Automation of city buses

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1. Summary

The project has investigated, analyze, study, test and demonstrate different proof of concept when it comes autonomous solution for a full-length 12 meter bus. The project has focused on automated functions for three different applications or use cases - bus train operation, autonomous bus stop docking, and autonomous depot processes.
Bus train operation can increase the capacity of the existing public transport system in a resource-efficient way and contribute to increased attractiveness for public transport, which also reduces the environmental impact of road transport
Autonomous bus stop docking the aim is to fully or partially automate the bus stop docking in order to primarily increase safety, make it easier for the driver and position the vehicle correctly. Shorter stopping times can be made possible by an automated precise docking both longitudinally and laterally and can reduce wear and tear on tires and on bus stop infrastructure as well as provide increased safety for unprotected road users.
Bus depots are confined areas in which the technology can be used to move the buses autonomously between different depot services such as washing, cleaning and charging or when parking or leaving the depot. Autonomous driving in the depot can reduce the risk of accidents or damage to the buses while at the same time reducing the need for depot staff relocating buses, especially at night.

Much work remains before full-size buses will run autonomously on public roads. The technology demonstrated in this project, has shown that autonomous driving is technically mature and possible to introduce in defined environments, such as depots as long the safety case has been proved on a high integrity safety system. On public roads, the technology can be introduced step by step in the form of advanced driver assistance, for use cases such as bus stop docking or narrow navigation, but still with a driver at the wheel, ready to take control of the vehicle. Bus train driving has been identified as an interesting concept. Bus trains are judged to be able to be introduced initially with purely manual technology, after which the degree of autonomous driving can be increased, much depending on whether the bus train is operated on dedicated bus lanes or shares a traffic environment with other vehicles and road users. Studies conducted in this project shown that both drivers and passengers are ready to use autonomous solution for public transportation.

2. Swedish Summary

Det övergripande målet med projektet har varit att för olika användarfall analysera, test, demonstrera olika koncept av automatiserad körning av elektrifierade 12-metersbuss. Projektet initierades i syfte att utforska hur man stegvis och i olika tillämpningsfall kan använda sig av autonom körning eller autonomt förarstöd för att på sikt kunna dra nytta av tekniken i verklig trafik. Projektet har fokuserat på utveckling av automatiserade funktioner för tre olika användarfall.

Busstågskörning - Busstågskörning kan öka kapaciteten i befintligt kollektivtrafiksystem på ett samhällsekonomiskt resurseffektivt sätt och bidra till ökad attraktivitet för kollektivtrafik vilket minskar vägtransporternas miljöpåverkan.
Autonom hållplatsinkörning - Autonom hållplatsinkörning med bussar som kan köra självt och upptäcka oskyddade trafikanter kan potentiellt minska antalet skadade och dödade i trafiken, minska busslitage och öka passagerarkomfort.
Autonoma depåprocesser – Att flytta bussar förarlöst mellan olika depååtgärder som tvätt, städ och laddning eller vid parkering respektive framkörning minskar risken för olyckor eller skador på bussarna samtidigt som behovet av personal i depån minskar, vilket är önskvärt, särskilt nattetid.

Mycket arbete återstår innan fullstora bussar kommer att köra autonomt på allmän väg. Projektet har visat att autonom körning kan vara möjlig att införa i avgränsade miljöer, till exempel depåer, en stor utmaning är på vilket sätt säkerheten garanteras. Tekniken kan även införas som förarstöd på allmän väg som vid hållplatsinkörning eller igenom trånga passager men fortfarande med en förare vid ratten, beredd att ta över kontrollen över fordonet. Busstågskörning har identifierats som ett intressant koncept. Busståg bedöms kunna införas till en början med rent manuell teknik varefter graden av autonom körning kan ökas, mycket beroende på om busståget körs på dedikerade busskörfält eller delar trafikmiljö med andra fordon och trafikanter. Studier som utförts inom projektet visar att både förare och resenärer är redo att använda autonoma lösningar.

3. Background

Several companies have communicated their larger scale of activities when it comes to autonomous solution for cars, shuttles, minivans among others, but very few initiatives have been seen for larger vehicles as for example buses for public transportation. Could autonomous solution be utilized on a full-length bus and how could it be suitable for the society.

