American Public Transportation Association

Battery Electric Bus Charging Infrastructure: Key Performance Indicators

OCTOBER 2023

This document was prepared by a group of volunteers who are members of APTA's Zero Emission Fleet (ZEF) Committee. It is based on the experiences of the volunteers and the organizations they represent and is intended to serve as a resource for the committee and other APTA members.

Committee Chair: Carly Macias, King County Metro, Manager Zero Emission Strategy

Committee Vice-Chair: Aaron Vogel, IndyGo, Chief Operating Officer

Committee Secretary: Carrie Desmond, Metro Transit, Manager Electric Bus Infrastructure

Working Group Members:

- Erik Bigelow, Center for Transportation and the Environment, Director of Midwest Operations
- Cecil Blandon, AC Transit, Director of Maintenance
- Carrie Desmond, Metro Transit, Manager Electric Bus Infrastructure
- David Haas, Metro Transit, Program Manager Bus Technologies, Bus Maintenance
- Ben Tomhave, AECOM, Transit Planner
- Aaron Vogel, IndyGo, Chief Operating Officer
- Kyle Whatley, San Diego MTS, ZEV & Sustainability Manager

Introduction

The public transit industry has extensive experience developing and publishing key performance indicators (KPIs) to communicate a wide variety of performance characteristics of the services provided. The industry has historical experience producing KPIs for vehicles. As the public transit industry transitions to zero emission fleets (ZEFs), KPIs need to be developed for the supporting infrastructure for operators to report on performance of the entire ZEF system.

This document, developed by a working group of members of APTA's ZEF Committee, focuses on KPIs that can be used for battery electric bus (BEB) charging infrastructure. It is designed to act as a menu that agencies can use to consider which metrics may best meet the unique needs of their program.

This menu documents approaches and considerations from agencies leading the charge around the nation with a goal of suggesting ways the public transit industry can standardize approaches for charging infrastructure KPIs to help communicate progress and be able to compare experiences where possible. The recommendations here are not the only ways an agency may choose to measure performance of charging infrastructure. Ultimately, each agency will need to determine what is best and most applicable to their unique circumstances.

KPIs can be used for a variety of business purposes. It is important to consider who will use the information when developing the final visualizations and/or reporting outputs for a given metric. Some examples of potential audiences include:

- **Project Manager or Operations Manager** – This is an internal audience focused on the day-to-day management and implementation of projects and operations. This audience is often looking for more granular data to enable them to drill down to understand and identify trends, the root cause of issues, and potential remedying actions.
- **Senior Leadership and Board Members** – This is an internal audience concerned with using KPIs to inform business decisions. This audience is often looking for summary level information highlighting key business impacts.
- **External Constituents** – This is an external audience which may include customers, community members, advocates, policy makers, manufacturers, regulators, and others. External constituents often want to understand progress towards commitments or goals an agency has set. Summary level metrics are often most appropriate for communicating with this audience.

How to Use the Menu of Key Performance Indicators

The KPI menu is sorted by areas of interest to improve the understanding of charging infrastructure functionality and performance. To define and highlight the type of information each KPI communicates, each KPI begins with a description of the topic followed by five supporting components including: the purpose, equipment applicability, methods, data sources, and additional considerations associated with the metric. An overview of the five components is summarized below.

1. PURPOSE

The KPI's purpose is a statement to describe why this metric is relevant and how it can impact the business of operating transit service.

2. EQUIPMENT APPLICABILITY

There are many types of charging equipment. Different types of metrics may need to be adapted based on the unique characteristics of each installation. Examples of charging equipment include:

FIGURE 1—*Conductive charger with ground mount plug-in dispenser* (courtesy Metro Transit)

FIGURE 2—*Conductive charger with pantograph, King County Metro facility* (courtesy Lisa Jerram)

FIGURE 3—*Conductive charger with overhead reel plug-in dispenser* (courtesy Foothill Transit)

FIGURE 4—*Wireless inductive charging* (courtesy IndyGo)

3. METHOD(S)

The method(s) section describes different approaches to analyzing, calculating, and communicating performance in a given area. In some instances, several examples of different methodologies an agency could choose from are presented. It is important to consider anything unique to the local jurisdiction or specific ZEF program when selecting a method to use.

