Further testing of ZEBs can help identify potential benefits and challenges. Elements such as grade, temperature, and weight can affect the power load and need to be a part of the testing (Mobility E3 and Eno Center for Transportation 2020).

CTE Findings

The author's team at the Center for Transportation and the Environment (CTE) has supported or is currently supporting more than 50 ZEB deployments across the United States, most of which involve BEBs. These deployments are geographically diverse, and include conditions ranging from high heat in the Southwest to extreme cold in the upper Midwest and New England. They also cover a variety of topographical environments, including settings where buses operate on routes featuring high grades.

For each of its ZEB deployments, CTE performs energy modeling activities prior to launch, and then tracks energy consumption and battery performance data while vehicles are in service. Even beyond extra power loads required to heat and cool the cabin, and driving up hilly terrain, CTE has observed that ZEBs can experience significant variability in energy consumption from the driver behind the wheel.

CTE's measurements found that inefficient driving behavior, particularly acceleration and braking, can reduce battery range by more than 25 percent. For buses that employ regenerative braking, poor use of the system minimizes potential gains. Eco-drive features, essentially automated acceleration and braking, would both reduce this variance and increase battery range (Xu, et al. 2016).

REDUCED CAPITAL AND OPERATING BARRIERS TO ZEB PROCUREMENT

Automation can reduce both capital and operating costs for a bus fleet. Optimizing vehicle charging to use as few chargers as possible allows for fleet electrification without additional operating costs.

Infrastructure costs are one of the more significant impediments to BEB adoption, as agencies typically procure a charger for each BEB they add to their fleet. These can cost anywhere from $20,000 to $100,000 for each yard unit, depending on vendor and capacity (Nelder and Rogers 2019). This cost does not include installation, which is highly situational and can cost as much as the unit itself, or more. Some agencies design their operations to have personnel on site overnight who can rotate buses through charging cycles, allowing them to manage with fewer chargers, which can reduce capital costs but drive up operating costs. However, CTE has observed that most agencies will instead procure yard chargers on a one-to-one basis with each new BEB. This is in large part because capital costs are supported by federal grant funding and are therefore easier for the agency to fund over the life of each bus than additional maintenance staff.

Transit bus automation can reduce costs by managing charge cycles with less human intervention, eventually allowing agencies to use one charger for multiple buses. Plug-in chargers currently lack the capability for automated docking, but demand for automation of other vehicle platforms may incentivize parallel development of that technology. Some startups are already developing automated plug-in technology, but these devices are in an early stage of development. Though overhead pantograph and ground inductive fast chargers are currently capable of automated docking and charging, both can cost half a million dollars or more per unit.

Transit agencies are planning to transition to ZEB fleets at a time when BEBs lack the range to replicate the duty cycle of every legacy CNG and diesel vehicle in their fleets. Vehicle range plays a major role in both the capital and operating costs of a BEB fleet. In order for agencies to maintain existing routes, which may be too long for BEB range, they currently need to either add expensive on-route charging infrastructure, maintain mixed fleets, or procure multiple buses per legacy vehicle to meet duty cycle requirements.

Depending on an agency's operating model, this can impose either additional operating costs from keeping more vehicles in service, or higher capital costs in the form of additional vehicles and yard space requirements for spare storage. Transit agencies that opt to either procure more BEBs than the legacy vehicles replaced or simply retain their old diesel and CNG vehicles as spares may potentially breach FTA's 20 percent spare ratio requirement. This is the ratio of vehicles operating in revenue service versus those held as reserves in an agency's fleet, and barring an FTA exemption for ZEBs, breaching the requirement significantly could put an agency at disadvantage when pursuing new grant funding.

Operationally, the increase in reserve vehicles will demand additional yard space. Especially for urban agencies facing high real estate costs, expansion may prove challenging and costly to address. Alternatively, agencies can either wait for battery capacity to improve, which may run up against political considerations, or find additional efficiencies in operating behavior to increase range.

