Automated Bus Rapid Transit
A New Mode for High- Quality, High-Capacity Transit Corridors

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Executive Summary

Elected officials and transit executives today face operating crises due to the unprecedented COVID-19 pandemic, uncertain future demand, funding shortfalls, and competition from new services and technology. This paper describes a new technology that may help transit leaders address some of these problems as they look toward the future.

This paper describes a new approach to high-capacity transit, Automated Bus Rapid Transit (ABRT). ABRT uses state-of-the-art technology to enhance conventional Bus Rapid Transit (BRT). This document provides information for elected officials, transit executives, transit planners, and engineers who seek options to improve transit service while taking advantage of new technology.

Automated BRT enhances conventional BRT by leveraging various technologies of automated driving systems (ADS). ADS cover a wide range of capabilities, including:

- automated collision avoidance and emergency braking to increase safety,
- automated lane-keeping to allow running on narrow rights of way and sharp turns,
- automated precision docking, which allows level boarding at platforms to maintain an ADA-compliant gap and reduce damage to buses and platforms,
- automated smooth acceleration, deceleration, and speed control, and
- "platooning" which can create an electronically linked train of buses controlled by a single driver in the lead bus.

These ADS features have been tested and demonstrations are under way at several locations. The pace at which transit authorities are incorporating ADS features is accelerating. Robotic Research LLC and New Flyer Industries have rolled out a full-size autonomous battery electric transit bus. With funding from the Federal Transit Administration (FTA) and Connecticut Department of Transportation, the CTfastrak Hartford – New Britain BRT line will deploy several of these vehicles in revenue service in 2021.

This paper describes the general characteristics of Automated BRT and the advantages for transit operators and the traveling public. The paper provides an overview of the major automation technologies and the specific benefits that each provides.

Introduction

This paper aims to highlight the advantages of an Automated BRT system for cities that are planning transit infrastructure investments in anticipation of growth or to serve unmet transport needs. ABRT may also fit in cities that have begun to prepare for the deployment of self-driving technology. Automated BRT provides a scalable option for cities that plan for urban renewal and growth and that see value in integrating technology as part of a forward-thinking plan.

Comparing Current Modes of Transit

Light Rail (LR) is defined by the FTA as a transit mode that typically is an electric railway with a light volume traffic capacity compared to heavy rail (HR). It is characterized by:

- Passenger rail cars operating singly (or in short, usually two-car, trains) on fixed rails in shared or exclusive right-of-way (ROW);
- Low or high platform loading; and
- Vehicle power drawn from an overhead electric line via a trolley or a pantograph.[1]

LRT - Newark, NJ *Source: J. Lutin*

Bus Rapid Transit (RB) is defined by the FTA as fixed-route bus systems that operate at least 50 percent of the service on fixed guideway. These systems also have defined passenger stations, traffic signal priority or preemption, short headway bidirectional services for a substantial part of weekdays and weekend days. [1]

Most LRT and conventional BRT vehicles now have low floors throughout most of the vehicle which eases boarding and alighting. New LRT vehicles have Americans with Disabilities Act (ADA) -compliant boarding with floors level with platforms at each door to allow wheelchair access. Some BRT systems also have level boarding.

BRT Articulated Bus - Cleveland, OH *Source: J. Lutin*

Most LRT vehicle operators are located away from the boarding areas which makes on-board fare collection impractical. Although bus drivers for conventional BRT vehicles can collect fares, most systems are trending toward off-board fare collection or electronic fare collection which allows passengers to use all doors on the bus. This is particularly useful to help avoid COVID-19.

Landscaped BRT Station - Los Angeles, CA *Source: Google Earth*

In many ways, LRT and conventional BRT are similar, but each has distinct advantages and disadvantages. LRT has greater passenger capacity potential with a single operator, but the need to construct track, signals, electric power systems, and specialized maintenance facilities means that infrastructure costs will be substantially more than BRT.

