Lima eBus
Maintenance Servicing & Tools

Naeem Farooqi, Principal Consultant
WSP Canada Inc.
Workshop Agenda

1. Intro Naeem Farooqi & Bus Lifecycle Research
2. Bus Lifecycle Overview
3. Subsystem & Component Differences (Diesel vs. eBus)
4. Specialized Tooling Needs
   1. Personal Protective Equipment
   2. On-site Equipment
   3. Mechanic Tools
5. General Maintenance Overview
   1. Preventative Maintenance Intervals
   2. Standard Repair Times (SRTs)
6. Key Performance Indicators (KPIs)
   1. Elements of Work Order Tracking
7. Session Wrap & Questions

Session 8 – Day 3
Maintenace Servicing & Tools
9:00am to 10:00am
Naeem Farooqi
BBA, MSc. PI, PHD*

• Fleet & Asset Management Lead for Canada with over 10+ years experience. Focusing on fleet procurement specifications and production quality assurance. Overseen inspections of over 650+ vehicles in the past 3 years.

• Completing a PHD at University of Toronto in Mechanical & Industrial Engineering focusing on optimal vehicle lifecycle and reliability performance. Supervisor Chairman of Global Research journal for operations Research.

• Recipient of various awards including “Top 40 under 40” in transit from MassTransit and “Clean50 Emerging Leader”

• Global faculty member of C40 clean bus finance academy
UofT Bus Operations Research Lab

Strategic Partnership

- Database of over 6,500 vehicles (Class 1 to 8)
- Ability to extract trends in maintenance cost & fleet reliability
- North American transit systems & municipal fleet vehicles
- 5+ years of O&M lifecycle data available on E-Bus operations
Fleet Lifecycle Model

Objectives of Lifecycle Analysis:
- Optimize useful life by minimizing “Total Cost of Ownership”
- Provide strategic asset management

Model Inputs:
-**Procurement:**
  - Vehicle Capital Cost (Procurement)
-**Operations & Maintenance:**
  - Fuel
  - Annual Fleet Mileage
  - Consumables (ex. Bulk Fluids, Batteries)
  - Parts & Labor (Work Order maintenance cost, Road Calls)
  - Misc O&M (ex. Vehicle Insurance)
-**Rehabilitation & Overhaul:**
  - Powertrain (Engine, Transmission, Battery)
  - Body & Structure
-**Disposal:**
  - Salvage value
  - Secondary parts market
Bus Lifecycle

- **Urban Transit Buses design, certification and testing in North America 12-years under Altoona Test Program**

- **Long lifecycles risk exceeding “design life” of major components (ex. structure, Hubner joint)**

- High capital midlife/overhaul intervention required to prolong bus operations
  - Dependent on vehicle usage:
    - Route topography
    - Passenger Load
    - Annual mileage

- Optimize midlife interventions with shorter lifecycle (warranty coverage post-midlife)
Transit Bus Anatomy
Diesel vs. Electric
Transit Bus Anatomy - Subsystems

Proprietary classification algorithm

10 Major Subsystems* (Articulating Joint, 18m only)

• Subsystems used to classify Work Order Maintenance
• Identify cost drivers according to subsystem

1.0 Propulsion
2.0 Windows, Structure & Exterior Body
3.0 Electrical
4.0 Steering
5.0 Brakes, Pneumatic and ABS Sensors
6.0 Wheels, Axles, Suspension and Differential
7.0 HVAC
8.0 Farebox & ITS
9.0 Doors & Ramps
10.0 Interior
11.0 Articulating Joint*
Diesel Engine Generations - EPA Impact

EPA 1998
State of Diesel Engine Propulsion System

<table>
<thead>
<tr>
<th>Emission Standards</th>
<th>Date</th>
<th>CO</th>
<th>THC</th>
<th>NOx</th>
<th>PM</th>
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<td>Euro I</td>
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<td>Euro V</td>
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<td>0.036</td>
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<td>2.7</td>
<td>0.45</td>
<td>3.6</td>
<td>0.036</td>
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<tr>
<td>Euro VI</td>
<td>2013</td>
<td>2.7</td>
<td>0.234</td>
<td>0.72</td>
<td>0.018</td>
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</tbody>
</table>

High Pressure Fuel Injection & Improved Timing (EPA 1998)

