Scheduling, Planning, Operations and Training Leading Practices and Guidance

Current Deployment Lessons & Future Considerations

Ontario Public Transit Association Zero Emission Bus Committee - Scheduling, Planning, Operations and Training Workstream

June 2022

OPTA

Ontario Public Transit Association

A partnership of transit, business, government and non-profit agencies.

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Forward

The Ontario Public Transit Association (OPTA) is the collective voice of the transit industry in Ontario. As a member-driven trade association, OPTA represents public transit systems, health and social service agency transportation providers, suppliers to the industry, consultants and government representatives.

Its Zero Emission Bus (ZEB) Committee provides OPTA members with a forum to build and exchange ideas and knowledge to support the deployment of zero-emission vehicles across Ontario. The ZEB Committee's mandate is to:

1. Establish and maintain a forum for OPTA transit system members to share best practices, lessons learned, standard documentation and key performance indicators for the implementation of ZEB technology;
2. Identify the need for any targeted advocacy or discussion with federal, provincial and municipal governments relating to the successful implementation of ZEB technology across the Province and make recommendations to the OPTA Board as necessary
3. Investigate and evaluate different procurement strategies for ZEB implementation and undertake collaborative procurements;
4. Advocate for and advance the standardization of ZEB infrastructure across the Province; where appropriate;
5. Engage the vendor community, both bus OEMs and others involved in greening transit, with a view to developing a market-sounding process;
6. Provide guidance for considerations and impacts on planning, scheduling, training and operations.

As part of the ZEB Committee work, OPTA partnered with the Canadian Urban Transit Association (CUTA) to undertake a review of leading practices in ZEB scheduling, planning, operations and training. This report is the result of that collaboration.

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Toronto Transit Commission
Winnipeg Transit
York Region Transit

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List of Abbreviations

Abbreviation	Term/Phrase/Name
API	Application Programming Interface
AVL	Automatic Vehicle Location
BAS	Building Automation System
BEB	Battery-Electric Bus
CAD	Computer-Aided Dispatch
CAN	Controller Area Network
CMS	Charge Management System
CNG	Compressed Natural Gas
CSO	Charging System Operator
DMS	Depot Management System
EMS	Energy Management System
FCEB	Fuel-Cell Electric Bus
FIFO	First-In First-Out
GHG	Greenhouse Gas
HV	High-Voltage
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
IT	Information Technology
MOC	Management of Change
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
RNG	Renewable Natural Gas
SAE	Society of Automotive Engineers
SOC	State of Charge
SOP	Standard Operating Procedure
SPOT	Scheduling, Planning, Operations, and Training
TA	Transit Agency
VDV	Verband Deutscher Verkehrsunternehmen
ZEB	Zero-Emission Bus

Executive Summary

The OPTA Zero Emission Bus (ZEB) Committee provides OPTA members with a forum to build and exchange ideas and knowledge to support the deployment of zero-emission vehicles across Ontario. A central mandate of the ZEB Committee is to establish and maintain a forum for OPTA transit system members to share best practices, lessons learned, standard documentation and key performance indicators for the implementation of ZEB technology;

This report was written to explore the leading/best practices and future considerations for Transit Planning, Operations, & Training (SPOT) in relation to battery-electric bus (BEB) deployments. Eleven Canadian Transit Agencies (TAs) participated in focus groups to explore the practices utilized in SPOT areas, the path that led them to where they are today, and the challenges and lessons learned along their electrification journey.

There remains a lot of exploration, idea sharing, and innovation to be done in the domain of transit electrification. Before an initial BEB deployment, the focus (to this point) has been mainly on the viability of BEBs as a replacement for conventional buses. However, the limitations of BEB technology in its current form are now well understood, and the focus must now shift to how BEBs will slot into a TA operationally while maintaining exceptional service levels and experience for its end users.

Based on the current state of BEB deployments, it became clear that BEB fleets can be classified based on their charging strategy and size. The two main charging strategies currently used are In-Depot Charging (centralized charging location within a transit facility) and On-Route/Opportunity Charging (distributed charging locations outside a specific transit facility). A third charging strategy – Mixed Charging – is a combination of the previously mentioned strategies and is not currently widely used, although this is expected to change in future. BEB fleet size factors into the complexity and requirements of a BEB deployment. This report has broken down BEB fleet size (small, medium, large) based on the number of vehicles housed within a single facility.

The responses recorded during the focus group interviews were used to identify commonalities and exceptions in SPOT areas. Beyond what TAs are doing today, we extend considerations to the future with an eye toward full-fleet electrification, giving the reader a sense of changes to come as BEB fleets expand.

Key Findings

Many of Canada's earliest BEB pilot deployments utilized an on-route charging strategy. These pilots often gave TAs their first chance at gaining hands-on experience with BEBs technology and the associated charging infrastructure. As a result, many valuable operational and technical lessons were learned and shared with the transit industry. Although the learnings from monitoring these deployments have been invaluable, it is now the case that TAs are pursuing a shift to in-depot charging in part due to the complexity and cost challenges that would be associated with large-scale on-route/opportunity deployments. In the short-term, in-depot charging will be used as the charging strategy of choice by many

TAs as they look to accelerate deployment and lower barriers to adopting zero-emission technology. Ultimately, on-route/opportunity charging, and other alternative fuel technologies will be used to further the electrification of transit networks in the future.

Among the benefits of utilizing in-depot charging is the deferral of planning & scheduling impacts. It is the case that a significant (if not the majority) of a TAs current network can be electrified from day one without changes to service schedules, blocks, or other planning & scheduling artifacts. This allows the deployment of BEBs to initially occur without changes needing to be made to these areas and pushes changes to a point in the future when there is more familiarity with the technology and additional change is more manageable.

In the interest of expanding the electrification of transit networks in the future, TAs can choose from many options. These options include (but are not limited to) the usage of on-route/opportunity charging, Renewable Natural Gas (RNG) buses, Fuel-Cell Electric Buses (FCEBs), or making changes to scheduling processes. Of all scheduling processes, blocking will likely see the most significant changes when complete electrification is pursued. During blocking, the way routes are grouped to form trips can be modified to accommodate the range limitations of BEBs. Blocking modifications will inherently impact the number of vehicles needed to meet service schedules and the number of operators required to complete all shifts. These cost impacts are in the early days of analysis and will require continued development and collaboration between TAs to determine their true benefits or disadvantages.

Within the operational realm, significant changes are set to occur regarding the in-depot operations with the deployment of BEBs. The shift from conventional bus technology to zero-emissions technology will likely be the most significant change that most TAs have ever experienced. This shift will be well represented in the changes to the day-to-day operations of a fleet. Procedures directing how vehicles are moved, fueled, scheduled, cleaned, and so on will be affected by the deployment of BEBs and will be a central theme of implementation planning for large BEB fleets. Many changes to internal structures, standard operating procedures (SOPs), roles, and systems will occur with the onboarding of this new technology.

Although the (in-garage) operations of BEBs are likely to be more complex than their conventional bus counterparts, these complexities will largely be managed using advanced software systems. It is expected that BEB deployments will require some level of future-focus IT solutions, depending on the fleet size and expected future growth. Depot Management Systems (DMS) & Charge Management Systems (CMS) are most important for operating a BEB fleet. The requirement for new IT solutions also represents an opportunity for TAs to request the development and adoption of open communication standards to be utilized by these new systems. Open Standards will allow for more customized, cost-effective, and modular solutions to be deployed for the end user's benefit. The successful operation of large zero-emission fleets will depend on the IT systems used to manage them; the importance of these systems cannot be overstated.

Regarding planning for a BEB deployment, many TAs offered similar advice about what led to success in the early days of their programs. One of the most important notes is that change management is crucial and Management of Change (MOC) programs are highly beneficial. How impacts are identified and measured and ultimately how change is affected and phased will factor significantly into the success of a transition program. Long-term planning will also benefit a BEB deployment and allow a smoother transition to large zero-emission fleets while minimizing program costs. Planning for full-fleet electrification and working backwards to determine program needs at different times can help map an approach that will suit a deployment over the long term. Pilots and smaller deployments can be used to gather information needed to make long-term decisions. At the same time, do not delay the adoption of zero-emission technology. Instead, think about scalable solutions, minimize duplication of work efforts, and lean on other TAs to gut-check your plans as you move forward.

Understanding how BEB technology can be used effectively and what solutions are available to support operations will improve implementation plans and provide a better idea of 'how' electrification will actually 'work.' Future-state charging operations will depend on the charging infrastructure, BEB technology, and IT solutions deployed. Each deployment will be unique and function within its specific constraints. Therefore, understanding how charging operations will function within your organization will be critical in deploying large BEB fleets.

Early engagement from stakeholders and municipal branches is key to a successful BEB deployment. Bring in as many working groups as possible – you will likely be surprised by the wide-reaching impacts of the shift to zero-emission technology. In addition, complete and sustained engagement will allow for changes to be managed effectively across an organization. Finally, broad-reaching stakeholder engagement will help prepare other branches to pursue a low-carbon future if they have not begun their decarbonization process yet.

Early top-down recognition and acceptance of sweeping organizational changes will significantly benefit a BEB deployment from the onset. In the face of these significant changes, solving problems in isolation is not a path to be followed. Open sharing and communication are ubiquitous in the public transit industry and are encouraged to continue in the matter of electrification. Innovation is needed to confront the challenge of substantially reducing greenhouse gas (GHG) emissions. It will not only be on the vehicle, equipment, and software side of the equation where innovation is needed but also in transit scheduling, planning, operations, and training. These areas need to be brought to the forefront to lay the groundwork for the transportation industry to continue learning, growing, and leading the way to a zero-emission future.

1 Introduction

Transit agencies (TAs) across Canada have begun transitioning their bus fleets to zero-emission technology to meet greenhouse gas (GHG) reduction targets set at the municipal, provincial, and federal levels. Conventional transit vehicles typically contribute significantly to municipal GHG emissions. As a result, they have been targeted as a critical area where significant GHG emission reductions can be realized. This new focus on transit vehicles has led to accelerated investment in zero-emission bus projects that will ultimately replace today's conventional buses with a new generation of technology.

This report will focus on battery electric bus (BEB) deployments specifically; however, it is recognized that a combination of technologies, whether they be fuel-cell electric buses (FCEBs), compressed natural gas or renewable natural gas (CNG or RNG) buses or diesel hybrid buses, will likely be utilized by TAs to varying degrees to achieve net zero-emissions.

In the years preceding this report, the transit industry has assessed BEB technology as a replacement for conventional buses. Range anxiety and questions surrounding the performance, reliability, availability, and capabilities of BEBs have been top-of-mind as TAs look to maintain exceptional service levels for public transit users while balancing tight operational constraints. BEB pilot programs are ongoing across the country. As a result of these pilots, there is now a growing understanding that this technology is viable and will ultimately be a part of the solution to reducing municipal GHG emissions.

With this acceptance, it is now time to turn attention to how this technology will "work" within a TA's bus fleet. What organizational changes must be made during the transition to a zero-emission fleet? What electrification approach are other TAs taking in situations like yours? What has worked elsewhere from an operational perspective? What are some key operational lessons learned from deployments thus far? These are all valid questions that this report will look to address in a helpful way for a broad audience.

This transition will likely represent the most significant organizational change many TAs have ever experienced. This report will provide insight into how this change is occurring and what is next in the journey to zero-emission.

1.1 Objective

This report will focus on the aspects of transit Scheduling, Planning, Operations, & Training (SPOT) that the deployment of BEBs will impact and the leading practices implemented to accompany the new technology. We look to explore the paths TAs have taken, the decisions made, and what has worked to date in the early days of their zero-emission transition. We will also extend considerations to the future with an eye towards full-fleet electrification, giving the reader a sense of changes to come as BEB fleets expand and eventually account for a large (if not total) portion of transit fleets.

In preparation for this report, eleven TAs across Canada took part in leading practice focus groups to explore SPOT-related subjects. These TAs were selected to capture input from systems of different sizes, taking different electrification approaches and at different stages of their transition to BEBs. Commonalities and exceptions from these focus groups will be highlighted in this report, which aims to give all Canadian TAs a sense of what path their peers are taking toward net-zero emissions and what key areas need to be considered as they continue towards net-zero emission goals.

1.2 How to Read this Report – Fleet Size

Many aspects of a BEB deployment will depend on the size of the fleet which is being transitioned. These aspects include the order, rate, and complexity of the organizational changes that need to be executed, not to mention the scopes of infrastructure projects that need to be completed. This is not to say that smaller fleets (or TAs) will have an easier transition to zero emissions. Although the magnitude of their projects may be smaller, they may lack the internal resources and funding necessary to complete changes such as those discussed in this document. Conversely, larger TAs may have more in-house staff for such projects, but the added size and complexities make the challenges increasingly difficult to manage.

This report is meant to be used by TAs with fleets of all sizes to help them discern what should be considered and what is required to deploy BEBs. Additionally, this report is not meant to be prescriptive – each BEB deployment will be unique and should be treated as such. How the concepts, systems, processes, and changes discussed in this document apply to your organization should be questioned and assessed individually. It will be highlighted, where possible, which items are expected to be optional, desirable or required for the deployment of BEBs, and to what fleet size considerations are applicable.

Some changes and considerations will have to be made with a BEB fleet of any size, essentially from day one of any deployment. However, the timing of some other changes and considerations will depend on the size of a BEB fleet. The size of a BEB fleet housed in an individual facility will define fleet size in this document rather than the overall transit or BEB fleet size. BEB fleet sizes in this report will be categorized according to Table 1. These values estimate where an increase in deployment complexities will arise but are not definite. As large BEB fleets become more common, and all associated technologies mature, it can be expected that the values in Table 1 will shift; they are a snapshot of where the industry stands at this particular point in time.

With these categorizations, it can be the case that there will be different requirements at different facilities within the same organization. This level of granularity may be necessary for defining needs at different locations and can help assess variations in processes or systems that will be required across an organization. In addition, this granularity can help organizations better manage change by focusing efforts where changes are operationally required and more gradually implementing them in areas where it is less critical.

In addition to the pure number of BEBs housed in one location, the actual proportion of vehicles that are electrified in one location can also factor into the changes required. For example, 30 buses at a 100-bus garage would be more difficult to manage operationally than 30 buses at a 400-bus garage. However, for simplicity, only the number of vehicles per facility will be used to quantify fleet size and categorization in this document. This classification method is sufficient given the current state of BEB deployments and the size of those deployments expected in the next 0-5 years as TAs begin their transition. However, as BEB deployments grow in size, categorizing them in multiple dimensions (fleet size and electrified proportion) may be helpful in planning and phasing projects.

Table 1. Fleet size categorization in this report is based on BEBs housed within a facility.

Size Category	Per facility BEB Fleet Size
Small	0 - 30
Medium	31 - 75
Large	75+

1.3 What makes BEBs Different?

Besides the technological differences between BEBs and conventional buses (i.e., drivetrain technology), some other high-level limitations will affect how these vehicles can be deployed and the processes and systems that will support deployments. The core limitations that affect BEB transitions and that will lead to the operational challenges and organizational changes include:

- Limited range compared to conventional buses.
- Longer refuelling time than conventional buses.
- Limited power at the facility level.
- Limited Space within facilities.
- Budgetary and funding constraints.

These factors will carry different weights and impacts from TA to TA but must be understood to deploy BEBs successfully. Working within these constraints will be the defining challenge of BEB deployments.

In an ideal scenario, BEBs would have enough battery capacity to complete any work in any condition throughout their lifecycle. Each BEB would have a charger to return to in a depot. The charger would be able to charge the BEB very quickly and at full power regardless of what other charging sessions are occurring. Unfortunately, this is an unrealistic case for many reasons. Although technological advances can alleviate some of these issues to a degree, there will be some that just cannot be completely mitigated.

Current pilot programs represent BEB deployments that are not necessarily brushing up against all the mentioned constraints simultaneously. This lack of constraints separates the pilot projects from future large-scale deployments, so this report will include future considerations that look to account for more constraint-riddled deployments that will more accurately represent future scenarios.

1.4 Concepts & Definitions

The transition to BEBs represents a significant shift in the technology used to meet the service goals of TAs. New operating paradigms and language will likely need to be developed within your organization to accommodate this change. The section below will explore some important concepts developed and used for current BEB deployments and will be used regularly throughout this report.

1.4.1 Charging Operations

Charging Operations will refer to the combination of business processes and systems that function together to keep your fleet charged. Anything that is physically, digitally (or otherwise) "done" to manage or optimize the usage of your electrified fleet is considered a part of Charging Operations. Most Charging Operations will have analogous processes or systems to manage your conventional bus fleet.

An example of an analogous process is vehicle fueling. Your organization likely has a standard operating procedure (SOP) used to guide the fueling process for diesel buses, and there will also be an SOP used to guide the charging process for BEBs. The SOP for charging will be significantly different from the SOP for diesel fueling, although both have the same goal of fueling vehicles.

Examples of other in-garage processes that can be categorized as Charging Operations include (but are not limited to): parking, work assignment, garage organization, connecting the charger to the bus, bus charging, and pre-trip inspection.

1.4.2 Charging Strategy

The Charging Strategy refers to a TA's approach to carrying out most of its charging activities. The three common charging strategies are

1. In-Depot Charging (overhead pantograph or plug-in) - Requires a centralized location (maintenance, depot, or yard facility) where the charging activities occur while vehicles are not in revenue service. This charging strategy is typically used in combination with long-range high-capacity BEBs.
2. On-Route/Opportunity Charging (overhead only) - This charging strategy uses distributed charging locations outside specific maintenance, depot, or yard facilities. Charging activities occur while vehicles are in revenue service, for example, when a BEB is on a layover at a transit center. In-depot chargers may also be installed with this charging strategy but do not define how on-route operations occur. Vehicles would typically not be able to complete their assigned work without on-route charging. A combination of short and long-range BEBs can be deployed using this charging strategy, although High-Power BEBs must be used to maximize the charging abilities of a vehicle.

3. Mixed (Combination of in-depot & on-route) - A mixed charging strategy where vehicles can charge within a centralized location and at distributed charging locations while in revenue service. A combination of short and long-range BEBs can be deployed using this charging strategy.

The charging strategy is a primary factor in how SPOT areas are impacted and generally dictates how BEB deployments are approached. Each charging strategy is accompanied by its unique challenges, which will be explored in the main sections of this report.

1.4.3 Available Battery Capacity

Available Battery Capacity is the total amount of battery capacity (energy) available under normal operating conditions. This value represents the total available energy for use when a battery is fully charged. Available battery capacity varies between bus OEMs and bus models and should be understood as such. Available battery capacity is different from the Nameplate Battery Capacity, which is the total chemical capacity of a battery and the value that is most commonly used to identify the size of a bus battery (i.e., on a datasheet, etc.).

1.4.4 Battery Technology and Charging Strategy

There are two main battery types that are utilized on BEBs: high-energy batteries and high-power batteries. Put simply; High-Energy batteries have a larger available battery capacity but a lower charge rate than High-Power batteries. Conversely, High-Power batteries have a smaller available battery capacity but a higher charge rate than High-Capacity batteries. These characteristics directly affect the charging strategy with which a particular BEB can be optimally deployed. High-Energy (long-range) BEBs are better suited for the in-depot charging strategy, while High-Power BEBs are better suited for the on-route/opportunity charging strategy. The charge rate of the batteries themselves is another factor that needs to be considered so that planned charging infrastructure can be rightsized and utilized to its fullest extent during operation.

1.5 Overview of Participating Organizations

The TAs that took part in the leading practice focus groups can be classified according to their fleet sizes and charging strategies (as define in the previous sections). These classifications can be seen in Table 2.

When reading this report, it can be informative to keep in mind which agencies are represented by a given charging strategy as their commonalities have been assembled as key takeaways. When speaking of on-route charging, for example, BEB deployments from Bow Valley Regional Transit Service Commission, Edmonton Transit Service, Kingston Transit, OC Transpo, and Toronto Transit Commission are referred to. On the other hand, Brampton Transit, Coast Mountain Bus Company, and York Region Transit represent the on-route/opportunity charging strategy. Société de Transport de Montréal is unique as it has sizeable BEB deployments utilizing each charging strategy.

Table 2. Overview of Focus Group Participants

Transit Organization	Fleet Size Classification	Charging Strategy	Context
Bow Valley Regional Transit Service Commission (BVRTSC)	Small	In-Depot	1 Facility, 5 High-Capacity BEBs
Brampton Transit	Small	On-Route/Opportunity	1 Facility, 2 High-Power BEBs
Coast Mountain Bus Company (CMBC)	Small	On-Route/Opportunity	1 Facility, 2 High-Power BEBs
Edmonton Transit Service (ETS)	Small x1, Medium x1	In-Depot	2 Facilities, 40 High-Capacity BEBs
Halifax Transit	N/A	Future – In-Depot	Future – 1 Facility, ~60 High-Capacity BEBs
Kingston Transit	Small	In-Depot	1 Facility, 2 High-Capacity BEBs
OC Transpo	Small	In-Depot	1 Facility, 4 High-Capacity BEBs
Société de Transport de Montréal (STM)	Medium	On-Route/Opportunity & In-Depot	2 Facilities, 4 High-Power BEBs & 30 High-Capacity BEBs
Toronto Transit Commission (TTC)	Small x 3	In-Depot	3 Facilities, 60 High-Capacity BEBs
Winnipeg Transit	N/A	Past - On-Route/Opportunity Future – In-Depot	Past Deployment – 1 Facility, 4 High-Power BEBs
York Region Transit (YRT)	Small	On-Route	1 Facility, 12 High-Power BEBs

2 Planning

As a transit system is gradually electrified, changes to different aspects of transit planning will vary. The end goal of transit planners will be to preserve, or even improve, the current public transit service level while accommodating potential operational differences adopted with BEB deployments. Due to BEB deployments and the associated planning changes, no end-user should be worse off. There may be an opportunity to induce positive changes in the network design nudged along by BEB deployments and a climate-focused lens. Sustainability considerations can be incorporated into planning processes, further increasing the potential for these technologies to reduce GHG emissions.

The sections below will explore topics discussed during leading practice focus groups, summarize findings from typical deployments, and speak to future considerations that can be considered regarding transit planning moving forward.

2.1 Network Design

2.1.1 Typical Deployments

At a baseline, network design includes considerations for the types of vehicles available to be deployed in a network. These vehicles include broad vehicle classes such as transit buses, articulated buses, intercity buses, suburban buses, commuter rail trains, heavy rail trains, and light rail trains.

The approach taken concerning network design to accommodate BEBs will largely depend on high-level organizational mandates. At the root of these approaches is the question, "**Does your network have to suit your technology, or does the technology have to suit your network**"? This question was raised in each leading practice focus group to determine whether introducing a new type of 40' transit bus would factor into the high-level network design equation. There was unanimous agreement that technology must suit a network. It is generally unacceptable to impact network design due to the procurement of a specific vehicle within a class. This implies that the needs of the public will not change because of BEBs deployments alone - this is the case for both in-depot and on-route/opportunity charging strategies.

Takeaways	Technology must suit a network; the network will not change to suit a technology. BEB deployments have resulted in no impacts on network designs to this point in time. The priority is to maintain exceptional service levels for transit users.
BEB Fleet Size	All

2.1.2 Future Considerations

New urban transit modalities (i.e., On-Demand Transit, First Mile-Last-Mile services, Bus Rapid Transit) and evolutions in transit planning philosophies will likely impact network design more than the introduction of zero-emission technology. The exact level of network changes due to new transit modalities and philosophies remains to be seen but will have to be monitored to ensure synergy with the introduction of BEBs.