A huge challenge for an autonomous city-bus is that the passengers both can be seated and standing meaning the driving dynamic in autonomous mode needs to be smooth in order to avoid passenger from getting injured by harsh driving. Also, the fact that people are close to the vehicle example during driving to and from bus stops and crossing among others put high demands on functional safety to avoid accidents.

This project contributes to the Drive Swedens goal by demonstrate, new mobility solutions for people by using automated solution for road transport system to create a more sustainable society.

4. Project set up

4.1 Purpose

Very few initiatives exist or have been done when it comes to autonomous solution for public transportation with a full-length bus. Therefore, this project has played an important role. The purpose for the project was to generate conditions and environment to analyze the capabilities within the field of autonomous solution for a full-length 12-meter bus. By performing test, studies, and demonstrations of different concepts, build up knowledge and experience that can be used as foundation for future implementation of autonomous solution for public transportation.

4.2 Objectives

The general objective was to make existing electrified buses more efficient with the help of automated functions, by theoretical and practical knowledge develop automated driving of electrified buses. Together with various key stakeholders, the potential and effects of different use cases are evaluated, tested, and demonstrated.

The project focusing on three main use cases:

Bus stop docking - Effective and safe bus stops (in run and positioning).
Bus train - During peak hours connect two buses to operate in a train – increase passengers capacity, no extended time for intersections and stops.
Depot process - Autonomous relocation of buses within a bus depot.

During the execution, projects saw an opportunity to add additional use case that was in line with the main objective.
- ***Study Autonomous bus line*** – within a test track create a fictitious bus route to evaluate what frequent users of public transportation, especially people commuters by bus, thinks about travel with an autonomous full-length bus.

4.3 Project period

The original project period was stated 2017 Q2 to 2020 Q2 but due to the pandemic and shortage in resources because of short term lay off, mainly within the Volvo Group, progress couldn't align with the original time period and plan. Therefore, the period was prolonged to include 2022 Q4.

4.4 Partners

Project was done in collaboration with different partners:

- FFI project – Automatisering av stadsbussar busståg, hållplatsdockning och depåprocesser – served the project KRABAT with the technical solution used to evaluate, test, and demonstrate.

  Partners participate through the FFI project.
    - Västtrafik - Public Transport Provider, region of Gothenburg
    - City of Gothenburg - Transport authority

    - Lindholmen Science park - international business park focusing on mobile internet, intelligent vehicles, and transport systems

- Other partners
    - Chalmers University of Technology – department, Design and human factor
    - Keolis – bus operator

5. Method and activities

The project has been carried out via an iterative development process between system development, integration, and test / verification. Requirements in each application drive the further development, which in turn is simulated / verified before the chosen solution is implemented in the vehicles and evaluated, which leads to the next iteration. In parallel with technical development work, applications of the technology have been studied theoretically in workshop with different stakeholders, such as traffic offices, public transport authorities, public transport operators and more. The purpose of these workshops has been to express requirements and to confirm needs. For each major demonstration and study, special demo or study team was established to plan and prepare. Team contains different competences such as, communicator, film and photo, technical, researcher, safety, site manager (demo area), audio, coordination, guide, supervisor among others.

6. Results and Deliverables

The project has present and successfully demonstrate of each of use case stated in the project description.

Bus train

The project produced a definition to make it easier to relate and discuss bus train.

Two or more buses run on a bus line, or parts of a bus line, as a cohesive unit. The buses enter the stop close to each other and depart at the same time.

The idea of bus trains is to increase the capacity of public transport by running two or more vehicles as one train. By holding these vehicles together and entering the bus stop at the same time, they can divide the time, about 30-45 seconds, that is set aside for stopping at the stop. As more vehicles enter the stop at the same time, passengers can get on and off faster, and the risk of a vehicle becoming overcrowded is reduced. Public transport is usually delayed when vehicles become full during rush hour traffic, stop times are extended and throughput time increases. The vehicles clump together, so-called bunchning.

With bus trains, the capacity of the route can be increased without increasing the number of vehicle movements. With limited staffing in the vehicle train, the driver's share of total costs can be significantly reduced, as this cost item accounts for about 50% of the cost of operating public transport by bus in cities.

The project has done different trials with manual driven bus train, with two drivers who each operated their own bus, during one and the same trip. The bus train was initially tested without passengers and outside rush hour traffic along the line route for a trunk bus line in Gothenburg. The purpose was to see how a manual bus train can be held together in a real traffic environment along bus lanes, shared lanes and motorways. This was done in order to also be able to evaluate the infrastructure's adaptation to the concept, not least in terms of stop design. Roundabouts, intersections with traffic lights and public transport signals were considered to be the most problematic traffic environments with the greatest difficulty in keeping the bus train together.