Advanced Electronics on Valve Timing & Fuel Injection (EPA 1998)
Diesel Engine Generations - EPA Impact

EPA 2017
State of Diesel Engine Propulsion System
(Advancement Timeline since 2007)

- Common Rail Fuel Injection System with Separated Pump Design (EPA 2007)
- Single High Capacity ECM (EPA 2017)
- Single Module Aftertreatment (EPA 2017)
- Selective Catalytic Reduction to Reduce NOx (EPA 2010)
- Diesel Particulate Filter to Reduce Particulate Matter (EPA 2007)

Air Intake System → Fuel Injectors → Valve Assembly

Combustion Chamber → Crankshaft (Output to Transmission)

EGR → Exhaust Gas Recirculation (EPA 2007)

DOC (Diesel Oxidation Catalyst) → DPF (Diesel Particulate Filter)

SCR with DEF → Urea Tank
Propulsion System Focus

1970s–1980s
- Low Floor Designs
- 8% Ramps

1990s
- EGR Diesel Engines
- DPF + EGR Diesel Engines
- Hybrid Diesel Electric Buses Available
- Air Conditioning on All Future Bus Orders

2000s
- Rooftop Mounted HVAC Units
- SCR + DPF + EGR Diesel Engines
- Disc Brakes
- Smart Card Fare System (Proterra)

2010s
- Nova RTS Arctic

Diesel Propulsion System Comparison

- Cost per MLS/SM
- Bus Age (years)
- Pre EPA 2004
- Post EPA 2004

EPA Emission Improvements

- N0x Emissions (g/km)
- PM Emissions (g/km)
- Year
- 1990 – 2017

N0x
- PM
eBus Anatomy – Functional Overview

Drive Cycle
• Power electronics system manages energy distribution throughout drivetrain
• On-board battery pack powers traction motor
• Traction motor powers drive axle and wheels
• Electrical energy transformed to mechanical

Regenerative Braking
• Traction motor run in reverse to recapture mechanical energy from braking
• Regenerative braking used to recharge vehicle battery
• Managed through power electronics controller

https://www.youtube.com/watch?v=H7XGaGc0qek
Subsystem Comparison
## Subsystem Comparison

<table>
<thead>
<tr>
<th>System</th>
<th>Diesel Bus</th>
<th>Change to BEB</th>
<th>Major Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion</td>
<td>Internal Combustion Diesel Engine, Transmission, Fuel System and Exhaust Aftertreatment</td>
<td>Electronic Traction Motor, Battery (Energy Storage System)</td>
<td>Yes</td>
</tr>
<tr>
<td>Windows, Structure &amp; Exterior Body</td>
<td>Chassis, Roof &amp; Side Structures, Undercarriage, Windows</td>
<td>More Robust Structure to Support Battery Weight, Roof Structure, Low Center of Gravity (Floor Mounted Battery Packs)</td>
<td>Yes</td>
</tr>
<tr>
<td>Electrical</td>
<td>Low Voltage System to Power Auxiliary Components, Interior Lighting, Head Lights, Starter Motor, etc.</td>
<td>Addition of High Voltage Power Electronics to Manage Battery Charging, Regenerative Braking and Traction Motor Operation</td>
<td>Yes</td>
</tr>
<tr>
<td>Steering</td>
<td>Hydraulic Power Steering</td>
<td>Electrical Power Steering System</td>
<td>Yes</td>
</tr>
</tbody>
</table>
## Subsystem Comparison