Next Steps	Changes in transit network designs will be driven by new and emerging transit modalities and philosophies rather than zero-emission bus deployments. Monitor these new trends for zero-emission applications and new opportunities to increase the electrification of your network.
BEB Fleet Size	All

2.2 Service Planning

Service planning defines the short-term operational plans in response to land use (geography of a region, existing infrastructure, etc.), user travel patterns, and organizational resources. In addition, service planning typically considers service area characteristics, service coverage, route layout and design, and stop location and spacing. This planning is all done to provide a network of quality services, promote a positive alternative to auto travel, and run buses safely, cleanly, and conveniently. Service planning, of course, must be completed within TA's budgetary constraints and relevant policy framework.

2.2.1 Typical Deployments

Like network design, current BEB deployments have not impacted service planning processes. BEBs simply replace conventional 40' buses within a network and are not treated as a separate asset class. Instead of investigating and making service planning changes, TAs have opted to defer this task to the future when BEB technology is better understood. Regardless of implementing an in-depot or on-route/opportunity charging strategy, this stance holds.

In our leading practice focus groups, we explored the idea of service planning (route design) having to adjust to potentially different physical characteristics between BEBs and conventional buses. Height restrictions, turning radius restrictions, and weight restrictions are all examples of limitations that could theoretically inhibit bus travel. Typically, these physical differences are not significant enough to impact where the BEBs could travel within a network. However, there are cases where the turning radius is of concern, especially in the winter when snow build-up on some routes causes tight cornering. This difference was noticed due to deploying BEBs from a different OEM than the rest of the fleet. In these cases, road maintenance groups have been engaged to provide the proper service levels throughout the year but have not prevented BEBs from travelling freely within the network.

Many branches of municipal government can be engaged to verify if these vehicle differences will have impacts (i.e., road engineering) or if demands will increase elsewhere (i.e., road maintenance). Due to these physical characteristics, depot/garage design and retrofit will be more significantly impacted. This is especially the case in purpose-built BEB facilities where weight, length, and turning radius could be factors in facility design requirements.

Takeaways	BEB deployments have resulted in no impacts on service planning or design to this point in time. The priority is to maintain exceptional service levels for transit users. Physical BEB characteristics typically do not prevent them from being utilized within a network.
Fleet Size	All

2.2.2 Future Considerations

BEB technology comes with some immediate user benefits in the form of zero tailpipe emissions, a quieter ride, and a smoother driving experience. From the public's point of view, this offers a better alternative to auto travel as it offers a cleaner transportation modality than most users would otherwise access. Ridership draws due to BEB presence within a network is an area that has yet to be explored (mainly due to small deployment numbers and impacts from COVID-19 on ridership). However, this will be an area to explore as climate change awareness gains a larger audience and more people look to alternative transportation modalities to curb personal carbon footprints. The influence of BEBs on ridership draw can be captured in a data collection plan defined by transit service monitoring procedures.

Route design and layout are the most likely to be impacted by changes to service planning processes, although the likelihood of changes is low. Regardless, one approach is to modify routes to produce the most efficient routes possible for BEBs (i.e., reducing energy requirements & GHG emissions). This optimization would, of course, have to be balanced with regard to other service planning areas, such as service area characteristics or service coverage, and could not result in a negative impact on the network (in the eyes of the user). Data collection, planning software, and an understanding of a specific BEB technology within a TA's network will be required before these changes can be considered.

Next Steps	Utilize software to analyze and optimize route designs without impacting service levels and human resource needs. Study the effect that BEB deployments have on transit ridership and continue to offer low-carbon transportation alternatives.
Fleet Size	All

2.3 Planning for BEB Deployments

The implemented charging strategy will significantly impact a BEB deployment's effect on planning activities. The sections below will highlight the general transit planning activities that have been involved in BEB deployments to date and how transit planners have been and can be involved in BEB deployment planning regardless of the chosen strategy.

2.3.1 Typical Deployments

2.3.1.1 In-Depot Charging

With in-depot charging only, it has been found that there are often no impacts or changes to transit planning that arise with initial BEB deployments. A lack of changes results from charging infrastructure being contained in a controlled area and the fact that initial deployments typically make up a small proportion of a TA's overall fleet. As a result, TAs deploy these buses like another 40' conventional bus, with no impact on service planning, network design, route design, stop layout, or service level determination.

However, planning departments can have significant input on the initial blocks that can or should be assigned to your BEB fleet. For example, planners will have input regarding what the busiest blocks are, what the shortest blocks are, where BEBs will get the most public exposure and can provide you with information regarding the type of driving that is typical within a given block (i.e., duty cycles) if the correct data is collected. This input can inform where you initially deploy your BEBs. In addition, if planned correctly, it will allow you to gather essential data that will help you understand your technology's performance (i.e., energy consumption) within your network.

Takeaways	Initial BEB deployments have minimal impact on transit planners when using an in-depot charging strategy. Transit Planners can input pre-deployment block selection and determine what locations are best served by your specific BEBs. Complexity will arise as the BEB fleets get bigger and the number of blocks that work with current BEB ranges gets smaller.
Fleet Size	All

2.3.1.2 On-Route Charging

For TAs with on-route/opportunity chargers, the planning & scheduling departments typically played a significant role in determining the locations of the first installed chargers - more specifically, in identifying and assessing which routes can be electrified according to numerous constraints. The constraints applied to selecting routes to be electrified (and thus charger location) typically include ridership statistics, proximity to bus depots/yards, terminus points, route length (limits based on BEB characteristics), available layover time, and public visibility. In addition, land ownership and other installation constraints are further considered before finalizing the selection of the route(s) to be electrified.

The most common installation location for on-route/opportunity chargers has been transit hubs at the terminus of the selected route(s). Here, chargers are either installed within a passenger loading location or separately in a staging area typically reserved for buses on layovers (where passengers do not load). As a note, it was indicated on a couple of occasions that there were initial hesitations regarding passenger loading during charging activities; this is no longer seen as a safety issue. Isolating charging sessions to staging areas has been done due to the pilot nature of deployments and some accessibility issues with early BEB models (i.e., the charging mast would prevent wheelchair ramps from being deployed). Moving forward, passenger loading while charging is expected to occur (where physically possible) and will decrease the amount of time that will potentially have to be added to any layovers (discussed further in the Scheduling sections).

Takeaways	Transit Planners play an integral role in assessing potential on-route charging sites considering several essential factors, including ridership, public visibility, route selection, land ownership, and policy requirements.
Fleet Size	All

2.3.2 Future Considerations

TAs who have initially deployed an on-route/opportunity charging strategy are now showing a unanimous shift towards in-depot charging as their primary charging strategy. This shift is caused, in part, by the limitations and constraints associated with on-route charger installations and the recognition that many of their blocks can be electrified more quickly using in-depot charged long-range BEBs. In addition, this will accelerate the number of BEBs that can be deployed in a given amount of time while concentrating infrastructure impacts on an area owned and controlled by the TA already (i.e., depot, garage or yard).

In the long term, however, on-route/opportunity charging is still considered a key piece in full-fleet electrification, along with other zero-emission technologies such as fuel-cell electric buses (FCEBs). With proper planning, the on-route/opportunity charging strategy is expected to allow TAs to electrify even their longest blocks and help reduce the scheduling impacts that BEB deployments may cause (if this is a goal of an agency). If this is the path selected to electrify your network further, early planning and identification of the many physical constraints associated with this charging strategy will benefit your organization in the years to come.

Transit planners and schedulers can have valuable insight into the locations which chargers could best serve. Within a network, routes, utilization rates, and service frequencies can impact charging infrastructure placement and cost-effectiveness, especially for wholly electrified routes/lines. Although there are likely "optimal" locations for on-route chargers along a transit route, there are also the realities of zoning, land ownership, or aesthetic restrictions, which can be prohibitive to an agency's ability to install on-route chargers in specific locations. Transit planners will have great insight into these realities. They can provide early feedback about the feasibility and outlook of electrifying your network using an on-route/opportunity or mixed charging strategy. Finally, transit planners can help determine which routes may be of most interest as a TA look to maximize charger utilization for current or future charging infrastructure deployments. This would be done while managing other complicated variables such as headway and the number of extra buses needed to maintain service levels.

Next Steps	In-depot charging will likely allow for significant short-term electrification; on-route charging may be essential in full fleet electrification in the future. Utilize transit planning insights to help you plan to deploy multiple charging strategies to achieve a zero-emission network. The charging strategy may impact the fleet size and spare ratio – this will have to be considered as planners manage fleet sizes.
Fleet Size	All

3 Scheduling

The goal of transit scheduling is to prepare accurate and efficient schedules that help to increase the quality of public service. There is no unique solution for scheduling, where success is reached by continuous work and analysis to optimize efficiency and costs. Frequent schedule changes result from even small changes in passenger demand, service policy, or traffic conditions.

Transit scheduling is challenging because it requires a scheduler to know internal (transit operations) and external factors (agency policies and collective agreements). One of the most common issues of transit scheduling is vehicle and driver assignment due to some constraints presented by labour union agreements. With the introduction of BEBs in a TA's fleet, further constraints may become relevant to transit schedulers that have not existed before and significantly affect their work processes. It should be mentioned that software tools help the scheduler speed up the process and do the work accurately. However, utilizing these tools does not eliminate the need for knowledge and understanding of the entire transit scheduling process.

The transit scheduling process will be broken down into four categories and explored. These categories are Timetabling, Blocking, Runcutting, and Rostering. The changes to scheduling processes seen to date and the changes that may occur with larger BEB deployments in the future will be discussed in the sections below.

3.1 Timetabling (Trip Building)

Timetabling is the process of creating the master service schedule for each planned route. The scheduler, when timetabling, typically considers the span of service, headway, timepoints, running times, round-trip cycle time, and layover/recovery time. Akin to network and service design, the timetable for a particular route is typically driven by external factors and should not be impacted by the technology deployed on a route. Again, the technology must suit the network. It will be a priority to maintain (or improve) current service quality during the transition to BEBs, although this may add to the complexity and operating costs of a transit system. As will be discussed in the following sections, the impacts on timetabling are primarily tied to the charging strategy

3.1.1 Typical Deployments

3.1.1.1 In-Depot Charging

TAs that rely on an in-depot charging strategy have indicated that timetabling remains unimpacted by BEB deployments. The typical case sees BEB work assignments being considered at the block level and not based on a route's service schedule. As a result, blocks are left unchanged, with an assessment of those blocks completed before BEBs can be assigned a particular block for revenue service. During this assessment, a block's distance and duration characteristics are typically compared against a TA's specific BEB characteristics (i.e., energy consumption, available battery capacity, etc.).

Takeaways	In-depot charging strategy has not impacted timetabling processes to date. Low impacts are seen because BEBs can be utilized on many blocks, just like conventional buses.
Fleet Size	All

3.1.1.2 On-Route/Opportunity Charging

Timetabling for the on-route/opportunity charging strategy is impacted more than the in-depot charging strategy. For TAs which deploy this charging strategy, an isolated number of predetermined routes are modified to accommodate charging activities. These routes are carefully selected and often planned simultaneously while determining on-route charger locations.

Once a route is selected for electrification, an assessment of the required charging needs of a BEB is completed. This assessment includes considerations for the distance and duration of the route (typically round-trip) and the battery capacity of the BEBs used for those routes. The number of trips a BEB can complete before needing to charge is determined, and charging time is then added into the service schedule for that route at appropriate intervals. These intervals typically allow for a large amount of error to be introduced into the system without impacting a BEB's ability to continue service. For example - if a BEB misses a charging session at a route terminus, the built-in energy contingency will allow the BEB to continue the route in anticipation that charging will occur at the next opportunity.

The amount of energy contingency that a BEB can carry depends on the amount of available battery capacity of a given vehicle, the on-route energy consumption, the distance to be covered, and the time until the next charging session can occur. It is noted that there are cases where a BEBs can miss a charge for a one-way trip and others where a BEBs can carry enough residual energy for a complete round trip (or more).

The charging session time (strictly for power delivery) and some buffer time to account for travelling and connecting to a charger are typically added to layover or recovery time. The amount of added time varies from TA to TA, with the allotted time for charging sessions being between 3 to 10 minutes. There are cases where no time had to be added to a service schedule because sufficient layover time was already built-in, although this is the exception rather than the rule.

Timetabling changes have been completed manually and do not rely on scheduling software capabilities. This manual process is enabled by the small number of impacted routes (one or two per system). In addition, electrified routes are isolated using modified blocking processes (i.e., removing any interlining - discussed in the following sections).

In the majority of on-route charging deployments it has been noted that an unexpectedly high number of revenue service hours had to be added to accommodate the addition of on-route/opportunity charging. This increase in service hours is caused by continuously applying timetabling changes to the route, not just isolating changes to when BEBs are utilized, which is not operationally feasible. As a result, diesel bus operators must follow the same schedule as BEB operators, which leads to increased (and unneeded) layover times for diesel operators.

Further to this, (CMBC deployment, for example), charging of BEBs is required at the end of a day before a BEB returns to a depot. This added charging time has resulted in additional overtime being paid to BEB operators. This can be an operationally critical task where a skipped charge can result in requests for vehicle tows. Additional operator education is required to understand the impact of missing scheduled charging.

Takeaways	The on-route/opportunity charging requires changes to timetabling, except in rare cases where built-in layovers are already long enough. Timetable changes only impact the electrified route(s) but lead to an increase in operator hours needed to provide the same service level.
Fleet Size	All

3.1.1.3 IT Impacts

Minor timetabling impacts have been seen with the on-route/opportunity charging strategy. However, these impacts have been minimal due to the low number of BEBs deployed and the limited blocks on which they run. Small deployment volume has allowed manual processes to be implemented when adjustments to specific blocks are made, adding length to layover times to account for charging periods. Modifications occurred without TAs purchasing new software or upgrading their current software. In-depot charging has not resulted in new transit planning software capabilities either.

3.1.2 Future Considerations

3.1.2.1 In-Depot Charging

Timetables are closely linked to service designs. With the expectation that service designs are not likely to change with BEB deployments, it is also likely that timetabling will not be impacted when an in-depot charging strategy is pursued. A low level of scheduling changes is one of the attributes of the in-depot charging strategy that makes this an attractive initial step toward large BEB deployments.

This is not to say that there is no room for improvement in timetabling processes related to BEB deployments. An analysis of a TA's service design can be completed to verify optimizations that can be found within the system and may be a helpful tool to further reduce a TA's GHG emissions or electricity costs. Timetabling changes will be deferred, for the most part, until BEB technology is deployed, well understood, and a long-term commitment to the technology has been made.

Next Steps	Monitor upstream scheduling or planning processes for changes to accommodate in-depot-charged BEBs and adjust timetabling accordingly to make routes & schedules more efficient.
Fleet Size	All

3.1.2.2 On-Route/Opportunity Charging

An expansion of on-route/opportunity charging will likely result in more vehicles being deployed on a single route, whether partially or fully electrified. This increase in vehicles results from longer layover times being built into timetables to accommodate additional time for charging sessions.

Suppose multiple routes are electrified, and those routes depend on the same charging infrastructure. There must be careful planning of timetables to ensure sufficient charging time and proper coordination of charging sessions. For example, it would be less than ideal to have multiple vehicles queued for on-route charging at any given time as layover times built into a single route would have to account for the charging time of multiple vehicles. A solution to decrease crossover time would be to stagger on-route charging sessions, potentially shifting when buses arrive at a charging location (i.e., bus terminus). However, this would potentially affect the timetabling for other electrified routes and must be approached carefully, so service schedules are not impacted. Alternatively, additional on-route chargers could be installed to alleviate possible charger congestion and provide system redundancy/resiliency in the case of an out-of-service charger.

Careful consideration must be given to the degree to which capital and operating costs of on-route/opportunity charging deployments will increase due to timetable modifications for BEBs. Whether it be the case where additional vehicles or charging infrastructure are needed or increased layover times are added, on-route/opportunity charging will have cost impacts resulting from the requirement to maintain original service levels.

Next Steps	Analyze service schedules for routes that can be electrified with the current charging infrastructure. Next, assess the impact of modifying service schedules to enable the electrification of more routes using current infrastructure. Finally, plan additional charging infrastructure to allow for further electrification of your system.
Fleet Size	Medium, Large

3.1.2.3 IT Impacts

A part of the appeal of the in-depot charging strategy is the low impact on service schedules and timetables that deployments have initially. As such, software systems will likely not require additional or specific features related to timetabling for in-depot charged BEBs until fleets expand to medium or large sizes.

Conversely, the on-route/opportunity charging strategy is accompanied by a complex timetabling problem that will require software to manage changes. Adding appropriate charging time and frequency to a high number of electrified routes, for example, is one of these complex problems that need to be addressed. Another is ensuring the availability of charging infrastructure required to meet the charging needs of multiple electrified routes. This coordination will be required to ensure that non-overlapping sessions can be accommodated and that impacts to delays and issues facing one route do not domino to other routes.

During timetabling, it will be necessary for scheduling software to consider your unique system configuration (i.e., charger locations, power levels, availability) and to make decisions and recommendations accordingly. The decisions will likely draw from changes to layover and recovery times that need to be added to timetables to account for charging sessions.

3.2 Blocking

Blocking is the process of linking trips together into vehicle assignments for a single workday. Blocking is based on the requirements of policies (i.e., layover and recovery time) and optimizes the number of vehicles required to adhere to service schedules. Blocking serves as the basis of revenue and non-revenue vehicle operating costs and influences labour costs.

During blocking, critical attributes of the blocks are determined (pull-in times, trip numbers, departure and arrival times at terminal points, total work distance, recovery time, layovers, and pull-out times). These block attributes are not typically considered constraints with today's conventional bus technology. However, considering these factors when deploying BEBs may be reminiscent of conventional bus technology's distance and running time constraints from decades ago. This is to say - the days of constraint-free blocking may be over once again.

When completing the blocking process in a system reliant entirely on current conventional buses, factors such as collective agreement or union requirements are more restrictive than the technology itself. With a transition to BEBs, it will likely be the opposite (in the near term). For example, on-route/opportunity charged (high-power) BEBs could need to charge before an operator needs a break, whereas an operator would typically need a break before a conventional bus needs to refuel.

Blocking will likely be the single most impactful step in the transit scheduling process concerning BEB deployments. It will determine if a given BEB can physically complete a piece of work and play into the outcomes of downstream processes such as runcutting & rostering. Factors determined during the blocking process include total running time, total distance covered (including deadhead), trip topography, and seasonal impacts. For the in-depot charging strategy, these block attributes will be the limiting factors that may prevent further electrification of a TA’s network.

The approach TAs have taken concerning BEB scheduling is primarily tied to the type of charging method deployed. The differences in these approaches and their respective impacts on transit scheduling will be explored below.

3.2.1 Typical Deployments

3.2.1.1 In-Depot Charging

Centralized charging has allowed TAs that have chosen the in-depot charging strategy to forgo significant changes to their scheduling processes to accommodate initial BEB deployments.

The most crucial scheduling task in the early days of a BEB deployment is assessing available blocks for a viable BEB work assignment. TAs generally analyze their current revenue service blocks, determine which blocks are appropriate for their given BEB technology, and select which blocks can be assigned to BEBs accordingly.

Depending on the overall number and composition of blocks (i.e., distance, duration, etc.), there will likely be many blocks suitable for assignment to BEBs on day one of deployment. As a result, changes do not typically have to be made to blocking processes upfront to find a sufficient number of blocks for assignment to BEBs. Therefore, initial data collection and assessment of BEBs within a network can be completed before transit scheduling processes are modified (if needed at all).

It is most common for TAs to decrease the distance and duration of blocks assigned to BEBs by limiting their utilization to mainly during peak (rush) service times. This reduction in service length allows the BEBs to complete service runs in the morning, return to the garage to charge midday (if required), and complete other runs later in the day.

After gaining an initial understanding of the BEB's in-service performance, TAs will typically increase the allowable distance & duration of BEB work assignments. The use of BEBs on a broader set of serviceable blocks advances the TA's understanding of the performance of their technology over a more extensive set of blocks and conditions (i.e., topography, loading & weather conditions, etc.). For example, in the winter and summer months, a lower maximum run distance or duration may be set when assessing suitable runs due to the higher expected energy consumption of the BEBs. The opposite is true in the spring and fall months as the temperature becomes more moderate and the range of BEBs increases. It is best to plan for worst-case energy consumption factors that are expected within a given season and adjust allowable distance & duration accordingly.

It is noted that the number of blocks that are suitable for assignment to BEBs will vary significantly - typically as a function of the size of a TA. It is generally the case that smaller TAs have longer average block distances and durations. A longer average block distance may impact the need to modify scheduling processes initially or the timing of these changes in the future.

Takeaways	Defer impacts on blocking processes to a later point in time. Your system will likely have enough runs where BEBs can be deployed from day one. Start small, gather data, and expand BEB-eligible blocks as you become more comfortable with your technology. Small TAs may find that they may have to make scheduling changes sooner than larger systems as they look to expand the electrification of their system. SOPs will have to be adjusted to accommodate changes for BEBs.
Fleet Size	Medium, Large

3.2.1.2 On-Route/Opportunity Charging

It was found that each TA that currently utilizes the on-route/opportunity charging strategy requires BEB-assigned blocks to be re-blocked. TAs have noted that the removal of interlining has been done when a route is electrified. Removing interlining simplifies the scheduling process with an initial BEB deployment and ensures that BEBs remain on the same route for the duration of a shift. This blocking modification also ensures that the BEB can predictably charge at set distance intervals at the route terminus upon each trip or round-trip. The energy required between charges can be reliably measured, and the associated layover time (charging session) can be added during timetabling (considering charger power, bus power limits, and required connection and travel times). Re-blocking affects all blocks containing the electrified route(s) and requires adjustments to other relevant blocks to accommodate the removal of interlined routes.

Takeaways	On-route/opportunity charging has required re-blocking of the routes that utilize BEBs. Removing interlining simplifies scheduling and allows BEBs to remain on a single route for the duration of a run. Blocking changes are also depending on timetabling adjustments that are made.
Fleet Size	All

3.2.1.3 IT Impacts

Any blocking changes made to date have been minimal and are readily accomplished using current tools or manual processes. These changes are small one-time events that can be managed due to the low volume and impact of the changes.

3.2.2 Future Considerations

3.2.2.1 In-Depot Charging

When changes need to be made to blocking processes will depend on several factors, including a TA’s electrification goals and strategies. That is - beyond the blocks that can be electrified with today’s technology, TAs need to consider how they plan on continuing the electrification of their network in the future. Re-blocking to reduce the overall length or duration of blocks may be an effective strategy that, when combined with appropriate in-depot charging operations, can lead to a relatively small increase in operational and capital costs. Alternatively, a TA may pursue alternative technology solutions (i.e., higher capacity batteries or FCEBs), a mixed charging strategy (i.e., introducing on-route/opportunity charging), or any combination of these choices to electrify their network further.

Depending on the technology deployed and the local climate, it may be the case that blocking constraints vary with the seasons. For example, block lengths in the spring/fall may be able to be longer in distance and duration than those in the winter/summer due to the more moderate outdoor air temperatures typically seen during these seasons. Therefore, an understanding of a TA's specific bus technology and its energy consumption related to temperature (and other factors) will be required before the most effective changes can be made to blocking.

Winnipeg Transit has indicated that an “Energy Twin” study has been completed to assess the impacts of re-blocking on several factors. These factors included the ability to electrify 40’, 60’, and BRT bus blocks and the make-up of shifts available for operators after the changes. To increase the electrification of a system, the distances of the blocks were modified to accommodate a fixed BEB battery capacity. The re-blocking resulted in a higher number of shorter blocks, which requires more operator hours to cover the work and less overall time-in-service per operator per shift. The number of additional vehicles required to meet the simulated scenarios can also be assessed at this point.

