operation on public transportation buses and the automation of urban transportation routes. The flowride.ai platform consists of modular automated driving software in the bus and a cloud-based back-office platform. The bus module handles all aspects of the automated operation of the vehicle through an integrated, fault-tolerant set of sensors and HD-Maps, where enhanced sensor fusion and deep learning techniques are utilized. The cloud-based platform supports mission control, data sharing, and fleet management operations.

Operational Design Domain description

Operational Design Domain (ODD) of Autonomous e-ATAK is defined for urban/sub-urban automated public transportation operations. The flowride.ai system has a map-based approach. This provides more certain, safer, and more comfortable operation to the autonomous vehicle. All road and area ODD conditions and specifications are defined in the HD Map. If the autonomous vehicle exits in the ODD, appropriate minimum risk maneuvers (MRM) are activated to achieve the target minimal risk condition (MRC) and/or warning messages are published. The ODD document of flowride.ai and Autonomous e-ATAK has been prepared following the Automated Vehicle Safety Consortium™ (AVSC) best practices and PAS 1883:2020 requirements and recommendations.

Site Assessment

The project has also have conducted a detailed site assessment by scanning through the chosen route between Arlandastad and Arlanda Airport. The site assessment results are summarized in Appendix 1.

Safety Approach

Safety plays a vital role in any system design, and design by safety is the primary design phase. In computer-based systems, safety is essential not only for the user to use the system safely but also for the safe operation of the codes, ensuring traceability and having a structure that can be changed. In automated vehicles, which is the implementation area of flowride.ai, safety has an extensive and

important role. Safety procedures and methods need to be applied in the design of each item, system, and element, starting from the concept phase.

This part describes ADASTEC holistic safety approaches for the autonomous driving system (flowride.ai) and its integrated autonomous vehicle (AV). For a continuing pilot study, the approach and methods will be used and evolve according to the requirements of the airport operations. The major components of the safety approach are discussed below.

Standards, regulations, and technical reports

Safety plays a key role from the beginning of the development, including the concept phase, to the deployment of the product, and then to operation and maintenance.

Automated Vehicles have more complex E/E systems than conventional vehicles. Accordingly, all systems (including drive-by-wire, actuators, sensors, etc.) used in the flowride.ai, are developed or selected based on ISO 26262. Their backup systems are also designed following the same structure. In addition, ISO 26262 recommendations and guidelines are followed and developed in safe software and system designs with a holistic development approach. This means not only ISO 26262 but also different related standards like ISO 21448 (SOTIF), ISO/SAE 21434, ISO 22737, UL 4600, and PAS 1883 are followed for ADASTEC development, safety & security, V&V, and operational studies.

On the other hand, there are no clear and precise standards since automated vehicle technologies are a new and rapidly developing field. Therefore, the evaluation of standards such as ISO 21448 – "Safety of the intended functionality (SOTIF)" and ISO 22737 – "Intelligent transport systems – Low-speed automated driving (LSAD) systems for predefined routes" together with the existing ADASTEC procedures and standards play a significant role. SOTIF is handled together with functional safety in automated driving system design, ensuring the functional safety of the elements, as well as evaluating the effects of misuse, lack of capacity, environmental factors, and covering known, and unknown use cases and non-E/E technologies the Operational Safety is provided. SOTIF HARA and Systems Theoretic Process Analysis (STPA) methods are used to generate and evaluate SOTIF-related hazards efficiently and holistically with the other methods. ISO 22737 is one of the most recently published related standards and directly covers Low-speed automated driving (LSAD), providing guidelines and test procedures. In this context, ADASTEC has added these directions to safety procedures and has established an inclusive test and development infrastructure by adding the specified cases to the test scenarios.

As safety is the most important term for safe operation, security relates to safety for providing secure, and comfortable autonomous operation. For cyber security, a pilot project must follow ISO/SAE 21434 "Road Vehicles – Cybersecurity Engineering", UN Regulation No.155, and other standards, regulations, and technical reports. Threat Analysis and Risk Assessment methods are used to predict cyber threats and generate security goals. These goals are used to produce security requirements for development and design studies.

There are also plenty of regulations for conventional and public transport vehicles, but the newest regulation directly focused on vehicles implemented with Automated Driving Systems (ADS) and fully driverless vehicles is just released.

The European Commission has started to work on regulations and rules to increase occupant and vulnerable traffic user safety in Europe with new, mandatory, and active safety features under the title of General Safety Regulations (GSR). Likewise, NHTSA and other authorities are working on a similar approach in the US, supporting it with accident reports and analysis and aiming to increase traffic safety. The study of the European Commission on automated and fully driverless vehicles is also gathered under this roof.

The studies of the European Parliament and the Council started with Regulation (EU) 2018/858 and continued with Regulation (EU) 2019/2144 to develop the implementing legislation for the type-approval of the automated driving system implemented vehicles. On August 5, 2022, the last updates were shared under Regulation (EU) 2022/1426. As the next stage, the Commission will continue the work to further develop and adopt by July 2024 the requirements for the EU whole vehicle type approval of fully automated vehicles produced in unlimited series. Also, the general safety rules shall be covered by the systems like better blind spot detection, warning for pedestrian and cyclists' collisions, and tire pressure monitoring for the buses. The rules will first apply to new vehicle types from today onwards and all new vehicles from 7 July 2024. Some of the new measures will be expanded to cover different kinds of road vehicles until 2029.

The other important regulation is UN Regulation 157, referred into Regulation (EU) 2019/2144 about automated lane-keeping systems. The requirements of this regulation should also be followed. It is also important to follow other Regulations such as UN 155, UN 156, UN 160, UN 94, UN 100 and to comply with the requirements. ADASTEC Safety and Quality Management Team follows the requirements of regulations via the requirement management system and leads to studies to achieve these requirements with other related teams.

Safety Risk Management

Risks are conducted in all components and sub-systems of flowride.ai, therefore, all analyzing, and mitigation management is provided for all item's elements and components. Moreover, the item is directly connected and depends on the vehicle. Therefore, vehicle-level risks (including environmental effects and limitations) are analyzed in and studies need to be carried out with the safety teams of the OEM. Safety Risk management studies started with Hazard identification and continued with Risk Assessment and Mitigation.

Hazard Identification and Analyzing

Hazard identification is the first step of safety risk assessment studies. Hazards are the potential source of harm to the item. Also, defining vehicle-level hazards is essential for autonomous vehicle development. These hazards are defined as accidents to identify potential harmful effects on the vehicle and around the vehicle. These hazards and accidents are defined in the dynamic Hazard and Accident List.

There are two main sources of Hazard generation:

- Knowledge Base:
 - HAZOP is executed to generate Hazards with Guide Words.
 - Site Experience gathering via brainstorming sessions.
 - Development Experience gathering via brainstorming sessions.
- Data Based:
 - Hazard scenario generation from Real Road (closed-track) Test results analyses.
 - Hazard scenario generation from Simulation Test results analyses.
 - Hazard scenario generation from Open Traffic Operation data analyses.

Safety Risk Assessment and Mitigation

Three main terms are considered below for the steps of the risk assessment and mitigation process.

- ✓ Analysis (e.g., in terms of the probability of occurrence as well as how severe the impact can be and how easily can the hazard be controlled).
- ✓ Assessment (to risk prioritization and tolerability).
- ✓ Control (until risks are reduced to an acceptable level).

For the holistic approach, different levels of the item (sub-system, system, item, vehicle) must be covered with different analysis methods to generate mitigations for all related hazards. In analyses such as HARA and FMEA, it is examined whether the system is functionally safe. Even if the system is functionally safe, it cannot be guaranteed that it will operate completely safely. For this reason, misuse, system limitations, environmental effects, and different triggering events are questioned with SOTIF HARA and STPA for the control aspect. Also with TARA, it is aimed to minimize the vulnerabilities of the system against cyber-attacks that may come from outside. The analysis methods for different levels are identified in the figure below.

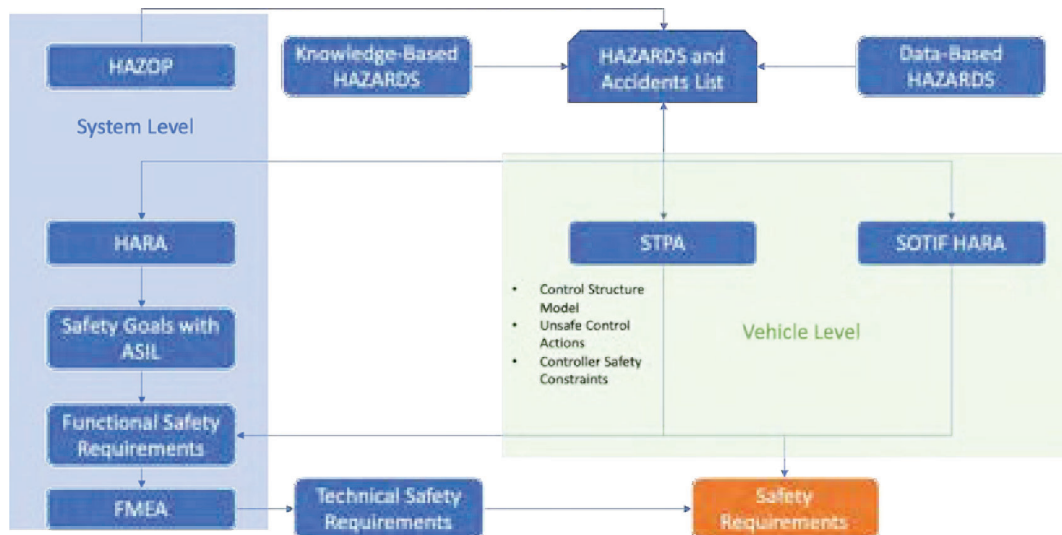


Figure 6 Different Safety Analysis Methods for Different Levels

During the initial phase of the risk management process, the project safety manager is responsible for conducting the analysis, while the Team Leader holds the authority to exercise final control and present the findings to the Safety Committee.

In the product development phase of the risk management process, team members from the relevant development teams bear the responsibility for conducting the analysis. The safety manager has the authority to exercise final control and present the results to the Safety Committee.

Safety Performance Monitoring and Measurement

ADASTEC has a statistical based performance analysis method for monitoring, reporting, and analysing the performance of flowride.ai and the autonomous vehicle. The data logging procedure

is an important part of proper monitoring and performance analysis. ADASTECC analyses these data and reports system performance with Key Performance Indicators (KPI), Safety Performance Indicators (SPI), and Comfort Performance Indicators (CPI). Some main indicators are represented below,

| SPI | KPI | CPI |
|---|---|--|
| Number of Unintended Disengagements | Minimum/Mean/Standard Deviation Values of TTC | Max/Min/Mean Longitudinal Acceleration |
| Number of Incidents | Minimum/Mean/Standard Deviation Values of Time Headway Distance (THW) | Max/Min/Mean Lateral Acceleration |
| Number of Near misses | Max/Mean/Std of Velocity | Longitudinal Discomfort Ratio |
| Number of MRM engagements (according to ADS Mode Manager Decisions) | Error in Velocity | Lateral Discomfort Ratio |
| Number of Redundant Avoidance System Activations | Min/Max/error in Steering Rate | Max/Min/Mean Longitudinal Jerk |
| Number of Emergency brakes | Min/Max/error in Steering Angle | Max/Min/Mean Lateral Jerk |
| Number of errors in Time to Collision (TTC) | Average/Total Energy Consumption | |

Table 2 Performance indicators considered.

For transparent monitoring by all stakeholders (transportation operators, OEM, authorities, etc.) flowride.ai uses the automatic reporting systems (xFlow and ADASTECC Reporting System) to generate safety and performance reports to present Command Control Centre and Authorities Control Centres. Also, real-time monitoring is provided to command control centres.



Figure 7 ADASTECC AV Monitoring System

Moreover, if any onboard operator is existing during the operation, It is possible to monitor system actions, conditions, and failures by Operator HMI.



Figure 8 Safety Operator HMI

Operational monitoring, reporting and data sharing strategy

Flowride.ai Autonomous driving and Cloud

The flowride Cloud enables information access for the status and the planned operations of automated transit systems from a control center through managed APIs (Application Programming Interface) and APPs (Applications).

Open API platform for the automated fleet includes all the required interfaces for automated fleet management from a control center. flowride Cloud handles all the requirements for secure and high-performance data sharing, analysis, and integration. It provides seamless integration to all stakeholders for automated and modern transportation.

Operators, automated fleet owners can develop their flowride APPs for the automated fleet using flowride API. flowride APPs support remote management of fleet operations.

For the purpose of monitoring the automated vehicle from the Operation Control Center, all relevant information is transmitted via a live network such as 4G, 4.5G, and LTE. In order to provide autonomous functions during operation, a network connection is not required.

