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Semi-automated bus depot Gaisburg

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Summary

The aim of this study was to develop implementation recommendations for semi-autonomous driving in a defined area (depot). To this end, the automation potential of operational procedures at the SSB bus depot in Gaisburg was examined and the depot's boundary conditions analysed. Today, the industry already offers various solutions for autonomous driving and for automating operations. The different options were examined and compared. Furthermore, the possible risks were assessed and economic considerations on the implementation and potential savings were made. In conclusion, recommendations are provided for the future planning of bus depots.

1 Introduction

In order to offer emission-free public transport in urban areas, it is necessary to use electrically-driven vehicles. Electric vehicles also meet all the requirements for autonomous driving. The current development of autonomous driving is primarily offered on the market as a support for the driver. It will still take quite some time before all vehicles are actually autonomous and the legal framework is fully in place.

The partial automation of operational processes or logistic applications already has a high potential today. In comparison to public roads, realisation of autonomous driving on private premises, in an off-road traffic situation and inaccessible to non-authorised personnel is much easier to implement.

2 Analysis of the boundary conditions

2.1 Operational processes

At the SSB depots, the buses are prepared for their next deployment after returning from their service. The "road tests" in particular play an important role due to the responsibility of the operating personnel according to German law (StVZO Section 31.2 Sub-section 1 and BGV D29 Sub-section 2). As the current legal framework does not allow a road test to be automated, it is not relevant for any further considerations regarding automation.

Part of the preparation of the buses for service are first of all refuelling and washing as well as cleaning the inside of the buses. Also included are minor maintenance and inspection operations. For this purpose, each bus is driven by an employee to the various stations where the individual operational procedures are carried out with the help of qualified personnel. The figure and table below show the conducted operations and give an indication which processes could potentially be automated.

Operational processes:

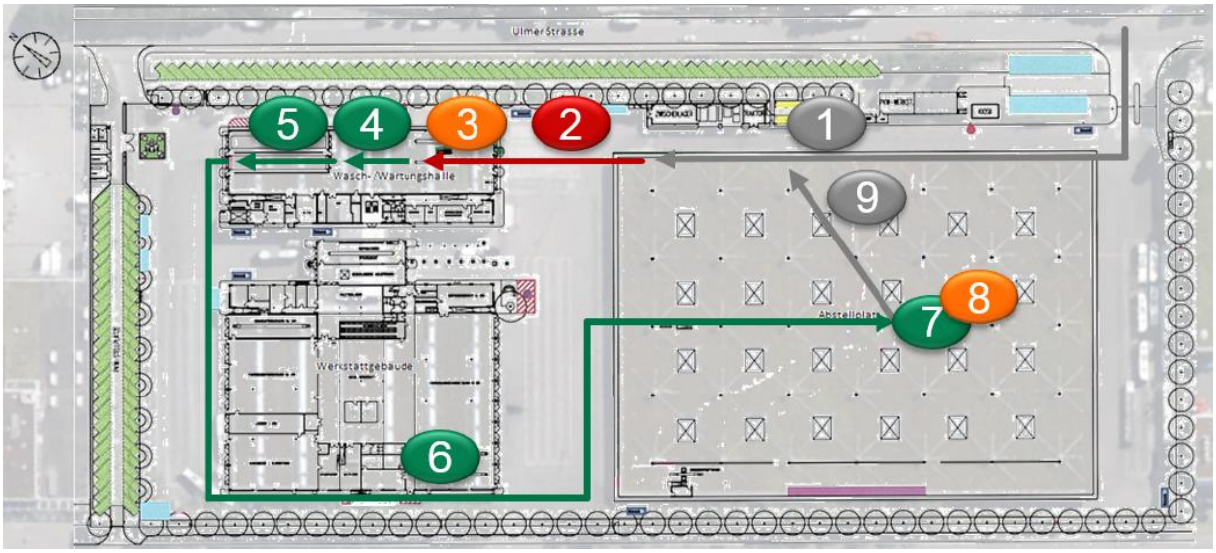

Figure 1: Potential for automation

	Function	Time (min)	
1	Bus is driven into the bus depot by bus driver		
2	Drive by maintenance personnel to maintenance hall including road test	1	Not automatable as prescribed by law (owner responsibility, SSB-specific)
3	Fuelling, cleaning	7	Only automatable using robotics
4	Drive to washing system	0.5	Automatable under manageable conditions
5	Washing	4	Automatable under manageable conditions
6	Drive to parking area	3	Automatable under manageable conditions
7	Parking the vehicle	0.25	Automatable under manageable conditions
8	Vehicle supply (electric power, compressed air)	0.25	Only automatable using robotics
9	Retrieving the next vehicle	2	Not considered

