UNIVERSITY OF CALIFORNIA CENTER ON ECONOMIC COMPETITIVENESS IN TRANSPORTATION

BERKELEY ◆ IRVINE ◆ LOS ANGELES ◆ RIVERSIDE ◆ SANTA BARBARA — UCCONNECT — CAL POLY POMONA

QUARTERLY PROGRESS REPORT

Fiscal Year 2014/2015 , Quarter 4th

Caltrans Task Manager:Harold Hunt Task ID/Project ID (for Caltrans use only):

Task Order No.: TO 19 Contract No.: 65A0529

1. Task Title: Potential Greenhouse Gas Emission Reductions from Optimizing Urban Transit Networks

2. Describe last quarter’s tasks/deliverables:

The first quarter of our project runs from March 1 to June 30, 2015, which corresponds to the 4th quarter of the 2014-15 fiscal year. Our work was focused on Task 1 (literature review).
The deliverable for Task 1 is : A literature review on the state of the art in Emissions from Public Transportation and Transit Network Design.
This deliverable was completed one month ahead of schedule, and is attached.
Consistent with our Project Timeline, we also started working on Task 2 (Model Extensions) and have made good progress to date.

3. Describe next quarter’s tasks/deliverables and their due dates:

Task 2: Model Extensions. No deliverable is due in the second quarter.

4. Describe Project Status:

- Are you on time with your schedule?
  ☒ YES
  ☐ NO

- Are you on budget?
  ☒ YES
  ☐ NO

- Are you on scope?
  ☒ YES
  ☐ NO

If the answer to any of the above is NO, please explain below:

5. Estimated percent of work completed: 25%
Estimated percent of budget expended: 20%

6. What are your expenditure projections for the next four quarters or until the project's end?

FY 15/16; Q1	FY 15/16; Q2	FY 15/16; Q3	FY 15/16; Q4
$ 30	$ 30	$ 20	$

Use this area for any additional information. Clearly identify which Section this information applies to.

Submitted By: Samer Madanat
Date: July 1, 2015

Literature Review for Potential Greenhouse Gas Emission Reductions from Optimizing Urban Transit Networks

Contract Number:	65A0529
Task Order Number:	TO 019
Authors:	S. Madanat, A. Horvath, H. Cheng, A. Mao

Introduction

In recent decades, public transportation's role in mitigating climate change has received more attention. Compared to private automobiles, studies suggest that public transit systems with high occupancy rates and efficient designs can reduce greenhouse gas (GHG) emissions significantly (Hodges 2009). However, many current transit systems are not designed to reduce environmental impacts. In the U.S., the average energy intensity of transit buses is even higher than passenger cars due to the current low ridership rate of transit buses (Davis et al. 2009, Chester and Horvath 2009). Recent investments in the transit sector to reduce GHG emissions have concentrated on purchasing efficient replacement vehicles. There has been little focus on the potential of operational and design modifications, such as changes in headways, route and stop spacings, to reduce transit emissions.

This literature review consists of three parts. The first part discusses the GHG emissions inventories from public transportation. The second part discusses current approaches to reducing public transit emissions. The third part describes different methodologies for solving transit network design problems.

Emissions from public transportation

With all the combustion of petroleum-based products, GHG emissions from transportation have accounted for about 28% of total GHG emissions in the United States, making it the second largest contributor after the electricity sector (EPA 2014). This highlights the need to better understand the GHG emissions in transportation. Among all the potential ways to reduce emissions, shifting automobile trips to public transit systems is a common option. However, the GHG emissions from public transit itself are not negligible.

Many studies have attempted to measure the amount of GHG emissions of public transit. Yet most of them have focused on measuring the tailpipe emissions that occur during the vehicle operations phase and are largely dependent on the vehicle-miles-traveled (Small 1988, Faiz 1996, Pruca et al. 2001, Turrio-Baldassarri et al. 2003, Nylund et al. 2004, Wayne et al. 2004 and 2008, Shorter et al. 2005, Vincent et al. 2006, Zhai et al. 2008, Hesterberg et al. 2008, Tong et al. 2011, Lau et al. 2011, Li et al. 2012, Wayne 2013). Davis and Hale (2007) analyze the GHG emissions inventory of public transit based on the estimations of total passenger-miles-traveled, mode splits of bus and rail, and the carbon-dioxide tailpipe emissions factors of transit vehicles. They find that in 2005, the U.S. public transportation sector emits approximately 13 million metric tons of CO_2. Weigel et al. (2009) present a calculation tool for estimating the emissions for a complete vehicle operations phase, considering tailpipe exhaust emissions along with other affiliated sources such as fugitive refrigerant emissions.

In a wider scope, transit emissions do not only occur during the vehicle operations phase. Some studies assess the transit emissions over the life cycle of fuel consumption (Sheehan 1998, Beer et al. 2002 and 2004, Brinkman et al. 2005, Puchalsky 2005, Karman 2006, Clark et al. 2007, Edwards et al. 2011), which may include fuel production, transportation, storage, distribution, and finally combustion. The emissions from these sources are also called wells-to-wheels emissions. Puchalsky (2005) compares the partial fuel-cycle emissions of Light Rail Transit (LRT) and Bus Rapid Transit (BRT), considering both fuel delivery and fuel combustion. Karman (2006) presents a case study of Beijing, measuring the GHG emissions of compressed natural gas (CNG) buses and conventional diesel buses. The analysis defines factors of fuel-based life-cycle emissions that account for both tailpipe emissions and the emissions from all the upstream stages of fuel consumption.