4. DATA SOURCE(S)

It is essential to understand where the data will come from to allow for implementation of a given metric. This is a new area of data for agencies and each department has unique needs to execute their business functions. Collaborating across departments and having an identified person or department who is responsible for bringing the information together is important for understanding the bigger picture. Key questions to consider when identifying data streams include:

- What data sources are available now, or may be possible in the future?
- Is the data readily available?
- Can the data set be developed through an automated process?
- Is significant manual manipulation or tracking required?
- Are there any requirements that should be included in future procurements to facilitate access to the necessary data?
- Is the data stream reliable?
- How is data quality ensured?

5. ADDITIONAL CONSIDERATIONS

This section highlights potential questions to consider when developing the KPI as well as areas for further refinement and future development.

Menu of Key Performance Indicators

The following KPI menu suggests potential ways the public transit industry can standardize approaches for charging infrastructure KPIs to help communicate progress and be able to compare experiences where possible. Three primary areas of performance are identified: (1) infrastructure availability, (2) energy and efficiency, and (3) demand charges and cost drivers. The document then identifies potential secondary areas of performance to consider for additional depth when monitoring and reporting charging infrastructure performance. As each agency faces a unique set of circumstances, the following recommendations are not exhaustive, but rather are intended to outline examples of KPI definitions used by agencies leading the charge around the nation.

PRIMARY AREAS OF PERFORMANCE

Indicators in this section are the recommended topics to start any charging infrastructure KPI program as they are critical to the operation and performance of the ZEF system.

1. Infrastructure Availability (Uptime)

Infrastructure availability (uptime) metrics quantify the amount of time chargers are available to charge a bus for revenue service. A charger must perform based on the specified technical requirements of the equipment to be considered available.

1. PURPOSE

The availability of charging equipment to charge electric buses directly impacts an agency's ability to make pull-out and provide reliable service to customers. Historically, diesel fueling station availability has not been a concern for agencies. However, early charger models have had reduced availability, prompting the need to track charger availability to ensure that buses are sufficiently charged to be ready for pull-out.

Depending on data granularity, agencies can use availability (uptime) metrics to identify and track:

- Overall cumulative amount of charger uptime (%) over a specific period of time by individual charging component including, but not limited to, the power cabinet, plug-in station, pantograph, or inductive unit
- Known problems and their impact on individual charging equipment units
- Whether availability issues are due to problems within or outside Original Equipment Manufacturers (OEM) control

In addition to providing high-level trends and insight into potential impacts on service reliability, availability KPIs may also be included in contractual language to assess vendor performance.

2. EQUIPMENT APPLICABILITY

- Availability (uptime) is applicable to both conductive and inductive charging equipment

3. METHOD(S)

Multiple methods for calculating infrastructure availability may be applicable based on an agencies' unique operating environment, charging infrastructure product types, and data availability. Several potential calculation methodologies are outlined below:

$$1.\ \textit{Charger Availability \%} = \frac{\textit{Days Available for Service}}{\textit{Cumulative Days in Performance Reporting Period}}$$

$$2.\ \textit{Charger Availability \%} = \frac{\textit{Days Available for Service + Days Out of Service Outside OEM's Control}}{\textit{Cumulative Days in Performance Reporting Period}}$$

$$3.\ \textit{Availability} = 1 - \frac{\textit{Days down per Issue} \times \textit{Number of Chargers Impacted}}{\textit{Days in Reporting Period} \times \textit{Number of Chargers in Reporting Group}}$$

4. DATA SOURCE(S)

Potential data sources that could be used to develop the availability KPI include:

- Log of charger out-of-service days
- Log of warranty claims while under warranty
- OEM dashboard, charger back-end telematics, and/or charge management system (CMS)
  - Calculation could be automated based on when repair tickets are created after troubleshooting fails to fix an issue and the charger or related equipment is unable to charge a bus for revenue service
- Manual spreadsheet entry or email reporting by front line worker validated by management/leadership