Table 1: Current processes at the depot and possibilities for their automation

2.2 Legal and technical requirements for vehicle and depot

The defined area of a depot today already provides protection against unauthorised access and therefore allows autonomous driving without the need for any legal changes. Classifying the depot in line with StVO

for controlling buses is therefore sufficient. The permitted driving speed is less than 10km/h and thus also approved in line with the Vienna UN Agreement[1].

In order to autonomously perform operational processes, various requirements must be fulfilled. The following requirements must be considered:

- Automation of the operational processes is to be made possible with the help of StVO-compliant means, since a development of a custom build system is not independent of a specific manufacturer. The legal boundary conditions call for non-discriminatory tendering.
- Ensure that no additional central controls or technologies are required in the depot.
- Obstacles (vehicles, persons, rubbish bins, etc.) must be detected and circumnavigated or the bus must stop in front of them (safe state).
- The buses must be able to automatically switch off upon reaching the parking position (ignition off, lights off, …).

3 Comparison of implementation approaches

3.1 Automation of the vehicle

Today, the industry already has various implementation solutions for automated driving. Possible approaches include rail tractors, automated guided carriage vehicles (AGV), track-guided vehicles, guidance systems, track buses, conveyor belts, semi-skilled/ tutored buses and autonomous buses.

The implementation ideas were compared within the study and assessed regarding the required implementation efforts (retrofits, modifications, StVO compatibility and practicality) (see Table 2). In modern vehicles, driving assistance functions already actively intervene in longitudinal and lateral control. The autonomous bus should therefore be considered as the variant to be implemented for this case. However, this solution does have the disadvantage that not all SSB buses are electrically powered today, and this would therefore entail considerable retrofitting efforts.

[1] Convention on Road Traffic, Vienna, 8 November 1968. United Nations. Acceptance of amendments to articles 8 and 39 of the convention. April 23, 2016.

	Retrofitting of vehicles	Number of buses for retrofitting	Modification of depot	Implementation possible as per StVO	Control of lane	Weather conditions	StVO bus operation in field	Site implementation
Rail tractor								
Automated guided vehicle (AGV)/ Carriage trolley								
Track guide								
Guidance system								
Track bus								
Conveyor belt								
Autonomous tractor								
Tutored/ Semi-skilled bus								
Autonomous bus								

Good		Average		Poor	

Table 2: Evaluation matrix for vehicle automation

3.2 Solutions for the washing system

The washing system automation was considered separately (see Table 3). A drive-through car wash arose as the solution here – as already used today at the depot. It has higher throughput compared to a portal system or a car wash with a conveyor belt. Unlike the portal system, no shunting work is required and difficult-to-automate backward movements are not required. In case of any problems with the system, it is easy to turn off the vehicle.

	Autonomous driving possible	Stop+Go during washing	Washing system throughput	Space requirements	Stationary vehicle
Portal system					
Conveyor belt car wash					
Drive-through car wash (currently in place)					

Table 3: Evaluation matrix for washing system automation

3.3 Hangar lane selection

After weighing up the alternatives, only a lane signal solution is conceivable for the drivers for parking the busses on-site. All other solutions, such as a traffic light array and rotating barriers are not compliant with StVO or require additional mechanical components.

	StVo-compliant	Modification of depot	Identifiable under snow	Identifiable at night	Identifiable in deep snow	Simple evaluation
Lane signal						
Traffic light array						
Drive-through digit sequence						
Rotating barrier						

Table 4: Evaluation matrix for parking automation

4 Economic potential

Automating operational processes makes it possible to reduce personnel costs and even allows employees to use the time gained to perform higher-value activities that are currently kept short due to time constraints.