Flowride.ai autonomous driving systems secure data transmission to the cloud provider, such as telemetry, status, events, and logs, are done with the MQTT (MQ Telemetry Transport) network messaging protocol. This protocol can create lossless, bi-directional connections with the remote-control center and the vehicle with minimal latency. Since flowride.ai uses AWS IoT (Amazon Web Service – Internet of Things) Core as a service, there is no overhead on managing and scaling the MQTT broker infrastructure. This big data coming from the vehicles are stored within the cloud data lake for further real-time monitoring and analysis. Upon any suspicious activity or disengagements from the vehicle, a set of telemetry and diagnostic logs are also uploaded to the remote serverless data store to be reviewed by the developers. An MQTT connection is always open between the AV and the remote-control center. It can publish messages to the vehicle with very low latency. The set of APIs opens a way to interact with the vehicle in a modeled and secure manner and is documented in OpenAPI specification and allows interacting with the vehicle HMIs for remote information, such as possible traffic events or a way to interact with the vehicle in a forced disengagement scenario. flowride API also enables company applications to overview analytic data generated by the vehicles by querying the data stores. For partners that require more observability on the vehicles, we offer one-way direct communication with the MQTT network for real-time monitoring of the raw data. ADASTEC's API and Applied Autonomy's xFlow® Smart

Flow Management have already been integrated to provide the full capability of the Command Control Center.

xFlow Smart Fleet Management

The application to be used for the management of the operation in the Command Control Centre is the xFlow Smart Flow Management application developed by Applied Autonomy and integrated with the flowride API.

xFlow® Smart Flow Management extends the smartness of autonomous vehicles by connecting them to transport companies and public service control centers. It makes it possible to integrate and connect to an unlimited number of vehicles, road condition sensors, traffic regulation functions, and end user services to achieve a holistic system for transport automation. All data is stored in a cloud platform in Europe and secured against unauthorized intrusion. xFlow® comprises four main different tools designed to provide different stakeholders in the autonomous bus operations with means to monitor, control and analyze the operations.

The xFlow monitor allows real-time vehicle and road sensor monitoring for situation awareness. Real-time situation awareness is crucial for the safe and efficient operation of an autonomous fleet. Vehicle statuses can be monitored, and changes in road conditions might imply an immediate change in the vehicle assignment or route.

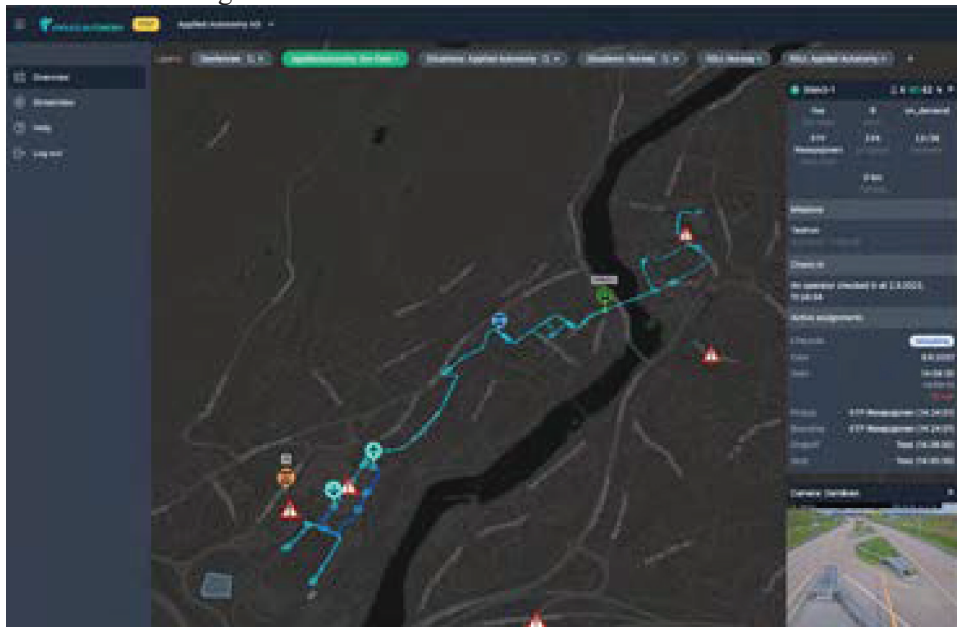


Figure 9 xFlow monitor

| Function | Data available from selected vehicle services: |
|---|--|
| Real Time Vehicle and road sensor monitoring | 3D map visualising selected layers of information like: <ul style="list-style-type: none"> - Telemetry visibility of all vehicles with their status - Defined routes of the vehicles with defined bus stops - Defined geofence areas with their functions. Geofence might work as regulation of where the vehicles can operate or can be used to inform the field operators of ongoing activities in certain areas of the trajectory. - Configurable status of the vehicles; Status might be; Test ride, |

| | |
|--|---|
| | <p>Operation mode, garage mode, critical mode - need assistance</p> <ul style="list-style-type: none"> - Road sensors with their status updated frequently - Situations on the road network from the road administration where available, e.g., road works <p>The remote controller might select vehicles to see more details such as:</p> <ul style="list-style-type: none"> - Energy level of selected vehicles - Speed level of selected vehicles - Ongoing mission of the vehicles - Destination of the ongoing missions of vehicles, e.g., the next bus stop - Estimated time of arrival to the destination of the ongoing mission - Driving mode and activity of the integrated and connected vehicles. E.g., autonomous mode and on-demand or timetable/metro activity. - Critical status information |
|--|---|

Table 3 xFlow monitor functions.

The xFlow mobile tool

The xFlow is tool for the safety driver and/or operator of the autonomous bus, allowing them to digitally document the work they perform. The tool is a web-based application used for field personnel and is configurable based on operational needs. The operator might use a mobile phone or a tablet for this application. The tool is used to document checklist operations and to register events that the vehicle itself is not capable of, and which are of great interest for supporting an efficient transport operation.

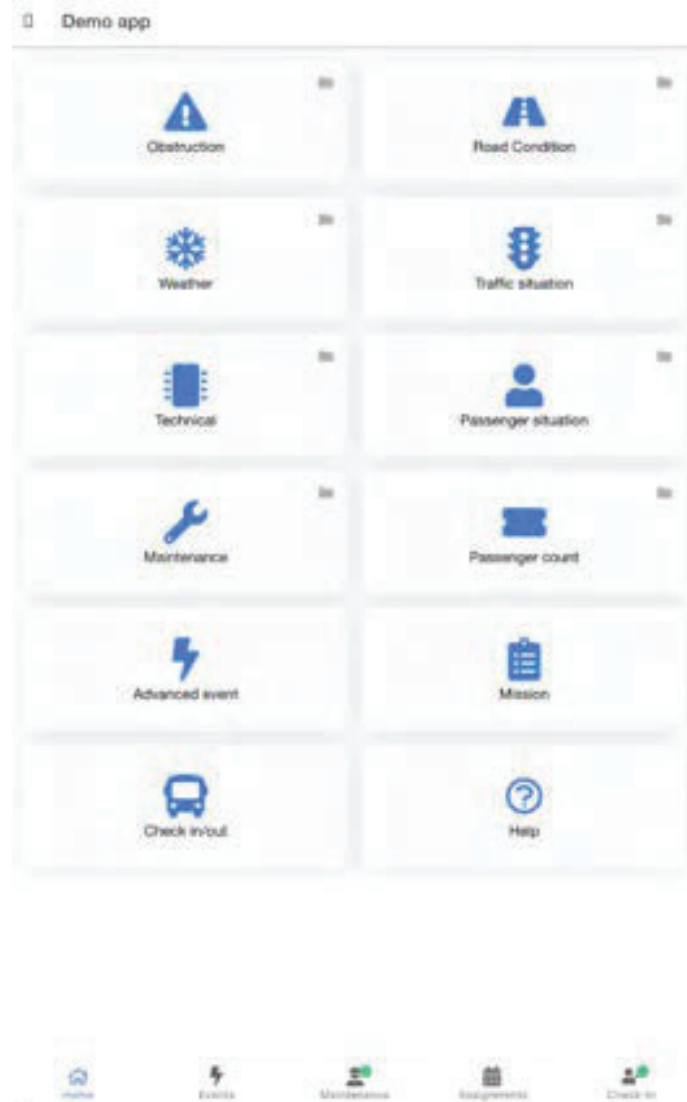


Figure 10 xFlow App

| Module | Functionality |
|---|---|
| Safety driver/ operator Tool | <p>Documentation of responsible operator and the vehicle's main task by:</p> <ul style="list-style-type: none"> • Safety driver/operator checking in/out on the vehicle and claiming the responsibility until the end of the shift. • Safety driver/operator starting/ending a defined mission/task for the vehicle including filling out configurable checklists (e.g., mission can be <City>: Line xx or Test run) <p>During operation, the safety driver/operator may register time- and location-based events to be used to create operational insights e.g. passenger counts, emergency stops (incl. reason) or provide information to the road owners</p> |

| | |
|--|--|
| | <p>about problems in an area (e.g. potholes, snow banks). This information can be used to improve both the vehicle, road infrastructure and the customer experience for the operation.</p> <p>The tool also provides the possibility to register free text, photo and video as events to get a better documentation of the situations. Blurring of sensitive data (e.g., licence plates, faces) is automatically done.</p> <p>The setup of this tool is configurable for each customer in regards to the events, mission definitions and checklists to be defined.</p> |
|--|--|

Table 4 xFlow app function

The xFlow remote tool

Is a tool that enables autonomous vehicle task operation and remote operations. To dispatch the autonomous bus according to a timetable or on-demand orders, xFlow® can schedule, execute, and update the assignment due to vehicle-internal or road-external disruptions and needs. In case of road situations (e.g., slippery roads), xFlow® may command the vehicle to slow down in the defined area to maintain for safety reasons. If available, xFlow® may control specific vehicle functions like acknowledging overtaking, usage of wipers, passenger audio/video communication, vehicle internal screens, etc.

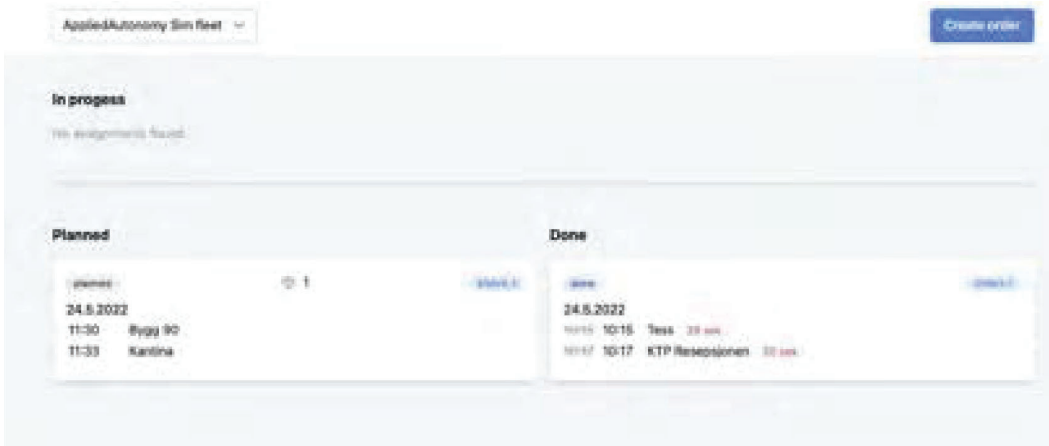


Figure 11 xFlow remote tool

The xFlow® console tool

Is a tool used for configuring the organisations assets and road regulations and for visualising the customised dashboards, insights and reports. Customers of Applied Autonomy can give their partners and customers access to the data from the Console or the Monitor. This is organised by the Applied Autonomy Security and Sharing definition tool. Third party applications can also integrate data from the system through the Application Program Interfaces. Typical third-party applications are for example real-time transport systems presenting real-time status information to passengers at a bus station. They might also be an information system providing information on buses.

Geofences

Title *

Rush hour zone

Description

Rush hour extra toll cost

Weights

No weights added yet

+ Add

Validity

Description

Increase toll by 20%

All day

Start (UTC) *

27/06/2022, 07:00

End (UTC)

27/06/2022, 09:00

Recurrence

every weekday

Repeat every 1 week

Repeat on M T W T F S S

End repeat Never

X Remove

+ Add

Geometry *




Figure 12 xFLOW consol (1)

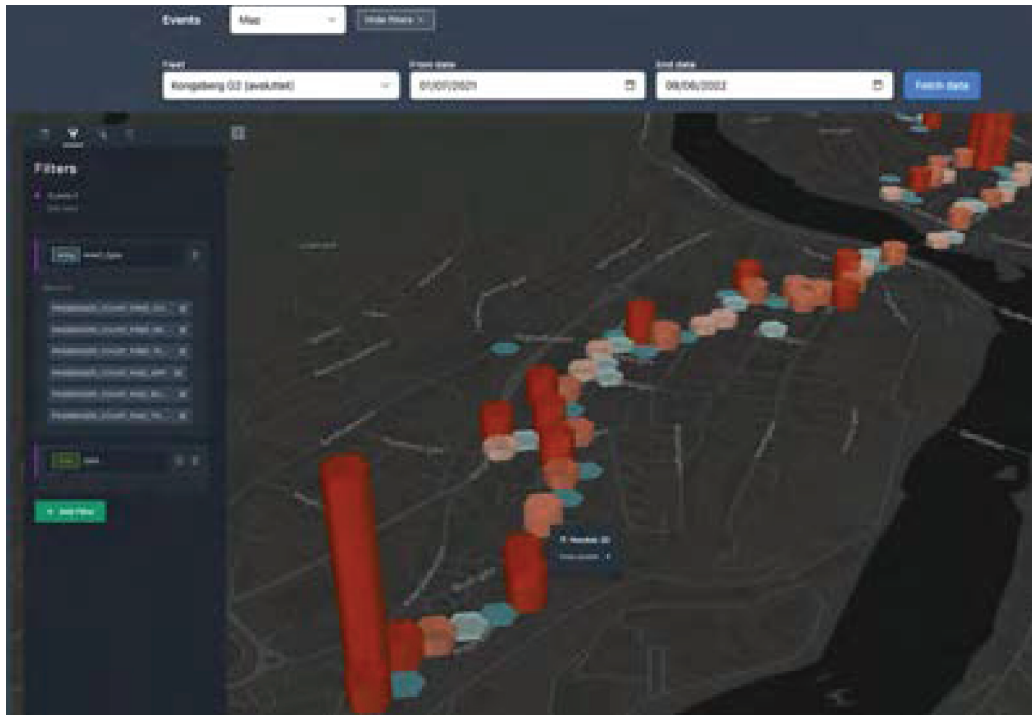


Figure 13 xFLOW consol (2)

| Module | Functionality |
|--|--|
| Configuration | <ul style="list-style-type: none"> • Administer company asset in xFlow® (fleets, users, routes, stations) • Set up and administer Geofences, e.g., increased toll. • Set up and administer Situations, e.g., road work or accidents |
| Dashboards, Analytics & Reports | <p>The dashboard might contain the most important data such as:</p> <ul style="list-style-type: none"> • Main KPIs for the Company e.g., number of passengers transported today, this week. • News from the company and solution provider <p>Standard reports</p> <ul style="list-style-type: none"> • Passenger ticket types • Events registered for vehicle or operator tool. Can be visualised in a table or map view. • Missions historical log including responsible operator and filled checklists. • Operators work log. • Vehicle telemetry insight statistics like battery consumption and mileage. Reports in table or map-view <p>Customer tender specific reports and analytics can be made on request.</p> |

| | |
|--|---|
| | Reports may be exported to CSV files for further analysis and graphical interpretation. |
|--|---|

