Automation Potentials in Public Transport based on a Depot Model

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Abstract: This paper examines the automation of public transport depots and the associated opportunities. Furthermore, the benefits for public road operations through a step-wise transferability of these depots developments is introduced. To this end, we first analyse which areas of public transport are not yet suited for the unrestricted use of fully automated vehicles, before motivating why depots are well suited for this purpose. In the following, the operations at two different depots and the previous work done so far are presented and abstracted in a generic model. For the description of the model, modeling methods are introduced and a graphical notation, defined by the unified modeling language, is applied. Based on the developed model a structured analysis of which operations may be automated and how savings might be achieved is enabled. Finally, the transferability to the operation on duty is discussed and the need for early inclusion of this consideration is highlighted.

1 INTRODUCTION

The hype about automated driving is increasing continuously, in the field of passenger cars as well as for commercial vehicles. According to (Altenburg et al., 2018) automated driving will prevail slow, but nevertheless up to 70% of the vehicles will be equipped with a high grade of automation until 2050. This includes the city pilot, where the driver temporarily leaves the driving task completely to the vehicle. As already discussed in (Brenner et al., 2019), the use of Advanced Driver Assistance Systems (ADAS) provides several advantages, which should be transferred to the public transportation sector. Therefore it is important to address the benefits that transportation companies could get out of this development too.

Particularly areas of recurring processes offer the chance for a step-wise approach to a fully automated operation. Suitable starting points are characterized by a lower-variance environment and derived from infrastructural features or special use cases. Once potential areas of application are identified, the economic feasibility of automation has to be evaluated, taken into consideration whether associated advantages will be enhanced or weakened by further automation in other areas. In public transport, for example these characteristics can be found in the fixed routes, the known schedule and the infrastructural characteristics, as outlined in the following section.

2 AUTOMATION OF COMMERCIAL VEHICLES AND PUBLIC TRANSPORT

Depending on the degree of automation, different levels of automated driving are defined by the Society of Automotive Engineers (SAE) (SAE, 2019), especially for cars and commercial vehicles. Level 4 of this definition means that a driver is no longer needed to fulfill the driving task in limited conditions. Level 5 will even replace the driver constantly.

In the commercial vehicle sector, several advanced driver assistance systems (ADAS) are already available today. These include passive, so purely warning, and active, therefore intervening, systems. Passive systems are lane departure warning and turn collision warning systems, where the former warns the driver when the vehicle exits the current lane and the latter warns from collisions with pedestrians or cyclist in the vicinity of the vehicle. Active lane keeping functions, Adaptive Cruise Control (ACC) and advanced emergency breaking functions are examples of already available active systems. These technologies are available from suppliers (Robert Bosch GmbH, 2021) as well as in new vehicles on the market (Daimler, 2021).

In case of public transport, with one focus on the automation of trains, trams and metros, automation levels were also defined through the Grade of Au-

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tomation (GoA) levels (UITP, 2019). Thereby level 2, 3 and 4 include different degrees of operational automation. Compared to the SAE levels, the focus of the GoA levels is more on the automation of the infrastructure, such as through feedback devices at the tracks and corresponding external systems for generating and processing the control signals.

For a reliable operation, it is necessary to ensure the predictability of events and situations and to enable a safe operation of the vehicles. This applies on the one hand to the planned route of the own vehicle, which is in general defined by a starting point and the desired destination. In the special case of public transport, the advantage is that the route is fixed during a circulation and the stops are predefined. Operation of vehicle fleets brings further advantages, as they offer the opportunity to gain extensive knowledge, by recording data and acquire experience at any time of the day or year for a wide range of vehicles. By knowing the route and the conditions that occur there, certain situations can be ruled out or limited during operation. This reduces the number of variants and the system can be better adapted to typical situations.

Unfortunately, the current legal requirements, for example in Germany, forbid the unrestricted operation of driverless vehicles on public roads (Krampitz, 2020). But starting with a driverless operation of the automated vehicles on restricted areas such as depots as analysed in (Brenner et al., 2021) or bus rapid transit (BRT) the first test fields are found. To further reduce the number of difference and unpredictable situations, closed-off areas as depots are obvious candidates. Due to the repetitive processes, they're already today ideal starting points for automated driving sequences. This makes it possible to test the systems under simplified conditions today and to generate large data sets for a comprehensive evaluation and the further development steps.

