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# Electrifying bus rapid transit systems: a Canadian case study

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## Executive Summary

Bus Rapid Transit presents many advantages to serve public mobility, including frequent service, short stops and quick commute that aren't impacted by traffic, provided that the buses run on dedicated laneways. London Transit and the city of London in Ontario are in the process of planning the implementation and construction of two major Bus Rapid Transit Routes served by buses with dedicated lanes. These routes will provide a quick connection from the four poles of the city to the downtown core. Each route is about 30km long round trip and will take around 35 min to complete one way. To make the commutes comfortable for passengers, improve overall air quality and reduce emissions, London Transit is currently considering the option of fully electrifying the routes by deploying battery electric buses. The Canadian Urban Transit Research and Innovation Consortium (CUTRIC) performed an energy consumption analysis using their in-house build model TRiPSIM © (Transit Route Performance Simulator) on these two routes using the planned schedule to assess the feasibility of electrifying them using standardized overhead fast chargers. The methodology developed to perform this study and the results of this analysis, such as the electricity use, operational costs and emission reductions will be discussed in this paper.

*Keywords: BEV (Battery Electric Vehicle), Energy Consumption, Environment. Public Transport, Bus*

# 1 Introduction

Diesel engines are high particle matter (PM) and nitrogen oxides (NOx) emitters which in a urban context can increase cases of adult lung cancers, asthma and premature deaths [1]. In 2009, 94% of the Canadian bus fleet operated diesel buses [2] which contributes greatly to the PM and NOx emissions in cities.

Battery electric buses (BEBs) are a clean alternative to conventional diesel buses as they do not release emissions when operating. Additionally, an important part of the electricity in Canada is generated from hydropower and nuclear power plants which are sustainable power sources. In 2015, the generation intensity of the Canadian electricity grid was 140 g CO2eq/kWh [3] which compared to an average of 340 g CO2eq/kWh in Europe [4] makes Canada an ideal candidate to deploy BEBs to reduce greenhouse gas emissions (GHG) and improve cities air qualities.

One particular application of BEBs that is being investigated currently in London (Ontario) is to deploy them on a Rapid Transit way. Bus rapid transit (BRT) systems are designed to have a high ridership, low downtime and high frequency to connect major transfer points within cities. Many cities in Canada such as Montreal, York Region or Ottawa have implemented a BRT system, with or without dedicated laneways. In London, the BRT system is intended to link the north-east (route “L”) and south-west (route “7”) corridors of the city in an efficient and reliable way. Smart traffic signals as well as real-time bus information will be set up to make bus rides as easy and convenient for passengers as possible [5]. Some of the advantages of BRT systems compared to rail-based solutions such as light rail transit (LRT) in the context of mass transit are that it takes less time to plan for and implement a BRT line and that the capital cost of infrastructure is lower than for a LRT system [6].

The city and local transit agency of London sought help to determine the feasibility of fully electrifying the proposed routes for their BRT systems. To the knowledge of the authors, if the project were to go forward it would constitute a world’s first [7] and would help drive the electrification of buses forward.

The modelling team of the Canadian Urban Transit Research and Innovation Consortium (CUTRIC) performed an energy consumption analysis on these two routes using the planned schedule to assess the feasibility of electrifying the two proposed routes with standardized overhead fast chargers. The high level methodology of the TRiPSIM © tool and main results of the analysis including the electricity use, operational costs and emission reductions will be discussed in this paper.

# 2 Methodology

## 2.1 Duty cycle development

The first step of the feasibility study is to model the system’ routes once they have been identified. To do so, the transit agency route and timetable data (including bus stop locations) are imported in General Transit Feed Specification (GTFS) format. The highest resolution elevation dataset available for the location is then selected. Then, this information is mapped on another set of data containing the intersections’ locations, stop signs’ locations and pedestrian crosswalks.

A speed and a topography profile are then generated for three duty cycles (baseline, medium and worst-case). In the baseline duty cycle, the bus doesn’t stop at anywhere along the route. In the worst-case duty cycle, the bus stops at every location (including every street lights intersections, pedestrian crosswalks etc…). Lastly, in the average duty cycle, the bus stops at 50 % of the scheduled stops. The speed profiles generated assume typical and feasibile acceleration patterns.

Figure 1a and 1b below show the resulting worst-case duty cycle for route L and its associated topographic profile, respectively, that were obtained using this methodology.