Table 5 xFlow consul function

(EU) 2022/1426 (2019/2144) Regulation on type approval

In order to accurately follow the recommendations and requirements of the Regulation, a correct categorization and management approach is required. We have categorized the Regulation in accordance with the development, safety, and security, testing and simulation, and operation processes within ADASTEC. These categories also match the regulation's topics. These categories are:

- Documentation & Reporting
- Safety & Security
- Test and Simulation
- Data Management
- Operational

These requirements are managed in a Requirement Management system. The system gathers Customer Level Requirements (Customer requirements, Regulations, Technical Reports, Inside Requirements, etc.) and generates System Level Requirements to prepare inputs to Development Tasks (under different projects). Under these categories, we have gathered and focused on 498 Requirements in different sizes (as workload) to have full coverage of Regulation. The status (by December 2022) is shown in the following figure and the work is ongoing.

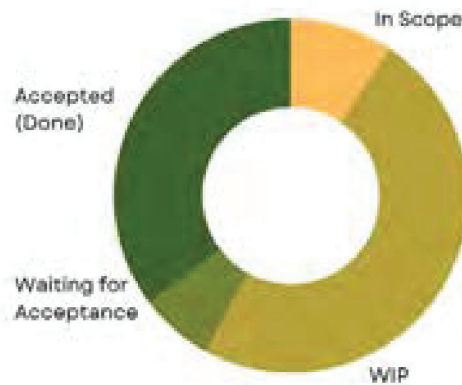


Figure 14 : Current status of studies about Regulation Requirements

ADASTEC has Scenario Based Safety Assessment approach with different test stages. Safety Case is the main focus and tests with different scenarios are integrated with ADASTEC system development studies. These test scenarios should be inclusive of all claims of the Safety Case. For this reason, two different sources are used to generate test scenarios.

- ✓ Knowledge-based. Requirements and ODD initiate claim generation and claims generate arguments. Each argument must have proper evidence and each of this evidence has a minimum of one test scenario and report.
- ✓ Data-based approach. Data are collected from our deployment sites to generate new test scenarios. Some scenarios may be unpredictable in controlled areas. The advantage of this approach is the creation of real operational scenarios with real-operation data. These test scenarios are tested in controlled areas and improvements can be made to make the system work most safely and efficiently. These test scenarios are tested in controlled areas to generate test reports. These reports provide inputs to improvements that can be made to ensure the ADS operates most safely and efficiently.

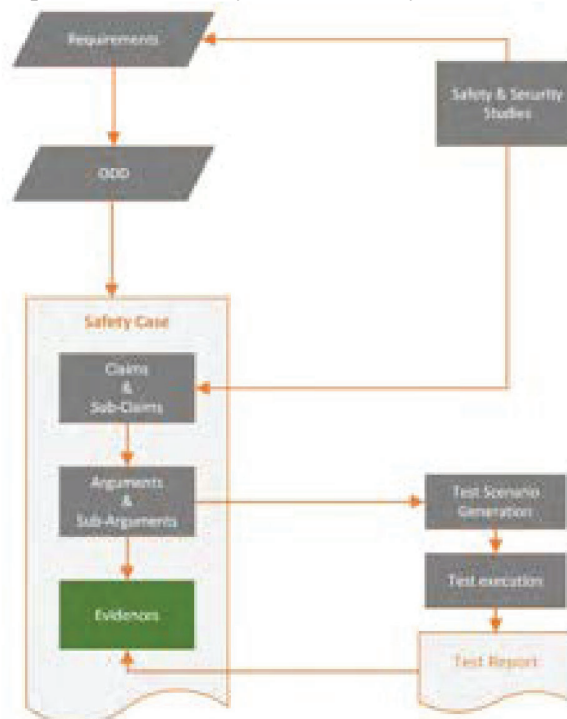


Figure 16 Test scenario generation from requirements and ODD

Test Scenarios for Standards and Regulations

Initial Different standards and regulations are followed within ADASTEC Safety and Test Management and harmonized in the most appropriate version for the system.

ISO 22737:2021 is one of the standards that consist of test scenarios for Low-speed automated driving systems. ADASTEC’s Safety Case Based test scenarios also contain LSAD test scenarios to obtain evidence according to this standard.



Figure 17 Test Scenarios Examples from LSAD test

The other important terms are Fail-Safe and Fail-Degraded capabilities of the system as defined in ISO/TR 4804 Technical Report. The failure modes and risk analysis are carried out with different methods like FMEA, HARA, STPA, and Safety Goals are identified to ensure system safety in every condition. Test scenarios cover all these actions testing to obtain evidence for the Safety Case.

The recent ADS focused regulation, (EU) 2022/1426 (2019/2144) has also different test scenarios and test & simulation-related requirements. These scenarios are integrated into our Scenario Catalogue and requirements are followed with RMS.

Tests with Stakeholders

Feedback from stakeholders is also important for the comfort and intended usage of the system. Stakeholders stand for, sometimes end-users, sometimes operators, and sometimes local authorities. It is necessary to convert this feedback into development requirements and integrate them into development studies. To meet these requirements and ensure operational safety, test scenarios and evidence for the Safety Case structure are created.

As an example, ADASTEC has had test studies with the New Mobility Team of Keolis Group (as our Operator stakeholder) at Autonomous Vehicle Test Site (SEMA) in Châteauroux, France. Different test scenarios from real operation experiences of Keolis are tested in SEMA. All test scenarios and cases are reported and evaluated. This collaborative test study is very beneficial for developing flowride.ai to increase the safety and comfort of autonomous public transportation capabilities.

System dimensions

In this section the project's outcomes are presented based on the system dimensions that, include user needs, technology, policy, business models, and infrastructure. For each of these themes, we have explained what needs to happen to enable a full-scale pilot.

Technology, products, services and processes

A pilot project represents a **significant leap forward** in the field of autonomous transportation beyond previous pilots. It marks the first attempt to explore the possibility of establishing a full commercial service based on automated transportation for a transformative, commercially viable solution to address transportation needs effectively. It plays a pivotal role in introducing larger automated vehicles to Sweden's transportation landscape and represents a vital component of the country's journey toward the future of public transportation. For a safe and effective pilot, key aspects of autonomous driving technology need further development and refinement. These changes and developments are essential to ensure the seamless integration of autonomous buses into the public transportation ecosystem:

A pilot project would necessitate ongoing **refinement of the software algorithms** that power autonomous driving systems. These algorithms must be fine-tuned to navigate complex urban environments, anticipate, and respond to various traffic scenarios, and prioritize passenger safety and comfort. Continuous testing, simulation, and validation using real-world data are integral to enhancing the technology's robustness.

Autonomous buses rely on advanced sensor systems to perceive their surroundings accurately. Further development of these sensor systems is crucial to ensure they can operate effectively in diverse and challenging conditions, including adverse weather and environmental factors. **Improvements in sensor technology** contribute to the vehicle's ability to make real-time decisions and navigate safely.

Another crucial element is **effective communication between autonomous vehicles and the surrounding infrastructure**. This is vital for safe and efficient operations. Developing and optimizing vehicle-to-infrastructure communication systems ensures seamless integration into the existing transportation network, enabling autonomous buses to interact with traffic signals, infrastructure sensors, and other elements of the urban environment.

The project will implement **iterative updates to the autonomous driving system**. These updates address challenges encountered during real-world testing, incorporating lessons learned and enhancing the system's capabilities. Each iteration brings the technology closer to achieving the level of reliability and performance required for public transportation.

Upgrades to the embedded vehicle hardware and sensor suite are imperative. These improvements enhance automotive-grade functionality, allowing autonomous buses to operate effectively in extremely adverse weather conditions and challenging environmental circumstances. Robust hardware ensures the technology's resilience and suitability for mass transportation solutions.

The project would need to develop and test methods and processes of **safety validation of autonomous vehicles** in mixed traffic, which contribute to the global efforts in these areas. The project leverages the bus platform to generate **large open datasets** on autonomous driving that supports research and innovation, which again support the building of frameworks for safety validation.

The test and validation the **xFlow control centre** which is a critical component of the project, requires further development to adequately support the envisaged operations. Stakeholder input, including direct users of the control centre and Swedish road authorities, is essential to ensure that all operational needs are met. Gathering the correct data for later analysis is a priority, emphasizing the importance of ongoing development and adaptation to evolving requirements.

Business models, procurement, and cooperation

The business model for this mobility service would need to be dynamic due to its aim to address a clearly stated need among potential customers. VY and Arlandastad have actively worked in identifying and exploring necessary steps to adapt their current business models to the evolving circumstances.

To establish a revenue base, the initial approach will involve introducing the autonomous bus service to two hotels that have expressed interest in participating. These hotels see the value in offering a sustainable, zero-emission, high-capacity service to enhance their attractiveness compared to hotels located at Arlanda Airport or in Stockholm city. The business model will gradually expand as the project demonstrates the potential of such an automated service.

Currently, existing business models do not account for the integration of autonomous electric buses into public transportation networks. The project aims to modify and develop business models that

incorporate autonomous buses, taking into consideration factors like operational costs, ticketing, and infrastructure maintenance. This adaptation requires collaboration with transportation authorities, bus manufacturers, and technology providers to ensure the financial sustainability of the model.

Policy, standardization, and regulations

The continuing project would need to address the legal requirements associated with the operation of autonomous vehicles, particularly in the realms of road safety and liability in case of incidents. To successfully introduce the proposed solution, it is imperative that regulatory frameworks evolve to accommodate autonomous public transportation.

Our project's strategy revolves around active collaboration with regulatory bodies such as the EU Autonomous Driving Vehicles Committee and the NHTSA (National Highway Traffic and Safety Administration). We actively contribute to the development of new standards and engage in discussions concerning liability and safety protocols. Initiating change in this domain involves extensive policy advocacy, the presentation of comprehensive safety assessments, and the demonstration of the myriad benefits of autonomous buses within controlled environments.

While we have not yet identified any major legal obstacles, it is crucial to recognize that the technology we aim to introduce represents a significant leap into an uncharted domain. This presents a unique challenge for road owners, Sweden, the Swedish Transport Administration, and the Swedish Transport Agency. Therefore, our commitment lies in fostering close collaboration and ensuring that the introduction of milestones occurs in a judicious and well-considered manner, thereby navigating the legal landscape with diligence and foresight.

The Swedish Transport Agency is currently working on guidelines for conducting tests where the safety driver is removed. This will be an opportunity for them to see if the guidelines they set up need to be changed.

Behaviour, culture, and values

The current transportation setup at Arlanda Airport heavily relies on taxis and a single circular bus route primarily serving hotel visitors, which has led to significant mobility challenges. However, our project envisions a substantial shift in user behaviour. In a pilot project the aim would be to transition hotel visitors away from traditional transportation methods towards an innovative, eco-friendly, and high-capacity autonomous bus system.

To facilitate this transition, it is imperative that end users adapt their behaviour to trust and embrace autonomous public transportation buses. Passengers should feel confident and comfortable when boarding and riding these driverless vehicles. To achieve this goal, the project would need to take a comprehensive approach focused on enhancing user acceptance.

Firstly, we plan to conduct thorough safety demonstrations to build public trust in autonomous technology. These demonstrations will illustrate the buses' capability to navigate complex urban environments and handle challenging situations. Another critical aspect is maintaining transparent communication regarding autonomous operations. We will emphasize the technology's safety protocols and advantages, drawing from previous pilot experiences that highlight the importance of keeping passengers well-informed and engaged throughout their journey. Furthermore, we intend to create interactive engagement opportunities for passengers through educational campaigns about autonomous technology, safety measures, and the numerous benefits, such as

reduced congestion and emissions. In addition, we are committed to implementing user-centred design principles to ensure that the autonomous transportation experience is intuitive and user-friendly, catering to the unique needs and preferences of passengers.

Changing user behaviour is a multifaceted endeavour. While some hotel visitors may readily embrace the new autonomous bus service, others who are accustomed to using their own cars, rental cars, or taxis may require more effort. To address this, we propose a dual-pronged approach. Firstly, we will ensure that the autonomous bus service offers an efficient and appealing alternative to conventional options. Secondly, we will collaborate with relevant stakeholders to explore strategies such as adjusting parking fees and reducing parking areas, incentivizing users to shift from private vehicles to the autonomous bus service. Additionally, we will implement dynamic pricing during the project to encourage users to embrace the new transportation paradigm gradually, fostering changes in attitudes and behaviours over time.