3 GENERIC MODEL OF PUBLIC TRANSPORT DEPOT OPERATIONS

While autonomous cars have been a hyped topic for decades, the automation of public transport has been a marginal issue. However, the idea of this being a sidelined topic is considered as outdated. Quite the contrary, an growing number of research projects, papers and publications are appearing (for example (Tirachini and Antoniou, 2020), (Drescher et al., 2021) or (Intelligent Transport, 2021)), accompanied by an increasing attractiveness of the research field around automated trams. Easily explained by the amount of positive enabler of automated commercial vehicles, such as an higher safety and flexibility or filling in the lack of qualified drivers (Brenner et al., 2019). In order to profit from this hype for the automation of public transportation depots, the current operations on depots have to be investigated, the automation potential identified and a well-structured basis for further analysis with regard to automation established .

On the one hand, the automation of trams involves a lower degree of freedom while calculating automated driving movements. The lateral control is handled by the rails and guidance system. On the other hand, the ratio of employees to passengers is more significant in case of buses. Since the economic use case of the latter is more attractive, buses should not be disregarded. Therefore, in the following, the operations for trams are presented first, followed by those for buses, in order to derive a generic model of public transportation depots.

3.1 Current Operations on a Tram Depot

To start, we focus on the current operating tasks for trams, exemplary introduced for the depot in Potsdam (based on section 6), but attention is paid to a transferability for the processes on bus depots.

The most common procedure at the tram depot is composed of sanding and, if necessary, washing of the vehicle. The sequence consists of 9 steps (see also table 1 and fig. 1), starting with the return of the tram by its driver at the end of his shift. The tram is parked at the (interim) parking lot (1) and gets picked up by a shunter or maintenance staff to various stations (2) for different services, such as sanding, washing, etc (3-4). After completing all the services the maintenance staff drives the tram to the parking hall (6) and parks the tram for the night (8). During this time span further services, like interior cleaning, are possible (7). This operation sequence is completed by the start of the next shift of the tram driver, leaving the depot (9).

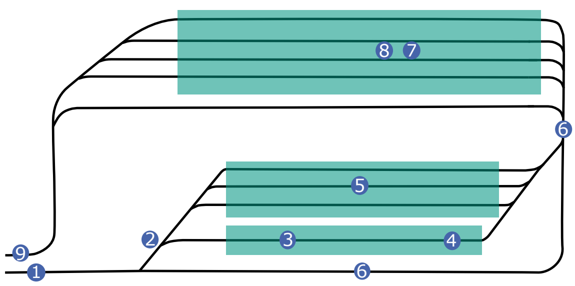


Figure 1: Abstract representation based on the depot in Potsdam, Germany.

Table 1: Overview of operation sequences on the depots for trams and buses and its responsibilities.

No.	Operation Sequence	responsibilty
1	Entry of tram/bus	driver
2	Drive to stations for services (maintenance hall)	shunter/staff
3	Refilling Resources (e.g. sanding/refuelling)	shunter/staff
4	Washing	shunter/staff
5	Workshop	staff
6	Drive to parking hall	shunter/staff
7	Interior Cleaning and further services	—
8	Parking and shut down	shunter/staff
9	Exit of tram/bus	driver

Although the described sequence is the most common one, there are various other alternatives. One example occurs in case of a damage report by the driver while returning the tram to the depot, which results in the tram driving directly into the workshop (5). The depot of Potsdam has two different types of workshop tracks. Some allow passage after finished workshops and can therefore be used for minor repairs. The others are used for major repairs, because the tram has to be shunted in an elaborate way for returning to the main tracks. After the completed repair, the tram either is directly parked or also needs additional service.

3.2 Current Operations on a Bus Depot

The operating procedures at bus depots have already been investigated several times. While (Lauth et al., 2019) focuses on the processes for electric bus fleets, (Brenner et al., 2019) and (Brenner et al., 2021) investigate the operations for bus fleets with combustion engines. The facilities and the layout, under optimal conditions, such as a rectangular property, are described in detail in (VDV et al., 2016). Based on this, an abstract representation was sketched and used to illustrate the operation on bus depots (see fig. 2). In addition, the current most common steps were highlighted, which were also elaborated in (Lauber et al., 2019). Started by the return of the bus by the bus driver (1) and the drive to various steps by a shunter or maintenance staff (2). Different services are provided, such as washing or in case of vehicles with combustion engines also refueling (3-4). In case of damage, the bus is driven to the workshop (5) but the service ends with the drive to the parking lot anyway (6) and for electric vehicles with the service "charging" (7). After the parking for the night (8) the bus driver picks up the bus for the next shift (9). So despite the differences between bus and trams, the operation steps for bus depot are also covered by table 1.

