FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

Assessing Transit Providers' Internal Business Case for Transit Bus Automation

FEBRUARY 2021

FTA Report No. 0187

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U.S. Department of Transportation
Federal Transit Administration

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Courtesy of Volpe Transportation Center

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SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C

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14. ABSTRACT
This report explores how transit providers make decisions and assess their internal business case for transit bus automation. It aims to inform transit agencies and other transit industry stakeholders interested in understanding how agencies are approaching automation decisions. This report covers decision-making for all capital investments, decision-making specifically for automation projects, the benefits and costs of transit bus automation, and the challenges to assessing the business case for transit bus automation. Findings are that agencies often approach automation projects the same way they would other capital investments, but they often have to rely on qualitative measures to assess the fast-moving world of transit bus automation. The ability of agencies to assess their business case for automation is limited by data availability and a lack of knowledge on regulatory issues as well as uncertainty over operational changes, customer acceptance, and the applicability of findings from various pilot projects.

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TABLE OF CONTENTS

LIST OF TABLES

Abstract

This report explores how transit providers make decisions and assess their internal business case for transit bus automation. It aims to inform transit agencies and other transit industry stakeholders interested in understanding how agencies are approaching automation decisions. This report covers decision-making for all capital investments, decision-making specifically for automation projects, the benefits and costs of transit bus automation, and the challenges to assessing the business case for transit bus automation. Findings are that agencies often approach automation projects the same way they would other capital investments, but they often have to rely on qualitative measures to assess the fast-moving world of transit bus automation. The ability of agencies to assess their business case for automation is limited by data availability and a lack of knowledge on regulatory issues as well as uncertainty over operational changes, customer acceptance, and the applicability of findings from various pilot projects.

EXECUTIVE SUMMARY

To support the development and deployment of automated transit bus services, the Federal Transit Administration (FTA) developed a five-year Strategic Transit Automation Research (STAR) Plan that outlines the agency's research agenda on automation technologies. As part of the research outlined in the STAR Plan, this research effort outlines the process for analyzing the internal business case (and/or benefit-cost analysis) for transit bus automation and combines this with information on transit agency decision-making processes for capital investment.

The research relies on interviews with transit agencies and other organizations pursuing transit automation as well as an extensive literature review on topics related to transit agency decision-making and transit bus automation. The findings cover known data sources, technical issues with monetization and discounting, and other considerations for conducting a quantitative benefit-cost analysis (BCA).

A rigorous BCA requires agencies to gather data across a wide range of impacts, including but not limited to:

- Capital costs for a variety of ownership models
- Expected maintenance costs
- Staff retraining costs
- Staff time commitment for the proposed project
- Service changes (area, hours, etc.)
- Safety benefits of the technology
- Estimated improvements to travel time, travel time reliability
- Labor costs
- Fuel, oil, and other operating costs
- Emissions changes
- Public opinion and acceptance of automated transit
- Potential changes in customer satisfaction

An important finding from this work is that there is little to no public information available for many of the cost and benefit categories, and much of what does exist from small-scale pilot tests may not be broadly applicable. Agencies also do not always have the resources to seek out available information, as there is no single clearinghouse for this information and much of it is unpublished.

Agencies have a variety of specific decision-making processes for capital investments, but there are some discernable trends. One common approach is to assess a project with respect to the agency's strategic goals or objectives, with projects assessed qualitatively on their ability to achieve those goals. There is a large variety in the types of quantitative measures used to analyze projects, with some agencies conducting benefit-cost analyses and others using simplified scoring measures, although agencies generally encourage their staff to quantify measures when possible. In any of these processes, the qualitative or quantitative assessment is not the final say; agency leadership must approve projects before they can begin.

As noted, quantifying the benefits and costs of an automation project is challenging for agencies because of lack of data and forecasting tools. To determine whether to pursue automation, agencies often rely on more qualitative measures to assess the project, such as the learning potential and general benefits of innovation. Other agencies have chosen not to pursue transit bus automation at this time because there is still much unknown about it, and agencies cannot sign off on an automation project without a fuller understanding of the benefits and costs. There is also a distinction between agencies that view automation as inherently a benefit in and of itself vs. agencies that view it only as a means to an end. Agencies that view it as the former are more likely to pursue automation projects even when a robust analysis cannot be performed, whereas agencies in the latter category compare automation projects to any other capital investment project and, accordingly, typically need more quantitative data before pursuing automation.

It is often difficult to quantitatively assess the benefits and costs of transit bus automation due to data limitations. However, even if an agency wants to do a more qualitative assessment of the business case for automation, it will still face barriers. This report documents these barriers and categorizes them into four areas—regulations, applicability of findings, operational changes, and customer acceptance. Overcoming these barriers is possible, as proven by agencies that have already conducted or are conducting transit automation pilot tests. However, these challenges can cause some agencies to abandon automation projects or at least increase the costs associated with a project. It is also often easier to overcome certain barriers for pilot projects, whereas a longer-term investment may face more obstacles.

This report concludes with five recommendations for agencies on overcoming these barriers and assessing their business case for transit bus automation:

- Start with a clear agency consensus about the intended goals of the automation project and whether a quantitative business case is needed.
- Ensure that a comprehensive list of benefit and lifecycle cost impacts is considered.
- Use scenarios and sensitivity testing to address uncertainties in a quantitative BCA.
- Connect with agencies with more experience in automation to share data.
- Review the latest FTA publications and research findings on bus automation.

SECTION 1

Introduction

To support the development and deployment of automated transit bus services, the Federal Transit Administration (FTA) developed a five-year Strategic Transit Automation Research (STAR) Plan that outlines the agency's research agenda on automation technologies. As part of the research outlined in the STAR Plan, this report discusses the business case for transit bus automation.

When new technologies enter the marketplace, transit agencies must make a strategic business decision regarding whether and how to adopt them. A business case assesses the extent to which a proposed project generates cost savings, ridership gains, or other benefits that justify the costs of the investment. This report discusses the elements of a transit bus automation business case and provides an overview of how agencies are making decisions today. Benefit-cost analysis, an analysis that seeks to determine if and by how much a project's benefits exceed its costs, is explained in-depth in the report, and specific information is provided for how to apply a benefit-cost analysis to transit bus automation.

This research was performed to provide agencies with relevant considerations on how to assess the business case for transit bus automation and to provide stakeholders with information on how agencies approach the business case. For agencies, there may be barriers that prevent them from fully assessing the business case for automation, such as limited resources and lack of available data. This report documents those limitations but also seeks to help agencies overcome them by providing information on available resources and estimates. For other stakeholders that are active in transit automation (such as universities or original equipment manufacturers [OEMs]), this report helps to provide an understanding of how agencies assess transit bus automation, potentially allowing them to better understand the needs of agencies and adjust their research and project proposals accordingly.

The scope of this report considers transit bus automation systems across all levels of automation (SAE Levels 0–5).[1] For the purposes of FTA's STAR Plan, "bus" is defined broadly to consider a range of passenger capacities and both

[1] SAE Level 0 systems include both systems without any automation that provide warnings to drivers (e.g., collision warning systems) and systems which provide momentary automated control of the vehicle (automatic emergency braking). Systems that provide momentary automated control of a vehicle are considered within scope for this report. SAE International (2018), "J3016_201806: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles," SAE International Standard, https://www.sae.org/standards/content/j016_201806/.

traditional and novel vehicle designs (e.g., ranging from smaller shuttle vehicles to 40-ft transit buses and longer articulated buses). This report also is not limited to traditional transit agencies but includes any organization that may consider implementing transit bus automation.

It should also be noted that this research was completed primarily before the beginning of the public health emergency in the U.S. and does not consider the impacts that it may have had on agency strategic goals and decision-making processes. Although the general principles for assessing the business case are largely unchanged, the pandemic and its effects on ridership, revenue, and operations may have significant impacts on agency priorities and potentially on decision-making processes. These types of changes are not reflected in this report.

SECTION 2

Methodology

This report relied on qualitative research—a literature review and a set of interviews. FTA's past work in this area indicated that a qualitative methodology would be appropriate, given the differences across agencies and the novelty of this field. FTA's research to-date on transit bus automation also helped to identify relevant literature and potential interviewees.

Literature Review

The research team reviewed academic journal articles, news reports, trade publications, government reports, transit agency reports, webinar materials, and presentations related to transit bus automation and transit agency decision-making. A general internet search was conducted, as were searches in specific databases including the Repository & Open Science Access Portal and Transport Research International Documentation (TRID). The specific search terms used included but were not limited to "transit agency decision-making," "transit bus automation," "transit bus automation benefits and costs," and "transit agency business case." Some information was also available from prior FTA reports, webinars, and grant applications.

The review uncovered three main topic areas that are addressed in the published literature:

- Benefits and costs of transit bus automation
- General transit agency decision-making processes for capital investments and technology deployments
- Current challenges that transit agencies face related to transit bus automation, such as technology readiness and regulatory requirements

The research team was unable to find any literature that directly addressed transit agency internal business cases for transit bus automation decisions. Given the relative novelty of the topic, a lack of literature is understandable. However, analysis of these three topic areas can be combined to provide insight into this question. Looking at the findings across all the available literature provides a foundation for understanding the business case for transit bus automation.