As the vehicles are currently being driven by the maintenance personnel, the gross salary of a technical maintenance employee of € 2,200 per month was used to determine the economic potential. An additional 25% night shift premium and 28% employer contributions were included in the calculation for the daily service which takes place between 17:00 and 02:00. As a result, the arising personnel expense amount to a

total of € 42,000 per year. Based on these personnel costs, the automatable operational processes of SSB were examined and their potential savings shown in

2. The figure gives the costs per year for a) 150 buses per day and b) 50 buses per day.

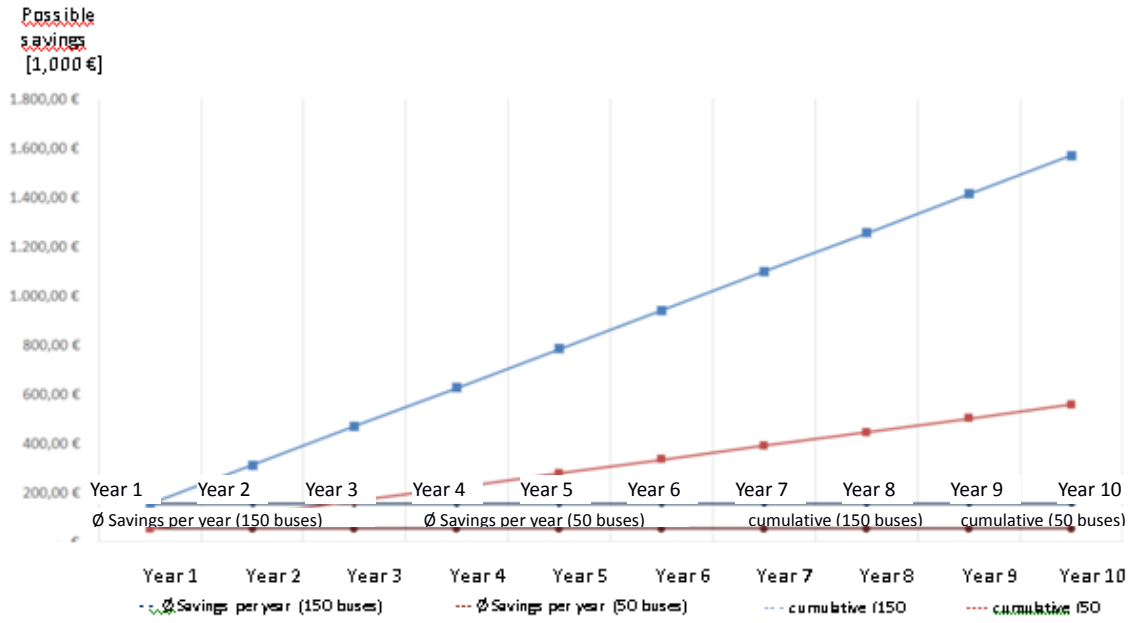

Figure 2: Potential savings (annually and cumulative) for autonomous driving at the SSB bus depot in Stuttgart-Gaisburg

5 Implementation at the depot

The results of the study verify the basic technical feasibility of autonomous driving at the depot. It is possible to operate the vehicles using assistance systems. It is also feasible to detect the surrounding environment by means of currently available sensors (camera systems) to identify obstacles, lanes or signs. However, there are still individual work steps that need to be performed manually. When planning new depots, there is a list of points to be noted to enable automation. On the other hand, use of autonomous systems within a depot always requires further consideration of possible hazards and risks.

6 Conclusion

The potential for automation was determined at a depot as an example. However, there are still many open questions that now need to be checked when it comes to the implementation. These questions include both legal and economic issues. The assessment of personnel costs represents only part of the possible costs. Possible cost for retrofitting the vehicles or the depot and additional investment costs were not investigated.

The SSB is planning an initial test at the depot in cooperation with partners from the industry in order to further examine possible technical solutions and also to check the economic efficiency of such a solution.

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After passing his degree at the 'Berufsakademie Stuttgart' as a mechanical engineer, Mr. Markus Wiedemann has worked at NEOPLAN Bus Company in Stuttgart. Amongst his tasks, he has been working in R&D for public transport buses, production manager for Starliner buses and finally as the responsible engineer for all public transport buses and alternatively powered buses.

Mr. Wiedemann is the responsible Senior Manager for all vehicles with rubber tires at Stuttgarter Strassenbahnen AG in Stuttgart since 2002. In his scope of work, he has been the project manager for the CUTE (Clean Urban Transport for Europe) project in Stuttgart and all subsequent projects involving electrical driven buses.