Conventional BRT has less passenger capacity potential per operator than LRT, but significantly lower infrastructure costs and greater flexibility, since BRT buses can use lanes on existing streets as part of the permanent route or temporarily, as part of construction phasing.

On LRT systems, expensive trackwork and signals may be needed at terminals and junctions. BRT can use conventional traffic signals, roundabouts, and intersections at such locations.

Automated BRT has the potential to improve BRT performance to equal rail in most respects, but with lower capital costs, and greater flexibility to adapt with changing technology.

AUTOMATED BRT – THE TECHNOLOGY

Levels of Automation

There has been a lot of hype associated with automated vehicles, resulting in growing skepticism about the speed with which fully autonomous vehicles will be deployed. In the transit bus industry, however, real progress is being made based on sound scientific and engineering work.

Much of the press attention focuses on fully autonomous vehicles with the ability to go anywhere, any time (called SAE Level 5 vehicles). More practical (and ready to be deployed) are vehicles that can travel on predetermined routes, such as a dedicated lane for BRT. These are called SAE Level 3 or 4 vehicles. These vehicles have a human driver ready to take over if needed. The individual technologies described here carry out a specific function, such as tracking location in the lane or ensuring that the doors on the bus are close to the platform.

Adding the Right Technology

Buses have been retrofitted with automated driving technology in demonstrations over the past two decades, and bus original equipment manufacturers (OEMs) plan to incorporate various automated driver assistance systems (ADS) into future production models. Existing buses can be retrofit with proven technology.
For example:

- Drive-by-wire systems – Throttle, braking, and steering systems are modified to allow electromechanical activation.
- Imaging sensors – Cameras, radar, and lidar (light detection and ranging) sensors are placed on the vehicle to generate a virtual model of the operating environment in real time. Each type of sensor has its own advantages in terms of the type of objects that it can identify and the distance over which it operates.* The cost of these technologies has dropped dramatically, and performance has increased.
- Locating devices – GPS and inertial measurement units (IMU's) that incorporate gyroscopes and accelerometers to measure position, speed, and changes in motion. Other methods track distances from objects (buildings, signs, trees etc.) along the right of way.
- Stored high definition maps and landmark databases - to guide the vehicle from origin to destination and ensure it stays within the geofenced operating area.
- Autonomy systems – computing devices that accept inputs from sensors, maps, and localizing devices; fuse the data; and use artificial intelligence to provide directions to the vehicle by activating functions through the drive-by-wire system.
- Data recorders and analyzers – to collect and mine the data to evaluate vehicle and system performance.
- V2X communications (between vehicles and with roadside sensors) allow vehicles to communicate wirelessly with roadside units to exchange data, and with each other to enable them to operate collaboratively. An example is traffic signal priority in which Automated BRT buses can communicate with traffic signals to gain extra green time to avoid delays, or to slow down in advance of a red light.

* Examples:
  - Radar directly measures velocity, whereas lidar indirectly measures velocity
  - Each sensor has different resolution: camera being the highest, lidar being the middle, and radar being the lowest
  - Passive vs Active sensors: Cameras are sensitive to light conditions, whereas radar and lidar are not
  - Atmospheric conditions (rain, snow etc.) have different impacts on electromagnetic frequencies

Using Automation to Assist, not Replace, Drivers
In 2018, the Federal Transit Administration published the *Strategic Transit Automation Research (STAR) Plan* including an automated BRT use case.[2] The authors describe it as follows: "The automated Bus Rapid Transit technology package uses a full-size or articulated bus to provide BRT service without a driver on board the vehicle". … "Fully-automated BRT could be of interest to cities that are considering cost-effective alternatives to light rail transit or other high-capacity transit systems."

The goal of Automated BRT as defined in this paper is not to remove the driver but rather to provide technology that will enable transit authorities to transport more passengers safer, more comfortably, and with greater accessibility for the mobility impaired. Therefore, the definition of ABRT used in this whitepaper can include fully autonomous operation but does not require it.

