Maximizing the Fine Particulate Matter ($PM_{2.5}$) Public Health Benefits of Urban Bus Fleet Retrofits

Susan L. Greco, Steven J. Melly, and Jonathan I. Levy, Harvard School of Public Health, Boston, MA, USA

ABSTRACT

Installing diesel particulate filters (DPF) in urban buses is a common retrofit under consideration by transit authorities and other stakeholders to reduce fine particulate matter ($PM_{2.5}$) emissions. As resources are generally limited, transit authorities may be faced with choices regarding which buses and which routes to upgrade. Optimizing based on public health benefits would be desirable, as the population exposure impacts of motor vehicle emission reductions can vary greatly in an urban area, but data are not generally available to incorporate spatial variations in the emissions-to-exposure relationship. In this study, we investigate using the intake fraction (emissions-to-exposure relationship) to maximize the public health benefits resulting from DPF retrofits. We consider a case study of 25 Massachusetts Bay Transportation Authority (MBTA) bus routes, and we develop route-specific $PM_{2.5}$ intake fractions based on estimates for all road segments in the Boston area. We illustrate the implications of optimizing based on the intake fraction by first evaluating the benefits associated with retrofitting half of the buses from each route, and then comparing these benefits to those obtained by retrofitting the same number of buses, but exclusively from the high intake fraction routes. Under our baseline model assumptions, we found benefits to increase by 20% when optimizing based on intake fractions, with net benefits (benefits less costs) increasing by a factor of 2.
The concentration-response (C-R) function and the value of a statistical life (VSL) were extremely influential in the benefit-cost analysis, with lower bound C-R and VSL estimates yielding negative net benefits and the upper-bound C-R function increasing net benefits by an order of magnitude compared to baseline assumptions. Regardless of model uncertainties, our analysis demonstrates a viable approach for maximizing the population exposure benefits of motor vehicle retrofits, and subsequent analyses will investigate how the benefits are distributed among impacted communities, to arrive at socially optimal control strategies.

Fig. 1. Study Area

OBJECTIVES

•When half of 138 buses on 25 routes are retrofit with diesel particulate filters (DPFs), can the iF be used to maximize public health benefits of $PM_{2.5}$ reductions?
•Compare **Uniform** DPF application (half of buses on each route) with **High iF** Retrofit Scheme (all buses on 11 highest routes)

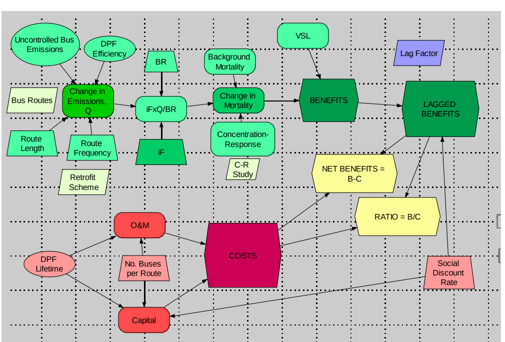

Fig. 2. Benefit-Cost Analysis Framework

The intake fraction for the j^{th} Road Segment at the k^{th} hour is:

iF_{jk} = Population Exposure/Emissions

= $\sum_i(\Delta C_{ik} P_{ij})$ BR / Q, where

ΔC_{ik} = Concentration from CAL3QHCR model output in Region i at Hour k

P_{ij} = Population in Region i for Road Segment j

BR = nominal Breathing Rate of 20 m^3/d

Q = Fixed mobile source $PM_{2.5}$ emissions from road segment j

METHODS

STUDY AREA (Fig. 1)

- 25 MBTA bus routes included in the study coded in ArcGIS

BENEFIT-COST ANALYSIS (Fig. 2)

CHANGE IN EMISSIONS, ΔQ

- DPF reduces $PM_{2.5}$ emissions by 85-99%

POPULATION EXPOSURE, iF ΔQ / BR

- Vehicular iFs were determined for 23,398 road segments (see Equation above) using:

1. CAL3QHCR, a Gaussian line-source model for assessing the impacts of motor vehicle traffic on roadside air quality. It allows for a year's worth of hourly-resolved meteorological inputs including temperature, wind speed and direction, Pasquill-Gifford stability class, and urban mixing height. -> ΔC_{ik}
2. ESRI (2000 Census) to determine the populations in 6 Regions around the midpoint of each road segment: between 0-50 m, 50-100 m, 100-200 m, 200-500 m, 500-1000 m, and 1000-5000 m. -> P_i