Automation can help address these challenges by allowing for more efficient storage of buses by parking them closer together and automating parking and recall. In FTA's STAR plan, Volpe assessed the potential impact both of in operational efficiency and cost savings from yard automation. While the analysis found a significant return on investment for the specific scenario used, it assumed a completely mature technology ready for mass deployment. Cost reductions on a $1 million 12-year investment for a fleet of 50 buses were estimated at $1.93 million, providing a net savings of $930,000 (FTA and Volpe 2018b). As the report states, the requisite enabling technology was not available on the market at the time of writing, and yard configurations and operations vary significantly between transit agencies. However, agencies can plan ahead to incorporate new efficiencies through yard design when thinking about future fleet characteristics. The report provided an example of more efficient parking configurations enabled through automation, shown in **Figures 1 and 2** below.

TELEOPERATIONS

Most yard automation benefits do not actually require full automation of the buses, with teleoperations technology offering similar capabilities. Teleoperations is the use of telecommunications technology to either remote-control a vehicle in real time (telepresence) or map a precise route for the vehicle, with automation managing maneuvers (path planning) (Ohnsman 2018). In both cases, vehicles require the same drive-by-wire capabilities that a fully-automated bus would, but may not require the same extensive sensor architecture and sophisticated automation software.

Freight and logistics firms are currently piloting the use of teleoperations technology in yard settings to reduce labor costs and improve safety (Ohnsman 2018). Rather than employing runners to move vehicles between the yard entrance, loading bays, and parking spaces, firms would instead use remote teleoperators to maneuver vehicles at low speeds around their facilities. These remote operators can activate any authorized vehicle, allowing them to achieve roughly the same efficiencies as complete yard automation. For a transit operation, this does not necessarily mean labor reductions, since most of the benefits achievable through teleoperation do not involve labor in the first place. Procuring fewer chargers and parking vehicles in much tighter arrangements are not labor-cutting measures. While there's a possibility some agencies may find areas where the technology obviates a few jobs, labor response will likely preclude that outcome. Agencies may also create new jobs involving remote operators at their central maintenance facilities. However, more analysis of yard operations on a multi-agency basis would provide a better picture of the impact from introduction of teleoperations.

Figures 1 and 2. Example of yard realignment through use of bus automation, with current conditions (left) and potential efficient re-configuration of the same rolling stock (right). (Courtesy of FTA's Strategic Transit Automation Research Plan)

The hardware is available today, and both 3G and 4G networks are capable of supporting latency requirements. However, current barriers for transit bus integration include electric drivelines with drive-by-wire capabilities, and accepted protocols for managing cybersecurity concerns.

TESTING FACILITY REQUIREMENTS

Unlike the private sector, which can often afford to sink tens or hundreds of millions of dollars into research and development of new technologies, funded either through investors or other profitable areas of firms' operations, the transit bus industry relies heavily on federal research dollars to fund development. Because FTA-funded development is expected to diffuse among hundreds of agencies with widely varying operating requirements, testing beyond the demonstration phase must address most, if not all, scenarios. Federal bus testing at Penn State University - Altoona has fulfilled this need for nearly forty years, but will need modernization to address a multitude of automation scenarios.

As part of the STAR plan, FTA released a report detailing requirements for automated transit vehicle testing, including all on-road vehicle platforms (FTA and Volpe 2019b). It lists all imagined required scenarios for transit vehicles, and accounts for test facility features, functionality and performance, safety, environmental resilience, human factors, and data collection and management. The report envisions testing for the following high-level scenarios:

- Transit Bus Advanced Driver Assistance Systems
  - Smooth Acceleration and Deceleration
  - Automatic Emergency Braking and Pedestrian Collision Avoidance
  - Curb Avoidance
  - Precision Docking
  - Narrow Lane/Shoulder Operations
  - Platooning
- Automated Shuttles
  - Circulator Bus Service
  - Feeder Bus Service
- Maintenance, Yard, Parking Operations
  - Precision Movement for Fueling, Service Bays, and Bus Wash
  - Automated Parking and Recall
- Mobility-on-Demand Service
  - Automated First/Last Mile
  - Automated Americans with Disabilities Act (ADA) Paratransit
  - On-Demand Shared Ride
- Automated Bus Rapid Transit

