TECHNICAL APPENDICES

Moving Cooler

AN ANALYSIS OF TRANSPORTATION STRATEGIES FOR REDUCING GREENHOUSE GAS EMISSIONS

Cambridge Systematics, Inc.

ULI Urban Land Institute

TECHNICAL APPENDICES

Moving Cooler

An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions

Prepared for
***Moving Cooler* Steering Committee**

Prepared by
Cambridge Systematics, Inc.

Revised October 2009

Urban Land Institute

About the Urban Land Institute

The mission of the Urban Land Institute is to provide leadership in the responsible use of land and in creating and sustaining thriving communities worldwide. ULI is committed to

- Bringing together leaders from across the fields of real estate and land use policy to exchange best practices and serve community needs;
- Fostering collaboration within and beyond ULI's membership through mentoring, dialogue, and problem solving;
- Exploring issues of urbanization, conservation, regeneration, land use, capital formation, and sustainable development;
- Advancing land use policies and design practices that respect the uniqueness of both built and natural environments;
- Sharing knowledge through education, applied research, publishing, and electronic media; and
- Sustaining a diverse global network of local practice and advisory efforts that address current and future challenges.

Established in 1936, the Institute today has more than 35,000 members worldwide, representing the entire spectrum of the land use and development disciplines. ULI relies heavily on the experience of its members. It is through member involvement and information resources that ULI has been able to set standards of excellence in development practice. The Institute has long been recognized as one of the world's most respected and widely quoted sources of objective information on urban planning, growth, and development.

Library of Congress Cataloging-in-Publication Data

Moving Cooler : an analysis of transportation strategies for reducing greenhouse gas emissions / prepared for Moving Cooler Steering Committee ; prepared by Cambridge Systematics, Inc.

p. cm.

"July 2009."

ISBN 978-0-87420-118-5

1. Transportation--Environmental aspects--United States. 2. Transportation and state--Environmental aspects--United States. 3. Greenhouse gas mitigation--United States. I. Cambridge Systematics. II. Moving Cooler Steering Committee.

TD195.T7.M68 2009

363.738'746--dc22

2009029872

Copyright ©2009 by the Urban Land Institute

All rights reserved. No part of this book may be reproduced in any form or by any means, electronic or mechanical, including photocopying and recording, or by any information storage and retrieval system, without written permission of the publisher.

Urban Land Institute
1025 Thomas Jefferson Street, N.W.
Washington, D.C. 20007-5201

ULI Catalog Number: M87

10 9 8 7 6 5 4 3 2 1

Printed in the United States of America.

ULI Project Staff

Dean Schwanke
Senior Vice President, Publications

James A. Mulligan
Managing Editor

Elizabeth Horowitz, Publications Professionals LLC
Manuscript Editor

Betsy VanBuskirk
Creative Director/Book Design

Byron Holly
Senior Designer

Anne Morgan
Designer/Cover Design

Craig Chapman
Director, Publishing Operations

Cambridge Systematics, Inc., Research Team

Joanne R. Potter
Project Manager

Technical Team

William Cowart
Robert Hyman
David Jackson
Christopher Porter
Arlee Reno

Contributors

Daniel Beagan
Laurie Hussey
David Kall
Danny Kwan
Richard Margiotta
Robert Taggart
Wendy Tao
Herbert Weinblatt

Project Facilitation

W. Steve Lee
Collaborative Strategies Group, LLC

Study Author

Cambridge Systematics, Inc.

Cambridge Systematics, Inc., specializes in transportation, dedicated to ensuring that transportation investments deliver the best possible results. It is recognized as a leader in the development and implementation of innovative policy and planning solutions, objective analysis, and technology applications. Cambridge Systematics works to build the capacity of the transportation community to understand and address both sides of the climate change challenge: to develop strategies to reduce greenhouse gas emissions from transportation, and to prepare for the potential effects of climate change on transportation systems.

Moving Cooler Steering Committee

American Public Transportation Association

Rob Padgette

Environmental Defense Fund

Michael Replogle

Federal Highway Administration

April Marchese and John Davies

Federal Transit Administration

Tina Hodges

Intelligent Transportation Society of America

Leslie Bellas

Natural Resources Defense Council

Deron Lovaas and Nathan Sandwick

Shell Oil Company

Miriam Conner

Urban Land Institute

Robert Dunphy, Rachelle Levitt, and Dean Schwanke

U.S. Environmental Protection Agency

Ken Adler

Project Facilitation

Collaborative Strategies Group, LLC

Collaborative Strategies Group, LLC, is a consulting firm specializing in facilitation, public outreach and communication, project management, and public policy development for governments, businesses, communities, and organizations that need help navigating complex problem-solving, decision-making, and relationship-building issues

Introduction

The technical appendices contained in this document provide documentation of the analysis conducted for the *Moving Cooler* research. *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions* (July 2009) assessed the potential effectiveness of a broad variety of transportation strategies – under a wide range of different assumptions – to reduce greenhouse gas emissions. The independent, peer-reviewed study was cosponsored by 13 organizations representing government, industry, nongovernmental organizations, foundations, and the transportation community. This study does not provide any specific recommendations about the direction of transportation and climate change policies. The *Moving Cooler* report is available for purchase at: http://www.uli.org

For those interested in further detail about the technical approach underpinning the *Moving Cooler* research, the following appendices provide the information, data, and methods used during the analysis and support the findings documented in the Report.

