AutoDepot

Autonomous bus depot

Project	**AutoDepot**
Partners	**Transports publics fribourgeois Trafic (TPF Trafic SA)** **SwissMoves (HEIA-FR, HEG-FR, UNIFR)** **AMAG Innovation & Venture Lab** **BERNMOBIL Städtische Verkehrsbetriebe Bern** **Embotech AG** **PostAuto AG** **SAAM Swiss Association for Autonomous Mobility** **TPG Transports publics genevois** **VBSH Verkehrsbetriebe Schaffausen** **VBZ Verkehrsbetriebe Zürich**
Funded by	**Federal Office of Transport (FOT)** **SAAM Swiss Association for Autonomous Mobility** **Partner’s in-kind**

Table of contents

1 Introduction

Buses of public transport operators enter their depots one or more times every day and the bus drivers spend many working hours in the depot every year (approximately 15,000 hours for depots with around 100 vehicles, depending on site configuration, exploitation and routine maintenance steps). Indeed, the drivers wait for their turn to enter the depot, they drive the buses through the various stages and places of maintenance and finally to the parking space ant it can even be several times a day. All these working hours are deemed non-productive as they are not directly performing transports services for the passengers but are required for the safe and smooth operation of public transport services and to ensure a certain level of service.

All these working hours should be (re)converted into more productive hours for the end-user of public transport systems and could also help to solve new challenges such as the decreasing availability of bus drivers. A possible solution to avoid unproductive working hours is the automation of the bus traffic in the bus depots. Accordingly, the present project aims to investigate the possibility of automating depot-related traffic of buses. To reduce complexity, the project does not deal with the automation of the tasks to be performed on the buses (e.g. washing, refueling).

The technical, economic and legal feasibility of automating depots is a matter of current debate within public transport operators. In particular, the emergence of automated vehicles, including bus fleets, raises questions as to how such as concept could be implemented. The present study – called “AutoDepot” – was carried out by a group of people who are active in different fields related to automated systems and public transport and have joined forces to address the key issues of automating depot-related traffic of buses with a focus on the Swiss landscape. It sets out the advantages, disadvantages, possible obstacles and conditions of implementing such a system.

The results of the study demonstrate the feasibility of such a concept provided that certain technological levers are validated. A technological key element of the project is an unconventional but promising reversal of traditional roles. Instead of conceiving and implementing a system based on highly automated vehicles that (partially) take over the driver’s tasks, the task of the driver is assigned to the infrastructure. This approach allows to concentrate the technological efforts on the infrastructure while minimizing them on and in the vehicles, which engenders a significant economic leverage. By reducing the amount of integrated hardware in the quantitatively most important elements of the system (vehicles), this approach was deliberately chosen to achieve economic optimization and financial viability for this system.

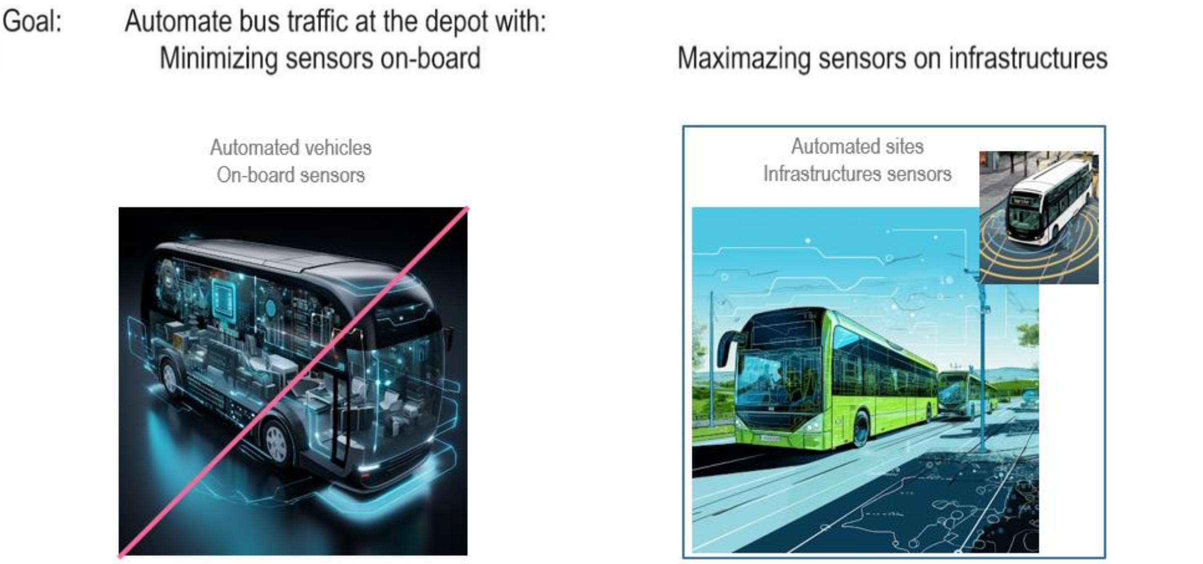


Image 1 : Basic concept “AutoDepot”

As some partners are public transport operators, the study also leads to an automated bus depot concept that could be considered at some relevant sites in Switzerland. The project proposes a criteria grid for evaluating the feasibility of an autonomous bus depot and outlines the framework conditions for implementing a Swiss prototype of automated traffic at a bus depot. This prototype, while ambitious, must address a significant challenge identified so far, the need to have access to drive-by-wire technology-equipped vehicles in the bus sales market.

2 Partners

The importance of the consortium established for this project, and the support obtained from other partners during the project, demonstrate the growing interest in this type of technological innovation in the development of public transportation systems of the future.

It is also worth noting that, in addition to the internal funding provided by the partners and the Swiss Association for Autonomous Mobility (SAAM), the project has received support from the Federal Office of Transport (FOT).

As said before, this study couldn't had been made without the collaboration of different partners. The consortium established for the project consists of the following:

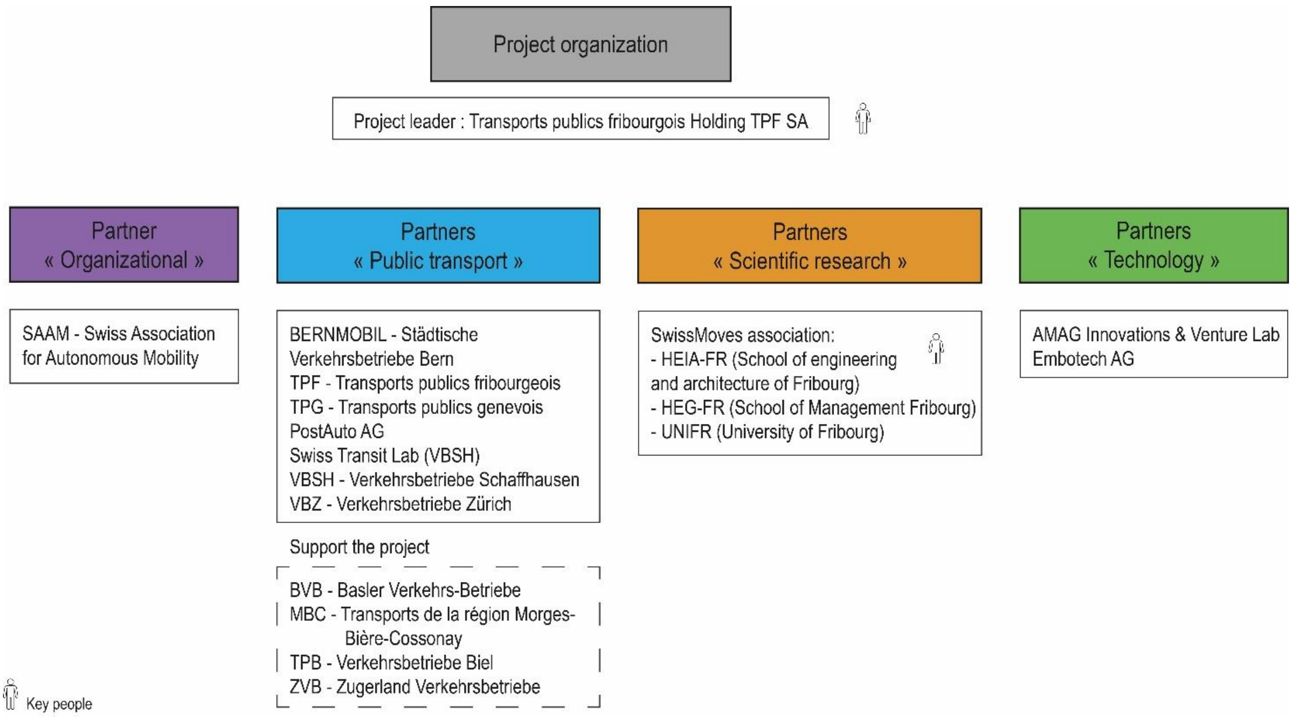


Image 2 : "AutoDepot" consortium

3 Current situation

Problematic

Today, bus drivers spend several hours a year waiting their turn to enter the depot, driving the bus during the various maintenance stages (recurrent daily activities), then maneuvering it to its parking space. Each time that a driver enters the depot with a bus and does all the process explained above, this can take between 10 and 15 minutes, depending on the size of the depot. If you multiply this by the number of bus entries per day at the depot, this is a lot of non-productive hours per year (G7-Givisiez TPF: 15,000 hours per year). These valuable hours could be avoided if bus traffic were automated inside the depots and could then be redirected to more rewarding activities in favor of public transportation system users. This is what this study is about.

To avoid those hours where a bus driver is needed, which create non-productive hours, one solution among others is to automate the process of bus circulation within the depot. This means that only the part of the bus driver is automated and not tasks. As a bus entering the depot has to move to several points, it is this part which is automated. This means that the route of the bus has to be known as soon as it enters the depot in order to indicate to the bus where it has to go. For each task performed during the process, with the exception of circulation (exterior washing, interior cleaning, refueling, etc.), we assume, for this study, that they will continue to be carried out by a human. However, some of these tasks could certainly be automated as well, but to reduce the complexity of the study, it focuses on the traffic automation, which is the crucial element for depot automation.

Some tasks (such as washing, tire checks, and recharging) can be automated regardless of the operational traffic situation (with or without a driver, with or without traffic automation), while other tasks may be carried out by other personnel (washing, charging). However, if tasks are automated but not the traffic, the driver's work remains unchanged. Therefore, there is no gain in this area, especially in terms of unproductive time. This is why the interest in bus traffic automation within a depot is significant.

Many players, especially public transport operators, are wondering about the technical and economic feasibility of implementing an autonomous bus depot. It is understandable because this has never been done before. This is why an on-site automated traffic pilot project is planned to develop, implement, test, validate and optimize such a concept in the current Swiss context of these operators. Before that, it is necessary to have a pre-study in order to analyze what could be implemented on a bus depot and analyze different dimensions (financial, technical, legal). This is why this pre-study is separated in different steps, different workpackages.

Altogether, there are four different workpackages which are all linked together like bricks in a wall. The first workpackage, WP1, is about collecting data from project partners, information about potential pilot sites and the state of the art in bus depot automation.

The second workpackage, WP2, concerns feasibility studies. In this one, there are three different studies: technical feasibility study, economic and financial study, and legal framework study.

The third workpackage, WP3, is about the development of criteria to evaluate the different pilot sites which will also enable to interpret the results of this evaluation.

The last workpackage, WP4, is about the potential pilot site on which to implement and test an automated bus traffic system. The WP4 aims to develop the framework to test this project in reality.

If the expected results seem promising (avoiding driver downtime, better management of flows during peak periods, reducing the risk of parking errors, saving space, anticipating vehicle preparation, increasing profitability, etc.), the fact remains that this pre-study was necessary to define the framework of the proof-of-concept.

4 Project description

4.1 Description of the innovative solution and its advantages

This preliminary study makes it possible to establish the feasibility and the necessary prerequisites in technical and legal terms from the point of view of operators, vehicles and infrastructure for the establishment of a large-scale autonomous bus depot pilot project in a Swiss context. It should be mentioned that the pre-study focuses mainly on the traffic of vehicles in the depot between places relating to the different processes that a bus follows (measurement of tire pressure, washing, workshop, parking, loading or filling of fuel, etc.) and not directly on these activities.

The economic aspect is also discussed in order to estimate the profitability and financial impact of this concept. Finally, on the basis of these different parameters, an evaluation of potential pilot sites makes it possible to define the repositories conducive to the implementation of the «proof-of-concept» of automation.

The methodology of the pre-study is as follows:

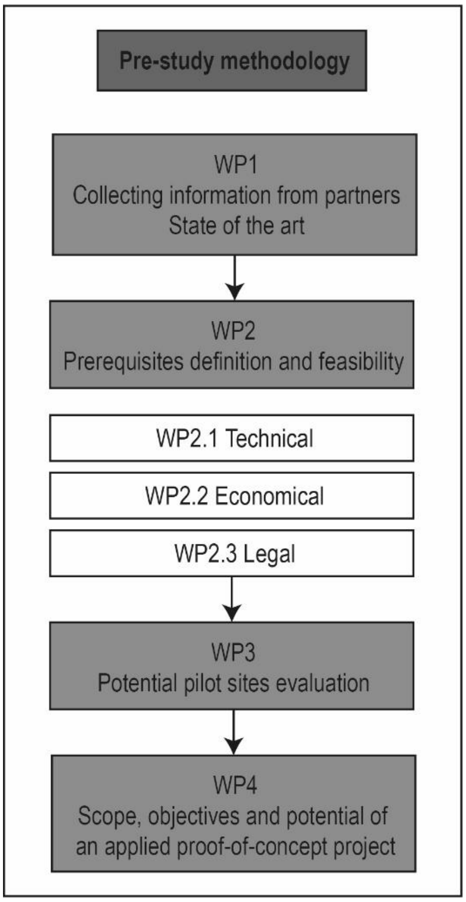


Image 3 : “AutoDepot” pre-study methodology

The first phase, **WP1**, consisted of collecting all necessary information from the partners proposing a potential pilot site including:

- **Vehicles**: Type of vehicle fleet (retrofit features, drive-by-wire, sensors, embedded systems);
- **Operators**: Depot management system, current communication system with vehicles;
- **Infrastructure**: Routes and activities at the bus depot, public/private environment of the site, interactions with other modes of transport (trains, private vehicles, pedestrian crossings, etc.), sensors, integrated networks, local site conditions.

On the other hand, a literature review of the experiments conducted abroad and the avenues of reflection developed in Switzerland (e.g. depots of the future) has been developed (cf. chapter 3.2). This literature review consists of various studies on different topics related to automation in connection with bus depots.

The second workpackage, **WP2**, was used to define the various prerequisites needed for the implementation of a standalone bus depot pilot project. From a technical point of view, particularly on the basis of skills in vehicle automation and remote operation, the systems necessary for the automation of the autonomous bus depot are described. In economic terms, a first approach was aimed at determining the system's potential for profitability (balance between the costs of the equipment needed, the installation and maintenance of the system, training for employees and other factors related to the implementation of automation taking into account the effect of deployment vis-à-vis the expected gains). Finally, from a legal point of view, it was a question of determining the legal framework within which a concept of an autonomous bus depot would fit in (generally, depending on a specific site, and with a view to authorizing a pilot project).

The third part of the project, **WP3**, led to the ranking of pilot sites based on the assessment of all potential sites. This evaluation is performed using a multi-criteria analysis, based on the previous two workpackages. Those criteria have different weight because their importance is not the same for all.

Finally, in **WP4**, the framework conditions for the pilot project have been defined (site, material conditions, personnel required, control, safety, methodology, planning, project costs, project organization, responsibilities), as well as the project objectives (expected goals) and its potential (technical, societal and economic impact), this in view of the elaboration of a project of national scope expected by many actors in the sector.

Such a project, which makes it possible to envisage an economic impact which will have an impact on passenger users (cost reduction), falls within the framework of FOT's priority areas of promotion and encouragement in the field of regional passenger traffic (PRT), notably automation of processes and automatic operation.

4.2 Project objectives and expected results

1	Information related to potential pilot sites
Expected results : Collection of information on: fleet of vehicles; on-board technologies; purchase plan; deposit management system; V2I communication systems; site configuration; site activities; estimate of the volume that can be potentially automated; personnel roles; operational processes; security protocols; training; and associated costs.	
2.1	Technical requirements
Expected results : Definition of the equipment and systems necessary for the automation of the circulation on depot.	
2.2	Economical requirements
Expected results : Balance of the estimated costs and assessment of the economic profitability potential of the bus depot for the implementation of a pilot project.	
2.3	Legal requirements
Expected results : Description of the general legal framework for the automation of bus depot traffic in order to the implementation of a pilot project.	
3	Multi-criteria assessment of potential pilot sites
Expected results : Validation and weighting of criteria; Multi-criteria assessment; Selection of pilot site(s).	
4	Proof-of-concept
Expected results : Definition of the framework, objectives, potential, funding of the pilot project.	

Tab. 1: Project objectives and expected results

4.3 Different workpackage and plan

1	WP1 - Collection of information
Manager	SAAM
Work : Collect of information from project partners. Information on potential pilot sites (vehicles, infrastructure, personnel). Carried out on the basis of questionnaires allowing uniformity of information processing. Additional information will be collected further, during the multi-criteria evaluation, if necessary.	
Deliverables : List of information from the various pilot sites allowing multi-criteria evaluation (WP3).	

2	WP2 - Definition of requirements and accounting
Manager	SwissMoves
Work : Definition of technical prerequisites; Technical feasibility study. Study of the economic potential of traffic automation. Study of the legal framework.	
Deliverables : Technical, economic and legal evaluation report.	

3	WP3 - Evaluation of potential pilot sites
Manager	SwissMoves
Work : Definition of evaluation criteria and weighting of criteria. Evaluation of pilot sites on the basis of established criteria (aggregation, rating). Interpretation of results.	
Deliverables : Multicriteria grid. Results interpretation report.	

4	WP4 - Definition of the framework, objectives and potential of an applied proof-of-concept project
Manager	Transports publics fribourgeois Trafic (TPF TRAFIC) SA
Work : Define with the potential implementation partner(s) the framework and objectives of the pilot project of autonomous bus depot. Depending on the selected site, description of the economic potential related to automation.	
Deliverables : Potential and implementation report.	

Tab. 2: Workpackages

4.4 Legal authorizations

No specific authorization was required for this preliminary study (provisional authorizations for vehicles, derogations, provisional concessions, etc.). On the other hand, in view of the autonomous bus depot project, this preliminary study makes it possible to determine the necessary requirements and authorizations.

Similarly, no regulatory requirements needed to be clarified with the Federal Office of Transport (FOT) within the scope of the preliminary study, as it does not involve any regulatory requirements.

5 WP1 Collecting information from partners – State of the art

This workpackage, as explained before, is about collecting information from the partners proposing a potential pilot site. That information mainly concerns vehicles, infrastructures and operators. This package is also about making a literature review about technologies and examples in the world but also in Switzerland about automation.

It should be noted that several partners wished to keep certain information confidential. As a result, this information was extensively addressed by the academic partners but is only presented here in a generic manner to ensure their request for confidentiality.

5.1 Collecting information

For each question asked to the public transport partners, BERNMOBIL, TPF, TPG, PostAuto, and VBZ, a summary of the responses is provided here. Some information is deliberately conveyed succinctly to ensure confidentiality is maintained.

Bus fleet

Questions:

- *How many vehicles are there in your fleet?*
- *What are the different bus models you have?*
- *What are the different types of motorizations for your buses?*
- *What are the costs of those vehicles?*
- *When do you plan to buy new vehicles or second hand, what is your 10-year vehicle purchase plan?*
- *Do your buses have GPS receivers?*
- *Are the buses connected to a network (4G, WIFI, etc.)?*
- *Is it possible to get live information on the location (GPS position) of the buses (API in a supervision center, reception of GPS positions from the receivers on the buses)?*
- *What kind of information can you get about the buses arriving at the depot?*
- *Do you have drive-by-wire vehicles?*
    - *If yes: What are the additional costs of these vehicles in comparison to standard vehicles?*
    - *Why do you have drive-by-wire vehicles?*
    - *What benefits have you seen compared to regular vehicles?*
    - *If not: Why don't you have drive-by-wire vehicles?*
    - *How much would you be willing to spend for drive-by-wire vehicles?*
- *What are obstacles you see when it comes to drive-by-wire vehicles?*
- *What kind of on-board systems do your buses have? What sensors (radar, lidar, sonar, etc.) do your buses have?*
- *Do the buses have a 12V battery?*
- *Is it possible to access the bus battery?*

In summary (see Tab. 3), local public transport operators (project partners) have fleets ranging from 150 to 260 buses, with the exception of PostAuto, which manages around 2,400 vehicles, with a maximum of 35 vehicles in a depot. The various bus models include school buses, minibuses, electric or diesel midibuses, articulated trolleybuses, double-articulated buses, with or without batteries, standard diesel, hybrid, electric, or gas buses, as well as standard articulated diesel, hybrid, and electric buses and autonomous shuttles.