It is noted that changes to overall blocking will likely result in changes to projected power demand (load) profiles that will be seen at the facility level (i.e., with in-depot charging). This potential change in load profile is due to more BEBs having earlier return times, which will allow a higher number of charging activities to begin earlier. This may positively impact lowering the overall electrical requirements of a facility and operational peak demands. These impacts should be assessed on a case-by-case basis and considered in long-term electrification plans.

Next Steps	Collect real-world data and understand how the BEB range varies according to different factors. Then, using collected data or worst-case scenarios, compare the business case for re-blocking your runs versus utilizing different charging strategies and technologies to electrify your system further.
Fleet Size	All

3.2.2.2 On-Route/Opportunity Charging

With the shift to long-range in-depot charged BEBs, the role of opportunity charging is more commonly seen as a step towards full-electrification that will be considered in the future rather than relied upon today. As such, most TAs that use the on-route/opportunity charging strategy are not making any further blocking modifications to increase their opportunity charger network in the short term.

CMBC remains an exception where the planning for an increase in opportunity charging deployments is currently in progress. However, how opportunity charging will be deployed does treat this charging strategy as an electrification enhancement measure and not a primary charging strategy. The on-route charging will help extend the range of High-Capacity BEBs on longer suburban blocks within the network. High-frequency routes in highly populated areas of this TA's network will be electrified using in-depot charged BEBs. In-depot charging is expected to be the primary charging strategy that will allow for large-scale electrification. This deployment will be an excellent case to monitor as it will provide valuable insight into a solution that can be deployed to electrify a system using multiple charging strategies. It is yet to be seen if blocking changes will be required or whether changes can be made to timetabling processes to deploy on-route charged BEBs.

Options are available to further the electrification of a network using an on-route/opportunity charging strategy. For example, there is potential to schedule charging during shift changes or other times with sufficient layover already built in a schedule, like before returning to a depot after the morning rush. Additionally, if the charger is located where multiple routes/lines intersect, interlining is still possible; it will just be restricted to routes that intersect with the charger. With multiple charging locations, interlining becomes more flexible.

Next Steps	Assess the on-route/opportunity charging strategy as a secondary charging strategy that may not require re-blocking to the same extent as in-depot charging. Compare the business case for blocking modifications versus adding on-route charging infrastructure.
Fleet Size	Medium, Large

3.2.2.3 IT Impacts

Bocking modifications will likely be required to increase the utilization of BEBs regardless of the charging strategy deployed. As a result, software systems will have to adapt to account for these changes and help a TA understand and plan for the impacts (i.e., costs) associated with the changes relative to baseline operation.

Relative to in-depot charged BEBs, the total energy (or worst-case energy) required to complete a block will be the most important factor for scheduling software to know. This value should, however, consider the distance and duration of a block and should account for expected weather conditions (outdoor air temperature, road conditions, etc.), combined route topographies, and loading conditions expected to be encountered at the route level. These factors can be informed by analysis of past collected data (integration with telematic streams or post-processed data) and projections/simulated values based on expected or worst-case operating conditions.

A central capability of in-depot charging-enabled scheduling software will be to understand the specific performance characteristics of a TA's BEBs and to provide the ability to modify blocks to a degree which allows an optimal level of service to be electrified. This level of electrified service (electrification index) may be variable over time, and a target should be set according to the relative ratio of BEBs within a fleet. For example, the software should be able to adapt your blocks to meet an electrification target, which the range of BEBs will ultimately determine.

Careful considerations should be given to operating cost impacts associated with re-blocking and preventing, when possible, an increase in the number of vehicles or staff required to meet existing service schedules.

3.3 Runcutting

Runcutting is the process of creating operator assignments from a set of vehicle blocks. Runcutting is often an iterative process, and a series of changes to both blocks and runs may be necessary before an optimized solution can be developed. Runs may be made up of one or more complete or partial blocks.

During runcutting, blocks are cut in such a way as to create straight runs and split runs. A straight run typically consists of a single block of approximately 8 to 10 hours of continuous work. Straight runs can also be created using two block pieces that a short break may join. A split run generally consists of two (or more) blocks with break time between the pieces.

Cost-efficient blocking is vital in minimizing the number of vehicles needed to operate a given level of service, and runcutting is essential in determining the number of operators needed to operate a given level of service. The transit scheduler is to assign all of the block pieces to the fewest number of operators while adhering to all relevant policy guidelines, agreements, and procedures.

3.3.1 Typical Deployments

There have been no noted impacts on runcutting processes in our engagement with leading practice focus groups. This lack of change is the case for both in-depot and on-route/opportunity charging strategies, resulting from minimal changes to blocking processes. As a result, electrified blocks remain similar to their pre-electrification counterparts and can be bid on by operators as such.

Takeaways	Runcutting has not been impacted by either in-depot or on-route/opportunity charging strategies. Block makeups remain similar to before any BEB-specific modifications were made.
Fleet Size	All

3.3.1.1 IT Impacts

There have been no impacts concerning runcutting, from an IT perspective, on any current BEB deployments.

3.3.2 Future Considerations

Runcutting processes will likely see a degree of change related to the degree of change made to the blocking process. For example, suppose a TA re-blocks their network to reduce block lengths of their longest blocks (to account for range limitations of BEBs). In that case, they will also have to assess how the increase in shorter blocks will affect the resulting pieces of work available to operators and the need for more operators to operate on those blocks. Additionally, there will be more constraints regarding runcutting for in-depot charged BEBs as they will likely have to return to a depot or yard to charge after a certain distance or time has elapsed. There will likely be an increase in the number of split shifts and straight shifts that have a “bus swap” time to maintain service levels (depending on how your system is currently blocked).

This “bus swap” refers to when an operator has to return their BEB to the depot for charging but quickly turns around with another pre-charged BEB to continue revenue-service work. Building this time into a shift may be more effective than offering a larger number of shorter shifts, although this will have to be evaluated on a case-by-case basis.

Modified runcutting will factor into changes in operational costs incurred by a TA due to BEB deployments. Cost impacts will depend on the number of modified blocks - which may only be in the top 20-40% in terms of distance. Overall, it is likely that BEB deployments will require an increase in non-revenue time that the average operator has during a shift. This change in shift composition will have to be assessed along with operator unions and collective agreements to comply with the policy.

Next Steps	Assess how modified timetabling and blocking processes will result in changes to shift composition and the associated impacts of shifts offered to your workforce. Monitor for a potential increase in operational costs and assess the feasibility of a mixed charging strategy.
Fleet Size	Medium, Large

3.4 Rostering (Crew Assignment)

Rostering is the grouping of runs into packages of weekly work (repeating) assignments. Drivers select their work assignments for the next time interval (sign up or booking) during the bid process, where they are typically awarded work based on seniority.

3.4.1 Typical Deployments

Like runcutting, no impacts on rostering processes have been noted with current BEB deployments regardless of their primary charging strategy. This lack of change is due to BEB deployments having limited impacts on blocking and runcutting processes thus far.

Electrified work assignments are typically available for any operator to bid on upon initial BEB deployment. For example, if an operator had not been previously trained to drive the BEB, they would be prioritized in the training process to assure they received training by the start of the following sign-up. However, exceptions to this case have been found, and some TAs elect to be selective with the availability of electrified work assignments to select operators during the bid process. This is the case during the initial deployment of BEBs but can also remain for a significant amount of time afterwards.

Most TAs open up eligibility to all operators once broader training and a certain comfortability with their new technology is achieved. Noted benefits of maintaining selective operator eligibility are increased operator accountability to the evaluation of the technology and detailed troubleshooting and feedback due to familiarity with the vehicles. Regardless of the case, it is recognized that the long-term strategy will be to make electrified blocks available to at least all spareboard operators and operators who are based in a depot with BEBs.

Takeaways	Rostering processes have not been impacted by either in-depot or on-route/opportunity charging strategies. During initial deployments, there may be a small group of operators who can/are allowed to drive the BEBs, but this group grows substantially as training programs advance.
Fleet Size	Small

3.4.1.1 Rostering

There have been no impacts concerning rostering, from an IT perspective, on any current BEB deployments.

3.4.2 Future Considerations

Like runcutting, changes to blocking processes may have downstream effects on the output of rostering. Each agency will need to assess the magnitude of these changes and their associated impacts individually. This assessment should include measuring impacts of the type of work available to be bid on by operators and monitoring these impacts to ensure compliance with unions is maintained (where applicable).

Next Steps	Assess how re-blocking will change the work assignments that can ultimately be offered to operators. Monitor for a potential increase in operational costs and assess the feasibility of a mixed charging strategy.
Fleet Size	Medium, Large

4 Operations

Operations related to BEBs (Charging Operations) are an area still in their infancy. This immaturity is mainly a product of TAs not having to implement large-scale operational changes as programs remain in the pilot stage. However, as BEBs make up more significant portions of fleets, charging operations will mature and become better defined. This section will deliver a snapshot of the charging operations that have been implemented so far, the impact of charging strategy on charging operations, and what is to come as deployments grow. Each section groups together crucial components that will make up charging operation processes and explores the importance of these processes as they relate to BEBs.

4.1 Work Assignment

Work assignment refers to a single instance of assigning a specific run to a specific bus. Typically, work assignment for conventional buses occurs after a vehicle has been parking in a depot/yard and when the vehicle is in position to depart from the depot/yard on a run (i.e., after servicing or other restacking). Work assignments are based on the positioning of a vehicle in a depot/yard in relation to other vehicles (i.e., the vehicles at the front of a track will book out first, and so on). With conventional buses, work assignments are limited by the type of vehicle (i.e., 40-foot bus, 60-foot bus, community shuttle, etc.) and distance to upcoming preventative or planned maintenance activities. Impacts on work assignment processes as they relate to current and future BEB deployments will be explored in the sections below.

4.1.1 Typical Deployments

4.1.1.1 In-Depot Charging

The work assigned to BEBs that rely on in-depot charging is typically predetermined (with input from transit Scheduling & Planning departments) and primarily based on run distance and duration factors. It is typical for TAs to deploy BEBs on a small set of short blocks initially. Once a level of comfort with the technology is achieved with those blocks, the maximum allowable distance/duration is increased. This results in the set of runs gradually increasing until a distance/duration plateau is reached, dependent most on bus technology (i.e., battery capacity) and externalities (i.e., weather, loading conditions, etc.).

The overall sample of runs that BEBs are deployed on varies significantly from TA to TA, with some running the same blocks daily. In contrast, others choose from a larger pool and prioritize placing BEBs on as many different blocks as possible without necessarily repeating assignments daily (i.e., TTC & ETS).

A reassessment of suitable runs can be done occasionally (i.e., per board period or signup). There are several ways in which this reassessment can be carried out, which depend on a TA's electrification goals. For example, there are cases where the longest suitable runs are assigned to BEBs (to increase BEB utilization). At the same time, there are also cases where blocks which have not had BEBs travel on them are prioritized for assignment. A broader set of blocks allows for increased energy consumption data collection and a better understanding of bus behaviours under a more extensive set of conditions.

Takeaways	Work Assignments are vetted by planning & scheduling teams up-front. Work is typically assigned to BEBs on a repeating daily basis to start. Once some comfort is achieved, a less structured work assignment process is implemented.
Fleet Size	Small

4.1.1.2 On-Route/Opportunity Charging

Work Assignment for BEBs that rely on On-Route/Opportunity Charging is done in a very controlled manner, given the restrictions and planning required to execute charging sessions. It is typical that when an on-route charged BEB is available for revenue service, it has a small number of dedicated blocks on which it can operate. Beyond BEB availability, work assignments for these vehicles are not typically reliant on other factors and remain similar daily.

The BEB fleet at YRT contains vehicles with different battery capacities, resulting in work assignment impacts. There are limitations to work assigned to each make of BEB as one has enough battery capacity to be assigned to both blocks, but the other can only be assigned to one.

Inter-vehicle differences within a vehicle category (40-foot buses in this case) add a layer of complexity that may have to be accounted for during work assignments. This is an example of a “fleet-within-a-fleet” that can arise when BEBs with different characteristics are based within the same overall fleet. This scenario is seen as undesirable but may be unavoidable in some situations, especially as many BEBs are procured and deployed over a long period (i.e., battery degradation impacts within a fleet). Software solutions that manage and mitigate the impacts of fleet-within-a-fleet situations are discussed later in this section.

Takeaways	Work assignments are pulled from a small pool of blocks, leading to similar daily utilization of on-route charged BEBs. Data-Collection on a broad set of routes is lacking.
Fleet Size	Small

4.1.2 Future Considerations

This section will provide a detailed expansion of concepts and considerations that may aid in developing and deploying in-depot charging operations **for fully electrified fleets**. The implementation of these concepts will likely rest within software systems. However, understanding and refining them will be essential for developing mature charging operation processes. These concepts, or variations of these concepts, may be deployed to different extents by different organizations and will expand and mature as the industry learns and shares what charging operation pieces work best.

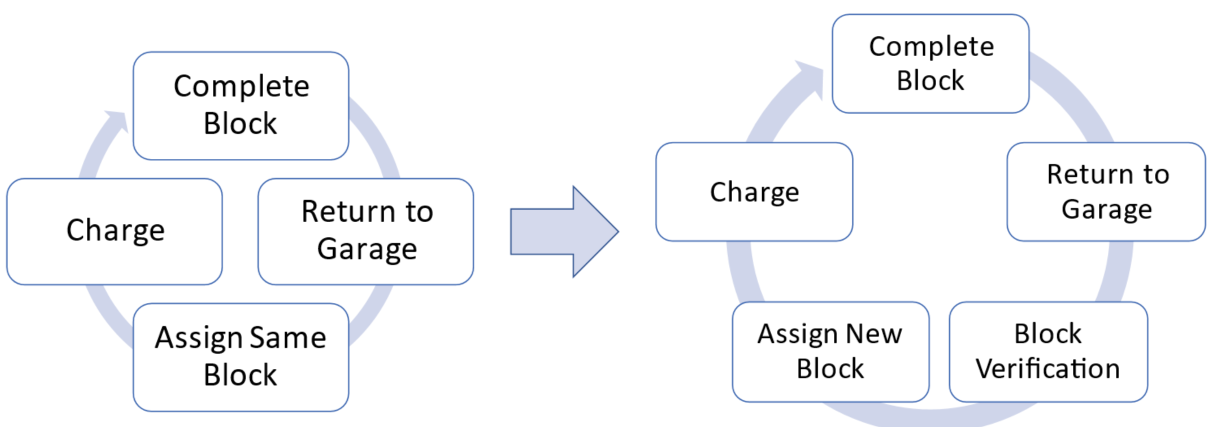
For our purposes, work assignment will be considered the starting point of in-depot charging operations, and many downstream processes will depend on this step. On-route/opportunity-charged BEBs are expected to recoup most of their energy outside a depot. That does not mean that there will be no in-depot charging utilized with these BEBs, but it may be utilized to a lesser extent. The concepts described below are expected to extend to any charging operations within a depot, regardless of the overall charging strategy.

There will come the point where in-depot charged BEBs will make up a significant portion of a fleet. Verifying work assignments for each BEB multiple times a day will become arduous, time-consuming, and difficult to manage manually. This issue is compounded by the complexities that will arrive when considering inter-vehicle differences (i.e., fleet-within-a-fleet, as discussed in the previous section). A run verification system (as part of a depot management system - DMS) is expected to be required to manage this complex task (among many others). As a capability of a DMS, run verification will help assess, in real-time, the factors that need to be considered as a BEB returns to a depot/yard and begins to prepare for its next service run.

It is important to note that in-depot charging operations will likely require work assignments to be made as vehicles return (book in) to a depot/yard. This change in assignment timing may be a significant process change that will impact many downstream return-to-garage processes and will have to be managed accordingly. The simple rationale for this change is as follows: If work is assigned to a BEB upon book-in, key parameters (such as how much energy the bus needs for its next piece of work) are resolved at the earliest possible moment, thus maximizing the time for coordinated charging activities to occur within the depot. As a result, higher coordination of charging sessions (managed by an Advanced Charge Management System - CMS) can lead to more efficient charging operations by reducing each vehicle's overall charging time.

The shift from the current typical work assignment processes versus what the work assignment process may look like in the future is shown in Figure 1. The result of the new process is similar to the current process, although there is less pre-planning of the blocks that BEB are assigned – similar to today's conventional bus processes.

Figure 1. Typical current (left) versus a possible future (Right) work assignment process for BEBs



When assigning a block to a BEB, some factors should be considered before a particular piece of work is given to a BEB (Block Verification). These factors will need to be assessed by software systems, although system users will need to understand them from an operational perspective. These factors include:

<u>Ability to Complete Work</u>

The ability of a BEB to complete a block must be considered before assigning a block to a BEB in real-time. This consideration may seem obvious but can have significant implications in large BEB deployments. The verification that a BEB can complete a block is based on physical factors, including

1. Block Characteristics; and
2. BEB Characteristics.

Energy consumption projections can be completed in real-time using a system that accounts for several factors, including upcoming block distance & duration, topography, expected passenger loading, current outdoor air temperature, and expected road conditions. The worst-case estimated energy value based on historical data may suffice, with (TA-defined) safety margins adjusted accordingly to buffer significant variations in these values. If a block requires too much energy for a particular BEB, it should not be assigned to that BEB, and the system should assess another block.

Figures 2 & 3 compare these two energy consumption projection methods. Each is a valid approach to estimating the energy required for any given block. However, a real-time energy projection will allow seasonalities to be factored in and improve charging operation efficiency. On the other hand, when initially planning for BEB deployments, the worst-case energy consumption is important to understand and will be critical in electrical infrastructure planning.

Figure 2. Example of Real-Time Energy Consumption Factors

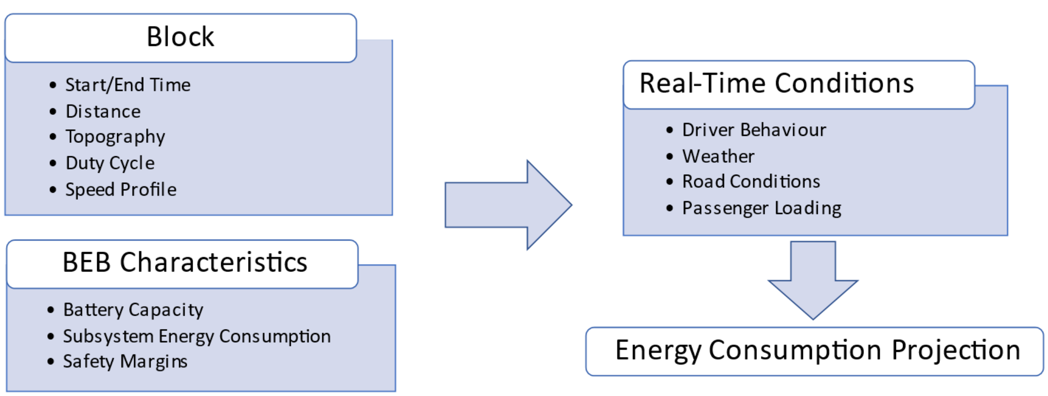
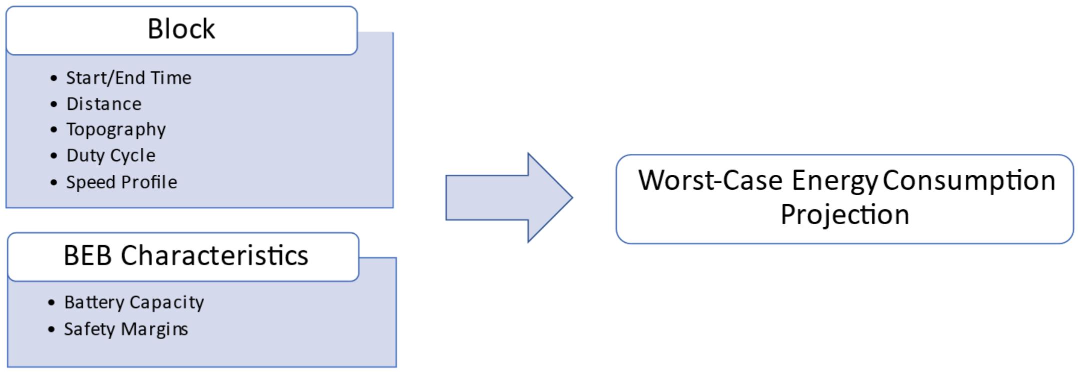


Figure 3. Example of Worst-Case Energy Consumption Factors

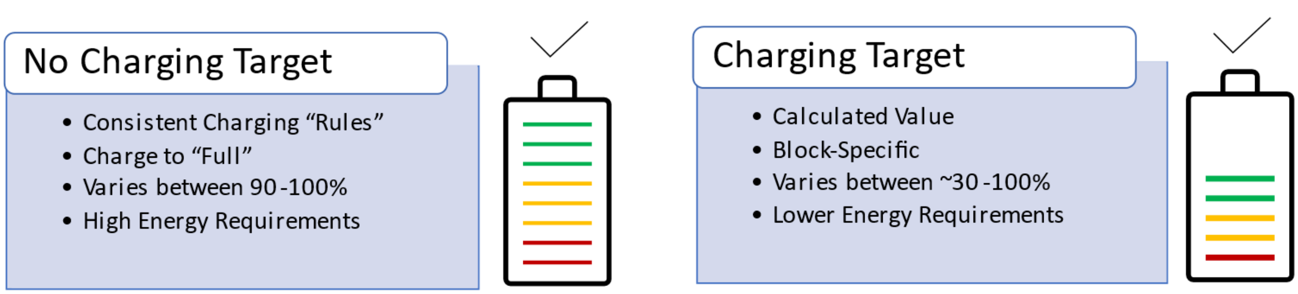


<u>Charging Target</u>

A 'Charging Target' defines the minimum energy/charge required before a BEB can leave a garage/depot for revenue service. The charging target can be determined by considering parameters such as the block's distance, the projected energy consumption of the vehicle while completing that specific block, and additional safety margins. This factor will be set when a block is assigned to a BEB. The Charging Target will likely be a concept enacted in software systems only and won't necessarily directly impact manual processes, save for exceptional cases. Software systems that have operationally focused capabilities will benefit a TA and must be specified and determined before systems are procured.

Charging Targets can be a powerful tool in optimizing the amount of charging that needs to occur over an entire BEB fleet. For example, the charging target allows you to define an energy level on a per-vehicle basis rather than setting fleet-wide charging goals (i.e., every BEBs needs a full charge before booking out). This optimization comes with the benefit of reducing the overall amount of energy that needs to be delivered to the fleet, thus lowering the time BEBs will spend charging. As each BEB will require less energy, a reduction in overall facility peak demands (and resulting energy costs) may also be seen.