<table>
<thead>
<tr>
<th>System</th>
<th>Diesel Bus</th>
<th>Change to BEB</th>
<th>Major Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brakes, Pneumatic &amp; ABS Sensors</td>
<td>Friction Braking System with Caliper Brakes</td>
<td>Regenerative Braking System, Partially Recharges Battery During Deceleration</td>
<td>Yes</td>
</tr>
<tr>
<td>Wheels, Axles, Suspension &amp; Differential</td>
<td>Pneumatic Suspension Front &amp; Rear, Rear Differential, Standard Wheel &amp; Tire Size</td>
<td>Rear Axle to be Compatible with Regenerative Braking, Higher Axle &amp; Suspension Rating to Support Battery Weight</td>
<td>Yes</td>
</tr>
<tr>
<td>HVAC</td>
<td>Diesel Powered Heater</td>
<td>Diesel Heater or Electric Heater (to reach Zero Tailpipe Emissions)</td>
<td>Yes</td>
</tr>
<tr>
<td>Farebox &amp; ITS</td>
<td>Fare Payment Equipment, Communications and Destination Signs</td>
<td>Fare Payment Equipment, Communications and Destination Signs</td>
<td>No</td>
</tr>
<tr>
<td>Doors &amp; Ramps</td>
<td>Bifold Doors Front &amp; Rear, Manual or Powered Ramp Deployment</td>
<td>Bifold Doors Front &amp; Rear, Manual or Powered Ramp Deployment</td>
<td>No</td>
</tr>
<tr>
<td>Interior</td>
<td>Passenger Seating, Stanchions, Stop Request, Signals, etc.</td>
<td>Optimize weight of Interior components to compensate for additional battery weight (i.e. plastic seats, plastic stanchions)</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Subsystem Module – Cost Driver Comparison

Propulsion system is the main subsystem driver of maintenance cost

Other notable contributors:

- Brake System
- Windows and Exterior Body
- Farebox & ITS

Diesel 40FT bus propulsion system accounts for:

- 34% of Diesel Bus Maintenance
- 7% of Electric Bus Maintenance
- Propulsion -> Electrical System Cost for BEB
### Fleet Total Cost of Ownership – Propulsion Type

#### Bus Lifecycle Cost Model
January 2019

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Annualized Cost</th>
<th>Scenario</th>
<th>Total LifeCycle Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>40FT Diesel</td>
<td>$100,049</td>
<td>14 Years</td>
<td>$1,400,691</td>
</tr>
<tr>
<td>40FT BEB</td>
<td>$120,646</td>
<td>14 Years</td>
<td>$1,689,042</td>
</tr>
<tr>
<td>40FT CNG</td>
<td>$91,993</td>
<td>14 Years</td>
<td>$1,287,903</td>
</tr>
<tr>
<td>40FT Diesel Hybrid</td>
<td>$127,805</td>
<td>14 Years</td>
<td>$1,789,270</td>
</tr>
<tr>
<td>40FT Hydrogen FC</td>
<td>$192,156</td>
<td>14 Years</td>
<td>$2,690,189</td>
</tr>
</tbody>
</table>

**Best Lifecycle Scenario**

- $91,993
- 14 Years
- $1,400,691
Maintenance Summary
Diesel vs. Electric
Pros and Cons of Maintenance

Advantages of eBus vs. Diesel:

1. Annual brake maintenance expected to be lower. Regenerative braking extends life by 3 to 4x.

2. Direct drive traction motor has less mechanical and wearing components compared to diesel engine.

3. Bulk fluids (engine/transmission oil) not required. Reduced environmental impact and spill risk

4. No diesel fuel reducing spill risk and fuel expense

5. Diesel aftertreatment system. Removes maintenance of Diesel Particulate Filters (DPF), Exhaust Gas Recirculation (EGR) and other systems
Pros and Cons of Maintenance

Disadvantages of eBus vs. Diesel:
1. Unproven total lifecycle cost
2. More complex electrical systems (power electronics, battery thermal management system)
3. Mechanics and staff training required for High Voltage systems. Need time to become familiar with troubleshooting
4. Additional cost of PPE and specialized static-free tools
5. Diesel AUX Heater will incur higher HVAC maintenance costs at the trade-off of less impact on operating range
Specialized Tooling & PPE
eBus Safety Hazards

- High Voltage components (i.e. battery, power cables)
  - Electrocution
  - Arc Flash (Thermal and Flash)
  - Burn Risk (Hot Surfaces)
- Working at Heights (i.e. roof mounted battery packs)
- Pinch points (i.e. access panels, doors, latches)
- Crush hazard
  - Lifting heavy components (i.e. hoists, lifting cranes)
Working at Heights

- eBuses can have roof mounted battery packs and/or power electronics
- Need for working at heights safety training and use of fall arrest equipment
- Regular inspection of all fall arrest equipment (legislative requirements)
Static Free Toolkits