Regarding the types of propulsion, buses can be powered by diesel, electricity, hybrid mode, or gas. Vehicle costs vary between 300,000 and 1.3 million Swiss francs per vehicle, depending on the type of bus. The average replacement cycle for a bus is approximately 12 years.

All buses are equipped with GPS receivers and most are connected to a network (WIFI, 3G, 4G, ready for 5G). Real-time information on bus location is available, except for certain older models that may not be equipped with this technology. This data can generally be utilized in a control center. The collected data includes the position (GPS), vehicle status (including driver feedback), tire data, operational status (ready or not), charging point readings, and vehicle data monitoring (according to manufacturers).

As for "drive-by-wire" vehicles, most buses are not equipped with them, except for braking systems and autonomous shuttles. No additional cost could be evaluated compared to conventional vehicles, as "drive-by-wire" technology is not currently available on the market, and the reasons for acquiring or not having vehicles incorporating this technology are not specified. Potential obstacles to a "drive-by-wire" system include reliability, costs, availability, regulations, safety, and approvals.

Buses are equipped with various onboard systems such as passenger information systems, rear cameras, front and side radars (only on certain buses), sometimes a driving assistant (Mobile-Eye) and an onboard computer. Some buses have a 12V battery (2x12V in series), while others operate with a 24V battery. Accessing the bus battery is possible in some cases, but this information is not always known to the operator.

Bus fleet	TPF	BERNMOBIL	POSTAUTO	TPG	VBZ
Number of buses	241 (school buses and service vehicles not counted)	164	35* (thereof 2 minibus)	228 buses	255
Type of buses	Standard bus / Articulated / Diesel Standard bus / Diesel Trolleybus / Articulated Trolleybus / Articulated / With battery Midibus / Diesel Midibus / Electric Schoolbus	Standard bus / Hybrid Standard bus / Diesel Standard bus / Gas Articulated Trolleybus Trolleybus double-articulated	Standard bus Standard bus (low-floor) Midibus	Trolleybus / Double-articulated Trolleybus / Articulated Trolleybus / Articulated / With battery Autonomous bus Standard bus / Articulated / Diesel Standard bus / Diesel Minibus	Midibus / Electric Trolleybus / Articulated Trolleybus / Double-articulated Standard bus / Electric Standard bus / Diesel Standard bus / Hybrid Standard bus / Articulated / Electric Standard bus / Articulated / Diesel Standard bus / Articulated / Hybrid Midibus / Diesel Minibus / Diesel
Type of motorization	Diesel Electric	Diesel Gas Electric (Trolley, Battery, both) Hybrid	Diesel	Diesel Electric (Trolley, Battery, both)	Diesel Electric (Trolley, Battery, both) Hybrid
Cost of buses	340'000 to 1'300'000 CHF	480'000 to 950'000 CHF	N/A	1'000'000 CHF (new TOAS)	N/A
Renewal schedule	Replacements every year to smooth out costs Every 10 years (Urban 12 m buses) Every 15 years (Urban Trolleybuses) Every 12 years (regional buses)	14 Articulated battery (from 2023) 13 Trolley double-articulated (from 2025) 34 Standard battery (from 2025) 15 Midibus battery (from 2033)	Every 12 years	N/A	Renewal chart
GPS receivers	Yes	Yes	Yes	Yes (SAE System)	Yes
Connection to a network	WiFi (not on all vehicles) 3G/4G	3G (via IBIS) 5G (from 2025)	4G 5G (later)	4G	WiFi (garage) 4G
Live information on bus location	Yes	Yes (except some older buses) via Trapeze LIO / IBIS	Yes (update every 1s)	Yes (GPS position from supervision centre)	Yes On the road: GPS via Chargepoint (from 2022) Depot: Depot management system (from 2024)
Type of bus information arriving at depot	Position Tyre scan data	Data monitoring (HESS and Volvo) No monitoring for other buses (feedback of driver)	Position (GPS) Detection of arrival in the depot (radius of 50m around depot)	State of the vehicle (feedback of the driver)	Operating condition (ready for use or not) via BMS CAN-FMS data via Chargepoint (e.g. SoC)
Vehicle "drive-by-wire"	No (Only for braking system and accelerator)	No	N/A	No	No
Additional cost of "drive-by-wire" buses	N/A	N/A	N/A	N/A	N/A
Reason for "drive-by-wire" buses	N/A	N/A	N/A	N/A	N/A
Benefits with "drive-by-wire" buses	N/A	N/A	N/A	N/A	N/A
Reason not to have "drive-by-wire" buses	Costs No added value Does not exist in series production	N/A	No series production	N/A	Currently not available
How much would you be willing to spend on drive-by-wire vehicles?	N/A	N/A	N/A	N/A	Can currently not be evaluated
Obstacles to have "drive-by-wire" buses	Reliability Costs Availability	Potentially problematic autorisation	Regulations Safety	Not many obstacles	Costs
Embedded systems of buses	On-board information systems for passengers Rear cameras Frontal and lateral RADAR (only some buses)	Trapeze IBIS (position, schedule, announcements) No RADAR currently	N/A	N/A	No (from 2022: Mobile-Eye drive-assistant)
V12 battery	Yes (2 x 12V batteries in series)	Yes (2 x 12V batteries in series)	No, 24V	No, 24V	No, 24V
Access to the battery	Yes	Yes	Yes	Yes	Unknown (Additional loads on ICE buses are limited, on electric buses possible)

Tab. 3: Partner's information – Bus fleet

*Information: for PostAuto, the number of buses indicated if for one depot only.

Depot

Questions:

- *How many vehicles are there in your depot?*
- *Who is the owner of the depot premises (private company, public transport operator, canton, town etc.)?*
- *Who has access to the premises (drivers and maintenance workers only, all employees of transport operator, open to public (e.g. pedestrians), other):*
- *How many vehicle entries and exits are there in your depot (daily average)?*
- *How many vehicles enter and exit at the peak hour (per hour)?*
- *How much time do the drivers spend inside the depot?*
- *Through which process do the buses go through in the depot (washing, parking, etc.)?*
- *Which tasks do the drivers have in the depot?*
- *Do you have a checklist of activities that the driver must do before leaving the depot?*
- *Are driving operations in the depot performed by people other than drivers (technicians) and if so, for which tasks?*
- *Do you already have a system for planning the different maintenances of the buses?*
- *What is the average insurance prime (especially for e.g. fire at the depot)?*
- *Are there already automated or semi-automated solutions in place?*
    - *If yes: For bus washing?*
    - *For bus parking?*
    - *For the technical controls of the buses?*
- *Did you consider other options in the past to make processes at your depots more efficient?*
    - *If yes: Which ones?*
    - *What were the results of those options (implemented or disregarded)?*
    - *Why were they implemented or disregarded?*
- *Are there any areas of your depot secured with restricted access (no pedestrians or vehicles)?*

The number of vehicles in a depot varies from 10 to 170 depending on the public transport company (see Tab. 4). Each public transport partner has at least one site with 100 vehicles, except for PostAuto (maximum 35). The depot premises are owned by public transport operators, affiliated companies or cities.

Access to depots is generally restricted to drivers, maintenance personnel, authorized staff, employees, and delivery services. It may eventually be open to the public at specific passageway. Certain areas of the depot are secured with restricted access, excluding pedestrians and vehicles other than buses.

The depot may have 10 to 195 vehicle entries and exits per day, with 5 to 60 movements per hour during peak hours. Drivers spend an average of 10 to 14 minutes inside the depot at the end of a service. Buses undergo several processes at the depot, including tire checks, refueling, interior and exterior cleaning, fluid checks, daily maintenance, parking, and loading.

Drivers have various tasks at the depot, including maneuvering, retaking various material, washing, recharging (air, electricity), vehicle closure, handling lost items, safety checks, and parking. There is a checklist of activities that the driver must follow before leaving the depot. Some depot tasks, such as maintenance, are performed by technicians. There are also planning systems for different types of bus maintenance.

The average amount of insurance, especially for depot fires, is not disclosed.

Regarding automation, most depots have primarily automated or semi-automated solutions, especially for bus washing, parking, and technical inspections. Options have been considered to optimize processes, manage the depot, implement a battery management system and an electronic system. Some of these options have been implemented, while others are still under evaluation. Implementation or rejection decisions are motivated by financial considerations, increased automation and effort reduction.

Depot	TPF	BERNMOBIL	POSTAUTO	TPG	VBZ
Number of vehicles in depot	117 (Total) 85 (bus 18m) 32 (bus 12m)	156 (Total) 110 (Eigerplatz) 36 (Freiburgstrasse) 10 (Bolligenstrasse)	33 (Total)	131 (Total) 30 (bus 18m) 101 (bus 24m) (+ 102 trams)	255 (Total) 90 (Hagenholz) 165 (Hardau)
Owner of the depot	TPF	City of Bern (Eigerplatz) City of Bern (Freiburgstrasse) BERNMOBIL (Bolligenstrasse)	Post Immobilien	Public transport operator	City of Zürich
Access to the premises of the depot	Drivers Maintenance personnel People able to justify their presence	Open to public on defined passage (Eigerplatz) Only BERNMOBIL personnel, neighbouring work traffic, and delivery service (Freiburgstrasse) Only BERNMOBIL personnel, and delivery service (Bolligenstrasse)	Employees of TH Employees of the garage	Employees of TPG Employees of subcontractors	Generally only authorised personnel (Legally depots are public space due to not being closed off enough)
Number of entries and exits (daily average)	195	178 (Total) 140 (Eigerplatz) 28 (Freiburgstrasse) 10 (Bolligenstrasse)	60 - 80 (seasonal)	145 (+ 48 trams)	N/A
Number of entries and exits at peak hour (per hour)	50 (5h00-6h00) 21 (6h00-7h00)	50 (Total) 30 (Eigerplatz) 10 (Freiburgstrasse) 10 (Bolligenstrasse)	5 to 10	56 (6h00)	N/A
Number of work hours by drivers in the depot (by year)	15'070 hours (year 2022)	10 min (Bolligenstrasse)	N/A	~12'000 hours/year (Each driver takes about 13min at end of service)	N/A
Process of the bus in the depot (time by activity)	Around 11 minutes Refuel + ad-blue Cleaning (interior + exterior) Coal check (Trolleybus only) Parking	Arriving at the depot - Detection of the vehicle - Entering in the bus depot - Targeting - Tyres control - Daily maintenance - Washing - Manoeuvring - Load Getting out of the depot - Turn on the bus electronics - Checking fitness to drive - Getting out of the bus depot	N/A	Refuelling Washing	At least 13.5 minutes Exterior cleaning -> ca. 3.5 Min Refuelling -> ca. 5 Min Parking -> ca. 3 Min Start charging -> ca. 2 Min Interor cleaning -> situational
Task(s) of drivers in the depot	Parking Retake various material (monnexchanger, etc.) Connect air and electricity Close vehicle	Exit: All-round check Entry: Park vehicle safely, log off from the system, drive down	Refuel Set-up workspace Safety check	Fuelling Washing Dispatching Parking Securing and inspecting vehicle	Drive through washing station Wait for refuelling to finish (separate operator for refuelling) Parking Start charging (battery bus) Handle lost items
Checklist for drivers before leaving the depot	Control exterior and interior Control water level Remove air and electricity Input data into board computer	Yes	Yes	Yes	Yes (listed above)
Person doing the tasks + tasks	Mechanics (drive bus into workshop) Pit-stop agent (advance bus in parking line)	No	No	Technicians (for maintenance)	Technician (drive bus into workshop)
Systems of planning of different maintenance	Yes (GMAO)	Yes (SAP)	Yes	Yes	Yes (SAP)
Automated or semi-automated solutions	No	Yes	Yes	Yes	Yes
If yes : bus cleaning ?	N/A	No	Washing station	Yes (Driven through)	No
If yes : bus parking ?	N/A	Yes (BMS : Operational Management System)	No	No	No
If yes : bus inspection ?	N/A	No	No	Yes (Tyre pressure and profile, driven through)	Automatic coal control for Trolleybuses
Other options to make the deposit process more efficient	Yes	Yes	No	Yes	Yes
If yes : which ?	Research during contruction of G7 to optimise processes (positions of elements, types of materials, etc.)	BMS SAP Mobile Auftragserfassung Elektronisches Wagenbuch	N/A	N/A	Implementation of depot management ongoing
If yes : results ?	Implemented (depot G7)	All implemented	N/A	Fewer accidents Easier access Simpler to manoeuvre Closed and covered environment	Cannot yet be evaluated
If yes : why implemented or abandoned ?	Financial motives	Reducing effort	N/A	N/A	Augment automation
Type of zone in the depot area	N/A	Open to public on defined passage (Eigerplatz) Only BERNMOBIL personnel, neighbouring work traffic, and delivery service (Freiburgstrasse) Only BERNMOBIL personnel, and delivery service (Bolligenstrasse)	N/A	N/A	Public area
Secure deposit area with restricted access	Yes (Entrey/exists ramps)	Yes	Yes (Lockers for the drivers' bags with cash)	Yes (Roof inaccessible for vehicles and pedestrians)	No (parking) Yes (workshop)

Tab. 4: Partner's information – Depot

Supervision

Questions:

- *Do you have a supervision/monitoring center to obtain information on the buses in circulation? Where is it located (at the depot or delocalized)?*
- *Do you have a supervision/monitoring center to obtain information on the depot (e.g.: parking lot)? Where is it located (at the depot or delocalized)?*
- *Are there already cameras to monitor the depot? What type of cameras do you have and what are their specifications (resolution, frame rate, etc.)?*
- *Do the members of staff at your supervision center have a bus drive's license?*

In general (see Tab. 5), public transport operators have a control/supervision center to gather information about buses in operation as well as depot-related information, such as parking. This center may be located at the depot or decentralized for certain information. Most personnel in the supervision center hold a bus driving license.

Some depots are equipped with surveillance cameras. The type of cameras and their specifications (resolution, frame rate, etc.) are not detailed.

Supervision	TPF	BERNMOBIL	POSTAUTO	TPG	VBZ
Supervision/monitoring centre to have informations about bus in circulation	Yes (Control centre in maintenance building)	Yes Control centre (Eigerplatz)	Yes ISA control system	Yes Ineo SAE (RCT Bachet and En Chardon) Backup supervision center in En Chardon	Yes Control system (Trapeze) -> only visible in control centre ChargePoint (Viriciti) -> decentralized
Supervision/monitoring centre to have informations about the depot	Yes (Control centre in maintenance building)	Yes (BMS, decentralized in every depot)	No	Yes (eParker)	Yes (via BMS, ongoing implementation, decentralized)
Security camera for the depot? Which type ?	Yes (Surveillance cameras in depot)	No	Yes (7 cameras)	Yes (Surveillance cameras in depot)	No
Have the monitoring centre staff a bus driving licence ?	Yes (most of them)	Yes	Yes (most of them)	Yes (most of them)	Yes

Tab. 5: Partner's information – Supervision

Accidents

Questions:

- *How many accidents occurred at the depot in the last 10 years?*
  - *If any, how much damage was caused in each accident (in CHF)?*
  - *What kind of accidents were they?*
- *How many accidents occurred on vehicles running outside of the depot (average per year)?*
  - *How much did/do those accidents cost (in CHF)?*

Within the depot premises, the number of accidents ranges from 3 to 50 per year per depot (see Tab. 6). Details regarding the damages incurred in each accident, measured in Swiss francs (CHF), are not disclosed for the report. The recorded types of accidents involve collisions between buses or between a bus and an obstacle.

As for vehicles operating outside the depot, the number of accidents varies from 70 to 3,300 per year on average per public transport company. The costs associated with these accidents, also expressed in Swiss francs (CHF), are not revealed for the report.

Accidents	TPF	BERNMOBIL	POSTAUTO	TPG	VBZ
Number of accidents in the depot in the last 10 years	Circa 50 cases/year/depot	N/A	3-5 cases/year	4 accidents 2022 (Accidents in the depot are rare)	Regularly
If so, what was the amount of damage caused by each accident (in CHF)?	Not disclosed				
Type of accidents	Bus with bus Bus with obstacle	Property damage	Careless manoeuvring in depot	Bus	Bus with bus
Number of accidents outside the depot (average per year)	500	200 (+ 250 passengers falling over)	70	3263 (in 2022)	N/A
How much these accidents cost ?	Not disclosed				

Tab. 6: Partner's information – Accidents

Salaries

Questions:

- *How much does a driver cost including social charges and overheads (average per year)?*
- *Do you plan to increase the salaries of your drivers?*
  - *What are the reasons for increasing them / not increasing them?*

Salary information is not disclosed within the scope of this report. A few job postings can give an estimate of drivers' salaries. These range from 55kCHF to 80kCHF per year. However, as part of the economic analysis, the human cost associated with driving a vehicle has been set at 80 CHF per hour.

Human resources

Questions:

- *Is there a risk of facing a shortage of drivers?*
  - *If yes: What is the probability that this happens in the next decade?*
  - *How many drivers do you estimate to lack in the next decade?*
  - *What measures are you undertaking to avoid a shortage of drivers?*

The risk of facing a shortage of drivers is primarily present in all public transportation operators (see Tab. 7). As for the likelihood of this occurring over the next decade, the number of responses is insufficient to be judged.

Various measures are being implemented to prevent a shortage of drivers, including communication, internal training, promotion of part-time work, early detection of needs, and collaboration with authorities. These initiatives aim to mitigate the risk of a driver shortage and ensure an adequate workforce in the coming years.

Human resource	TPF	BERNMOBIL	POSTAUTO	TPG	VBZ
Risk of driver shortage	Yes	N/A	Yes	Yes	N/A
If yes : likelihood of that happening in the next decade?	High (Many drivers 50-60 years old)	N/A	N/A	N/A	N/A
If yes : how many drivers will be short in the next decade?	> 200 drivers (retirement)	N/A	30 (retirement)	We estimate that we should be able to find the required drivers	N/A
If yes : what measures to avoid a shortage of drivers?	Communication Internal training Promotion of part-time	N/A	Early detection of people leaving Career changers Participation in apprenticeship/training Online advertisement	Working with the unemployment at the state level	N/A

Tab. 7: Partner's information – Human resources

Collecting this information from partners has not only helped determine whether transportation operators are ready, both technically and legally, to adopt an automation system like AutoDepot, but also identify the key factors of interest for such a system.

5.2 State of the art

Some studies and projects had already been done or are in progress in the field of vehicles automation or automated processes. Here, you can find a list of those with an explication for each of them. The aim of this list is to show various project and studies, from different areas in the world and with a focus on technical elements close to bus depot automation.

Netherland – Future Bus with CityPilot – Mercedes-Benz, EvoBus, Daimler Truck – 2016

In 2016, Mercedes-Benz unveiled its new semi-autonomous Future Bus with CityPilot technology. During a demonstration, the bus was able to travel around 20 kilometers independently. CityPilot technology is what allowed it to follow a predefined route without human intervention.

The vehicle is equipped with various sensors including ten cameras in total and radars that allow it to perceive the environment around it and adapt in real time to changes in road conditions. The sensors are used to detect obstacles such as pedestrians, cyclists, cars and other buses, as well as to monitor traffic lights and ground markings. The bus is also in constant exchange with the infrastructure via a WLAN communication and is therefore informed about the traffic density or the state of the traffic lights for example.