In a next step, the concept was tested on a bus line in Gothenburg within the so-called area traffic, where the bus train performed a number of extra trips with real passengers, but still outside rush hour. In this test, one could study the passengers' behaviors linked to bus trains. The tests clarified the need for communication with passengers that both buses constitute the same trip. It became clear that communication between drivers was also desirable, for example an indication to both drivers that the passenger had pressed the stop button in one of the buses in the train. The project group was also able to observe the connection between the design of the stop and the passengers' tendency to choose a bus 1 or 2 in the bus train. As these effects could only be studied during a couple of extra trips, it would be desirable to investigate this type of effects and behaviors during a long period of bus train operation. It would also be desirable to study how drivers experience bus train driving for a longer period of time and which elements are particularly interesting to simplify or eliminate with technical support.

Another test of bus trains with passengers was conducted in connection with a major workshop in October 2021 with participants from several traffic authorities, traffic operators, regional organizations, the City of Gothenburg's traffic office, industry and the academy. The test was carried out on a section of a bus line in Gothenburg between two major hubs for public transport within the city line network. The purpose of the test was to demonstrate the concept to relevant parties in the public transport area to stimulate and anchor discussion in subsequent workshops in a real traffic environment. The purpose of the workshop was then to jointly discuss needs, conditions and necessary adaptations to be able to implement the concept in real traffic, but also to jointly highlight the benefits of bus trains. During the workshop, it was clarified that there is great interest in the continued development of the bus train concept.

Project were not able to do any major tryout or demonstration with train with digitally connected buses, where the second bus autonomously followed the first. Technically the solution was not ready and did not reach significant level to operate in a suitable way. The project has tried basic functions with digitally connected buses such as:

- Establish communication between two buses and transfer data such as position and speed from bus 1 to bus 2.
- Bus train - the second bus follows the first one
    - Start stop - Start from a standstill, drive forward and then go to a standstill again.

- Lateral movement - driven in an eight figure on an open test surface, also tested on a road with curvature.
- Drove at 25-30 km/h with a time difference between the vehicles set to 0.5 seconds, which gives a distance of about 4 meters.

The project has not performed any test of driving at 50 km/h at 1-meter intervals, i.e., time difference of less than 0.1 second due to the fact that safety cannot be guaranteed in the event of an emergency where the front bus is forced to perform heavy braking, so-called panic braking.

Bus stop docking

In low speed <30 km/h the driver can hand over the controls to the bus that executes a predefined autonomous driving task, example drive and stop at a bus stop. Driver is still responsible and can whenever deactivate the autonomous drive and take over and drive manual.

June 2018 - First concept was showcased during Volvo Ocean Race Stopover. The first version the autonomous mode could only be activate when the bus was standing still.
May 2019 – System upgraded to manage handover while the bus was driving, this made the system more convenient to use and add the practical value.
September 2019 – System upgraded with function for object detection and braking. Bus now able to stop for object that's in the way of the, when object is removed the bus continue to drive according to the predefined path.
March 2021 - Scientific study, project engaged Chalmers University of Technology – department, Design and human factor, to execute a study. Experienced bus drivers from bus operator Keolis to evaluate the system each driver spend half day together with researchers from Chalmers to use and evaluate the system.

Question for the study
Will an "automated driving support" improve the working environment for a bus driver?

Main theories stated by the project to study and evaluate
- Easier to focus on traffic situation.
- Reduce stress.
- Less physical load (arms, shoulders, neck).
- The driver's professional skills are questioned.
- The driver ignores using the system.

System evaluation
- Interview & questionaries → pre, mid and after practical drive.
- Practical drive → predefined test route with bus stops. Total 250 autonomous driving tasks has been executed (25 per driver)
- Analyse body movement → analyse shoulders, arms, foot, eyes movements from videos recordings.

Result
The driver – trusted the system and showed great acceptance.

- Found it safe and convenient to use, release tension both physical and mentally.
- Could switch focus to things that increase the safety of passengers, both inside and outside the bus when they didn't need to control the bus manually.
- Could see themselves utilizing the system and give them supports in their daily work.