CHANGE IN MORTALITY

- Concentration-Response functions from the ACS cohort mortality study (Pope *et al.*, 2002); background mortality rate for MA

BENEFITS

- The value of a statistical life (VSL) framework; Benefits lagged over 5-years

COSTS

- Capital and O&M; social discount rate

RESULTS

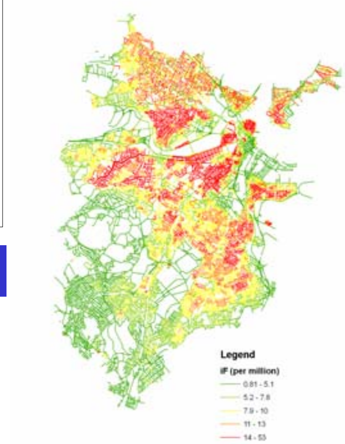

Fig. 3. Intake Fraction per Road Segment

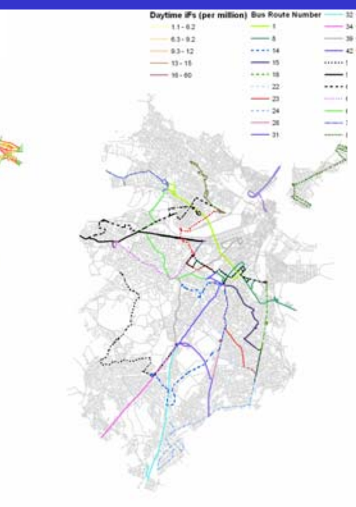

Fig. 4. 25 Bus Routes Considered for Retrofits

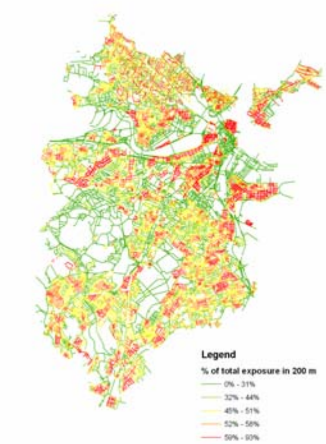

Fig. 5. Fraction of Total Exposure within 200 m

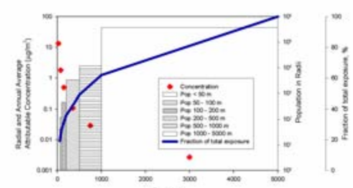

Fig. 6. Variation in Concentration, Population and iF Around a Road Segment

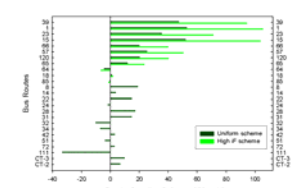

Fig. 7. Mid-Value of Benefit-Cost Assessment per Bus Route for both Retrofit Schemes

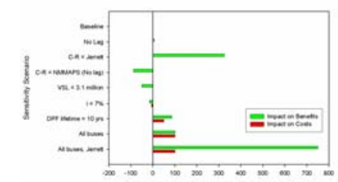

Fig. 8. Sensitivity Analysis of BCA

DISCUSSION

•The intake fraction varies over 2 orders of magnitude across the road segments (Fig. 3)
•The average intake fraction per Bus Route varies by a factor of 3 across the 25 routes (Fig. 4)
•The fraction of total exposure that is met within 200 m of the midpoint of each road varies from 0 – 93% across all road segments, indicating that modeling within that domain can capture most, or almost none, of the impacts for different road segments (Fig. 5)
•The population distribution around each road segment (P_{ij}) is unique. The attributable concentration (ΔC_{ik}) varies by hour. The combination of P_{ij} and ΔC_{ik} determine the intake fraction and fraction of total exposure (shown in Fig. 6 for one road, annual average).
•Under Baseline conditions, Net Benefits can be twice as great for the High iF Retrofit Scheme compared to Uniform (Fig. 7). Using the Jerrett et al, 2005 C-R estimate yields positive net benefits across all routes. Halving the VSL halves the Benefits. (Fig. 8)

NEXT STEPS

•Examine socioeconomic distribution of these Benefits.

ACKNOWLEDGEMENTS
This research was supported by the EPA/Harvard Center on Ambient Particle Health Effects (R827353) and the National Science Foundation (SES-0324746). The authors wish to thank Trinity Consultants for use of the BREEZE suite of models and Steve Hanna and Jack Spengler for providing useful input on the framing of the study.
Please e-mail sgreco@hsph.harvard.edu for more information.