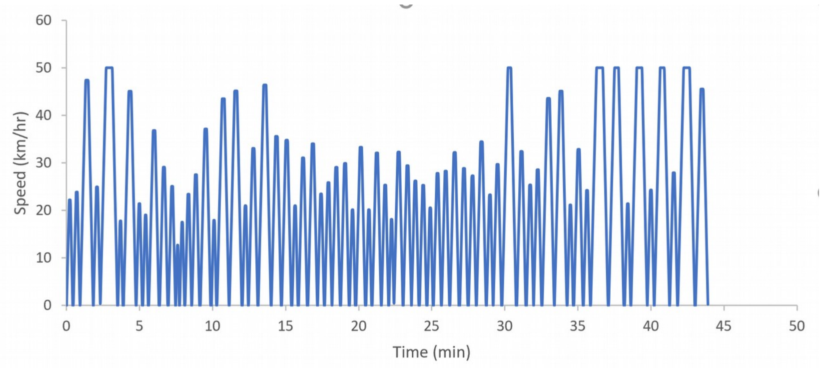


Figure 1a: Worst-case duty driving cycle for one direction on route “L”

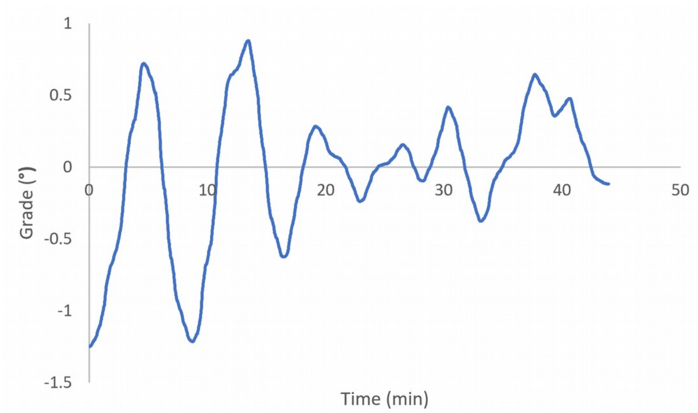


Figure 1b: Topography profile for one direction on route “L”

## 2.2 Calculate the energy consumption and state-of-charge of the electric buses

Every transit route is different because of its length, topography, ridership and overall utilization profile. It is therefore crucial to model each route of the system separately. CUTRIC developed an in-house modeled called TRiPSIM © (Transit Route Performance Simulator) to model the powertrains of two fully electric 40 ft – a New Flyer XE40 and a Nova Bus LFSE (New Flyer and Nova Bus being two large North American manufacturers). Regenerative braking was accounted for, as well as different auxiliary load use. In the worst-case duty scenario, the heating/cooling load and the passenger load were set to a maximum, while in the average duty scenario the bus was half full with half of the maximum auxiliary load on. In the baseline duty cycle, no heating or cooling was included and the bus didn’t carry any passenger.

## 2.3 Calculate the fuel consumption of a diesel bus with the same operating profile

To compare the operating costs and emissions to the electric buses, a diesel bus model was implemented based on the method developed by Edwardes et al. in [8]. The model is reproduces the fuel consumption of a New Flyer 2013 XD35.

## 2.4 Schedule assumptions

The Route “7” Corridor will operate on a 10 minutes frequency for 18 hours from Monday – Saturday and 16 hours on Sunday and statutory holidays. Similarly, the “L” corridor will operate on a 5 minutes frequency for the same number of hours per day. That is, 5 minutes of downtime is scheduled at each terminus stations for the buses to charge. This analysis focuses on assessing the feasibility of using overhead 450 kW standardized chargers developed by ABB and Siemens at the four terminal locations [9].

# 3 Results

Table 1: Average energy consumption on route "L"

| | kWh/km | Total kWh | SOC * | Charging time (min) | kWh required for charge ** |
|---|---|---|---|---|---|
| Baseline duty cycle | 0.4 | 5.8 | 89.5% | 0.90 | 6.71 |
| Average duty cycle | 1.0 | 14.6 | 81.2% | 2.26 | 16.91 |
| Worst-case duty cycle | 1.7 | 24.8 | 71.4% | 3.83 | 28.74 |

* The usable state-of-charge (SOC) accounts for a battery buffer that is set to enhance the battery lifetime
** The kWh required to charge the bus accounts for losses at the charger and battery management system level

Table 1 shows the average results for the two direction of route "L" for the two manufacturers. It can be seen that the range of energy consumption varies greatly depending on the operating conditions – between 0.4 to 1.7 kWh/km. Additionally, the average state-of-charge (SOC) after a one way trip shows that there is enough charge remaining in the battery to complete a roundtrip without requiring a fast charge. However, it is easier from an operational standpoint to charge the bus everytime it stops at a terminus. The next two columns show the charging time it takes and the energy required from the grid to charge the bus after one way is completed, respectively. As shown in this simulation, the maximum time required to fully recharge the battery at 450 kW is less than 5 minutes, therefore it is technically feasible to electrify the route according to the prescribed schedule.