Questions raised by the driver

- Will it work in a more active and dense traffic?
- It drives really careful, can it be adjusted to go little quicker? As is it now the timetable needs to be adjusted in order to keep up.

The project also participated in investigating the potential economic benefit that advanced driver support or purely autonomous driving in depots could constitute for the operator but also for drivers, passengers and fellow road users as well as the public sector, e.g., the city's traffic management or healthcare system. Many of the costs that an introduction of the technology could eliminate or greatly reduce are, for various reasons, difficult to estimate. However, the overall study that was done was able to establish that there appears to be a significant savings potential in purely economic terms, but also indications that the technology can also potentially lead to less stress and increased quality of life.

Together with a traffic operator, the project group has investigated the size of various costs that arise in connection with collisions, e.g., when driving through narrow passages or in depots, but also connected to wear and tear of tires or fixed infrastructure when driving in at a stop. These are various types of damage to buses that occur in traffic, such as sheet metal damage, damage to side mirrors and external position lighting and lamps. Costs have been calculated for a case corresponding to a large depot with about 150 buses. Examples of common damages that can be reduced in number or avoided altogether by fewer collisions:

- Less damage to body / turn signals
- Less damage to the windows
- Less damage to rear-view mirrors / side mirrors

The technology can also contribute to reduced damage to the bellows or joints on articulated buses when driving over speed bumps. Indirect costs that are avoided are also the fine that is imposed in connection with a delayed or delayed trip and the cost of buses having to be taken out of service.

Damage to infrastructure is, according to the City of Gothenburg's Traffic Office, difficult to estimate. Reduced damage to curbs or damage to fences / dividers occurs quite rarely, but in cases where it happens more frequently, rebuilding is required, which can be costly. In connection with new construction, damage to infrastructure is relatively common, especially if the location changes and drivers need to change their way of driving from day to day. A navigation system that can be easily updated almost on an hourly basis could prevent damage to surfaces that have been prepared but which e.g., not yet had time to pave.

An indirect benefit is that the surface requirement could be reduced in so-called narrow cuts. There are examples of places where the area is severely limited and a rebuild is not possible.

In addition to property damage, the technology has the potential to reduce personal injuries of various kinds. The most serious type of injury is, of course, that which occurs in a direct collision with a surrounding pedestrian, e.g., in connection with running in at a stop. Other examples are fall accidents or the like on board the vehicle, e.g., at rapid deceleration or acceleration. A number of different typical cases have been identified:

- Fewer bus collisions with people outside the bus thanks to the driver being able to focus entirely on personal safety and not having to position the bus
- Fewer fall accidents in the event of deceleration leading to minor injury or more serious injury
- Fewer fall accidents during acceleration leading to minor injury or more serious injury
- Fewer fall accidents with lateral (lateral) acceleration leading to minor injury or more serious injury

In collaboration with a health economist in the Västra Götaland region, VGR, cost per type of accident has been estimated. The first typical case can involve very large societal costs but is better very unusual. Fall injuries of a more serious type that occur on board the vehicle and that may require inpatient care incur significantly higher costs and have been valued at SEK 100,000 per claim, but do not occur very often. Mild injuries of a minor type, on the other hand, occur relatively often, but the direct cost for these is relatively low, perhaps in the order of SEK 5,000.

The project has taken part in statistics from VGR on costs for reported accidents during 2016-2019. During this period, the costs amounted to SEK 42 million, but in the statistics, it is not possible to read whether the accidents are related to bus or truck. If half of the accidents are related to bus accidents, this will be approximately SEK 21 million, or SEK 7 million / year. This would then apply to the entire Västtrafik fleet of 1,857 buses. In our case, we expect 150 buses (8% of the fleet), which would correspond to a cost of approximately SEK 550,000 / year.

The risk of fall accidents mainly affects older people's travel behaviour and willingness to use public transport (bus / tram). A dynamic effect of a reduced risk of falls on board could be that more people use public transport instead of transport services. For each business trip that is instead made by public transport, Västtrafik is estimated to save SEK 287. Approximately 655,000 journeys are made with travel services in Gothenburg during one year. If 1% of all journeys are instead made by public transport, this means a saving of just under SEK 2 million / year.

Another dynamic effect could be that more people choose public transport thanks to increased comfort.