The current legislation does not yet allow vehicles of this type to drive without a driver, so it is necessary that a safety driver is present in the bus in order to be able to take back control if necessary. [Mercedes-Benz, 2016]

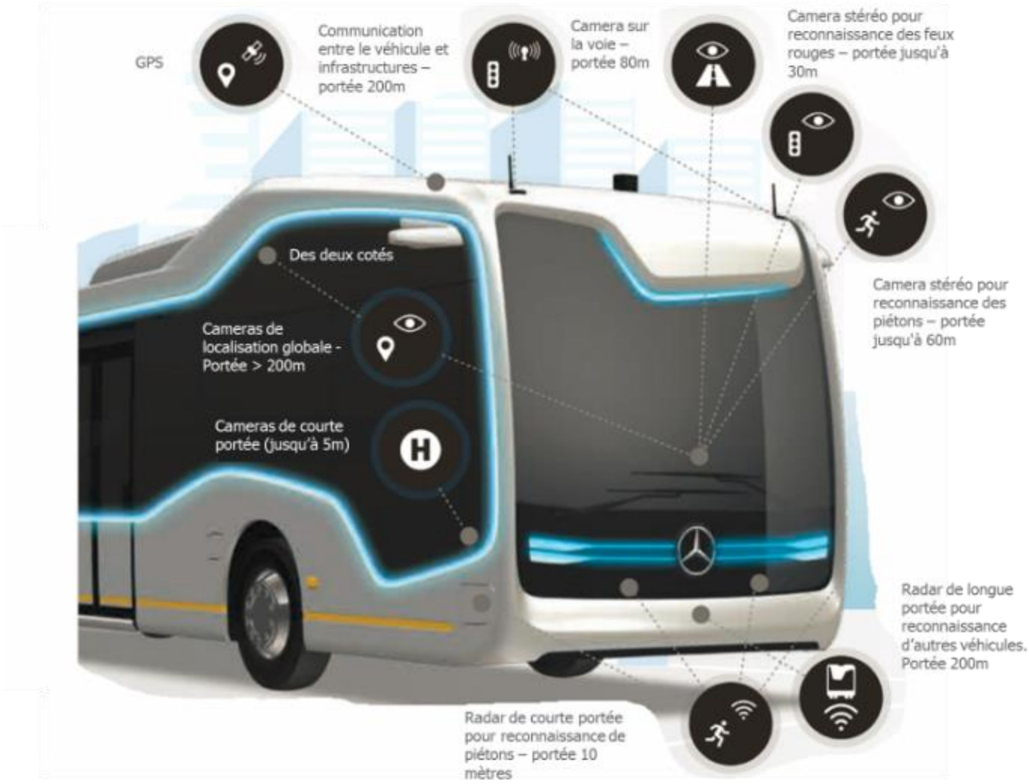


Image 4 : Future Bus and its various sensors.
https://www.transportshaker-wavestone.com/mercedes-benz-bus-autonome-du-futur/, accessed July 3rd, 2023.

Germany – Feasibility and cost reduction analysis – KIT, FZI, SSB Stuttgart – 2017

In 2017, the Karlsruhe Institute of Technology (KIT) and its partners conducted a technical and economic feasibility study for the automation of a bus depot [KIT 2017]. The study covered the various automated processes (exterior washing, interior cleaning, refuelling, compressed air supply) as well as the traffic and parking phases. Based on the principle of fusion of information from different sensors (GPS, cameras, ultrasound, radars), the technology potentially integrable on vehicles allows to envisage an automation of the circulations. This study should lead to a new prototype project developed in a real environment.

France – RATP and partners – 2018

In 2018, a research project of the RATP group with partners CEA List and Iveco Bus demonstrated the potential for automation of a bus depot. One of the RATP fleet buses was retrofitted, equipped with various sensors and a navigation controller to perform the parking maneuvers, on a predetermined site, autonomously. During the tests, it should be noted that an operator remained on board the vehicle in order to intervene, if necessary.

The RATP [RATP 2018] and its partners see in the success of this project a strong potential in terms of reducing the working time of drivers, assistance to drivers in their tasks with adequate technological devices and also a reduction of the necessary parking area, through the precision of automated maneuvers.

Singapore – NTU, Volvo – Autonomous electric bus – 2019

Volvo's Bus Department, in collaboration with the Nanyang University of Technology (Singapore), demonstrated the traffic and parking of an automated electric bus in 2019 [Volvo May 5th, 2019].

Equipped with several sensors (Lidars, cameras, GPS, IMU), the automated bus sailed on a determined test track on which several obstacles were placed. With the results of this proof-of-concept, Volvo Bus wants to move into an experimental phase in a real-world environment with the aim of assessing the feasibility of automation in travel situations between on-site operations and parking phases.

Sweden – Autonomous bus on depot – Volvo, Keolis – 2019

In 2019, Volvo and Keolis tested an autonomous bus at a depot in Göteborg, Sweden. During this demonstration, the electric bus moved from its parking area to various workstations in the depot, including the cleaning area and the charging station without third-party intervention.

The charging area does not require connection because it uses the OppCharge technology mentioned above. The bus can therefore simply move around the terminal using autonomous driving. [Volvo November 13th, 2019]

Great-Britain – Fusion, Stagecoach Group Plc, Alexander Dennis Ltd – 2019

In the United Kingdom, two oeprators and a bus manufacturer have pooled their expertise to develop and demonstrate the feasibility of an automated bus system to run between different areas of operation and while parking the vehicle.

If during the tests carried out in bus depots in Sharston and Cambridge the bus remained under the supervision of a driver, this test also demonstrates the significant potential of such a technology. [StageCoach November 13th, 2019]

South Korea – LV5 CTRL TWR – Seoul Robotics and BMW – 2021

The Level 5 Control Tower (LV5 CTRL TWR) is a new solution developed by Seoul Robotics to manage vehicle fleets via the infrastructure only using a few sensors. This technology is a mesh network of sensors (cameras and LiDARs) and computers on an infrastructure that guides the vehicles autonomously without requiring sensors to be placed on individual vehicles, this controlled by a central processing unit. The result allows thousands of vehicles to drive autonomously simultaneously in a controlled network, navigating safely around obstacles and other vehicles with very high precision.

Developed in partnership with BMW, it is currently being used to automate fleet logistics at a manufacturing plant in Munich. The system has great potential for use in various commercial applications ranging from vehicle distribution centers to car rental companies or in our case, bus depot management.

Thanks to the few sensors needed to implement this system, the costs of autonomous vehicle navigation are considerably reduced.

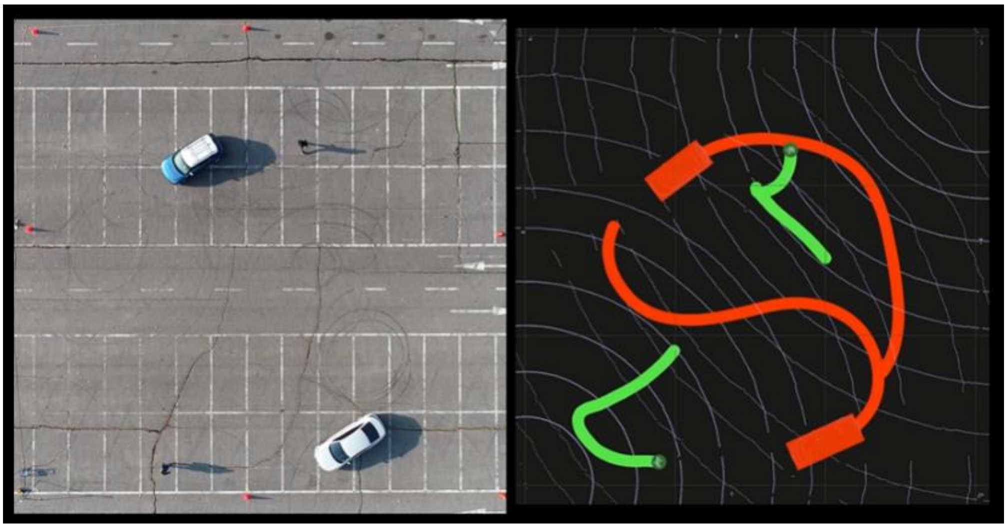


Image 5 : Vehicle management by LV5 TWR CTRL. Source: Seoul Robotics

LV5 CTRL TWR uses SENSR software, also developed by Seoul Robotics, which allows traffic visualization and is able to differentiate between cars, bicycles and pedestrians. [Seoul Robotics December 30th, 2022]

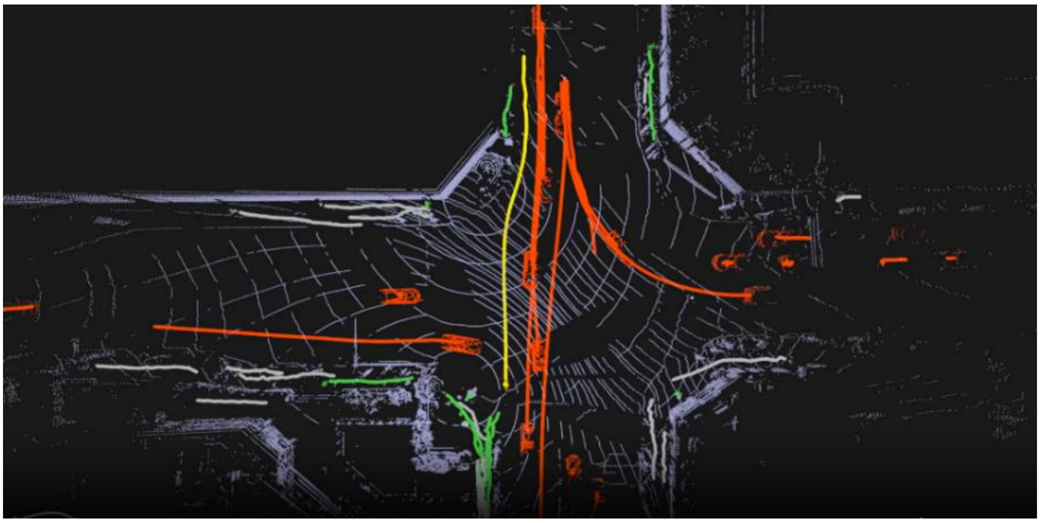


Image 6 : Traffic visualisation by SENSR. Source: Seoul Robotics

Germany – AMR & AGV Fleet Management – Kinexon

Similar to Seoul Robotics, Kinexon offers vehicle fleet management technology. Their product however specializes in vehicles of type AGVs (Automated Guided Vehicle) for industrial purpose.

With the help of a control tower, their system is able to manage fleets of autonomous vehicles in places of type depots in order to transport various materials in premises. One of the technologies used is the Ultra-Wideband to generate a location of vehicles in real time with an accuracy of 10cm and a latency of up to 100ms. [Kinexon]

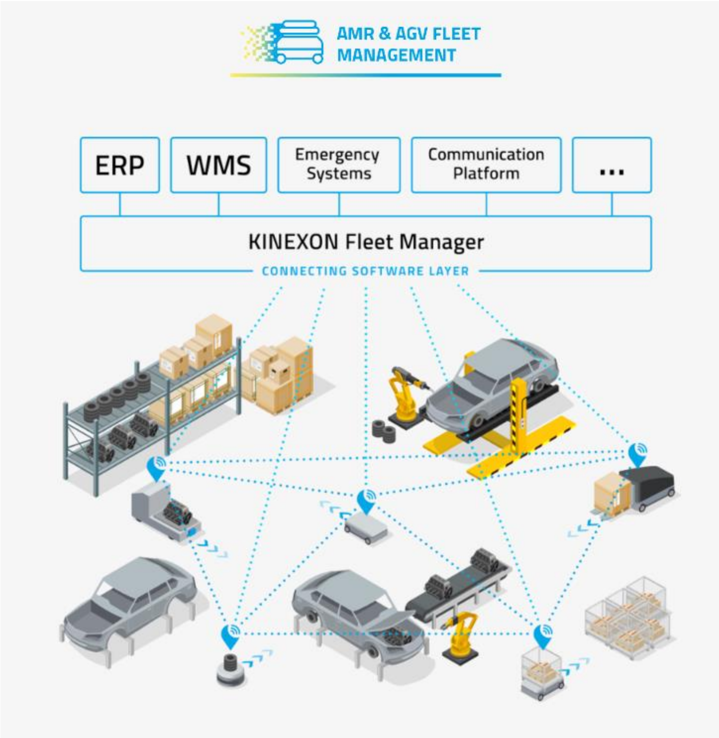


Image 7 : Fleet management system of Kinexon.
https://kinexon.com/products/kinexon-fleet-manager/, accessed July 3rd, 2023.

Germany – BMW Startup garage – BMW, Seoul Robotics, Embotech & others

In 2021, the BMV Group launched a new concept involving various startups in order to promote and facilitate the creation of innovative automotive projects. The project involved two startups mentioned above; Seoul Robotics, specialized in perception by LiDAR, and Embotech, a software expert for planning movements. The developed technology allows autonomous driving of cars in their production premises.

This project, called «Automated Driving in the Plant», is innovative and differs considerably from the other techniques used so far. This project is based on communication through infrastructure. Instead of equipping each vehicle with additional sensors, the sensors are installed on the infrastructure directly and allow cars to drive through the depot without cameras, radars or cameras installed on the cars. This allows the control of any type of vehicle, which is a considerable economic advantage. [BMW Group, July 1th, 2022]

Image 8 : “Automated Driving in the Plant” project. Source: BMW Startup Chronicles

Switzerland – SwissMoves and partners – Vehicle teleoperation – 2021

In 2021, the SwissMoves group, in the meantime transformed into an association, created the first Swiss prototype of a remotely operated vehicle [ROSAS, July 15th, 2021]. This prototype demonstrated the possibility of maintaining the operation of an automated vehicle when it encounters a situation in which it is unable to react. In this case, the vehicle is taken over by a remote operator who allows the vehicle to pass the problematic situation and then be put back into automated mode.

This solution makes it possible to envisage the possibility of no longer having one supervisory operator per vehicle but only one operator for a fleet of vehicles and thus to guarantee the implementation of global automated vehicle systems.

Switzerland – Master thesis – O. Schwyter – OST (Ostschweizer Fachhochschule) – VBSG – 2021

This diploma project [Schwyter 2021] tackles the possibilities of automation of the various processes carried out on an automated bus depot, with the future St-Gall public transport bus depot (VBSG) as a case study.

The most interesting points for our case are developed through different chapters:

- Bus depot requirements (Chapter 4)

    This chapter describes the structure of the bus depots as well as the steps of the process through which the bus passes. Several lists of criteria and requirements result from this analysis; concerning buses, infrastructure and communication (V2I, V2V and I2I).

- Automated Vehicle Requirements (Chapter 5)

    We can find in this chapter different states of art. The first concerns automated vehicles and the second concerns the technologies available to carry out the various stages of the process through which buses pass when they are at the depot.

- Feasibility study of automation of a depot (Chapter 6)

    With the help of the requirements and criteria determined in the previous chapters, different scenarios with proposed solutions are established. In addition, a cost-benefit analysis is conducted.

- Concrete Implementation proposals for the automation of the future VBSG bus depot (Chapter 7)

    This chapter focuses on proposals for concrete solutions for the future bus depot located in St Gallen, considering the developments of the previous chapters.

While the study concludes that the complete automation of a bus depot is currently not financially viable, the fact remains that automation of some systems appears to be efficient. Following discussions with the author of the study, this reinforced the need to investigate the possibility of developing a proof-of-concept automated bus depot, with vehicle traffic on site as the main axis.

Germany – Fully autonomous bus line – ADASTec Corp., Karsan

By the end of 2023, the first fully autonomous bus line will be in operation in Germany in the Hannover region. It will be able to travel on predefined roads up to a speed of 40km/h but will still have to be supervised by a safety operator during the journeys.

This line will be operated with a bus manufactured by ADASTec, an American company specialized in the development of autonomous driving technologies for public transport, in collaboration with Karsan, a Turkish bus manufacturer. Together they have developed e-Aatak, an electric and autonomous bus with a level 4 of automation.

The software developed by ADASTec combines several technologies such as artificial intelligence and different sensors such as LiDARs and radars, RGB and thermal cameras, high-precision GNSS localization and ultrasonic sensors.

ADASTec and Karsan have already produced a dozen buses, many of which are already in service, notably in Stavanger in Norway and at the State University of Michigan in the United States. [ADASTEC Corp., August 7th, 2021]

Research needs

The state of the art demonstrates that the automation of vehicle fleets, particularly buses, is gaining momentum worldwide. However, when it comes specifically to buses, the literature gives the impression that the main focus is on the complete automation of bus circulation activities, rather than solely on a specific location property of a public transport company. Numerous studies emphasize the development of fully autonomous buses, with little interest in for partial automation or the integration of infrastructure-based control systems.

On the other hand, it is interesting to note that in the field of automotive research, there is a growing interest in controlling vehicles using sensors primarily placed within the infrastructure, especially for specific traffic activities. This aligns with the fundamental concept adopted in our study, where the idea of leveraging the infrastructure for vehicle control was taken into consideration.

Additionally, it is observed that several stages, other than bus circulation within a depot, could also be automated in the future. Indeed, technologies are currently under development in this direction. It will be important, therefore, that although autonomous fleet management through infrastructure is considered as our approach, the ongoing developments in fully vehicle automation are continuously monitored. Indeed, the AutoDepot system must be compatible with the developments made towards achieving fully autonomous vehicles.

The present study and the resulting prototype would likely complement international developments in a context suitable for Switzerland. However, it is essential to bear in mind that the economic aspect, particularly in the domain of public transportation, which heavily relies on government funding, will have a significant impact not only on the development of prototypes but also on their dissemination and implementation on a nationwide scale.

6 WP2 Prerequisites definition and feasibility

6.1 Technical part

The purpose of this study is to study, as already explained, the automation of buses when they arrive at the depot. This involves automating their movements through the various stations (tire control, external washing, internal washing, etc.). This is not about automating the different maintenance tasks. Automation will be possible thanks to various systems to be installed within the depot infrastructure and also some elements on the buses themselves. For such automation, a management system within a control center as well as a supervision and teleoperation system are required, also allowing to take decisions and to take in hand a remote bus if necessary.

Bus arrival at the depot and driver disembarkation

Upon arrival at the depot, the driver will exit the bus in a specific area designated for vehicles waiting to enter the depot site (this area will already be physically inside the depot). Whenever possible, this waiting area for vehicles should not obstruct the surrounding traffic flow at the bus depot site.

Once the driver has exited the bus, they will acknowledge their disembarkation and activate the autonomous mode of the bus, for example, using a key. This autonomous mode should only be enabled in an authorized area or drop off areas (refer to bus recognition by the central system).

The driver's disembarkation can take place during the first maintenance step performed on the bus, such as tire checks (tire scan).

Image 9 : Tire scanning process at Givisiez, modeled

External emergency button

Currently, it is advisable for any automated vehicle system to have an external emergency button accessible to anyone. This push-button allows for stopping an automated vehicle from outside the vehicle if necessary. In non-autonomous mode, the function of this button should be disabled to avoid any sudden vehicle stops.

In the event that the position of the emergency stop button on the vehicle is a problem for vehicle approval, it may be considered to have emergency stop buttons on the infrastructures that allow stopping the progression of vehicles.

Recognition of the bus by the central system

Once the bus is switched to autonomous mode, the central system of the public transport operator or the community of public transport operators should be able to recognize the bus’s autonomous status. This involves locating the vehicle through its geopositioning (GPS or other localization system) and validating its position using infrastructure sensors.

If the vehicle is indeed in an area where it is authorized to enter autonomous mode, the activation of autonomous mode will be permitted. The bus is then controlled by the “AutoDepot” central system.

Bus circulation within the depot – Speed

The bus circulation within the depot is planned at a speed of 3 km/h. This speed helps to reduce numerous risks. For instance, if a vehicle collides with a wall or pillar, the damage to the vehicle is minimal, and the infrastructure sustains only minor harm. In the case of an accident involving a human or an animal, the damages at this speed are generally low. Speed is a dual factor that increases both the stopping distance and the impact force (kinetic energy dissipation into mechanical energy). Hence, a low speed is recommended.

According to our philosophy, an automated system must, at a minimum, match the capabilities of a typical human user, as defined, for example, by the standards of the Swiss Association of Road and Transport Professionals (VSS). This means that a potentially higher accident rate with an automated system than with a human driver is not acceptable. From a computational perspective, such a speed also simplifies the algorithmic development since the maneuvers required at 3 km/h demand less computational capacity. Similarly, any possible latency in the vehicle control system by the infrastructure is likely not problematic due to this low speed.