Infrastructure

Autonomous vehicle may need support from infrastructure which has been investigated by the Swedish Transport Administration in previous studies. In our pre-study we have conducted a preliminary SAR (Site Assessment Report) for the suggested route. It has been identified that the existing infrastructure will need some modifications and mitigations to facilitate the operations. This project will demonstrate how autonomous buses can be introduced into mixed traffic with minimum infrastructure adaptations with recommendations for future integration. The project's approach involves collaborating with road owners, urban planners, public transportation operators, and local authorities to adapt existing infrastructure and allocate space for charging and bus operations. The change will be realized by retrofitting infrastructure and ensuring smooth interaction between autonomous buses and other traffic participants.

Dissemination and publications

1.1 Dissemination

| How are the project results planned to be used and disseminated? | Mark with X | Comment |
|--|-------------|--|
| Increase knowledge in the field | x | <ul style="list-style-type: none"> • The latest development of autonomous busses globally • The latest safety standards and methods on autonomous vehicles • The feasibility of autonomous buses on the chosen route in Sweden • The business viability and integration potential of autonomous busses in Sweden |

| | | |
|---|---|---|
| Be passed on to other advanced technological development projects | X | <ul style="list-style-type: none"> The results are aimed to be used by the potential pilot study on the chosen site. |
| Be passed on to product development projects | x | |
| Introduced on the market | - | |
| Used in investigations / regulatory / licensing / political decisions | - | <ul style="list-style-type: none"> Not yet. The Swedish Transport Agency is currently looking into developing guidelines for pilots with the safety drives removed. The continuation of a pilot could contribute to the development of those guidelines. |

Conclusions and future research

The pre-study summarizes the latest development of the autonomous buses and conducts a feasibility study on the chosen test route with considerations of different system dimensions. Technical feasibility can be demonstrated by the ongoing pilot studies in other countries and regions, and business feasibility is discussed with bus operators for commercial operation. Integration has been considered with the local authorities, landowners, potential customers such as hotels. The project team concludes that autonomous buses are at the phase for introduction in mixed traffic while challenges need to be addressed through realistic, local pilot studies. The project team suggest the following future research and is working on potential continuous of a pilot study.

Safety validation and verification: There are no globally accepted standards or frameworks to ensure autonomous driving safety, and many ongoing works address the challenges globally. Existing standards, practices, and guidelines need to be implemented with consideration of the local environment such as the road conditions, weather, and traffic behaviors. Pilot experiences and first-hand data are extremely important to support such processes.

Service introduction and integration: Commercially available autonomous busses are very few though some of the pilot studies claim to be commercial (free to use) and are open to the public. Developing a viable business case for the integration of autonomous buses to address the needs of different stakeholders requires broad collaboration using a viable case. The Arlandastad to Arlanda Airport route provides such a case for potentially the first real commercial autonomous bus operations.

Regulations at national and international levels: Regulations on autonomous vehicles are on their way and the Swedish regulations need to catch up with the global pace. Robotaxis are largely deployed already in the US, and the neighboring country Norway has been running autonomous buses in mixed traffic for over a year and is considering taking away the safety drivers. Synchronization with global efforts to combine with the EU and local regulations is important to generate experiences for accelerating the permit process.

Research and innovation: Autonomous driving systems are partially enabled by different artificial intelligence methods which have experienced rapid advancement in the latest years. Data holds the key to training those algorithms that are adapted to the local environment and features such as behaviors. There is in general no such large dataset in Sweden to support the development of

autonomous buses. Adding such a dataset is extremely useful for the Swedish and global research community to test and validate different AI methods for safety and interpretability.

Participating parties and contact persons

Contact persons

Mahdere DW Amanuel, RISE

Zakaria Abna-Aissa, VY

Anna Stenströmer, Arlandastad

Ali Ihsan Danisman, Adastec

Olav Madland, Applied Autonomy



Appendix I, Site Assessment Report

This document describes the site assessment of the chosen route.

Arlanda Airport Project Site Assessment Report Version 2



Contents

- SAR Revisions
- Glossary
- Site Characteristics
- General Mitigations
- Project and Route Information
- Route Sections
- Legend
- Sections
- Route Sections Risk Assessment
- Bus Stop
- Garage Location
- Way Speed Limits
- Traffic & AV Average Speeds
- Crowded Sections
- Crosswalks
- Critical Intersections
- Air Condition
- Precipitation
- V2X Information
- Recommendations

SAR Revisions

| Process | Revision | Date | Author | Description |
|-------------------|-----------|------------|-------------------------------|--------------------------|
| Pre-Deployment | ARL-PD-V1 | 08.06.2023 | Berkin Aral Oğuzhan Topgöç | Creation of the document |
| Pre-Deployment | ARL-PD-V2 | 06.07.2023 | Berkin Aral | Update to the document |
| During Deployment | | | | |
| Pre-Operation | | | | |
| During Operation | | | | |

Glossary

AV: Autonomous Vehicle

V2X: Vehicle to Everything

QR: Quick Response

RAM: Risk Assessment Matrix

RSU: Road-Side Units

TBD: To Be Determined

Site Characteristics

| | |
|--------------------------------|-----------------------------|
| Duration of the service | TBD |
| Road / Traffic Type | Public / Mixed |
| Road Surfaces | Asphalt/Concrete |
| Maximum speed limit | 70 km/h |
| Operating Mode | Bus/shuttle |
| Fleet Management | Yes |
| AV Stops | 2 |
| Supervision | ADASTEC, AppliedAutonomy |
| Passengers | Open to public |
| Route length | 15 km |

| | |
|--|---|
| Number of vehicles on the route | 3 |
| Vehicle Type | Autonomous e-ATAK |
| Maximum vehicle speed | 40 km/h |
| V2X Intersection | Projected |
| Safety Driver | Yes, VY |
| Safety Operator | Yes, ADASTEC |
| Remote Operator | Yes, VY |
| Vehicle Maximum Capacity | 21 Seated, 25 Standing, 1 Disabled chair, 47 Total |

General Mitigations

General safety mitigations (environmental, operational etc.) are defined briefly to ensure safe operation of Autonomous Vehicle



Safety driver(s) will be trained and certified on board



Safety and Information stickers on the vehicle

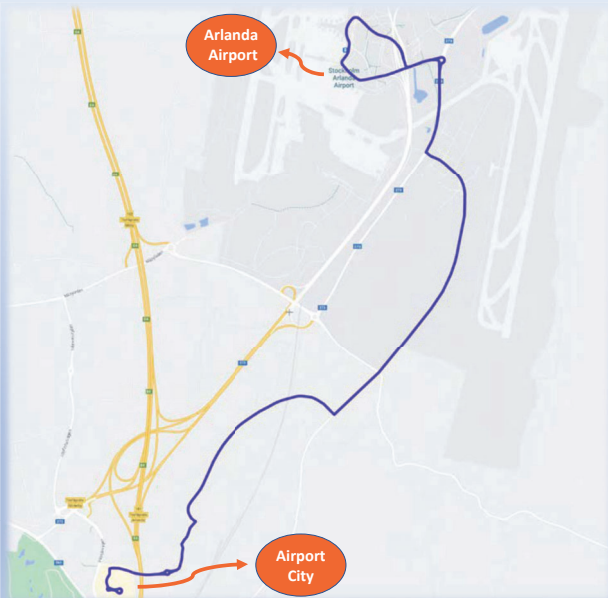


Install Signs to warn traffic participants on the route



Awareness announcement and publicity to citizens about the AV Operation on the route

Project and Route Information



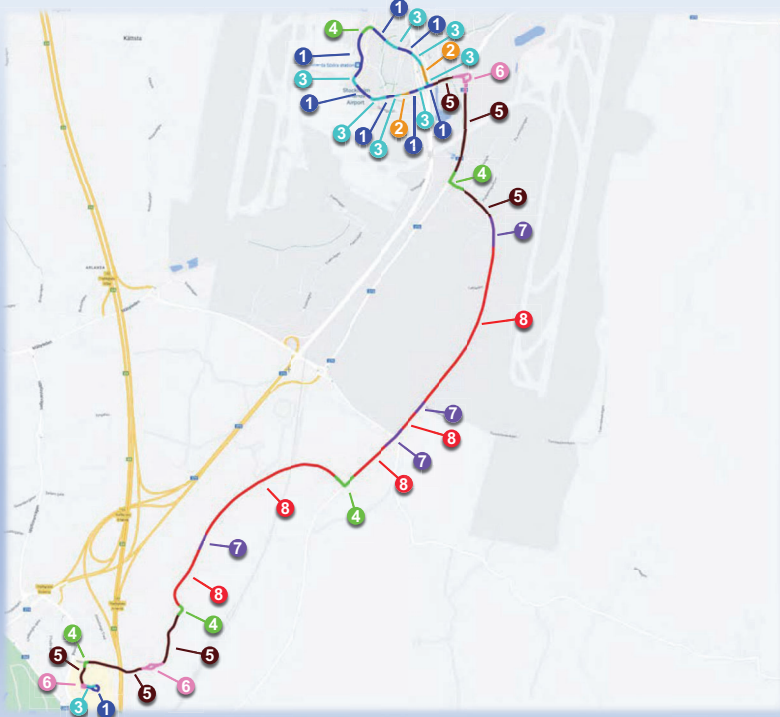
Purpose

- Site Assessment of Arlanda Project according to:
 - Route Dynamics
 - General Behavior of the AV
 - Scenes and events
 - Risk Factors and Mitigations

Route

- Between Arlanda Airport and Airport City
- 15 km route length
- 2 bus stops
- Speed limits between 50-70 km/h
- Low traffic
- 8.5 km road through the forest

Route Operation Sections

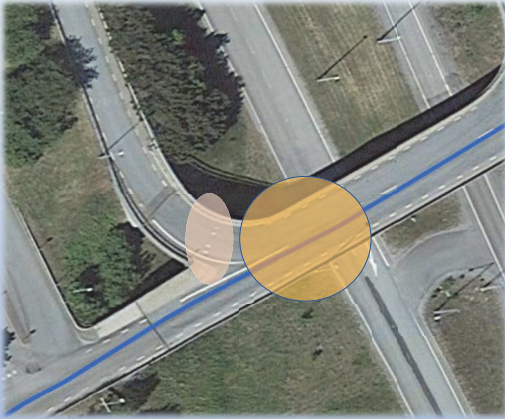




Route Operation Sections

- The trajectory traveled by the vehicle is divided into numbered 8 segments
- Each segment has different properties described in the following slides
- The colors do not have any particular meaning; they highlight the segments defined by their properties




Legend

The marks we will use on the pictures are explained in these examples.

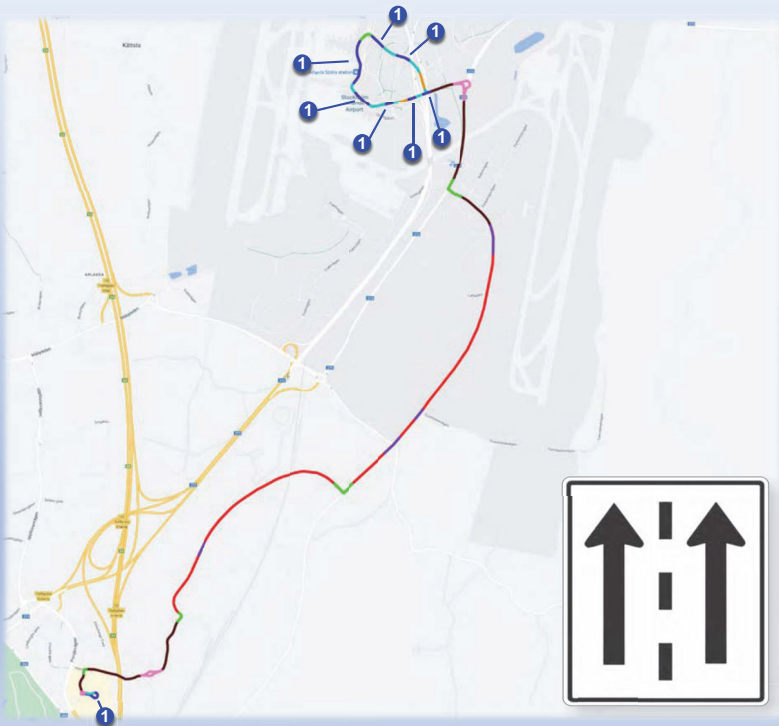


-  The "Give Way" mark
-  Merge / Intersection point



-  AV road
-  AV path
-  Other vehicle paths

Section-1



Section Properties

- One lane – one way road

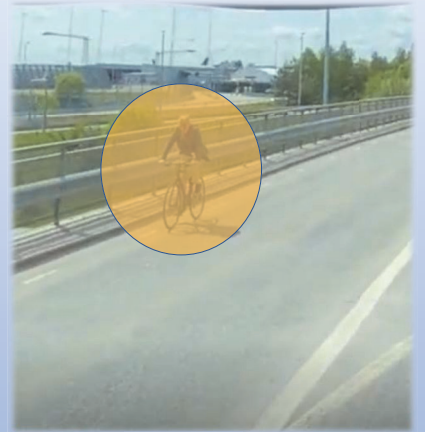
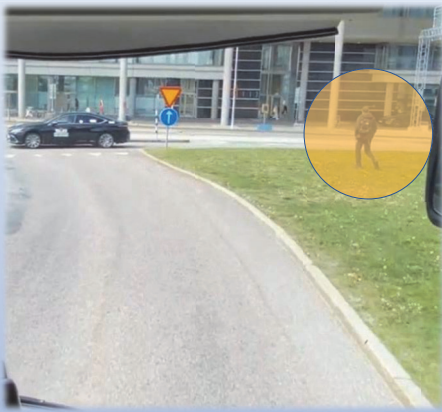
Section-1