Much of the automated functionality needed for ABRT to match LRT can be achieved with lower levels of automation, most of which has already been demonstrated on autos, trucks, and buses The ADS capabilities described here include:

- Automated Precision Docking
- Automated Collision Avoidance and Emergency Braking
- Automated Lane Keeping
- Automated Bus Platooning
- Smooth Acceleration and Deceleration

Most of the specific ABRT technologies described below are available now. An integrated ABRT deployment should be available soon.

ADVANTAGES OF AUTOMATED BRT TECHNOLOGY

Precision Docking
Disabled riders often need lifts or ramps deployed when boarding and alighting from buses. In addition to the inconvenience this creates for the disabled user, they often report feeling stigmatized by the delay created for other riders. The operational inefficiencies encountered by lack of access to BRT by disabled individuals are reflected by a vast difference in operating expenses. FTA data shows that nationwide, the average conventional BRT trip cost is $3.43 per trip while the cost for accessible service (demand-responsive paratransit) is $39.51 per trip.[3]

To provide ADA-compliant level boarding for all riders without using lifts or ramps, bus door openings must be no more than three inches (8 cm) away from the platform. Larger gaps can lead to passenger accidents and injuries, and smaller gaps can lead to bus and platform damage.

Consistently achieving that gap is challenging for drivers. This can be particularly difficult to achieve for rear doors, especially for articulated buses.

Automated systems that can aid the driver in precision docking were successfully demonstrated first at Lane Transit District in Eugene, Oregon from 2013 to 2015.[4]

Level Boarding in Wheelchair - Kansas City, MO
Source: KCATA

Additional testing of precision docking is being included in an FTA-funded demonstration by Connecticut Department of Transportation (CTDOT) on the CTfastrak Hartford – New Britain BRT line. New Flyer and Robotic Research will provide the buses for this project.[5] In 2020, The Kansas City Area Transportation Authority was awarded an FTA Accelerating Innovative Mobility (AIM) grant to partner with Robotic Research LLC to test precision docking technologies on the Prospect MAX BRT system.[6]

Automated Lane Keeping
Automated lane keeping has been successfully tested by the Minnesota Valley Transit Authority (MVTA) in 2010-2011.[7] MVTA operates express buses on freeway shoulders in the Twin Cities area. Automated lane keeping helped drivers keep buses centered on the narrow shoulders, improving safety, and reducing driver stress. In addition to facilitating the use of freeway shoulders, for Automated BRT, this functionality can reduce lane widths resulting in narrower rights of way, less paving, and lower infrastructure costs. This technology is particularly important for BRT systems that operate on narrow city streets.

Automated Bus on Shoulder - Minneapolis, MN
Source: FTA Lane Assist Technology Report 2003

Automated Bus Platooning
Sometimes called “leader-follower” operation can use connected vehicle communications (CV2X) to form trains or “platoons” Of buses. Leader-follower operation has been successfully implemented by Robotic Research on full-size trucks for the US Army under rigorous combat conditions. Related deployment is underway for commercial trucks. The Port Authority of New York and New Jersey (PANYNJ) plans to demonstrate bus platoons to increase capacity and reliability on the Exclusive Bus Lane (XBL), a contra-flow lane that carries 1,850 buses into the Lincoln Tunnel during the four-hour morning peak period each weekday.[8]

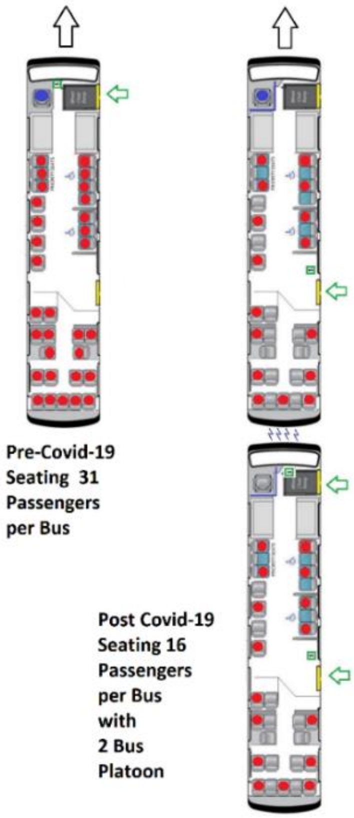
Exclusive Bus Lane (XBL) – Weehawken, NJ *Source: PANYNJ*