This 3 km/h speed is also reasonable as it is already the speed to be adopted on certain sections of the depots. Since travel time is not a criterion to achieve, considering the bus returns to the depot without direct human control or passenger transportation, this 3 km/h speed is appropriate. Thus, this speed has been chosen to maintain a system as straightforward as possible while ensuring a high level of safety.

It would be conceivable and wise to achieve higher circulation speeds, especially in the case of rescuing vehicles in the event of a depot fire, due to the closure of partition doors. However, the different systems (algorithmic quality and latency) must ensure safe circulation. Causing an accident that blocks access due to speed and thereby preventing the retrieval of other vehicles being rescued would be counterproductive.

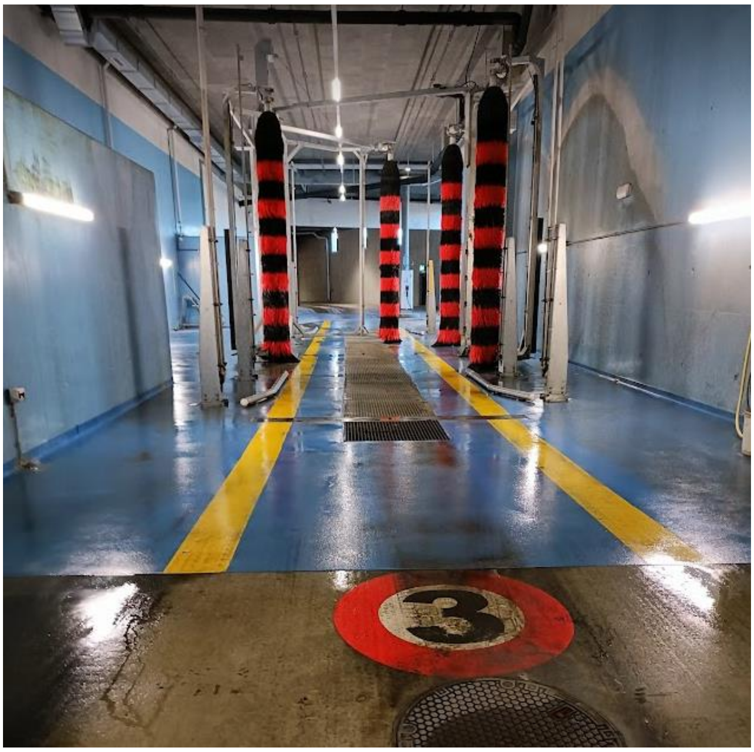


Image 10 : Example: Speed limit during washing operations

For the system's capacity, this reduced traffic speed of 3 km/h within a depot is not a problem. Indeed, the bus entering the depot and undergoing maintenance operations generally parks and does not immediately exit to be assigned to a public transportation activity.

The traffic theory is as follows: $K = Q/(N*V)$, where K is density, Q is flow, N is the number of traffic lanes, and V is speed. Assuming a single traffic lane at the entrance of the depot (N = 1 lane), a speed V of 3 km/h, and a maximum hourly flow of 60 vehicles (see chapter 5.1), the resulting density is 20 vehicles per kilometer.

The maximum density for transportation systems is typically around 20 vehicles per kilometer, taking into account human behavior.

An average human has a reaction time of 2 seconds, meaning that at 3 km/h, the minimum distance between two vehicles to ensure their safety moving at the same speed should be 2 meters. However, an automated system equipped with vehicle-to-vehicle (V2V) or infrastructure-to-vehicle (I2V/V2I) communication could significantly reduce the reaction time.

Let's take an even greater safety margin than that for a human, say 10 meters between each vehicle, allowing for the insertion or passage of other vehicle flows or users (pedestrians), and a relatively large vehicle size of 25 meters. This means that over 1 kilometer, we could have approximately 28 vehicles. Therefore, there is no problem; we are above the determined density value, and we could even decrease the speed to 2 km/h if needed.

The speed is relevant only in the circulation spaces. What will be decisive are the “system reaction times” and the “blocking” times for tasks. But the speed itself should not pose any issues. For example, when a bus arrives at a depot, if tasks such as tire scanning, refueling, or fluid level checks require the vehicle to wait for a few minutes, it becomes the critical determining factor during which it would be interesting for the driver to exit the vehicle and switch it to automated mode. The rest of the circulation can then be carried out in an automated manner.

However, if a vehicle does not require routine maintenance (for example, a trolleybus going directly to its parking spot), it may not be necessary for the automated system to be engaged, as the time lost in circulation within the bus depot is significantly reduced. The driver can then remain on board the vehicle until its stop.

In this case, the system may need to manage the arrival and circulation of "fast-entry" driver-operated vehicles alongside vehicles operated by the automated system, which move at slower speeds.

Bus circulation within the depot – Ways

Firstly, the route that the bus must take needs to be defined in advance, a process that is generally actually followed when a bus arrives at a depot (Bus Management System). The driver receives information regarding the specific wash ways to use, the parking area for the vehicle, or any other procedures to follow upon depot arrival. Instead of transmitting this information to the bus driver, these instructions are integrated into the central control system “AutoDepot”, so there is a possible interfacing with current systems.

The route information for the vehicle consists of a series of waypoints based on the designated route. At a defined site, the various series of waypoints can be established during the site’s conception, taking into account the vehicle turning characteristics and the type of vehicles to be maneuvered. In the case of temporary or permanent modifications to the site, the series of waypoints can be easily updated.

The determination of these waypoints can be facilitated using turning software (e.g., AutoTurn), which considers the vehicle type, the positioning of the location sensor integrated into the vehicle, and the travel speed to generate the optimal path for the vehicle’s movements.

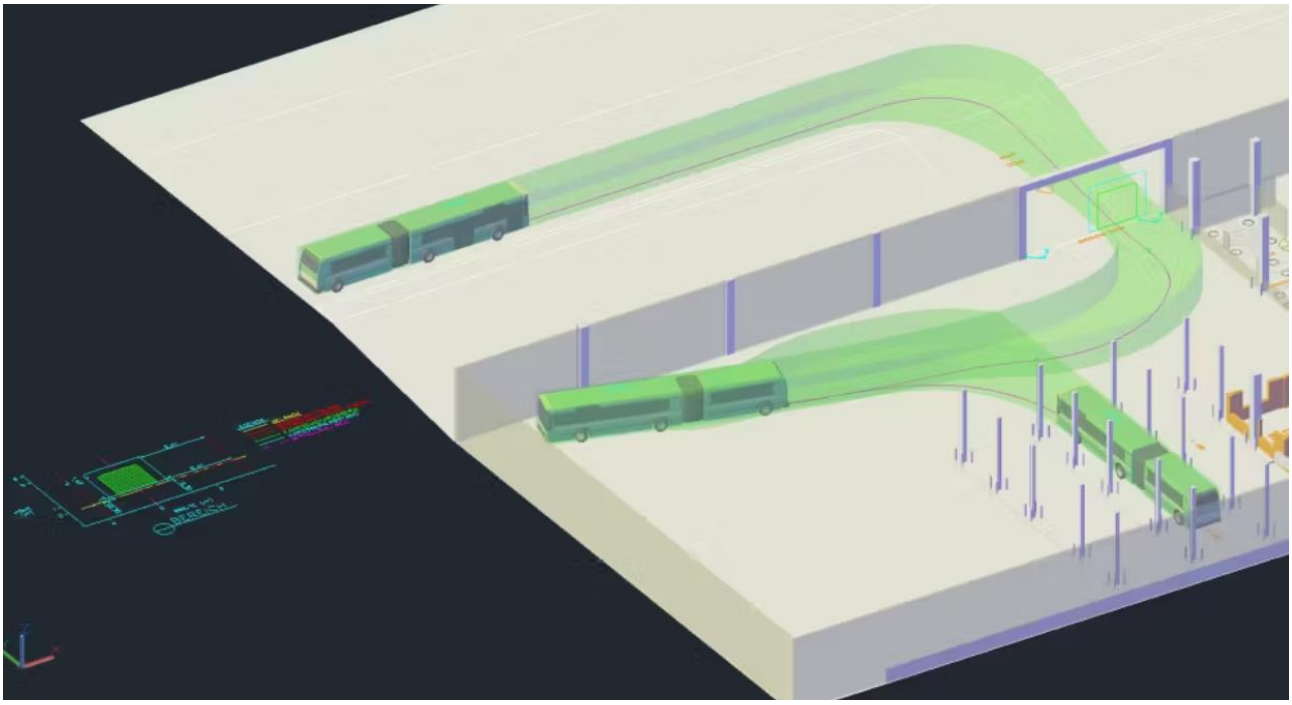


Image 11 : An example of verifying vehicle turning, including in three-dimensional mode. Source: Capterra.fr with AutoTurn Pro

The interval of the series of waypoints will be determined based on the characteristics of the onboard geolocation systems of the buses or the infrastructure-based bus position detection systems. A 10cm interval should be sufficient in most cases.

It will also be necessary to define the characteristics of the routes on which the buses can circulate autonomously (e.g., priorities, probable weather conditions, types of sensors present in the infrastructure, etc.). This will involve completing the criteria matrices of the ODDs (Operation Design Domain) as defined.

Bus circulation within the depot – Route shifting to avoid ruts

A potential issue may arise at this stage. Continuously driving buses along the same path could lead to the development of ruts and ridges on the bituminous pavements of the circulation roadways over time. Even though the loads are lower on the depot roads due to empty buses, such phenomena could still occur.

To mitigate this effect, it is proposed, wherever feasible, to establish three distinct axes of routes, spaced approximately 10cm apart. Each vehicle circulating on the route will be shifted by 10cm compared to the path of the preceding vehicle. The formation of ruts depends not only on the vehicle geometry but also on tire pairing. Therefore, this proposed route shifting should be validated through on-site observations.

These offsets will only be possible when a precision margin can be allowed for the vehicle's position. During certain operations, as mentioned in the following, higher precision is required.

Bus circulation within the depot – Precise positioning

Certain activities may require a higher level of positioning precision. Depending on the characteristics of the onboard location sensors and those of the infrastructure, it will be necessary to determine cases where their precision is sufficient and situations where more precise sensors or a combination of sensors are needed to achieve the required accuracy.

At this stage, it is also possible to consider activating the bus’s camera to perform sensor data fusion and obtain a refined position using techniques like vSLAM (visual simultaneous localization and mapping).

The following are examples of situations where more precise positioning is necessary (non-exhaustive list):

- Positioning on pressure and tire profile sensors
- Positioning between the guiding rails of washing stations
- Positioning for executing turns (turn initiation)
- Positioning for refueling, oiling, electric charging
- Positioning on workshop pits

Bus circulation within the depot – Circulation pauses for tasks

All maintenance tasks are allowed by assumptions to be non-automated and carried out by a human. Whenever a task needs to be performed, the individual executing it must inform the system that they are taking control of the bus and indicate when they have completed the task by returning it to autonomous mode. This ensures that the task is performed safely in relation to a moving/non-moving bus. This can be achieved through a device such as a screen or interface.

It is also worthwhile to record the various tasks performed by a comprehensive management system in terms of predictive maintenance. Indeed, if the system can capture certain task-related information (e.g. the number of liters and frequency of oil refills), it would enable the system to conduct overall predictive maintenance for the bus fleet.

Bus circulation within the depot – Coordinated circulation with a task

For certain tasks, such as exterior bus washing, it may require coordination between the circulation system and the active machines during the task. Currently, in some depots and depending on the vehicle configuration, drivers need to perform forward and reverse maneuvers to facilitate the exterior bus washing. The central management system “AutoDepot” would enable communication with the machine to coordinate the necessary maneuvers on the vehicle during the task.

Bus circulation within the depot – Vehicle stop

After completing these various stages, the bus needs to be parked in the designated parking area. Currently, there are existing lines on the ground that drivers must follow for parking. The idea is to utilize these pre-existing lines to define the path for parking. As mentioned earlier, when the bus needs to turn (execute a turn), higher precision may be required.

Regarding the bus parking process, similar to the current setup, the information is typically integrated into a central parking system (or Bus Management System). To ensure that the bus is in the correct position, a parking sensor could be installed, and as soon as it is triggered (interrupted by the bus), the vehicle will come to a stop, indicating it is in the right position. If we wish to retain the option for agile (modifiable) parking, it would be possible to rely on information from lidars, vehicle cameras, and their positioning to declare that the vehicle is properly parked.

As parking spaces are usually arranged in a line, one behind the other, the central management system should be able to activate the correct parking sensor. However, this situation appears relatively straightforward, as if the preceding sensor is free, the parking sensor for that position does not need to be activated, since the first arriving bus will park in the space at the beginning of the line.

Once the bus is correctly parked, the central management system can remotely shut down the bus vehicle.

Image 12 : Example of parking lines, BERNMOBIL

Bus circulation within the depot – Vehicle exit

Regarding the bus's departure from the depot, the central management system remotely restarts the bus vehicle and directs it, as explained in the previous steps, to an exit location area. Once the vehicle is authorized by the system for the autonomous to be switched off, the driver can deactivate the automated system and start the manual driving mode.

Image 13 : Example of a driver pickup zone, modeled

Bus circulation within the depot – Event or obstacle blocking the bus

If a bus encounters an issue that it cannot handle, the central management system will be notified, and a warning may be issued to the operations center. At this point, an operator at the center will be able to make a decision based on the system's recommendations (supervision), can either take control of the vehicle (teleoperation) or disable the alarm through visual inspection of various sensors, both on the infrastructure and on the vehicle itself. It is important to note that if an obstacle is detected on the bus's path or in its immediate environment and is detected by sensors, unlike fully automated vehicle systems, the vehicle is not designed to automatically circumvent the obstacle. The project's concept does not aim to achieve that level of automation, as the required algorithmic developments would not align with the project's objectives and would have a direct impact on the economic aspect.

During obstacle detection, if the detection occurs within a short period, the system will not send an alert message to the operating center and will continue its path in automated mode when the obstacle is removed. An alert message will be sent when the obstacle is detected for a relatively longer period of time (~30 seconds, depending on the depot configuration and vehicle frequency). Through obstacle detection, the system can also self-learn. The system has the capability to learn from its experiences to better handle obstacles in the future and generate more appropriate responses.

Examples of situations that may lead to a vehicle blockage include (non-exhaustive list):

- Loss of bus localization or a sensor
- Loss of a sensor in the infrastructure
- Object or person blocking the bus's path
- Mechanical issues with the bus (e.g. battery loss)

While some situations can be managed by the operations center, others may require on-site personnel interventions.

Security and safety of the central management system

While this may seem obvious, it is essential for the central management system to be sufficiently robust and secure. Vigilance is necessary to guard against any attempts to breach established security protocols or launch attacks on the system.

Devices on vehicles

The number of onboard devices (includes sensors) inside the bus will be kept to a minimum, only including the essential ones for proper automation. The goal is to equip the vehicles with the least number of systems necessary to minimize costs. It is more expensive to have many systems on the vehicles than to have more systems on the depot infrastructure due to economies of scale. The strategy is to equip the vehicles with as few systems as possible and install additional systems in the buildings and infrastructure to reduce costs. Having most sensors on the infrastructure can also help reduce latency and bandwidth issues.

The buses will be equipped with five devices: an onboard computer, one camera (at the front), a communication system with the central management system, and a GPS system. The camera at the front of the bus will primarily be used for teleoperation when remote driving is required within the depot. It can also be activated if improved positioning is needed. It will be regular color camera; there is no need for thermal camera (cost reduction) because most depots or circulation areas are equipped with nighttime lighting or if not, the lights of the vehicles should be sufficient.

As for the GPS system, it is already present in most current vehicles. The GPS system relies on signals from three satellites, and by knowing the positions of these satellites, the GPS receiver in the bus can calculate its position on Earth using mathematical formulas. To enhance accuracy, a fourth satellite synchronizes the bus's clock with the satellite clocks.

While GPS precision might be sufficient in open areas, it may be more challenging between or inside buildings. In such cases, depending on the complexity of the site, it will be necessary to work with sensors installed in the infrastructure or utilize the vehicle's camera (vSLAM).

The onboard computer receives various vehicle-related information (telemetry), processes data from the onboard devices, and manages communications with the central system. The communication system between the central management system and the vehicles will be designed and implemented based on the site's requirements. Testing the communication reception will be essential to ensure information transmission functions correctly. Additional antennas may need to be strategically positioned within the depot if needed.

As mentioned earlier, the vehicles can also be equipped with an emergency stop button that can be activated by a human and a system to indicate whether the bus is in manual or autonomous mode.

Drive-by-wire vehicles

Finally, from the perspective of onboard vehicle technology, it will be necessary for buses to be “drive-by-wire” and for the system to be accessible (via CAN messages). The current bus system is predominantly mechanical, and order to integrate an automation infrastructure, the bus must have an electrical or electro-mechanical system called "drive-by-wire." Without this, it is not possible to automate the circulation of buses within a depot. Therefore, it is imperative that this system be in place for the fleet of vehicles in question. This is a current blocking factor as bus manufacturers do not seem to consider this alternative, at least not in its entirety.

Generally, on automobiles, the drive-by-wire system includes the brake-by-wire system, which is an electronic braking system, the shift-by-wire system that enables electronic gear shifts, the steer-by-wire system, which is the vehicle's electro-mechanical steering, the throttle-by-wire system, which allows acceleration of the vehicle, and the park-by-wire system, which enables activation or deactivation of the vehicle's parking. It is also possible that some buses are already equipped with one of these subsystems today, especially for acceleration and gear shifts, partially for braking with electronic brake controls (usually redundant with a mechanical system). In this field, the upcoming application (2024) of the General Safety Regulation (GRS2) is expected to require some modifications, presumably particularly on the steering system since lane-keeping will need to be monitored.

Therefore, currently, the state of these technologies on buses vehicles can be summarized as follows:

Technologies	Drive-by-wire	Throttle-by-wire	Shift-by-wire	Steer-by-wire	Brake-by-wire	Park-by-wire
Actual state	☐	☑	☑	☐	(☑)	☑

(☑) = partially

However, we are relatively confident that this technology should become available on bus fleets in the coming years. If we consider the complete automation of buses, as seen in the state of the art (chapter 5.2), the drive-by-wire system is then necessary. Indeed, without it, it is not feasible to have an automated vehicle. This "race for automation" will, at some point, push certain actors to develop systems to avoid disappearing in the face of this new competition. It should also be noted here that the level aimed for the automation of bus depots, as the targeted algorithmic level is much lower than that required for complete vehicle automation, will inevitably result in the arrival of drive-by-wire buses compatible with the "AutoDepot" system on the market more quickly than buses of a high autonomy level.

To date, it is worth noting that vehicle automation is not limited to individual cars. Indeed, there are also automated trucks and tractors. If such vehicles can benefit from such technologies, we believe that buses will also follow suit in the coming years.

However, while the technical feasibility of a system of autonomy level compatible with the system seems more rapidly attainable, it will be necessary for one or more bus manufacturers to consider it. In this sense, a prototype of an automated bus depot or at least a test route with infrastructure-based circulation seems to be the best solution to demonstrate this feasibility and the interest in such systems.

Following a request from a bus manufacturer expressing interest in the project, the list of requirements on the following pages has been established.

Drive-by-wire technology for rolling stock (buses)

This list does not serve as a rolling stock order, nor does it constitute a request for a proposal or a rolling stock specification. Its purpose is to describe the specific onboard equipment required within the rolling stock for a prototypical concept of bus depots automation, titled "AutoDepot."

Brief description of the AutoDepot concept

This project does not aim to make vehicles completely autonomous. Indeed, full vehicle automation requires significant technological expenses, multiplied by the number of vehicles in the public transportation operator's fleet. The goal is to minimize sensors within the bus while maximizing the number of sensors installed at the infrastructure level. The bus must be controlled automatically by the infrastructure, rather than operating autonomously through its own system.

Geolocation System

The geolocation system embedded in the vehicle must be sufficiently accurate to validate that the bus is within the depot perimeter and, if possible, also provide the bus's position during its movements within the depot. The precise geolocation will be confirmed by various sensors, including LiDAR's, placed within the infrastructure. The quality of the confirmed geopositioning by infrastructure sensors depends on the accuracy of the onboard geolocation system. Details regarding the precision of the geolocation system must be provided by the manufacturer.

Camera

A wide-angle (~120°) RGB camera will be installed at the front of the vehicle. This will primarily be necessary in situations that cannot be handled by the automation system.