Interviews

Interviews were used to supplement the literature review and provide insight into how transit agencies have made (or will make) decisions specifically related to transit bus automation. The agencies interviewed were selected by consulting FTA's Transit Bus Automation Quarterly Update (FTA, 2020) and through conversations with FTA. When selecting agencies to interview, the research team endeavored to include a variety of organizations in terms of location, organizational type and structure, public transportation services provided, and progress toward automation. Eight semi-structured interviews were conducted from February to April 2020. Details on the interviewees can be found in Appendix A.

The interviews generally began with a discussion of the agency's overall decision-making process as it applies to capital investment decisions, not specific to automation. Interviewees were asked about qualitative and quantitative factors used in decision-making as well as the organizational aspects of decision-making. After establishing a baseline, the interviews shifted to discussing transit automation. Some agencies interviewed had automation projects underway or planned, and others were only beginning to research automation. Accordingly, the discussion with each interviewee varied but, generally speaking, interviewees were asked about how their agency approaches or would approach automation decisions, what types of benefits the agencies anticipated, and whether a pilot project would be assessed differently from a long-term investment. Agencies were also asked about the data gaps and other barriers that exist in their assessment of the business case for automation. The interviews concluded with the agencies offering recommendations to FTA, to industry, and/or to other agencies about how to help advance the state of transit bus automation and make it easier to assess the business case.

SECTION 3

Findings

This section begins by covering the types of information that agencies would need to quantitatively assess their business case through a benefit-cost analysis (BCA), which estimates the benefits and costs of a project relative to a baseline, identifying the extent to which the benefits outweigh the costs, if at all. The types of benefits and costs that can be included are numerous and are identified in this section to help guide agencies when thinking about what types of categories they may want to analyze. There are challenges associated with that type of analysis, which are addressed in this report.

However, as is discussed in more detail below, many agencies may choose not to conduct benefit-cost analyses when evaluating projects. This is especially true for automation projects, where a lack of quantitative data often renders a BCA difficult if not impossible. Even when a BCA is used, it is never the only decision-making tool; agencies always consider other factors. As such, the report also includes discussion of how agencies make decisions and how automation is assessed in those contexts. Each agency has a unique decision-making process, but there are general themes found across agencies.

Benefit-Cost Analysis

A rigorous BCA requires a significant amount of information on the impacts of a project or action, relative to a scenario in which the project does not take place (often referred to as the "baseline"—see Table 3-1). This section describes the information needed for a transit agency to perform an internal BCA or business case analysis for transit automation investment and also discusses the extent to which this information is available. Where possible, specific values from prior research are cited for context, but readers are urged to identify resources relevant to their specific project before undertaking a BCA. This section discusses what information would be needed for such an analysis, and Appendix B of this report provides tables with quantitative data on automated buses. Additionally, for a detailed benefit-cost analysis for multiple transit bus automation scenarios, agencies are encouraged to review Appendix D of the STAR Plan (Machek et al., 2018), with the caveat that the analysis may become outdated as technologies continue to evolve over time.

Table 3-1

Parameters/Factors for a BCA

Parameter/ Factor	Definition/Importance
Baseline	What would happen if the automation project did not occur; also referred to as the "no build" scenario.
Scope of Analysis	Does the analysis pertain only to the costs and benefits to the agency, or is it looking at societal costs and benefits? This determines the way in which the agency will measure the costs and benefits.
Discount Rate	Economic principle that costs and benefits realized today are valued more than costs and benefits realized in the future; also known as the "time value of money."
Analysis Period	How many years into the future will the analysis cover? Generally, it should cover initial development and operational period. In the case of automated bus transit projects, the operational period could mean the useful life of the automated bus.

As noted throughout this section, **data availability is the biggest barrier to conducting a BCA or any quantitative assessment of the business case**. The data that currently exist are preliminary and based on pilot tests and often are applicable only to the specific conditions of the pilot and the agency that conducted the test. Cost estimates drawn from early prototypes typically are not reflective of subsequent generations of the technology or to production vehicles and systems. Impacts on agency operations and ridership are also highly context-specific and can involve complex interactions that are difficult to forecast. Understanding the process of conducting a BCA can help agencies assess their automation projects, but without robust data, the BCA cannot be fully implemented. Accordingly, agencies do not fully rely on BCAs for their decision-making, and some agencies may not conduct a BCA at all.

If an agency does want to conduct a quantitative BCA to assess its automation project, it will need information on parameters, cost estimates, and benefit estimates. The types of parameters needed are shown in Table 3-1.

Apart from the relevant parameters, the type of data necessary for a BCA can be separated into two categories—Costs and Benefits. The distinction between costs and benefits is not always clear, and a number of different conventions can be used. A definition given in USDOT BCA guidance is that a cost is a resource necessary to deploy or maintain a transit project or service, and a benefit is an outcome that results from the implementation of the project, whether directly to users of the transit system or to the general public (USDOT, 2020). Using this definition implies that some benefits can be negative (a disbenefit; for example, if there was an increase in travel time or emissions) and that some projects may yield negative costs (such as a savings on fuel or labor costs). To avoid confusion, this report describes Costs as cost increases and undesirable project outcomes or instances of cost increases, and cost savings and other positive outcomes are grouped under Benefits. An agency may group these categories differently in its own internal analyses, but this definitional characterization does not affect the calculation of net present value[2] or the overall determination of whether a project is cost-beneficial. The typical cost and benefit categories are shown in Table 3-2.

Table 3-2

Typical Cost and Benefit Categories for a BCA

Cost or Benefit Category	Definition/Importance
Capital Costs	Capital expenditures for the bus and/or automation technologies, including any costs associated with acquiring the bus through leasing, purchasing, or other means. May also include some infrastructure changes, depending on the technologies selected; for example, some pilot projects have included integration with traffic signals. For electric vehicles, installation of charging facilities may be needed.
Maintenance Costs	Costs to maintain and repair the automated buses. Some maintenance costs may not differ between the conventional baseline and the automated bus, but others will likely differ, including the cost to ensure that the automation technologies remain up-to-date.
Operating Costs (Labor)	If a traditional driver is not required, an agency may experience lower labor costs. Conversely, agencies could experience higher labor costs if training is necessary. There may also be labor costs associated with overseeing a pilot project or with public outreach.
Operating Costs (Non-Labor)	All other operating costs beyond labor. Could include fuel, oil, insurance, and more. Automation may cause increases in insurance costs, at least in the near-term, but it could also cause reductions in fuel burn.
Other Costs	Any other costs not captured elsewhere. There are often unexpected project costs that agencies may not account for; for automated vehicles, this could include cybersecurity or public outreach costs. It may be useful to build in extra budget to any cost estimates to cover unexpected cost areas.
Safety	Benefits from a reduction in crashes. Could be quantified either as the benefit to agency through reduced casualty and liability claims and avoided property damage or quantified as the societal benefit from reduced crashes. It is possible to have disbenefits if crashes increase.
Travel Time Savings and Reliability	Time-related benefits that could include benefits to the agency from improved yard operations, benefits to riders in reduced travel times, and/or benefits to riders in improved reliability.
Service and Ridership Changes	Any impacts to service levels or ridership can impact other cost and benefit categories.
Environmental Impact	Reduced emissions from fuel savings can be an environmental benefit. This is typically a very small benefit category. Fuel savings can be converted into avoided emissions using estimates of emissions rates per gallon of fuel. If the automated vehicle is electric, that could result in substantial emissions reductions if the baseline is a conventional diesel bus (whereas if the baseline is a non-automated EV, there would be no savings unless the automated EV is more efficient).
Qualitative Benefits	Other categories of benefits may be difficult to quantify, or a lack of data may prevent quantifying the categories listed previously in this table. This could include intangible categories such as rider convenience and comfort. Agencies can choose to note these categories qualitatively.

[2] Net present value is the difference between the discounted benefits and the costs, calculated as (Total Discounted Benefits - Total Discounted Costs).

Challenges with BCA for Transit Bus Automation

There is one very large barrier that agencies must overcome to conduct a BCA for transit bus automation—data availability. Without data on how automation impacts the various cost and benefit categories, agencies cannot determine whether an automation project will be cost-beneficial. **The limited data that are available may allow agencies to conduct some scenario tests[3] and do very rough benefit-cost or business case analyses**. Agencies could consider how large these benefits would have to be for them to justify the costs of transit bus automation for their particular agency and then consider whether they believe that level of benefit is possible, based on the information available to them. As more data become available, agencies could then begin including these impacts quantitatively. Such analyses can be adequate to support an up-or-down decision on a particular investment, even if considerable uncertainty remains.

Even when relevant data do exist, access to those data can still be a challenge for agencies—there is no single clearinghouse for automation-related information that agencies could use to assess their internal business case for automation. Additionally, monitoring research is not the core mission of transit agencies, and it can be a challenge for agencies with limited staff to devote time and resources to remaining current with the state of the practice. Research findings from one agency may not be broadly applicable due to differences in operating environments and other factors, but these differences are not always fully documented and may be difficult to analyze. The fast-moving nature of the automation industry also means that data and information can quickly become out of date, further complicating the issue of data availability.