Table 2: Operating benefits of electrifying route "L"

| | Yearly MWh | Charging costs (CAD$) | Diesel costs (CAD$) | **Benefits (CAD$)** |
|---|---|---|---|---|
| Baseline duty cycle | 1,037 | 148,123 | 459,686 | **311,564** |
| Average duty cycle | 2,614 | 366,065 | 773,446 | **407,382** |
| Worst-case duty cycle | 4,443 | 618.653 | 1,199,593 | **580,940** |

Table 2 shows the yearly operating costs benefits of electrifying the full BRT route when comparing electricity versus diesel costs. These calculations were performed using London Hydro General Service rates for services greater than 50 KW with no interval meter rates. It can be seen that more savings are achieved in the worst-case duty cycle which is due to the fact that electric buses are far more efficient than their diesel conterparts when subjected to a worst-case utilization.

Lastly, the emissions savings of deploying fully electric 40 ft as opposed to diesel buses were calculated. A constant emission factor of 43 g CO2eq/kWh [3] for the electricity grid in Ontario and a mobile fuel combustion of 2.63 kg CO2eq/L for diesel worst-case-duty vehicles [10] were used for this calculation. It was estimated that between 1,279-3,263 TCO2eq can be saved per year, which corresponds to a 90 – 94 % emission saving over diesel each year of operation. This GHG saving in this projects would be significant and should be acknowledged as one of the main benefits of transitioning to fully electric bus fleets in Ontario.

# 4 Conclusion

This paper presented the main outcomes of the modelling efforts lead by CUTRIC to assess the feasibility of fully electrifying London's Bus Rapid Transit system using standardized overhead fast chargers. The modelling tool TRiPSIM © used was developed in-house by CUTRIC and uses first hand data from manufacturers and feedback from other electrification projects. The study described in this paper showed that it is possible to fully electrify rapid transit ways with standardized overhead fast charging technology while seeing significant yearly operational cost benefits with proper planning. Electrifying a full Rapid Transit route has the potential to save up to 94% emission compared to diesel in Ontario for a year of operation

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Anaïssia Franca is a Research Strategy Manager at CUTRIC. She leads CUTRIC' modelling and simulation projects and has built the electric bus capacity of TRiPSIM © collaboratively with OEMs to support transit agencies in their transition to alternative bus technologies – including battery electric, hydrogen fuel cell and RNG/CNG drivetrains. She also develops the research strategy for CUTRIC and supports the growth of the Quebec office. She holds a MASc. in Mechanical Engineering from the University of Victoria as well a B.Eng with Honours from the same university.



Ryan (Yutian) Zhao is a Researcher and Projects Development Officer at CUTRIC. Dr. Zhao is responsible for developing low-carbon smart mobility projects and developing mathematical models for TRiPSIM©. His prior research background is focused on mathematical modelling of branching polymer productions. Recently, Dr. Zhao extended his field to data science and machine learning. His interest in green energy and care for the environment provides him with the passion to work on the emerging technologies involved in the uptake of electric cars and buses. Dr. Zhao received his Ph.D. from Queen's University and his B.Eng. with Honours from Zhejiang

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Garret Duffy is a Geospatial Analysis Consultant based in Chestermere, Alberta. For this report, he applied his spatial analysis expertise to the co-creation of the TRiPSIM © tool that was extensively used. in 2005, he was awarded a PhD in Geodesy and Geomatics Engineering from the University of New Brunswick which was subsequently followed by post-doctoral fellowships in Natural Resources Canada and National University of Ireland, Galway. In a professional capacity, he enjoys applying his geospatial skills in fields that include transit analysis, cartography, marine survey, remote imagery classification, geomorphology, sediment transport, physical oceanography, and precision agriculture.

Josipa Petrunic is the Executive Director & CEO of CUTRIC. She is leading the formulation of several national transportation technology trials related to zero-emissions transportation and “smart vehicles” innovation, including the Pan-Canadian Electric Bus Demonstration & Integration Trial, the Pan-Canadian Hydrogen Fuel Cell Demonstration & Integration Trial, and the National Smart Vehicle Demonstration Project. Dr. Petrunic has built up CUTRIC’s consortium to include more than 100 private and public sector companies and organizations across Canada. Previously, she served as the lead researcher in electric vehicle policy studies at McMaster University, and as a senior research fellow in the history and philosophy of mathematics at University College London (UCL) in the United Kingdom in Science and Technology Studies. Dr. Petrunic continues to lecture in Globalization Studies at McMaster University. She currently sits on the Board of the Women's Transportation Seminar (WTS) Foundation and InnovÉÉ, an electrical vehicle R&D funding body in Quebec. In 2018, she was named as one of Canada's a Top 40 Under 40 by Bloomberg News.