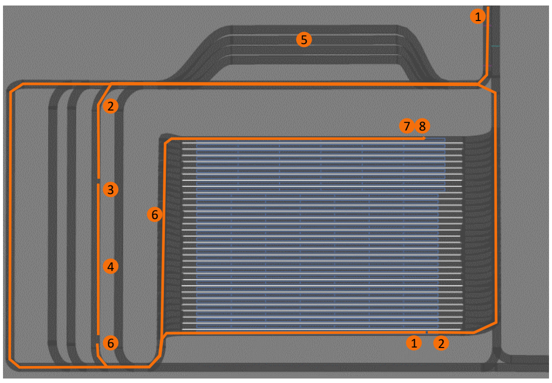


Figure 2: Abstract representation of a bus depot based on the recommendations of (VDV et al., 2016).

3.3 Generic Model for Depot Operations

For transferability of the insights, a generic model is developed. In addition to the various instances and their interfaces, the model provides the information to be exchanged as well. Thereby the findings become adaptable to other depots. Thus, every depot operator may place his depot as part of the overall, generic model and assess which aspects are suitable for automation and should be focused on. Furthermore this placement provides the operator with a structured overview of the information required in the further procedure of his automation project.

As already derived in section 3.1 and 3.2 and clarified by the summary in table 1 there are no major differences for the operational depot processes for trams and buses, they only differ in the details of the services. Unfortunately, the two previous descriptions do not form a solid basis for structured analyses. A generic model, in contrast, provides the necessary structure for further investigations of the processes. This model should be based on the General Model Theory according to (Stachowiak, 1973). A subject, motivated by a certain purpose, observes the reality and depicts it as an model. The model has the following three characteristics:

- Depiction: A model always depicts the original. It is never identical to the original.

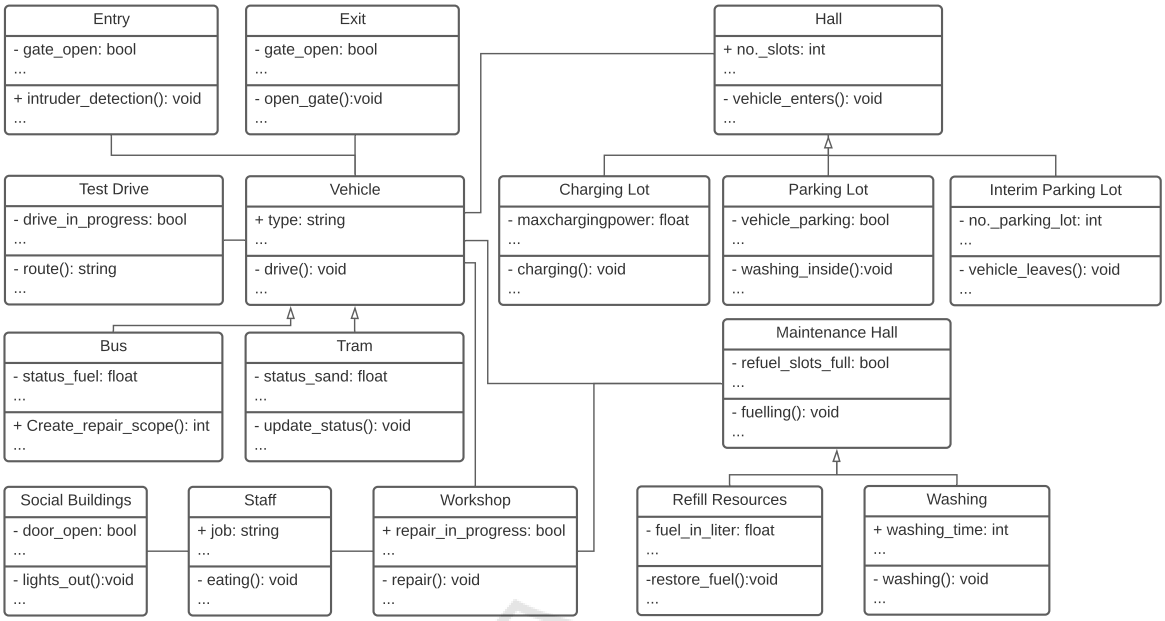


Figure 3: Model of public transportation depot through depiction as a class diagram.

- Abbreviation: A model never contains all features of the original.
- Pragmatism: A model is not unambiguously assigned to its original.

By mapping the depot to a class diagram according to the defined unified modeling language (UML), these three properties are fulfilled. Only relevant properties of depots will be represented as a class diagram. Therefore, no conclusions about a specific depot are possible.

The correlations between the individual instances are clearly apparent from the class diagram, shown in fig. 3. Required information, communication interfaces or similarities can be identified. An assessment of the automatibility of each instance is possible. For instance, the processes of `tram` and `bus`, both sub classes to the parent `vehicle`, has already been described in section 2.