The appendices address the specific strategy definitions, baseline and sensitivity test assumptions, greenhouse gas (GHG) emission reduction assumptions and methodologies, and cost and savings assumptions and methodologies. The appendices are organized into five sections:

A. *Moving Cooler* Emission Reduction Strategies and Actions;

B. Assumptions and Methodology Used in *Moving Cooler* Effectiveness Analysis;

C. Assumptions and Methodology Used in *Moving Cooler* Cost Analysis;

D. *Moving Cooler* GHG Reduction and Cost Result Tables; and

E. *Moving Cooler* Equity Discussion and Analysis.

Appendix A describes the GHG reduction strategies selected as a focus in *Moving Cooler*. This includes strategy-specific implementation details (geographic scope and timing) at each of the three levels of deployment. Appendix A overall supports Chapter 2 in the Report and provides additional detail of the parameters used for each strategy, as summarized in Table 2.1 in the Report.

Appendix B provides background information regarding the major assumptions, data sources, and analytic approaches used to assess the effectiveness of individual strategies and strategy bundles in reducing GHG emissions. This information supports Section 3.2, 3.3 and 3.5 of the Report.

- Section I presents the major assumptions about overall baseline and trend conditions that are used throughout the analysis regarding growth in vehicle miles traveled (VMT), fuel prices, and fuel efficiency.

- Section II presents the specific assumptions, data and analytic methodologies applied in the assessment of measures in each of the nine strategy groups.

- Section III presents the methodological approaches and assumptions for developing different National on-road transportation GHG emission baselines, and the related impact on individual strategy effectiveness results.

- Section IV presents the method supporting the bundle development process, GHG emissions accounting, and assumptions on accounting for strategy interactions.

- Section V presents the assumptions and method of accounting for the impact of induced demand in the assessment of the effectiveness of strategies in reducing GHG emissions.

Appendix C provides background information regarding the major assumptions, data sources, and analytic approach used to assess the costs and cost-effectiveness of individual strategies and measures in reducing greenhouse gases. This information supports Section 3.4 of the Report.

Appendix D provides detailed data tables showing annual GHG reductions and costs by strategy and by bundle. This information supports the results presented in the tables and figures in Chapter 4 of the Report.

Appendix E provides background on the equity considerations raised by transportation greenhouse gas reduction, identifies the equity issues associated with implementing the different *Moving Cooler* strategies, and looks at some of the actions needed to resolve them.

The authors hope this information is useful to the transportation community and contributes to the body of research underway on this critical topic.

Cambridge Systematics, Inc.

October 2009

Table of Contents

Appendix A – *Moving Cooler* Emission Reduction Strategies and Actions **A-1**

Appendix B – Assumptions and Methodology Used in *Moving Cooler* Effectiveness Analysis **B-1**
- I. Baseline Assumptions B-1
- II. Strategy-Specific Assumptions and Methodology B-7
- III. Sensitivity Analysis Assumptions and Methodology B-67
- IV. Bundles and Interaction Assumptions and Methodology B-67
- V. Induced Demand Assumptions and Methodology B-72

Appendix C – Assumptions and Methodology Used in *Moving Cooler* Cost Analysis **C-1**
- I. General Cost-Effectiveness Methodology C-1
- II. Fuel and Vehicle Operating Cost Assumptions C-2
- III. Strategy-Specific Cost Assumption C-4

Appendix D – *Moving Cooler* Data Tables **D-1**

Appendix E – *Equity* **E-1**

List of Tables

APPENDIX A

A.1 *Moving Cooler* Greenhouse Gas Emission Reduction Strategies A-4

APPENDIX B

Section I – Baseline Assumptions

1. *Moving Cooler* Fuel Economy Summary B-7

Section II – Strategy-Specific Assumptions and Methodology

1.1 Share of CBD Public Parking On-Street B-9
1.2 Annual Percent VMT Reduction for On-Street Parking Strategy B-10
1.3 Percentage of Free Spaces B-11
1.4 Annual Percent VMT Reduction (Aggressive Deployment) B-11
1.5 Annual Percent VMT Reduction (Maximum Deployment) B-11
1.6 Households with Free On-Street Parking B-12
1.7 Annual Percent VMT Reduction (Aggressive Deployment) B-12
1.8 Annual Percent VMT Reduction (Maximum Deployment) B-13
2.1 CUTR VMT Forecasts by Census Tract Density (Annual VMT per Capita) B-17
2.2 Population Forecast Comparison B-19
2.3 Growth Allocation Assumptions B-20
2.4 VMT Reduction for Compact Development B-22
2.5 Comparison of *Moving Cooler* and Growing Cooler Parameters and Results B-22
2.6 Housing Demand and Density B-23
3.1 Application of Pedestrian Environment Factor (PEF) Elasticities to VMT B-25
3.2 Percent Population Living in Area with Pedestrian Improvements B-26
3.3 Urban Area Bicycle Mode Shares by Fuel Price and Implementation Level B-29
4.1 Automobile VMT Displacement by Corridor and Level of Implementation B-38
4.2A CO_2 Emission Factors (Fuels) B-40
4.2B CO2 Emission Factors (Electricity Generation) B-40

List of Tables
(continued)

4.3 Other GHG Emission Factors B-41
4.4 Baseline GHG Emissions per Passenger Mile B-41
4.5 Transit Mode Share B-42
4.6 Passenger miles per Unlinked Trip B-42
4.7 Transit Load Factors B-44
4.8 Baseline GHG Emissions per Passenger-Mile B-44
4.9 Transit Load Factor Forecast B-45
4.10 Scenario GHG Emissions per Passenger-Mile B-45
5.1 Percentage of Expressways with 3+ Lanes per Direction Suitable for HOV Lanes B-48
5.2 Urban Expressways at LOS F B-48
5.3 Reduction in Fuel Consumption per One Minute of Time Savings B-48
5.4 Percent Reduction in Fuel Consumption for Five-Minute Savings (Strategy 5.5.1) B-49
5.5 Urban Expressways at LOS D or Greater B-49
5.6 Percent Reduction in Fuel Consumption for Five-Minute Savings (Strategy 5.1.2) B-49
5.7 Percent Reduction in Fuel Consumption for Five-Minute Savings (Strategy 5.1.3) B-50
5.8 Percentage Reduction in Fuel Consumption per One Minute of Time Savings .. B-50
5.9 Average Savings in Time B-51
5.10 Percent Reduction in Fuel Consumption for Five-Minute Savings (Strategy 5.1.4) B-51
5.11 2030 Population by Urban Group B-52
5.12 Shared Cars B-52
5.13 Commuter Measures Unit Impacts B-54
5.14 Commuter Strategies and Assumed Impacts B-55
6.1 Share of Total VMT Operating in Speed Ranges B-60
7.1 Eco-Driving Definition B-63
7.2 Initial Assumptions for Deployment of Operations Strategies B-64
7.3 Operations Strategies Relationships B-65