Furthermore, when evaluating a transit system as a whole, the process of manufacturing and repairing transit vehicles, constructing and maintaining the transit infrastructure creates GHG emissions as well. Life-cycle emissions from entire transit systems have not been commonly addressed in the literature. What is available includes: Ally and Pryor (2007) analyze the GHG emissions of diesel, natural gas and hydrogen fuel cell bus systems, introducing both the fuel-cycle emissions and the emissions from bus manufacturing. Cui et al. (2010) present a case study of the BRT system in Xiamen, China. They assess the carbon footprint of Xiamen BRT system on a wider scope that includes vehicle and infrastructure production, maintenance, recycling. Chester and Horvath (2009) and Chester (2008) employ a hybrid life-cycle-assessment model to provide a generalized analysis on the emissions inventory of various transit technologies by considering four emissions sources: fuel production, infrastructure, vehicle operation and vehicle non-operation. The emissions estimation results from Chester and Horvath

(2009) and Chester (2008) will be used in this work.

Approaches to reducing public transit emissions

EPA has suggested using alternative fuels that are less carbon-intensive, improving fuel-efficiency of vehicles, and more compact land-use patterns to reduce passenger-miles-traveled as efforts to mitigate GHG emissions (EPA 2014). There have been many real-world examples corresponding to these categories; mainly as use of alternative fuels such as biodiesel, CNG, LPG and hybrid; retrofitting existing engines or purchasing more fuel-efficient engines; cities that employ transit-oriented development.

Most investments in the transit sector to address GHG emissions have focused on purchasing efficient replacement vehicles and encouraging mode shifts from private automobile by increasing transit LOS (Gallivan and Grant 2010). Those approaches can be expensive. Meanwhile, simply increasing the transit service level, aimed at attracting drivers to the transit systems, can sometimes backfire, causing a net increase in GHG emissions (Griswold et al., under review). Public transit systems that operate with low ridership rates have been shown to have higher per-passenger-kilometer emissions than the automobile (Davis et al. 2009, Chester and Horvath 2009, Taptich and Horvath 2014). Evaluating the effect of transit system design and operational modifications on GHG emissions is essential.

There have been important studies done in this area, but some questions still remain. Saka (2003) concludes that bus stops impede the flow of traffic, which depending on the traffic intensity can result in congestion and excessive emissions on the bus route. Shrestha and Zolnik (2013) provide a case study of the bus service for the city of Fairfax, Virginia, and find that eliminating some bus stops could improve travel time and reduce operating costs. Bus-related emissions could also be substantially lower after the elimination of the bus stops. Alam and Hatzopoulou (2014) present possible approaches to reducing transit bus emissions on a busy corridor: using alternative fuels or improving traffic operations. They find that improving traffic operations alone, such as applying transit signal priority (TSP) and relocation of bus stops, could significantly reduce GHG emissions.

Besides the redistribution of transit stations, there are other network design and operational modifications that have not been commonly considered, such as improving schedule, changing route spacing, and choosing the best transit technology for the city characteristics. Griswold et al. (2013) provide a thorough investigation of the relation between costs and GHG emissions in transit systems while considering a broad range of potential transit system design and operational modifications. They demonstrate that, for a trunk-only, grid-network transit system designed to minimize societal costs while serving a fixed demand elasticity, a city can achieve reductions in GHG emissions by reducing the transit LOS provided to the users. However this result might not hold for the more realistic case where transit demand is elastic. The reductions in the transit LOS, aimed at reducing the transit GHG emissions, may lead to a city-wide increase in the emissions as users shift to more polluting modes such as private automobiles. Moreover, Griswold et al. (2013) used a simple trunk system without network hierarchy in their model, which limits the realism of their results. Sivakumaran et al. (2014) suggest that capital-intensive and large-capacity transit technologies, such as metro, are economically feasible only when combined with other transit technologies that act as feeders. A metro system is usually designed with large stop and route spacings. With walking assumed to be the only access mode to the transit system, the trunk-only model utilized in Griswold et al. (2013) may unfairly place metro at a comparative disadvantage. In order to make mode comparisons realistic, it is necessary to incorporate feeder transit modes and to investigate how it affects the comparisons between different trunk transit modes.

Methods for solving transit network design problems

There have been several studies on optimizing transit system design with respect to minimizing agency and user costs, yet the environmental impacts are rarely addressed (Dessouky et al. 2003; Saka 2003; Diana et al. 2007; Griswold et al. 2013 and 2014). Continuum approximation (CA) methods are widely employed to optimize network attributes such as stop spacing (Kuah and Perl 1988; Parajuli and Wirasinghe 2001) and headway (Chien et al. 2010). Some other studies analyze the structure of transit networks using CA methods, such as grids, radial networks (Byrne 1975; Tirachini et al. 2010), and hub-and-spoke networks (Newell 1979). Based on a grid network, Sivakumaran et al. (2014) use CA methods to quantify the cost-effectiveness of providing bus access to different trunk technologies. While CA methods use stylized transit network types and simplifying approximations, they are able to provide closed-form solutions and allow the identification of cause-and-effect relationship between inputs and design outputs (Daganzo 2010). Furthermore, the results can be implemented by adjusting the optimal design values to existing street networks with minor loss in optimality, as the recent design of the Barcelona bus system has shown (Estrada et al. 2011).

Some studies use heuristic methods instead to solve transit network design problems. Most of them address the complex, non-stylized networks of real cities where it is usually impractical to obtain analytical optimal solutions. With increasing computational capacity of computers in recent decades, meta-heuristic methods such as Genetic Algorithm and Tabu Search and Simulated Annealing are used to find efficient transit routes on existing street networks and efficient timetables for operating transit vehicles (Pattnaik et al. 1998; Yang et al. 1999; Chakroborty 2002 and 2003; L. Fan and Mumford 2007, 2008 and 2009). However, these methods can still be computationally expensive while providing few general insights into the cause-and-effect relationship between inputs and design outputs.

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