Though FTA has not designated any bus test center(s) for ADS technology, any future test centers should be designed to accommodate the FTA's priorities detailed in its test facilities report. Though yard automation is fairly straightforward in terms of scenarios development, heavy duty bus test centers would benefit from infrastructure that supports drive cycle testing. Steering and braking actuation controlled by ADS will be affected by bus stops, traffic signage, signals, and a variety of interactions with other road users, and a test environment needs to be able to simulate these scenarios to assess energy efficiency impacts.

FEDERAL FUNDING

FTA's STAR plan from early 2018 outlined a program of research and demonstration projects. As of this writing, none of the demonstration projects have been awarded, despite plans to do so in FY18 and FY19 (FTA and Volpe 2018b). Through its Integrated Mobility Innovation (IMI) program, FTA allocated $5 million for two demonstration projects in FY19: $2 million for low speed automated shuttles, and $3 million for advanced driver assistance systems (ADAS). Per its FY20 budget request and federal appropriations, FTA has not indicated plans to open additional grant opportunities for transit automation in this fiscal year.

The Federal Highway Administration (FHWA) awarded $60 million across eight projects for its Automated Driving Systems Demonstration grants program in 2019. Though several projects included automated low speed shuttles and light vehicles for rural and paratransit service, none of the seven projects proposing transit bus automation were awarded. FWHA has not publicly indicated whether it will launch a second round of the ADS Demonstration grants program in FY20.

Outside of FTA's research budget, there are currently no other programs offering significant public resources specifically for research and development of heavy-duty transit bus automation. The Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) offers opportunities annually to develop and demonstrate a multitude of vehicle technologies, including those discussed in this paper. However, those opportunities vary greatly from year to year and even where applicable, do not restrict funding categories to only heavy-duty buses.

COMMERCIALIZATION STATUS

Though several transit bus manufacturers have invested small amounts in ADS development to date, these investments are a tiny fraction of the tens of billions of dollars automakers and venture-backed firms have spent on other vehicle platforms. Low speed automated shuttle developers, such as Navya, EasyMile, May Mobility, Local Motors, and Optimus Ride, have drawn tens of millions of dollars in investments, and have been able to generate significant revenues through state- and city-led pilot projects (Mobility E3 and Eno Center for Transportation 2020). Some federal grants have funded shuttle projects for last-mile connectivity as well. Even with this degree of development, those vehicles have not demonstrated a near-term path to commercial viability.

Outside cost and ADS software capabilities, one of the more significant barriers to scalable transit bus automation is immaturity of electric driveline systems for these vehicles. FTA highlighted this challenge in its "market assessment" and "transferability of technology" STAR plan research reports. Standard bus drivetrain components simply are not conducive to automation, and integrating drive-by-wire capabilities require expensive workarounds (FTA and Volpe 2018a). Since drive-by-wire is foundational for any automation use case, the transit bus industry needs to focus greater attention on developing those capabilities.

Transit buses led the automotive industry on development of battery electric and hydrogen fuel cell technologies, but significantly lags behind the light passenger and medium- and heavy-duty trucking industries. Though this may mean a longer path to commercialization, the transit bus industry will reap the benefit of lower costs for ADS components, specifically sensors and highly-precise positioning systems. Manufacturers can also partner (and have partnered) with existing ADS technology developers to port their technology from other vehicle platforms to buses. Additional configuration is necessary, but much of the software development is transferable.

CONCLUSIONS

Additional gains are possible through vehicle-to-infrastructure communications (V2I) and transit signal priority strategies that reduce idle time, and allow for synchronized acceleration and braking. The collective transit industry should identify which automation use cases for heavy-duty buses are most feasible, and which development is likely to deliver industry-wide benefits in the near-term.