List of Tables
(continued)

9.1 Higher Weight Limits for Haulers of Natural Resources B-73
9.2 VMT Breakdown B-76
9.3 Calculation of Fuel Savings from Truck-Only Lanes B-77

Section IV. Bundles and Interaction Assumptions and Methodology

4.1 Population by Census Tract Density B-81
4.2 Application of Pedestrian Environment Factor (PEF) Elasticities to VMT B-81
4.3 Shared Cars B-82

APPENDIX C

1. Average Vehicle Operating Costs C-6
1.1 Total Implementation Costs – Congestion Pricing C-9
1.2 Total Implementation Costs – Intercity Tools C-10
1.3 PAYD and VMT Fee Implementation Costs C-11
2.1 Summary of Land Use Costs C-17
3.1 Pedestrian Master Plans and Cost Estimates C-19
3.2 Pedestrian Strategy Costs C-20
3.3 Bicycle Facility Assumptions C-21
4.1 Transit Load Factor Adjustment C-26
4.2 Operating Cost per Transit Trip C-26
4.3 Annual Implementation Costs C-27
4.4 Total Implementation Costs C-27
4.5 Transit Load Factor Adjustment C-28
4.6 Annual Implementation Costs (2010-2050) C-29
4.7 Total Implementation Costs C-29
4.8 Annual Implementation Costs (2010-2050) C-31
4.9 Total Implementation Costs C-31
4.10 Annual Implementation Costs C-32
4.11 Total Implementation Costs C-32

List of Tables
(continued)

5.1 New HOV Lane Annual Costs C-34
5.2 Car-Sharing Costs C-35
5.3 Commuter Program Costs C-38
5.4 Commuter Strategy Costs C-39
6.1 Total Implementation Costs C-40
6.2 Total Implementation Costs C-42
7.1 Operations Strategies Implementation Costs per Mile C-44

APPENDIX D

D.1 Annual Reductions (Level A, B, and C) (Short-Term: 2015, 2020) D-1
D.2 Annual Reductions (Level A, B, and C) (Long-Term: 2030, 2040, 2050) D-3
D.3 Percent Annual Reductions from Baseline (Level A, B, and C) (Short-term: 2015, 2020) D-5
D.4 Percent Annual Reductions from Baseline (Level A, B, and C) (Long-term: 2030, 2040, 2050) D-7
D.5 Percent Annual Reductions from 2005 (Level A, B, and C) (Short-term: 2015, 2020) D-9
D.6 Percent Annual Reductions from 2005 (Level A, B, and C) (Long-term: 2030, 2040, 2050) D-11
D.7 Cumulative Reductions (Level A, B, and C) (2020, 2030, 2050) D-13
D.8 Percent Cumulative Reductions from Baseline (Level A, B, and C) (2020, 2030, 2050) D-15
D.9 Annual Costs and Savings (Level A, B, and C) (2015) D-17
D.10 Annual Costs and Savings (Level A, B, and C) (2020) D-19
D.11 Annual Costs and Savings (Level A, B, and C) (2030) D-21
D.12 Annual Costs and Savings (Level A, B, and C) (2050) D-23
D.13 Cumulative Costs and Savings (Level A, B, and C) (2015) D-25
D.14 Cumulative Costs and Savings (Level A, B, and C) (2020) D-27
D.15 Cumulative Costs and Savings (Level A, B, and C) (2030) D-29
D.16 Cumulative Costs and Savings (Level A, B, and C) (2050) D-31

List of Tables
(continued)

D.17 Annual Reductions (Aggressive and Maximum) (Short-term: 2015, 2020) D-33

D.18 Annual Reductions (Aggressive and Maximum) (Long-term: 2030, 2040, 2050) D-33

D.19 Percent Annual Reductions from Baseline (Aggressive and Maximum) (Short-term: 2015, 2020) D-33

D 20 Percent Annual Reductions from Baseline (Aggressive and Maximum) (Long-term: 2030, 2040, 2050) D-34

D.21 Percent Annual Reductions from 2005 (Aggressive and Maximum) (Short-term: 2015, 2020) D-34

D.22 Percent Annual Reductions from 2005 (Aggressive and Maximum) (Long-term: 2030, 2040, 2050) D-35

D.23 Cumulative Reductions (Aggressive and Maximum) (2020, 2030, 2050) D-35

D.24 Percent Cumulative Reductions from Baseline (Aggressive and Maximum) (2020, 2030, 2050) D-36

D.25 Annual Costs and Savings (Aggressive and Maximum) (2015) D-36

D.26 Annual Costs and Savings (Aggressive and Maximum) (2020) D-36

D.27 Annual costs and Savings (Aggressive and Maximum) (2030) D-37

D.28 Annual Costs and Savings (Aggressive and Maximum) (2050) D-37

D.29 Cumulative Costs and Savings (Aggressive and Maximum) (2020) D-37

D.30 Cumulative Costs and Savings (Aggressive and Maximum) (2030) D-38

D.31 Cumulative Costs and Savings (Aggressive and Maximum) (2050) D-38

APPENDIX E

3.1 Equity Impacts of Greenhouse Gas Emission Reduction Strategies E-31

3.2 Weekday Toll Rates: PSRC Pricing Study E-38

3.3 PSRC Daily User Benefits From Tolling Application E-39

3.4 PSRC Daily User Benefits Versus Tolls From Tolling Application E-40

3.5 Analysis: Return on Investment by User Group: From Pricing Alone, From Reinvestment of Revenues, and From Combined Pricing and Reinvestment E-43