• Wrenches, Socket Sets, Screwdrivers, Pliers and Calipers

• Electro Static Discharge (ESD) safe tools required to safely dissipate natural build up of static electricity charge
  • ESD can be released through contact with conductors (i.e. metallic vehicle frame)
  • Risk of electrocution
  • Risk of damage to electrical components (i.e. logic controllers, circuits)

• Follow Toolkit OEM requirements for recertification (typically 3 years)

• Keep all certification records on-site

• Regularly inspect toolkits for any damage to protective coating (i.e. scratches, chips)

• Clearly separate (certified vs. certification required toolkits) and lock access to tooling to prevent tampering
## Tooling Cost Impact

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Est. Unit Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluke Multimeter - CAT 111 c/w Test Leads</td>
<td>$ 835</td>
</tr>
<tr>
<td>Wiha Insulated Master Electrician’s Tool Kit</td>
<td>$ 3,760</td>
</tr>
<tr>
<td>Wiha 1/4 in ratchet set insulated SAE</td>
<td>$ 506</td>
</tr>
<tr>
<td>Wiha 1/4 in ratchet set insulated Metric</td>
<td>$ 510</td>
</tr>
<tr>
<td>Wiha open end wrench insulated metric</td>
<td>$ 572</td>
</tr>
<tr>
<td>Wiha open end wrench insulated sae</td>
<td>$ 574</td>
</tr>
<tr>
<td>Wiha insulated Serrated Tweezers Straight</td>
<td>$ 61</td>
</tr>
<tr>
<td>Wiha insulated Serrated Tweezers Angled</td>
<td>$ 86</td>
</tr>
<tr>
<td>Insulated Torque Wrench 1/4&quot;</td>
<td>$ 612</td>
</tr>
<tr>
<td>Insulated Torque Wrench 3/8&quot;</td>
<td>$ 683</td>
</tr>
<tr>
<td>Insulated Torque Wrench 1/2&quot;</td>
<td>$ 737</td>
</tr>
<tr>
<td>Torque screwdriver set</td>
<td>$ 418</td>
</tr>
<tr>
<td>Insulated crimpers 30 - 6 Awg 7&quot;</td>
<td>$ 62</td>
</tr>
<tr>
<td>Insulated hex key set 10pc metric</td>
<td>$ 333</td>
</tr>
<tr>
<td>Long SAE Natural insulated hex key set 12 pc</td>
<td>$ 295</td>
</tr>
<tr>
<td>Wiha Insulated “bitFlip” Set</td>
<td>$ 126</td>
</tr>
<tr>
<td>Phase tester</td>
<td>$ 206</td>
</tr>
<tr>
<td>Pulse width meter</td>
<td>$ 492</td>
</tr>
<tr>
<td>Fluke meter</td>
<td>$ 364</td>
</tr>
<tr>
<td>Modular test lead kit</td>
<td>$ 166</td>
</tr>
<tr>
<td>Test probe flat blade</td>
<td>$ 20</td>
</tr>
<tr>
<td>Test probe back probe</td>
<td>$ 20</td>
</tr>
<tr>
<td><strong>Total PPE Cost (Set per Person):</strong></td>
<td><strong>$ 11,440</strong></td>
</tr>
</tbody>
</table>

*Cost estimates only. Consult eBus OEM for specific requirements and recommended toolkits

- Recommendation one (1) set per person
- Approx. $11,500 USD per person
Arc Flash

Minimum PPE Category 2 (8 cal/cm²)

- Fire Rated Coveralls
- Fire Rated Balaclava
- Face Shield
- Hard Hat
- Safety Glasses
- Ear Plugs
- High Voltage Rated Gloves
- Electrical Hazard (EH) Rated Boots (Insulated up to 600V)
Arc Flash PPE Requirement per Person

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Est. Unit Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc Flash Protective Clothing Kit</td>
<td>$850</td>
</tr>
<tr>
<td>Black Electrical Glove Kit</td>
<td>$130</td>
</tr>
<tr>
<td>Leather Protector - For Rubber Gloves</td>
<td>$27</td>
</tr>
<tr>
<td>Over Boots</td>
<td>$150</td>
</tr>
<tr>
<td>Balaclava Head Cover (one size fits all)</td>
<td>$32</td>
</tr>
<tr>
<td>Hard Hat and Face Shield (one size fits all)</td>
<td>$206</td>
</tr>
<tr>
<td>Fall Safety Harness 425LBS</td>
<td>$163</td>
</tr>
<tr>
<td>Brady Personnel Lockout Pouch Kit</td>
<td>$92</td>
</tr>
<tr>
<td>Steel Lock Hap with Tab</td>
<td>$12</td>
</tr>
<tr>
<td>American lock A1100RED</td>
<td>$17</td>
</tr>
<tr>
<td>Lock Out Tag</td>
<td>$24</td>
</tr>
</tbody>
</table>