Technical specifications: Latency less than 80 milliseconds; Connectivity: power pins (PWR), Ethernet port; Connected to the onboard computer of the vehicle.

Onboard Computer

The vehicle's onboard computer (such as NVIDIA Jetson Xavier or equivalent) will collect information from sensors inside the bus (geolocation system, camera) and transmit it to the operations center. Connectivity with the operations center's computer is established through a wireless network specific to the public transportation operator. Depending on the defined prototypical case, wireless connectivity may use Wi-Fi technology or a secure telephony network (4G/5G) via interfaces such as WebRTC. The onboard computer must also be capable of receiving information transmitted by the operations center through wireless connectivity or the telephony network.

Vehicle Modes Activator

It is requested to implement an activator for multiple vehicle modes. Activation of different modes can be done by a key, preferably located on a flap on the exterior of the vehicle. The two requested modes are as follows:

- Manual driving mode (for driving with a driver outside the depot). This function must involve the complete deactivation of the autonomous mode
- Autonomous driving mode (for driving within a depot). Activates the request for automated circulation to the operations center and enables autonomous driving via the onboard computer. Also activates the integrated camera

The possibility of a third activation mode should be considered (characteristics to be defined during the AutoDepot prototype).

Drive-by-wire

The vehicle must be fully drive-by-wire (DbW technology). This includes, in particular:

- Throttle-by-wire
- Shift-by-wire
- Steer-by-wire
- Brake-by-wire
- Park-by-wire
- Commands-by-wire

- Start/Stop-by-wire
- CAN messages

Throttle-by-wire

The vehicle's acceleration is defined and controlled by electronic throttle control (ETC) technology. The specific technology chosen is at the discretion of the manufacturer. The operating speeds within depots are low (targeted at 3 km/h during normal operation, up to 20-30 km/h in emergency situations).

Shift-by-wire

Gear shifting is defined and controlled by electronic technology (automated gearbox). The specific technology chosen is at the discretion of the manufacturer.

Steer-by-wire

The vehicle's steering is defined and controlled by electronic technology. The specific technology chosen is at the discretion of the manufacturer.

Brake-by-wire

The braking of the vehicle is defined and controlled by electronic command. The specific technology chosen is at the discretion of the manufacturer. The braking system is left to the choice of the manufacturer.

Park-by-wire

The activation of the parking brake is defined and controlled by electronic command. The specific technology chosen is at the discretion of the manufacturer.

Commands-by-wire

All current controls available on buses (wipers, turn signals, headlights, etc.) must be defined and controlled by electronic commands.

Start/Stop-by-wire

For the parking duration, the vehicle should be able to be set in standby mode, requiring only electrical consumption at the lowest possible level. The starting actuator, defined and controlled by electronic command, should allow the vehicle to be started remotely (driving mode, engine on) or put the vehicle in standby mode.

Any potential consequences on premature vehicle wear due to the use of the standby mode need to be defined and communicated to the public transportation operator.

CAN messages

The CAN messages from all technologies constituting the drive-by-wire, to be transmitted by the operations center, and conversely, the messages to be transmitted from the vehicle to the operations center (telemetry data), must be communicated and documented for the development of the AutoDepot automation.

Sensors on the infrastructures

The building infrastructure will consist of either a light system or a heavy system, depending on the needs and precision requested.

The lightweight infrastructure includes cameras, colors and thermal, as well as lidars to identify moving points. The two systems will complement each other. This means that if one system detects an anomaly or an obstacle, the other system can confirm or deny the detection. All this is managed by the control center.

Before continuing, it is important to explain how a lidar works. First, the technology was developed for the aerospace. More specifically for the Apollo 15 mission. The aim was to know where the lunar module can land safely. To have that, the need was to have a system that can scan the environment and create a numeric 3D map to have a real representation of the surface for the landing. That's why the lidar was created. It works as a camera which maps live and in 3D. It is a laser that scans the environment to recreate it digitally with great precision. For an automated drive, this allows guidance. The lidar is the eye of an automated vehicle. (Le Parisien 2019; String Theory FR 2018).

It is also important to understand the operation of a thermal camera. It works with infrared. With that, it cans detect the heat. What is interesting with such a camera is to detect the difference of temperature in a specific environment. When we observe the image from this type of camera, we see different colors which recreate the environment. It means that you can see the image of a color camera but only with a spectrum from yellow (light) to blue (dark). The darker, the colder. And conversely, the clearer, the hotter. (EasyWatt 2019).

The heavy infrastructure includes cameras, colors and thermal, lidars but also in larger numbers. The heavy infrastructure allows to have a better precision when it is necessary (maneuver requiring a great precision). In this case, the lidars are oriented to obtain the best possible precision on what one seeks to have. For example, the tolerance may be low during certain maneuvers, which requires high precision to be in the desired area. Finally, lasers may help to know when the vehicle is in the desired position for various tasks (for example: final parking position) but this can also be done using cameras or lidars in some cases.

For specific maintenance tasks, typically vehicle washing, it will be necessary to be aware that moisture may disrupt certain sensors. Therefore, a careful study will be conducted, depending on the site to be developed, to determine the most suitable type of sensor for the specific situation.

Operations center, supervision and teleoperation

The operating center of a depot already allows real-time monitoring of the situation of public transport traffic, particularly at the depot site and interact with the vehicle drivers (especially by communicating the different parking or washing lanes they should use). With an automated system, the operating center will have to be equipped with a teleoperation station to be able to act in case of problems. This is equivalent to having a seat with a steering wheel and several screens to simulate driving as if you were inside the vehicle.

Image 14 : Example of a potential teleoperation center. Source: ROSAS (SwissMoves)

Teleoperation is therefore seen as a backup system when, for example, a bus stops moving, there is a problem during the journey, etc. The goal with teleoperation is to be able to take control of the bus to solve the problem remotely before putting it back in automated mode afterwards. One camera, located at the front of the vehicle, as well as the support from sensors located in the infrastructure, allow this remote driving. If the vehicle in question is equipped with digital mirrors (cameras), it is also possible to have the vision of the mirrors from the remote operation station. The goal is to have all the information, at least at minimum, that a driver can have access to.

At the operating center, people authorized to drive remotely must have the permit of the vehicle they are driving via the teleoperation center. Even if not legally required on private sites, we recommend having a driver's license for familiarity with operating these vehicles. This is generally the case because the people at the operating centers are former drivers, so they already have the proper driving license. In case of issues which cannot be solved remotely, a mechanic will, therefore, have to take control of the vehicle himself physically. Because the mechanics have the proper driving license, this is not a problem.

Calculation of the number of teleoperation stations required

The method for calculating the number of teleoperation stations required was developed by Prof. M.-A. Fénart as part of the "NPR Teleoperation" project (SwissMoves). It is also necessary to take into consideration, in these calculations, by analogy of activities, the ordinance on the duration of work and rest periods for professional drivers of light vehicles used for the transport of passengers and heavy tourist cars (OTR 2, RS 822.222), as well as any internal regulations of the company regarding this matter.

It will also be necessary to consider other tasks assigned to the person who is required to teleoperate.

Information to be entered

- At what percentage does the vehicle fall into the necessary teleoperation mode? N_{teleop} [% of travel time]
- Number of vehicles in the fleet? n_{float} [vehicles]
- Vehicle travel time? $t_{circulation}$[hours/vehicle/day]
- How long can a teleoperator operate consecutively? t_{teleop} [hours/cycle]
- How much break time does a teleoperator need? $t_{timeout}$ [hours/cycle]
- How much latency is there during a teleoperator change? t_{change} [hours/cycle]
- How many hours can a teleoperator work per day? t_{work} [hours/day teleoperator]

Risk factors

- What is the acceptable delay before taking control of the vehicle? f_{charge}
- Other risk factor f_1
- Other risk factor f_2
- …

Information obtained

Number of hours for teleoperation:

$t_{teleop} = N_{teleop} \cdot n_{float} \cdot t_{circulation}$ [hours/day]

Number of active teleoperation cycles per operator:

$n_{cycle\_op} = ROUND.INF\left(\frac{t_{work}}{t_{teleop} - t_{timeout} - t_{change}}; 0\right)$ [number of cycles/day per teleoperator]

Number of active teleoperation hours per operator:

$t_{cycle\_op} = n_{cycle\_op} \cdot t_{teleop}$ [hours/day per teleoperator]

Number of teleoperators:

$$n_{op} = \max\left(2\,;\ ROUND.SUP\left(\frac{t_{teleop}}{t_{cycle\_op}} \cdot \prod f_i\,;0\right)\right)$$

Evacuation of vehicles in case of fire

In case of problems on the site such as a fire, the automated system can reduce the damage. The buses can be ordered to move to a specific point or/and remotely controlled via the teleoperation center, which can save them, for example in case of fire. A safe storage area will need to be predefined in advance and the minimum mode, increasing the risk of a slight collision between buses, can be activated to evacuate as many buses as possible (Example: Higher speed, lower precision, ...).

In the event of a fire at the operations center site, it is evident that personnel from the operations center will also be evacuated. However, it might be potentially considered, with convertible systems among different public transport operators, to remotely take control of vehicles from one site's operations center to another in case of emergencies.

It should be noted that some depots have fire compartments that close automatically to contain the fire. In such cases, it will be necessary to assess whether implementing an automation system for bus movements and evacuation is advisable or not.

Benefits of a small depot for an operator with a central management system

When a public transport operator or a community of operators has a site where automated bus circulation is implemented with the support of a central management system, and some vehicles "sleep" one night at one site and another night at another site, the second site may not necessarily need to meet the same thresholds, especially from an economic standpoint (in terms of the number of vehicles).

Indeed, the second site can benefit from the software developments carried out at the central site, can be supervised by the central site, and also benefits from the sensors present on the vehicles. However, specific routes (Operation Design Domain) for the second site need to be developed and equipped with sensors.

Level of automation

Based on the technological aspects considered, it is allowed that the bus depot automation system as envisaged in this pre-study will be at level 4+ automation. This means that under specific conditions of use (Operation Design Domain - ODD), the vehicle no longer requires a driver. However, in the event of a problematic situation, the vehicle can request assistance from an operations center.

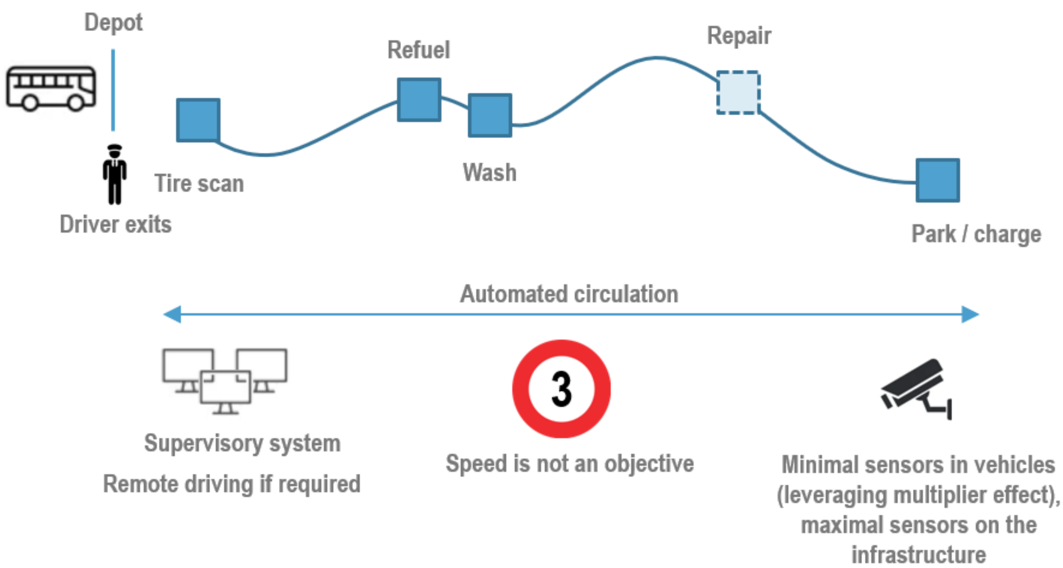


Image 15 : Diagram of the "AutoDepot" Technical Concept

6.2 Economic viability

Regarding the financial analysis conducted at the beginning of the feasibility study to address the queries from the experts at the FOT, it is necessary to provide some comments on the appendices found at the end of the document.

The purpose of the pre-study is to carry out a detailed financial analysis of the feasibility and efficiency of implementing an automated bus depot.

The analysis was conducted in two phases. The first to 12 years (Annex 1), that is over a period of service of a new rolling stock (bus), considering the equipment related to the site and the remote operation without maintenance and renewal and therefore considered more expensive to the single purchase. The second 24 years (Annex 2), over a period of service of a rolling stock (bus), considering a renewal of the equipment of the site, teleoperation and continuity of the development of the automation necessary for the long-term operation.

As a basic element, we took into account not 50 automated vehicles but 100 vehicles in order to approach the actual number of «sleeping» vehicles on the G7 site of TPF (Transport public Fribourgeois) in Givisiez. The 15,000 hours mentioned of potential savings of drivers are also considered on the real traffic of the G7, about 100 vehicles.

One of the important points of the financial analysis is that we have taken into account the international innovative phenomenon of such an automated depot. This implies, because this is a prototypical project, that the engineering costs will be relatively high (variant “Trend”, 2.5 million). However, it seems to us necessary to mention that, with the experience gained on the prototypic project, if other depots of public transport operators were to be automated at the end of the project, the experience acquired in Switzerland would no longer require hours of engineering (~ -40%, variant “Best”), the potential for replicability being an important criterion for project partners.

When a company comes to automate several depots, with “sleeping” vehicles on different sites, the financial impact would also be positive since the equipment of the vehicles can be identical for all depots.

Although all the expense positions inherent in an automated bus depot were taken into account, only driver hours were considered as saving. Other induced savings should be mentioned here:

- In case of a depot fire, the automation system could probably save a few vehicles and the potential exposure of staff will be reduced (no driver intervention at the depot). However, it is difficult to quantify the probability of fire occurrence. A decrease in the insurance premium could be negotiated;
- Regarding road safety, some of the equipment on board vehicles intended for automated bus depot automation (example: AEB, automatic emergency braking) could be used in other situations and avoid accidents when driving off depots also. Moreover, if they have been considered here in the costs induced on the vehicles, in reality, the manufacturers already offer them in their traditional range. The costs of these equipment and the costs induced by accidents could be raised as potential savings linked to this automation;
- In depots, slight collisions of vehicles with the infrastructure or between vehicles can occur (no cases identified at G7, but several cases at the bus station of Fribourg). With the integrated equipment on these vehicles the number of such incidents or accidents could be reduced;
- The hours “saved” of driving by drivers are today unproductive hours. These hours could be transformed into productive hours on a global scale, for example by offering a new offer to customers. It is worth recalling the TPG study (Kaufmann and al., p. 19), which mentions that a franc invested in public transports results in a 1.18 overall gain for society. This potential leverage arm, by reinvesting these hours, is also not considered in our analysis.
- In 2021, several Swiss journalists echoed a potential shortage of truck drivers. If it does not currently seem to affect the partner operators currently, this may become an issue in the 5 to 10 years horizon. An increase in the wage costs of drivers or direct impacts on the public transport service (cancellation of races, decrease in supply, etc.) could therefore intervene.

Adecco does a quarterly evaluation of the different industries and their need for personnel. The position of the bus drivers is currently in the lower second tier. This means that there is not a current shortage, but it might come. Keeping a close eye on these numbers can help to predict when there is a shortage on the horizon. In addition, the age of the employees can help to predict potential upcoming retirements and therefor an arising of a lack of workforce.

Les difficultés s'accumulent pour TransN

La compagnie de transports publics neuchâtelois fait face à un manque de personnel qui l'a poussée à supprimer des courses certains jours

LAUSANNE

Lausanne : la pénurie de personnel s'intensifie encore aux TL

Publié Il y a 2 ans, le 10 janvier 2022
De Emilien Verdon

Image 16 : Examples of challenges faced by certain public transport operators due to a shortage of drivers, sources: RTN, LFM

The Swiss television [RTS] has covered in different news reports the lack of drivers of Swiss transportation operators, especially during autumn and winter 2022/2023 as well as summer 2023. The main reasons mentioned were short-time illness and not work-related accidents. However, none of the reports looked at how the transportation operators could help avoid/prevent e.g., accidents from happening. One point that was mentioned is that women only account for about 15% of the total number of drivers and though the job profiles for drivers need to be adapted – part-time work option, etc.., Surveys amongst drivers show that only 3.9% of them have no health issues. The different types of health issues have been surveyed [Syndicom] [SEV], it is however not for all clear if they arose from their job, other activities or are the result of other underlaying health issues.

The implementation of a facility operating with self-driving buses will reduce the number of drivers required, but will necessitate training employees on the new system, i.e., hiring individuals with technical expertise. This implies that an autonomous bus depot can help mitigate the risk of a shortage of bus drivers and allocate them where they are most needed.

No insurance in Switzerland is yet insuring self-driving vehicles, as they are not legally allowed/cannot get permits. However, several insurance companies have started to work on potential solutions and organized information sessions during conferences.

The big insurance company AXA, for example, has signed an agreement with Oxbotica, a software company that focuses on self-driving vehicles. This cooperation was done to understand how the introduction of those vehicles and the risk management for insurances can work out. In addition, they have worked on the international project DRIVEN in the U.K. as well as collaborated with operators and clients that work in the fields of robotics and autonomous machines. The result of this collaborations is an insurance solution within their business insurance company AXA XL. Its goal is to support companies from the development phase until the market launch. Also, the insurance company Helvetia has started to work on the potential options of insuring self-driving vehicles.

In Germany the TV station ZDF covered the topic of insurance in several short interviews. The responses show that the whole situation is very complex, and it has not yet been finally decided how it will be handled in the future. One lawyer sees a high chance that in the future it will not anymore be the driver that has to be hold responsible in case of an accident, but the builder of the vehicles.

A question is if using autonomous buses within the depot could help to save money on the yearly insurance payments for the depot. E.g., the buses could drive themselves out of the depot in case of a fire without any human interaction or risk of humans getting hurt and through this the insurance would have to pay for less damage, as less vehicles were destroyed.

Research shows that there is not yet a lot of information on this topic available. The big insurance company General Re Corporation has done some research on a fire within a depot and estimates it as very difficult to define how to insure a depot. They see a higher risk especially with electric buses (lithium batteries), which autonomous vehicles usually are as well. What could probably be done is ensure the depot at a lower value as it is estimated that the buses will not all be destroyed. However, this is a high risk to take by the transportation company, as the insurance will then not cover the destruction of the buses if they were not able to get out of the building – e.g., the fire blocks all exit, or the technical infrastructure has broken down and through this no communication with the internet is possible, buses will not be able to drive. Therefore, it is challenging to make a definitive statement on this specific point at the moment.

Considering the above assumptions and for a first prototype for a public transport company ("Trend" variant), it would then be possible to benefit from material optimizations, technical and technological experience acquired by the prototypical repository to replicate this large-scale automation in Switzerland. By admitting 9 other automated bus depots after the prototypical depot, it would then be possible to achieve savings of more than CHF 60 million over 24 years (163 million expenses for 227 million savings, Annex 3).

In conclusion, the attached brief financial analysis at 12-year or 24-year maturity indicates that the prototypical project ("Trend" variant) has a positive RBC (ratio benefit-cost).

The "Best" variant could be a good indication of the replication to other repositories of the prototypical project and thus demonstrates the need for an experience on the Swiss territory in this matter with an RBC ratio of 1.5 to 1.6.

The differences between the three variants (0.4 to 0.6 points), the quantification of the potential underlying economies explained above, as well as the impact of the hardware and technology, demonstrate to which point this feasibility pre-study was needed to refine the financial analysis of bus depot automation before a national bus depot automation project is launched.

This initial analysis, conducted as a preamble to the present pre-study, has been verified. However, we are providing some additional information in the following sections.

Discussions on the assumptions adopted for the "Trend" reference scenario.