Since the base class `vehicle` has relationships to the other classes, the two sub classes `bus` and `tram` share these connections too, although they may have different characteristics. Thus the `vehicle` passes the entry and exit, an electric `bus` would be driven to a `charging lot`, while a `tram` would be parked at the `parking lot`, both part of the parent class `hall`. Also both vehicle sub classes could be driven to the workshop by a `staff`. In order to provide an accurate overview, fig. 3 not shows all inheritances, such as the different options of power trains for buses, e.g. electrified, combustion engines, hydrogen-based or hybrid variants. Also the class of `staff` could be broken down into various child classes for more details.

By having a detailed look into the attributes and operations a deeper understanding of the required communication interfaces is given. In case of a needed refuelling of resources in the maintenance hall, specific information about the vehicle has to be provided. For instance the sanding level `status_sand` (in case of trams) or the fuel level `status_fuel` (in case of buses) has to be transmitted by `update_status()`. Possible implementation options for permanent communication interfaces are discussed in (Brenner et al., 2021) and will therefore not outlined in detail.

However, in order to evaluate the operational processes in their entirety and the benefits of the automation, two further forms of representations will be derived.

4 DEPICTIONS OF DEPOT OPERATIONS FOR STRUCTURED ANALYSES

With regard to an evaluation of both the automatibility and the associated benefits two approaches seem to be essential. For the former concern a depiction of the whole operation processes seems a right approach. For the second issue individual scenarios need to be considered. A model showing the diversity of variants of the scenarios builds a good starting point.

4.1 Depot Operations as a Circular Representation

For an evaluation of the operational processes in their completeness, a representation showing the entire process at the depots is suitable. Depending on chapter 3.1 and 3.2 it is obvious, that the processes are repeated for each vehicle every day. Therefore, a circular representation is appropriate. By picking the core parameters out of fig. 3 and taken the respective operation steps into account we developed a generic cyclic representation (see fig. 4). The respective daily operation of each individual bus at the depot can be summarized by the five steps: Entry, Status, Service, Parking, and Exit.

4.2 Automatability of Depot Operations

The generic cyclic representation enables a initial basis for a well structured approach to the evaluation of the automatability of the individual operation processes. For this purpose, each step is examined in more detail and options for an automation are derived.

1. Entry: There is a need of well defined handover areas, where the driver leaves the vehicle and the "automatic mode" is started. These handover areas have to be unambiguously marked and if necessary cordoned off by automated gates or retractable bollards (for higher safety against possible intruders).

   Due to the missing of the driver the authorization of the vehicle needs to be checked automatically (depending on placement of handover areas). Possible solution are installed easily by small adjustments to the vehicle and the infrastructure. By an installed camera either the infrastructure is able to identify the vehicle uniquely by f.e. the plate. Or the vehicle scans a code and registers at the entry. In each case a match between the individual vehicle and the list of admissions is necessary. (Brenner et al., 2021)

   After the entry the depot operating system needs to be updated about the current position of each vehicle (Brenner et al., 2021). While the common way for trams is based on segments via sensors in the track itself, various types of implementation exist in case of buses. Besides the conventional localisation via GNSS, self-positioning of the vehicle (Noda et al., 2011), WLPS (Zekavat and Buehrer, 2012) or RFID (Ngai et al., 2007) are also promising options. Each implementation variant offers its own advantages and disadvantages, resulting in a suitability depending on the depot layout. Probably a combination of several possibilities is appropriate to exploit advantages and balance disadvantages. For instance, the GNSS inside the parking lot could be supported by low-cost RFID chips.

2. Status: Irrespective of the absence of a driver, the depot operator needs to get informed about the status of the vehicle. Previously the driver notified about the state of charge (SoC), fuel level, the need of the vehicle to get washed, minor or major damage and so on. With self-driving buses this status has to be updated either by the driver at the end of his shift or by itself. A promising method is component monitoring or predictive maintenance. Both can be realised via AI-based anomaly detection (Chalapathy and Chawla, 2019). To recognize the damage to seats or lost items as an anomaly and thus report a need of action could be conceivable. It is necessary to determine which information has to be available for a smooth workflow. Therefore the data can be stored in a status vector or database and queried by the depot operator or management system.

3. Service: Depending on the queried status, the planning and execution of the respective services follows, what often consists of several subprocesses. The most common service includes the drive to the maintenance hall, the refuelling of resources, the exterior cleaning and finally the drive to final parking position for the night.