If an agency is unable to perform a benefit-cost analysis, this does not mean the agency cannot still make an informed decision about automation. As is discussed in more detail later in the report, agencies do not rely solely on BCAs for decision-making, and many do not conduct a full-fledged BCA for regular capital investments, although some level of financial analysis typically is present.

Baseline

When conducting a BCA, it is important to consider what the baseline scenario is, also referred to as the "no build" scenario or the base case. The purpose of the baseline is to establish what the world would like if the automation project did not go forward, which allows an agency to then understand what the benefits

[3] Scenario tests look at the outcomes of the project under varying sets of assumptions about the impacts of the project, which are grouped into distinct scenarios. This approach can be useful in instances where there are minimal data and multiple assumptions must be made. The scenarios typically range from optimistic (high benefits, low costs) to conservative (low benefits, high costs) and may incorporate assumptions about other important parameters (such as low or high values of technology adoption, future fuel prices, or ridership growth).

and costs of the project will be relative to the baseline. Thus, establishing the baseline is an essential first step for a BCA.

For many project types, there are certain benefits and costs that will occur equally in both the project scenario and the base case and, thus, would not necessarily need to be included in the BCA, as they would cancel out. For example, an agency considering automated vs. conventional vehicles for a new route would not need to include the service planning costs of developing the new route (e.g., rider outreach, surveys, geographic information system analysis, etc.), as these may be the same for either vehicle type. However, if the baseline scenario was that the new route would not be established at all, then these costs and benefits would need to be considered in the BCA.

The baseline will differ for various projects. In some cases, the baseline will be that no new actions are taken and operations continue as is, and in other cases the baseline will be that some other, different action is pursued. An agency may also want to conduct BCAs for multiple scenarios using different baselines to see how the results change, but agencies should be careful to not confuse the different scenarios or baselines. For example, a vehicle that is both electric and automated could be compared against an electric but non-automated vehicle and against a conventional vehicle that is neither electric nor automated. The BCA would need to take care to consider the incremental benefits and costs that are relevant to each comparison.

Parameters

There are parameters that are necessary to conduct a BCA but are not necessarily project-specific. An agency can define most of these parameters once and then use the same parameters for future analyses, with small updates for factors such as inflation.

The first such parameter is the **discount rate**. The discount rate reflects the economic principle that costs and benefits in the near term are valued more than costs and benefits in the long term. This concept is sometimes referred to as the "time value of money" and is distinct from inflation. The U.S. Department of Transportation's (USDOT's) Benefit-Cost Analysis Guidance for Discretionary Grant Programs provides further explanation on discounting as well as example formulas for agencies to use (USDOT, 2020). That guidance recommends a value of 7% as the discount rate for societal benefits (USDOT, 2020); however, agencies conducting an internal business case would be more likely to use a discount rate that reflects their cost of borrowing or similar factors. The choice depends on how heavily an agency wants to weight near-term vs. longer-term impacts, or the effective "payback period" of the investment.

The next parameter to consider is the **analysis period**. This can differ based on project type, but the general rule is to cover the initial development of the project and the operational period of the project's primary capital assets. Thus, many transit bus projects will have similar analysis periods, covering the expected useful life of the vehicle. If an agency is uncertain about the useful life of an automated transit bus, it is recommended to use the best available information from other projects, or to conduct a sensitivity analysis test different potential lifespans.[4] At present, it is probable that an automated transit bus will have a shorter useful life than a similar conventional bus; the lifespan of the automation hardware, such as the sensors, and supporting software, is unknown, and there is rapid turnover in the market, as this is an emerging field. Thus, it may not make sense to use estimates from conventional buses as a proxy. Over time, as the market becomes more mature and agencies gather more experience with these technologies, the expected lifespan may become known with greater certainty.

The final set of parameters is **monetization factors**. This refers to the values that a BCA will use to monetize non-monetary benefits, including reductions in crashes, travel time, emissions, and more. These factors are generally based on research on how transportation system users (or society as a whole) value the outcomes; for example, the value of an avoided hour of travel time can be derived from labor markets, tolled express lanes, and other settings in which time and money are traded off.

An agency may or may not need these values, depending on the type of analysis performed. If an agency wants to examine the societal benefits and the benefits to passengers that will come from the automated bus, then it will need monetization values for various benefit categories. However, if an agency wants to look solely at the direct impacts of the automated bus on the agency itself, then these types of monetization values may not be necessary because the relevant values will already be in monetary terms. USDOT's BCA Guidance has recommended monetization values but these may need to be adjusted to the details of a transit bus automation project and/or local conditions (USDOT, 2020).

Costs

The costs of a project are not limited to the initial capital cost to acquire the automated vehicle; they also include other categories such as incremental maintenance and operating costs. This section discusses only the ways in which automation projects are expected to produce cost increases; cost savings are discussed under the Benefits section.

[4] A sensitivity analysis examines the influence of a change in a specific parameter on the overall results of the BCA. It may also be referred to as a "what-if" analysis. In this case, it could be used to test whether the automation project remains beneficial given different potential lifespans of the automated bus.

Capital Costs

Project costs will include all costs necessary to fund a project, including inputs of capital, land, labor, or materials. An agency may want to include only the costs to the agency or choose to include all costs of the project, regardless of the funding source; this is a choice that may vary from project to project or agency to agency, depending on the specifics of the project and agency. In either case, it is important for the agency to consider all possible cost categories.

The most obvious cost category is typically Capital Expenditures, which may include the cost to purchase or lease the automated transit bus or the cost to equip a new vehicle (or retrofit an existing vehicle) with the necessary technology. Capital cost is typically a one-time upfront cost, but if an agency is leasing a vehicle, then it may be a periodic cost. Agencies currently are pursuing a variety of models in their automation pilot tests, but a long-term investment may use a more traditional ownership model. Thus, **an agency needs to know not only the cost but the planned ownership model and payment structure** to conduct a benefit-cost analysis.

There is limited information available on capital costs for an automated bus, given that transit bus automation systems that exist are still prototypes rather than commercialized products (Cregger, Machek, and Cahill, 2019). The data that do exist on the prototypes vary considerably but are currently the best indication at what future costs for market-ready automated buses will be. One study estimated that the added cost of an automated bus over a conventional alternative would be $80,000 (Quarles, 2017), which could be a 16–27% price premium, assuming that the average price for a conventional diesel bus ranges from about $300,000 to $500,000 (EESI, 2007; Tong et al., 2017). Another study estimated the capital cost of a smaller automated shuttle (typically 6-seat/12-passengers) at $200,000, compared to $45,000 for a conventional 15-passenger van (Peirce et al., 2019). Information received by FTA suggested that the cost of purchasing an automated bus could be approximately $1 million and that the cost of leasing a single vehicle for a month could be around $20,000. This is based on a small selection of cost estimates and likely does not represent the full market. The relatively wide range of estimates suggests that the market has not yet reached a steady state. Any agency considering automation will need to reach out to manufacturers to get the latest cost estimates for their preferred ownership model.

For driver assistance technologies, costs are generally better known, and the capital cost estimates for automated driver assistance technologies are much lower than the costs for a fully-automated bus. Available capital cost estimates include $1,800 for adaptive cruise control, $1,800 for a camera-based lane-centering system, and $4,750 for automatic emergency breaking and blind spot detection systems (Peirce et al., 2019). Agencies will need to research their specific automated driver assistance technology to get up-to-date cost information. Some technology companies may also be unwilling to install their technology on an older vehicle and may prefer to install it only on a new vehicle, which would also impact an agency's business case calculations.

Maintenance Costs

Maintenance costs can be just as important as upfront capital costs in a BCA, and these maintenance costs could apply to both partial and full automation systems. **Automated vehicles could have much higher maintenance costs than conventional vehicles, due to necessary maintenance or upgrades on expensive systems.** By contrast, automated vehicles may also be involved in fewer crashes (discussed later in the Benefits section), resulting in reduced repair expenses. A demonstration project in Eugene, Oregon, found that precision docking and curb avoidance produced benefits through reduced tire wear and impacts with station platforms, although this benefit was not quantified (Peirce et al., 2019).

It is also important for agencies to understand that their maintenance costs may change in ways that are not immediately obvious. For example, a simple cracked windshield may be much more expensive to repair due to the need for camera or sensor re-calibration (Preston, 2020). In the absence of O&M cost data, analyses may choose to use a rough estimate, such as 10% of the capital costs—10% would be a high estimate and therefore conservative based on typical maintenance costs for transit vehicles, which tend to be closer to 6% for diesel buses and even lower for EVs (Peirce et al., 2019; Aber, 2016). Automated buses may have higher maintenance costs than conventional buses, indicating that a conservative, higher estimate may be reasonable. Although these kinds of estimates are somewhat arbitrary, they are better than assuming that such costs are zero.