Grand Total (PPE) per Person: $1,704

*Cost estimates only. Consult eBus OEM for specific requirements

Recommendation two (2) sets per person

- One PPE set
- One spare set
eBus Maintenance and Standard Repair Time (SRTs)
eBus Maintenance Policy Changes

Regular Inspections to include:

<table>
<thead>
<tr>
<th>Component</th>
<th>Check For:</th>
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</thead>
<tbody>
<tr>
<td>Electrical Harness/Wiring</td>
<td>Chaffing/Rubbing, Vibration and Potential Pinch Points</td>
</tr>
<tr>
<td>Battery Compartment</td>
<td>Enclosure Damage, Loose Terminal Connections, Leaks</td>
</tr>
<tr>
<td>Power Electronics</td>
<td>Abnormal Noise/Hum, Voltage, Current Readings</td>
</tr>
</tbody>
</table>

• Engine oil change every 5,000 km no longer required due to traction motor

• Traction motor powertrain coolant replacement every 30,000 km
### eBus Maintenance Policy Changes

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Task</th>
<th>SRT, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection every 6,000 miles (~10,000 km)</td>
<td>Check rear access hatch</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check motor compartment lights</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clean around traction motor and around electrical connections using air</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check coolant hose and clamp condition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check coolant filter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check motor and transmission connections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check transmission motor and transmission mount bolts are torqued to 48 ft-lbs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check traction motor data cable connector is torqued to 27 in-lbs with strap wrench</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check fire alarm wiring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check for oil leaks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lube all pivoting mechanisms</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check 12/24V bulkhead stud connections (at rear, curbside rear vertical bulkhead low-voltage plate) for condition and torque</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check HV battery pack mounting fasteners for condition and torque</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check HV battery pack rubber mounting isolators</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check green salt plugs on either end of the pack</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visually check the desiccant window in each battery pack ancillary bay. Replace if the color for 40% saturation has changed from blue to pink or if DEM140 is asserted. If desiccant is replaced, record the value and rest value of the timer to 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check general exterior condition of HV battery boxes. Note any damage on the give image.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Open high voltage distribution box and check for connection condition and torque</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check general condition of manual charge ports</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Task</th>
<th>SRT, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Compartment Inspection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20 mins</td>
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</table>

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Task</th>
<th>SRT, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Voltage System</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20 mins</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Task</th>
<th>SRT, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Voltage System (motor compartment)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20 mins</td>
<td></td>
</tr>
</tbody>
</table>

### PM Program Blocks

<table>
<thead>
<tr>
<th>Task</th>
<th>SRT, minutes (Approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Inspection</td>
<td>20 mins</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>90 mins</td>
</tr>
<tr>
<td>Battery compartment</td>
<td>0</td>
</tr>
<tr>
<td>Fuel System (out of scope for eBus)</td>
<td>0</td>
</tr>
<tr>
<td>Lower inspection</td>
<td>20 mins</td>
</tr>
<tr>
<td>Lower inspection brakes only</td>
<td>30 mins</td>
</tr>
<tr>
<td>Engine Compartment (out of scope for eBus)</td>
<td>0</td>
</tr>
<tr>
<td>Interior</td>
<td>60 mins</td>
</tr>
<tr>
<td>Exterior</td>
<td>60 mins</td>
</tr>
<tr>
<td>Climate control system</td>
<td>20 mins</td>
</tr>
<tr>
<td>Tires/wheels/ axle</td>
<td>20 mins</td>
</tr>
<tr>
<td>Paperwork</td>
<td>15 mins</td>
</tr>
</tbody>
</table>

**Total Time, minutes (hrs)** 335 mins (5.6 hrs)

**Changes from Diesel PM A Inspection**

- eBus preventative maintenance (PM) inspections could **save 1 to 2 hours** labor time*
- *Once initial training, familiarization level reached with mechanics
Cost per Mile Comparison