   For executing of all those subservices driving a predefined route and highly accurate stopping at each service station is required. (Mercedes-Benz,

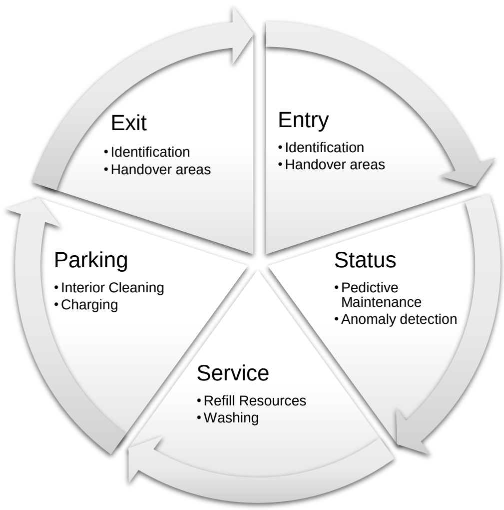


Figure 4: Representation of the daily operation processes on bus and tram depots arranged with focus on the cyclic behaviour.

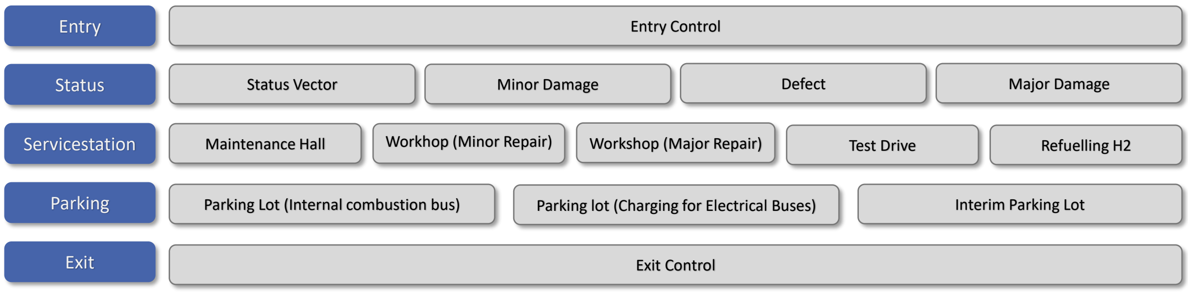


Figure 5: Morphological matrix of the generalized Model of the daily operation processes on bus and tram depots.

2014) in 2014 and (Verkehrswesen, 2016) in 2016 have shown that technology is already capable of the fulfilment of those requirements. In both cases the vehicle drove a specified route by itself, including stopping at specified positions.

For underlining the request of highly accurate stopping the washing and charging process are mentioned. In case of cleaning self-driving vehicles, the ”moving part” should be realised by the washing system. The automated vehicle, due to the implemented and learned functionality, will avoid the collision with an (moving) obstacle. Therefore, for this process, the associated safety function would have to be deactivated to avoid the collision with the car wash component. As this will lead to safety-critical situations, once maintenance staffs are present, it should be prevented to disable safety-relevant functions. Therefore, it is preferable that the washing procedure is carried out for a stationary vehicle, which is parked at an predefined position (Verkehrswesen, 2016).

But also in case of electric buses an impaired accuracy of the stop position while charging could influence the efficiency. (Walzel et al., 2016) an future work deal with different concepts for automated charging and their challenges including the required accuracy and the difficulty of shifting.

4. Parking for the night: The parking time during the night offers the perfect period for charging electric buses. Depending on operating strategies and the infrastructure, different charging methods are possible. In addition to common plug-in charging, there are also the possibilities of inductive and conductive charging methods. They differ mainly in their charging power, their power loss, bus also in the feasibility of automation and the costs of the implementation. These different charging methods have already been described in depth for example in the mentioned literature (Walzel et al., 2016) and will therefore not be considered in detail. The resulting strategies are described in more detail in (Randhahn and Knote, 2020). Conductive charging offers the advantage of charging at terminal stop, while inductive charging even offers the possibilities of charging at every stop. A challenge for inductive charging were the increasing losses with displacement of the two coils involved in relation to each other. Bus as mentioned before, self-driving vehicles enables a high degree of accuracy while stopping. Nevertheless the adaption to the infrastructure for this charging strategy (at every stop) entails the highest cost.
5. Exit control: Similar to the entry, the driver takes the control within the defined handover area, where the automated mode of the vehicle is turned off. But in contrast to the entry control at the beginning, now the correct takeover by the proper and assigned driver has to be checked before leaving the depot.