3.6 Quantitative Equity of San Francisco Long-Range Plan (T2035) Expenditures... E-44

3.7 Equity Analysis by Quintile of Income: Motor Fuel Expenses E-45

3.8 Equity Analysis: Return On Investment By User Group: From Fuel Taxes and Reinvestment of Revenues E-46

3.9 Distributional Impacts of Carbon Tax and Lump Sum Rebate E-47

3.10 Equity Analysis by Quintile of Income: Motor Fuel Expenses as a Percent of Income of U.S. Households (2007) E-49

3.11 Distributional Impacts of Carbon Tax and Lump Sum Rebate E-50

List of Figures

APPENDIX B

4.1 Historical and Projected Intercity Rail Passenger Miles B-37

4.2 Average CO_2 Emission Rates by Mode.. B-39

APPENDIX E

1.1 Willingness to Pay for Road Pricing by Income versus Price................................ E-6

1.2 Types of Road Pricing Strategies E-11

Appendix A

Moving Cooler Emission Reduction Strategies and Actions

Moving Cooler Emission Reduction Strategies and Actions

The attached table summarizes the greenhouse gas emission reduction strategies selected as the focus for *Moving Cooler* analysis.

The actions are organized into nine strategy categories:

1. Pricing Strategies;
2. Land Use and Smart Growth Strategies;
3. Nonmotorized Transportation Strategies;
4. Public Transportation Improvement Strategies;
5. Regional Ride-Sharing, Car-Sharing and Commuting Strategies;
6. Regulatory Strategies;
7. Operational and Intelligent Transportation Systems (ITS) Strategies;
8. Bottleneck Relief and Capacity Expansion Strategies; and
9. Multimodal Freight Strategies.

■ Levels of Deployment

The cost and effectiveness for each of these strategies will be assessed at three levels of implementation that assume increasingly aggressive scope, speed, and scale of effort:

A. **Expanded Current Practice: Expansion of Current Trends and State of Innovation.** This level of deployment assumes that the strategies are expanded and steadily implemented, consistent with existing practices for reducing GHG emissions, and focusing predominantly on major metropolitan areas.

B. **More Aggressive: Faster, Broader, Stronger Implementation.** Strategies are implemented sooner, more broadly, and more intensively. For example, pricing strategies would be implemented in a wide range of metropolitan areas, and requirements would be established for the penetration of PAYD insurance in all 50 states.

C. **Maximum Effort: Comprehensive, Rapid, Intense Implementation.** At this level, substantial policy changes and very significant increased levels of funding would be required to ensure that timely implementation of strategies at very high levels of intensity is achieved nationwide.

Illustrative specific thresholds for each strategy are defined below for each of these levels of implementation.

The parameters in Table A.1 include for each strategy the following dimensions: 1) the intensity of implementation; 2) disaggregated by the metropolitan/region type; 3) referencing the timing of implementation; and 4) describing the targeted area or activity (e.g., CBD, commute trips). The short hand for metropolitan/region type is as follows:

- **LH –** Large metropolitan areas (over 1M population, with higher per capita baseline transit use);
- LL – Large metropolitan areas (over 1M population, with lower per capita baseline transit use);
- MH – Medium metropolitan areas (between 400K and 1M population, with higher per capita baseline transit use);
- ML – Medium metropolitan areas (between 400K and 1M population, with lower per capita baseline transit use);
- SH – Smaller metropolitan areas (between 50K and 400K population, with higher per capita baseline transit use);
- SL – Smaller metropolitan areas (between 50K and 400K population, with lower per capita baseline transit use); and
- NU – Nonurban areas: outside a metropolitan area and rural, exurban, or with a population center of less than 50K inhabitants.

Timeframe for Analysis

The cumulative level of greenhouse gas reduction achieved by 2020, 2030, and 2050 will be calculated for each action, as will annual reductions through 2050. These benchmark years provide a common timeframe for analysis across strategies and actions. It is important to note that the amount of time required to implement individual strategies varies considerably: Implementation of some actions is underway now and will occur incrementally over several years (for example, many operational strategies); some actions can be initiated and put in place relatively easily within a few years; other actions require long lead times. Therefore the number of years a strategy is in place – and the resulting length of time it is assumed to contribute to GHG reductions – varies in this analysis.

Four approximate start-up dates are used: 2010, 2015, 2020, or 2025. These provide the estimated timeframe within which an action is started and begins to effect GHG levels. In instances where these dates do not fit a reasonably anticipated approach to a specific strategy, the Cambridge Systematics team used professional judgment to adjust these standardized dates.