FTA and other researchers should also seek to quantify the benefits of developing and deploying specific ADS capabilities. The transit bus industry is profitable, but lacks the margins or capital to invest in ADS development at the scale seen in the light vehicle–both passenger and commercial- and heavy-duty truck markets. Therefore, agency customers ultimately need to demand ADS technologies before manufacturers will prioritize development, and supporting research would strengthen their arguments. In the meantime, increased federal funding for demonstration projects can generate increased interest for these projects, and development of federal testing center capabilities can prepare the industry. The transit bus industry can also seek partnerships with other USDOT administrations on mutual ADS development interests (e.g. FAA for airport ground transportation, FMCSA for heavy-duty platforms), to share resources and accelerate development.

The focus of this paper is ADS benefits directly impacting BEB adoption, but yard automation and ADAS features offer other financial and non-financial benefits not discussed here. Improved yard and on-road safety would not only offer social benefits, but also reduce collision liability and eventually insurance premiums incurred by agencies. ADS steering actuation features can facilitate precision docking, with accessibility benefits for the mobility-impaired. Reducing a driver's active engagement with steering, acceleration, and braking may also reduce job stress, and ultimately help with retention when agencies nationally are facing chronic driver shortages. Finally, labor concerns are unavoidable when discussing automation. Some agencies may seek ADS capabilities to replace or consolidate specific yard roles and reduce operating costs, even as drivers themselves are insulated due to the challenge of on-road automated operations. Agencies should proactively engage their workforce and identify explicit objectives that do not involve eliminating jobs, as these benefits almost certainly exist.

ADS technologies have progressed considerably from the components, costs, and trajectories cited by FTA and Volpe in formulating estimates for returns on investment from integration of specific ADS capabilities (FTA and Volpe 2018b). Subsequent research programmed for the STAR plan seeks to address some of those shortcomings, but more research specifically addressing the ability of ADS to augment zero emission objectives, would benefit the industry at-large.

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Next Generation Urban Maglev Systems: Design and Assessment of Optimized Maintenance and Repair Facilities for the Transport System Boegl

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ABSTRACT

The Max Boegl Group has successfully developed and implemented a next generation urban maglev people mover system. This paper will describe the conception, development, manufacturing, and status quo of the new maintenance, repair, and operations facility of the Transport System Boegl. Compared to conventional wheel-rail automated people mover systems, the running gear of the Transport System Boegl is inlying in the guideway. This aspect results in large advantages in sound emission as well as reliability but it is a challenge for optimized operation and maintenance. Optimium access needs to be granted to the running gear, which is the centerpiece of the TSB vehicle. To minimize occupied floor space of the maintenance system, a normal moving platform was eliminated during the conception phase. The Max Boegl Group developed a new style of operation and maintenance facility allowing the vehicle to autonomously drive in. Furthermore, the new concept guarantees the independent accessibility on all different vehicle levels. The design and the maintenance processes have been were significantly improved. The paper will report about the occurring challenges the Max Boegl Group has solved during the development process and describes the final solution. Moreover, it points out the additional benefits of the new operation and maintenance system. This system is designed not alone for light and heavy maintenance of the vehicles. In addition to rerailing, connecting of cars and efficient logistic processes are further benefits of the new system. Test data that demonstrates the achieved improvements will also be included.

INTRODUCTION

The company Max Boegl has developed a Next Generation Urban Maglev People Mover System during the last few years. With the further design development of a prototype vehicle and new operation and maintenance facility, the Transport System Boegl has reached its serial stage this year. As a single turnkey partner for the customer, Max Boegl delivers all subcomponents of the overall system. The following paper will describe the conception, development, manufacturing and status quo of the new maintenance, repair and operations facility of the Transport System Boegl. The paper also describes the design improvements as well as the improvement in the maintenance processes.

PRINCIPLE SYSTEM FUNCTIONS TRANSPORT SYSTEM BOEGL

The Transport System Boegl vehicles are divided into cars with length of 39 feet. Up to six cars can be set up for one vehicle. One car itself can accommodate a maximum of 127 people, depending on the interior layout. **Figure *1*** shows a schematic of the TSB system.