Operating Costs (Labor)

For full automation (and to a lesser extent, partial automation), agencies need to carefully consider how the project will impact labor costs relative to their baseline scenario. Salaries, wages, and fringe benefits for all employees accounted for over 60% of the total operating cost for public transit agencies in 2017 (APTA, 2019), indicating that this is a large and important category for agencies to consider in their decision-making. This section discusses the possibilities for increases in labor costs; labor cost savings are discussed in the Benefits section.

Many automated bus pilots have had unexpected costs and delays, primarily associated with increases in staff time not originally planned for (Hughes-Cromwick and Dickens, 2019). Getting an automated bus up and running, either in a pilot or a long-term deployment, involves labor time costs, some of which would likely be present in any establishment of a new project or bus route, meaning they are not necessarily an additional cost for the automated pilot relative to the baseline. However, because automation is a new and changing technology, there is a large learning curve. Other labor costs may be incurred in conducting research on automated buses, procuring the vehicles, planning the routes, and providing information and outreach to their community about the changes in transit service.

Automation can increase labor costs through the increased staff labor time necessary to organize the initial transition to the automated bus and through training costs. Training costs could be substantial, even if only a few hours per operator, as those hours will quickly add up across all bus operators. FTA's *Vehicle Assist and Automation (VAA) Demonstration Evaluation Report* noted the importance of training during the project but did not specify costs (Gregg and Pessaro, 2016).

Transit agencies may choose not to eliminate jobs and, accordingly, not reduce labor costs, even in a future scenario in which all tasks could be automated and there is no need for an onboard operator. Agencies have indicated that customers may feel more comfortable with an operator on board, at least in the initial years of technology adoption. There are also regulations to consider, such as Section 13(c) of the Urban Mass Transportation Act of 1964 (currently codified at 49 U.S.C. §5333(b)), which contains provisions that generally prohibit worsening the condition of transit employee conditions as the result of federally-funded projects. Changes to staffing levels would require negotiation with labor unions (where present) and, under Section 13(c), could involve significant severance payments or re-training costs. Given the technology, customer acceptance, and policy uncertainties, agencies may wish to factor in continued operator costs in any assessment of transit bus automation. One agency interviewed specifically noted that it is continuing to include operator costs in its decisions related to automation. There could also be training and other costs associated with changing the nature of the onboard staff position to focus on customer assistance rather than driving.

The impact of automation on the future trajectory of labor costs can be difficult to forecast. There is a possibility that an agency's organizational structure or operational model could change as a result of automated buses, which could change labor costs. Public reaction to the automated vehicles could also have a strong impact on whether or not an onboard operator is still required, and an agency may not fully realize how an automated vehicle will impact its operations and labor needs until the automated vehicle is up and running and commuters have adjusted their patterns. Labor-management and union agreements could also change over time, affecting labor costs.

Some of the more indirect effects of automation will likely be difficult for an agency to estimate, but it is worthwhile for an agency to at least begin considering the cost changes and look across the agency as a whole to estimate whether the change will be a cost increase or a cost decrease. Accordingly, the agency may need to conduct various scenario tests to see how different changes in labor costs would impact overall cost-effectiveness.

Finally, it is particularly important to consider the baseline scenario when estimating changes in labor costs. If an agency is comparing adding a new route with an automated bus to a baseline of not having the new route at all, then any labor costs are an increase over the do-nothing baseline.

Operating Costs (Non-Labor)

A variety of other operating costs could be considered by agencies in their analysis. The types of operating costs that will be impacted will vary depending on the specifics of the agency and the automation project.

Certain operating costs may not differ between an automated vehicle and a conventional one, but costs such as fuel, oil, tire wear, and insurance could differ. As noted, repair costs can be more expensive for vehicles with automated technology, as even minor collisions may require the repair, replacement, or recalibration of exterior sensors. These higher costs would result in costlier insurance claims, which then translate into higher insurance premiums for the agency. Premiums may also rise as insurers adjust for the perceived additional risks associated with new technologies. Over the longer term, these perceived risks may decline, and automation may lead to an overall reduction in crashes that further lowers insurance costs. In the near term, however, agencies should be prepared for potentially higher insurance costs.

Other Costs

It would also be beneficial for transit agencies to consider other categories of costs that could arise from conducting an automated bus project. There can be unexpected, additional costs in any cost category, but one example could be cybersecurity-related costs (Hughes-Cromwick and Dickens, 2019). Automation projects may also require higher-than-expected costs for public outreach and information—for example, to address rider concerns or any changes to agency policies. It is possible that some agencies may fail to consider these types of indirect costs of a pilot project (or of a long-term investment). These costs and delays may be fairly small, but planning for them in any assessment of the business case could make the project run smoother. Although unanticipated costs are, by definition, unexpected, agency business cases will likely need to build in a range of sensitivity testing on key cost variables. An agency could consider, for example, whether the project would still be cost-beneficial if the costs were 5–10% higher than expected as potential scenario tests.

Benefits

There are multiple types of quantitative benefits that could be considered in a BCA of transit automation, and the specific categories will depend on the level and type of automation, the specific use case, and the agency's preferences. A 2018 survey of 258 transit agencies found that 30.7% of rural transit agencies, 54.4% of small urban transit agencies, and 89.3% of urban transit agencies believed that transit vehicles with automated functions will be beneficial for transit operations (Godavarthy, 2019). A different survey of 50 transit agencies from 2018 found that transit agencies believed the biggest benefit of automated buses was attracting new riders, followed by the potential to expand the service area, improve peak hour service, and increase revenue, with all survey respondents except one believing that there would be at least some type of benefit from automating transit buses (Han et al., 2019).

This section covers a wide range of possible benefits and how an agency could quantify them, but it may not be exhaustive. An agency could choose to include other categories of benefits if they are relevant to that particular agency's automation project.

Safety

Transit agencies often approach automation from the perspective of being able to improve safety, a benefit that can be derived from both partial and full automation systems. There are two main ways in which agencies could quantify safety benefits—reductions in liability costs for the agency or the societal benefits of reduced accidents, injuries, and fatalities.

Casualty and liability claims tend to be a large cost for transit agencies. A reduction in accidents from an automated bus would lead to a reduction in this cost category, which would act as a benefit to transit agencies. To estimate safety benefits in this way, agencies would need three main types of data—historical crashes for the transit agency with conventional buses, the expected crash reduction from the automation technology, and the average cost per crash for liability claims. These numbers could be averaged across all types of crashes, or the agency could break out the data into more specific crash-types, such as property-damage-only crashes, crashes with injuries, and crashes with fatalities. The latter approach of breaking out the crashes specifically is generally preferred, but if there are data availability issues, using an average across all crashes is a possible proxy.

The second approach uses monetization values for accidents instead of using liability cost estimates. This approach assigns a monetization value to an accident based on its severity to estimate the societal cost of the crash. Like the previous approach, agencies still need historical crash data on their conventional buses and an expected crash reduction from the automated bus, but the specific agency-related liability costs are no longer relevant. Instead, the number of reduced crashes would be multiplied by the appropriate monetization value to estimate the benefits of the reduced crashes. As noted in the Parameters section, USDOT BCA guidance recommends monetization values for different crash severities.

The choice of approach depends on the nature of the agency's decision-making process. An agency looking solely at its own internal business case would consider only direct financial impacts, such as liability claims. Conversely, an agency attempting to include society-wide costs and benefits as a means of assessing the merits of the project would want to include the injury monetization factors as a way of capturing crash impacts that go beyond liability claims.

Published estimates of safety benefits are available, but they are limited in scope and may not be generalizable to other technologies and products. Some available safety-related data include the following:

- Safety benefits from automatic emergency braking and pedestrian collision avoidance are not known with certainty, but a previous FTA analysis used a crash reduction factor of 45%, based on data from other studies (Peirce et al., 2019).
- Denver RTD's test of a small driverless electric shuttle (capacity of 10–12 people) in 2019 showed that there were no crashes with the shuttle, although no other safety metrics were provided in the analysis of the project (Denver RTD, 2019).

It is impossible to quantify the safety benefits of automation without an estimate of how crashes will change, and this, in turn, requires analysis of crash rates and causality. Agencies may conduct various scenario tests of potential crash reduction levels to see the possible range of this benefit category, but without data it is difficult to know exactly how crashes will change. Safety data often exhibit year-to-year stochastic variation, and safety impacts can take time to manifest. Thus, robust data on safety impacts will not be available until agencies have operated automation technologies in regular service, and even then it may take several years of such data to serve as a reliable basis for forecasting.

Travel Time Savings and Reliability

There are multiple ways in which time can be a benefit of an automation project. There could be both benefits to riders in improved speed and reduced wait or travel times, and benefits to riders in terms of improved travel time reliability. Travel time savings are easier to quantify than changes in travel time reliability, but both categories are possible benefits of automation.

Changes in time can be monetized as discussed in the Parameters section. USDOT BCA guidance recommends values for travel time savings, which should be applicable to transit. It is important to note that changes in transit access and wait times are valued at a higher rate than savings in in-vehicle time, due to the greater disutility of the former. The most recent guidance at the time of this report suggests using a value of $15.20 for travel on a bus and $30.40 for wait time (USDOT, 2020). Agencies can use alternative values for their internal analyses—for example, based on local wage rates—but if an agency is unsure about what values to use, those in USDOT's BCA guidance are reasonable estimates. Again, these are societal impacts rather than direct financial benefits to the agency, so the choice of whether to include them depends on the nature of the agency's decision-making process.