- 2 bus stops in the section
- Roads with curves
- Vehicle traffic is more intense than other regions
- Higher interaction with passengers and other vehicles
- Way Speed Limit is 50 km/h
- Not suitable for vehicle overtaking

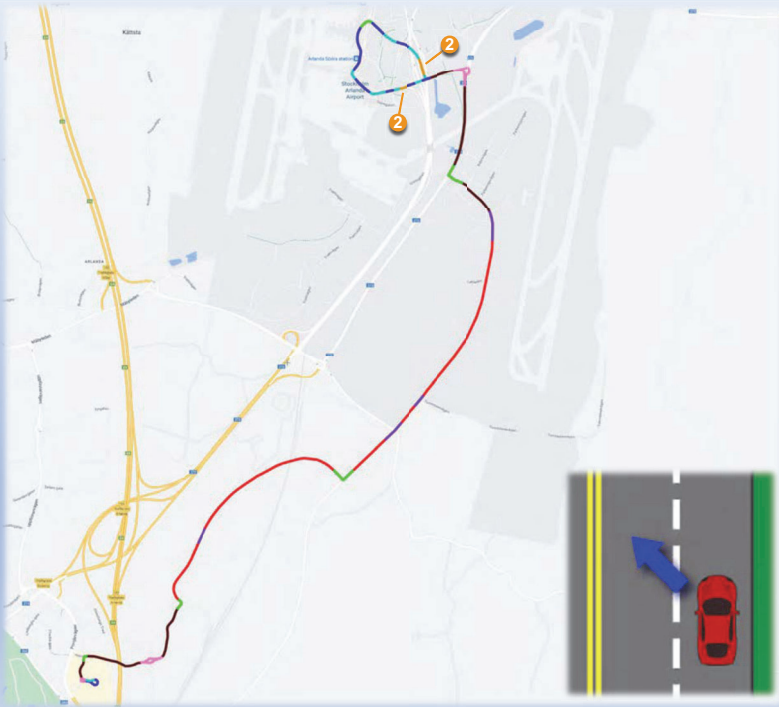


Section-1



- People and cyclists on the route

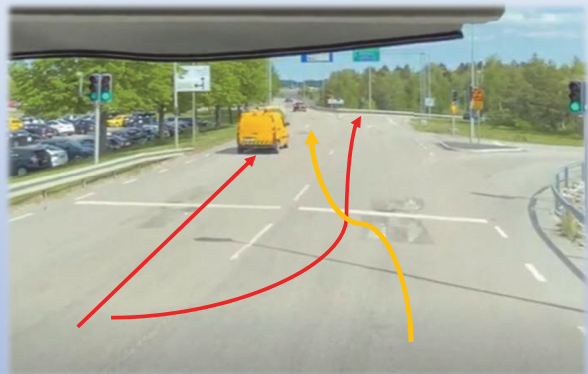
Section-2



Section Properties

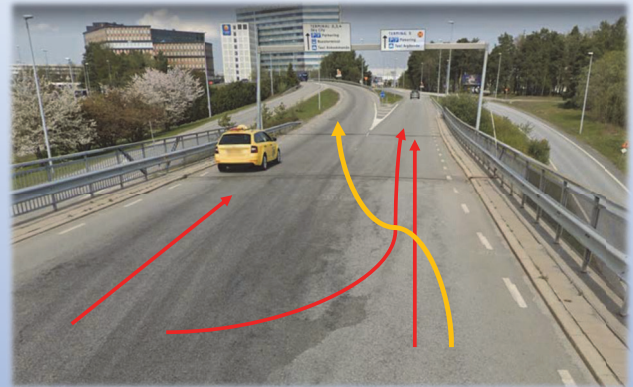
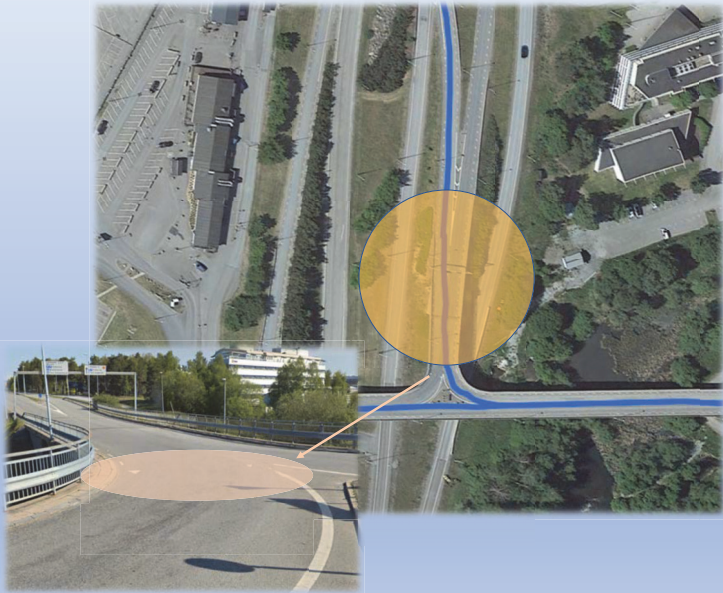
- Lane change
- Way speed limit 50 km/h

Section-2



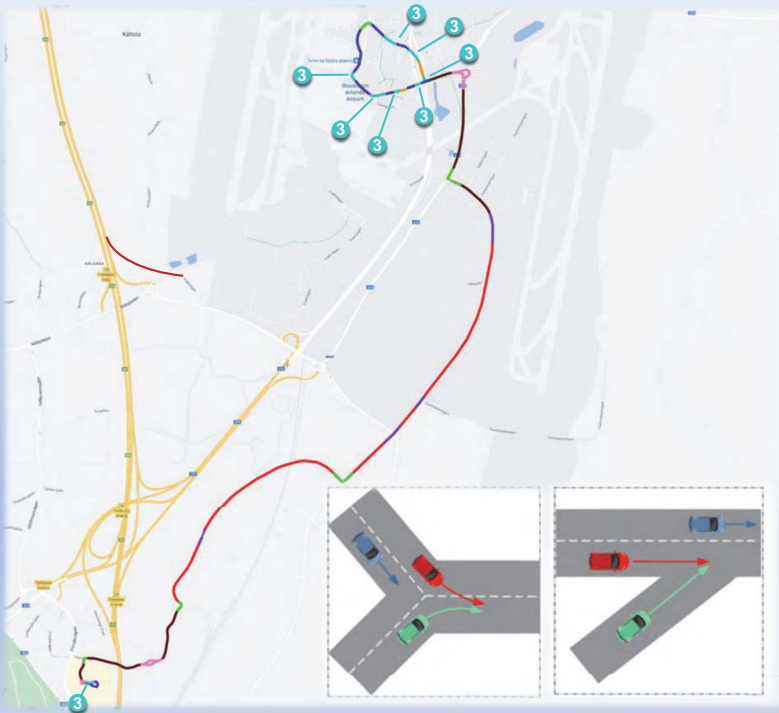
- The AV should make lane change on the route where there is a traffic light
- No one has a priority on the road

Section-2



- The AV should make lane changes on the route
- The other joining road has a "Give Way" mark on the road

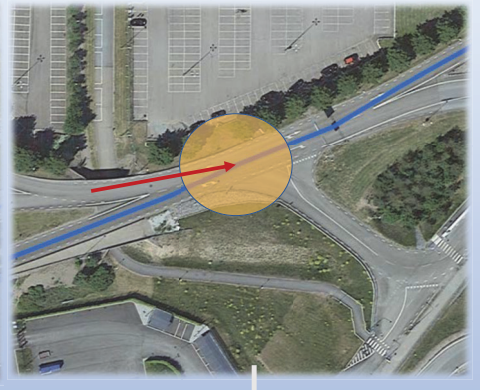
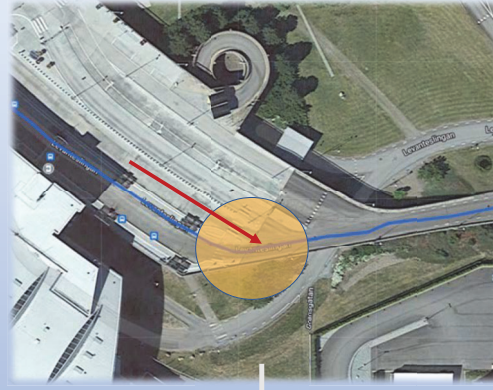
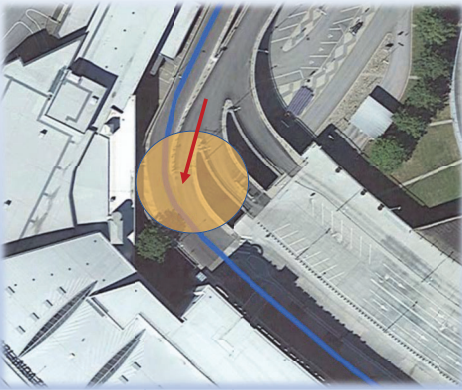
Section-3



Section Properties

- Ramp Merge and Y Intersection
- 3 types:
 - AV should give way
 - AV has the priority
 - Unspecified priority

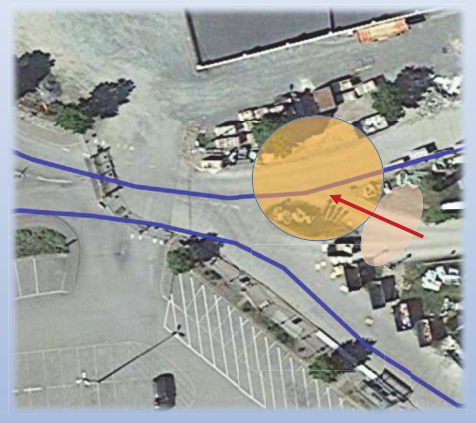
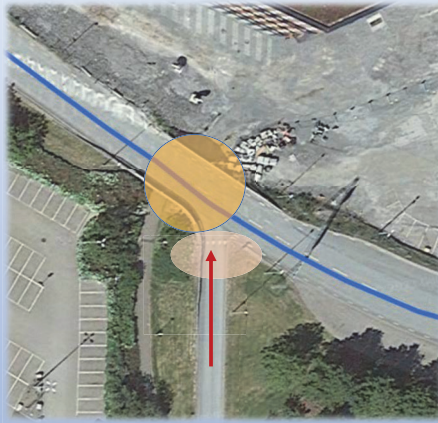
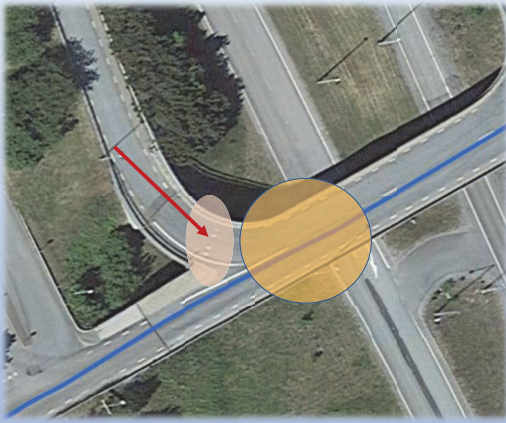
Section-3



- It is not clear who has the priority to pass

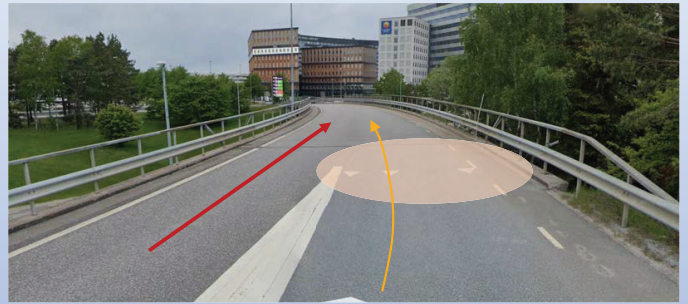
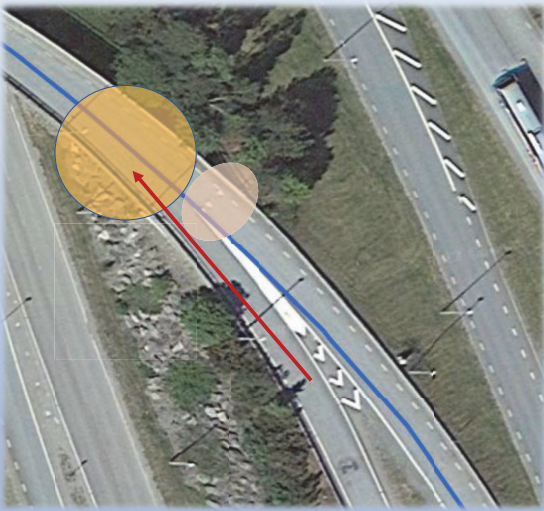