For the driver, the technology could mean an improved working environment and potentially:

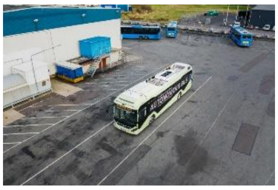
- Fewer sick days due to fewer strain injuries on, for example, hands, arms, shoulders, legs and calves
- Fewer sick days due to less stress
- Better focus on traffic in autonomous mode
- Increased commitment that can lead to better driving
- Increased safety for the driver as the bus runs in the same way every time
- Incentives for drivers to drive well - bonus for satisfied customer etc.

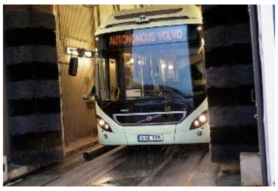
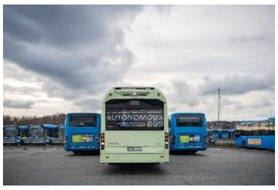
For the operator, this can potentially also reduce staff turnover thanks to less stress and increased well-being.

Depot process

The project has carried out autonomous depot driving in two different bus depots in Gothenburg. All vehicle movement in the maintenance flow was carried out autonomously. Inside the depot gates, the bus was handed over to the control room, which is staffed with a maintenance planner whose task is to plan, activate and monitor all vehicles within the depot. The planner determines the flow for each bus, for example specifying which parking it is to be used when the bus returns from a traffic assignment and including it in maintenance planning for cleaning, washing, vehicle inspection, charging, service, workshop, etc. The planner always has information about where the buses are within the depot and where it is in the maintenance flow and when it should be ready for a new traffic assignment. Vehicle movements can either be initiated via the control room or by the staff at each service unit via a tablet (handheld simple computer).

The project has fulfilled the following parts of the depot process that was included in the project description:

	Activity and description
	Control room – driver handover the bus to depot system for planning and optimization based on the bus's current status, available resources in the depot and the bus's upcoming traffic assignments.
	Autonomous movement of the bus - within the depot area drive to a number of given positions such as handover, collection, parking, charging, cleaning, inspection, washing.

	Switch between outdoor and indoor driving, for example driving in and out of the service hall for vehicle inspection and cleaning.
	Autonomous driving through the washing bay.
	Position, parking and charging OppCharge charging station.
	Parking - day and overnight parking, pick-up and driving for handover to drivers for operate the daily traffic assignments.

In a bus depot with 100 buses, more than 100,000 unique vehicle movements take place during a year at a corresponding value of approximately 9,000 hours. The project has shown that more or less all vehicle movements within the depot could be carried out autonomously. However, some movements may be less suitable depending on how the depot is designed, for example if the depot area is divided between different buildings with a public road between etc. A general assessment is that at least 20% of the driver's time should be able to be saved if the depot has a good demarcation with fences and gates so that the buses can move inside the carriage yard without having to take other traffic into account.

Scientific study - Passengers’ Experience of Travelling with a Full-Length Automated Bus

Study conducted, in which passengers’ experienced travelling with a full-length (12 metre), fully automated bus on a test-course that included nine simulated everyday traffic situations. The study also, based on the findings, disseminate how passengers’ view automated busses in the future public transport system i.e., their positive and negative expectations of the public transport system after automated busses have been implemented.

Method: The users' experience was created by allowing 22 participants travel with a fully automated bus on a test course with nine simulated everyday traffic situations. Furthermore, the automated bus experience was also used to trigger the participants expectations on how automated busses in the future might or might not change the public transport system. Data on the participants' experience was collected post-experiment and included questionnaires and semi-structured interviews. The quantitative data was analysed using descriptive statistics and the data from the semi-structured interviews was analysed using a thematic analysis.

Findings: The findings show that most participants experienced the ride with the automated bus as very positive. Most participants also experienced the bus and its driving behaviour as trustworthy, mostly since they experienced the bus as being competent, handling the simulated everyday traffic situations in a positive manner. Some also felt that after a while the experience of riding with an automated bus became mundane i.e., it felt like riding with a human operated bus which in turn was positive, since according to one of the participants -no one rides a bus in order to experience fun, it is a mode of transportation. The findings also show that participants expected several positive effects, on the public transport system, by implementing automated buses but they did not believe that automated buses would change their traveling behaviour to a great degree. The main reason being that merely implementing automated buses would not better fulfil their travel needs; their needs were to a high degree already fulfilled by the current public transport system. Another main reason was that the positive effects of automated buses were expected to be counteracted by external influences such as other road users. Finally, although many participants did not expect that automated buses would affect their own public transport travel behaviour to any significant degree, many thought that the implementation of such a system could improve travel in other use areas and that the automated technology could work as an enabler of new services that could radically improve public transport. The most common use area for automated buses that the participants saw, was in rural areas where the distances are long, and the departures few. Thus, the implementation of automated buses could help to increase flexibility and efficiency within the public transport system.