Figure 4. Charging Target impacts on Charging Operations



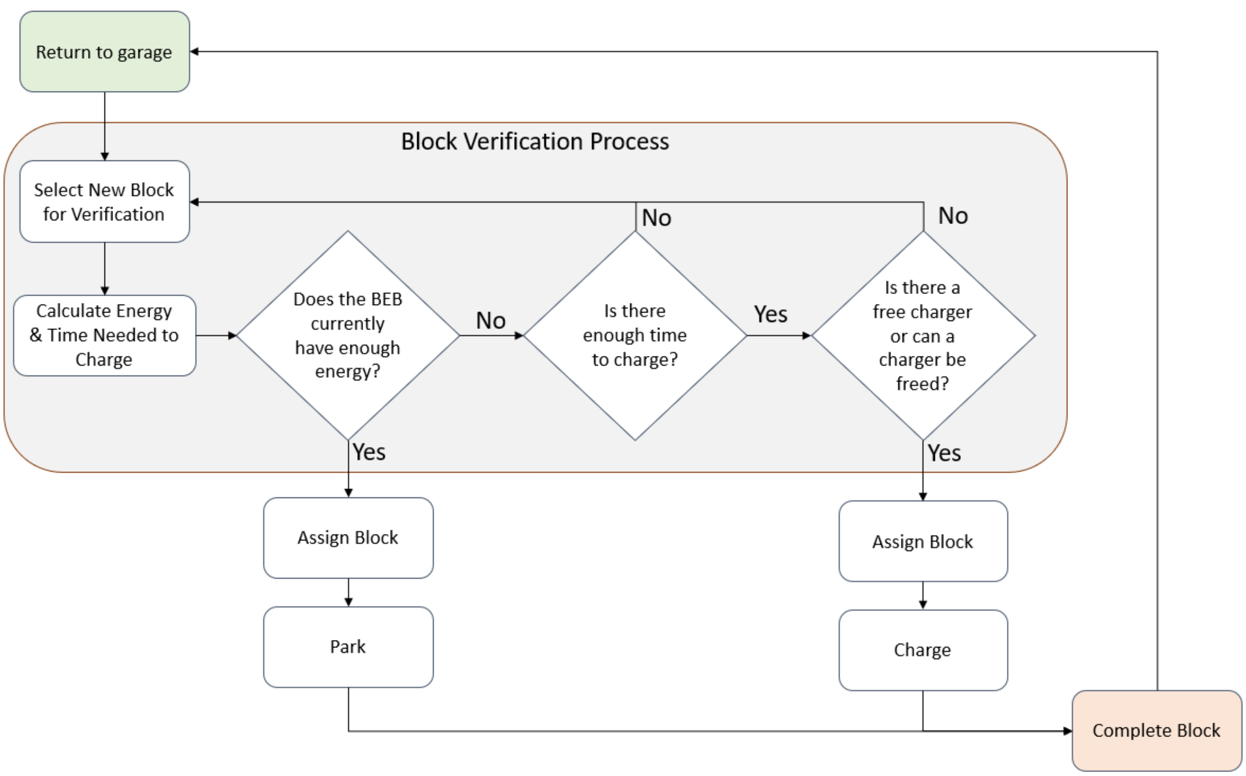
<u>Ability to Charge</u>

When evaluating a block for assignment in real-time, a verification that a BEB can charge for that block is needed. It will be increasingly challenging to run this check manually at a large scale, and there will likely need to be systems in place to verify each of these factors when assigning work to a BEB (see DMS & CMS). These systems are typically not currently in place as these verifications are not needed when assigning work to diesel buses. This verification should consider factors including:

1. The amount of energy needed to be delivered to the BEB to reach its charging target and depart the facility.
2. The available battery capacity of the BEB.
3. The BEB's time for charging (i.e., the time before booking out).
4. The availability of charging infrastructure to deliver energy to the BEB.

An example of a decision tree involving these factors can be seen in Figure 5. In this potentially iterative process, blocks are assessed according to the aforementioned factors. Each check acts as a filter to weed out unsuitable blocks for a given BEB based on real-time vehicle and charging infrastructure factors.

Figure 5. Example decision tree for real-time block verification and work assignment



It should also be recognized that there may be cases where BEBs do not need to charge before their next book out and, therefore, do not necessarily need to occupy a charging position. The exact handling of all use cases and exceptions will have to be discussed with solution providers and adapted to best meet a TA's charging operations.

Vehicle Equipment Requirements

Work assignments can be limited depending on the equipment installed on a particular vehicle. This limitation must also be considered when assigning work to a BEB (via process or system). Examples of equipment requirements for certain blocks can range from highway kits, onboard cameras, automated passenger counters, etc.

BEB Usage Optimization

Depending on program mandates & GHG emission targets, it may be beneficial to implement a system or process that maximizes the usage of BEBs. This optimization will prioritize work assignments to BEBs and provide a process to remove work assignments from diesel buses and give those assignments to BEBs.

Next Steps	Modify work assignment processes and consider a BEB's ability to complete work and charge in real-time. Use concepts like the Charging Target to optimize charging operations. Utilize software systems to manage complex decisions like scheduling charging and managing charger assignments.
Fleet Size	Medium, Large

4.2 Garage Organization

Garage organization processes are used to direct the movement of buses within a depot/yard as buses return from revenue service, leading up to the buses booking out for their next run. This includes the sequence in which vehicles are moved to specific areas in a depot and the timing of those moves. Each garage has a unique floor plan, a different number of housed vehicles, and different infrastructure configurations. As such, garage organization will differ in implementation from property to property, even within the same TA. The following are typical procedures or decisions considered part of garage organization:

1. Parking buses as they return to the garage.
    a. Parking in a staging area.
    b. Parking in specific tracks/lanes.
    c. Undirected parking.
2. Timing of servicing events.
3. Movement of vehicles to and from servicing areas.
4. Parking of vehicles after servicing.
5. Restacking or reordering of vehicles.
6. Parking buses after maintenance procedures.

As a byproduct of the fueling (charging) process being a time-sensitive and highly coordinated action, it is expected that the procedures that direct the flow of events within a depot/garage will have to be modified to accommodate charging operations. Current garage organization practices and anticipated changes to these practices will be discussed in the subsections below.

4.2.1 Typical Deployments

In the early stages of BEB deployments, the typical case is to dedicate areas within the garage where the vehicles will park separate from conventional buses. Regardless of the charging strategy, this will likely be the 'Charging Location' where vehicles are plugged-in/connected to chargers. The order in which vehicles are parked in these dedicated areas is usually not as crucial as their subsequent work (and order in which they will depart the facility), typically determined after the vehicles have been charged and serviced. Before charging, and depending on a TA's business as usual processes, buses may either:

1. Be parked in a staging position by the operator, serviced, then moved to final charging locations; or
2. Parked directly in a charging location by the operator, serviced later, and then returned to a charging location if further charging is required or a parking position otherwise.

All BEB deployments thus far have provided a clear dedication of space within the depot/yard for BEBs. Regardless of its impact, something as simple as dedicating a portion of your depot/yard to BEBs-only is a garage organization change that needs to be managed within a depot. For example, operators, service, and maintenance staff must understand the impact of parking a conventional bus in a track/lane dedicated to BEBs or parking BEBs in incorrect positions. Incorrect parking can lead to a missed opportunity to charge a BEB and requires vehicles to be moved (time-consuming). Although this may not be operationally critical with small deployments, the importance and criticality of these processes will grow with the size of a BEB fleet.

Takeaways	Charging tracks/lanes have been assigned in depots that house BEBs. Priority access to these tracks is given to BEBs. Due to small fleet sizes, the movement and positioning of BEBs within a depot are manually directed and not mission-critical procedures at this time.
Fleet Size	Small

4.2.2 Future Considerations

When considering larger BEB deployments, up to full-fleet electrification, the organization of BEBs will likely need to be a highly directed and software-guided process. For example, a Depot/Yard Management System (DMS) may be required to make real-time decisions as complexities and factors involved in organizational decisions may be too taxing to be made quickly by staff. These complexities arise due to the continuously changing status of a fleet as vehicles move in, out, and within a depot/yard, and while large numbers of charging sessions coincide.

Consider the case of when a BEB returns from revenue service. Upon return, there will be several potential locations where the BEB may be able to be parked, each potentially dependent on the future work assignment for that BEB. The parking decision may subsequently have downstream impacts on future bus moves and charging sessions. A DMS will be able to quickly assess parking positions of other vehicles and general charger availability, verify their charging status and work assignments, and determine an appropriate position for the returning vehicle in real-time. This assessment will be done while also coordinating the moves of other vehicles, if necessary.

An intelligent and customized solution for your facility will help improve operational efficiency and lower costs and complexities that staff need to manage constantly. Static garage organization rules (if there are any) may be replaced with fluid processes that are mainly software-driven and that adapt to the BEB fleet, vehicle charging needs, and space availability in real-time.

Next Steps	Implement Depot Management Systems to manage increasingly complex charging operations. Adjust staff SOPs and garage organization work processes to accommodate and work with direction from software systems.
Fleet Size	Medium, Large

4.3 Vehicle Parking/ Charger Alignment

The deployment of BEBs will come with some changes in the way buses need to be positioned within parking spots (especially if the parking position has a charger). More precise parking will be required as charging infrastructure can be sensitive to the positioning of the BEB to which it is to connect. For example, SAE J3105 (overhead pantograph) chargers are sensitive to the horizontal and vertical alignment of the vehicle, the approach angle, and the slope. On the other hand, SAE J1772 (Plug-in) deployments are less position-sensitive, although they still require horizontal and vertical alignment (due to cable length limitations).

The requirement to park a vehicle more precisely may seem like a small change, but it has significant implications when considering a large-scale fleet deployment. There are potentially significant cost implications (service or maintenance personnel time) resulting from misaligned vehicles. Other potential operational impacts such as missed book outs may occur if vehicles were not charging when they were supposed to because they couldn't connect to a charger (preventing BEBs from passing pre-trip inspection, for example).

Vehicle dimensions also factor into how vehicles are positioned. For example, different BEB OEMs have different overhangs, impacting bus spacing and clear aisle spacing. The type of connector (plug-in vs overhead) also affects the flexibility to mix and match 40-ft and 60-ft buses in the same lane without installing excess connectors.

4.3.1 Typical Deployments

4.3.1.1 In-Depot Charging

Plug-in chargers are the most common type of in-depot charger deployed to date. As mentioned above, these chargers are less sensitive to a misaligned vehicle than overhead systems. Nonetheless, it has been observed and noted by several TAs that alignment issues occur with plug-in chargers and that it is typical for misalignments to 'domino' down a track, leading to multiple misalignments at a time. This domino effect occurs when one or more vehicles are left multiple feet away from where they should have been parked.

Overhead pantograph chargers are more sensitive to BEB position and typically require that vehicle is parked +/- one foot in the horizontal & vertical directions. There are many potential solutions and driver aids that can increase the chances of successful alignment. The most common parking assistance method seen is horizontal and vertical painted lines that guide the operator to the correct location. With the proper training, the parking of a BEB to the needed accuracy is relatively easy for the operator to accomplish. Typically, it is not the physical alignment of the BEB that prevents the connection to a pantograph charger but software hiccups or other charger/bus-related hardware issues.

Compliance with new parking procedures has been high across the TAs which have BEB deployments regardless of the type of charger used. However, it has been noted that misalignments can be costly as they require servicing and maintenance staff to be pulled away from their regular duties so that the vehicles can be re-parked properly. Awareness and impacts of proper parking procedures will need to be reinforced through training programs to mitigate impacts due to improper parking.

Takeaways	Charger alignment is an essential component of charging operations. However, charger misalignment can add labour costs and reduce staff availability to complete other tasks.
Fleet Size	All

4.3.1.2 On-Route/Opportunity Charging

Charger alignment during on-route/opportunity is a common and frequent task. Operators who drive electrified blocks get much more exposure to aligning the vehicles and typically do this easily. Most commonly, software or hardware issues prevent on-route charging sessions from occurring, not operator misalignment.

The most common parking aids for on-route overhead pantographs are horizontal and vertical painted lines. However, it has been noted that complications can occur when two or more BEB models are meant to use the same on-route charger. This complication is a byproduct of buses having different body styles and alignment points, which lead to multiple sets of painted lines on the ground. Lines painted in different colours or thicknesses can be used to mitigate this problem, along with training materials and reminders (i.e., stickers placed somewhere in the vehicle).

Weather mitigation strategies may need to be considered for scenarios where painted lines get covered up by snow, ice, or leaves. Managing these scenarios may require engagement from other municipal branches to organize (i.e., road maintenance). Charging sessions have a narrow window where they need to occur, or they may cause a service delay. A high frequency of missed charging sessions (due to misalignment or other causes) can be prohibitive to BEBs remaining in service.

Takeaways	On-route charger alignment is completed frequently and with ease by operators. Missed charging sessions are usually caused by software or communication issues.
Fleet Size	All

4.3.2 Future Considerations

4.3.2.1 In-Depot Charging

The larger BEB deployments become, the more critical proper alignment of parked vehicles will be. Misalignments can be expensive over time, and if proper preventions are not made, an increase in resources may be required, resulting in higher operational costs.

Integrated DMS & CMS solutions may be beneficial in helping service staff quickly identify when misalignments occur (or when vehicles are not adequately connected to a charger). These systems can function together to evaluate where vehicles are expected to be parked and can use localization systems and charger communication to confirm when and if a vehicle is parked correctly. These systems can offer servicing staff an early warning system, allowing them to realign vehicles before multiple misalignments occur.

Although it may be some years down the road, autonomous parking systems may be effective at parking in a controlled environment like a bus depot/yard. This solution could ultimately take the onus off the operator and provide immediate feedback to servicing or maintenance staff if there are parking problems.

Next Steps	Use DMS, CMS, and localization systems to verify BEB-charger connection, catch charger misalignments early, and improve the efficiency of in-garage processes.
Fleet Size	Medium, Large

4.4 Connecting Vehicles to Chargers

The decision regarding who will/can connect vehicles to chargers has differed across TAs. There are discussions about requiring input from union representatives as connecting vehicles to chargers may be seen as a fueling activity or working with electricity and may require a change in job scope for the affected roles. Regardless of who connects the vehicle to the charger, scope changes will be dependent on the types of charging infrastructure deployed. For example, SAE J3105 systems simply require pressing a button to connect a pantograph to the bus (beyond proper vehicle alignment). In contrast, SAE J1772 systems require physical work to plug the connector into the vehicle.

4.4.1 Typical Deployments

For in-depot charged vehicles, it is most common for the operator who returns to the garage/depot with the vehicle to connect the vehicle to a charger. However, depending on the sequence of events that occur when the BEB returns to the garage, it may also be servicing staff who ultimately park the vehicles and connect them to chargers. A note of interest is that it is typically not the operator's responsibility to ensure that connectivity of the bus and charger has been initiated successfully. Once the physical connection between the BEB and the charger has been established, it can take several minutes to confirm the connection, which is often too long to ask the operator to wait around. Confirmation and monitoring of general charging activities typically involve servicing, maintenance, or dispatch staff completing manual checks or utilizing charger monitoring software (typically supplied by the OEM).

The responsibility for connecting on-route/opportunity-charged vehicles lies solely with the bus operator. They are the only staff members who are typically present during charging sessions, and they do not have to do physical work to connect the vehicle to the charger. There have been no notable instances of this being a point of contention with unions, although this will have to be discussed case-by-case.

Takeaways	Operator, maintenance, or servicing staff connect BEBs to chargers depending on return-to-garage processes. Bus Operators are generally not responsible for confirming successful bus-charger communication.
Fleet Size	All

4.4.2 Future Considerations

In the cases where it is not an operator's responsibility to connect BEBs to chargers, there is a desire to make this a responsibility in the future. It is thought that this will prevent a significant amount of work from being required from servicing staff as BEB deployments grow. However, it is noted that this is the most common desire and not necessarily the solution for every TA. In-garage processes can vary from organization to organization, and implementations will differ accordingly. Ultimately, the most efficient process will direct the staff who parks the BEB also to connect it to a charger. TAs will continue to work with unions to align job descriptions with efficient charging operations.

The charger monitoring solutions that TAs use today do not offer much information regarding the charger's location within a depot/yard, nor do they monitor the expectation of a vehicle connecting to the charger. Centralized DMS & CMS solutions can mitigate these problems. Using software solutions, the connection of a BEB and a charger (or lack thereof) can be verified quickly without the staff looking at the charger physically.

Next Steps	Take steps to make parking the BEB and connecting it to a charger happen in tandem with the same staff member. Utilize software to monitor expected bus-charger connections and to confirm issues in real-time.
Fleet Size	All

4.5 Charging Buses - In-Depot

This section will explore how energy is delivered to a fleet of BEBs considering an in-depot charging strategy. Although this may seem straightforward (and is, for small deployments), this issue will quickly become complicated as BEB fleet sizes grow and facility power capacity remains capped based on utility limitations. Controlling factors such as the order in which charging sessions occur, the number of simultaneous charging sessions, and the duration of charging sessions may impact the effectiveness of charging operations and result in increased energy costs if not managed correctly. The sections below look at the rudimentary systems currently deployed and the features of more complicated systems required in the future.

4.5.1 Typical Deployments

At a baseline, how BEBs are charged is dependent on the configuration of individual power cabinets and their associated connector(s). Regardless of this configuration, the default charging method is typically "uncommunicative" - that is, there are a limited amount of factors that a charger monitoring system (provided by the charger OEM) automatically considers, other than restricting the peak power of an individual or small group of chargers, for example.

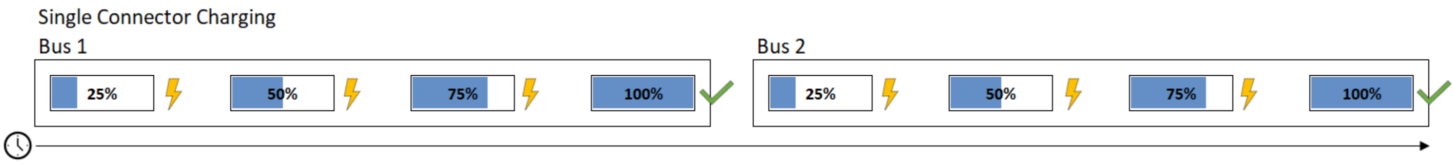
In most deployments, chargers can begin power delivery to vehicles without input from other systems, enabled mainly by the low number of chargers installed within facilities (i.e., grid overload scenarios are not typically possible). This uncoordinated charging is not expected to be the case moving forward. It has been found that larger deployments already require more advanced systems to utilize their systems as designed.

Power derate of chargers has had to occur in some instances where having each charger used simultaneously would cause an overload scenario. A lower than initially expected charging rate is seen in these cases because inter-charger communication or management from charger OEMs remains rudimentary. More advanced CMS solutions and smart charging methods are needed to manage charging operations. There are three uncommunicative charging methods typically available from OEMs "out-of-the-box." The specific charging method utilized will depend on charger OEM, model and connector configuration. These charging methods do not necessarily require control from centralized CMS systems to function as charging actions can occur automatically upon vehicle connecting. These include:

4.5.1.1 Single Connector (Plug and Charge)

When a power cabinet has a single connector, it will typically begin charging a BEB automatically once it is connected and will continue charging the BEB until it is fully charged. Rudimentary charger monitoring systems may prevent a high number of sessions from coinciding.

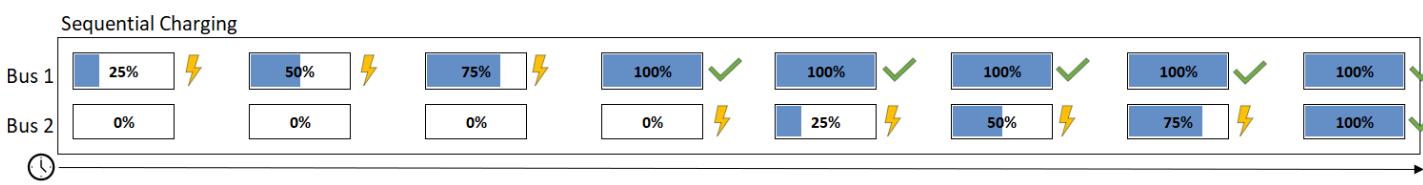
Figure 6. Charging two BEBs with the single connector charging method



4.5.1.2 Sequential Charging

If a single power cabinet has multiple connectors, the unit will typically deploy what is known as sequential charging. Sequential charging allows multiple BEBs to charge one after another, with vehicles being charged in the order they are connected to the charger. Sequential chargers will sometimes charge one vehicle to a high SOC (i.e., 90%) and then begin charging other connected vehicles with low SOC. Once all connected vehicles have a high SOC, the charger will trickle charge the buses individually until 100% SOC is achieved.

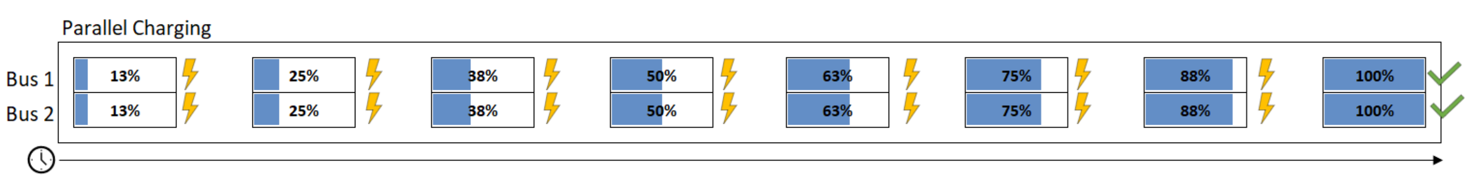
Figure 7. Charging two BEBs with the sequential charging method



4.5.1.3 Parallel Charging

A third charging method is now emerging on the market, known as parallel charging. Parallel chargers have a single power cabinet and multiple connectors like sequential chargers. However, parallel charging allows multiple vehicles to charge simultaneously, with power being distributed to vehicles according to the number of vehicles connected and their individual SOC.

Figure 8. Charging two BEBs with a parallel charging method



Takeaways	Charging activities typically occur uncommunicatively using a single connector, sequential, or parallel charging method. Power delivery through connectors is generally undirected, unrestricted, and often derated by facility power limitations.
Fleet Size	Small

4.5.2 Future Considerations

As BEB deployments grow, so will the number of installed charge points. An advanced Charge Management System (CMS) will likely be required to help TAs manage the high number of charging sessions and maintain efficient charging operations. With the appropriate CMS systems in place, TAs will reap the benefits of keeping vehicle availability high and energy costs to a minimum. A CMS will monitor chargers at a depot level and provide 'Smart Charging' functionalities that override the uncommunicative charging methods typically implemented at the power cabinet level.

Once a vehicle is connected to a charger, an advanced CMS will direct the charging sessions at the connector level using a 'smart' charging method. A smart charging method describes 'how' a CMS coordinates and executes charging sessions. This coordination can be completed in several ways and will likely differ depending on TA preference or vendor recommendations. A level of flexibility in terms of the solutions deployed should be expected from the vendor, along with proper planning and selection of the smart charging method that will best suit your needs. It is noted that a CMS is likely to be an integrated feature of a DMS and not necessarily a standalone product. This integration will offer the greatest communication, data transparency, and coordination between the two systems.

In brief, a CMS with smart charging will work to "Flatten the Curve" when it comes to power delivery to your fleet over time, minimizing demand costs while providing sufficient energy to your fleet. But, again, 'how' charging sessions (power delivery through individual connectors) are coordinated and executed will vary from solution to solution. Some examples of different smart charging methods can be found below. Implementation of these (and any other smart charging method) can be achieved through OCCP 1.6 (or later) communication with the chargers via a CMS, effectively overriding standard out-of-the-box 'uncommunicative' charging strategies described above.

4.5.2.1 First-In-First-Out (FIFO) Smart Charging

First-In-First-Out (FIFO) ensures that each vehicle gets its required charge as fast as possible based on when it is connected. The first bus to make a connection is the first bus to charge (up to an optimized charging target, if defined), and so on. The CMS monitors each session, and the number of simultaneous charging sessions can be limited based on facility power constraints and energy tariffs.

4.5.2.2 Round-Robin Smart Charging

Round-Robin charging works by supplying vehicles with a charge at full power for a configurable amount of time and cycles power to vehicles based on when they are connected. Vehicles remain in the round-robin queue until they reach their charging target. The CMS monitors each session, and the number of simultaneous charging sessions can be limited based on facility power constraints and energy tariffs.