4.3 Depot Operations as a Morphological Matrix

Setting the focus on specific, individual processes, the generic cyclic representation is not suitable. For the envisaged evaluation with regard to an automation of whole scenarios, composed of several processes, a representation as a morphological matrix is appropriate. (Göhlich et al., 2018) has already shown, the morphological analysis is suitable for public transportation issues, by using it for the design of an electrical depot. In the following the methodology is adapted to the variety of depot process sequences. The morphological matrix provides a structured visualization for further analysis. In our case we derived the five functions with one to five options. For example, entry and exit only provide a single choice (see also fig. 4). But during the function ”status” a distinction between four options is possible. While the status vector contains constant as well as dynamic vehicle values, such as the fuel/battery level or the cleaning state, a distinction has be made between individual cases of damage. The categorization is based on ”roadworthiness” and ”road safety” (see table 2). If a vehicle is defined as

Table 2: Categorization of the three damage options according to roadworthiness and safety.

Damage Category/Option	road-worthiness	safety
Minor damage		
Defect		x
Major damage	x	x

still safe but not roadworthy, it may still complete the route or return to the depot on its own without a towing service. In the case of minor damage, the vehicle is withdrawn from operation on duty at an appropriate opportunity, but it may still be scheduled for service. The individual options for each functions are illustrated in fig. 5.

In the following for each function there must be at least one option selected, but a combination between the individual option is possible too. Without any restrictions this would lead to

$$n_{\text{sequences}} = 1 \cdot 4! \cdot 5! \cdot 3! \cdot 1 = 17.280 \quad (1)$$

possible scenarios. For not analyzing this amount of possible sequences, restriction have to be defined. An excerpt of those restriction is:

1. If a vehicle has a *defect*, option *minor damage* is not of interest
2. If a vehicle has a *major damage*, options *defect* and *minor damage* are not of interest
3. A *major damage* has to be repaired at the *Workshop (major repair)*.

After taking the restrictions into account, round about 80 different scenarios remain. For example, after reporting a defect, the subsequent visit to the workshop and the journey to the parking garage (see fig. 6). Using the representation of the depot operation as a morphological matrix, individual scenarios can be examined in detail with regard to their time and cost saving potentials, any gaps on automatibility that may occur or also their suitability with regard to a transfer to the public road.

4.4 Elaboration of Automation Benefits

For the elaboration of the benefits we, once again, use UML tools. The chosen scenario will be illustrated as a system sequence diagram (SSD). It offers the options to show interactions between objects and instances arranged in time sequences.

The used instances and interactions were drawn from the class diagram (section 4.1 and fig. 3), but provided with the mentioned time dependency. The instances are the busdriver, a shunter, a maintenance staff, the entry/exit, the workshop, the maintenance hall and the parking lot. For enabling a statement of the cost and time saving potential, fig. 7 shows the depicted scenario with employees (shunter and staff) as well as the automated case.

As fig. 7a shows the bus driver ends his shift by driving through the entry and parking the bus. In case of a defect, the occupation of the workshop has to be planned. As soon as a time slot is available in the workshop, a shunter is informed to catch up the bus. But after requesting a shunter, often waiting times occur until a shunter becomes available, as they build a limited resource of the depot. After successful handover to the workshop, the shunter is free again and ready for the next job. The vehicle is now in the workshop, a maintenance staff is requested, which again results in waiting and idle time. After the vehicle has been successfully repaired (which can take up to several days) again a shunter is requested to supply the bus with resources through the maintenance hall. Again, waiting times occur until a shunter picks up the vehicle. The vehicle is then supplied with the needed resources and, if necessary, gets washed. This process takes up to 10 minutes. The shunter ends his interaction with the vehicle by parking it in the parking hall. The scenario ends with the bus driver picking up the vehicle the next day and leaving the depot through the exit. The automated scenario (fig. 7b) primarily shows the absence of the shunter. As soon as a time slot is available the vehicle drives to the workshop and park at the assigned parking position on its own. Next, a maintenance staff is requested, for example by reporting the arrival by the vehicle to the depot. After the repair, the vehicle will drive directly to the maintenance hall on its own. As described in section 4.2, a complete automated supply of the vehicle would be possible, including refilling resources and washing. The vehicle finally leaves the maintenance hall and drives to its parking position for the night. The scenario also ends with the bus driver driving out of the depot through the exit.