Table A.1 *Moving Cooler* Greenhouse Gas Emission Reduction Strategies

Where not otherwise indicated, all measures are cumulative at higher levels of implementation.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Pricing Strategies			
Parking Pricing	**2015:** [LH, MH] **2020:** [LL, ML, SH] **2020:** [SL] Begin pricing all CBD/employment center/retail center street parking; price to encourage "park-once" behavior; complete over eight years.	**2010:** [LH, LL, MH] **2015**: [ML, SH, SL] Begin pricing all CBD/employment center/retail center street parking; price to encourage "park-once" behavior; complete over six years. **2020**: [LH, LL, MH] **2025:** [ML, SH, SL] Introduce tax/higher tax on free private parking lots with >100 spaces (retail and employer). This includes employer-subsidized/paid spots for employees and validated parking **2020**: [LH, LL, MH] **2025:** [ML, SH, SL] Require residential parking permit for on-street parking in residential areas; minimum cost: $200 biannually.	**2010**: [LH, LL, MH] **2015**: [ML, SH, SL] Begin pricing all CBD/employment center/retail center street parking; price to encourage "park-once" behavior; complete over four years. **2015**: [LH, LL, MH, ML, SH, SL] Introduce tax/higher tax on all free private parking lots with >50 spaces (retail and employer). This includes employer-subsidized/paid spots for employees and validated parking **2015**: [LH, LL, MH, ML, SH, SL] Require residential parking permit for on-street parking in residential areas; minimum cost: $400 biannually. Delivery and service vehicles must purchase multi-zone permit at double cost; visitor's permits at $3 per day. Phase in by 2020.
Cordon Pricing	Expanded best practice defined as implementation of currently proposed area pricing programs plus new implementation in longer term. **2015** LH; **2025** MH, SH; **2035** ML, LL, SL. Implement area pricing in CBD and major employment and retail centers. Ramp up over 10 years GHG emission benefits includes congestion reduction effects.	**2015** LH; **2020** MH, SH; **2025** ML, LL, SL. Implement area pricing in CBD and major employment and retail centers. Ramp up over 10 years. GHG emission benefits includes congestion reduction effects.	**2010** LH; **2015** MH; 2020 LL, ML, SH, SL. Implement area pricing in CBD and major employment and retail centers. Ramp up over 10 years. GHG emission benefits includes congestion reduction effects.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Congestion Pricing	Expand existing congestion pricing proposals to include all large regions starting in 2015 with pricing completed within 15 years. Average peak hour per mile price of $0.49 on congested segments GHG emission benefits includes congestion reduction effects.	**2015** LH and LL; **2020** MH and ML; **2025** SH and SL. Begin implementing areawide congestion pricing on all congested urban highways and roads with prices sufficient to maintain LOS D on facilities previously LOS F. Complete pricing within 10 years. Average peak hour per mile price of $0.65 on congested segments. GHG emission benefits includes congestion reduction effects.	**2015** LH and LL; **2015** MH and ML; **2020** SH and SL. Begin congestion pricing on urban roads with prices sufficient to maintain LOS D. Begin implementing congestion pricing on congested rural freeways and arterials with prices sufficient to maintain LOS C. Average peak hour per mile price of $0.65 on congested segments. GHG emission benefits includes congestion reduction effects.
Intercity Tolls	**2020** [All regions] Toll all intercity (rural) Interstates at a minimum of $0.02 per mile	**2015** [All regions] Toll all intercity (rural) Interstates at a minimum of $0.03 per mile	**2010** [All regions] Toll all intercity (rural) Interstates at a minimum of $0.05 per mile
Pay-As-You-Drive (PAYD) Insurance	**2010**: Require all states to permit the offering of per-mile insurance rates	**2010**: Require all states to permit the offering of per-mile insurance rates **2015**: At least 50 percent of policies in each state must have at least 50 percent mileage-based premiums. Assume increasing penetration due to market forces to 75 percent by 2025.	**2010**: Require all states to permit the offering of per-mile insurance rates **2015**: All auto insurance policies must have at least 75 percent of premiums paid for on a mileage basis, allowing but not mandating adjustments in mileage rates based on time of day, location, driving style or other factors. Assume 100 percent penetration by 2025.
VMT Fee	**2015:** Introduce a $0.01 per mile VMT fee to be paid based on odometer audit during each vehicle inspection/sale. Transition to electronic monitoring. [Include making annual inspections mandatory.]	**2015:** Introduce a $0.03 per mile VMT fee to be paid based on odometer audit during each vehicle inspection/sale. Transition to electronic monitoring.	**2015:** Introduce a $0.12 per mile VMT fee to be paid based on odometer audit during each vehicle inspection/sale. Transition to electronic monitoring.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Motor Fuel Tax and Carbon Price	**2015:** Increase the Federal and/or state gasoline and diesel taxes by $0.01 per mile (current $0.02 per mile). New tax is $0.40 per gallon indexed to fuel economy. Includes effect on fuel economy/carbon content.	**2015:** Increase the Federal and/or state gasoline and diesel taxes by $0.03 per mile (current $0.02 per mile). New tax is $0.82 per gallon indexed to fuel economy. Includes effect on fuel economy/fuel carbon content.	**2015:** Increase the Federal and/or state gasoline and diesel taxes to equivalent of current European fuel taxes; $0.12 per mile. New tax is $2.71 per gallon indexed to fuel economy. Includes effect on fuel economy/fuel carbon content.
Land Use and Smart Growth Strategies			
Combined Land Use Strategies	**2015** [Urban] All MPOs (or another regional agency designated by the MPO) develop a regional transportation and land use plan meeting-defined criteria for process and content. Plans collectively provide for at least 60 percent of new development in attached or small-lot detached units, in pedestrian- and bicycle-friendly neighborhoods (e.g., sidewalks, bicycle facilities, good connectivity) with mixed-use commercial districts and high-quality transit. The majority (nearly three-quarters) of communities adopt zoning and planning standards allowing for sufficient densities and requiring pedestrian-friendly design in these areas. State, regional, and local agencies work collaboratively on other implementation policies identified through these efforts.	2015 [Urban] Metropolitan land use plans call for at least 70 percent of new development in neighborhoods as described under [A]. Local plan/zoning code compliance is higher than under [A] (about 90 percent) as a result of stronger funding incentives. **2015** [all] All states adopt comprehensive planning laws similar to Washington State's Growth Management Act, requiring local comprehensive plans meeting-defined objectives, designation of urban growth/priority funding areas, and interagency plan review. Require comprehensive plan adoption and revision of zoning and other municipal codes for consistency by 2020. Require consistency with regional plans in metro areas (see above).	**2015** [all] States and metro agencies adopt enforceable growth boundaries around urban areas consistent with Oregon's model. **2015** [NU] Communities outside of metro areas adopt designated growth areas around town/village centers, accommodating growth at a minimum of eight units/acre. **2015** [all excluding NU] Metropolitan land use plans and local zoning collectively provide for at least 90 percent of new development in neighborhoods as described under [A]. Local plan/zoning code compliance is 100 percent. Density minimums are established inside urban growth boundaries. Requirements are established for minimum fractions of new jobs and housing to be located within walking distance of high-frequency transit service.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Combined Land Use Strategies (continued)	**2015** [all] Provide Federal and state transportation funding incentives/set-asides for: a) regional comprehensive planning activities; and b) local planning and implementation (infrastructure) activities that support land use objectives as described above.	Federal and state housing, community development, and economic development programs include requirements for consistency with regional plan and smart growth objectives. State, regional, and local governments work collaboratively on other implementation strategies.	**2015** [all excluding NU] MPOs have authority to disapprove local land use plans and ordinances if not consistent with regional plan; enforced through withholding of funding for transportation projects. Continuation of cooperative action on implementation strategies.
Nonmotorized Transportation Strategies			
Combined Strategies – Pedestrian	**2015 [Urban]** All new developments have buffered sidewalks on both sides of the street, marked/signalized pedestrian crossings at intersections on collector and arterial streets, lighting New or fully reconstructed streets in denser neighborhoods (>4,000 persons/sq mi and business districts) incorporate traffic calming measures such as bulb-outs and median refuges to shorten street-crossing distances "Complete streets" policies adopted by state and local transportation agencies, requiring appropriate pedestrian accommodations on all roadways **2025 [Urban]** Existing streets within one-quarter mile of transit stations, schools, and business districts are audited for pedestrian accessibility and retrofitted with curb ramps, sidewalks, and crosswalks	**2020 [Urban]** Existing streets within one-half mile of transit stations, schools, and business districts are audited for pedestrian accessibility and retrofitted with curb ramps, sidewalks, crosswalks, and limited traffic calming measures as appropriate to improve pedestrian accessibility.	**2020 [Urban]** Same as Level B, but with more extensive traffic calming.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Combined Strategies – Bicycling	**2015** [all] "Complete streets" policies adopted by state and local transportation agencies, requiring appropriate bicycle accommodations on all roadways Bicycle parking provided at all commercial destinations All new commercial buildings >100,000 square feet required to provide showers, lockers, and covered/protected bicycle parking; all new multi-unit residential buildings have indoor bicycle parking Buses fitted with bicycle carriers, rapid transit stations have bicycle parking, all rapid transit lines are bike-accessible during off-peak hours School curriculums include safe cycling skills for children **2015** [Urban] Primary central business districts have a "bike station" that provides services, including parking, rentals, repair, changing facilities, and information	**2015 – plan/2020 – implementation** [all excluding NU] Bicycle accommodations provided to create a continuous network of routes with approximately one-half-mile spacing. The bicycle network consists of a combination of bicycle lanes, bicycle boulevards, and shared-use paths provided at combined one-half-mile spacing (half bicycle lanes and one-quarter each bicycle boulevards and shared-use paths), implemented in areas with population density >2,000 persons per square mile. Bicycle boulevards (on residential streets) include traffic diverters to limit automobile traffic on these routes.	**2015** [all excluding NU] New development areas are planned with a network of off-street paths at approximately one-quarter to one-half-mile intervals. City-level plans support linkages among local paths. **2015 – plan/2025 – implementation** [all excluding NU] The bicycle network consists of a combination of bicycle lanes, bicycle boulevards, and shared-use paths provided at combined one-quarter-mile spacing (half bicycle lanes and one-quarter each bicycle boulevards and shared-use paths), implemented in areas with population density >2,000 persons per square mile. **2015** [all excluding NU] "Bike stations" are located at all major activity centers and transit hubs as well as in the CBD.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Combined Strategies – Bicycling (continued)	**2015 – plan/2025 – full implementation** [all excluding NU] Citywide and/or regional plans developed and implemented for on-street bicycle accommodations to create a continuous network of routes. The network includes bicycle lanes at one-mile intervals, and other facilities (shared-use markings, signed routes using neighborhood streets) at one-mile intervals, for a combined network density of one-half mile, implemented in areas with population density >2,000 persons per square mile.		
Public Transportation Improvement Strategies			
Fare Measures	**2010** [LH] **2015** [LL, MH, SH] **2020** [ML, SL] Lower fares by 25 percent except where already at capacity. Decrease the cost of passes so as to provide at least a further 25 percent discount from the cost of equivalent single-fare purchases.	**2010** [LH**] 2015** [LL, MH, SH] **2020** [ML, SL] Lower fares by 33 percent. Decrease the cost of passes so as to provide at least a further 33 percent discount from the cost of equivalent single-fare purchases.	**2010** [LH, LL, MH, SH, ML, SL] Lower fares by 50 percent