This technology will also ensure that the buses stay within the narrow lane used for the XBL and avoid knocking down the lane delimiters that help keep oncoming traffic in adjacent lanes from entering the bus-only lane. The CTDOT project will also deploy bus platoons along the CTfastrak

For Automated BRT, bus platooning will enable a driver in the lead bus to control one or more following buses, providing additional capacity and reducing the distance between buses to improve speed and flow. This increases the potential number of passengers per driver.

Leader follower systems can also provide management with the flexibility to use buses as part of a bus platoon during rush hours and then as individual buses for passenger pickup and drop off on either ends of the BRT section. Another option would use the leader-follower platoon during peak hour traffic and use buses individually during off-peak periods when less capacity is needed. The train-like capabilities offered by platooning result in a mode of transit that offers the capacity potential of LRT, with the flexibility to modify based on peak vs. non-peak needs, reach of service, and population growth changes.

During this era of Covid-19, automated bus platooning can avoid the need to expose additional drivers and to accommodate social distancing while maintaining capacity, as shown below.



Automated Platooning to Maintain Capacity *Source: J. Lutin*

Automated Collision Avoidance and Emergency Braking

In 2018, the most recent year for which cost data are available, US transit agencies reported for bus transit modes 4,767 collisions, 16,348 injuries, 84 fatalities, and $684 million in casualty and liability expenses.[9] Research has shown that 74 percent of high value bus insurance claims (more than $100,000) were attributed to collisions.[10]

Automated collision avoidance and emergency braking (AEB) systems to prevent forward collisions with vehicles and collisions with vulnerable road users (such as pedestrians and cyclists) are now common options for passenger cars and are increasingly becoming options for commercial vehicles. Adapting these systems for buses is currently under way in several FTA-sponsored projects and bus OEMs. Research has indicated that AEB systems could yield a significant return on investment in terms of reducing collision related insurance claims for the transit industry. Much of the technology needed for AEB, including sensors, drive-by-wire kits, and computers can be shared with other ADS functions enabling AEB to be an integral part of Automated BRT. This technology could also monitor other blind spots such as the rear door area.

Bus Collision Avoidance Testing *Source: Virginia Tech Transportation Institute*

Smooth Acceleration and Deceleration

The ability to control acceleration and deceleration in a coordinated fashion will improve rider comfort while also reducing the prospect of passenger slip and fall incidents. The ability to smooth bus movement supports other automated controls including lane keeping and platoons. In addition, CV2X technology can allow the bus to anticipate traffic signal changes which can also reduce fuel use. The same infrastructure that enables vehicle-to-infrastructure communications between automated transit buses and traffic signals could be utilized by future connected vehicles, as they become more common. This dual-use infrastructure is another example of how Automated BRT allows transit agencies to scale their transit solution as technology advances.

AUTOMATED BRT – A SUMMARY

While the value of an integrated ABRT system is likely greater than the sum of its parts, the table adjacent summarizes the benefits of its individual components.

The Value of Automated Bus Rapid Transit	
Automated Collision Avoidance and Emergency Braking	• Save lives • Fewer collisions • Fewer injuries • Reduce insurance claims • Reduce collision damage repairs • Reduce spare bus ratios
Automated Lane-Keeping	• Narrower busways • Support turning lanes • Fewer sideswipe collisions • Fewer mirror replacements • Less ROW acquisition and infrastructure cost • Use of shoulders for buses
Automated Precision Docking	• Level boarding at all doors • ADA-compliant access for mobility impaired users • Improved service to disabled community at lower cost to agency • Fewer boarding and alighting accidents • Reduce damage to buses and platforms from manual docking
Automated Smooth Acceleration, Deceleration and Speed Control	• Better ride quality • Greater comfort for passengers • Fewer slip and fall incidents • Increased fuel savings
Automated Bus Platooning and Automated Leader-Follower Capability	• Increased passenger capacity on high volume routes • Increased flexibility to adjust passenger capacity by time of day • Increased passenger spacing with social distancing • Improve passenger to driver ratio

Together, the above benefits combine to enhance Bus Rapid Transit into a mode of high-quality, high-capacity transit that compares with LRT while offering, less infrastructure costs, and greater flexibility to meet changing demand over time.