4.5.2.3 Averaging/Equal Smart Charging

Averaging/Equal Charge shares power equally among all connected vehicles based on the charger's maximum power output and the available facility power. Each power cabinet (or connector) will deliver energy simultaneously, and the average energy delivered will decrease with an increase in the number of connected vehicles. The CMS monitors each session, and the number of simultaneous charging sessions can be limited based on facility power constraints and energy tariffs.

4.5.2.4 Prioritized Smart Charging

The prioritization method constantly assesses the needs of all vehicles, whether connected to a charger or not. This method determines which buses are most important to charge based on their upcoming book out times and their current energy relative to their charging target, for example. Priority is determined in real-time as new vehicles enter the garage, finish charging, or reposition. This method allows for the vehicles with the shortest amount of time or the most required energy to charge first while monitoring the fleet to ensure BEBs will be ready for book out.

Next Steps	Charging operations for larger BEB fleets will require a centralized CMS that deploys a smart charging method. Various smart charging methods should be assessed to ensure an optimal solution is deployed for a particular facility. Assess how smart charging methods will function in concert with DMS and how they can affect charging operation processes.
Fleet Size	Medium, Large

4.6 Pre-Trip Energy Verification

It is not typical for TAs to have a business process to verify exact fuel levels on conventional buses before they depart a depot/yard for revenue service. This lack of fuel verification even extends to these vehicles' physical fuel gauge, which is usually non-existent. Instead, regular fueling processes (typically a servicing task) are relied upon to ensure vehicle fuel levels remain sufficient for any potential work assigned by the bus. Therefore, fuel levels are not usually important to an operator when completing a pre-trip inspection.

Fuel levels are a different story for BEBs, and electric vehicles in general, where range anxiety is usually top-of-mind for those who operate these vehicles. Given the variability in the expected range that any single BEB can travel (due to both installed battery capacity and fluctuations in energy consumption), new processes and procedures will likely be required to verify that BEBs have sufficient energy before booking out.

4.6.1 Typical Deployments

It is common amongst current BEB deployments that monitoring charging sessions is the responsibility of servicing, maintenance, or dispatch staff. These staff members ensure that the BEBs are prepared (i.e., have enough charge) for their next piece of work. Charge monitoring is needed for both the in-depot and on-route/opportunity charging strategies.

Across TAs, the most common charging target that TAs set for their BEBs before booking out is a 'full charge.' Depending on the bus OEM, the SoC typically associated with a full charge (as read on the vehicle's dashboard or reporting dashboard) is usually between 90% and 100%. When completing a pre-trip inspection, operators are typically trained to look for these values and give notice if a different value is seen. The servicing, dispatching or maintenance staff will then assess the charge of the bus and decide if it can complete its run or if a conventional bus will need to be assigned the run instead.

There are cases where TAs deploy BEBs mainly on peak service runs with short-run distances. These TAs recognize that their BEBs do not necessarily need a full charge to complete this shorter work. In these cases, TAs have trained both servicing staff and operators to look for a minimum acceptable charge value that a BEB must have before departing for a service run (i.e., 60% SoC) rather than specifying a full charge. If a BEB has below the minimum acceptable charge, servicing, maintenance, or dispatch staff are made aware, and a conventional bus is used instead. TAs with a lower required pre-trip SoC value usually begin their deployments using full charge as a target and decrease the SoC target as they become more comfortable with their BEB technology.

Takeaways	Servicing, maintenance, or dispatching staff monitor charging activities and verify that vehicles are fully charged before booking out. Operators must report lower than expected SoC values when completing a pre-trip inspection. When the TA utilizes BEBs on short runs, they don't require that the BEB is fully charged before booking out, but a minimum SoC is required regardless of block distance.
Fleet Size	All

4.6.2 Future Considerations

Several factors impact the minimum amount of energy a BEB must have to complete its next revenue service run. With a firm understanding of these factors gained through energy modelling, experience with a given BEB technology, and historical energy consumption analysis, a TA may be able to refine pre-trip energy requirements. For example, if a given block only requires 50% SOC (including safety margins), a BEB would pass its pre-trip inspection with any charge greater than 50% SOC.

Due to the variable nature of this energy verification (i.e., it could be different each shift), TAs will need to adapt and provide service, maintenance, or dispatching staff with the information they need to verify SoC on the fly. This verification can be in the form of providing pre-trip SoC value checks using a DMS/CMS and developing processes to handle cases when the expected charge is not reached. Operators may be trained to accept the SOC value of the vehicle as valid for their work unless the value appears erroneously low (i.e., 20% SoC to start a shift). There has been discussion surrounding removing SOC indicators from BEBs altogether, ultimately shifting the onus of pre-trip SOC verification away from operators.

Servicing, dispatch, or maintenance staff will likely be responsible for monitoring the DMS/CMS to verify that the fleet is on track to meet its overall charge requirements. The DMS/CMS will likely know well ahead of time whether a vehicle will achieve its charging targets and can prompt users to take action to remedy the situation. These systems will need the necessary integrations to know when a BEB needs to be charged and how much charge it needs and prioritize charging sessions accordingly.

Next Steps	Pre-trip verification will likely be shifted from away operators completely. DMS/CMS systems will provide feedback to servicing, maintenance, or dispatch staff ahead of time if a BEB cannot be charged in time for its book out. SoC indicators may be removed from BEB dashboards.
Fleet Size	Medium, Large

4.7 Out-of-Garage Monitoring (Telematics)

The monitoring of vehicles while in revenue service is no new task for TAs, as CAD/AVL systems are ubiquitous in today's transit landscape. However, BEB technology is forcing the industry to adapt and consider the inclusion of continuous monitoring of vehicle energy levels along with typical CAD/AVL data such as vehicle location, route, and schedule adherence information.

4.7.1 Typical Deployments

All TAs indicated that real-time monitoring systems (from Bus OEMs) monitor and report a vehicle's energy consumption statistics to a dashboard. However, none of these systems are integrated with a CAD/AVL or DMS system. As a result, they do not provide the feedback that is expected to be required for mission-critical on-route energy monitoring and alerts for an entire fleet of BEBs.

On-route energy levels are typically monitored by the onboard operator, who will call in to dispatch if they suspect that the SoC values are too low or lower than anticipated. This call is set to occur when the Soc drops below 15-30% depending on the TA, the block the BEB is running, and weather conditions. The dispatcher will then assess the SOC value against the distance and time the BEB must complete in-service. The dispatcher will deploy a changeover if the energy is too low or indicate to the operator that they can complete their shift. BEB not completing work is rare (if it has occurred at all), as pre-trip energy verification typically acts as a preventative measure for the situations.

Takeaways	On-route SOC is monitored by bus operators. Low SOC is reported to dispatch (between 15-30% depending on the TA, the block the BEB is running, and weather conditions), who decides whether the vehicle will remain in service. Pre-trip SoC verification is a reasonable risk mitigation strategy to prevent low-SoC changeovers.
Fleet Size	All

4.7.2 Future Considerations

With the large-scale deployment of BEBs, there will be too many moving parts for on-route energy levels to be monitored manually by either servicing staff or dispatchers. Dispatchers could also become overwhelmed with energy verification call-ins if the operators remain responsible for this task. A system which takes input from CAD/AVL systems and combines that with other data (i.e., work assignments, historical block energy consumption data, etc.) may need to be deployed.

In short, this system may monitor each BEB's current SoC and compare it to an expected value considering historical data for a particular block. If the energy is found to be used at a rate far exceeding expectations, the BEB may run the risk of needing to be changed out. This early warning system could warm dispatchers and operators to monitor energy levels and make recommendations regarding changeovers when needed. These systems should also be configurable to send real-time alerts to other relevant staff.

Regardless of the deployed systems in the future, operators should be made aware of the limitations of the BEBs that they drive. For example, depending on the vehicle OEM, each BEB will have an SoC (i.e., 5-15%) below which it will begin to derate power to specific subsystems to protect battery pack health. These conditions will lead to driving conditions that are unsuitable for in-service operation and require the off-boarding of passengers. Additionally, if the SOC gets low enough, this could lead to a "dead bus" requiring towing to return to the depot/yard.

Next Steps	Assess CAD/AVL systems that provide feedback about a fleet's on-route energy consumption and act as an early-warning system for low-SOC scenarios. Small deployments may be successful without these systems as long as operators remain aware of BEB limits
Fleet Size	Medium, Large

5 Training

Depending on the size of your organization, training your workforce will likely represent one of the most significant challenges you will face as you electrify your fleet. The following sections will focus on training areas and considerations for SPOT-related roles. However, it is recognized that many other roles and responsibilities will be impacted as BEBs are deployed. Training is especially relevant for maintenance support staff, who will, over time, must learn to perform their technical duties on a whole new set of technologies. Maintenance is an area that is being discussed at length as TAs push for trade programs and support from local colleges to develop the necessary workforce skills and training required in the years to come.

5.1 Typical Deployments

5.1.1 Scheduling & Planning Training

There have been no identified cases of new training being developed or delivered to scheduling & planning personnel due to BEB deployments. As a result, these roles remain largely unimpacted, save for some engagements relating to selecting blocks that can/should be assigned to BEBs, and planning on-route/opportunity charging infrastructure.

Winnipeg Transit has purchased and is testing a route modelling software with a BEB-specific module. Schedulers and planners are involved in developing a simulated schedule and creating scenarios representative of a 100% electrified garage using this software. This work is done to support energy consultation work and will be important in detailing the next electrification stages.

Takeaways	Changes to scheduling & planning roles have been contained to date; no additional formal training has been required.
Fleet Size	All

5.1.2 Operator Training

5.1.2.1 Training Approach

The typical approach TAs have taken concerning developing in-house BEB-related training material is to engage bus OEMs before and shortly after receiving their first BEB(s). A “Train-the-Trainer” approach is typically (not always) taken, where the OEM provides hands-on training and materials to a TA’s operator training group (this is usually specified in procurement contracts). The training staff then develops in-house materials according to the organization's specific training requirements. When a train-the-trainer model is not used, the TA will still receive BEB training manuals and guides from OEMs and use those resources to develop wholly internal training programs.

Once training procedures and documentation are developed, training is delivered to operators. These training courses vary in duration, although typically are in the 3-6 hours range and include in-class and on-road training. The differences in BEB technology compared to conventional buses are typically highlighted during vehicle operation. The use of regenerative braking, changes in operational feel (i.e., due to the different center of gravity, etc.) and other operational nuances are typically demonstrated or explained.

Training always includes information on connecting the BEB to the TA's charging infrastructure, whether in-depot or on-route, plug-in, or overhead pantograph.

Contents of training courses can also touch on modified pre-trip procedures, including new vehicle start-up procedures and energy (SoC) verification (i.e., a check for specified minimum energy). In addition, modified return-to-garage procedures may be included in the training, where BEB parking procedures and charger connection procedures are taught.

5.1.2.2 Operator Selection

The most common approach to training operators during the initial phases of BEB deployment is block-based training. Block-based training results from TAs pre-selecting a small number of blocks to which BEBs will be assigned consistently and repetitively over time. The blocks that BEBs will be assigned are determined) and an indication of which blocks will be electrified is given to operators as they bid on work for upcoming signup(s). Whichever operators win the bid for the electrified work are trained to operate the BEBs.

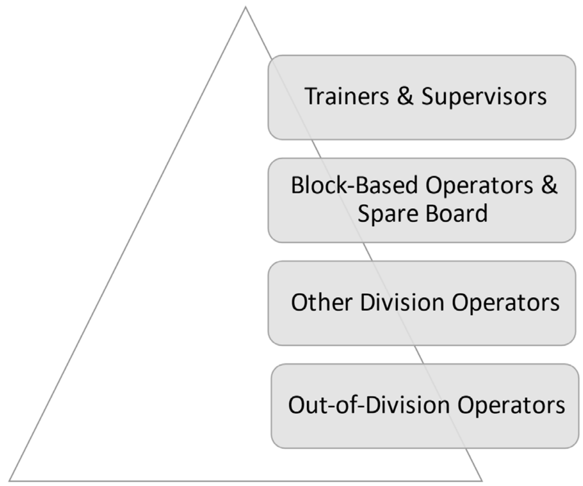
After this initial round of training, the next steps in a training program typically depend on how work is regularly assigned to BEBs. Some common approaches that have been taken include

1. Limited Block-Based Training: Training continues as new operators signup for electrified work. Limited Block-Based training throttles the overall amount of training that needs to be delivered and limits who can operate the BEBs. This is more common with the on-route/opportunity charging strategy.
2. Expanded Block-Based Training: Expanded block-based training occurs when TAs begin to select a more random set of blocks that can be electrified and where work assignments typically vary day to day. Any operator who has signed up for a block that could be electrified is given training, followed by all spareboard operators. This approach is common among TAs that utilize an in-depot charging strategy and allows a broader set of operators to receive BEB training.
3. Broad Training: Broad training includes training all spareboard operators and all other operators based out of the garage where BEBs are deployed.

These approaches are gradual processes that depend on the trainer and BEB availability. It is noted that during the training ramp-up period, a sizable portion of the BEB fleet is typically reserved for training purposes and, therefore, not used for revenue service.

The level of BEB training completed after these initial approaches varies, with some TAs electing to train their entire operator workforce or only offering training to new operators or those that move to a garage with BEBs (i.e., new signup or otherwise). There are cases where operators who typically drive a different class of vehicle (i.e., only community buses or shuttles) do not get offered BEB training, as they will not likely ever drive the 40' BEBs at this time. Most TAs have the goal of eventually training their entire operator workforce. Still, the methods above allow for a more gradual training process that will not interrupt BEB utilization or service levels.

Figure 9. Typical BEB training hierarchy.



Kingston Transit represents an exception where the group of trained operators is small (and unchanging) as they assess their pilot program. With a small group of operators, an onus has been developed to troubleshoot BEBs and learn more about the operation of BEBs in general. The added benefit is having more attuned operators to the vehicles while a TA develops its internal understanding of the technology.

5.1.2.3 Impact of Operator Training on BEB Deployments

Operator training has a much more significant impact on in-service BEB availability than it does with conventional buses. This impact is caused by the greater extent to which the driver's behaviour impacts (positively or negatively) the overall range of the BEB in real-world operation. Therefore, areas of importance that should be highlighted to operators when being trained to drive BEBs include their direct and indirect impacts on the BEB range during operation. Direct impacts can be reduced by educating operators on the proper usage of regenerative braking, limiting acceleration, and limiting time spent at high speeds. On the other hand, indirect impacts can be limited by educating operators about the proper usage of HVAC systems, including defrosters, temperature setpoints, when diesel heaters are or are not utilized, and the impacts that climate and weather conditions can have on BEB range.

Beyond training measures, many of the factors mentioned above can also be preemptively controlled on BEBs, to a greater extent than on convention buses. For example, the aggressiveness of regenerative braking and the rate at which the BEB is allowed to accelerate can both be modified by adjusting vehicle settings. This feature offers TAs the ability to decrease potential driver-to-driver range variability, allowing for more accurate energy consumption estimates to be used to determine suitable vehicle work assignments, for example. Training operators to drive as efficiently as possible and implementing preemptive controls have many upsides, including increasing vehicle range and lowering operations costs (i.e., electricity costs).

5.1.2.4 Monitoring Driving Behaviours

Several TAs have mentioned monitoring operator driving behaviours as part of a data collection plan. This data point can be used to reduce overall fleet energy consumption by applying corrective actions when and where needed. However, there is no consensus on the extent to which an individual driver's behaviour will be monitored. Some TAs find it appropriate to analyze each driver's performance and offer feedback when they appear to be above acceptable energy consumption thresholds. However, others do not wish to make the operators feel as if their actions are being closely monitored at all times and will not be monitoring energy usage at the individual's level. Nevertheless, important conclusions are drawn from monitoring driver behaviours at the fleet and individual level regardless. The pros and cons of each data collection method will have to be considered in each deployment instance.

5.1.2.5 Operator Refresher Training

When the board training approach is taken, there is generally a need to offer refresher training to operators. This need stems from the fact that BEB deployments remain small and a rotation of drivers on BEBs typically only happens at the beginning of new signup; therefore, only a small number of operators get to drive BEBs regularly. It can be the case that an operator last had training months before they get the opportunity to drive a BEB in revenue service. Some time to reacquaint with the vehicle and to rehash charging procedures is typically requested by operators who feel the need for this refresher.

5.1.2.6 Operator Training Budgets

It was noted that there are significant costs associated with BEB operator training programs. These costs are sometimes an oversight that is excluded during budgeting for BEB programs. Training programs can be quite expensive and resource-consuming, and if they are not accounted for may cause unnecessary budget constraints as a program progresses. Any BEB program budget should include the time and resources required to develop the program & materials, execute all operator training, and contingencies for refresher training.

Takeaways	A "Train-the-trainer" approach is typically taken to initially help TAs development BEB training programs. Training programs are then delivered to operators using Limited Block-Based Training, Expanded Block-Based Training or a Broad Training strategy. The impact of driver behaviours (i.e., regenerative braking, HVAC usage) must be communicated during the training of BEB operators to minimize risk. In addition, BEB technology allows for data collection at the level of individual drivers – this can be used to optimize operations and provide additional cost-saving opportunities.
Fleet Size	All

5.1.3 Servicing Staff Training

To date, comprehensive servicing staff training has focused on driving BEBs, connecting BEBs to chargers, BEB-specific servicing requirements, and SOPs that differ from conventional buses. It is typical that all servicing staff within a depot/division that houses BEBs receive this general training. As new servicing staff are assigned to a facility, they receive BEB-specific training as facility orientation or onboarding training. In addition, there are cases where service staff also receive standardized High-Voltage (HV) and arc flash safety training from a certified safety trainer. These programs can be developed as a part of an Intro EV technology program in concert with local colleges.

Enhanced BEB-related duties are typically assigned to senior servicing staff or servicing supervisors. These duties include monitoring BEB charging sessions, pre-trip energy (SOC) verifications, hardware troubleshooting, and issue resolution & escalation. These staff typically coordinate the movement of BEBs within a garage/depot and ensure that each vehicle is charged before their next book out. They will all utilize new charger software systems to monitor charging sessions.

Takeaways	Servicing staff typically receive training that builds on operator training programs. Additional training areas include servicing-specific tasks and, at times, HV safety training. BEB operational tasks such as charging session monitoring and energy verifications typically lie with senior servicing staff or servicing supervisors.
Fleet Size	All

5.2 Future Considerations

5.2.1 Scheduling & Planning

Schedulers & Planners will likely be the most impacted by the requirements to use new or modified software systems to aid them with BEB-specific aspects of their roles. Beyond this, transit scheduling & planning staff may benefit from understanding how BEB technology differs from conventional buses and how these differences impact the transit planning & scheduling processes. This may include a more technical understanding of the vehicles and factors that impact a vehicle's performance and the consequences of these impacts on other business areas.

Some areas that transit Schedulers & Planners may need an advanced understanding of include (but are not limited to):

- BEB Energy Consumption factors.
    - Distance & Duration considerations.
    - Weather & Temperature Impacts.
    - Topography Impacts.
    - Loading Impacts.

    - Duty Cycle Impact.
- Charging Needs of the Fleet as a whole.
    - Minimizing energy requirements.
    - Minimizing operational costs.
- The impact that charging operations will have on vehicle availability.
- BEB maintenance plans (preventative or otherwise).
- On-route/opportunity charger location selection factors.
- Blocking impacts.

Next Steps	Utilizing new software and understanding the nuances of BEB technology, operations, and associated processes/procedures will be critical areas of interest in future planning & scheduling training areas. Planners and Schedulers will be central to cost-effective, highly efficient, and sustainable transit systems of the future, and their roles will grow accordingly.
Fleet Size	All

5.2.2 Operator Training

Most impacts on operator training will occur at the beginning of a BEB deployment. It will likely result in programs that include this training as a standardized offering like today's conventional bus training. However, a coordinated training program will be required to get to that point.

BEB and charging infrastructure technology are quickly evolving, and so are the details on operating these pieces of equipment. It is unlikely that a TA will have an identical set of BEBs or charging stations deployed throughout its network, and capturing changes in the operation of different pieces of equipment will be key in future training programs. Changes such as recognizing different locations of emergency stop buttons on charging stations can be impactful in maintaining safe operations down the line. Commonly, TAs have different BEB makes or models housed in different garages at this point. This will likely be the case with many deployments (depending on size) and must be accounted for in training programs.

Next Steps	Operator training programs must evolve and adapt to a rapidly changing technology field and equipment manufactured by multiple vendors. For example, year-over-year differences in vehicle models, the introduction of new vehicle makes, and changes to charging equipment will need to be accounted for in future programs. This is in addition to any additional learnings and insights which can be extracted from today's data collection programs.
Fleet Size	All

5.2.3 Servicing Staff Training

The role and responsibilities of servicing staff are potentially primed for significant changes. This results from changes that are likely coming to in-garage procedures and software systems that will direct many future-state BEB-related activities. As will be discussed later in this document, the servicing staff will likely take on, to varying degrees, the responsibilities of the Charging Systems Operator (CSO). The main goal of the CSO is to ensure smooth charging operations are carried out within a depot, as the staff (with the help of DMS & CMS) organize and execute a high number of charging sessions to prepare all BEBs for their subsequent blocks. For initial BEB deployments, the CSO would likely be actualized as added responsibilities to existing roles as it would be difficult to make this a full-time job with only a small percentage of BEBs in a fleet.

New training programs will likely have to be developed for those that take on these new responsibilities. With large-scale BEB deployments, the operating principles upon which current servicing roles & responsibilities are built will face significant changes. With the assistance of a DMS, the servicing staff will carry out highly coordinated physical activities (which are, for the most part, analogous to what they do today), intended to manage many charging activities (different from today). The duties and responsibilities of the CSO will be a byproduct of the systems (software or procedural) that are put in place, the configuration of charging infrastructure, and the overall size of a BEB deployment. Change in the scope & responsibilities of an existing role or creating a new role will have to be done in coordination with unions while working within existing collective agreements and policies.

Next Steps	Depending on how BEB tasks and responsibilities are distributed in the future, the servicing staff role could see significant changes. The development of a role akin to the described "Charging System Operator" may warrant the creation of training programs for a new or augmented role within your organization.
Fleet Size	All

6 IT Impacts - Looking Forward

Commonly, TAs with BEB deployments have mainly focused on the hardware and infrastructure (buses, chargers, and facility) aspects of these projects up to this point. The next step in this process will shift focus to the systems & processes required to tie vehicles and infrastructure together to allow them to function harmoniously on a large scale. The lack of attention paid to this area is a byproduct of current deployments being small relative to the entire fleet of buses and manual processes being sufficient to manage the new technology. Manual processes have allowed charging sessions, for example, to occur automatically and without a centralized CMS or work assignments to occur without input from a DMS.

Charging operations will be constrained in ways that conventional bus operations are not, especially related to in-garage procedures. These constraints are the root cause(s) for the expected complexities of large-scale charging operations and the need for sophisticated software solutions. Some of these constraints include (but are not limited to):

- Limited facility power → Restricts the number of buses that can be charged at any one time.
- Limited Budget → Restricts the number of charge points installed, for example.
- Limited Space → Restricts the number of charge points installed.
- Long fueling time → Causes time constraints in the fueling process.

An in-depot charging facility would have unlimited power, at least one connection point per vehicle, and very high-power chargers in an ideal scenario. That is, the constraints mentioned above would not exist. There are several reasons this is unrealistic and will likely not be the case in any BEB deployments. In realistic cases, charging operations will need to be more complex and granularly managed to offset the existing constraints and allow a TA to maintain a high level of service.