It is not currently clear exactly how automation may impact travel times. Many small automated shuttles tested have operating speeds in the range of 10 mph, which is slower than conventional buses in uncongested traffic, and Advanced Driver Assistance Systems (ADAS) can yield slight speed improvements in some settings (Cregger, Machek, and Cahill, 2019; Machek et al., 2018). One estimate suggests that ADAS for narrow lane/shoulder operations improves average travel speed by 3.5 mph (Peirce et al., 2019), which could be converted to time savings when combined with the specific elements of the route on which it would be used. Agencies will need to consult available research to estimate speed and travel time changes. In other cases, there may be a range of impacts that requires more sophisticated modeling—for example, if automated vehicles have slower operating speeds but are able to provide point-to-point service that reduces commuter waiting or transfer times.

Service and Ridership Changes

If the automated transit bus project has impact on an agency's service levels or ridership, it could impact all other benefit categories as well as some previously-discussed cost categories. Changes to an agency's service could come in several forms, as each agency may deploy automation in different scenarios. Possible changes include:

- Expansion of evening/night-time service
- Additional routes in low-density environments
- More frequent buses along established routes
- Adding stops along an established route

There are other ways in which service could change, but the above list is meant to provide a starting point for agencies to think about how their service will be impacted.

Service changes may naturally lead to changes in ridership. The easiest way to quantify this is to consider the potential number of riders in the baseline scenario where the project does not occur, and in the project scenario with the automated transit bus. **Changes in ridership affect agency revenues and other factors that may be considered in a BCA**. The benefits of the new trips can also be estimated using economic models of consumer surplus, to the extent that the agency wishes to include this in its analysis. Ridership changes, if large enough, can also require operational changes that will affect the business case.

Operating Cost Savings (Labor)

Automation could change labor costs without any change in the number of operators or employees, but simply by saving time. A technology such as automated parking and recall could reduce pull-out and pull-in time by 5–10 minutes, resulting in labor savings (Peirce et al., 2019). This either allows staff to spend time on other activities or results in a shorter shift for affected employees.

One of the largest ways in which automation could impact labor costs is if an automated bus does not require a traditional operator on board; however, there are driving-related tasks that are unique to transit that could be difficult to automate. Bus operators also perform a wide variety of non-driving tasks, including fare collection and passenger assistance (Machek et al., 2018). Bus drivers provide multiple types of assistance to passengers, including helping them with directions, knowing when to lower the bus to make it easier for passengers to get on and off, and providing instructions when problems arise with fare payment. FTA provides a fuller description of non-driving responsibilities in Appendix C of the STAR Plan (Machek et al., 2018).

These tasks could necessitate the continuing presence of transit agency employees on the buses even if they are not responsible for the driving task itself. Such employees could potentially be paid less than a traditional bus operator, which could still result in labor cost savings, but the cost differential may not be very large.

Some of the more indirect effects of automation will likely be difficult for an agency to estimate, but it is worthwhile to at least begin considering the cost changes and look across the agency as a whole to estimate whether the change will be a cost increase or a cost decrease. Accordingly, the agency may need to conduct various scenario tests to determine how different changes in labor costs would impact overall cost-effectiveness.

Finally, it is particularly important to consider the baseline scenario when estimating changes in labor costs. If an agency is replacing a conventional bus with an automated one, then there is the possibility for labor cost savings in the automated scenario.

Operating Cost Savings (Non-Labor)

Some ADAS technologies have been found to improve fuel efficiency. For example, USDOT's GlidePath prototype application for smooth acceleration and deceleration estimated 22.2% fuel savings. This level is likely not achievable for transit vehicles due to the operational environments and frequent stops, but using a value of 7.4% (one-third of 22.2%) may be a reasonable estimate for transit (Peirce et al., 2019). This would reduce the amount of fuel the transit agency needs to purchase, resulting in operational cost savings for the agency. The amount of fuel savings will depend on both the specific technologies deployed and the operational environment of the vehicle, so an agency should be conservative when estimating the potential fuel savings. In particular, the fuel savings may be proportionately lower for an electric vehicle than for a diesel vehicle, as these vehicles have regenerative braking and do not use fuel to idle at stops.

Consideration of fuel savings would also need to consider the full lifecycle of vehicles and any associated re-charging or re-fueling infrastructure. Again, it is important to consider the baseline—for example, if the automation project is not pursued, would electric or diesel conventional buses be used? If electric vehicles would be used irrespective of the decision on automation, then the benefits of electrification would be present in the baseline and should not be considered part of assessing the automation project.

Environmental Impact

As noted, automation technologies could have fuel savings; this means automation could have a positive impact on emissions compared to a non-automated transit bus. To estimate the benefit of an emissions reduction, an agency can use its own values to monetize a reduction in emissions or the values in USDOT's BCA guidance, which breaks out values for different types of emissions, the recommended approach (USDOT, 2020).

This benefit category, if quantified, might be a relatively small value compared to other benefit categories. If an agency is unsure of the exact change to emissions from the project, this benefit could be included qualitatively.

Qualitative Benefits

There may be various benefit categories that are difficult or impossible for an agency to quantify. Some of this may be due to specific benefit types being naturally difficult to quantify in a BCA, such as travel time reliability. Some agencies may also view innovation itself as a benefit that cannot be quantified. Agencies may also want to qualitatively consider the demographics of people riding the bus; certain changes in service from automation could expand transit to underserved populations.

An agency can choose to simply note these benefit categories qualitatively and state whether it thinks that these benefits would outweigh the costs qualitatively. These categories should be determined by the agency and will be specific to each unique project. Different agencies may have differing opinions on what types of benefits they want to note in their analyses.

Agency Decision-Making

A BCA can be a valuable tool in decision-making, but every agency and organization has a different process for making project-related decisions and prioritizing capital investments in a context of finite resources. Agencies consider a variety of factors that would not be included in a traditional, quantitative BCA but are nevertheless important for agency decision-making. Understanding how agencies make decisions can be helpful to organizations interested in partnering with a transit agency for an automation project. Information in this section is based on a literature review and interviews of transit agencies.

This section discusses findings related to five key elements of this process:

- Quantitative decision-making
- Qualitative decision-making
- Role of external funding opportunities
- Differences between the assessment of pilots and long-term investments
- Considerations specific to automation

Quantitative Decision-Making

There was wide variety among agencies regarding quantitative assessments of projects. Some agencies may require a quantitative analysis, and others only encourage it, and still others do not emphasize this element in decision-making. Many agencies do not have the staff or resources to conduct a quantitative analysis for all projects. The type of quantitative analysis can also differ across agencies, ranging from a full-fledged benefit-cost analysis to a more simplified assessment of costs and benefits or, in some cases, a quantitative points-based scoring system. Within each of these overall approaches are multiple categories of benefits that could be considered. The entire lifecycle cost of a project could be considered, or a simpler method may evaluate only the initial capital cost and an estimate of future maintenance costs. On the benefits side, agencies can consider a mix of direct agency impacts such as avoided fuel and labor costs as well as benefits that accrue to riders and society as a whole, such as safety, travel time savings, travel time reliability, emissions, and/or customer satisfaction. When a cost or benefit cannot easily be quantified (for example, customer satisfaction can be difficult to quantify), it may be incorporated qualitatively into the analysis.

Even at agencies that use formal benefit-cost analysis, the results are only one input to the process. Agencies may also choose to prioritize certain benefits over others—a traditional benefit-cost analysis would favor a project that has $1.5 million in travel time savings compared to a project that has $1 million in safety benefits, but the agency may still choose to pursue the project with the safety benefits based on its priorities. A small amount of evidence from the interviews revealed that quantitative benefit-cost analyses are becoming more common or more frequently required in agencies in recent years, but this set may not be broadly representative.

Additionally, **most state DOTs do not do a formal, quantitative BCA, although they do consider benefits and costs**, according to a 2015 survey (FHWA, 2016). The survey also found that even when a BCA is conducted, the results were never the most important factor considered in decision-making and project selection (FHWA, 2016). Although these results were from state DOTs and not transit agencies, they provide some insight into public-sector decision-making, and most state DOTs are FTA grantees. It was noted that transit projects are more likely to have a BCA because of the requirements of various federal transit funding programs, but BCAs are still not typical (FHWA, 2016). A 2013 study found that BCA use in state governments generally—not limited to transportation—was not yet mainstreamed and that other factors were more important than BCAs when making investment decisions (FHWA, 2016). These surveys were conducted several years ago, but the findings are generally consistent with the interviews.

Qualitative Decision-Making

Previous research from FTA and the Shared Use Mobility Center suggested that there are six main areas that agencies consider in their business models (Faust, 2020):

- **Value Proposition** – what is the project/service offering that is new, different, or better?
- **Capitalization and Revenue** – how is the project/service financed and what revenue will it bring in?
- **Customer Base** – who are the targeted customers, and does the service substitute or complement transit ridership?
- **Regulations** – is the technology/service already regulated, and is there strong potential for future regulatory actions that could disrupt the current business model?
- **Partnerships** – what partnerships are available to the agency for this project?