5. ADDITIONAL CONSIDERATIONS

- **Why is charger availability important to the agency?** If it is for operational reasons and quantifying the ability to make service ***Method #1*** may be best, if it is to track contractual performance, ***Method #2*** may be most suitable.
- **Will the availability KPI be used to track contractual performance?** If so, the reason why a charger is unavailable will need to be tracked to identify issues that are outside OEM control such as preventative maintenance or other non-revenue service needs.
- **How does charger configuration impact availability?** For instances where multiple dispensers are connected to a single power cabinet, it is recommended that individual dispensers/connection points are used as the primary availability reporting mechanism. Thus, if a power cabinet is connected to three pantographs and the power cabinet goes down, all three dispensers would be unavailable.
- **Do existing service-level agreements (SLAs) have more specific nuanced requirements around uptime to consider?**

2. Energy and Efficiency

Energy and Efficiency metrics quantify the total amount of energy used to charge electric vehicles and the degree to which energy is lost from the utility meter to the bus.

1. PURPOSE

All charging systems will have some energy loss between what is measured at the utility meter, and what is dispensed to the bus. Some agencies have experienced notable energy losses from the meter to the charging system's dispenser. Understanding the true cost (utility meter) to dispensed energy (from charger) can help agencies understand where the energy purchased from the power utility is ultimately used and how efficient charging systems are throughout the lifecycle of the charging and/or power distribution equipment.

Depending on data granularity, agencies can use Energy and Efficiency metrics to identify and track:

- Irregularities in energy usage
- Whether different project locations or charger types are more or less energy efficient
- Areas to increase energy efficiency

2. EQUIPMENT APPLICABILITY

- Energy and Efficiency metrics are applicable to both conductive and inductive charging equipment. Calculations should be independently performed for each unique charger connection method, electricity type (AC or DC), and charger location.

3. METHOD(S)

To quantify energy usage, it is recommended that agencies use the total throughput and use a comparison of this throughput at different locations along the system to quantify energy efficiency.

1. **Throughput** – Total kWh delivered (a) from the meter, (b) by the charger, and (c) to the bus
2. ***Efficiency*** – Comparison of (a) energy purchased at the meter to (b) energy dispensed at the charger to (c) energy received by the bus to (d) energy consumed by the bus

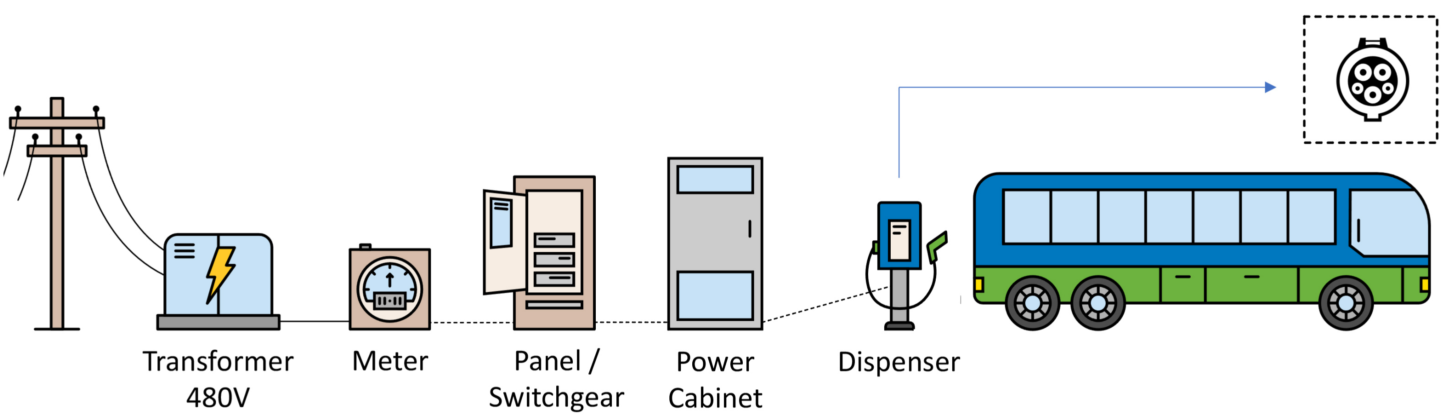

FIGURE 5—*Examples of different locations along the charging system* (courtesy HDR)