Conclusion: The participants were in general positive to the idea of using automated buses in the public transport system. However, just implementing automated buses would not improve their traveling experience to a large extent. However, automated buses could be used as an enabler for new public transport system solutions that could have a great impact on how public transport commuting is used i.e., a more individually adapted, efficient and flexible public transport system.

7. Conclusions, Lessons Learnt and Next Steps

Although the project has presented and demonstrated several successful and interesting concepts, a lot of research and development is still required to be able to drive an autonomous bus on a public road without a safety driver. The big challenge is to prove that the system is safe and can be run without risk of incidents and accidents. Practically testing and verifying all types of traffic situations is impossible as the combinations are endless. Existing standards and frameworks used by the automotive industry to classify safety are not fully applicable or adapted for complex autonomous systems, which means that each manufacturer needs to make its own interpretation of what is required to classify the system as safe, which creates ambiguity. A step-by-step rollout is preferred and a first phase where safety can be met by either the driver still remaining and monitoring the autonomous driving such as the bus docking function, or by the area being physically demarcated so that no other road users are near the vehicles, for example within a bus depot that have fences and gates, or in bus lanes with physical barriers. Whatever solution is realized, the autonomous vehicles need to have a priority accessibility to the road to be able to drive safely and efficiently.

Bus train. The project has established that there are great benefits from bus train driving. A step-by-step implementation with manual driven buses could accelerate a possible roll-out before there is a robust solution for how the rear bus autonomously can follows the first one. Three main parts have been identified in order to realize bus trains:

1. *Accessibility* - Practical tests show that it is very difficult to hold the bus train together and that it is very sensitive to disturbance, especially when it is operates in mixed traffic. Intersections, roundabouts, traffic lights, bus stops are some examples where the bus train is difficult to keep together because it needs to consider other traffic. The project has NOT studied how a potential solution might look like, but in general it can be said that it is much easier to keep the bus train together on bus lines with dedicated lanes compared to bus trains that run on public roads. Some type of dedicated infrastructure, e.g., traffic lights with signal priority, bus stop design for easy inrun and take-off, etc. would probably also facilitate the operation of bus trains.
2. *Technology* - Further development of the autonomous technology to achieve robustness so that bus 2 autonomously follows bus 1. Communication between buses so that passenger notification and announcements take place synchronously in the buses, for example before and at bus stops. For fully manually operated bus trains, the bus drivers need to have some type of communication, verbal and digital, with each other to be able to communicate about disturbances, obstacles or sync departures, etc.
3. *Policy* - Is it allowed to drive in a bus train formation and how does it fit in with the current traffic regulation? In the case of manually operated bus trains, the distance between the vehicles is determined by the reaction time. For a human driver in traffic, the reaction time is about 0.5–1 second, which means that the rear bus, at a speed of 50 km / h will have a reaction distance of 7 to 14 meters, i.e., the distance the vehicle moves before the driver reacts and presses, for example, the brake pedal. In order to be able to handle situations where bus 1 performs a panic brake, bus 2 must always have a sufficient distance to bus 1 in order to have time to react and brake. Being too close means that the operation NOT meet the traffic regulation. In the case that bus 2 runs autonomously, there is NO rules for that type of driving in the current traffic regulations and it is uncertain how the Swedish Transport Agency should classify such operation.

Bus stop docking. The project has discovered that there are several other areas of use automatic operation then just drive to and from a bus stop. The system can be used in narrow passages where demands are made on precision driving and to increase comfort by avoiding uncomfortable jerks in the bus that can occur, example sharp curves, roundabouts, intersections etc. By using predefined autonomous driving task that are linked to a geographical location, the bus driver can activate the autonomous driving task, when the bus is at the location. When the automated driving task is activated, the bus is optimally driven in terms of position and speed, the energy is also optimized in the best way. The automated driving task is limited in speed <30 km / h, and distance 20–100 m and the driver monitoring the driving and ensure that the vehicle is driven safely. The driver remains behind the steering wheel and can at any time go in and interrupt the autonomous driving and take over if something unplanned should occur. The system fits into a level 2 system according to SAE J3016:

- *You drive whenever these driver support functions are engaged - even if you do not have your feet on the pedals or steer*

  What the driver behind the steering wheel must do:

- *You must constantly monitor these support features; you must steer, brake or accelerate as needed to maintain safety.*

Even if the driver remains and monitors the driving, it is not a given that the system should be used everywhere. Some places may be unsuitable, so each driving task needs to be analyzed based on the type of traffic situation that may occur and the risks involved. Would the driving task be too difficult in relation to the current traffic situation, the use of the system should be avoided or adjust the infrastructure in order to limiting dangerous scenarios that could occur.