- **Operational Characteristics** – how is this service operating in the mobility space (one mode, multiple modes, mobility as a service)?

Agencies may prioritize certain areas over others or may not always fully consider all these areas, but they provide a high-level summary of the key aspects that are important to decision-making for transit agencies.

All agencies interviewed include qualitative components in their decision-making process, generally related to strategic goals and objectives. That is, projects are assessed on the extent to which they advance agency-defined strategic goals, as established by leadership or through other internal processes. Although projects may be developed and proposed by a division within the agency, there is generally a process by which the project must be formally approved by agency leadership (e.g., Boards). Some agencies must also receive approval from their external funding organizations.

In the most extreme case of using strategic goals to guide decision-making, some agencies have certain types of projects that will almost always be prioritized over others, without reference to formal measures of cost-effectiveness. For example, keeping bus fleets and equipment in a state of good repair was mentioned by multiple interviewees as a top priority, with one agency specifically stating that these basic needs must be met before anything else can be considered. There was division among transit agencies with regard to whether strict standards or flexible guidelines are more desirable for service decisions (Perk and Hinebaugh, 1998), but all agencies seemed to have at least some type of guidelines they follow.

When analyzing the potential benefits and costs of an automation project, **an agency may rely more on qualitative measures than quantitative ones.** This is due partly to the difficult-to-quantify benefits of automation, including the value of research and the learning potential. Additionally, it can be difficult to quantitatively assess automation projects because of a data gap; not all benefits and costs of automated transit are known. Even basic elements of project cost can vary significantly based on vendor offerings and changes in the market, which is atypical for the long-established transit bus industry.

Some agencies also approach automation decisions differently from typical projects, as **the agencies consider automation and innovation to be benefits in their own right.** They are interested in learning about new technologies for the sake of advancing the future of transit. Other agencies, however, treat automation simply as another tool that could be used to improve transit service quality or reduce costs, and they evaluate the investments on that basis. These agencies do not consider automation as a benefit in itself but rather consider automation investments through the same lens they would view any other project. There are also agencies that are open to pilot programs to learn about new technologies but are still mostly motivated by traditional goals such as cost savings. In all cases, this is a qualitative type of assessment—an agency cannot quantify the benefit of innovation.

External Funding Opportunities

Among the interviewees, **external funding opportunities were near-universally identified as motivating factors in the decision to pursue a project**. Transit agencies often have tight budgets, and budget constraints prevent agencies from being able to pursue all projects that they may be interested in or limit agencies to only a small number of projects at a time. This is particularly true for agencies dependent on annual funding appropriations, as opposed to agencies that may have more reliable, dedicated sources of funding. Some agencies are also more opportunistic with regard to external funding. If a new competitive funding opportunity is announced (which could include local or nonprofit challenge grants or a funding opportunity from FTA that provides additional federal funds), these agencies may consider projects that they otherwise would not have engaged in so they can leverage the funding opportunity. Other agencies seek grants only for projects that they have already decided to pursue, with the grant opportunity simply giving them more flexibility to complete the project sooner.

Differences between Pilots and Long-Term Investments

Although there may not be a formal agency policy distinguishing pilots and long-term investments, agencies generally noted that they would be evaluated somewhat differently. There is more room in a pilot for the project to not meet all the objectives it would need to meet in a long-term investment, such as lifecycle cost savings. Additionally, a pilot has learning benefits that are difficult to quantify, whereas a long-term investment may need a more rigorous quantitative analysis before an agency decides to pursue the project long term.

Automation Considerations

In many ways, decision-making for transit bus automation is the same as decision-making for any other project, based on interviewee descriptions. Multiple interviewees emphasized that an automation project would need to be approved through the same processes as any other project. However, there are ways in which it can differ from a typical project. This section highlights both traditional decision-making, as well as specifics related to automation.

Risk

There is a larger risk associated with automation than with the typical projects that agencies might pursue. Agencies are concerned about the possibility of potential liability risks, although the extent of these potential risks is unclear. Transit agencies cited liability concerns that could arise should the technology fail and cause injuries.

Agencies described their efforts to strike the appropriate balance between trying new, innovative ideas and being a smart steward of public money—if an agency loses the trust of the public, it could be detrimental to the agency. A different type of risk is associated with the low level of technological maturity in this area. Automation is still developing, and it is not yet clear how successful it will be for transit buses. By pursuing an automation project, agencies are taking a risk in the hopes that the project will result in long-term benefits to their service, even though it is currently unclear exactly what those benefits might look like.

Consortia

Some agencies have chosen to join together through various consortia and organizations. The reasons for joining a consortium may vary, but part of the potential benefit is allowing agencies easier access to information, particularly when an agency may not have the resources to do research or pilot projects on its own. Due to the rapid evolution of the automation market, any technology tested today could become outdated quickly, and many agencies do not have the staff resources to conduct continuous tracking of developments within the industry. Such consortia will often have a cost to join, which not all agencies can afford; staff time to assess and engage with these consortia must also be considered.

Procurement Considerations

There is also a variety of procurement considerations associated with automation that are not necessarily present for other types of projects. **Procuring an automated vehicle may require a different strategy from conventional vehicles**, such as leasing instead of purchasing or retrofitting existing vehicles rather than buying new. Choices related to the ownership model can affect the cost of the project and potentially can introduce extra risk or liability concerns. For smaller agencies, the cost of pre-purchase market research and due diligence could be prohibitive. One potential mitigation strategy is a bulk purchase (joint procurement or purchasing schedule), potentially at a state level. This approach reduces information costs and may yield more advantageous pricing through volume discounts but can also require the agency to implement alternative procurement procedures and decision-making dynamics to participate.

In addition, **some agencies indicated that there may be a mismatch between their preferred approach and what is available in the current market**. One agency noted that it had to put an automation project on hold partly because it wanted to retrofit existing vehicles, whereas bus OEMs were interested primarily in selling or leasing new vehicles. Agencies also noted general uncertainties surrounding data ownership, minimum useful life, and the spare ratio, all of which factor into their decision-making for transit bus automation to a much greater extent than for conventional bus purchases.

Agencies Not Considering Automation or in Early Stages

It is important to remember that the majority of agencies are not currently considering automation or are only in the early stages of considering automation. The agencies interviewed for this report represent a non-random sample of the small number of agencies and organizations that have conducted or are in the early stages of considering transit automation projects. But when looking at all transit agencies across the U.S., it is likely that there are more agencies that have not considered automation in detail than those that have. This is due, in part, to the fact that there are many more small agencies than large ones, and smaller agencies do not have the capacity to conduct the types of automation projects that larger agencies are considering. Many large transit agencies have at least begun thinking about automation, whereas small and rural agencies typically do not have the capacity to do so (although there are exceptions).

A 2019 study surveyed 258 U.S. transit agencies, the majority of which were rural or small-urban agencies, and found that over 80% of them were not interested in operating fully-automated shuttles in the near future (Godavarthy, 2019). The overall trend suggested that demand for various transit automation technologies was positively correlated with system size. The survey also found that the level of interest varied by the specific type/level of automation, with certain technologies, such as curb avoidance and collision avoidance, appearing much more likely to be implemented in the near future in agencies of various sizes (Godavarthy, 2019). Agencies that are not currently interested in automation may not be capable of making an informed decision at this time, and choosing to pursue an automation pilot requires a large amount of research, planning, and funding that is simply unavailable to certain agencies.

Challenges to Assessing the Business Case

There are multiple, inter-related barriers that prevent agencies from being able to fully assess the business case for transit bus automation. As previously discussed, a significant barrier to conducting a quantitative BCA is data availability and accessibility (meaning both the existence of the data and the ability of agencies to locate and access the data). This section discusses other challenges that impact all types of decision-making for automation, even qualitative decision-making. Information in this section is based on a literature review and interviews of transit agencies. This section categorizes these barriers into four groups:

- Regulations
- Applicability of Previous Research
- Operational Changes
- Customer Acceptance

Overcoming these barriers is possible, as proven by the agencies that have already conducted or are conducting transit automation pilot tests. However, these barriers can cause some agencies to abandon automation projects or at least increase the costs associated with the project. It is also often easier to overcome certain barriers for pilot projects, whereas a longer-term investment may face more obstacles.

Regulations

Transit agencies are subject to a number of federal, state, and local regulations that may introduce uncertainties into their assessment of the business case for automation investments. In particular, for agencies using federal funding, regulations such as Buy America affect the availability and cost of automated vehicles and technologies. Federal procurement rules about spare ratios and minimum useful life can also be relevant, thus requiring an additional layer of analysis and influencing determinations of cost-effectiveness. Regulations can also affect calculations on the benefit side of the ledger—for example, if the labor cost savings that might otherwise be realized from automation are limited by local regulations or offset by required employee payments under Section 13(c).