Section-3



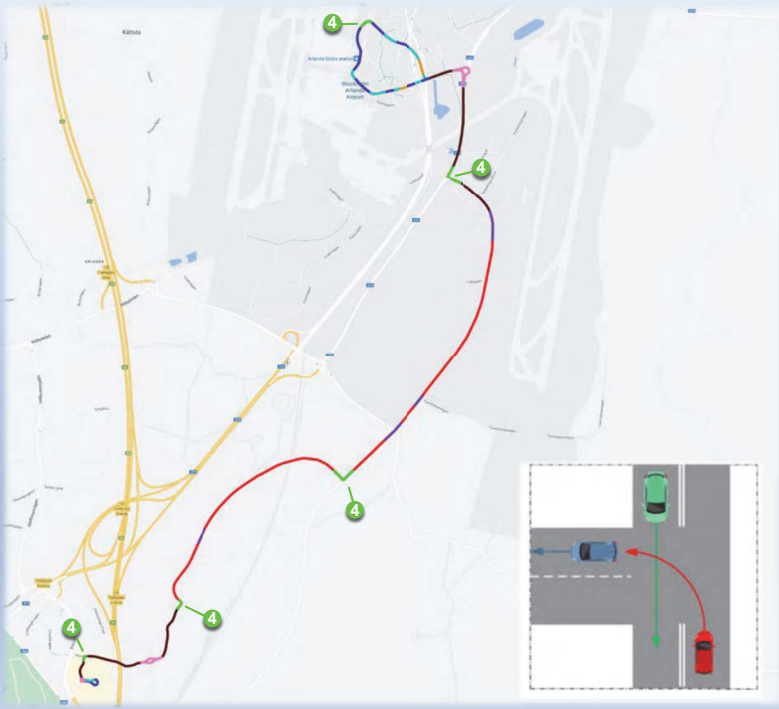
- AV has the priority
- Vehicles coming from the side roads should give way

Section-3



- Vehicles coming from the other road has the priority
- AV should give way

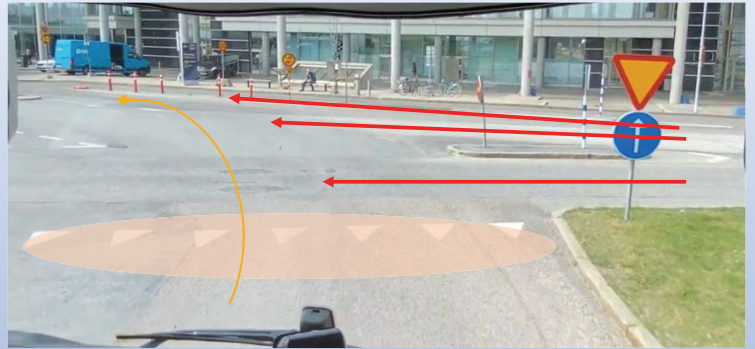
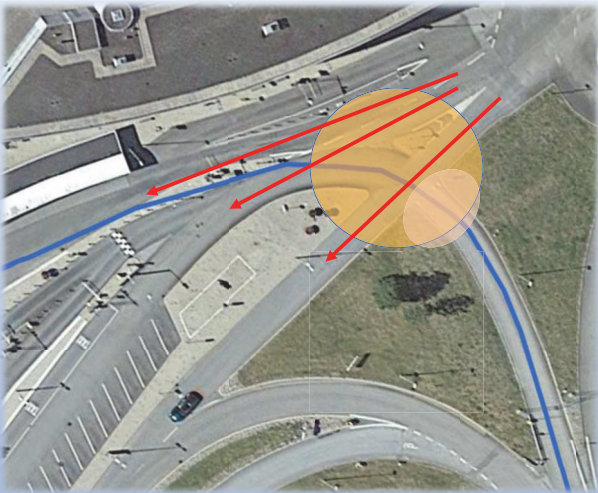
Section-4



Section Properties

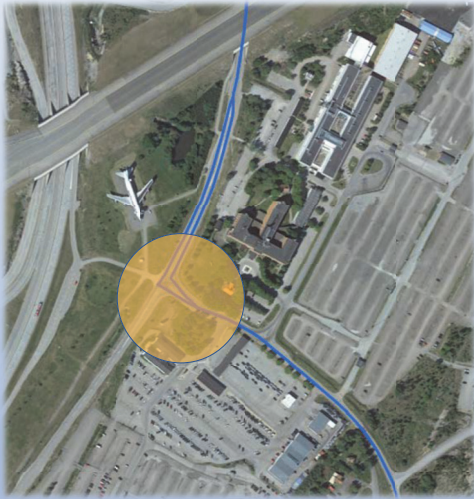
- T Intersection
- AV turns by passing through the path of high-speed vehicles coming from the opposite direction (like the red vehicle in the picture)

Section-4

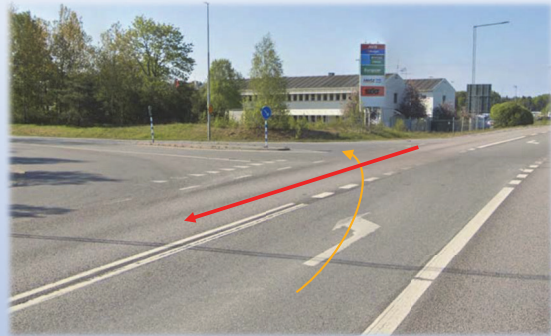


- AV goes on its own way by cutting 3 roads going in different directions
- AV should give way

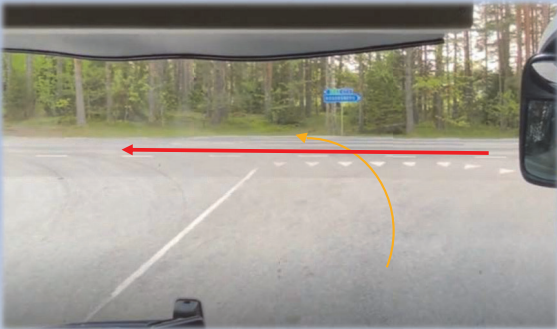
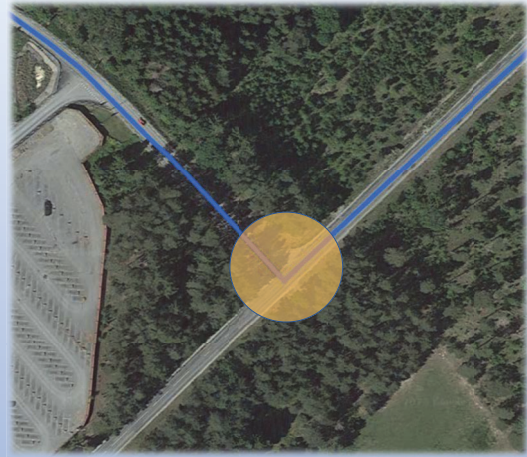
Section-4



- AV cuts the opposite road while entering and exiting the side road

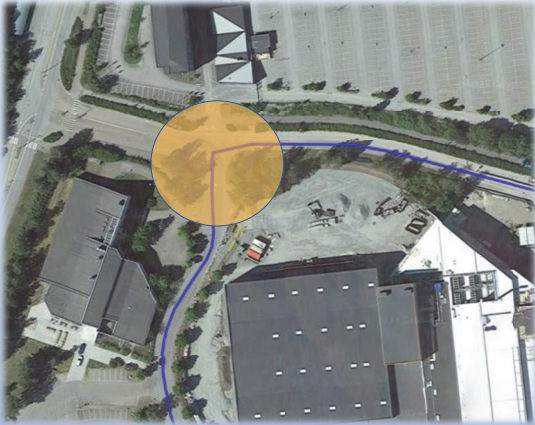


Section-4



- AV cuts the opposite road while entering and exiting the side road

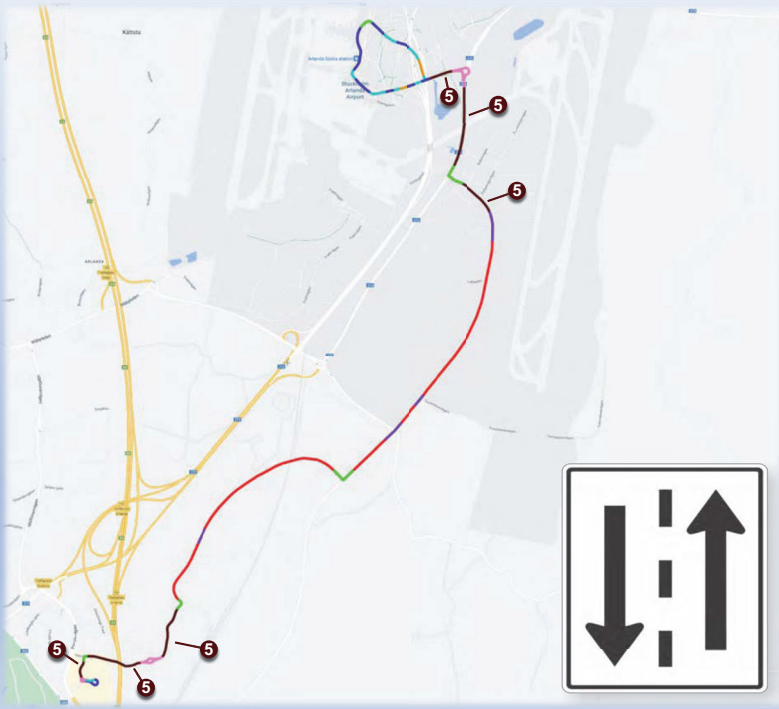
Section-4



- AV cuts the opposite road while entering and exiting the side road



Section-5



Section Properties

- Two-way road

Section-5



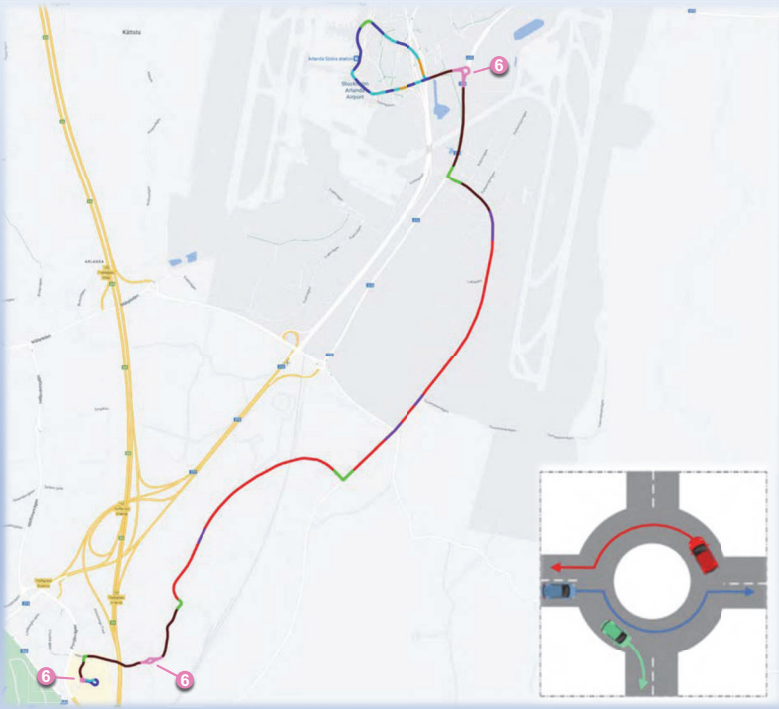
- Away from the city center and high buildings
- There is a clear vision through the road
- Not many curves and turns along the route

Section-5



- Low interaction with cyclists and pedestrians
- Suitable for vehicle overtaking
- Way Speed Limits range between 50-70 km/h

Section-6



Section Properties

- Roundabout

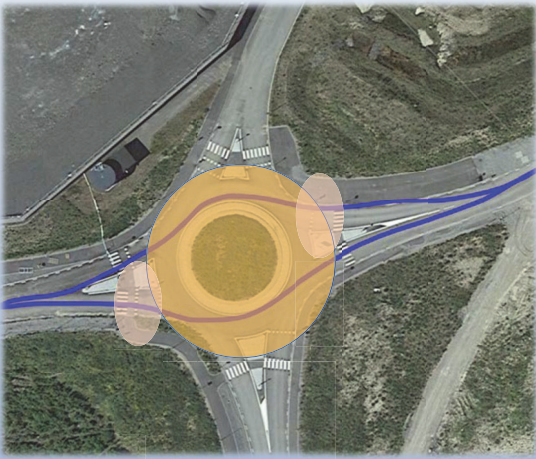
Section-6



- AV should wait and give way before entering the roundabout

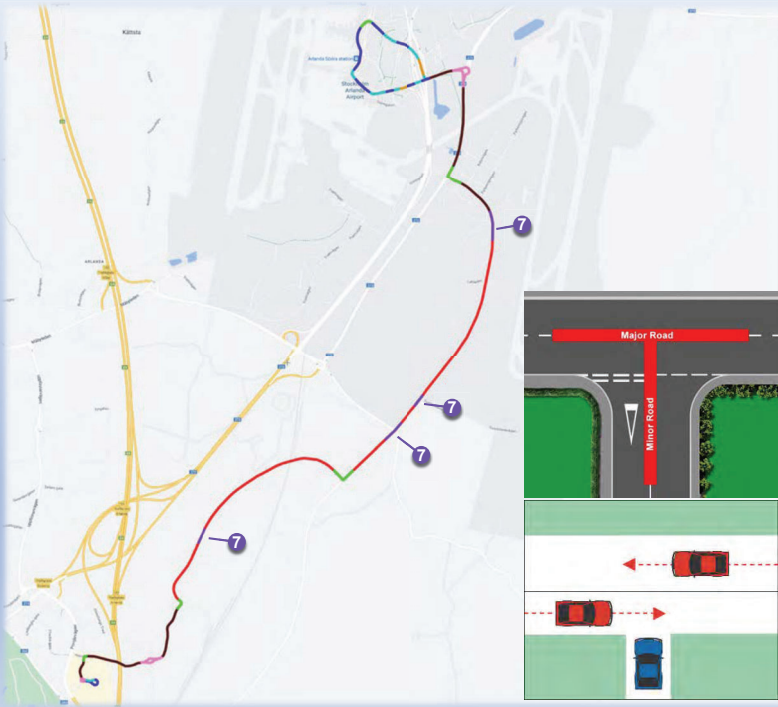


Section-6



- AV must wait before entering the roundabout and give way to other vehicles in the roundabout