A comparison of the two SSDs reveals a time saving of the scenario through automation. The idle time

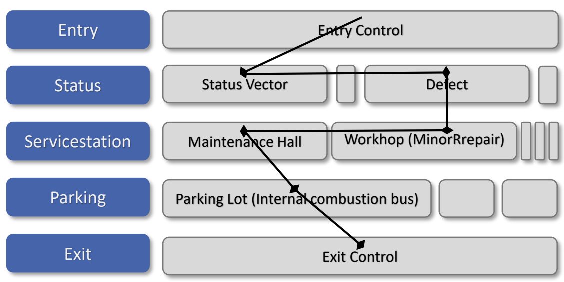
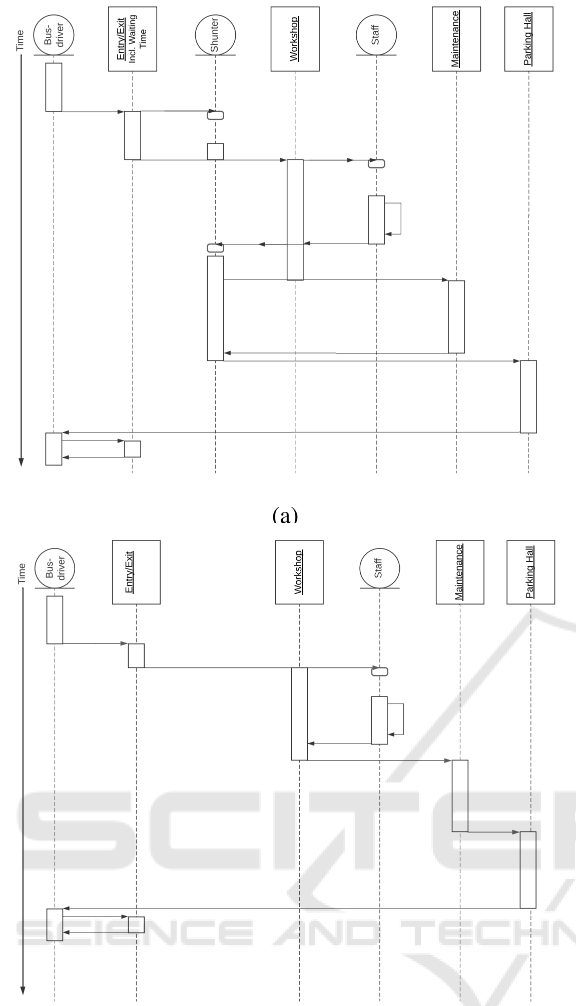


Figure 6: Morphological matrix of the generalized Model of the daily operation processes on bus and tram depots.



(a)

(b)

Figure 7: Sequence System Diagram of the scenario (see fig. 6 a) with personal (shunter and staff) and b) automated operation.

caused by the shunter is reduced to a minimum. Obviously the personnel cost can be minimized by elimination of the shunter. As elaborated in (Lauber et al., 2019) the personnel costs can be reduced by at least 120.000 euros per year for depots with a fleet size of 200 buses. In addition figs. 7 show the potential time savings, by eliminating the idle time for available employees. The workshop staff, who sometimes have to be scheduled into the overall process due to a lack of personnel, would have more time for repairs. This, in turn, can lead to fewer unroadworthy vehicles. Therefore, and due to the faster executed operational readiness of each vehicle, an automated operation will lead to a possible dispatching and provision of more vehicles in the same period of time.

5 TRANSFERABILITY OF AUTOMATION TO OPERATION ON DUTY

Numerous challenges still need to be solved before vehicles of SAE Level 4 or 5 can be operated in public transport on a daily basis. Since developments in the field of automated driving are progressing more slowly than expected, it makes sense to define intermediate developments in order to gather wide ranging experience. In the field of bus automation, there are already areas where the automation potentials analyzed for depots can be transferred. Examples of this are, on the one hand, given by existing infrastructural characteristics such as bus stops or Bus Rapid Transit (BRT) lanes. Knowledge gained through the depot automation can be applied, because conditions occur there which have already been discussed.

For example, a characteristic aspect of BRT is that the entire route, or a large part of it, is used only by buses and therefore there is no interaction with other road users such as cars, cyclists or pedestrians.(Volvo Buses, 2021) Thus, the operation is characterized by a dedicated, exclusive bus lane and therefore of an operation with fewer variants. In addition, the automated bus must be able to approach the stops precisely so that passengers can board safely. The Future Bus operated for several days on a BRT without human intervention, including navigation through tunnels and approaching stops with the required precision. (Verkehrswesen, 2016)

On the other hand, aspects that are covered by the generalized concept can also be used for the development of new functions and applications in the field of automation in public transport. The vehicle sensors

Figure 8: Extended representation based on fig. 4.

required for depot automation can be used for other applications on duty. This makes the vehicles suitable for the realization of systems and applications which constitute next steps towards fully automation. Up to now, automated vehicles have always driven alone in solo operation. Due to the already existing sensors through the automation, additional functions can be implemented with the help of additional software. One example of this is the Platooning of city buses.