Regulations can also have an indirect effect on automation business case decisions by introducing additional risk and uncertainty, and creating additional analytical needs that can strain agency resources. Automation technologies intersect with existing regulations in ways that are novel and sometimes complex; for example, it may not be clear to a transit agency whether a new vehicle type or service pattern is compliant with the Americans with Disabilities Act (ADA), since ADA's implementing regulations generally pre-date the advent of automated vehicles. Analyzing these novel regulatory questions may require considerable staff time and expertise, the costs of which may weigh considerably in an agency's assessment of the business case. Unresolved regulatory issues also expose the agency to liability and risk, which may be considered qualitatively in the business case. FTA has begun addressing these information needs through an online FAQ on automation-related regulatory issues (FTA, 2019).

Applicability of Previous Research

Another barrier for agencies is **determining whether or not the findings from one agency's pilot are applicable to them**. Operational capabilities and results may be different in different climates (e.g., sunny weather, snow, rain, etc.) and different operational design domains (e.g., mixed traffic, dedicated bus lanes, etc.). Every region and every agency have unique characteristics that make it challenging for an agency to apply the full benefits and costs of a different agency's pilot project to their own project. This barrier is related to the previously-mentioned barrier of data availability—even when data are available, they may not be applicable to all agencies.

Moreover, **research findings may be expressed using metrics that are not universal to all agencies or that may be difficult to interpret**. For example, results that are not normalized, such as not being adjusted for transit route length or fuel type[5] or that report results using non-standard metrics, may not be meaningful for other agencies, even if the data collection effort is rigorously conducted. Similarly, evaluation reports that provide only key findings without providing the underlying data and assumptions used are less valuable to other agencies, as they are less able to adapt the results to their own service patterns and cost parameters. For example, a report may discuss how a shuttle was impacted by extreme weather events but without specifying any temperature ranges or precipitation levels, making it difficult for other agencies to learn from the experience. Reports may also note the overall project cost but do not break down the cost into categories or distinguish capital from maintenance costs, again somewhat limiting the usefulness for other agencies seeking to learn from that experience.

Operational Changes

When analyzing the business case, **agencies have to predict how automation may change their service patterns or division of labor**; at least two interviewees specifically mentioned labor and operational changes as areas that need consideration. This is a difficult question to answer, as there is no true experience upon which to draw. Agencies have to make predictions as to how their operations may change in the face of limited data. Perhaps they will be able to extend service hours or add a route, or, instead, existing routes will become more efficient. Ridership changes and any associated needs for service adjustments are a further unknown.

The division of labor and organizational changes are also potential effects of automation that are difficult to predict. This extends beyond just estimating

[5] Normalizing can mean converting data to per-mile, per-VMT, per-gallon, etc. The purpose is to convert the data to a form that can be applied to other projects. A reduction in travel time of 30 seconds is very different on a 2-mile route and a 10-mile route.

potential labor cost savings from not requiring a bus driver; it includes understanding what new jobs there may be, what jobs may be able to be consolidated, which teams within the organization will need to take on new roles, and more. Because no agency has implemented a fully-automated bus into regular service yet, there is no relevant experience upon which to draw. An upcoming report on this topic (TCRP J-11, Task 34) may provide useful information on changes in labor cost, but agencies will still need to adapt these findings to their own situations. Likewise, agencies can look to their own history to draw inferences from past service changes, but these impacts may have little relevance to transit automation.

Customer Acceptance

The final barrier identified to understanding the business case is not knowing how customers will respond to the new technologies. Customer acceptance can be predicted to a certain extent through surveys and through the results of other pilot tests, but it is difficult to completely understand how customers will react until there is a full deployment. With many new technologies, there is an initial period in which people are wary and then adapt over time. The reaction of customers to transit automation is a crucial factor to being able to estimate the benefits of automation. If transit riders are going to take many years to feel safe using an automated bus, then the benefits of an automated bus are minimal simply because there are not many people riding it and benefiting from it. In fact, it is possible for transit bus automation to have negative impacts and drive ridership down if people are wary and refuse to ride on a fully-automated transit bus. Agencies have to ensure that all customers are able to ride and feel safe and comfortable riding an automated transit bus. Customer acceptance can be difficult to fully predict.

SECTION

4

Recommendations

The findings of this report lead to recommendations for transit agencies to consider when assessing the business case for transit bus automation. This section also discusses FTA resources.

Clearly identify intended project goals and determine if a quantitative business case is needed. If an agency is pursuing automation for reasons such as the pursuit of innovation, a desire to test a new technology, or in response to rider feedback, then a quantitative assessment may not be necessary, as it would not provide the information the agency wants to know. Conversely, if an agency is pursuing automation as a tactic to achieve goals of improving safety, reducing costs, or decreasing travel time, then a more quantitative analysis may be necessary.

Consider a comprehensive list of benefit and lifecycle cost impacts. Automation could have numerous impacts that agencies should carefully consider before deciding to pursue automation. No agency is required to assess all possible benefits and costs; this recommendation is meant to help ensure that agencies do not overlook certain impacts and to emphasize the importance of considering full lifecycle costs. Even if an agency is not able to quantitatively assess all these categories, it would likely be useful to consider whether the agency expects any changes in these categories due to the automation project. These categories include the quantitative costs and benefits discussed earlier in the BCA section, but also include other, more qualitative categories that may not always be appropriate in a BCA but may influence decision-making.

Examples of the types of information to consider include the following, although other factors may also be relevant for some agencies and situations:

- Capital costs for a variety of ownership models
- Expected maintenance costs
- Staff retraining costs
- Staff time commitment for the proposed project
- Service changes (area, hours, etc.)
- Safety benefits of the technology
- Estimated improvements to travel time, travel time reliability
- Labor costs
- Fuel, oil, and other operating costs
- Emissions changes

- Public opinion and acceptance of automated transit
- Potential changes in customer satisfaction

Use scenarios and sensitivity tests in the BCA when there are data challenges or other unknowns. Scenario testing essentially means an agency conducts multiple quantitative analyses to determine how different assumptions would change the outcome of the analysis. If an agency is unsure of specific cost or benefit categories, a particular form of scenario test called a breakeven analysis can allow an agency to determine how great the benefits would have to be to exceed the costs, or vice versa.[6]

Scenario testing can be especially beneficial when there are only one or two key unknowns. For example, an agency might know all the costs and benefits except for the safety benefits, and it could then conduct tests to determine if even under conservative assumptions the safety benefits are likely to allow the project to be cost-beneficial. If there are multiple unknowns, it becomes more complicated, as there are multiple assumptions that can be varied in any single test. In this case, an agency could develop three sets of assumptions—the most conservative estimates for all categories, the most optimistic estimates for all categories, and a middle-ground set of estimates between the two extremes. The analysis could then be conducted separately with each set of assumptions to generate low, high, and medium estimates. One advantage of this type of analysis is that it allows the agency to identify which of the unknowns has the greatest impact on the ultimate BCA results, thus allowing it to prioritize the areas of further research that would improve decision-making.

Consider reaching out to peers. Agencies with more experience with automation projects are a valuable source of information, particularly since not all relevant information is published. These agencies can provide hard data on technical performance and cost and on institutional issues such as procurement and training. Even if some elements of that knowledge are very specific to that agency's experiences or context, it could still be helpful for new agencies to form connections to more experienced ones. There are also larger groups that provide information on automation research, such as the American Public Transportation Association's committee on automated transit.

[6] A breakeven analysis identifies the point at which the benefit/cost ratio would equal one—in other words, at what points the costs equal the benefits. Such an analysis can be used when either the costs or the benefits are known with some certainty but the other side of the ledger is not. For example, if project costs are known, then a breakeven adjusts the benefit assumptions to determine at what point the project "breaks even." The purpose of such an assessment is to assess whether it is likely that the benefits will exceed the costs and thus support decision-making. If the "breakeven point" arises only with extremely optimistic benefit assumptions, then the project may be unlikely to have the benefits exceed the costs; conversely, if the breakeven point is reached even with very minimal benefit assumptions, then the project is highly likely to have the benefits exceed the costs.

FTA Resources on Transit Bus Automation

FTA is continuously working to provide agencies with relevant resources on transit bus automation. Existing resources at the time of this report include the following:

- Strategic Transit Automation Research Plan (Machek et al., 2018) – Appendix D presents a benefit-cost analysis for various transit automation use cases; https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/114661/strategic-transit-automation-research-report-no-0116_0.pdf
- Transit Bus Automation Market Assessment (Cregger, Machek, and Cahill, 2019) https://www.transit.dot.gov/research-innovation/transit-bus-automation-market-assessment-report-0144
- Frequently Asked Questions: Transit Bus Automation Policy (FTA, 2019) https://www.transit.dot.gov/research-innovation/transit-bus-automation-policy-faqs
- Transit Bus Automation: State and Local Policy Scan (Fischer et al., 2020) – https://www.transit.dot.gov/research-innovation/transit-bus-automation-state-and-local-policy-scan-report-0162
- Considerations for Evaluating Automated Transit Bus Programs (Luna, Machek, and Peirce, 2019)– https://www.transit.dot.gov/research-innovation/considerations-evaluating-automated-transit-bus-programs-report-0149

FTA has also funded multiple transit automation projects through programs such as Accelerating Innovative Mobility (AIM), Integrated Mobility Innovation (IMI) Demonstration Program, Mobility on Demand (MOD) Sandbox Program, Strategic Transit Automation Research (STAR), Safety Research and Demonstration (SRD) Program, Congestion Mitigation and Air Quality (CMAQ) Improvement Program, and more. Agencies interested in pursuing an automation project could consider applying for a competitive FTA grant to receive funding to help pursue the project.