4. DATA SOURCE(S)

Data from a variety of different sources including the power utility, chargers, and buses could be used to develop the Energy and Efficiency metrics:

- **Power Utility Data:**
  - Utility invoices
  - kWh usage provided directly to the charger
  - Other potential avenues to obtain utility data depending on the utility's capability include site controllers, Supervisory Control and Data Acquisition (SCADA) systems, Application Programming Interfaces (APIs), and Modbus
- **Charger Data:**
  - Charger telematics or charge management system (energy consumption by charger/port)
  - kWh dispensed per charge event
- **Bus Data:**
  - kWh transferred (received) per charge event
  - kWh used while in operation

5. ADDITIONAL CONSIDERATIONS

- Consider the impacts of idle energy use as well as unproductive charging energy where the charge cycle has completed but the vehicle still draws energy
- Climate impacts on vehicle preconditioning for outdoor charging
- Industry-observed trends:
  - Energy efficiency drops at each state of energy transfer
  - Without defined charge event stop measures, on-route efficiency is typically higher than depot (garage) charging
  - Data availability depends on charger type

3. Demand Charges and Cost Drivers

Demand Charges and Cost Driver metrics quantify total energy costs and identify the sources of these costs so that agencies can understand their local utility tariffs. After establishing this understanding, additional KPIs can be identified specific to individual bill components. Examples of what might show up on a bill include standard elements based on energy usage, fixed fees, and demand charges. Subject to local utility tariffs, demand charges can vary by time of use (by season and time of day) with surge and peak pricing, or they can be based on the total potential power demand used when charging buses.

1. PURPOSE

Provides an understanding of what drives the total cost of the power utility bill and overall energy cost per mile. Understanding these cost drivers can be helpful for comparing industry policies as well as identifying ways to optimize charge management to lower demand charges and take advantage of lower time-of-day pricing when applicable. This is a key indicator for agencies to understand the operational cost, specific to charging an electric vehicle. Demand charges can be one of the highest cost components on a utility bill and understanding this demand charge component along with the specifics of your utility rate structure can help agencies manage and potentially reduce charging costs for an electric vehicle.

2. METHOD(S)

1. Energy cost per mile using total cost from utility divided by total miles driven
2. Percent of utility bill by cost category (demand, energy, fees, etc.)

3. DATA SOURCE(S)

Potential data sources that could be used to develop the Demand Charges and Cost Drivers KPIs include:

- Power utility bill
- Liquid fuel expense and quantity for auxiliary heater, if equipped
- Miles driven per vehicle from vehicle telematics or vehicle odometer
- Charge Management System Data
    - Meter data (site controller, API's, SCADA)

4. EQUIPMENT APPLICABILITY

Demand Charges and Cost Driver metrics are applicable to both conductive and inductive charging equipment.

5. ADDITIONAL CONSIDERATIONS

- **Do the BEBs use liquid fuel fired auxiliary heaters?** If so, it is recommended that the expense for this energy be included along with the cost from the power utility when calculating energy costs per mile.
- **Does bus charging infrastructure use a dedicated electric meter?** If the meter has mixed loads including both electricity usage for bus charging and general building loads, additional consideration on how to differentiate these loads such as submeters may be beneficial.
- **How are utility rates structured?** Many rate structures are nuanced and have many different associated costs/fees including structures for demand rates such as subscription fees. Understanding your specific rate design will help identify opportunities to reduce costs,
- **Is bus mileage data consistent across data sources?** Current industry experience indicates that data discrepancies may occur between bus telematics and other fleet information technology systems which can skew cost per mile metrics. As such, data sources should be clearly documented when defining this metric and consistently used.

