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Eco-driving for transit: An effective strategy to conserve fuel and emissions

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HIGHLIGHTS

- We analyzed real-world transit bus operations data to assess potential eco-driving benefits.
- We proposed a new eco-driving algorithm tailored for transit buses.
- We compared eco-driving benefits to those expected from the conversion to a CNG fleet.
- Eco-driving proved a cost-effective strategy to conserve fuel and emissions for transit.

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ABSTRACT

Eco-driving is one of the many options to reduce fuel consumption and emissions from transit operations. However, it is not yet clear how effective eco-driving is for different transit service and fuel types. As policymakers consider implementing eco-driving, they also need comparisons of eco-driving against other fuel-conserving strategies, such as purchasing alternative fuel vehicles. Using a case study of transit operations in Atlanta, Georgia, United States, this paper evaluated eco-driving for two very different service types – local urban service and express service. The authors simulated the implementation of transit eco-driving strategies using an innovative, streamlined algorithm designed to minimize fuel consumption by limiting instantaneous vehicle specific power while maintaining average speed and conserving total distance. Fuel consumption and fuel-cycle emissions were compared across the monitored driving cycles and their modified eco-driving cycles. The savings from eco-driving were also compared to fuel and emissions reductions expected via the conversion of the transit fleets to compressed natural gas (CNG), another popular fuel conservation strategy. The results showed that eco-driving would be a potentially very cost-effective strategy for local and express bus transit operations.

1. Introduction

Transit agencies are always seeking opportunities to conserve fuel (which typically provides simultaneous emissions reductions) to lower operating costs. Strategies range from making wise new vehicle purchase decisions, such as alternative propulsion/fuel buses, to making operational improvements, such as implementing anti-idle policies and eco-driving training. Each emissions reduction option offers different return-on-investment (ROI), depending upon the local conditions and operational characteristics of each agency. Further complicating the evaluation is the fact that emissions reductions from strategies are not necessarily additive. In selecting a set of emissions reduction strategies to implement, transit agencies need to evaluate multiple options simultaneously, under agency-specific operating characteristics.

Concerning operational improvements, eco-driving is a much-talked-about but often overlooked strategy to combat climate change [1]. Even though some researchers have suggested that transit operators should adopt eco-driving to reduce emissions and improve fuel economy [2], others have pointed out that benefits of eco-driving are unclear [3]. Alam and McNabola [3] argue that driver assistance technologies that do not account for real-world driving conditions limit the effectiveness of eco-driving. To this end, this paper presents a transit bus eco-driving algorithm that utilizes second-by-second GPS data to provide real-time feedback. We derive the potential reductions in fuel consumption from operational improvements achieved through driver behavior modification, predominantly limiting vehicle acceleration rates and top speeds. To assist transit agencies in deciding whether to adopt eco-driving policies, we evaluate fuel and emissions savings from the

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Nomenclature

CNG	compressed natural gas
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
GHG	greenhouse gas
GPS	global positioning system
GREET	greenhouse gases, regulated emissions, energy, and transportation model
GRTA	Georgia Regional Transportation Authority
GT	Georgia Institute of Technology
km	kilometer
kph	kilometers per hour
L	liter
LOS	level-of-service
MARTA	Metropolitan Atlanta Rapid Transit Authority
MJ	million joules
MOVES	MOtor Vehicle Emission Simulator
MY	model year
NTD	National Transit Database
QA/QC	quality assurance/quality check
ROI	return-on-investment
STP	scaled tractive power
VSP	vehicle specific power
USEPA	United States Environmental Protection Agency

aforementioned eco-driving algorithm based upon real-world operations data collected from two transit agencies in Atlanta, Georgia, United States. One agency, the Metropolitan Atlanta Rapid Transit Authority (MARTA), provides local urban service, featuring low speed and frequent stops. The other agency, the Georgia Regional Transportation Authority (GRTA), provides regional express bus service, featuring high-speed operations.