- From a hardware point of view only, the cost of setting up a teleoperation station for an automobile is currently around 5,000 CHF. To account for equipment renewal, the annual cost has been increased by 15% (assumption, equipment lifespan ~6.5 years). For the "Trend" scenario, a markup has been considered since the system will likely be more complex than a station dedicated to an automobile.
- Regarding the number of teleoperation stations, a total of 5 stations has been established. It is assumed that around 30 buses circulate simultaneously in a depot (realistic number) with a probability of requiring a teleoperator at a rate of 10-15% (pessimistic assumption). Thus, there is a need for 3 available stations, and 2 additional stations are implemented for security purposes (N+2, pessimistic approach). The required number of stations could be lower, possibly 2-3 for the main sites of the partner public transport operators.
- For a fleet of 100 vehicles undergoing renewal, it is necessary to cover the technological difference required for the bus depot automation, including the drive-by-wire technology and the onboard sensors described in Chapter 6.1. With the current development of autonomous vehicles, there are currently additional costs of approximately 10%. Although the required algorithmic level is not as advanced and the necessary hardware is less significant than full vehicle automation, a 10% surcharge is considered. However, as with the development of computers, for equipment with strong development potential, prices should eventually decrease.
- For a site like Givisiez (G7, TPF), the distance to be covered by buses is approximately 900m. It is assumed that approximately 2 cameras are needed per 50m section and 1 lidar per 100m section. Therefore, a total of 36 cameras and 9 lidars are required for the Givisiez site. Since several buildings or underground paths may hinder optimal positioning systems, it is proposed to double the number of lidars on-site (20) and round up the required number of cameras (40). Considering 1kCHF per camera and 15kCHF per lidar, the total hardware cost for the G7 site is approximately 340kCHF. Additionally, equipment renewal (+10%) and a tripling factor for all other technologies (antennas, cables, etc.) and necessary installations (including labor) are added.
- To develop a pilot site for automated bus circulation, a team of 6-7 full-time equivalents is assumed to be working for 2 years with an average salary of around 150kCHF per year per full-time equivalent (including social benefits).
- Regarding the hours of teleoperation performed, again a 15% teleoperation time requirement is assumed (pessimistic). As the hours worked by bus drivers at the G7 site amount to approximately 15,000 hours, this represents approximately 2,250 hours per year at 130 CHF/hour. Moreover, it is assumed that teleoperation personnel can perform other tasks during non-teleoperation hours.

In summary, the economic impacts for the automation of a bus depot, with a fleet of approximately 100 drive-by-wire compatible vehicles and a projection over the average lifespan of the fleet, are as follows:

1 depot, 100 compatible vehicles, 12-year projection.

[*10^6 CHF]	Trend case	Best case	Worst case
Cost	11.5	8.4	14.2
Benefits	12.7	13.8	10.2

Tab. 8: Economic analysis, 1 depot, projection over 12 years

6.3 Legal part

From a legal point of view, the present project essentially raises three issues, namely the involvement of state authorities for the authorization of an automated bus depot, the operation of the teleoperation center and the liability in case of any accidents.

Authorization for the automation of a depot

For the implementation of an automated bus depot, whether limited to a test/pilot site or for a permanent site with (commercial) operation, it is likely that consultation with federal and/or cantonal offices and possibly municipalities, will be necessary. It is advisable to contact these authorities in a timely manner so as to avoid any undue delay of a planned project. For test/pilot projects, the current and the future legislation provides for quite some flexibility that facilitates the implementation of such projects. With regard to the implementation of a permanent project, the legal requirements need to be satisfied more strictly and the ongoing drafting process for the relevant ordinance is not yet finished. However, it is expected that vehicles without any driver but under the control of a supervisor (remote telecontrol) will be admitted, which will pave the way for automated bus depots. Since the sites for such depots will typically be (more or less) closed to the public and the buses will not transport any passengers any more, the potential risk of operating such a site is comparatively low, which should simplify their authorization.

Driving personnel at the teleoperation center

The teleoperation center (TC) for an automated bus depot will operate under the control and responsibility of the public transport company even if it should be outsourced to a third party on a contractual basis. The telecontrol personnel of the TC will not only need to have the necessary skills and qualifications but also have to comply with the relevant rules on the duration of work and rest periods for professional drivers as well as with any internal regulations of the company.

Responsibility in case of an accident

In the event of any accident caused by a bus in operation on the premises of the automated bus depot, the public transport company (as the owner of the bus) will be liable for the damages caused to third parties or employees based on strict liability but covered by the liability insurance. From a practical point of view, the risk of accidents and damages in connection with the operation of an automated bus depot should be comparatively low since the bus speed is significantly reduced, there are not passengers on board the bus and the premises of the depot will normally not be accessible by the public.

The vehicle inspection remains, in any case, the responsibility of the driver, even in the case of a fully automated process. Drivers will always have to carry out the vehicle inspection as they are responsible for it in terms of traffic regulations (unless the company takes on this responsibility, but that seems more complex, and drivers may not agree as it represents a personal risk).

6.4 Summary of WP2

From a legal standpoint, it can be observed that the development of an automated bus depot prototype as envisaged is likely feasible.

From an economic perspective, the “trend” scenario, which achieves a B/C ratio greater than 1.0, indicates a probable viability of bus depot automation, subject to the conditions specified in Chapter 6.2. However, a significant economic investment will be required in the initial prototype development steps.

Finally, from a technical point of view, the concept of an automated bus depot appears achievable. However, it will take time to develop (estimated at 2 years of development) and is currently dependent on manufacturers developing drive-by-wire vehicles that can be purchased on the market at a reasonable price. It is essential to emphasize that the goal is not to have a fully automated vehicle, but rather a vehicle with non-mechanical controls, using electrical or electro-mechanical systems.

In conclusion, the concept of an automated bus depot is feasible in all of the three aspects (technical, economical and legal).

7 WP3 – Potential pilot sites evaluation

This third work package concerns the evaluation of potential sites where the study could be practically conducted.

7.1 Definition of evaluation criteria and criteria weighting

In order to proceed with the evaluation of various sites, a multicriteria evaluation is implemented. A multicriteria analysis is a decision support tool that, based on criteria established according to the objectives of a project, in this case, the implementation of the AutoDepot prototype, allows the comparison of different alternatives. In the current context, it involves comparing various potential sites for the application of the prototype.

This evaluation consists of several steps. First, the evaluation criteria were developed in order to make a criteria grid. The criteria grid is composed of four different categories: Technical requirements, Safety, Economic efficiency and Legal framework. More or less all of those categories are composed of sub-criteria with their own explanations (column "Details").

The weighting of evaluation criteria and sub-criteria is carried out by the project stakeholders, in this case, public transport operators and technological partners. Each variant is then evaluated under each of the proposed combinations rather than on an averaged value. In this way, a ranking is established for each combination proposed by the partners.

The first category, technical requirements, is separated in seven sub-criteria. The latter concern the network, vehicles and the depot. The second category, safety, has two sub-criteria which are about the risk of accidents and the remote operations center. The third category, economic efficiency, has two sub-criteria: material and personal efficiency. Lastly, the fourth category, legal framework, is only composed by one sub-criteria which is about legal requirements.

The project partners were asked to provide input on the comprehensiveness and completeness of the criteria as well as their weighting. They were also requested to perform a weighting of the different criteria and sub-criteria.

The results are as follows:

Criteria grid

n°	Weight	Main objective	n°	Weight	Sub-criteria	Details
1		Technical requirements	1.1		Global network quality	Vehicle fleet (number), motorization type, level of equipment (onboard) et vehicle connection network (communication V2I-I2V)
			1.2		Automated vehicles	Proportion of automated vehicles or drive by wire, level and skills in vehicle automatization
			1.3		Remote-operations	Operation center, skills in remote operation of vehicule, devices (on-board systems, connexion, infrastructure equipments)
			1.4		Depot infrastructure quality	Types of equipment, accessibility, space margins (maneuver), underground, open-air, closed
			1.5		Tasks on the depot (during vehicle circulation)	Personnel tasks (drivers, cleaners), checklist extent
			1.6		Vehicle power	Power supply (type), accessibilty to battery or fuel recharging
			1.7		Depot automation level	Infrastructure complexity (for depot automatization, incl. driver access, activities mix like tram, delivery)
2		Safety	2.1		Remote operations center	Monitoring equipment, training level (operators)
			2.2		Risk of accidents	Conflict areas, effects on the accident rate
3		Economic efficiency	3.1		Material efficiency	Potential system efficiency, equilibrium between costs (materials, installation, maintenance) and expected gains, effect of automatization deployment, incl. rescued fleet in case of fire
			3.2		Personnal efficiency	Potential cost-effectiveness of employee, costs versus expected gains
4		Legal framework	4.1	-	Legal requirements	Legal framework (related to the site, incl. types of locomotion, pedestrians presence), potential for pilot site authorization (specific authorization), potential for site authorization (non pilot, final authorization)

Tab. 9: Criteria grid

Weights - Main objective

n°	Weight	Main objective	Partner 1	Partner 2	Partner 3	Partner 4	Partner 5	Partner 6	Partner 7
1		Technical requirements	30	50	30	30	30	30	30
2		Safety	50	20	30	40	30	40	10
3		Economic efficiency	10	10	30	30	30	10	50
4		Legal framework	10	20	10	Blocking	10	20	10

Tab. 10: Weighting of main objectives

Weights - Sub-criteria

n°	Weight	Sub-criteria	Partner 1	Partner 2	Partner 3	Partner 4	Partner 5	Partner 6	Partner 7
1.1		Global network quality	10	20	20	30	9	11	5
1.2		Automated vehicles	40	15	10	Blocking	27	34	15
1.3		Remote-operations	5	15	10	20	14	11	10
1.4		Depot infrastructure quality	5	20	10	5	9	11	20
1.5		Tasks on the depot	5	10	10	40	18	11	10
1.6		Vehicle power	5	5	10	5	18	11	5
1.7		Depot automation level	30	15	30	Blocking	5	11	35
2.1		Remote operations center	10	40	50	40	50	30	70
2.2		Risk of accidents	90	60	50	60	50	70	30
3.1		Material efficiency	40	50	50	20	50	40	50
3.2		Personnal efficiency	60	50	50	80	50	60	50
4.1	-	Legal requirements				Blocking			

Tab. 11: Weighting of sub-criteria

7.2 Evaluation of pilot sites

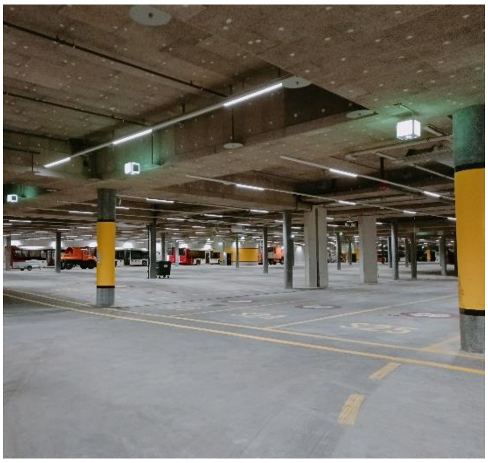
The evaluation of pilot sites, i.e., the scoring of different sites (scores ranging from 0 to 5, with 5 being the highest score and 0 the lowest), is conducted by HEIA-FR (academic partner). Thus, the academic partner is not involved in weighting the criteria but solely in scoring potential pilot sites.

If only the evaluation of 5 sites is indicated in the following, in reality, other sites of public transport partners have also been evaluated. However, either some sites do not meet the basic criteria for the current implementation of the prototype (e.g., the number of vehicles in the depot is less than 100 and without a main depot) or the construction planning of the depot does not allow, in terms of timing, to consider the implementation of the AutoDepot prototype in the coming years.

The proposed evaluation grid as well as the weights provided by the partners could also be applied to other sites if necessary.

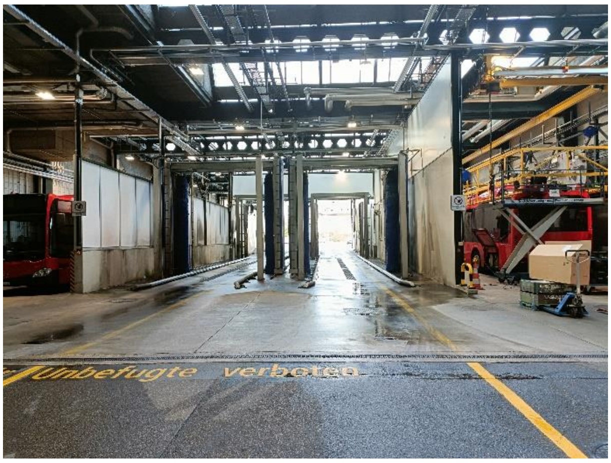
The various sites evaluated as part of the "AutoDepot" prototype development are as follows:

TPF – G7 - Givisiez

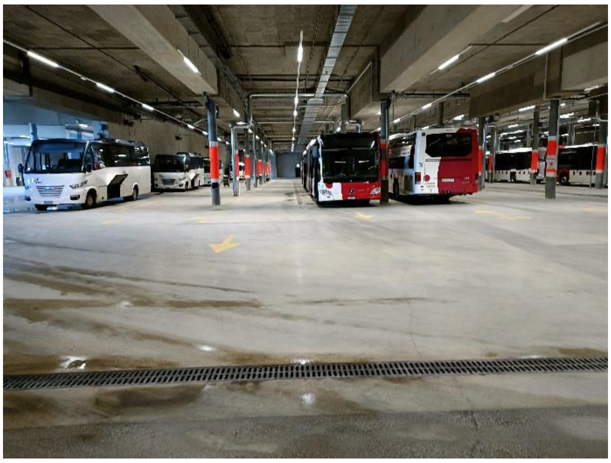


TPG En Chardon

BernMobil Eigerplatz



TPF Romont



BernMobil Freiburgerstrasse

Image 17 : Depots evaluated with the "AutoDepot" prototype concept

The rating of the different depots is as follows:

Criteria	TPF G7 - Givisiez	TPG En Chardon	BernMobil Eigerplatz	TPF Romont	BernMobil Freiburgerstrasse
1.1	5	5	5	2	2
1.2	1	2	1	1	1
1.3	4	4	3	4	3
1.4	4	4	2	4	2
1.5	5	5	5	2	1
1.6	5	5	5	5	5
1.7	4	4	3	4	5
2.1	4	4	4	4	4
2.2	4	5	4	5	5
3.1	4	5	5	1	1
3.2	5	4	4	1	1
4.1	4	5	5	5	5

Tab. 12: Depot ratings

Sub-criterion 1.1:

- Communication between vehicles and infrastructure (control center) is good at all depots.
- The Romont and Freiburgerstrasse depots do not reach 100 vehicles; however, their operations can be linked to a main depot reaching this value.

Sub-criterion 1.2:

- No public transport company currently operates automated bus vehicles.
- Operator’s skills in automated vehicles have been demonstrated through shuttle pilot projects.
- TPG's knowledge of automated vehicles is more advanced today compared to other public transport operators.

Sub-criterion 1.3:

- No public transport company currently has in-house expertise in remote operation. However, some have participated in projects related to remote operation (e.g., NPR Teleoperation Fribourg).
- The infrastructure required for teleoperation is partially available at different sites. Older sites (e.g., BernMobil) have fewer existing hardware options than newer sites.

Sub-criterion 1.4:

- The quality of depot infrastructures is relatively good for recent depots. However, there are likely to be more challenges in implementing the AutoDepot prototype in older depots.

Sub-criterion 1.5:

- On large depots, the number of tasks, and consequently, the time spent by drivers moving between different maintenance stages, is greater than on small depots. Implementing bus circulation automation is more beneficial on larger maintenance stage chains.

Sub-criterion 1.6:

- The accessibility and type of batteries of rolling stock are substantially similar across different public transport operators.

Sub-criterion 1.7:

- The more compact the depots are, the less complex the deployment of the “AutoDepot” prototype is. This explains generally higher ratings for small depots.
- For large depots, differences are explained by potential interactions with other modes of transportation or users (trams, pedestrians, private vehicles), the lengths of vehicle storage queues on-site without affecting adjacent road networks, and the proportion of outdoor spaces subject to weather conditions, which could pose more problems for infrastructure sensors than indoor conditions.

Sub-criterion 2.1:

- The safety level of operations centers in different public transport operators is similar. Developments will be required to enable the deployment of the “AutoDepot” prototype.

Sub-criterion 2.2:

- The probability of accident risk is lower for small depots due to a smaller number of vehicles.
- For large depots, BernMobil did not provide information on accidents. The TPF depot has a higher accident ratio compared to TPG, proportionate to the number of vehicles present. While this may be positive in terms of efficiency (potential reduction in accidents due to automation), from a safety engineering perspective, it signifies a greater potential for conflict zones to be described, defined, and analyzed.

Sub-criterion 3.1:

- For small depots, the economic potential is not viable in terms of material (too few vehicles compared to the costs incurred).
- For large depots, the TPF center in Givisiez has more outdoor areas than the other two, requiring more advanced sensors.

Sub-criterion 3.2:

- Expected gains are lower for individual small depots. The number of hours spent by driving personnel on small depots is lower due to the succession of maintenance tasks.
- For large depots, the potential driving time saved is reported to be greater at the TPF site in Givisiez.

Sub-criterion 4.1:

- Legally, the TPF site in Givisiez is slightly more complex as certain common circulation areas are authorized for visitors.

By combining the ratings with the weights, the following rankings are obtained:

Ranking	Partner 1	Partner 2	Partner 3	Partner 4	Partner 5	Partner 6	Partner 7	Final
TPF G7 - Givisiez	4	2	2	2	2	3	3	2
TPG En Chardon	1	1	1	1	1	1	1	1
BernMobil Eigerplatz	5	3	3	3	3	2	2	3
TPF Romont	3	4	4	4	4	4	4	4
BernMobil Freiburgerstrasse	2	5	5	5	5	5	5	5

Tab. 13: Depot ranking

As can be seen in the various proposals, partner #4 has deemed certain criteria to be eliminatory. However, these eliminatory criteria have been considered in potential technical developments of the “AutoDepot” prototype, notably the fact that no bus manufacturer currently offers a drive-by-wire vehicle (Chap. 6.1). Therefore, we have proposed a ranking that does not take into account any potential blockers.

Overall, it is observed that the “TPG En Chardon” depot is currently the most suitable among the evaluated depots to serve as a depot for the implementation of the “AutoDepot” prototype.

Following the evaluation of the different depots, the following comments can be made for the various public transport operators partnering in this project.

BernMobil:

- Eigerplatz Depot: Less recent but potential for AutoDepot system.
- New Bodenweid Depot (large depot) – Potential for AutoDepot system (delays).
- Other depots: Potential if AutoDepot system at large depot (taking advantage of a large depot).

BVB:

- New large depot – Potential for AutoDepot system (delays).

PostAuto AG:

- Depots that are too small in size (number of vehicles), more actions performed by drivers.
- Could benefit from depots of other operators, fostering synergies between depots.

TPF:

- G7 Depot - Givisiez – Potential for AutoDepot system.
- Other depots: Potential if AutoDepot system at G7 (taking advantage of a large depot).

TPG:

- En Chardon Depot – Potential for AutoDepot system.
- Other depots: Potential if AutoDepot system at En Chardon.

VBZ:

- New large depot Hagenholz – Potential for AutoDepot system (delays).

It is noteworthy, particularly in the case of a transport company such as PostAuto AG, which possesses the largest fleet of bus-type vehicles in Switzerland, that the current challenge in conceptualizing an AutoDepot prototype lies in the fact that the company has numerous medium to small-sized depots or parking locations scattered throughout the country to be closer to its users. The number of vehicles present in the depots (up to a maximum of around thirty) currently does not allow for the economic viability of the AutoDepot prototype. If interactions between multiple depots or with depots of other operators could be considered, then it would be possible to implement the “AutoDepot”.

Image 18 : Example of a PostAuto AG depot, Palézieux depot

8 WP4 – Scope, objectives and potential of an applied proof-of-concept project

This work package aims to define the framework, objectives, and potential of the autonomous bus depot pilot project.

8.1 Pilot project framework

Prototype project context

The prototype project for bus circulation automation within a depot must be placed within the national context of the Swiss transport system. While preliminary projects are also beginning to emerge internationally (for example: the IDEA project: Innovative Depotautomatisierung in Germany), differences in concepts, both technically, economically, legally, and geopolitically, need to be considered. Transport operators should be supported in the innovative development of a prototype bus depot automation system adapted to the Swiss context. The issues and inefficiencies addressed in the prototype project have been demonstrated during this project, notably the phenomenon of non-productive hours for drivers during circulation and regular maintenance stages at bus depots.