WHERE DO WE GO FROM HERE?

While Automated BRT can be described as a new transit mode, the underlying technologies are proven. The transit industry is under pressure to find cost-effective ways to improve service for their customers. ABRT (as well as its individual components) offer a promising solution.

Industry Developments – New Flyer Industries of America, Inc., the largest manufacturer of transit buses in North America, in collaboration with Robotic Research LLC, announced in June 2020 that it is building three Level 4 automated buses for the CTfastrak project mentioned above.[11] This deployment, which is funded by the FTA and CTDOT will be the first Automated BRT deployed in revenue service in the US.

Additional manufacturers have announced automated bus pilots in China, Germany, and Scotland, although it is unclear if these are intended to be operated as BRT. Over the next few years, it is expected that some bus manufacturers will be adding ADS equipped buses to their standard commercial lines.

An association of transit and transportation agencies has formed the Automated Bus Consortium, a collaboration designed to investigate the feasibility of implementing automated bus projects across the United States. The Consortium aims to accelerate the development of automated transit technologies.[12]

Federal policy – FTA includes an automated BRT use case with level 4 automation as an integrated demonstration in the STAR plan's five-year strategic transit automation research roadmap, starting in year four, Federal Fiscal Year 2021. The CTDOT project which is scheduled to begin in the fall of 2020 may meet the goals for that integrated demonstration. Although the STAR plan does not include future funding targets, there is clear interest in providing continued technical support for the various use-cases including ABRT.

Incorporating ABRT into the Planning Process - The purpose of this paper is to lay the groundwork for including Automated BRT in the planning process.

Planning for high-capacity transit corridors involves a multi-year process, especially if Federal funds are used. Most Federally funded capital grants are discretionary or competitive, require local matching funds, and are evaluated for funding based on a number of criteria.[13] Among the steps involved, prospective grantees must show that alternatives have been considered and evaluated for aspects such as mobility, cost-effectiveness, and environmental impacts. It is in this part of the planning process that an ABRT alternative can be developed and considered as a viable alternative.

It is hoped that this white paper will stimulate thinking about the potential offered by Automated BRT. While no integrated ABRT system is yet in operation, this paper aims to provide the basis for planners to engage with OEMs, autonomy firms, and experts to collaborate on planning and engineering needed to deploy for ABRT corridor deployments.

ABOUT THE AUTHORS

Richard Mudge is President of Compass Transportation and Technologies, Inc. He currently serves as a consultant to Robotic Research LLC. His experience includes work on the economic benefits of automated vehicles and work for the Society of Actuaries on recent changes in the automated vehicle industry. He also organizes a monthly series of debates among industry leaders regarding changes in the automated vehicle industry,

Jerome Lutin retired from positions as Senior Director of Statewide and Regional Planning at New Jersey Transit and Distinguished Research Professor at New Jersey Institute of Technology. He currently serves as Principal Investigator for the FTA Pierce Transit Automated Collision Avoidance and Mitigation Safety Research and Demonstration Project and as a consultant to Robotic Research LLC. He chairs the TCRP Panel on the Effects of Automation on the Transit Workforce.[14]

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Robotic Research, LLC has been at the forefront of bus transit automation, with four major demonstrations of automated bus technologies under way, including autonomy for Local Motors Olli autonomous low-speed shuttles, New Flyer Xcelsior CHARGE™ full size transit bus Level 4 automation, Connecticut DOT CTfastrak BRT automation, XBL automated bus platooning for the PANYNJ and precision docking for the Kansas City Area Transit Authority.

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