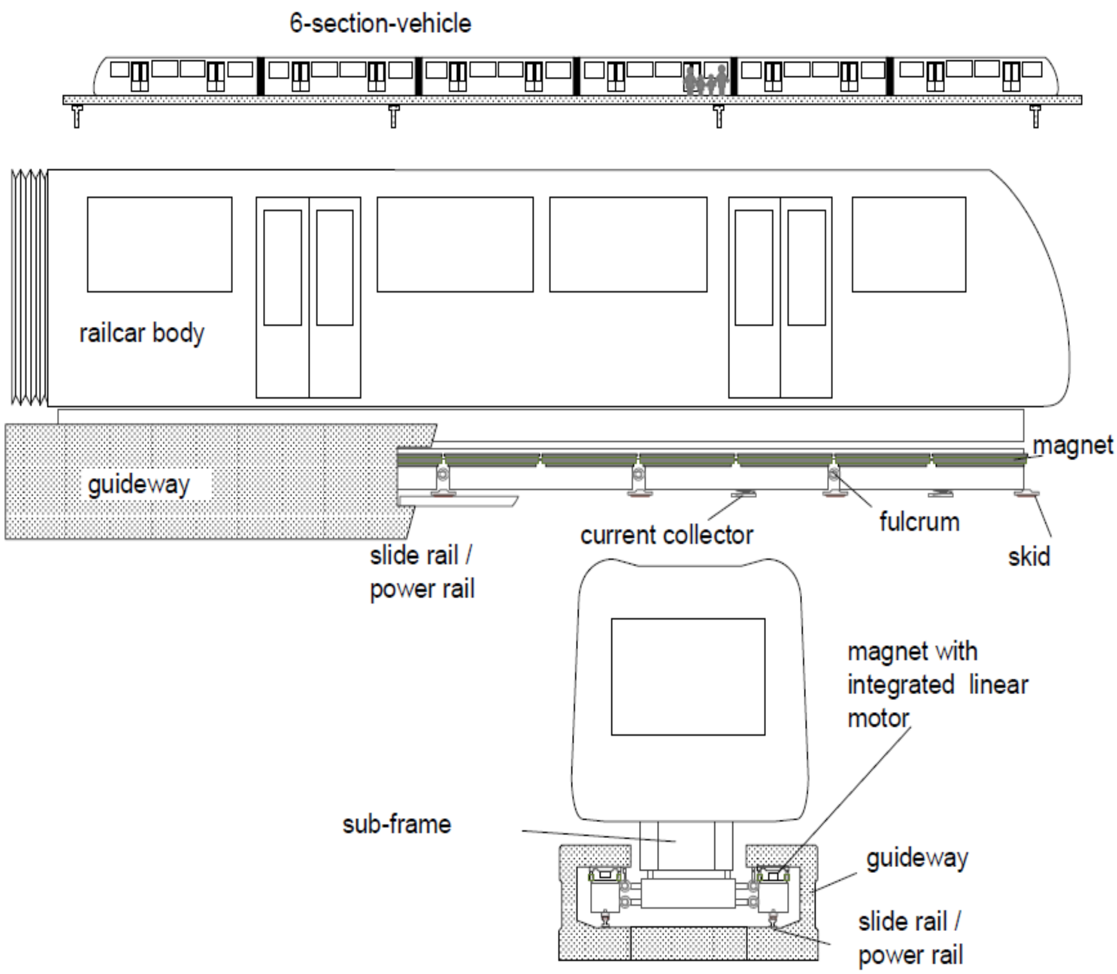

Figure 1: Transport System Boegl

The TSB vehicle drives with help of magnetic levitation technique inlying in a concrete guideway. The guideway is made as a passive system part and all drive components are designed into the vehicle. The aspect of the inlying running gear results in large advantages in sound emission as well as reliability but it presents a challenge for optimized operation and maintenance. The running gear, which is the heart of the system, presents the largest challenge.

In case of maintenance processes, four different components of the vehicle need to be considered. These are running gear, underfloor area, entrance area, and vehicle roof.