There are multiple other automation-related research projects planned or underway at FTA. Agencies can sign up to receive e-mail updates on FTA's future automation research[7] or provide input[8] regarding additional types of resources that would be beneficial.

[7] To sign up for updates or to access subscriber preferences, please go to https://public.govdelivery.com/accounts/USDOTFTA/subscriber/new?topic_id=USDOTFTA_108.

[8] Contact FTA's automation team at transitautomation@dot.gov.

SECTION

5

Conclusion

This research effort outlines the process for analyzing the internal business case (and/or benefit-cost analysis) for transit bus automation and combines it with information on transit agency decision-making processes for capital investment. The research relies on interviews with transit agencies and other organizations pursuing transit automation as well as an extensive literature review on topics related to transit agency decision-making and transit bus automation. The findings cover known data sources, technical issues with monetization and discounting, and other considerations for conducting a quantitative BCA. In addition, the report discusses barriers that agencies face when assessing automation decisions and puts this in the context of their overall decision-making framework.

A rigorous BCA requires agencies to gather data across a wide range of impacts, including the expected costs over the entire lifecycle of the vehicle, the proposed procurement strategy, the types of benefits that can be expected and how these can be monetized, how the vehicle will impact service levels, and more. An important finding from this work is that there is little to no public information available for many cost and benefit categories, and much of what does exist from small-scale pilot tests may not be broadly applicable. Agencies also do not always have the resources to seek out available information, as there is no single clearinghouse for this information and much of it is unpublished.

Agencies have a variety of specific decision-making processes for capital investments, but there are some discernable trends. One common approach is to assess a project with respect to the agency's strategic goals or objectives, with projects assessed qualitatively on their ability to achieve those goals. There is a large variety in the types of quantitative measures used to analyze projects, with some agencies conducting benefit-cost analyses and others using simplified scoring measures, although agencies generally encourage their staff to quantify measures when possible. In any of these processes, the qualitative or quantitative assessment is not the final say; agency leadership must approve projects before they can begin.

As noted above, quantifying the benefits and costs of an automation project is challenging for agencies because of a lack of data and forecasting tools. To determine whether to pursue automation, agencies often rely on more qualitative measures to assess the project, such as the learning potential and the general benefits of innovation. Other agencies have chosen not to pursue transit bus automation at this time because there is still much unknown about it, and the agencies cannot sign off on an automation project without a fuller understanding of the benefits and costs. There is also a distinction between agencies that view automation as inherently a benefit in and of itself vs. agencies that view it only as a means to an end. Agencies that view it as the former are more likely to pursue automation projects even when a robust analysis cannot be performed, whereas agencies in the latter category compare automation projects to any other capital investment project and, accordingly, typically need more quantitative data before pursuing automation.

However, even if an agency wants to do a more qualitative assessment of the business case for automation, it will still face barriers. This report documents these barriers and categorizes them into four areas – regulations, applicability of findings, operational changes, and customer acceptance. This report also includes five recommendations for agencies on overcoming these barriers and assessing their business case for transit bus automation:

- Start with a clear agency consensus about the intended goals of the automation project and whether a quantitative business case is needed.
- Ensure that a comprehensive list of benefit and lifecycle cost impacts is considered.
- Use scenarios and sensitivity testing to address uncertainties in a quantitative BCA.
- Connect with agencies with more experience in automation to share data.
- Review the latest FTA publications and research findings on bus automation.

APPENDIX

A

Interviews

Eight semi-structured interviews were conducted from February to April 2020. The eight organizations and their relevant characteristics can be seen in Table A-1.

Table A-1 *Interviewees*

Organization	Location	Modes	Status on Automation
TriMet	Portland, OR	Bus; Light rail; Commuter rail	Begun considering; no projects yet
Quad Cities MetroLINK	Rock Island County, IL Henry County, IL	Bus; Paratransit	Part of AECOM's Automated Bus Consortium
Pierce Transit	Pierce County, WA	Bus; Vanpool; Paratransit	Planning a test of automated braking on 40-ft buses
Greenville, SC	Greenville, SC	Bus; Paratransit	Canceled a planned test of an automated shuttle
Denver Regional Transportation District (RTD)	Denver, CO	Bus; Light rail; Commuter rail	Pilot test of automated shuttle completed
Regional Transportation Commission (RTC) of Southern Nevada	Clark County, NV	Bus; Paratransit	Pilot test of automated shuttle underway
LYNX	Orlando, FL	Bus; Vanpool; Demand-response; Paratransit	Conducting one-year feasibility study
Michigan Department of Transportation (MDOT)	Michigan	Does not directly provide service; bus and paratransit for subgrantees	Multiple projects underway/planned

APPENDIX

B

Estimates

This appendix presents a range of quantified estimates from available studies on the benefits and costs of transit automation. These estimates should be regarded simply as a summary of existing research and not as definitive or FTA-approved values. Agencies are encouraged to consider how these estimates may (or may not) apply to their own projects and to not simply take these values without fully considering the limitations of each estimate.

Estimates are presented in separate tables based on cost and benefit categories. Table B-1 shows capital costs, Table B-2 shows non-labor operating costs, Table B-3 shows safety benefits, and Table B-4 shows travel time benefits. Any categories of costs or benefits discussed in the report but that do not have tables here are categories for which the study team found no available information; this includes both maintenance and labor costs and cost savings.

Table B-1

Capital Cost Estimates

Estimate	Source
Automated bus would cost $80,000 over cost of conventional bus. Source did not specify baseline cost of conventional bus being used; however, $80,000 increase would likely represent 16–27% price increase.	Quarles (2017)
Smaller automated shuttle costs $200,000 compared to $45,000 for conventional 15-passenger van, with additional estimated $15,000 for route programming and mapping.	Machek et al. (2018)
Electric shuttle recharging equipment costs estimated at $22,558 per charging station.	Machek et al. (2018)
Capital costs for equipment for adaptive cruise control estimated at $1,800, which attempts to take into account additional cost from added complexity in transit bus compared to cost for light-duty vehicle.	Machek et al. (2018)
Capital costs for on-board equipment for dedicated short range communications (DSRC) estimated at $350 per vehicle.	Machek et al. (2018)
Published estimates list cost for DSRC roadside unit in range of $18,000, not including costs for backhaul telecommunications.	Machek et al. (2018)
Equipment for automatic emergency braking (AEB) and blind spot detection systems estimated at $4,750 in previous FTA study, based on estimates from other studies. Estimates for similar truck-based systems are lower, but higher estimate chosen to be somewhat conservative.	Machek et al. (2018)
Equipment costs estimated at $1,800 for sensor- and/or camera-based lane-centering system.	Machek et al. (2018)

Table B-2

Non-Labor Operating Cost Estimates

Estimate	Source
USDOT's GlidePath prototype application demonstrated smooth acceleration and deceleration and found fuel savings of 22.2% compared to uniform manual driving in a simple scenario; however, this was not a transit vehicle, and this level may not be achievable for transit vehicles due to frequent passenger stops and varied operational environments. Previous FTA analysis used one-third of GlidePath figure (7.4% savings) as a proxy.	Machek et al. (2018)
Approximately $16,000 spent on regulatory signage/installation and O&M costs during six-month pilot for Denver RTD.	Denver RTD (2019)

Table B-3

Safety Benefit Estimates

Estimate	Source
45% crash reduction from automatic emergency braking and pedestrian collision avoidance.	Machek et al. (2018)
Average casualty and liability costs estimated at $6,565 per bus per year, based on historical average for Motor Bus mode; includes crashes and incidents of all types, most but not all potentially addressable by automatic emergency braking (AEB) and pedestrian detection technology.	Machek et al. (2018)
For AEB and pedestrian collision avoidance, crash reduction estimates could be 1–65% based on expert panel estimating reductions for New York City buses.	Mangones et al. (2016)
Crash reduction factor for AEB estimated at 27–54% depending on crash scenario or more specific reduction in rear-end crashes for transit buses from AEB of 71%.	Kockelman et al. (2016)

Table B-4

Travel Time Benefit Estimates

Estimate	Source
One estimate suggests ADAS for narrow lane/shoulder operations improves average travel speed by 3.5 mph, which could be converted into time savings estimate but requires route-specific information such as distance traveled.	Machek et al. (2018)

ACRONYMS & ABBREVIATIONS

ADA	Americans with Disabilities Act
ADAS	Advanced Driver Assistance Systems
AEB	Automatic Emergency Braking
BCA	Benefit-cost analysis
FTA	Federal Transit Administration
OEM	Original Equipment Manufacturers
STAR	Strategic Transit Automation Research
TRID	Transport Research International Documentation
USDOT	U.S. Department of Transportation

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