Platooning describes the coupling of several vehicles to form a unit. These vehicles follow each other at a short distance from each other. From the point of view of the vehicle in front, the following vehicles represent a type of trailer that is not mechanically but electronically coupled. Therefore still a driver controls the first vehicle. The following vehicles are driven with the help of an electronic system for automatic vehicle guidance. Consequently the lead vehicle sets the trajectory and all following vehicles follow this this predefined path. (Kavathekar and Chen, 2012). This enables greater flexibility in public transport, as the coupling and uncoupling of buses can be used to react quickly to fluctuating numbers of passengers. Furthermore, a saving in personnel costs is conceivable, since not every bus needs a driver any more.

If the status vector of the vehicle is recorded by sensors, there is a chance to use it also for the predictive analysis of the components. This means that intelligent systems that are able to detect a fault, can also be used during daily circulation. By networking every bus of a fleet with the control center, the information obtained about the status of the individual systems can be transmitted directly and do not have to be recorded upon arrival at the depot.

Operation profiles and anomalies make it possible to generate a comprehensive overview of the operating status of each individual bus or tram in a fleet. In case of an error message or a conspicuous status value of the vehicle on the track, the networking of the vehicles can guarantee the most efficient possible procedure at the depot. This results from the fact that if necessary repair or maintenance work is known before the arrival of a vehicle, the operating procedures and spare parts procurement can be optimally prepared at the depot. In addition, it can be detected whether it is a minor damage, a defect or an major damage and the necessary procedure can be optimally planned. This includes, for example, a statement about the operational capability of the vehicle in its current condition. Based on this, a decision can be made whether the day's circulation can still be completed or that the vehicle should be taken directly to the depot to avoid consequential damage. This leads

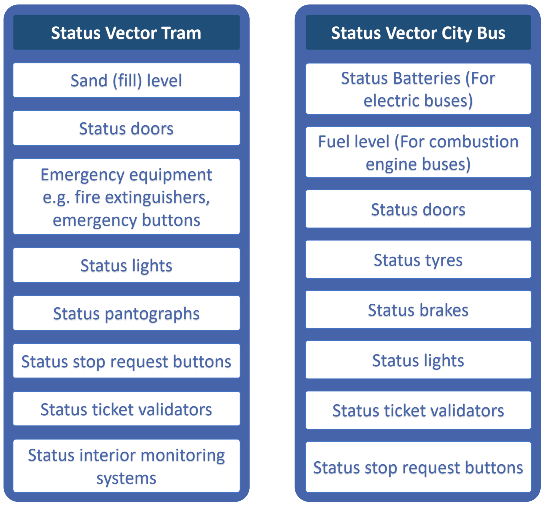


Figure 9: Extract from the status vector of a tram and a bus.

to time and cost savings. For the use of electric buses, this data exchange also supports an efficient charging management, as the charging status of each bus can be transmitted before it enters the depot.

To ensure safe operation, service personnel or the driver must check a variety of conditions of the vehicle. These are in particular the data shown in fig. 9 for trams and city buses. For example, information about the lights, the pantographs, the stop request buttons, the ticket validators and the interior monitoring systems is important for trams in addition to those mentioned in the Status query section in chapter 3.3.

For the automated update process during operation the monitoring of this vehicle data can be managed by using additional sensors or by evaluating existing vehicle protocols on the communication buses.

Through all the topics mentioned in this chapter, the generalized model presented in section 4.1 can thus be extended by an additional "on duty" section, as shown in fig. 8. This is intended to reflect both the further transferability and the need for close linkage of the specific topics. By implementing the systems for use in the field of depot automation and testing them in a closed environment, the first important findings can be obtained which are suitable for use in daily operation in the next step.

6 CONCLUSION

Automated driving on public roads faces a countless variety of diversity and challenges. Within this paper, depots are investigated as suitable starting scenarios for fully automated operation of trams and buses. A significant amount of the processes can be automated by smartly integrating the state of the art and science. Research that focuses exclusively on restricted areas such as depots could lead into a wrong direction. Thus, this paper addresses two key aspects to prevent this and to make research economically viable from the very beginning. First the automation potential and the saving potential has to be analyzed through scientific methods and subsequent analyses. In addition, the suitability of the transfer for operation on duty has to be considered. The insight of this paper is, that it is crucial to consider not only a single scenario or environment, such as the depot, but to ensure a future operation on duty, enabled with the chosen solution of automation. Furthermore, the information gathered on duty can be used for further optimization of the processes at the depot, using new insights. Following this approach, a first important step towards full automation of public transport vehicles can be made today in order to be better prepared for future operation and to ensure a faster market introduction and a higher acceptance and safety of the vehicles.

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