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Increased Levels of Service/Improved Travel Times	**2015** [LH] **2020** [LL, MH, SH] **2025** [ML, SL] Implement signal prioritization, limited stop service, etc. over five years to improve travel speed an additional 10 percent **2010** [LH] **2020** [LL, MH, SH] **2025** [ML, SL] Increase transit level of service by 1.5 times trend revenue mile expansion rates. Investments targeted in areas with at least 4,000 persons/square mile or that otherwise facilitate increases in pax/VRM	**2010** [LH] **2015** [LL, MH, SH] **2020** [ML, SL] Implement signal prioritization, limited stop service, signal synchronization, intersection reconfiguration, etc. over five years to improve travel speed an additional 15 percent **2010** [LH] **2020** [LL, MH, SH] **2025** [ML, SL] Increase transit level of service by two times trend revenue mile expansion rates. Investments targeted in areas with at least 4,000 persons/square mile or that otherwise facilitate increases in pax/VRM	**2010** [LH] **2015** [LL, MH, SH] **2020** [ML, SL] Implement signal prioritization, limited stop service, signal synchronization, intersection reconfiguration, AVS, etc. over three years to improve travel speed an additional 30 percent; boost reliability by 40 percent; boost ridership attraction through integrated transit fare systems; full scale BRT deployment where it makes sense. **2010** [LH] **2020** [LL, MH, SH] **2025** [ML, SL] Increase transit level of service by four times trend revenue mile expansion rates. Investments targeted in areas with at least 4,000 persons/square mile or that otherwise facilitate increases in pax/VRM
Expanded Urban Public Transportation	**2010** Expand service proportional to 3 percent per year ridership growth. Includes all transit modes.	**2010** Expand service proportional to 3.53 percent per year ridership growth. Includes all transit modes.	**2010** Expand service proportional to 4.67 percent per year ridership growth. Includes all transit modes.
Intercity Bus and Rail/High-Speed Rail	**2010** [all] Increase Federal capital and operating assistance over baseline trend by 5 percent per year for 20 years to improve service in existing markets and expand operation of Amtrak-associated motor coach service. **2015** Provide an additional pool of funding for high-speed rail, either incremental or in new rights-of-way, for 3-5 selected key markets, with a 20-year full implementation horizon	**2010** [all] Increase Federal capital and operating assistance over baseline trend by 10 percent per year for 20 years to improve service in existing markets, introduce rail in new markets, expand operation of Amtrak-associated motor coach service, and fund/subsidize intercity bus service in additional markets. **2015** Provide an additional pool of funding for high-speed rail, either incremental or in new rights-of-way, for 5-7 selected key markets, with a 15-year full implementation horizon.	**2010** [all] Double Federal capital and operating assistance over baseline trend in 2010 then increase by an additional 10 percent per year for 20 years to improve service in existing markets, introduce rail in new markets, and fund/subsidize a national network of intercity bus service. **2010** Provide an additional pool of funding for high-speed rail, either incremental or in new rights-of-way, for regional networks and additional selected key markets, with a 15-year full implementation horizon