Key Findings:

• Higher cost for diesel-hybrid driven by maintenance of dual propulsion system (i.e. electric motor and diesel engine)

• First year eBus cost higher due to component outfitting, training and learning curve
  • Diesel Cost ($0.31 to $0.90 per mile)
  • eBus Cost ($0.17 to $0.50 per mile)

• Comparison for North American transit agency

• Extrapolated cost per mile based on UoFT Bus Operations Research Lab Data
Lifecycle Considerations

1. Unproven lifecycle operations of eBuses
2. Budget for midlife battery pack replacement (est. $500/kWh)
3. Possible need for traction motor rebuild/replacement (est. $82,500 USD)
4. Staff tooling, PPE and training requirements to service high voltage systems
5. Modular swap out of battery to capitalize on new battery technology
6. Include Battery State-of-Charge (SOC) warranty in vehicle specification
KPIs & Maintenance Tracking
Maintenance Management System

Requirements of Work Order Management:
1. Unique Asset/Vehicle Identification
2. Each Work Order tied to Asset
3. Classification of Preventative or Corrective Maintenance
4. Warranty Repair (Yes/No)
5. Date/Time Stamp For:
   1. **Creation Date**: when repair need identified
   2. **Start Date**: when repair is initiated
   3. **Complete Date**: when repair is completed/resolved
6. Description of Work
7. Description of Parts/Materials Used
8. Parts/Materials Cost ($)
9. Labor Time (hrs)
10. Labor Cost ($/hr and total)
Key Performance Indicators (KPIs)

What are KPIs:
• Quantifiable standardized measure of evaluating the success of a technology, policy, etc.

Why KPIs are Important:
1. Track eBus implementation through pilot program
2. Validate OEM performance specifications (i.e. energy consumption)
3. Compare eBus vs. Diesel bus technology
4. Track maintenance policy and operations
5. Implement a feedback loop with KPIs to improve performance
eBus Pilot KPIs

Mean Kilometers Between Defect (MKBD)
- Average distance traveled between in-service bus failures (road call, tow call)
- Industry standard measure of reliability

Mean Time to Repair (MTTR)
- Average time between start and close of corrective maintenance repair
- Industry standard measure of staff training, troubleshooting and actionable repair time
- Establish Standard Repair Times (SRTs) for maintenance policy

Cost per Kilometer/mile ($/km) or ($/mile)
- Tracks parts, labor, fuel/electricity cost over distance travelled
- Compare operating portion of technology lifecycle cost
- Validate OEM claims on maintenance cost
eBus Pilot KPIs

Energy Efficiency Vehicle (kWh/km)
- Industry standard to compare vehicle operating efficiency throughout different operating environments
- Validate OEM specifications
- Correlate to Route Topography, Seasonality, Passenger Load
- Support fleet service planning

Energy Efficiency Charger (Grid vs. Charge kWh)
- Compares energy drawn from grid to energy delivered to bus battery through charger (i.e. charger efficiency)
- Validate OEM specifications
- Support future infrastructure planning
eBus Pilot Stakeholder Feedback

Gather qualitative feedback from stakeholder groups:
  • Operators (Bus Drivers)
  • Fleet Mechanics
  • Transit Customers
  • Transit Agency

Some questions to ask:
  • Top maintenance challenges
  • Recurring repairs
  • Ride quality (i.e. noise, gradeability, braking)
  • Familiarity with safety protocols
  • What can be improved from the pilot
  • Overall satisfaction
eBus Pilot

Stage 1: Understanding
- User Group and Vehicle Needs (Operations & Maintenance)
- GHG Inventory of Fleet Assets
- GHG Reduction Targets

Stage 2: Exploratory
- Market Research on Alternative Propulsion Technologies and Trends
- Technology Impact on GHG Reduction, O&M Cost
- Grants and Funding Opportunities

Stage 3: Implementation
- Change Management Plan
- Maintenance & Facility Modifications
- Buy-in from Stakeholders & Senior Management

Stage 4: Execution & Monitoring
- Pilot Vehicle Program
- Establish KPIs for Vehicles and Purchase/Lease Units
- Review of Pilot Data & User Feedback
- Wider Adoption Amongst User Groups

Currently in Stage 4
Thank you!

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