An example of the complexities of managing large-scale charging operations (considering full-fleet electrification) and where the constraints mentioned above play a role follows below. This situation looks at a BEB as it books in and begins the process of receiving its next work assignment. The BEB arrives at the depot, and the operator is to be told where the BEB is to park. Before this occurs, these steps may need to be carried out:

- An assessment of the runs which are appropriate for that specific BEB (considering distance limitations and the available battery capacity of that particular BEB);
- An estimation of the amount of additional energy the bus will need (compared to the current level) to complete the appropriate runs;
- A calculation of how much time is required to deliver the necessary energy to the BEB (Long fueling time);
- Verify that the BEB will have enough time to charge, considering other charging sessions and remaining facility power (Limited facility power & Budget);
- A check to confirm that there is an open charging station (Limited budget, space);
- A check to verify the BEB will not be blocked in by other buses at book out (Limited Space);
- Selection of the run and confirmation of the parking position;
- Communication of the chosen position to the bus operator;
- Parking of the BEB by the Operator;
- Connection of the BEB to a charger;
- Initialization of charging when appropriate.

Compared to the analogous process for a conventional bus, which is usually not very directed, the BEB process takes several factors into account in real-time. This process is best left to software systems rather than relying on staff and introducing the possibility of human error. The right software solution can carry out the above functions accurately, automatically, and in seconds without human interference.

TAs will reach a 'tipping point' beyond which tasks like assigning work to a BEB may become challenging to manage without software intervention. This tipping point has been unclear and will likely depend on the overall size of an agency and the amount of BEB technology and charging infrastructure deployed. For example, TAs with 20-30 BEBs currently housed within a garage can manage charging operations but recognize that they are not far from needing at least a basic CMS solution to organize charging activity.

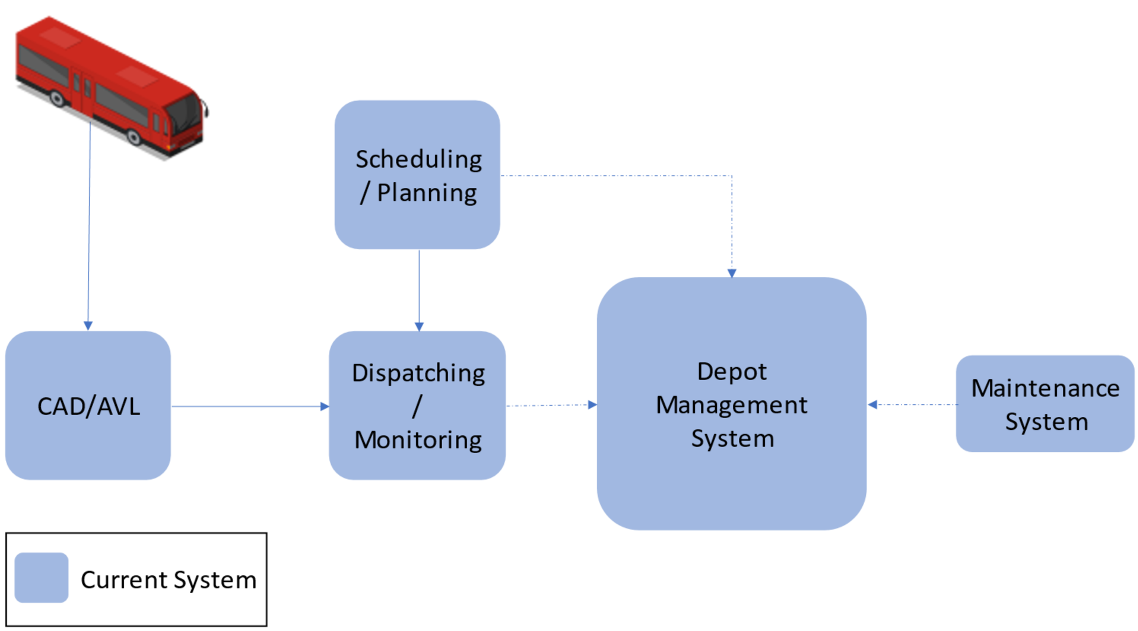
The following sections will look at the typical systems that are generally in use at TAs and the new systems that will likely be required to manage the charging operations of the future.

6.1 Current State IT

The current combination of Transit-focused IT systems typically comprises Planning Software, Scheduling Software, CAD/AVL Systems, Dispatch Software, Enterprise Resource Planning Software, Maintenance Software, Depot Management Systems, and others.

A diagram representing the typical connections between some common systems is shown below (Figure 10). It is noted that often these systems can function quite independently, especially if they come from different vendors. This diagram is meant for informational purposes only and is not intended to suggest a recommended system architecture.

Figure 10. The typical current state of transit-specific software architectures.



There are many instances where the tasks of a depot management system are carried out manually (i.e., using magnet board, excel sheets, or pen & paper). In these cases, the interconnection of other systems is usually non-existent, and these systems operate independently (to the dismay of the users). Therefore, even without introducing BEBs into a fleet, there may be a business case for assessing new DMS and localization solutions to help improve the efficiency and effectiveness of in-garage procedures.

6.2 Future State IT

Electric vehicles have matured with other technologies such as real-time data processing and machine learning. As such, big data and electric vehicles (not just BEBs) are inextricably linked at this point. One example of this is the amount of information available for instantaneous energy consumption of vehicle subcomponents on BEBs. This insight alone offers a deeper look into vehicle operating conditions than has ever been possible with conventional vehicles.

In a world where GHG reduction targets are driving change, utilizing as much data as possible will enable the operation of the most efficient and clean transit system possible. This change will require more integrated and smart solutions to use this data to make informed decisions and help your organization achieve its goals. The subsections below will offer a high-level description of these future-state IT solutions and the possible BEB-related functionalities of these systems that your organization could consider while assessing future options.

6.2.1 IT Systems and Fleet Size

The specific solutions utilized to manage BEB charging operations are expected to depend on the BEB fleet's size. In addition, staff availability from scheduling, planning, operations, servicing, maintenance, etc., to commit time and effort to manage charging operations will also play into the need for specific solutions. Table 3 looks at what IT systems will likely be required, desirable, or optional for BEB fleets of different sizes (housed in the same facility). Some of the systems in Table 3 are not novel to TAs (CAD/AVL, planning & scheduling, and maintenance software). Still, they will likely require additional capabilities to manage large-scale BEB operations. It is the inclusion of these additional capabilities/upgrades referred to in Table 3 and not the basic functionality of these systems. The remainder of the system will likely be new, and the introduction of these is considered here.

Ultimately, the need for new or upgraded IT solutions will have to be determined case-by-case. However, the following sections provide a brief description and feature set for these solutions that can be used as a starting point for determining when and where specific solutions will be needed.

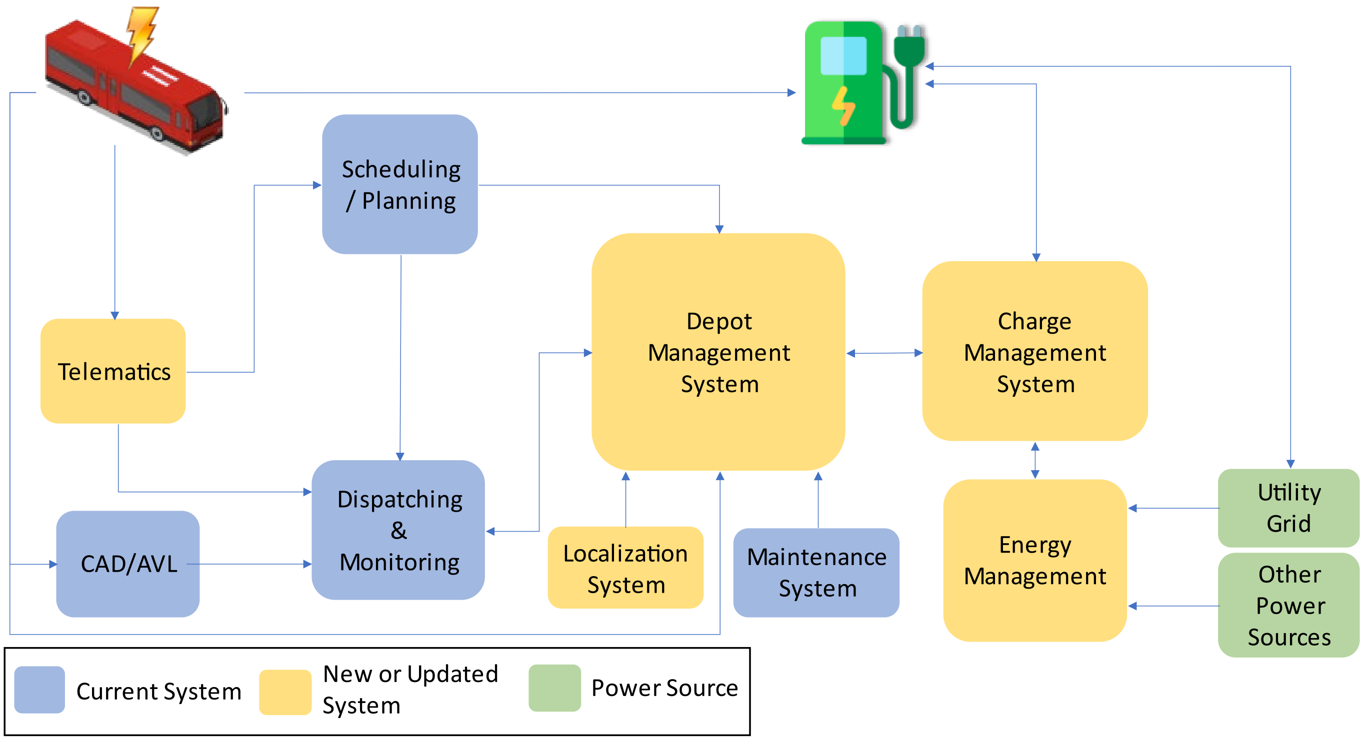
Table 3. Updates (Light Grey) & New (Dark Grey) IT systems for BEB deployments.

IT System	Small BEB Fleet	Medium BEB Fleet	Large BEB Fleet
CAD/AVL	Optional	Desirable	Required
Scheduling & Planning	Optional	Desirable	Desirable
Maintenance Systems	Optional	Desirable	Desirable
Telematics	Required	Required	Required
Depot Management System (DMS)	Desirable	Required	Required
Localization System	Optional	Desirable	Desirable
Basic Charge Management System (CMS)	Required	Required	Required
Advanced Charge Management System (CMS)	Optional	Desired	Required
Energy Management System (EMS)	Desirable	Required	Required

6.2.2 High-level System Architecture

The figure below shows a high-level look at what transit-related IT systems may be needed and where communication between systems will be required. Comparing the figure below (Figure 11) to Figure 10, it is clear that a significant overhaul of current systems and the integration of many new systems can be expected to accompany a transition to BEBs. With new technology (BEBs), there is also the introduction of direct interaction with the electrical grid that has not necessarily been of concern in the past. For most of their histories, the transportation industry and the electrical power industry have primarily been considered separately. With electric vehicles, this is changing significantly, and the merging of these sectors will require careful planning and execution (not to mention sophisticated solutions).

Figure 11. Example of a future state transit-specific software architecture.



6.2.3 Open Standards & Interoperability

As discussed in the previous sections, charging operations will be guided by many complex software processes. Further complexities will be introduced if processes are carried out by systems lacking highly coordinated communication between them - chargers, DMS, and telematics software, for example. Today, it is quite likely that individual vendors would supply each of these components, and each would work with its proprietary communication protocol. Working with several communication protocols will lead to long integration times, add further complexity to BEB deployments, and potentially slow down the rate at which TAs can electrify their networks.

Well-defined communications standards will be essential when different transit software components need to communicate. Unfortunately, there are currently few North American standards that define these communication standards. In Europe, the Verband Deutscher Verkehrsunternehmen (VDV) (Association of German Transport Companies) has developed standards for such applications. Many of these standards are now widely used by several well-known software vendors - including those with product offerings in North America.

Figure 12 displays how these standards have been deployed in European BEB deployments. Table 4 provides an index of these standards.

Figure 12. Example of a future state transit-specific software architecture with open standard communication protocols.

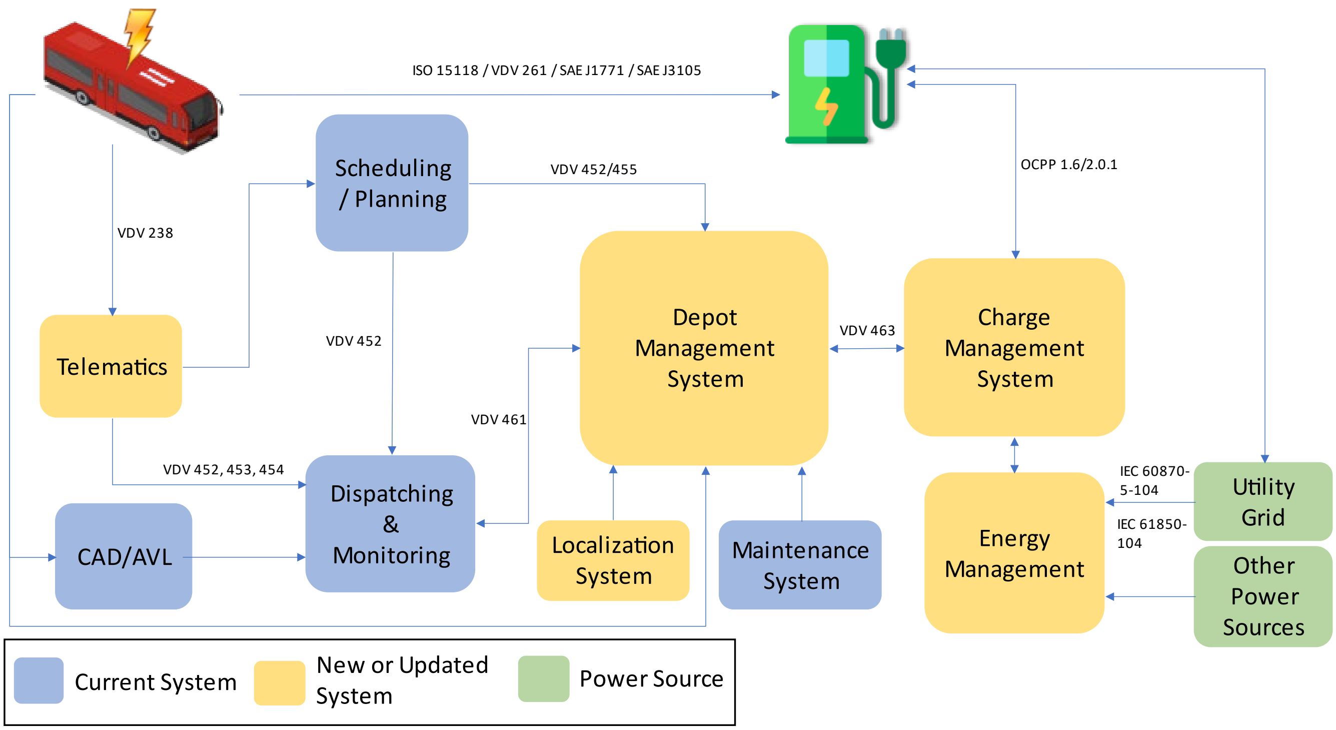


Table 4 . Standards Identified in open standard-based transit software deployments

Open Standards Utilized in Transit IT systems
ISO 15118 - Road vehicles — Vehicle-to-Grid Communication Interface IEC 61850 - Defined communication protocols for intelligent electronic devices at electrical substations IEC 60870 5-104 - The remote control of substations or power plants SAE J-3105 - Electric Vehicle Power Transfer System Using Conductive Automated Connection Devices SAE J-1772 - SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler VDV 238 - (TBD) Upcoming data communication standard for electric buses VDV 261 - Recommendations on Connection of Dispositive Back-end to an Electric Bus VDV 451 - Data transfer between public transport applications VDV 452 - Standard VDV Route Network / Timetable Interface VDV 453 - Integration Interface for Automatic Vehicle Location and Control Systems VDV 454 - Realtime data interface - Timetable information VDV 455 - Integration Interface of Computer-Aided Operations Command/Control Systems VDV 461 - Real-Time Interface - Depot Management System VDV 463 - Interface to the charging management - depot management & ITCS

These standards have been developed to ensure competitiveness while enabling customers to choose their vendors freely without experiencing a vendor lock-in. Selecting solutions that utilize open communication standards will come with benefits such as centralization, flexibility, compatibility, and overall quality. In terms of deploying system-level solutions, three different approaches can be taken:

- Proprietary solutions are provided by a single vendor - Which means various components/modules such as the DMS & CMS are provided by one vendor, and changing one system component to an equivalent from another vendor is not possible.
- An open system provided by multiple vendors - In this case, components/modules such as the DMS are from a different vendor than the CMS. These systems would communicate using an API.
- Solutions provided by a single vendor with no lock-in - All system components/modules are from the same vendor. You are free to switch one or more to another vendor if you prefer at a given point, as open communication protocols are used.

In the early days of BEB deployments, it may be helpful to encourage (via specifications) vendors to offer solutions that utilize open standards. A unique opportunity exists for TAs to push these standards to become the norm to make modular applications more widely available and software deployments smoother and quicker. An example of standardization has been seen in the past number of years in the development of SAE J3105. The standard became the norm for overhead charging after working groups were established and TAs began requiring its use in procurements. The same can, and should, be expected to be possible for software systems as well.

6.2.4 Telematics & Data Analysis

Predictive energy modelling will help understand how BEBs can be expected to behave before deployment. Still, nothing will beat the real-world data when vehicles are in service. A detailed data collection plan should be developed to capture, monitor, and analyze the information that is made available from telematics systems installed on BEBs. These systems will be essential in gaining a fundamental understanding of your specific technology within your specific network.

The data required to be communicated from a BEB will have to be specified during procurement by each TA. There are currently no standards that define essential data to be made available (from a vehicle's CAN) to allow for effective BEB monitoring. VDV 238 is currently in development and looks to take a step toward making standard data available, so TAs can monitor their electric buses without the need of any other special agreement(s) and regardless of vehicle OEM. Rather than writing data specifications within a tender, TAs could site the standard (i.e., VDV 238) and understand what they will be getting.

High-quality data collection and understanding of BEB energy consumption from several angles will help optimize charging operations and minimize operational costs. In addition, this analysis will be used to inform staff and provide data sets from which DMS & CMS systems, for example, can learn and make better decisions themselves.

Telematics hardware providers may or may not have the software components or analysis specifications required, and this will have to be assessed on a case-by-case basis. Regardless of the situation, some of the post-collection data analyses that can be considered include

- Energy consumption by vehicle subsystem;
- Energy consumption trends by block & route;
- Energy consumption trends by the operator;
- Energy consumption trends by vehicle;
- Battery energy & capacity over time;
- Fault Reporting;
- Energy consumption trends as a function of temperature, passenger loading, duty cycles, time of day, etc.;
- Variations in projected versus measured values;
- Minimum on-route SOC values;
- Diesel Heater Consumption;
- Battery Health indicators;

BEBs are highly configurable, and good quality data collection and analysis will provide a TA with the opportunity to optimize BEB performance continuously. Regenerative braking, acceleration profiles, and heater output temperature are some items that TAs have indicated they have modified due to data trends. The potential for cost savings and lower GHG emissions due to better BEB efficiency at the fleet level is significant. In addition, when combined with data from other sources (i.e., charging stations), there is the potential to utilize telematics data to improve charging operation efficiency (i.e., in-garage processes), which could result in further operational savings.

6.2.5 CAD/AVL

On top of current functionalities such as position monitoring, incident management, disruption management, and schedule adherence, CAD/AVL systems will have key BEB-specific information that will reduce potential range anxiety on the part of the operator. This lessened range anxiety will allow them to operate BEBs with the knowledge that energy is being constantly monitored, and if there is a problem, they will be the first to know. This feature will require that the CAD/AVL (or other) system be aware of the current work assignment, the battery SoC, and the energy required to complete the remainder of the assigned work.

In short, this system may monitor each BEB's current SoC and compare it to an expected value considering historical data for a particular block. If the energy is found to be used at a rate which far exceeds expectations, the BEB may run the risk of needing to be changed out. This early warning system could warm dispatchers and operators to monitor energy levels and make recommendations regarding changeovers when needed. These systems could also be configurable to send real-time alerts to other relevant staff.

Some of the BEB-specific CAD/AVL functionalities that can be considered include

- Real-Time SOC monitoring for dispatchers;
- Early warning signals for operators and dispatchers (low energy alerts);
- Predictive on-route energy consumption trends;
- Real-time vehicle range estimates;
- Communication with DMS (or other scheduling data source) via open standards;

6.2.6 Scheduling & Planning

The main BEB-specific functionalities of transit scheduling & planning systems will depend on a TA's electrification plan. Creating shorter blocks versus modifying timetables, for example, impacts how the Scheduling & Planning system will ultimately be used. Understanding your TA's path to electrification (and charging strategy) will help define requirements for software systems and ensure you can select the best system for your needs.

Some BEB-specific Scheduling & Planning functionalities include

- Energy Consumption projections based on historical analysis, route topography, loading, duty cycles, etc.;
- Service Design considerations for BEBs;
- Network Design considerations for BEBs;
- Features for Timetabling, blocking, runcutting, & rostering BEBs;
- Route & Block Optimization;
- Human resource estimations based on blocks and shift designs;
- Operational cost modelling & optimization;
- Communication with DMS via open standards;

6.2.7 Maintenance Systems

Maintenance systems are not expected to be impacted to a significant extent with BEB deployments. BEBs will represent a new asset subclass for most agencies and have new parts tracking requirements and preventative maintenance schedules, but these functionalities are likely already available with current systems. The most important consideration will be available for certain pieces of maintenance-related data to be made available to other systems. Maintenance system communication with the DMS, for example, will allow for work assignment distance to be cross-checked with preventative maintenance schedules automatically.

It is anticipated that the introduction of BEBs and the associated data will eventually allow for the move from scheduled preventative to predictive maintenance. The potential for cost savings and operational efficiencies to be found here are substantial, with maintenance perhaps only occurring on an as-needed basis when data and BEB subsystems indicate it is/will be needed.

Some of the Maintenance System functionalities that can be considered include

- Adding and monitoring new part stock;
- Adding and monitoring new maintenance schedules;
- Tracking new maintenance procedures, documentation, and techniques;
- Battery Health Monitoring/logging;
- Preventative Maintenance Projections;
- Communication with DMS via open standards;

6.2.8 Depot Management Systems (DMS)

Regarding a BEB deployment, the main function of a DMS will be to manage and control charging operations from the moment a vehicle returns to a depot/yard to the moment it departs. Making complex decisions in real-time and offering recommendations and guidance to users will be key in TAs managing BEB charging operations. These added complexities should occur in the background for the most part, and a sophisticated DMS should not make overall bus operations much more complicated for staff than they are today. The added functionalities and coordination brought about by the proper use of these systems can improve operational efficiency and cost-effectiveness.

The DMS will be at the heart of charging operations and will be the most integrated and pivotal software system in a BEB deployment. Great care must be taken when writing requirements/specifications for a DMS and will require understanding the short and long-term needs of a transition to zero-emission technology. That said, bridging the gap between current and future operational states will also be a defining characteristic of these systems. Your fleet will constantly be changing year-over-year for the foreseeable future, and further operational complexities will have to be managed.