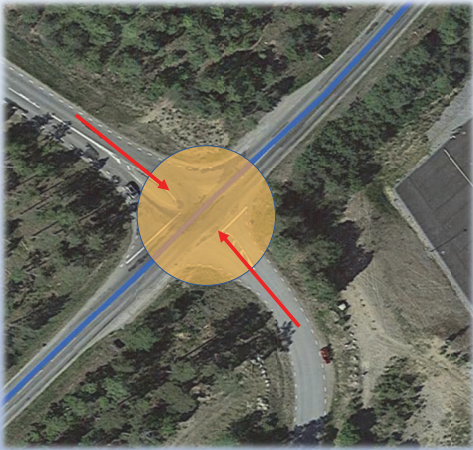
Section-7



Section Properties

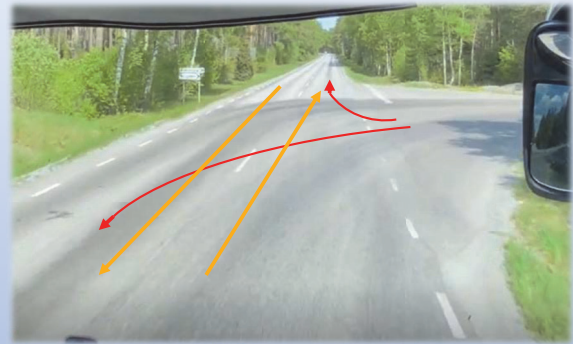
- T Intersection
- We are on the major road
- Other vehicles are joining the road from the intersection point
- We act like the red vehicle in the picture

Section-7



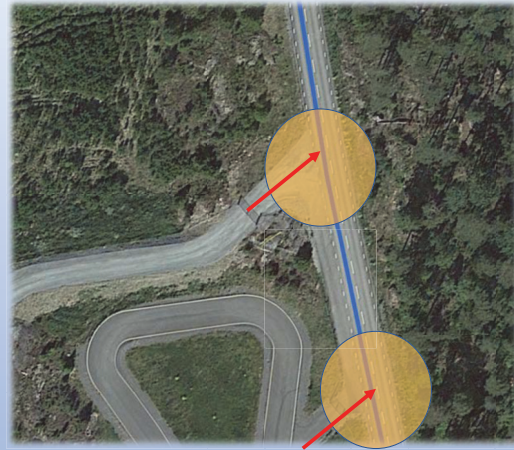
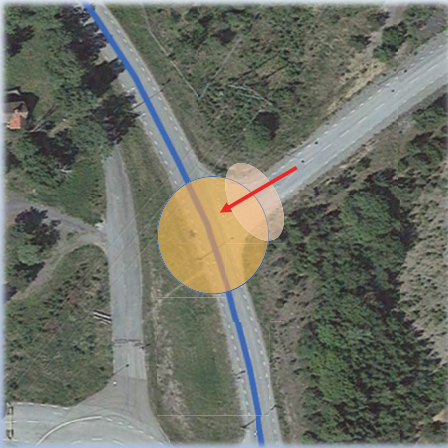
- Main road vehicles has the priority to side road vehicles

Section-7



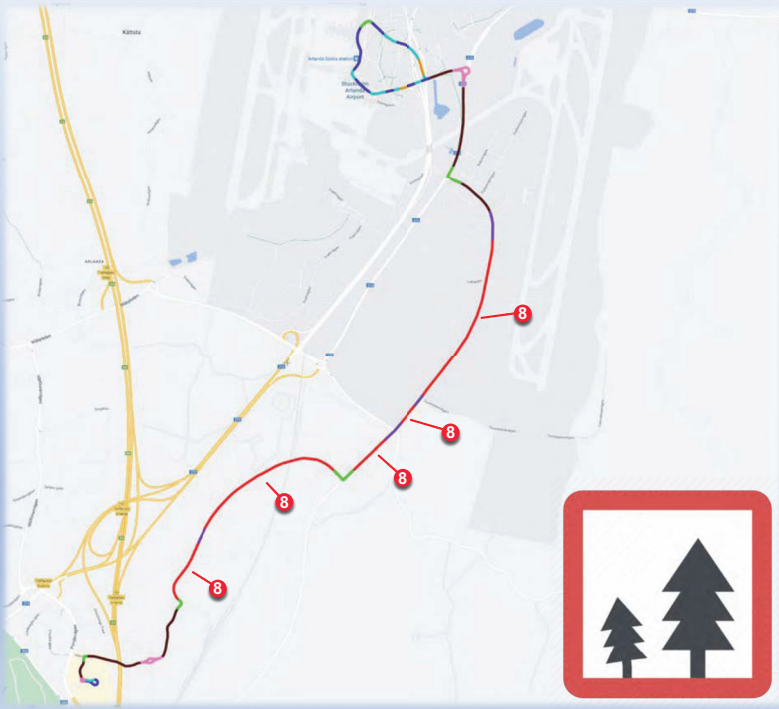
- Vehicles entering the main road should wait for the vehicles on the main road
- There is no "Give Way" mark on the sideways road

Section-7



- The “Give Way” mark does not exist in some of the intersections

Section-8



Section Properties

- Road in the forest
- One-lane route

Section-8



- AV route passes through single lane two-way forest road



Route Sections Risk Assessment



Risk Assessment Matrix (RAM)

| | | | | | |
|-------------|---|----------|----|----|----|
| | 5 | 10 | 15 | 20 | 25 |
| Probability | 4 | 8 | 12 | 16 | 20 |
| | 3 | 6 | 9 | 12 | 15 |
| | 2 | 4 | 6 | 8 | 10 |
| | 1 | 2 | 3 | 4 | 5 |
| | | Severity | | | |

Green: Acceptable risk. The deployment can be performed without additional mitigation

Orange: The operator or supervisor needs to be particularly attentive to the remaining risks in the area

Red: Some mitigations can be added to reduce the risks and improve travel quality

Route Sections Risk Assessment

Overview table of risk assessment of the route and Possible/Recommended Mitigations

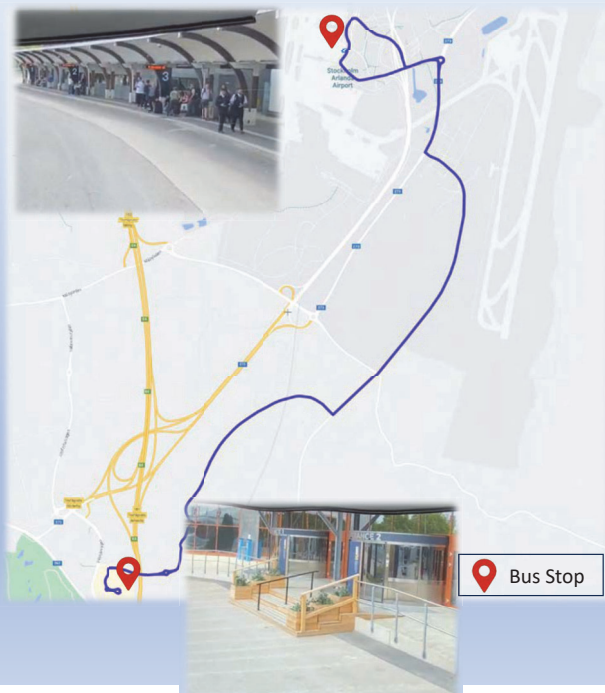
| Section Number | Section Specification & Interactions | Risk Factors | Risk Score Before Mitigation | Current System Behavior | Recommended Mitigations | Risk Score After Mitigation |
|----------------|---|---|------------------------------|--|---|-----------------------------|
| 1 | <ul style="list-style-type: none"> ➤ One-Lane One-Way Road • AV/Vehicles in Same Direction • AV/Pedestrian | <ul style="list-style-type: none"> • Pedestrians and cyclists on the route • Not suitable for overtaking if needed • Parked vehicles joining the road in the bus stop area | 12 | <ul style="list-style-type: none"> • If any object crosses the bus's trajectory, the bus will slow down and wait until the object goes away from the path | <ul style="list-style-type: none"> • Installing "Autonomous Bus Driving" sign in crowded areas • People should use the crosswalks for the crossing • Posters giving information about AV can be hung at bus stops | 6 |
| 2 | <ul style="list-style-type: none"> ➤ Lane Change • AV/Vehicles in Different Lanes in Same Direction | <ul style="list-style-type: none"> • Intersection without vehicle priority • The traffic light on the lane-change way | 9 | <ul style="list-style-type: none"> • While changing its lane, the AV waits until the road to which it will pass is available • The AV decides to stop or move according to the color of the traffic light | <ul style="list-style-type: none"> • Installing the "Give Way" marks or traffic signs for the vehicles coming from the different lane • V2X integration to the traffic light | 6 |
| 3 | <ul style="list-style-type: none"> ➤ Ramp Merge & Y Intersection • AV/Vehicles in Same Direction from Different Roads | <ul style="list-style-type: none"> • Uncertain road pass priority • Uncontrolled intersection of roads • High-speed vehicles joining the road | 15 | <ul style="list-style-type: none"> • The AV decreases its velocity when getting closer to the intersection points • If the predicted path of a vehicle from the other lanes crosses the AV trajectory, the AV properly decreases its velocity. And waits until its path is clear | <ul style="list-style-type: none"> • Installing the "Give-Way" marks or traffic signs on unmarked roads • Giving priority to the AV road • Installing "Autonomous Bus Driving" signs to inform traffic participants. | 9 |
| 4 | <ul style="list-style-type: none"> ➤ T Intersection, to side road • AV/Vehicles in Different Direction | <ul style="list-style-type: none"> • Crossing high speed roads to make turns. | 12 | <ul style="list-style-type: none"> • The AV waits for the other vehicles on the other roads until the road is clear | <ul style="list-style-type: none"> • Installing "Autonomous Bus Driving" signs to inform traffic participants. • Installing temporary traffic lights that activate while the AV is approaching the intersections | 3 |

Route Sections Risk Assessment

Overview table of risk assessment of the route and Possible/Recommended Mitigations

| Section Number | Section Specification & Interactions | Risk Factors | Risk Score Before Mitigation | Current System Behavior | Recommended Mitigations | Risk Score After Mitigation |
|----------------|--|---|------------------------------|---|---|-----------------------------|
| 5 | <ul style="list-style-type: none"> ➤ Two-Way Road • AV/Vehicles in Same Direction • AV/Vehicles in Opposite Direction | <ul style="list-style-type: none"> • High-speed vehicles • Aggressive driving behaves to pass the AV • Vehicle overtaking in the opposite lane | 8 | <ul style="list-style-type: none"> • The AV goes on its own way at its specified speed • If any object crosses the bus's trajectory, the bus will slow down and wait until the object goes away from the path | <ul style="list-style-type: none"> • Information signs to warn traffic participants about the AV | 6 |
| 6 | <ul style="list-style-type: none"> ➤ Roundabout • AV/Vehicles in Same Direction | <ul style="list-style-type: none"> • High-speed vehicles • Intersection of roads | 9 | <ul style="list-style-type: none"> • The AV waits for the other vehicles in the roundabout until the roundabout is clear | <ul style="list-style-type: none"> • Reducing traffic speed at roundabouts. • Information signs to warn traffic participants about the AV | 4 |
| 7 | <ul style="list-style-type: none"> ➤ T Intersection, on main road • AV/Vehicles on Side Roads | <ul style="list-style-type: none"> • Uncontrolled intersection of roads | 6 | <ul style="list-style-type: none"> • The AV slows down if any predicted path of the vehicles from the side roads crosses its trajectory path | <ul style="list-style-type: none"> • Installing the "Give-Way" marks or traffic signs on unmarked side roads | 3 |
| 8 | <ul style="list-style-type: none"> ➤ Forest • AV/Vehicles in Same Direction • AV/Vehicles in Opposite Direction | <ul style="list-style-type: none"> • Tree branches stretching to the road • Wild animals jumping to the road | 4 | <ul style="list-style-type: none"> • If tree branches are stretching to the AV road, the AV can detect them and make brakes. • If any object crosses the bus's trajectory, the bus will slow down and wait until the object goes away from the path | <ul style="list-style-type: none"> • Regular tree branch trimming | 2 |

Bus Stop



Risks

- The Bus-Stop area is not defined with markers or signs, so that, the drivers might park their vehicles at the AV bus stop location

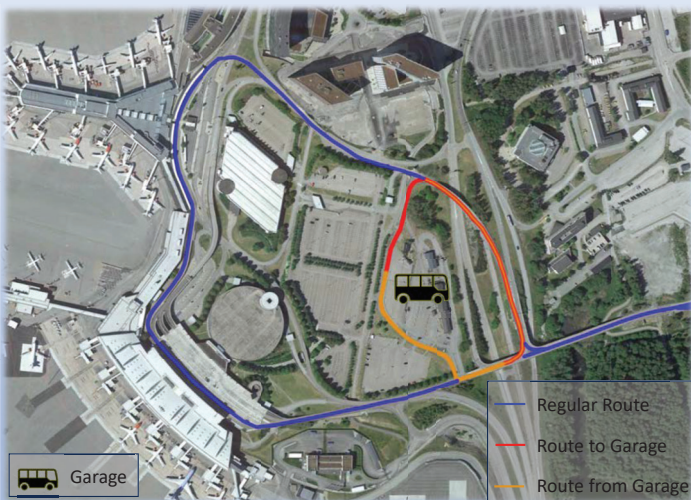
Current System Behaviors

- The bus performs autonomous driving on the dedicated route
- The AV stops at every bus stop
- Manual intervention by the safety driver or remote controller would be possible. However, the risk here is interrupting the smoothness of the ride due to those frequent stops and manual interventions