Figure *2* describes the maintenance levels of the vehicle. The main maintenance processes are in level 1, level 2, and level 3. To reach level 1 and level 2, a device that exposes the vehicle from the guideway is necessary.

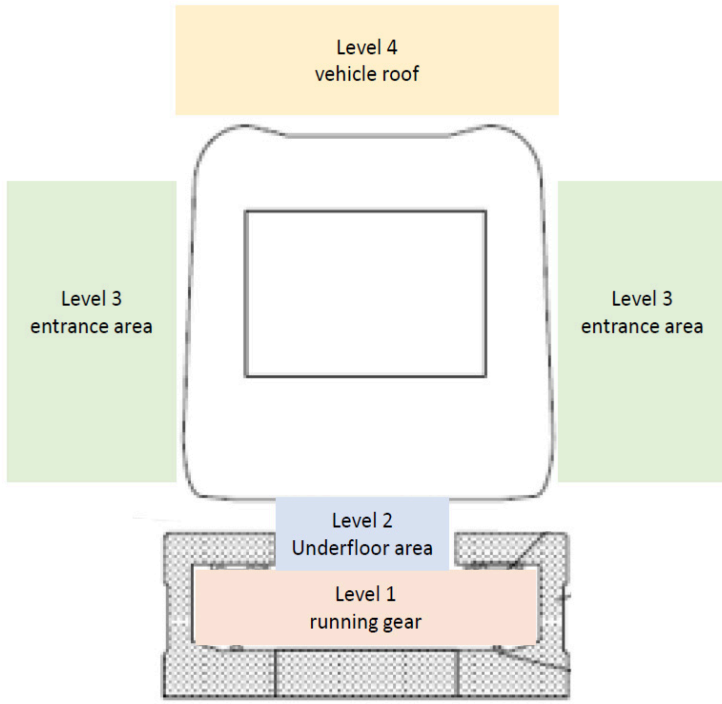

Figure 2: Vehicle maintenance areas

MAINTENCE FACILTY DURING TSB PROTOTYPE STAGE

During the testing phase of the TSB prototype vehicle a slight platform was used to expose the vehicle from the concrete guideway.

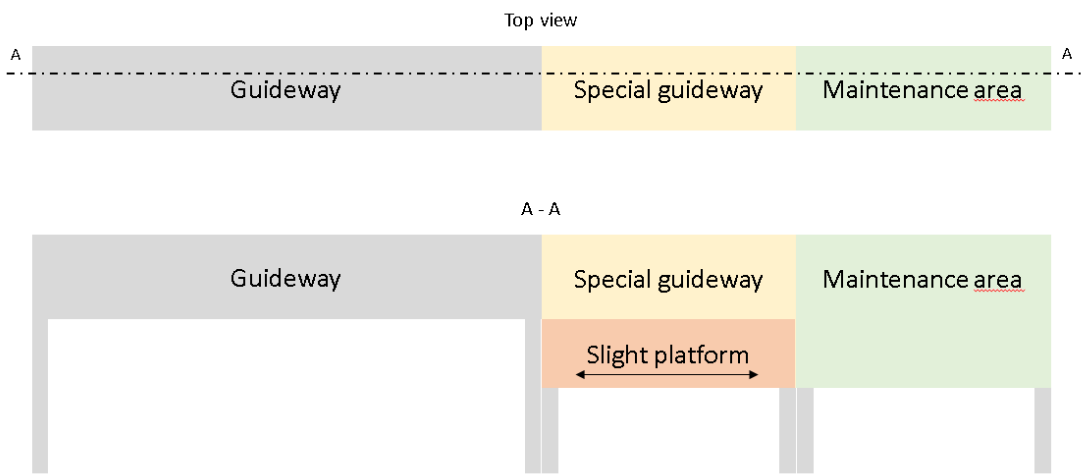

Figure 3: Maintenance concept prototype vehicle

Figure *3* describes the maintenance concept of the TSB prototype vehicle in detail. At the end of the normal guideway, there is a special higher guideway. At ground level, an axial movable slighting platform is located. In case of maintenance, the vehicle stops at this platform