Scope of the prototype project

It is important to specify here the geographical, technological, and temporal limits of the prototype project.

In terms of geographical delimitation, the prototype project must be limited to a single depot. This will allow for the development of a valid technological solution with potential for replication at other sites in Switzerland, with lower risks.

From a technological standpoint, it is important initially to focus on bus circulation within a depot. While other tasks could also be automated, we propose dedicating this prototype solely to bus circulation. Tasks such as washing, tire checks, charging, refueling, etc., could be automated regardless of operational circulation conditions (with or without a driver, with or without automated circulation). Some tasks (interior washing, charging, refueling, level checks, etc.) can be performed by other staff members or are already automated at certain depots (tire scanning, exterior washing).

If all these tasks are automated while circulation is not, the driver's working time in circulation within the depot will not be reduced, and therefore, the “potential gains” cannot be achieved. However, if circulation is automated, saving driving hours (for drivers) could then be feasible.

8.2 Pilot project objectives

The objectives of the “AutoDepot” pilot project will be as follows:

- Develop and test a prototype for automating bus circulation at a public transport depot.
- Confirm the benefits and challenges associated with implementing automation technologies in the public transport sector.
- Reduce operational circulation costs at depots that are unprofitable to customers.
- Validate the technical and legal feasibility of automating bus circulation operations at a depot.
- Provide implementation recommendations for potential large-scale deployment (replicability to other depots).

8.3 Pilot project potentials

The “AutoDepot” prototype pilot project represents a significant advancement in optimizing bus depots for public transport operators. By automating vehicle circulation processes, the project aims to streamline daily operations, which can result in considerable time savings in terms of non-productive driver hours (hours not spent serving passengers) for the operators. Additionally, automating depots offers the opportunity to reduce human errors, often the cause of incidents and accidents.

In addition to operational benefits, the “AutoDepot” pilot project also paves the way for technological innovation in the public transport sector. By testing and integrating new technologies such as IoT sensors, artificial intelligence, and advanced fleet management systems into infrastructures, operators can improve their efficiency and competitiveness. This technological innovation is also one of the pillars of the Swiss Association for Autonomous Mobility (SAAM), of which many of the partners in this project are members. Such developments in the field of automation also allow Switzerland, its operators, and academic partners to have international outreach.

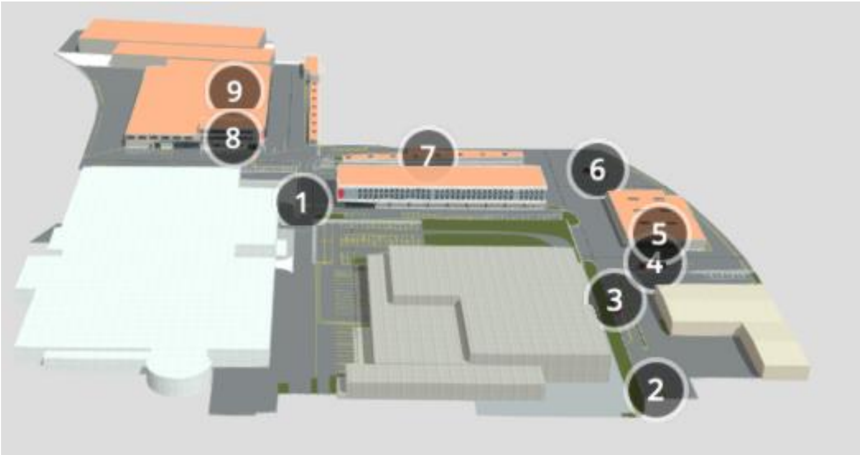
Finally, the “AutoDepot” pilot project, in support of this optimization of internal depot operations, will strengthen the efficiency and reliability of public transport services, as well as improve the overall passenger experience and increase their satisfaction. By automating bus circulation at depots, non-productive hours can either be utilized for new offers or considered to alleviate an area currently under strain (heavy pressure on drivers, staff shortages).

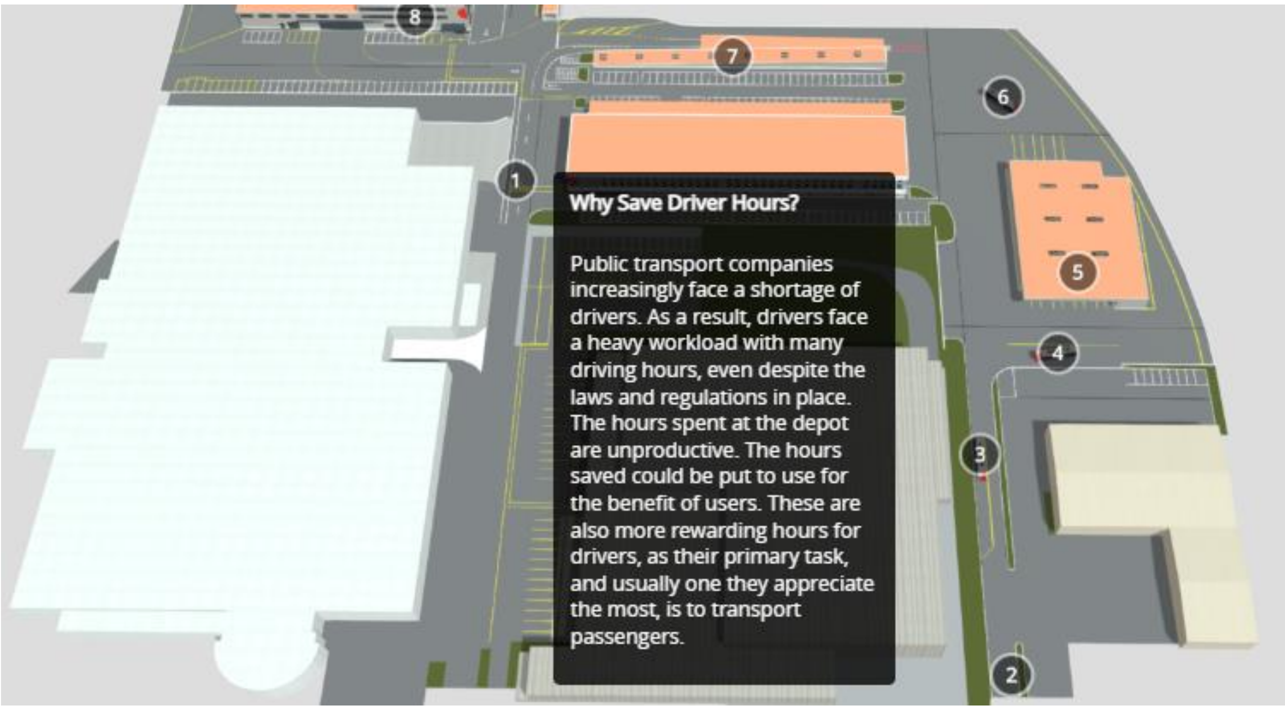
8.4 Pre-developments carried out

Illustrated model

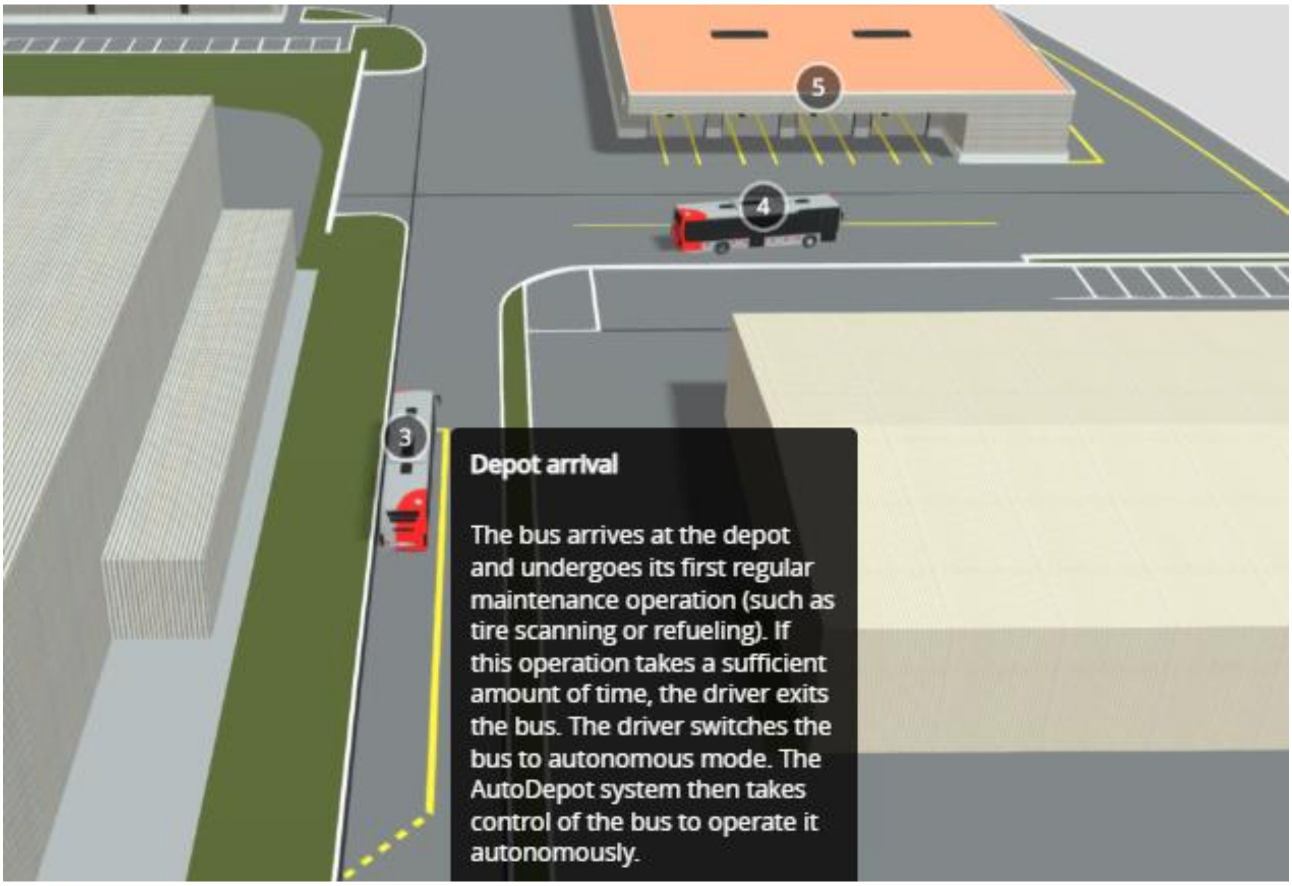
In view of the “AutoDepot” prototype project, as part of the present pre-study, a simplified model illustrating the various stages and conditions of the “AutoDepot” concept has been developed. This can be viewed using the following link: [LIEN]

The model is based on the realistic environment of the TPF depot in Givisiez (G7). Here are some excerpts.



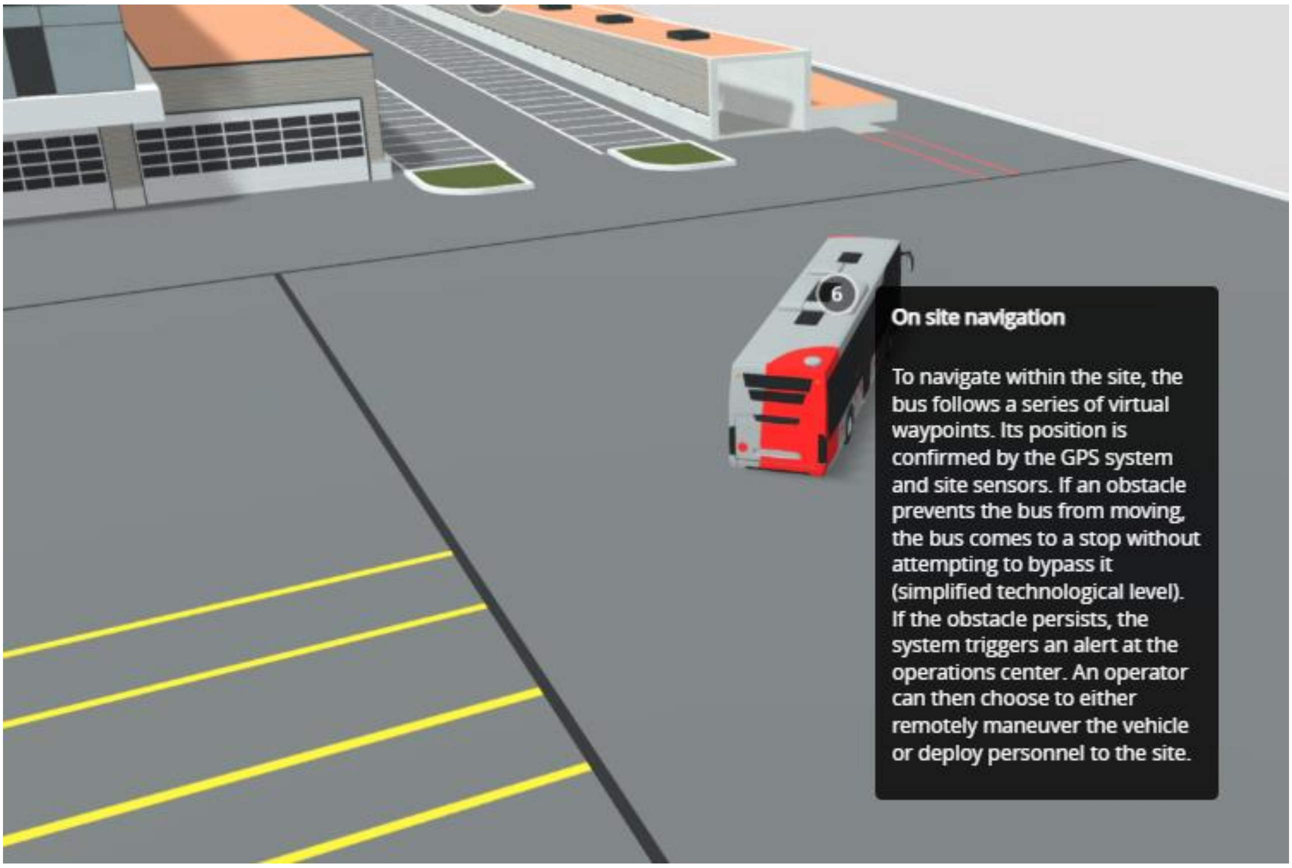


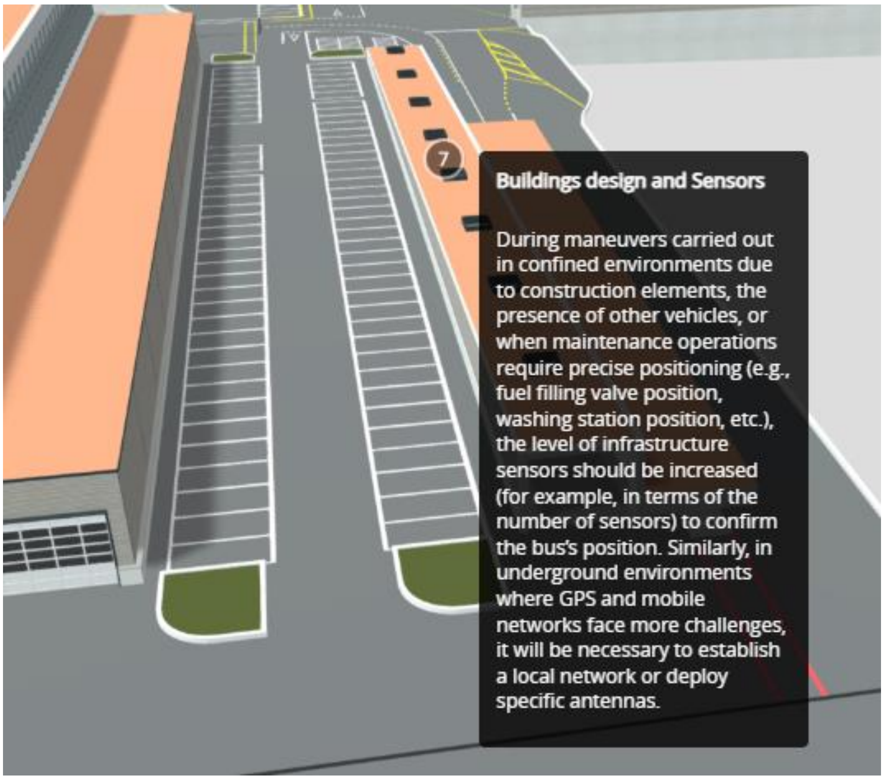

Goal of AutoDepot
The goal of the AutoDepot automation system is to save unproductive driver hours that occur during various maintenance activities at a bus depot. The different maintenance tasks (for ex. refueling, fluid level adjustments, cleaning) may feasibly be automated, although that is not the focus of the AutoDepot system. Maintenance tasks may be automated, but a driver would still have to drive the bus between them, resulting in no driver time savings. However, if circulation can be done autonomously, it opens up the possibility of saving driving hours and thereby considering the automation of other routine maintenance tasks as well.
5
2

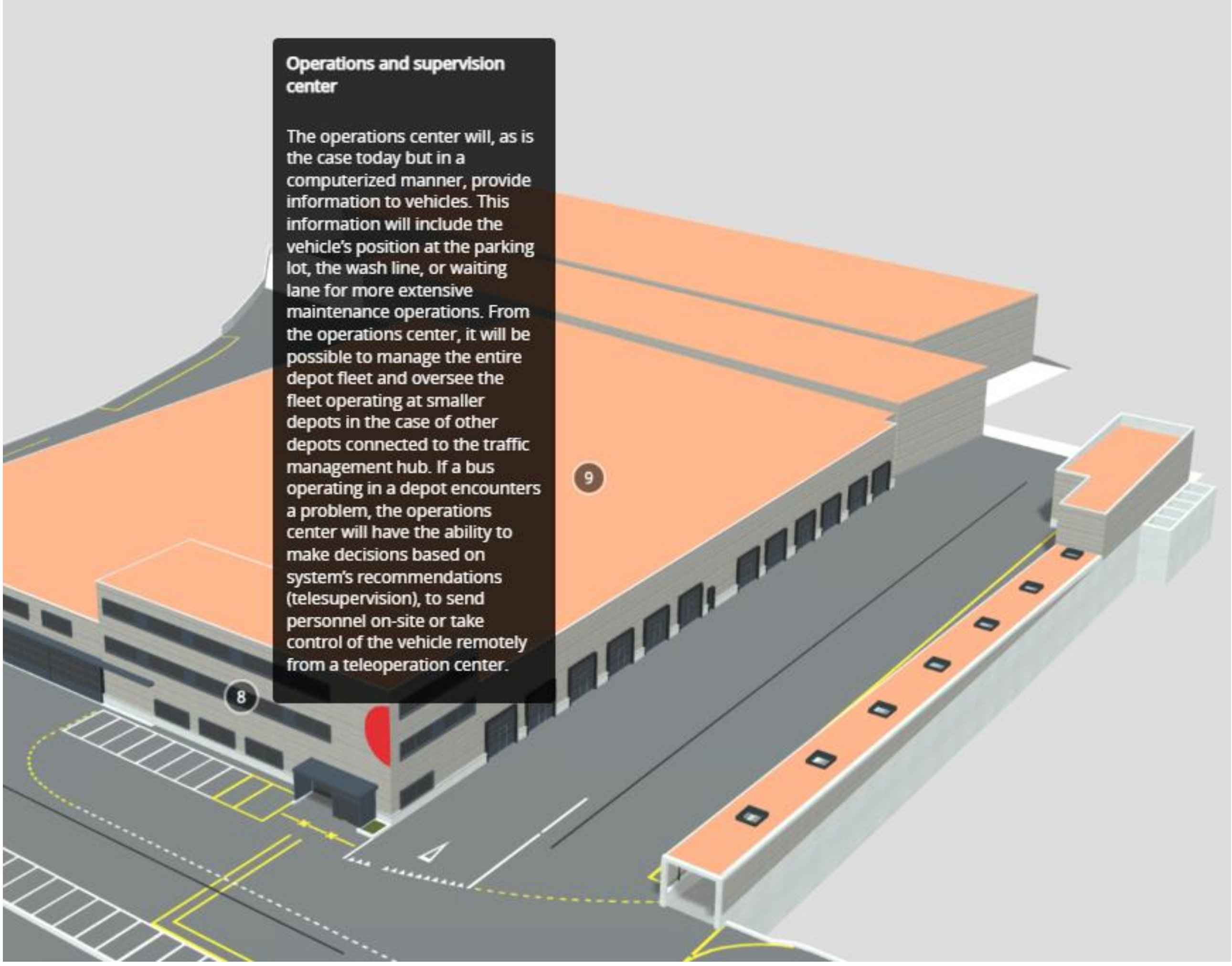

5
4
3
Depot arrival
The bus arrives at the depot and undergoes its first regular maintenance operation (such as tire scanning or refueling). If this operation takes a sufficient amount of time, the driver exits the bus. The driver switches the bus to autonomous mode. The AutoDepot system then takes control of the bus to operate it autonomously.