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Regional Ride-Sharing, Car-Sharing and Commuting Strategies			
HOV Lanes	**2010** [LH, LL] **2015** [MH, ML] **2020** [SH, SL] Introduce (through lane conversion using Quickchange moveable barriers QMB)) a HOV-2 lane on all expressways with 3+ lanes per direction or at LOS F over 10 years **2020** [All] for existing HOV lanes, otherwise 10 years after introduction convert HOV lanes to 24/7 applicability	**2010** [LH, LL] **2015** [MH, ML] **2020** [SH, SL] Introduce (through lane conversion using QMB) a HOV-2 lane on all expressways with 3+ lanes per direction or at LOS D over eight years. Convert to HOV-3 if HOV lane is at LOS D after two years **2015** [All] for existing HOV lanes, otherwise eight years after introduction convert HOV lanes to 24/7 applicability	**2010** [LH, LL] **2015** [MH, ML] **2015** [SH, SL] Introduce (through lane conversion using QMB) a HOV-2 lane on all expressways over four years. Convert to HOV-3+ if HOV lanes are LOS D. If 4+ lanes and general purpose lanes are at LOS D, introduce a second HOV lane starting at HOV-2. **2010** [All] for existing HOV lanes, otherwise 4 years after introduction convert HOV lanes to 24/7 applicability
Car-Sharing	**2010** [LH] **2015** [LL, MH, SH] **2020** [ML, SL] Provide subsidy or public procurement sufficient to allow two-year start-up of a public, private or nonprofit car-sharing organization. Provide long-term auctioned usage of convenient public street parking for car-sharing vehicles.	**2010** [LH] **2015** [LL, MH, SH] **2015** [ML, SL] Provide subsidy or public procurement sufficient to ensure two-year start-up of a public, private or nonprofit car-sharing organization. Provide free or subsidized lease usage of convenient public street parking for car-sharing vehicles. Ten-year goal of one car per 2,000 inhabitants of medium and 1,000 inhabitants of high-density census tracts.	**2010** [LH] **2010** [LL, MH, SH] **2015** [ML, SL] Provide subsidy or public procurement sufficient to ensure continuous presence of one or more public, private or nonprofit car-sharing organizations per market. Provide free or subsidized lease usage of convenient public street parking for car-sharing vehicles. Five-year goal of one car per 1,000 inhabitants of medium-density and per 500 inhabitants of high-density census tracts.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Employer-Based Telework and Compressed Work Week Programs	**2015** [Urban] Private Sector: Provide employer goals and tax incentives for the offering and adoption of telecommuting and compressed work week targets. Provide public funding or subsidies for the private provision of regional telework centers and shared satellite offices. Require elimination of telecommuting barriers in state and local tax codes (e.g., double taxation) Public Sector: All government agencies allow option of telecommuting and compressed work week for eligible employees	**2015** [Urban] Private Sector: Included as part of employer-based TDM requirements (see below). Public Sector: All government agencies require four-day work weeks	**2015** [Urban] Included as part of employer-based TDM requirements (see below). Public Sector: All government agencies require four-day work weeks
Employer-Based TDM Requirements, Outreach, and Support	**2015** [Urban] States and/or MPOs provide on-line ride matching and vanpool services and guaranteed ride home program for all areas where services already are not provided by TDM service providers. MPO or other designated agencies (such as TMAs) implement aggressive outreach program to inform major employers (100+ employees) of alternative travel options, assist with providing information and incentives to employees. Transit agencies make monthly passes available through employers at discounted rates.	**2015** [Urban] Establish requirements for employers w/50+ employees to develop and implement plans to reduce SOV trips by 10 percent compared to baseline levels; offer technical assistance to employers for these plans; provide Federal tax incentives/disincentives for compliance. Continues regional ridematching, vanpool, GRH, and transit discount services. Value of parking benefits is taxed; value of cash-out or transit benefits is not.	**2015** [all] Federal/state tax levied on all commercial parking spaces ($5/space/weekday); employers required to pass along this cost to employees; proceeds used to provide free transit passes for employees and other TDM activities (e.g., transit shuttles). Coordinate with parking pricing measures above. Continues regional ridematching, vanpool, GRH, transit discount, and employer outreach programs (but no TDM plan requirement).