SECONDARY AREAS OF PERFORMANCE

As you grow your performance reporting for charging infrastructure, topics in this section represent areas where you can add additional depth to your reporting. It is up to each agency to determine which KPIs best meet the needs of their program.

Reliability

Infrastructure Reliability metrics quantify how often charging infrastructure must be temporarily removed from service for unplanned maintenance (mean days between failures) and how quickly this maintenance can be completed (mean days to repair).

The reliability of charging equipment to charge electric buses directly impacts charging infrastructure availability and an agency's ability to make pull-out and provide reliable service to customers. By tracking charging infrastructure reliability and comparing performance between different vendors and charger types (plug-in vs pantograph, conductive vs inductive), agencies can make informed decisions and proceed with greater confidence when transitioning towards larger scale deployments. Additionally, if fault codes are tracked as part of reliability monitoring, common issues can more easily be identified, analyzed, and resolved.

Reliability metrics are an emerging area of interest for the industry with limited data sources to quantify. Potential data sources could include charge management system information, notification logs, work order systems if in place, and/or warranty tracking data. When exploring monitoring infrastructure reliability, some additional items to consider include:

- Consider subdividing issues by severity and downtime
- Consider whether your agency has specified contractual response/repair time expectations such as uptime guarantees or other service level agreement terms
- The time to temporarily repair charging infrastructure (return to service) may be different than the time to permanently resolve an issue (repairs are no longer necessary as a long-term solution has been implemented).

Operator and Charge Behavior Analytics

Monitoring operator and charge behavior analytics is critical to affirming the success of one's charging infrastructure. Equipment can fail or stop working intermittently and remote data applications can share this, but ruling out operator behavior is important to verify if this could be a contributing factor to charging infrastructure downtime. Example contributing factors for on-route charging can include poor alignment, kneeling of buses, personnel refusal to charge, charger bypasses altogether due to service delay, etc. Additionally, charger behavior analytics are key to identify patterns and trends to troubleshoot any faulty components, connectivity to bus, hardware or manufacturing of a unit. By tracking the uptime of the charging infrastructure, service planners and operations can make an informed decision on what the range might realistically be when charging and at what rate of consistency to help determine how many miles can be planned for a bus to drive in a day, also known as maximum vehicle task or block mileage.

Operator and Charge Behavior Analytics metrics are applicable to both conductive and inductive charging equipment. Some methods to consider include monitoring utilization of equipment such as average charge session duration, which can be sorted by equipment type and location, state of charge at pull-out, state of charge at pull-in, and deviations in amount of energy dispensed per charging unit. This data can come from bus and charger telematics systems.

Conclusion

While electric bus charging infrastructure deployments across the country will vary, they do share similarities that transit agencies can consider to establish processes to measure performance. Each deployment may have unique attributes to consider within the software, hardware, and contractual language. There are several elements to consider which may enhance your ability to measure the performance of electric bus charging infrastructure.

1. Have a **method to track charger availability**. This could include software solutions, an infrastructure work order system, manual methods, and more, but understanding the availability of infrastructure will help inform the system's readiness to provide revenue service.
2. When possible, have **a dedicated electric utility meter for the charging infrastructure**, or submeter if needed, to understand the energy consumption of your charging infrastructure. This will assist with monitoring electricity costs.
3. **Automate as much as possible**. The more data streams that are automated, the more feasible it will be to scale up performance monitoring as an agency's electric bus charging infrastructure grows. Consistent and automated data flows will improve the integrity and consistency of the information being used to run the operation and make business decisions. Automation may include items such as the use of APIs, integration between multiple software platforms, establishing an internal data warehouse, and other projects.

Finally, remember to **keep it simple**, and start with what is meaningful to your specific installation and priorities. By starting to measure electric bus charging infrastructure performance, data can be used to better understand this element of the electric bus ecosystem, expand agency knowledge, and make data-driven business decisions as agencies continue their transition to zero emission fleets.