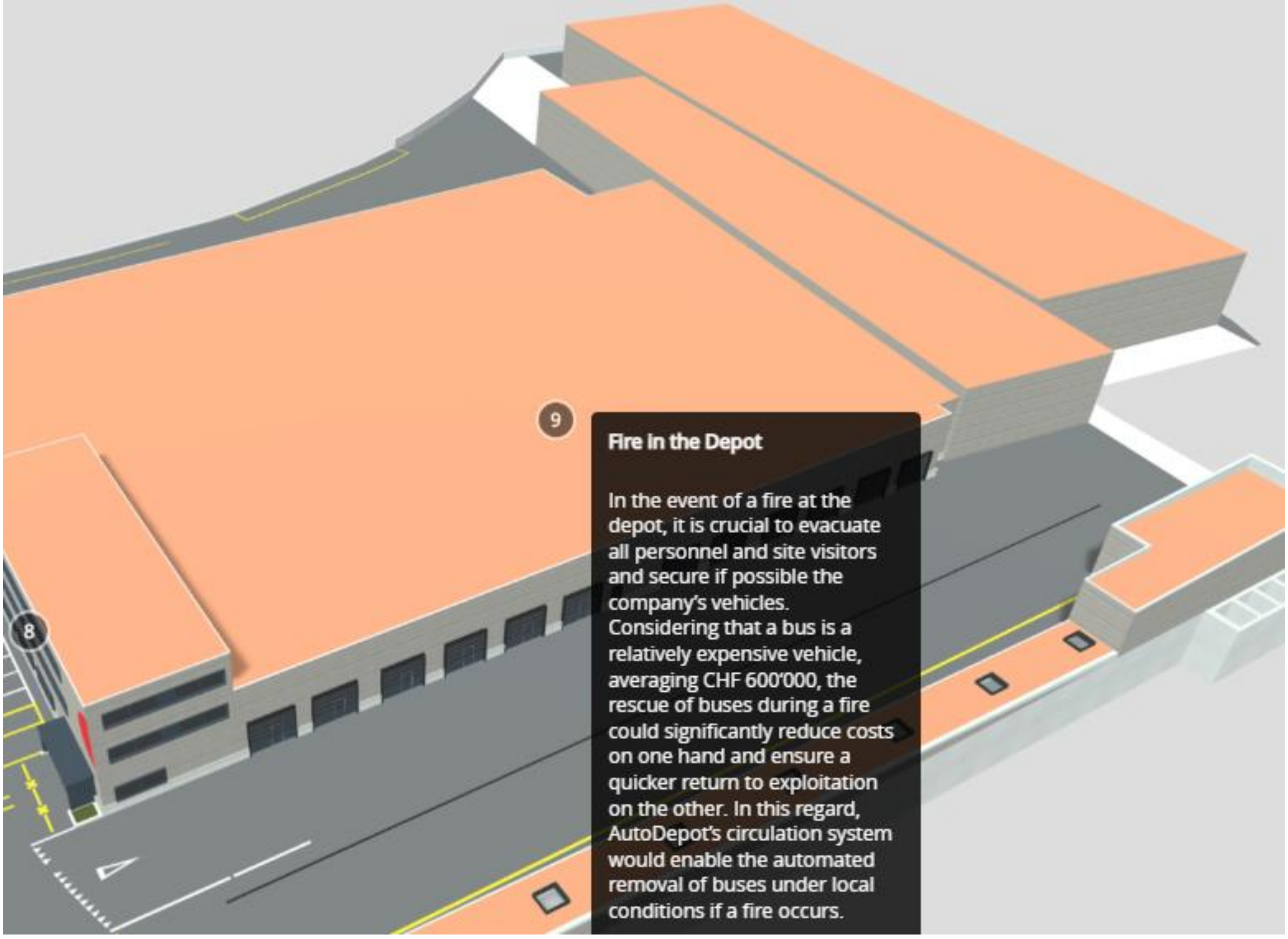

6
Sensors
The bus now operates in autonomous mode, without a driver. The majority of sensors are integrated into the infrastructure rather than the rolling stock, leading to significant cost savings. Each bus is equipped with an onboard computer, a GPS system and a camera (useful for teleoperation). All other sensors (lidars, cameras, etc.) are integrated into the infrastructure. The buses must be drive by wire.
4


5
Automated circulation and speed
The bus then goes through various stages of regular maintenance (refueling, fluid level adjustments, cleaning) while moving autonomously. The travel speed is limited to 3 km/h for safety and technological reasons. Speed is not a primary goal, as the crucial factor in terms of site circulation capacity revolves around the initial decisive maintenance operation.


6
On site navigation
To navigate within the site, the bus follows a series of virtual waypoints. Its position is confirmed by the GPS system and site sensors. If an obstacle prevents the bus from moving, the bus comes to a stop without attempting to bypass it (simplified technological level). If the obstacle persists, the system triggers an alert at the operations center. An operator can then choose to either remotely maneuver the vehicle or deploy personnel to the site.


7
Buildings design and Sensors
During maneuvers carried out in confined environments due to construction elements, the presence of other vehicles, or when maintenance operations require precise positioning (e.g., fuel filling valve position, washing station position, etc.), the level of infrastructure sensors should be increased (for example, in terms of the number of sensors) to confirm the bus's position. Similarly, in underground environments where GPS and mobile networks face more challenges, it will be necessary to establish a local network or deploy specific antennas.


Operations and supervision center
The operations center will, as is the case today but in a computerized manner, provide information to vehicles. This information will include the vehicle's position at the parking lot, the wash line, or waiting lane for more extensive maintenance operations. From the operations center, it will be possible to manage the entire depot fleet and oversee the fleet operating at smaller depots in the case of other depots connected to the traffic management hub. If a bus operating in a depot encounters a problem, the operations center will have the ability to make decisions based on system's recommendations (telesupervision), to send personnel on-site or take control of the vehicle remotely from a teleoperation center.
9
8



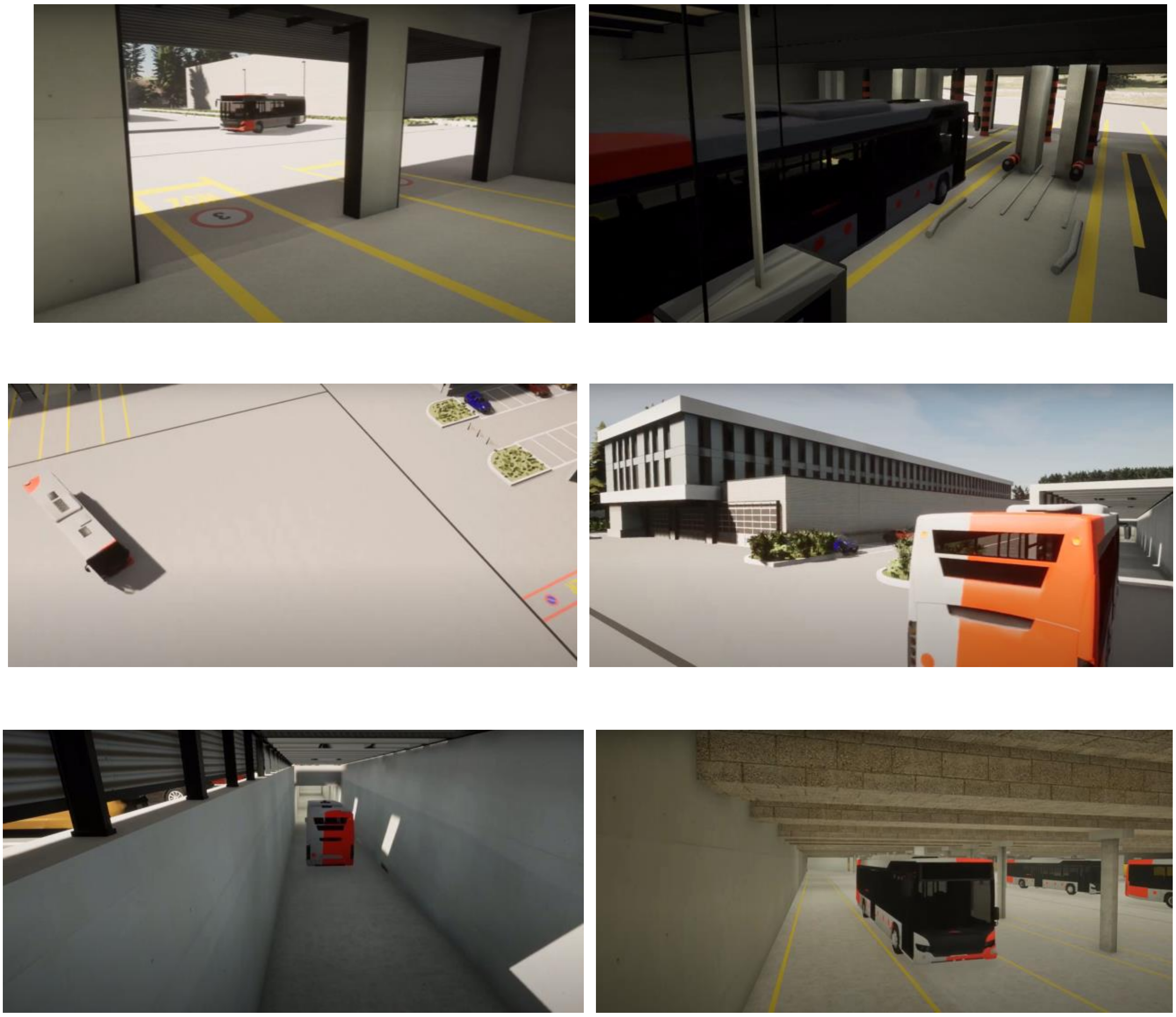
Carla model

On the other hand, a realistic simulation environment using the open-source tool CARLA has also been developed. This type of environment allows for all necessary tests for remote driving and vehicle automation in a realistic environment, including infrastructure, vehicles, and sensors, in a simulated and therefore safe environment.

The CARLA environment faithfully reproduces real driving scenarios either by an operator or in an automated manner. This allows to test and validate driving algorithms in various and realistic conditions, without the constraints and risks associated with on-road tests using real vehicles.

Similarly, this realistic simulation environment allows for easy variation of traffic situations (conflicting objects, presence of other vehicles, etc.) as well as testing different weather conditions. This helps identify any weaknesses in autonomous driving systems before their deployment.

The video of a bus-type vehicle driving on the Givisiez site, of which some excerpts are shown below, can be viewed using the following link: LIEN.



8.5 Developments steps of the pilot project and costs

Retrofit of a drive-by-wire vehicle

Firstly, in order to implement the “AutoDepot” prototype, it will be necessary to have a drive-by-wire vehicle available. Currently, and as explained in Chapter 6.1, there are no fully drive-by-wire bus-type vehicles available on the current market. The automated bus prototypes developed by some manufacturers have a technological level that is too advanced (and expensive) for the AutoDepot concept, which requires a minimum of onboard sensors in the vehicle fleet.

Therefore, it seems necessary, in this case, to proceed with retrofitting a standard market vehicle to make it drive-by-wire and compatible with the specifications of the “AutoDepot” concept. Note that this retrofit will require “immobilizing” a standard vehicle for the project, as it will likely no longer be allowed to be driven since certain mechanical and computer aspects will need to be modified, thus voiding its homologation.

Cost of the “Retrofit AutoDepot” development: ~500 kCHF (excluding the cost of purchasing the vehicle)

“AutoDepot” concept

Once this retrofitted vehicle is available, it will then be possible to develop the “AutoDepot” concept according to the concepts defined within the scope of this pre-study. The prototype will involve a step-by-step implementation process: remote driving, validation, automation under control, validation, ultimately leading to full automation of operations on defined operational design domains (ODDs) within the depot.

Cost of the “AutoDepot concept”: ~3'000 kCHF

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10 Annexes

Annex 1: Cost-benefit analysis on 12 years – 1 depot

Duration of the analysis: 12 years **Discount rate:** 2%

Costs in CHF:

Data

ID	Type of payment	Designation	Trend	Best	Worst	Year of single payment	Year of 1st periodic payment	Recurrence of payments [in years]	Year of last payment	Information / Assumptions	Results in discounted values: Trend	Best	Worst
C1	Single	Teleoperation station	60 000	37 500	75 000	0				Purchase of equipment per teleoperation station required (currently 5,000 per station for a car). Surplus-value (trend) for a more complex system like a bus. 5 stations (N+2). Higher material cost because not maintained and non-renewed.	60 000	37 500	75 000
C2	Single	Vehicle technology	5 000 000	4 000 000	6 000 000	0				Purchase of 100 vehicles. Only the technological difference (additional 8-10% of the cost of the vehicle) is considered. In the case of equipment with high development potential, prices should fall but not considered for trend.	5 000 000	4 000 000	6 000 000
C3	Single	Site material	1 200 000	1 080 000	1 440 000	0				Cost for all equipment on site for automation. ~ 40 cameras and ~20 lidars + other equipment. Higher material cost because not maintained and not renewed.	1 200 000	1 080 000	1 440 000
C4													
C5	Single	Site automation	2 000 000	1 200 000	2 500 000	0				Engineering for site development. 1 team of 6-7 FTE over 2 years.	2 000 000	1 200 000	2 500 000
C6													
C7	Periodic	Teleoperation	300 000	195 000	390 000		1	1		10% of the time should be in non-autonomous mode. For the trend, it is allowed 15% of the potential 15'000h with an hourly salary of 130. -/h. Teleoperation personnel will be able to perform other tasks on the time not covered by teleoperation.	3 172 602	2 062 192	4 124 383
											11 432 602	**8 379 692**	**14 139 383**

Data

ID	Type of payment	Designation	Trend	Best	Worst	Year of single payment	Year of 1st periodic payment	Recurrence of payments [in years]	Year of last payment	Information / Assumptions	Results in discounted values: Trend	Best	Worst
B1	Periodic	Personal savings on driving	1 200 000	1 300 000	960 000		1	1		15'000 hours of driver saved per year, hourly wage: 80. -/h. For Best, the difficulties caused by the lack of available labour and thus an increase in the basic wage are considered.	12 690 409	13 747 944	10 152 328
											12 690 409	**13 747 944**	**10 152 328**

	Trend	Best	Worst
Total benefits	12 690 409	13 747 944	10 152 328
Total costs	11 432 602	8 379 692	14 139 383
RBC	1.11	1.64	0.72

Annex 2: Cost-benefit analysis on 24 years – 1 depot

Duration of the analysis: 24 years **Discount rate:** 2%

Costs in CHF:

ID	Type of payment	Designation	Trend	Best	Worst	Year of single payment	Year of 1st periodic payment	Recurrence of payments [in years]	Year of last payment	Information / Assumptions	Results in discounted values: Trend	Best	Worst
C1	Single	Teleoperation station	40 000	25 000	50 000		0	8		Purchase of equipment per teleoperation station required (currently 5,000 per station for a car). Surplus-value (trend) for a more complex system like a bus. 5 stations (N+2). Life of 8 years.	128 146	80 091	160 183
C2	Single	Vehicle technology	5 000 000	4 000 000	6 000 000		0	13		Purchase of 100 vehicles. Only the technological difference (additional 8-10% of the cost of the vehicle) is considered. Life of 12.5 years.	8 903 623	7 122 898	10 684 347
C3	Single	Site material	1 000 000	900 000	1 200 000	1				Cost for all equipment on site for automation. ~ 40 cameras and ~20 lidars + other equipment.	980 392	882 353	1 176 471
C4	Periodic	Site material maintenance	100 000	90 000	120 000		0	1		Equipment renewal over 10 years.	1 991 393	1 792 253	2 389 671
C5	Single	Site automation	2 000 000	1 200 000	2 500 000	1				Engineering for site development. 1 team of 6-7 FTE over 2 years.	1 960 784	1 176 471	2 450 980
C6	Periodic	Development engineer	90 000	54 000	120 000		1	1		Maintenance and optimization of the system after development (1 FTE then degressive up to 0.6 FTE after 10 years).	1 702 253	1 021 352	2 269 671
C7	Periodic	Teleoperation	300 000	195 000	390 000		1	1		10% of the time should be in non-autonomous mode. For the trend, it is allowed 15% of the potential 15'000h with an hourly salary of 130. -/h. Teleoperation personnel will be able to perform other tasks on the time not covered by teleoperation.	5 674 178	3 688 215	7 376 431
											21 340 769	**15 763 634**	**26 507 754**

ID	Type of payment	Designation	Trend	Best	Worst	Year of single payment	Year of 1st periodic payment	Recurrence of payments [in years]	Year of last payment	Information / Assumptions	Results in discounted values: Trend	Best	Worst
B1	Periodic	Personal savings on driving	1 200 000	1 300 000	960 000		1	1		15'000 hours of driver saved per year, hourly wage: 80. -/h. For Best, the difficulties caused by the lack of available labour and thus an increase in the basic wage are considered.	22 696 711	24 588 103	18 157 369
											22 696 711	**24 588 103**	**18 157 369**

	Trend	Best	Worst
Total benefits	22 696 711	24 588 103	18 157 369
Total costs	21 340 769	15 763 634	26 507 754
RBC	1.06	1.56	0.68

Annex 3: Cost-benefit analysis on 24 years – 1 prototypical depot + 9 depots – simplified analysis

Duration of the analysis : 24 years **Discount rate :** 2%

Costs in CHF :

Data

ID	Type of payment	Designation	Trend	Best	Worst	Year of single payment	Year of 1st periodic payment	Recurrence of payments [in years]	Year of last payment	Information / Assumptions
C1	Single	Teleoperation station	265 000				0	8		Purchase of equipment per teleoperation station required (currently 5,000 per station for a car). Surplus-value (trend) for a more complex system like a bus. 5 stations (N+2). Life of 5 years.
C2	Single	Vehicle technology	41 000 000				0	13		Purchase of 100 vehicles. Only the technological difference (additional 8-10% of the cost of the vehicle) is considered. Life of 12.5 years.
C3	Single	Site material	9 100 000			1				Cost for all equipment on site for automation. ~ 40 cameras and ~20 lidars + other equipment per site.
C4	Periodic	Site material maintenance	910 000				0	1		Equipment renewal over 10 years.
C5	Single	Site automation	12 800 000			1				Engineering for site development.
C6	Periodic	Development engineer	576 000				1	1		Maintenance and optimization of the system after development on sites.
C7	Periodic	Teleoperation	2 055 000				1	1		10% of the time should be in non-autonomous mode. For the trend, it is allowed 15% of the potential 15'000h with an hourly salary of 130. -/h. Teleoperation personnel will be able to perform other tasks on the time not covered by teleoperation.

Results in discounted values

ID	Trend	Best	Worst
C1	848 969	-	-
C2	73 009 708	-	-
C3	8 921 569	-	-
C4	18 121 672	-	-
C5	12 549 020	-	-
C6	10 894 421	-	-
C7	38 868 117	-	-
	163 213 476	-	-

Data

ID	Type of payment	Designation	Trend	Best	Worst	Year of single payment	Year of 1st periodic payment	Recurrence of payments [in years]	Year of last payment	Information / Assumptions
B1	Periodic	Personal savings on driving	12 000 000				1	1		15'000 hours of driver saved per year, hourly wage: 80. -/h.

Results in discounted values

ID	Trend	Best	Worst
B1	226 967 107	-	-
	226 967 107	-	-

	Trend	Best	Worst
Total benefits	226 967 107	-	-
Total costs	163 213 476	-	-
RBC	1.39		