In addition to operational improvements, such as eco-driving, transit agencies have also shown increasing interest in the deployment of alternative fuel buses as a strategy to lower total fuel costs [4]. Compressed natural gas (CNG) is a particularly popular choice of alternative fuel, especially in light of recent decreases in CNG prices due to increased fracking activity. For example, in the United States alone, as of 2014, more than 10,000 buses in the United States are running on CNG, compared to about 4000 hybrid diesel buses (National Transit Database, 2014). Therefore, this paper not only evaluates eco-driving as a stand-alone strategy but also puts the savings from eco-driving into perspective by independently and simultaneously estimating fuel and emissions savings from converting the existing fleets to CNG. Because switching to alternative fuels may result in unintended life-cycle impacts [5], the analyses in this paper extend beyond fuel consumption and tailpipe emissions. Any reduction in fuel consumption at the vehicle also reduces fuel consumption and emissions along the entire fuel chain: harvesting fuel feedstocks, refining and processing the feedstocks into fuels, and distributing the fuels. The analyses that follow will report "pump-to-wheel" (occurring at the vehicle) fuel consumption, greenhouse gas (GHG) emissions, and criteria pollutant emissions and "well-to-wheel" GHG and criteria air pollutant emissions (associated with the entire fuel chain).

The paper first provides a literature review on eco-driving as a fuel consumption and emissions control strategy for surface transportation in general and transit operations in particular. The collection of the data employed in this study is then described and summary statistics of the data are presented. The development of the eco-driving algorithm used in the analysis of potential benefits is then outlined. The comparative fuel consumption and emission reduction results that could be achieved with eco-driving intervention for the monitored data are then summarized and compared to the benefits that could be obtained from fleet conversion to CNG. Conclusions on the effectiveness of eco-driving for transit and the innovativeness of the algorithm developed herein are presented at the end.

2. Literature review

Eco-driving training is well-known as a likely strategy to decrease fuel consumption and emissions. Eco-driving encompasses the following driving tactics [6]: anticipating traffic, limiting high-speed operations, avoiding hard acceleration, shifting to the highest available gear rpm will allow, maintaining a steady speed, and limiting idling. There is a large body of literature regarding the effectiveness of eco-driving, and its implementation strategies. Table 1 summarizes the results from the variety of studies identified and reviewed in this research effort.

Existing studies have evaluated the benefits of eco-driving through real-world implementation, through simulated vehicle activity data, or through a combination of both. In real-world implementations, the observed fuel savings range from 2% to 14% [7–15]. Also, Rolim et al. [16] reported that drivers with instant in-cab voice feedback showed much more reductions in hard accelerations compared to drivers who only received in-class eco-driving training, although the paper did not report the actual fuel savings from these two eco-driving strategies compared to a baseline condition. In simulated vehicle studies, estimated eco-driving benefits exhibit higher variability than observed in real-world implementations, ranging from 8% to about 35% in fuel savings and CO_2 reduction [7,17–21].

Eco-driving studies based on simulations have devised a range of driving strategies to represent the implementation of eco-driving objectives. Most studies simulate eco-driving strategies through modifying vehicle speed and acceleration. Barth and Boriboonsomsin [7] devised a dynamic eco-driving system that provided drivers with suggested speeds based on average traffic speed and the freeway link level-of-service (LOS). Mensing et al. [22] created a numerical model of the velocity trajectory of a vehicle operating according to eco-driving principles and real-life traffic constraints. Using simulated traffic data, Qian and Chung [19] evaluated fuel consumption and CO_2 emissions of eco-driving by reducing the maximum acceleration rates by 10% and 20% in a simulation. Suzdaleva and Nagy [21] developed a data-based Bayesian approach to identify and modify the speed to optimize fuel consumption for conventional vehicles. Zhao et al. [23] developed an eco-driving support system based on driving simulator and achieved about 5% reduction in CO_2 emissions and fuel consumption. Hu et al. [24] developed an eco-driving strategy for hybrid vehicles operating on rolling terrain based on simulation, and the results indicated an improvement in fuel efficiency from 5.0% to 8.9% on mild slopes and from 15.7% to 16.9% on steep slopes.

The literature search revealed three research gaps. First, despite the large body of research on the benefits of eco-driving, quantitative assessments performed for heavy-duty vehicles, in general, and transit fleets, in particular, are few. In the three papers that focused on buses, one did not provide any information regarding driving cycles or service type, and the remaining two [12,15] were limited to a single route. As such, little is known about the varying degree of fuel and emissions reduction eco-driving can achieve for different service types. The lack of evidence for the effectiveness of

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