Autonomous depot processes. Many hours can be saved if the buses within the depot area move autonomously. The project believes that most of the bus movement can be done autonomously. However, it put high demands on safety when people are close to the vehicles. A good first step can be to focus on moving buses within the areas that are furthest from people. A possible flow could be when the bus is going out or coming back from a traffic assignment. Driving from the parking yard to the service hall or similar could also be done autonomously. At the service station, service staff take over and drive manually on areas where service personnel are located, e.g., washing, cleaning and inspection. NO requirement exists on driving fast within the depo so the buses can maintain a low speed <5 km / h, which reduces the damage in the event of a collision. However, there are still serious scenarios such as crush accidents where humans can end up between the bus and a fixed object, such as another bus, a house wall etc. The probability of this type of accident occurring is low given that the bus probably has a function of detecting obstacles in the environment and also runs slowly, but a fault in the system would in the worst-case result in a serious accident.

Next step

More knowledge and experience is required to be able to operate completely autonomous buses in public transport in the future. A good way to build knowledge and gain more experience can be through different types of test beds where different actors such as manufacturers, cities, bus operators and public transport authorities together test the technology in a safe and controlled way. The test bed would preferably be part of an existing public transport system, for example an entire bus line or parts of a bus line. It is important that the section has the necessary infrastructure, digital and physical, to facilitate a gradual roll-out of autonomous functions in step with technological development and the degree of maturity of the system.

Further technical research and development is needed in all areas, mainly in terms of safety and the level of integrity required to enable autonomous driving on public roads or in bus depots. In addition to autonomous subsystems on the bus, there needs to be a V2X connection between the vehicles and infrastructure for communication between the vehicles and the control tower and this needs to have some type of security that is also redundant. Connection and disconnection of charging of electric buses should take place automatically for smooth operation in a depot but also out on public roads.

8. Dissemination and Publications

The project result has been presented in several ways during the project period. All from live events, conferences, webinars down to scientific report and publication in journals. Each event and publication have been presented with press releases containing text material, photos and film that has been distributed through each partner digitally media platform such as the corporate/institute homepage and social media among others. The major activities listed below but not limited to.

Live event

The project has done two major demonstrations in front of live audience:

- 2018 June – Volvo Ocean Stopover, Gothenburg
- 2019 November – Depo processes Keolis, Partille

Reports

Scientific report from study that has been conducted by the project:

- *Bus Drivers Acceptance of a Narrow Navigation System*
  Mikael Johansson, Fredrick Ekman Design & Human Factors, Industrial and Materials Science CHALMERS UNIVERSITY OF TECHNOLOGY, Göteborg, Sweden 2021

- *Passengers' Experience of Travelling with a Full-Length Automated Bus and Expectations of the Future Public Transport System –*
  Mikael Johansson, Fredrick Ekman Design & Human Factors, Industrial and Materials Science CHALMERS UNIVERSITY OF TECHNOLOGY, Göteborg, Sweden 2021

Publication

Article has ben approved and will be published journal Cognition, Technology & Work.

ADAS at work – Assessing professional bus drivers' experience and acceptance of a narrow navigation system".

Mikael Johansson, Fredrick Ekman, MariAnne Karlsson, Helena Strömberg - Design & Human Factors, Industrial and Materials Science, Chalmers University of Technology, Gothenburg, SWEDEN, Volvo Buses, Gothenburg, SWEDEN

Conferences

Abstract submitted to the Transport Research Arena (TRA) Conference – Lisbon 2022.

Automation as an enabler: Passengers' experience of travelling with a full-length automated bus and their expectations of a future public transport system

Mikael Johansson, Fredrick Ekman, MariAnne Karlsson, Helena Strömberg, Joakim Jonsson, Mikael Faleke

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