Mitigations

- The bus stop area should be marked with borders and coloring
- Other vehicles parking at the designated area should be prevented

Garage Location



Risks

- Crowded garage area
- Increased dependency to the driver

Current System Behaviors

- The AV stays in the garage outside the operation hours
- The AV is charged every day

Mitigations

- The AV route and stop location in the garage can be marked

Way Speed Limits



Way Speed Limits

- The legal speed limits of the AV route are determined by the authorities

Risks

- AV moving slower than the traffic speed can cause road congestion, particularly during peak traffic hours
- Unawareness of the AV's speed limit may lead to aggressive driving behaviors and accidents

Mitigations

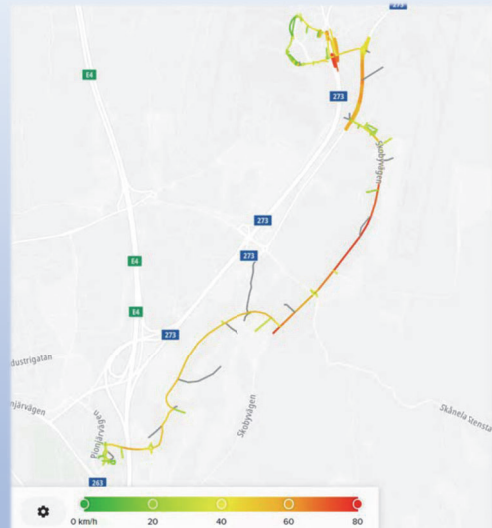
- Administrative arrangements to avoid speed violations
- Way speed limits can be adjusted for the AV for some hours

Traffic & AV Average Speeds



AV Speed Limits

- The maximum AV speed will be 40 km/h
- The AV speed changes dynamically according to road conditions

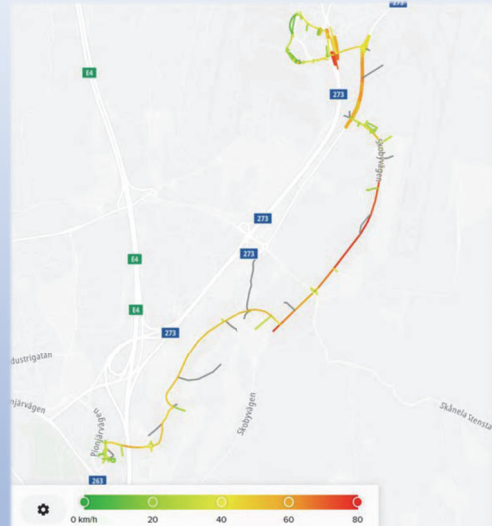


Average Traffic Speeds Between 8 am - 8 pm, source: TomTom

Traffic Average Speeds

- Vehicle densities at different time intervals are examined
- Average speeds along the route are shown regionally

Traffic & AV Average Speeds



Average Traffic Speeds Between 8 am - 8 pm, source: TomTom

Speed Limit Comparison

- Comparing planned AV and expected average traffic speed limits, the AV operation seems suitable

Crowded Sections



Risks

- Unpredictable behaviors of pedestrians and cyclists
- Aggressive driving behaviors

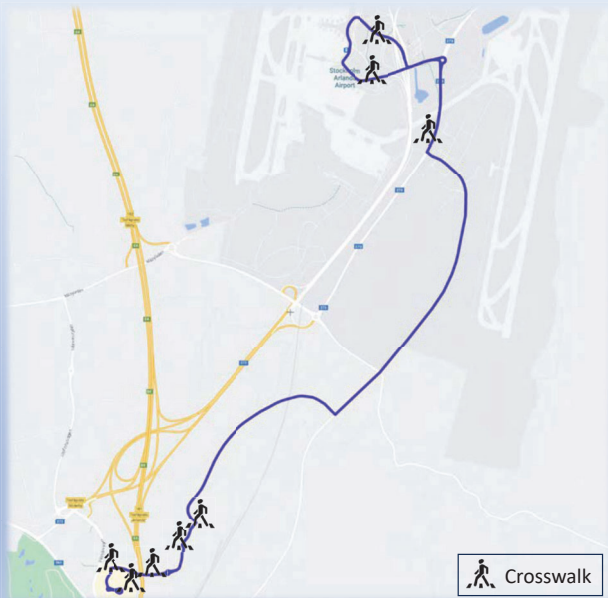
Current System Behaviors

- The bus smoothly brakes and waits for objects on the route

Mitigations

- Traffic signs to warn pedestrians
- Yellow warning line on the pavement
- “Non-Parking Area” signs between operation hours
- Bus stop information for AV

Crosswalks



Risks

- Waiting pedestrians on/nearby the crosswalks may affect smooth driving
- Pedestrians may cross the street without using crosswalks

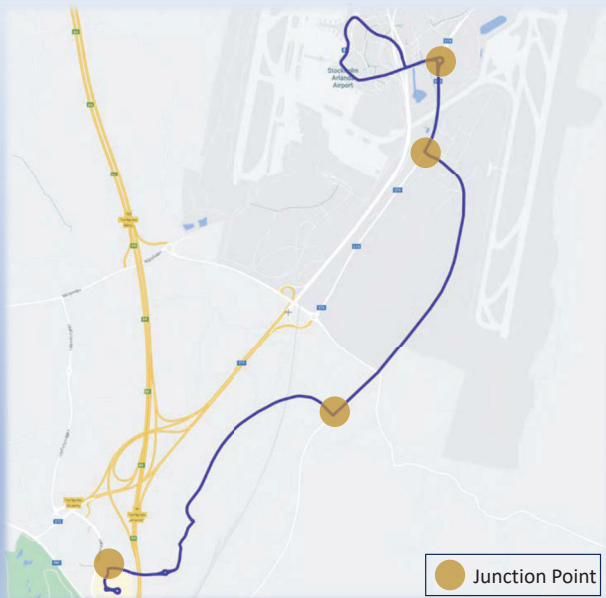
Current System Behavior

- The AV Bus smoothly brakes and waits for pedestrians crossing on the crosswalk
- When pedestrians are detected on the crosswalk while waiting, the bus decides to stop as they intend to cross the way. But the bus maintains driving if they stand still in the same position

Mitigations

- Information signs for the "Autonomous Bus Driving"
- Traffic lights for crosswalks in crowded areas during operation hours

Critical Intersections



Risks

- Vehicles in the merging roads can enter the route at high speeds without waiting for the AV Bus
- Vehicles in the opposite lane can merge in the same direction as the AV Bus

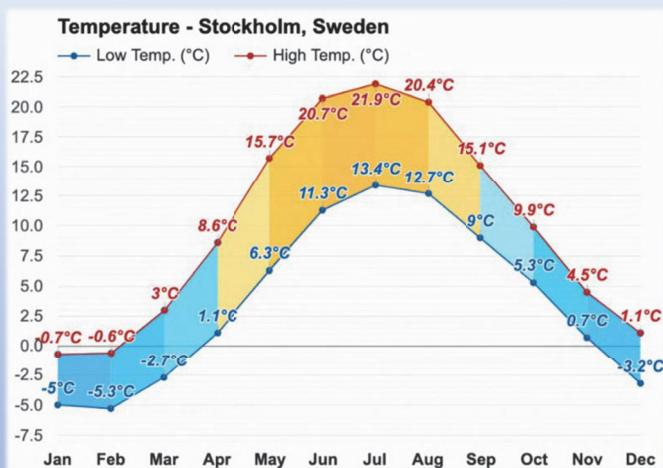
Current System Behaviors

- The AV detects objects on its way and slows down by making soft or harsh brakes
- The AV waits until the path is clear

Mitigations

- Installing temporary traffic lights with V2X (like RSUs to get light and time information of traffic lights) integration during operation hours
- Information signs for the “Autonomous Bus Driving”
- Awareness announcement and publicity of the AV Bus on the route

Ambient Weather Condition



Annual Average Air Condition Data for Stockholm, source: <https://www.weather-atlas.com/>

Risks

- Decreasing the system efficiency
- Higher energy consumption
- Reducing the travel range of the AV Bus

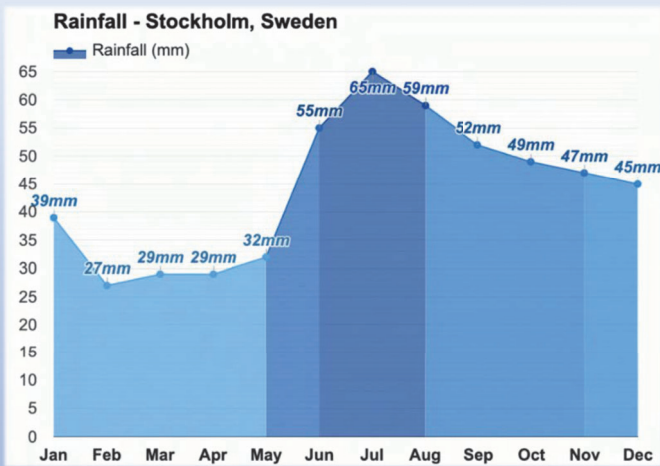
Current System Behavior

- The sensors can work between -20 °C to +55 °C degrees

Mitigations

- If the weather conditions are not suitable, AV operation can be rescheduled
- Support to the air conditioning system in the AV Bus may be added, if needed

Precipitation



Annual Average Precipitation Data for Stockholm, source: <https://www.weather-atlas.com/>

Risks

- Splashing water on the sensors may cause false detection
- Reducing the ability to detect obstacles

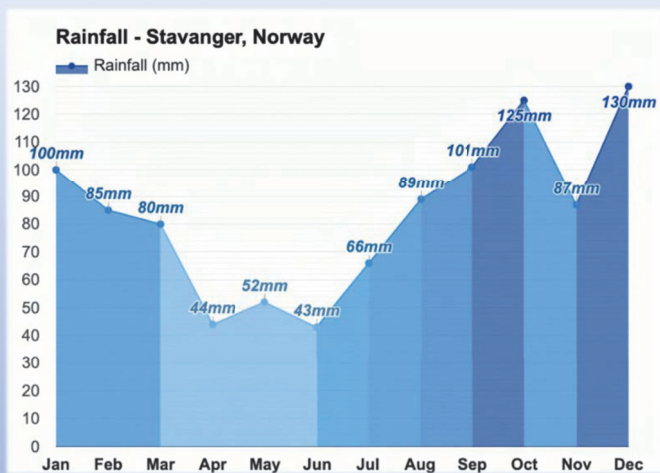
Current System Behavior

- ADASTEC ADS software has a module handling the Adverse Weather Conditions
- Multiple sensors are used to avoid detection errors
- In bad weather conditions, out of Operational Design Domain, the Control Center will share the information to cancel or postpone the operation. The Safety Driver can take over the control to continue to operate in manual mode

Mitigations

- Sensors will be cleaned regularly before and after the operation in the garage

Precipitation

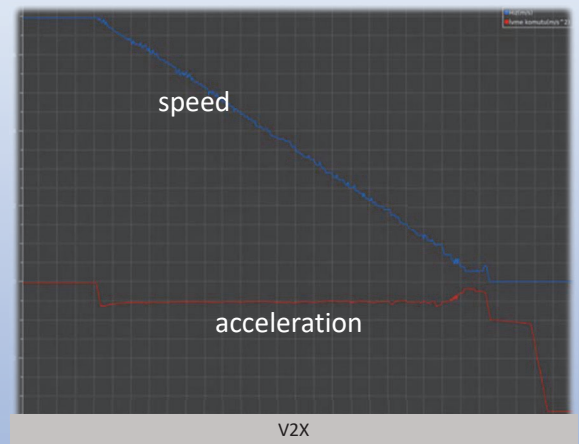


Annual Average Precipitation Data for Stockholm, source: <https://www.weather-atlas.com/>

Reference Project Data

- This graph is an example of the Stavanger - Norway operation that flowride.ai has handled
- Since there is no recorded issue related to weather conditions in Stavanger for the AV operation, we foresee no problem for Arlanda Operation

V2X Information



- The above graphs are example outputs from Michigan State University AV operation
- When V2X is used, there are more dynamic deceleration and acceleration values. Thus, driving comfort is not impaired
- Without V2X, time data in traffic lights cannot be used. As soon as the vehicle sees the red light, it stops with an irregular deceleration acceleration

Recommendations



QR Feedback System

- Passengers can scan the QR code at stations or in the vehicle with mobile devices to contribute to autonomous vehicle development via a brief feedback survey
- Survey responses will be anonymous, no identifiable personal information will be collected

Bus Stop Information

- Information posters can be placed at bus stops to inform the public about the autonomous buses

Recommendations



Traffic Signs

- To inform traffic participants on the AV route, traffic signs can be used

Recommendations



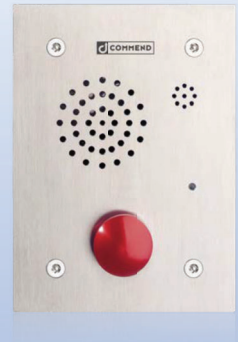
Emergency Light and Warnings

- Warning lights can be implemented on the bus to warn the other vehicles on the road



Emergency Calls

- In case of an emergency, there can be an emergency phone or button to call the emergency services quickly



Thank You

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