These scenarios result in conversations regarding managing typically undesirable “fleet-within-a-fleet” states. That is - having subsets of a fleet (say 40’ buses) with characteristics that lead them to be treated differently than the rest of a fleet (whether operationally or otherwise). BEBs, in general, will come with inherent operational differences, so a “fleet-within-a-fleet” may be practically unavoidable. Fleet management becomes more complicated when inter-BEB differences factor in (i.e., will the buses procured in year 0 of a program be similar to buses procured in year 10?). Again, utilization of DMS will be key in mitigating the operational impacts as they can take specific vehicle characteristics into account when assigning work, for example.

DMS software may also play an essential role in fire prevention solutions of the future. With a high amount of information from both bus and charger in one place, the DMS offers the opportunity to highlight data irregularities and to take or suggest preventative action. For example, continuous monitoring of data from Battery Management Systems (BMS) of a charging vehicle can help determine when the deactivation of a charging session may be necessary to avoid dangerous thermal conditions. This point further calls for open standards for vehicle communication to ensure interoperability between vehicles and software, in this case, to avoid potentially devastating situations.

More than any other system, the DMS will require an analysis of current IT systems and their ability to openly communicate and integrate with other systems. Recognizing that long-term contracts are typically in place for software solutions, an early analysis of your systems can help an organization identify potential bottlenecks and integration issues before these solutions are relied upon operationally.

Some of the DMS functionalities that can be considered include

- Monitor individual asset statuses & characteristics, including multiple asset classes;
- Monitor real-time vehicle locations;
- Direct BEB parking locations;
- Direct BEB work assignments;
- Energy Consumption projections based on historical analysis, route topography, real-time temperature, loading conditions, duty cycles, etc.;
- Visualization of bus & charger locations and statuses;
- Optimize servicing procedures;
- Direct & guide in-garage vehicle movement and organization;
- Monitor ability to meet charging targets and expected book outs;
- Alert users when charging targets cannot be met;
- Continuous monitoring & optimization of work assignments;
- Allow manual intervention on all processes (including charging activities);
- Track Operational BEB KPIs;
- Communicate with Localization systems, CMS, DMS, Maintenance Systems, Dispatching & Monitoring systems via open standards;

6.2.9 Localization Systems

High acuity position tracking of vehicles within a depot/yard combined with a DMS will be key to successful large-scale BEB deployments. The positions where vehicles are parked will likely be a highly directed operation that will be important in maintaining efficient Charging Operations and schedule adherence. Verifying the order that buses are parked with a track (to ensure that no blocking will occur) or verifying that a bus is parked at a charging station (but maybe not connected properly, for example) are helpful use cases for this technology. Position tracking integration with Depot Management systems can allow for guided vehicle movement (Track Collapse, Restacking, Servicing, etc.), which optimizes these activities, potentially reducing operational costs.

Localization systems are an example of a technology that could benefit a TA regardless of their BEB deployment status. For example, staff members often spend a significant amount of time verifying vehicle positions within a garage/depot. Localization systems could improve the efficiency of certain tasks and allow them to commit more time to other responsibilities. This technology is an example of a change that could be evaluated and implemented to make current-state operations more efficient while preparing your organization for future-state charging operations. In other words, this is an example of good change management related to a BEB deployment.

Some technologies that are available for depot/yard position tracking purposes include

1. Ultra-wideband (UWB) Tracking;
2. Radio Frequency Identification (RFID) Tracking;
3. GPS position tracking (outdoor only).

Some of the localization system functionalities that can be considered include

- Real-time position monitoring;
- Communication with DMS via open standards;

6.2.10 Basic Charge Management Systems

A basic CMS will provide a vendor-agnostic charger monitoring and customized reporting metrics. Typically, these systems can provide remote monitoring and management of charging infrastructure and can, in some instances, account for electricity tariffs and manage loads. Communication with chargers through a basic CMS is best accomplished with OCPP 1.6+. The basic CMS will exert a limited level of control on the chargers to which it is connected and will not likely consider service schedules and site-specific details. A basic CMS functions well when there is a 1:1 bus-to-connector ratio within a facility and when the BEB fleet size within a facility remains relatively small.

Some of the basic CMS functionalities that can be considered include

- Monitoring of Chargers;
- Charger Fault Reporting;
- Remote Charger Resets;
- Visual dashboard;
- Scheduling Charger Availability;
- Basic load management;
- Customized Reporting;
- Communicate with chargers via OCPP 1.6+.

6.2.11 Advanced Charge Management Systems

In addition to the functionalities of a basic CMS, the advanced CMS will take on a more active role in managing charging activities. The advanced CMS will utilize a smart charging method to manage and prioritize charging sessions and ensure that BEBs are charged for their next work assignment, considering a large number of factors in real-time. The advanced CMS system should also be highly integrated with other data streams to provide optimized charging operations (minimize costs and maximize BEB availability).

An advanced CMS with smart charging will work to “Flatten the Curve” when it comes to power delivery to your fleet over time, minimizing demand costs while providing sufficient energy to your fleet. But, again, ‘how’ charging sessions and power delivery through individual connectors are coordinated and executed will vary from solution to solution. For more information on smart charging methods, see Section 4.5.2.

The best application of an advanced CMS will come through close integration with a DMS. This integration will allow for a centralized location where a user can 'see' vehicle and infrastructure status and monitor charging operations at a high level. In addition, the DMS will inform the CMS and vice versa, as they make decisions with input from one another. For example, this is where the CMS can gain information about the work assignments of the vehicles currently in a depot and make charging prioritization decisions accordingly.

Another key integration of the advanced CMS will be with an EMS. This integration will allow the CMS to make informed decisions regarding the priority and sequence of charging activities while considering facility power limitations and electricity costs.

Along with other open communication standards, it will be important that a CMS utilizes OCPP 1.6+ to communicate with charging stations. This feature will ensure reliable communication across multiple charger OEMs and allow the CMS to control each charge point individually. Compliance with OCPP standards on the charger OEM side will be essential to understand as well, and to date has been noted to be lacking in some instances. Therefore, written requirements that specify OCPP compliance when purchasing charging infrastructure will be critical to successful integration in the future.

Some additional functionalities of a CMS may include:

- Start & Stop charging sessions remotely;
- Start & Stop charging sessions Automatically;
- Monitor charger status;
- Monitor charging sessions;
- Adjust charger power levels in real-time;
- Control charging stations at the connector level;
- Prioritize charging sessions;
- Account for service schedules & work assignments;
- Spatial awareness of chargers;
- Estimate charging session duration;
- Track utility rates;
- Optimize electricity cost (manage peak demands, etc.);
- Remote resets & emergency stops;
- Communicate with DMS & EMS via open standards;
- Communicate and control charge points via OCPP 1.6+.

6.2.12 Energy Management Systems (EMS)

An EMS will function to harness power information at the facility level, receiving input from grid connections, alternative power sources, networked power meters, and building automation systems (BAS). In addition, an EMS can inform a CMS of the power available to be dedicated to charging activities and optimize energy usage from many sources. Using an EMS can also detect poor equipment performance, support decision making, provide performance reporting and historical audits, and support energy budgeting and management accounting. As projects involving microgrids, energy storage systems, solar & other alternative energy become more viable and cost-effective as solutions, their consideration in systems such as EMS should not be forgotten.

Some of the EMS functionalities that can be considered include

- Monitor facility power demand;
- Monitor charger power demand;
- Monitor grid connection;
- Monitor alternative power sources;
- Projection of short-term charger & facility power demands (based on historical data and upcoming transit schedules);
- Allocating and managing power distribution throughout the facility;
- Prevent overload conditions and limit the number of simultaneous charging sessions;
- Communicate with the grid, CMS, BAS, and networked power meters via open standards.

7 Management of Change (MOC)

The introduction of BEBs into your transit fleet will likely represent the most significant change your organization has encountered in recent memory. Along with introducing new technology itself, various areas within your organization will be affected by this transition. Whether it be modifications or additions of new equipment, procedures, designs, or organizational structure, some considerations need to be made across various areas. Therefore, early planning and management of the changes associated with a transition to BEB technology will be key to the success of an electrification program.

A large portion of the conversations surrounding BEBs has been focused on buses and chargers, with little bandwidth being given to the effect that a large-scale technology shift will have on an organization itself. A telling quote from one of our leading practice focus groups was, "**organizational changes can take longer to implement than designing & building a facility**." Understanding the changes that will occur and developing associated MOC plans early on in a transition program will benefit your organization in the long run and make the introduction of BEBs easier and quicker.

This section will provide a general Management of Change (MOC) introduction and framework for those unfamiliar with these processes and highlights several BEB-specific MOC considerations. We wish to prompt the reader to begin thinking about a strategy that will allow their organization to manage many changes over time effectively.

7.1 MOC Introduction & Framework

Management of Change (MOC) is just that - managing change. It is used to prevent mistakes due to design, organizational, or operational changes. If change is not managed correctly, it can increase unwanted incidents and risks associated with practices that may be considered routine.

Management needs to look at changes (of all kinds) in terms of risk and the consequences of a change. Does the change introduce a new or different risk? Does the change affect the effectiveness of safeguards and control measures? Will the change alter engineering controls or require changes to existing engineering controls? Will the change alter administrative controls or require changes to existing administrative controls? Will changes to administrative controls be effectively and efficiently implemented through new or revised work practices? Are new work practices required and, therefore, new training materials and new or refresher training?

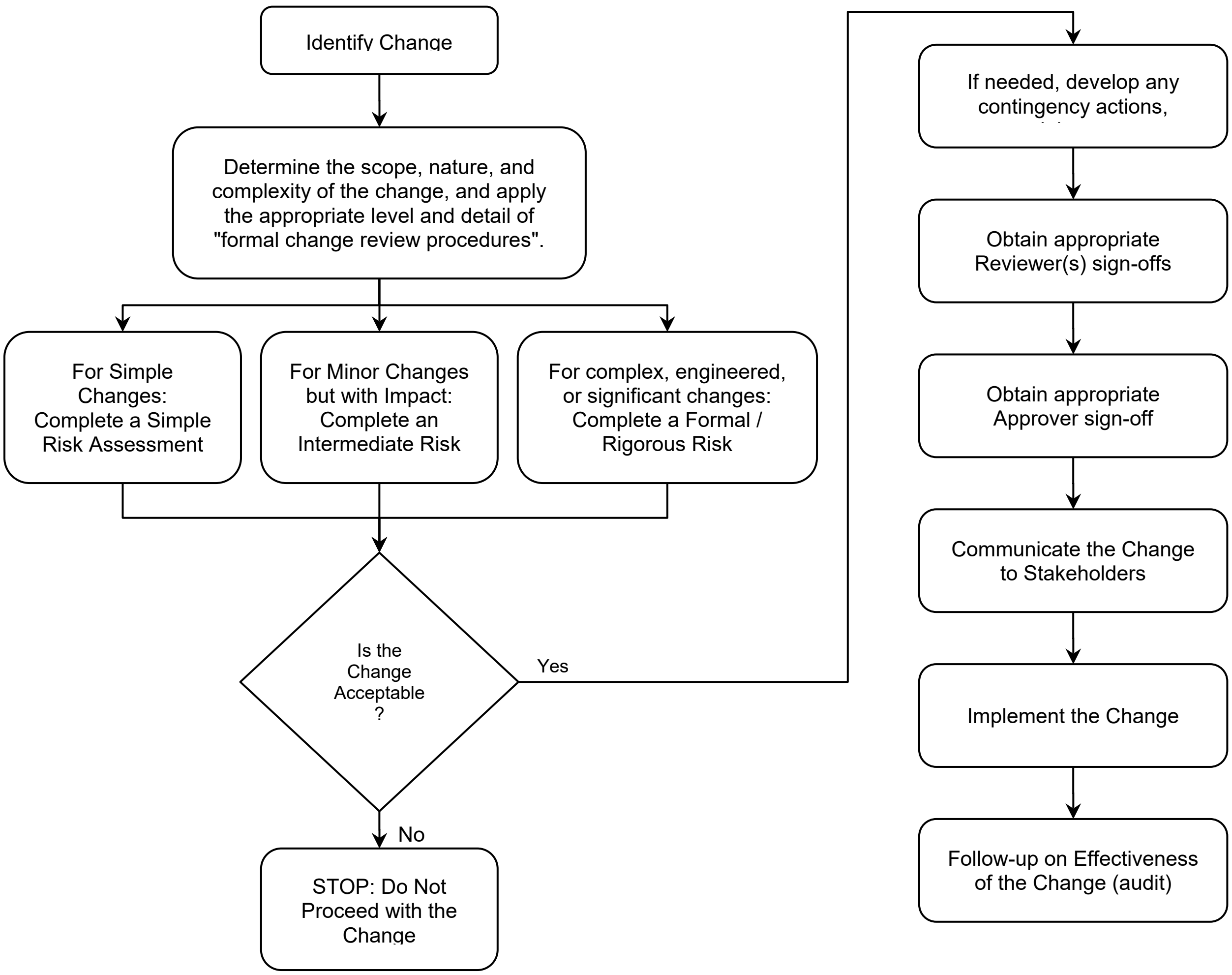
Almost anything not directly replaced ("like-for-like") is considered a change and should be subject to review and approval before the change is implemented. Changes to raw materials, equipment, procedures, suppliers, customers, contractors, designs, and organizational changes (such as a person moving into a role to replace another or job role changes) need to be managed.

Standard operating procedures (SOPs) are typically used to guide the way employees do work. Associated procedures are developed to ensure tasks will not be negatively affected; these are based on operational experience and lessons from previous incidents. Without a process to analyze changes to these procedures, there is a significant danger of creating a higher risk. Any variance to an existing procedure needs to be reviewed for consequence and risk. Change management is accomplished through policy, work process, and procedures with guidelines to assess the proposed changes to the activities.

The Management of Change Work Process flowchart (Figure 13) describes typical industry best practices for managing change. The work process starts with a change that triggers the start of the process. Associated change management guidelines may include general categories to define the type of change under consideration (e.g., process, design, organization, etc.) and make provisions for individual workplaces that identify hazards specific to that area. Clarity is critical to ensure that employees are clear on what is needed and do not skip some areas of concern. This first step, proposing a change, is usually initiated by the person who wants the change or who has been directed to initiate the change; this is the Change Owner.

As the steps in the MOC work process progress, they can become very complex: sufficiently complex to require a detailed and documented procedure to guide the Change Owner and formalized training for employees using the MOC process. Given that the MOC process requires significant effort, the involvement of associated personnel in periodic reviews or developing the MOC process for their departments builds commitment to the process.

Figure 13. Management of Change (MOC) Work Process flowchart



7.1.1 Four Critical Actions for MOC

Although there are many steps in the MOC work process, as shown above in Figure 13, there are four critical actions in the MOC work process that the Change Owner must do:

1. <u>Communicate the proposed changes</u> to all stakeholders before the change is finalized and before the change is implemented. Specific actions may need to be completed to do this on a case-by-case basis effectively. The objectives are to communicate and connect with those who can provide constructive input that may lead to an improvement in the proposed change. This step is critical in the MOC process as it allows engagement from areas which may not (at first) appear to be affected by the change or may have input to the change itself. Communication prevents changes from occurring in a siloed way.

2. Conduct appropriate reviews and risk assessments. Review the change with subject-matter experts and key stakeholders. The objectives are to gain constructive feedback/input from them, modify the proposed change based on feedback, check to confirm understanding and finalize the change. The channels for communication and approval also provide the opportunity to gather additional input as part of the review process.
3. Seek final approval. It is essential to secure appropriate approvals for the proposed change before it is implemented. After the Change Owner has finalized the change, the Change Owner must have it approved by the Final Approver (i.e., the manager responsible and accountable for the area in which the change is being proposed).
4. Communicate and implement the change. Implementing the change in the manner documented in the approved change is essential. If changes are needed, this re-sets the work process to the beginning. This work process should include communicating the change to all stakeholders, training if needed, updating user procedures and any means of access to those procedures, and finally, any commissioning and start-up of the equipment as may be needed. There may be many steps that are part of the complete change, and these may need to be implemented or executed logically (i.e., operators need to be trained on new equipment before starting up the new equipment).

7.2 MOC for BEB Deployments

This section will explore impacts that should be considered as you approach, plan, or continue with a BEB deployment from a MOC perspective, focusing mainly on the operations domain's standard operating procedures (SOPs). This section includes changes to systems that may be affected by BEB deployments and changes to the roles of the staff members working with new processes and systems. Operations are specifically represented in this section as roles in these categories tend to be more SOP-based than scheduling, planning, and training. Although not discussed here, operational changes will have to be managed along with those in many other areas, such as the maintenance of vehicles and charging infrastructure.

These lists are not exhaustive but will highlight changes anticipated to be needed regardless of organization size and BEB deployment timeline. The well-managed change will allow an organization to "flatten the curve" related to change over time (pardon the analogy). Many changes will be spread out over a long period rather than having a large number of changes occurring in a short period. Identifying and understanding the required changes in advance will allow your organization to plan, phase, and execute these changes effectively.

7.2.1 Fleet and organization size

Some changes and considerations will have to be made with a BEB fleet of any size, essentially from day one of any deployment. However, the order, rate, and complexity of the organizational changes that need to be executed may be a function of BEB fleets' size within each facility. Over time, the relative portion of a facility's fleet that is electrified will determine how and when changes need to happen. For example, a facility with 25 BEBs out of 100 total buses will have different change requirements than a facility with 75 BEBs out of 100 total buses. There will also be different organizational change requirements when a facility has 75 BEBs out of 100 total buses versus when three facilities each have 25 BEBs out of 100 total buses (75 total BEBs in each case).

This level of granularity may be important in defining needs at different facilities and can help assess variations in processes or systems that will be required across an organization. In addition, this granularity can help organizations better manage change by focusing efforts where changes are operationally required and more gradually implementing them in areas where it is less critical.

The ability of an organization to execute a baseline level of change will depend on the internal resources that the organization can commit to a BEB program. Even small deployments will likely require a team with a diverse background in transit operations, engineering, project management, and change management. Standing up a team with these skills may be challenging for smaller and more rural organizations - who are at risk of being left behind. For this reason, lessons learned will be especially important to be passed along and why transit must continue to share their challenges and wins with each other openly. External support is also available, and there are cases where external Program Management Offices (PMOs) have been set up to fulfil BEB programs using subject matter experts. Small and mid-size organizations may benefit from this approach to electrification.

7.2.2 Charging Systems Operator (CSO)

Along with organization process changes accompanying BEB deployments, added operational demands might require the definitions of new staffing roles. For example, a role may be required to manage responsibilities centred around charging operations, referred to here as the Charging Systems Operator (CSO). The CSO will have specialized knowledge of BEBs, charging infrastructure, organizational processes, and software systems that work together to make up charging operations. This position will largely be operationally focused and will not likely be responsible for carrying out general maintenance tasks related to any systems. The CSO will interface between the complex real-time decisions being made by the systems they utilize and the physical realization of those decisions within a depot/yard.

The CSO will be responsible for charging operation tasks such as:

- Engaging with DMS & CMS software to monitor BEBS & charging infrastructure.
- Managing BEB (and overall fleet) work assignments.
- Managing BEB (and overall fleet) utilization.
- Monitoring BEB & charger connection statuses.
- Monitoring active & pending charging activities.
- Verifying pre-trip energy of vehicles.
- Troubleshooting, resolving, and escalating issues specific to BEBs.
- Troubleshooting, resolving, and escalating charging infrastructure issues.
- Directing in-depot/yard organization of BEBs.
- Organizing BEB maintenance & servicing tasks.

- Generally ensuring that charging operations are carried out effectively.

In practice, the responsibilities of the CSO may not necessarily fall into one role but perhaps spread out over multiple roles and individuals. The CSO may not be an entirely new position but the evolution or modification of an existing role(s). The specifics will be determined by each TA's internal structure and existing roles and the ability to create new roles within collective agreements and relevant policies. The new skill sets and knowledge base differentiate this role from typically existing positions. These changes will be fundamental as TAs adopt new operating paradigms and zero-emission technology itself.

None of the TAs with current BEB deployments have had to dedicate a role to carrying out the full responsibilities of the CSO. This lack of change is due to the small number of BEBs (compared to the overall fleet) deployed by each TA. It has been found that CSO-related responsibilities (i.e., SOC verification, connecting vehicles to chargers, high-level BEB or charger troubleshooting) have generally fallen onto senior servicing staff, servicing supervisors, or dispatchers. These are the roles most likely to take on these additional or modified responsibilities across most TAs. As deployments grow and charging operations become more complex, the CSO's responsibilities will become more critical to a TA’s ability to maintain service levels and fleet availability.

7.2.3 Engineering Groups

Fleet electrification merges two industries (transportation & electrical) that historically have not been very interconnected – this will come with nuances that likely require internal engineering intervention and prowess. The continuous inclusion of engineering groups in decision-making for SPOT-related areas of BEB deployments may not be trivial. The more obvious involvement of these groups comes with pre-project implementation planning and in the domain of electrical, structural, civil, and mechanical engineering (i.e., facility design, assessment, maintenance).

The continuous involvement of engineering groups in SPOT-related decisions will vary but will likely come with significant operational upside. It may require an advanced understanding of electrical systems, operational processes and system interconnections for the effect of an operational change to be gauged before they are made. Having staff who can understand the downstream effects and requirements of changes will ensure that the changes do not have adverse operational effects. On the other hand, regular engineering analysis of electrical systems, operational processes, and system interconnections could find optimizations with considerable cost benefits.

7.2.4 Operation SOPs

Table 5 provides an entry list of operation SOPs to consider for change when deploying BEBs. This list is not meant to be exhaustive but to represent the depth to which technology changes can affect the roles and responsibilities of staff members.

Table 5. List of Operational SOPs to be considered when deploying BEBs – New or Modified

Operational SOPs	
Actor	**Procedures**
Servicing Staff Servicing Supervisors	Reporting for Duty Required equipment/supplies Operating the Battery Electric Bus Work Assignment Processes Parking Assignment Processes Garage Organization Processes Track Resorting Track Collapse Connecting buses to chargers (plug-in or pantograph) Connection errors (plug-in or pantograph) Bus Realignment (plug-in or pantograph) Emergency procedures Manually Charger Operation BEB Charge Verification Book-Out Processes Pre-Trip Inspection Book-In Process Bus Cleaning Steam Cleaning Interior Cleaning Bus Inspection Floor Wash (electrical elements, considerations) Outer bus cleaning Bus wash procedures Power Washing Fuel on Arrival Fluid Filling locations Changeover Procedures Towing Battery Boost Lock Out/Tag Out Fleet Utilization Practices Fleet Work Assignment Practices Garage Organization Practices Manual Software Overrides New Login Software Procedures New Software Operating Procedures Manual Software Overrides

Charging System Operator (CSO)	BEB Localization Connecting buses to chargers (plug-in or pantograph) Connection errors (plug-in or pantograph) Bus Realignment (plug-in or pantograph) Remote Charger Resetting Physical Charger Reset Charger Emergency Stop Charger Fault troubleshooting Charger Fault Reporting Charger Fault Resolutions Charger Fault Escalation BEB Fault Reporting BEB Fault Resolutions BEB Fault Escalation Manually Charger Operation BEB Charge Verification Pre-Trip Inspection Out-of-Garage BEB monitoring BEB Towing New Login Software Procedures New Software Operating Procedures Fleet Utilization Practices Fleet Work Assignment Practices Garage Organization Practices Manual Software Overrides
Operators Operator Supervisors	Reporting for Duty Required equipment/supplies Operating the BEB Pre-Trip inspection BEB Charge Verification Lock Out/Tag Out Out of Service Tag Fueling Vehicles Operating in the yard Work Assignment Processes Parking Assignment Processes Garage Organization Processes End of Shift at Transit Garage/Depot Bus Operation Destination Sign Layovers and breaks/unattended vehicle Communication procedures Passenger loading, unloading and seating Passenger Comfort

	Fare Collection Customer comment procedures General Operating Rules On-board Equipment Rules Operating in Inclement Weather Safe and Smooth Vehicle Operating Time Points/On-time performance 4-way Flashers Bus Stops and Shelters Definitions and General Expectations Lift and kneeler operation Emergency procedures Following Distance Accident/Incident Procedures Evacuation of Transit Vehicles In-Service mechanical problems/breakdowns In-Service electrical problems/breakdowns Placing warning devices Public statements Serving passengers with disabilities Mobility aid securement Door to door operation Book In Vehicle Parking Charger Alignment & Re-Alignment Connecting Vehicles to Chargers (Plug-in & Overhead) Book-Out Out-of-garage reporting (low SOC) Bus wash procedures Changeover procedures Towing Procedures Fuel on Arrival Reporting BEB Faults & Issues
Dispatchers Dispatch Supervisors	Reporting for Duty CAD/AVL System communication On-Route Energy Monitoring Low Energy Alerts Return to garage procedures Changeovers Operator Check-In (Pull-Outs) Late Operators Miss-Out Run Leaving Late Sick or Excused Request Excused Operators

	Sick Operators Relief Sick Transportation to Relief Point Management of the Extra List Assignment of Work Bus Traffic Control Radio Usage Out-of-Garage BEB monitoring CAD/AVL Using the CAD/AVL System to Monitor Schedule Adherence Buses Running Ahead of Schedule Buses Running Behind Schedule Field Supervisors Establishing Communications with Bus Operators Voice calls Text messages Schedule cards Processes Operator attendance records Service Failures New or Modified Services/Schedules Route Alignment Changes Bus Assignment Changes (route, run, or division) Changes in Operator assignments Managing Additional Service Requests Emergency Variations from Scheduled Work

8 Focus Group Debrief

The discussions held during the leading practice focus groups were invaluable in creating this report. Each TA provided a unique perspective and insight into their BEB deployments which allowed for a large net to be cast concerning the SPOT-related areas that were the focus of our discussions. From these discussions, it was apparent that some significant commonalities exist in how BEB deployments have been executed thus far and how they will move into the future.

