What Hinders the Adoption of Battery Electric Buses in Transit: A Techno-Economic Analysis

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Moataz Mohamed
Ph.D, MASc, BE, MILT, EIT

Assistant Professor of Smart Systems and Transportation
Department of Civil Engineering
McMaster University
The Social Costs and Benefits of Electric Mobility in Canada

- Consumer
- Transit
- Fleet
- Geographic
- Environment
- Infrastructure
- Economic
- Integration
Timeline
Bus Transit In Canada

2014 Canadian Transit Fleet Size

- Over 300
- 100-300
- 50-99
- < 50

Circle chart:
- Group 1 (> 2,000,000): 42%
- Group 2 (400,001 - 2,000,000): 13%
- Group 3 (150,001 - 400,000): 31%
- Group 4 (50,000 - 150,000): 11%
- Group 5 (< 50,000): 3%
RESEARCH FOCUS 1

REVIEW OF ALTERNATIVE POWERTRAINS
Review e-Bus Technology
Mapping e-Bus Technology

- Purchase Price
- Maintenance Cost
- Running cost
- Infrastructure Cost
- Total Cost of Ownership
- WTT GHG Emission
- TTW GHG Emission
- WTW GHG Emission
- WTT Energy Consumption
- WTW Energy Consumption
- TTW Energy Consumption
- Range
- Availability
- Acceleration Time (0-30 Km/h)
- Infrastructure Installation
- Refuelling/Recharging Time

Legend:
- ICE Diesel
- FCEB Hydrogen - Centenral NGSR
- BEB - Overnight
  - Electricity - EU mix
- BEB - Opportunity
  - Electricity - EU mix
Research Findings

• Hybrid, CNG and the so-called Clean Diesel will not achieve substantial reductions in GHG emissions

• Battery electric technology should be couple with electricity profile that produces no more than 600 tCO2e/GWh (Canada is 150)

• Electric buses are feasible for operation, despite the high capital cost

The Key question is

What Hinders the Adoption of E-buses in Canadian Transit?
Research Focus 2

What Hinders the Adoption of E-Bus?
## Participants

<table>
<thead>
<tr>
<th>Transit Provider</th>
<th>City, Province</th>
<th>Population Served</th>
<th>% of National Ridership</th>
<th>Fleet Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTC</td>
<td>Toronto, ON</td>
<td>2,808,503</td>
<td>26.40%</td>
<td>1,869</td>
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<td>HSR</td>
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<td>490,000</td>
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<tr>
<td>Windsor Transit</td>
<td>Windsor, ON</td>
<td>210,891</td>
<td>0.31%</td>
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<tr>
<td>GRT</td>
<td>Region of Waterloo, ON</td>
<td>434,437</td>
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<tr>
<td>Metro Transit</td>
<td>Halifax, NS</td>
<td>308,084</td>
<td>0.95%</td>
<td>312</td>
</tr>
<tr>
<td>Kings Transit</td>
<td>Kentville, NS</td>
<td>42,500</td>
<td>0.02%</td>
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<tr>
<td>Fredericton Transit</td>
<td>Fredericton, NB</td>
<td>50,000</td>
<td>0.08%</td>
<td>27</td>
</tr>
<tr>
<td>Winnipeg Transit</td>
<td>Winnipeg, MB</td>
<td>675,300</td>
<td>2.46%</td>
<td>583</td>
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<tr>
<td>Calgary Transit</td>
<td>Calgary, AB</td>
<td>1,195,194</td>
<td>5.44%</td>
<td>1,053</td>
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<td>OC Transpo</td>
<td>Ottawa, ON</td>
<td>857,890</td>
<td>4.79%</td>
<td>936</td>
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<tr>
<td>STM</td>
<td>Montreal, QC</td>
<td>1,959,987</td>
<td>20.56%</td>
<td>1,729</td>
</tr>
</tbody>
</table>
Attitude Towards the e-Bus

I would certainly be pushing that the electric bus would be the way that we need to go down the road. But we don’t like to be the guinea pigs with technology GRT, Region of Waterloo.

Show me a city that’s done it. Show me their experience, show me their mileage, maintenance history. that’s where we’re going to get the real information Metro Transit, Halifax.
We got a new bus that goes out for 22 hours or so a day. And our range for one of those buses is 400 miles. Just before we get into those electric buses we talked about, we’re not even close. TTC, Toronto.

I don’t think it will be usable for every service, there’ll be very specific ones... it will take a lot of work to work through the steps of how you select your routes I think. Calgary Transit, Calgary.
Risk Averse DM

We’re very risk-adverse ... when you’re dealing with a large volume of public funds, electric buses really got to be a proven technology and a cost-effective technology I think
Metro Transit, Halifax

The U.S Market Influence

We purchase new vehicles to replace old vehicles that were built in the early 80s. Environmentally it made more sense to replace more of those with new clean diesel than replacing a smaller number with a hybrid that was only marginally more fuel efficient”
Winnipeg transit, Winnipeg.

Replacement First

Procurement Process
Developing A Business Case

Top-down Approach

Political Intervention

Canadian Full-network databank

Regulatory Environment

Well typically I think it would come top-down... doing those things in isolation don’t really help, you know? ....There needs to be something on a more... on a higher level I think Calgary Transit, Calgary.

There’s nothing like having a successful operation over a period of time that yields positive benefits to have other people want to jump on. There needs to be targeted efforts at a controlled number of locations to make the changes necessary for this to, really work.

Winnipeg Transit, Winnipeg.
Service Providers Perspective

- **Attitude towards E-bus**: High risk of being an early adopter & fear of obsolescence. Technology is viable but still in development phases.
- **Operational Feasibility**: Perception of high cost of the electric bus.
- **Decision making process**: Risk-free decision making environment. Operation is optimized for long range Diesel & CNG. Limited financial capability to adopt E-buses.