This section will summarize some of these key findings, provide advice from interviewed TAs to those starting or continuing electrification, and highlight some of the biggest challenges that BEB programs have faced. These notes do not focus on the more technical issues that TAs have faced related to the vehicles or chargers themselves, as this is out of scope for this report. However, it is recognized that these technical issues represent some of the more considerable challenges associated with BEB deployments and that there are many channels available to share this information.

8.1 Key Findings

8.1.1 Shift to In-Depot Charging Strategy

The in-depot charging strategy with long-range BEBs is being adopted as the primary means to expand transit electrification projects moving forward. Many early BEB pilot projects focused on on-route/opportunity charging with short-range BEBs, offering a chance to analyze this charging strategy from a technological and operational perspective. Although many valuable lessons have been learned from these projects, this charging strategy alone will not support large-scale electrification in Canada.

Comparing in-depot & on-route charging, centralizing physical changes to a few locations (i.e., only depots) will allow more control over the electrification process and its rate. In addition, a smaller amount of changes (SPOT-related) need to be executed before BEBs can be deployed. These are but a few examples where these charging strategies can be contrasted. Ultimately, in-depot charging offers the fastest route to electrifying (in most cases) the majority of your transit network. The approach to electrifying the remainder of a network will vary, but this is where on-route/opportunity charging will likely have the largest impact and utilization.

8.1.2 Planning & Scheduling Impacts are deferred with In-Depot Charging

Adopting in-depot charging as the primary charging strategy comes with the benefit of deferring significant planning & scheduling changes to the future. A significant portion of networks will be electrifiable with current BEB technology from day one. However, the extent to which an individual network can be electrified will depend on the technology selected and how BEBs are utilized. Deferral of planning & scheduling changes represents a Management of Change (MOC) win, as it functions to lower the changes that need to occur within an organization before BEBs are deployed. Instead, organizations can focus on gaining an understanding and familiarity with the technology within their network.

8.1.3 Blocking processes will likely see changes

<u>In-depot Charging</u>

When scheduling changes occur due to BEB deployments, the most significant changes will likely occur to blocking. Upstream of blocking (i.e., timetable development), changes will be driven by service and network design, driven by factors that do not include the deployment of BEBs. Due to present-day limitations of BEB technology (range), the modification of blocks may be required to increase the portion of a network that can be electrified. This change will have a trickle-down effect on runcutting & rostering outputs and potentially impact operational costs and resourcing needs. These factors, along with policy and collective agreement adherence, will be vital in evaluating the ability of individual TAs to pursue full-fleet electrification through mixed charging strategies or the need for additional technology (i.e., FCEBs) to achieve their zero-emission goals.

On-route/Opportunity Charging

For on-route/opportunity charging deployments, single routes/lines are electrified at a time. These deployments require changes to blocks immediately to accommodate frequent and predictable charging sessions. The removal of interlining is typical, impacting other blocks that once contained the electrified route. These changes remain to the electrified blocks regardless of whether BEBs are utilized on them continually. The blocking changes impact operational costs and resourcing needs associated with electrified routes.

8.1.4 In-Depot Operations Will Evolve

Several factors will play into the need for in-depot operations to evolve with the deployment of BEBs. These include limited range and longer refuelling time than conventional buses, limited power and space within facilities, and budgetary and funding constraints of organizations. Software solutions will likely manage the complexity of these changes. Still, new operational paradigms will have to be implemented using new and updated SOPs, changes to roles, and other organizational changes. Procedures directing how vehicles are moved, organized, fueled, scheduled, inspected, cleaned, and so on will be affected by the deployment of BEBs and will be a central theme of implementation planning for large BEB fleets.

8.1.5 Requirement for Future-Focused IT Solutions

Charging operations for large fleets will involve many complex and ever-changing variables. As a result, there is a need for specialized solutions that consider these variables while optimally managing BEB and charging infrastructure interactions in real-time. DMS & CMS applications will be at the heart of BEB charging operations, which will look different for every BEB deployment. Utilizing new technologies in concert with advanced data collection and machine learning will give TAs an edge in managing their new fleets while keeping front-facing operations similar in complexity as they are today.

New IT solutions include Telematics, Depot Management, Localization, Charge Management, and Energy Management systems. These solutions should accommodate your transitioning fleet and allow your organization to approach zero emissions more efficiently.

8.1.6 The Need for Open Standards

To manage BEB charging operations effectively at scale, TAs will require a suite of systems they do not have today. To avoid vendor lock-in, accelerate procurements, and improve ease of implementation, TAs should specify open communication standards when sourcing these systems. TAs and advocacy groups are positioned to push for adopting foreign standards or pursue the development of analogous North American standards. Additionally, open standards will improve information sharing as they set a baseline for data definitions, ensuring that everyone uses the same data points when completing and comparing analyses.

8.1.7 Change Management is key

"The bus & the charger is the easy part." This message was often repeated during our focus groups and should be considered in all BEB deployments. BEB technology will be new to your organization - significant and broad changes can and should be anticipated. Approaching change with acceptance and developing a solid change management plan will help your organization successfully transition to zero-emission technology. Change can take a long time to prepare for and to execute. Begin assessing and phasing change as soon as possible so that new technology can be utilized to its fullest extent and then expanded effectively. Identify the Change Leaders that can champion change, providing the expertise and leadership needed to accomplish the goals of your electrification program.

8.1.8 The Approach & Technology Matter

Future-state charging operations will depend on the infrastructure, BEB technology, and IT solutions deployed. Each deployment will be unique and function within its own specific set of constraints. Understanding how charging operations will function within your organization will be critical in deploying large BEB fleets.

Planning for charging operations requires more than knowing the charging strategy that will be used. The ratio of BEB to chargers, the physical configuration of charging stations, bus battery capacity, and software solutions used, for example, will all play a role in how operations will need to adapt for BEBs. Understanding how the desired technology can be used effectively and what solutions are available to support operations will improve implementation plans and provide a better idea of 'how' electrification will actually 'work.'

8.1.9 Think Long Term

Planning for full-fleet electrification and working backwards to determine program needs at different times can help map an approach that will suit a deployment over the long term. Use pilots and smaller deployments to gather information needed to make long-term decisions. At the same time, do not delay the adoption of zero-emission technology. Instead, think about scalable solutions, minimize duplication of work efforts, and lean on other TAs to gut-check your plans as you move forward.

8.1.10Stakeholder Engagement

Early engagement from stakeholders and municipal branches is key to a successful BEB deployment. Bring in as many working groups as possible – you will likely be surprised by the wide-reaching impacts of the shift to zero-emission technology. In addition, complete and sustained engagement will allow for changes to be managed effectively across an organization. Finally, broad-reaching stakeholder engagement will help prepare other branches to pursue a low-carbon future if they have not begun their decarbonization process yet.

8.2 Post-Focus Group Notes – BEB Deployment Advice

At the end of each leading practice focus group, TAs were asked to advise other TAs looking to pursue or continue adopting BEB technology. The following are some notes from the answers we received:

- Each project must be treated as unique and must be approached as such. Therefore, a study for each system and even each facility within a system is needed. Studies should include energy and operational modelling, business impact analysis, and implementation planning.
- Think about projects from a full-fleet electrification standpoint first, not just a pilot. What will your needs be in the long-term (organizational, operational, infrastructure, vehicles, other)? Then, using scalable and future-proof designs, how can you work backwards from a full-fleet electrification scenario to today?
- Begin planning now – even if funding or full project approval is far out. Time is always a constraint on projects of this size; the more of a head-start you can get, the better off you will be. Also, engage stakeholders early and keep them engaged throughout the project.
- Study the routes you want to electrify. Think ahead - where do you want to be in 5 years? Ten years? Look at different options for charging infrastructure and think about how different options will impact operations. Retain some diesel buses until BEB technology matures enough to become the standard. Take advantage of grants and do a pilot if needed but get started ASAP.
- Talk to utility providers as early as possible. They will have valuable advice regarding what will be possible in the short and long term from a power availability perspective. Explore options for power redundancy as a risk mitigation strategy.
- Don't be afraid of failure - lots of lessons to be learned. First, assess whether problems are deal-breakers or not. Expect significant organizational changes to roles, infrastructure, processes, etc.
- Understand and plan for the worst-case performance of your BEB technology. Think about what implications these worst-case scenarios have on the overall electrification strategy. Inform decision-makers and blend municipal and provincial zero-emission plans with BEB implementation plans. Lifecycle management will be critical in a cost-effective transition to zero-emission technology.
- Change management of diesel/hybrid processes vs BEB processes. If you continue with your current operational processes, you will be "Trying to put a square in a circle" regarding how BEBs will operate. The technology is different, and you will have to change how you operate your depot and buses.
- Feed realistic bus lifecycle management insight into municipal-level climate action plans. Assess GHG reduction expectations and look at lifecycle management to ensure that additional costs are not incurred due to fast-track BEB implementation plans.
- Engage as many different groups and stakeholders as possible during BEB deployment planning. Preventing siloed communication will allow correct information to be spread and concerns from varying perspectives to be heard.

8.3 Post-Focus Group Notes – Biggest BEB Challenges

At the end of each leading practice focus group, TAs were asked to speak about some of the biggest challenges they have faced concerning their BEB deployments. The following are some notes from the answers we received:

- Fixing and troubleshooting issues with BEBs and chargers, especially cross-communication between various BEB and charger OEMs. Having many vendors involved can lead to trouble pinpointing where problems are from (on the technology side).
- Micro-fleeting, even with a small fleet. BEBs with different battery capacities can do different things. Having a standardized fleet would be ideal. However, managing year-to-year differences in vehicles will be difficult.
- There is a lack of transit planning, scheduling, and operations advice and guidance. This has and will continue to slow down deployments.
- Solutions do not work "out-of-the-box"; much work needs to be done to get chargers and bused communicating effectively.
- Each charger OEM appears to have slightly different interpretations of open protocols (i.e., OCPP). Although OCPP is supposed to be standardized in theory, some nuances affect how chargers function in practice.
- Technology is constantly changing and improving at a fast rate. Long-term planning must consider what is on the market today for the most part. Plans will be fluid and account for technology changes as they occur.
- Due to tight funding availability windows, short project timelines have forced programs to develop quickly. As a result, the race against time has been one of the biggest challenges.
- Construction & retrofit while operating facilities is a difficult thing to manage. Partial facility closures are needed for construction, installation, testing, and equipment commissioning. In addition, there are challenges in maintaining operations and storing vehicles while retrofits are occurring.
- Bus availability and reliability are generally lower than expected.
- As advertised by vehicle OEMs, the bus range is not a good measuring stick for range variations seen in service. Therefore, managing large seasonal differences in range and vehicle utilization is key to effectively deploying BEBs.
- Maintenance training and familiarization. Everything is initially slowed down with high voltage systems. Rightfully, there must be checks to ensure proper procedures are implemented to handle issues, even if it slows down issue resolution.
- Technology is so rapidly evolving. Battery degradation curves, amongst many other factors, are unknown. These unknowns make planning long-term difficult and require malleability in electrification approaches. Furthermore, there is a risk of procuring vehicles and chargers too early due to the pace of advancement.
- There is a tipping point where power redundancy is critical, even for small BEB deployments. Finding solutions to provide enough system redundancy can be a complicated and lengthy process

depending on your utility provider. Having low power redundancy can ultimately limit the number of BEBs that may viably function within your network, depending on the risk appetite.

Appendix A – Key Takeaway & Next Steps Summary

Planning			
Impact Area	**Takeaways/ Next Steps**	**Description**	**BEB Fleet Size**
Network Design	Takeaways	Technology must suit a network; the network will not change to suit a technology. BEB deployments have resulted in no impacts on network designs to this point in time. The priority is to maintain exceptional service levels for transit users.	All
	Next Steps	Changes in transit network designs will be driven by new and emerging transit modalities and philosophies rather than zero-emission bus deployments. Monitor these new trends for zero-emission applications and new opportunities to increase the electrification of your network.	All
Service Planning	Takeaways	BEB deployments have resulted in no impacts on service planning or design to this point in time. The priority is to maintain exceptional service levels for transit users. Physical BEB characteristics typically do not prevent them from being utilized within a network.	All
	Next Steps	Utilize software to analyze and optimize route designs without impacting service levels and human resource needs. Study the effect that BEB deployments have on transit ridership and continue to offer low-carbon transportation alternatives.	All
Planning for BEB Deployments	Takeaways – In-Depot Charging	Initial BEB deployments have minimal impact on transit planners when using an in-depot charging strategy. Transit Planners can have input on pre-deployment block selection and determine what locations are best served by your specific BEBs. Complexity will arise as the BEB fleets get bigger and the number of blocks that work with current BEB ranges gets smaller.	All
	Takeaways – On-Route Charging	Transit Planners play an integral role in assessing potential on-route charging sites considering several essential factors, including ridership, public visibility, route selection, land ownership, and policy requirements.	All
	Next Steps	In-depot charging will likely allow for significant short-term electrification; on-route charging may be essential in full fleet electrification in the future. Utilize transit planning insights to help you plan to deploy multiple charging strategies to achieve a zero-emission network. The charging strategy may impact the fleet size and spare ratio – this will have to be considered as planners manage fleet sizes.	All

Scheduling

Impact Area	Takeaways/ Next Steps	Description	BEB Fleet Size
Timetabling	Takeaways- In-depot Charging	In-depot charging strategy has not impacted timetabling processes to date. Low impacts are seen because BEBs can be utilized on many blocks, just like conventional buses.	All
	Next Steps – In-Depot	Monitor upstream scheduling or planning processes for changes to accommodate in-depot-charged BEBs and adjust timetabling accordingly to make routes & schedules more efficient.	All
	Takeaways – On-Route Charging	The on-route/opportunity charging requires changes to timetabling, except in rare cases where built-in layovers are already long enough. Timetable changes only impact the electrified route(s) but lead to an increase in operator hours needed to provide the same service level.	All
	Next Steps – On-Route	Analyze service schedules for routes that can be electrified with the current charging infrastructure. Next, assess the impact of modifying service schedules to enable the electrification of more routes using current infrastructure. Finally, plan additional charging infrastructure to allow for further electrification of your system.	Medium, Large
Blocking	Takeaways – in-depot	Defer impacts on blocking processes to a later point in time. Your system will likely have enough runs where BEBs can be deployed from day one. Start small, gather data, and expand BEB-eligible blocks as you become more comfortable with your technology. Small TAs may find that they may have to make scheduling changes sooner than larger systems as they look to expand the electrification of their system. SOPs will have to be adjusted to accommodate changes for BEBs.	Medium, Large
	Next Steps – In-Depot Charging	Collect real-world data and understand how the BEB range varies according to different factors. Then, using collected data or worst-case scenarios, compare the business case for re-blocking your runs versus utilizing different charging strategies and technologies to electrify your system further.	All
	Takeaways - On-Route Charging	On-route/opportunity charging has required re-blocking of the routes that utilize BEBs. Removing interlining simplifies scheduling and allows BEBs to remain on a single route for the duration of a run. Blocking changes are also depending on timetabling adjustments that are made.	All
	Next Steps – On-Route Charging	Assess the on-route/opportunity charging strategy as a secondary charging strategy that may not require re-blocking to the same extent as in-depot charging. Compare the business case for blocking modifications versus adding on-route charging infrastructure.	Medium, Large
Runcutting	Takeaways	Runcutting has not been impacted by either in-depot or on-route/opportunity charging strategies. Block makeups remain similar to before any BEB-specific modifications were made.	All

	Next Steps	Assess how modified timetabling and blocking processes will result in changes to shift composition and the associated impacts of shifts offered to your workforce. Monitor for a potential increase in operational costs and assess the feasibility of a mixed charging strategy.	Medium, Large
Rostering	Takeaways	Rostering processes have not been impacted by either in-depot or on-route/opportunity charging strategies. During initial deployments, there may be a small group of operators who can/are allowed to drive the BEBs, but this group grows substantially as training programs advance.	All
	Next Steps	Assess how re-blocking will change the work assignments that can ultimately be offered to operators. Monitor for a potential increase in operational costs and assess the feasibility of a mixed charging strategy.	All

Operations

Impact Area	Takeaways/ Next Steps	Description	BEB Fleet Size
Work Assignments	Takeaways – in-depot	Work Assignments are vetted by planning & scheduling teams up-front. Work is typically assigned to BEBs on a repeating daily basis to start. Once some comfort is achieved, a less structured work assignment process is implemented.	Small
	Takeaways - On-Route Charging	Work assignments are pulled from a small pool of blocks, leading to similar daily utilization of on-route charged BEBs. Data-Collection on a broad set of routes is lacking.	Small
	Next Steps	Modify work assignment processes and consider a BEB's ability to complete work and charge in real-time. Use concepts like the Charging Target to optimize charging operations. Utilize software systems to manage complex decisions like scheduling charging and managing charger assignments.	Medium, Large
Garage Organization	Takeaways	Charging tracks/lanes have been assigned in depots that house BEBs. Priority access to these tracks is given to BEBs. Due to small fleet sizes, the movement and positioning of BEBs within a depot are manually directed and not mission-critical procedures at this time.	Small
	Next Steps	Implement Depot Management Systems to manage increasingly complex charging operations. Adjust staff SOPs and garage organization work processes to accommodate and work with direction from software systems.	Medium, Large
Vehicle Parking / Charger	Takeaways – in-depot	Charger alignment is an essential component of charging operations. However, charger misalignment can add labour costs and reduce staff availability to complete other tasks.	All

Alignment	Takeaways - On-Route Charging	On-route charger alignment is completed frequently and with ease by operators. Missed charging sessions are usually caused by software or communication issues.	All
	Next Steps	Use DMS, CMS, and localization systems to verify BEB-charger connection, catch charger misalignments early, and improve the efficiency of in-garage processes.	Medium, Large
Connecting Vehicles to Chargers	Takeaways	Operator, maintenance, or servicing staff connect BEBs to chargers depending on return-to-garage processes. Bus Operators are generally not responsible for confirming successful bus-charger communication.	All
	Next Steps	Take steps to make parking the BEB and connecting it to a charger happen in tandem with the same staff member. Utilize software to monitor expected bus-charger connections and to confirm issues in real-time.	All
Charging buses In-Depot	Takeaways	Charging activities typically occur uncommunicatively using a single connector, sequential, or parallel charging method. Power delivery through connectors is generally undirected, unrestricted, and often derated by facility power limitations.	Small
	Next Steps	Charging operations for larger BEB fleets will require a centralized CMS that deploys a smart charging method. Various smart charging methods should be assessed to ensure an optimal solution is deployed for a particular facility. Assess how smart charging methods will function in concert with DMS and how they can affect charging operation processes.	Medium, Large
Pre-Trip Energy Verification	Takeaways	Servicing, maintenance, or dispatching staff monitor charging activities and verify that vehicles are fully charged before booking out. Operators must report lower than expected SoC values when completing a pre-trip inspection. When the TA utilizes BEBs on short runs, they don't require that the BEB is fully charged before booking out, but a minimum SoC is required regardless of block distance.	All
	Next Steps	Pre-trip verification will likely be shifted from away operators completely. DMS/CMS systems will provide feedback to servicing, maintenance, or dispatch staff ahead of time if a BEB cannot be charged in time for its book out. SoC indicators may be removed from BEB dashboards.	Medium, Large
Out of Garage Monitoring	Takeaways	On-route SOC is monitored by bus operators. Low SOC is reported to dispatch (between 15-30% depending on the TA, the block the BEB is running, and weather conditions), who decides whether the vehicle will remain in service. Pre-trip SoC verification is a reasonable risk mitigation strategy to prevent low-SoC changeovers.	All
	Next Steps	Assess CAD/AVL systems that provide feedback about a fleet's on-route energy consumption and act as an early-warning system for low-SOC scenarios. Small deployments may be successful without these systems as long as operators remain aware of BEB limits	Medium, Large

Training

Impact Area	Takeaways/ Next Steps	Description	BEB Fleet Size
Scheduling & Planning Training	Takeaways	Changes to scheduling & planning roles have been contained to date; no additional formal training has been required.	All
	Next Steps	Utilizing new software and understanding the nuances of BEB technology, operations, and associated processes/procedures will be critical areas of interest in future planning & scheduling training areas. Planners and Schedulers will be central to cost-effective, highly efficient, and sustainable transit systems of the future, and their roles will grow accordingly.	All
Operator Training	Takeaways	A “Train-the-trainer” approach is typically taken to initially help TAs development BEB training programs. Training programs are then delivered to operators using Limited Block-Based Training, Expanded Block-Based Training or a Broad Training strategy. The impact of driver behaviours (i.e., regenerative braking, HVAC usage) must be communicated during the training of BEB operators to minimize risk. In addition, BEB technology allows for data collection at the level of individual drivers – this can be used to optimize operations and provide additional cost-saving opportunities.	All
	Next Steps	Operator training programs must evolve and adapt to a rapidly changing technology field and equipment manufactured by multiple vendors. For example, year-over-year differences in vehicle models, the introduction of new vehicle makes, and changes to charging equipment will need to be accounted for in future programs. This is in addition to any additional learnings and insights which can be extracted from today's data collection programs.	All
Servicing Training	Takeaways	Servicing staff typically receive training that builds on operator training programs. Additional training areas include servicing-specific tasks and, at times, HV safety training. BEB operational tasks such as charging session monitoring and energy verifications typically lie with senior servicing staff or servicing supervisors.	All
	Next Steps	Depending on how BEB tasks and responsibilities are distributed in the future, the servicing staff role could see significant changes. The development of a role akin to the described “Charging System Operator” may warrant the creation of training programs for a new or augmented role within your organization.	All