**Risk**

**Oper.**

**Cost**

*Developing a business case: Risk mitigation by developing Canadian operational data. Demands for pilot projects that prove operational feasibility. Federal support & monetary incentives.*
A Framework for Bus Transit Electrification

Proposed Interventions

R&D and Standardization

Political Support (Finance & Regulations)

Demonstrations (Full Network)

Canadian Databanks

Expected Influences

Themes

Categories

- Electrical technology is viable.
- Passenger demand reliability not great technology.
- Contributed to GHG reduction.
- Future implementation only.
- High risk being the fear.
- Need someone else to test it.
- Fear of obsolescence.
- Lack of R&D direction.
- No practical Canadian data.
- Various unknowns in operations.
- Health and safety for passengers & employees.
- Safety standards for high voltage exposure.
- Range.
- Charging time.
- Overnight electric loads.
- Capabilities & electric bus.
- Battery Trolley electric bus.
- Route selection.
- Operational flexibility.
- Interfacing various feed rates.
- Increased fleet size.
- Mechanics.
- Drivers.
- Human resources.
- Capital cost.
- Operational costs.
- Leasing.
- Infrastructure cost.
- Fuel pricing & electricity rates.
- Human resource cost.
- Total cost of ownership.
- Standards.
- The role of CUTA & APTA.
- No Green electric policy in place.
- Bus has Decisions making processes.
- Multiple interdepartmental involvement.
- Policy-based driven decision making.
- Reputation factor.
- Age driven strategy.
- Performance requirements force G does not.
- Technology change is not often considered.
- Eliminating old does is less a priority.
- Manufacturers & meeting performance requirements.
- U.S. guide market direction not Canada.
- Different priorities for manufacturers and providers.
- Top down approach is the only solution.
- Providers can't act in isolation.
- Federal government is the key player.
- Procurement and municipalities are key building blocks.
- Federal incentives.
- Policy is the only feasible solution.
- Citynetwork cities are key for successful plans.
- Data solves for it bus in Canada.
- Regulation for en route chargers.
- Acquisition regulations & contracting.
So what?
Optimize and Predict Everything

Feasibility Analysis

Optimization & Sizing

Prediction Models

Operational Feasibility + Utility Impact Analysis

System Optimization + Component Sizing

Prediction Toolkits
RESEARCH FOCUS 3

OPERATIONAL FEASIBILITY AND UTILITY IMPACT
Simulation Model

Operation Constraints

- Fixed fleet size
- Satisfy timetable
- Minimum number of chargers
- Using currently available technology
Simulation of Belleville Transit

Charger data

<table>
<thead>
<tr>
<th>Charger</th>
<th>SoC (Wh)</th>
<th># Charges</th>
<th># Trips</th>
<th>Total km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charger 1</td>
<td>70.3987</td>
<td>0</td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>Charger 2</td>
<td>70.4127</td>
<td>0</td>
<td>0</td>
<td>1.512</td>
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Bus data

<table>
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<tr>
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</table>

Time: 5:04 AM
Charging Profile

[Graph showing charging profiles for different buses]
e-Bus Energy Demand

Scenario 1-B: Flash Electric (5*250kw) chargers

Scenario 1-A: Flash Electric (3*500kw) chargers

Scenario 2-A: Opportunity Electric (5*250kw) chargers

Scenario 3-A: Overnight Electric (3*80kw) chargers

Scenario 3-B: Overnight Electric (2*200kw) chargers
e-Bus Utility Impacts
Research Findings

• Predominantly, energy demand and the charging behavior of each BEB configuration were very distinct.

• Overall, flash electric bus coupled with fast-charging technology is shown to offer superior operation compared to other configurations.

• From utility perspective, operating flash and opportunity electric buses require a service transformer of a size 5–6 times that required from overnight operation.

• **Taken together, operational feasibility simulation and grid impact models generate contradictory recommendations.**

• This outcome in itself is significant, as it highlights the need to consider both operational constraints and grid impacts simultaneously.
RESEARCH FOCUS 4
OPTIMAL SIZING AND SYSTEM CONFIGURATION
Optimization of e-Bus System Configuration
Sizing e-Bus Components
Research Focus 5
Uncertainty Analysis
The Impact of Route Topology
CLOSING REMARKS!
What we have learned?

• A **mix** of overnight and on-route e-Buses **is required**, yet it might hinder the operational flexibility.

• e-Bus operation is very sensitive to **context**; different operational approaches are recommended for fixed-route vs interlining operation.

• Bus barn upgrade is expected especially for the overnight e-Bus due to its weight.

• The **guinea pig syndrome** is a significant hurdle, incentives should be offered to mitigate this syndrome.
What we have learned? Utility Vs. Operation

• Predominantly, energy demand and the charging behavior of each e-Bus configuration are very distinct.

• Overall, the on-route electric bus coupled with fast-charging technology is shown to offer superior operation compared to other configurations.
What we have learned? Utility Vs. Operation

• From a utility perspective, operating on-route e-buses require a service transformer of a size 5–6 times that required from the overnight operation.

• Taken together, operational feasibility simulation and grid impact models generate contradictory recommendations.

• This outcome in itself is significant, as it highlights the need to consider both operational constraints and utility impact simultaneously.
What is Next?
The Impact of Weather & AUX? 2019

The Impact of Driving Behaviour? 2019

Network Vulnerability? 2019

System Design? 2020
Thank You!

Email: mlohame@mcmaster.ca
Twitter @Moataz_Mmohamed
https://www.eng.mcmaster.ca/civil/people/faculty/moataz-mohamed