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Regulatory Measures			
Urban Nonmotorized Zones	**2015** [LH] **2020** [LL, MH, SH] **2025** [ML, SL] Over 10 years, convert 2 percent of CBD and regional employment and retail center centerline miles to transit malls, linear parks, or other nonmotorized zones.	**2010** [LH] **2015** [LL, MH, SH] **2020** [ML, SL] Over 10 years, convert 4 percent of CBD and regional employment and retail center centerline miles to transit malls, linear parks, or other nonmotorized zones.	**2010** [LH] **2015** [LL, MH, SH] **2020** [ML, SL] Over 10 years, convert 6 percent of CBD and regional employment and retail center centerline miles to transit malls, linear parks, or other nonmotorized zones.
Urban Parking Restrictions	**2015** [LH] **2020** [LL, MH, SH] **2025** [ML, SL] Implement a parking freeze on new parking supply (similar to Boston and San Francisco), capping the absolute number of commuter spaces in CBDs and regional employment and retail centers. Exceptions may be made for carpool-designated spaces. Includes effect on noncommute trips	**2010** [LH] **2015** [LL, MH, SH] **2020** [ML, SL] Implement a parking freeze on new parking supply (similar to Boston and San Francisco), capping the absolute number of commuter spaces in CBDs and regional employment and retail centers. Exceptions may be made for carpool-designated spaces. Includes effect on noncommute trips	**2010** [LH] **2015** [LL, MH, SH] **2015** [ML, SL] Implement a parking freeze on new parking supply (similar to Boston and San Francisco), capping the absolute number of commuter spaces in CBDs and regional employment and retail centers. Over 10 years phase-in the conversion of 10 percent of spaces to carpool-designated. Includes effect on noncommute trips
Speed Limit Reductions	**2015** [All] Lower the national speed limit to 65 mph. **2020** [All] Lower the national speed limit to 60 mph.	**2010** [All] Lower the national speed limit to 65 mph for light-duty and 60 mph for heavy-duty vehicles and provide significantly increased enforcement, including speed cameras. **2015** [All] Lower the national speed limit to 60 mph. **2020** [All] Lower the national speed limit to 55 mph.	**2010** [All] Lower the national speed limit to 65 mph for light-duty and 60 mph for heavy-duty vehicles and provide significantly increased enforcement, including speed cameras. **2012** [All] Lower the national speed limit to 60 mph for light-duty and 55 mph for heavy-duty vehicles. **2015** [All] Lower the national speed limit to 55 mph.
Operations and Intelligent Transportation System (ITS) Strategies[a]			
Eco-Driving Training and Vehicle Maintenance Programs	Implement program, 10 percent of population reached, 5 percent net adoption	Implement program, 20 percent of population reached, 8 percent net adoption	Implement program and fund public awareness campaigns and driver education, 50 percent of population reached, 20 percent net adoption

[a] 1) Different congestion thresholds are used to get distinction in the scenarios; 2) Deployment of strategies except for VII is assumed to occur continuously throughout the analysis period; 3) V/C = Volume to Capacity ratio, a measure of roadway congestion that compares the traffic volumes to the roadway capacity.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Operations and Intelligent Transportation System (ITS) Strategies (continued)			
Ramp Metering (Centrally Controlled)	Implement with electronic roadway monitoring in large urban areas where V/C >1.05 by 2030 with new and expanded Traffic Management Centers (TMC)	Implement in with electronic roadway monitoring large/medium urban areas where V/C >1.0 by 2025 with new and expanded Traffic Management Centers (TMC)	Implement with electronic roadway monitoring in all locations where V/C >0.90 by 2020 with new and expanded Traffic Management Centers (TMC)
Variable Message Signs (VMS)	Implement with electronic roadway monitoring where V/C >1.05 by 2030	Implement with electronic roadway monitoring where V/C >1.0 by 2025	Implement with electronic roadway monitoring where V/C >0.9 by 2020
Active Traffic Management	Not deployed	Implement on facilities in large/medium regions with V/C >1.0 (speed harmonization + lane control + queue warning)	Implement in all locations where V/C >0.90 (speed harmonization + lane control + queue warning + hard shoulder running)
Integrated Corridor Management	Not deployed	**2010-2025**: Large/medium with V/C >1.0	**2010-2020**: All locations where V/C >0.90
Incident Management	**2010-2030**: V/C >1.05 (detection algor/free cell call, CCTV cameras, on-call service patrols, TMC integration/coordination)	**2010-2025**: V/C >1.0 (detection algor/free cell call, CCTV cameras, on-call service patrols, TMC integration/coordination)	**2010-2020**: V/C >0.90 (detection algor/free cell call, CCTV cameras, on-call service patrols with aggressive on-scene management, TMC integration/coordination)
Road Weather Management (Snow/Ice/Fog; Freeways)	**2010-2030**: Fully deployed on freeways by 2030	**2010-2025**: Fully deployed on freeways by 2025	**2010-2020**: Fully deployed on freeways by 2020
Arterial Management	**2010-2030**: Upgrade to closed loop or traffic adaptive when V/C >1.0	**2010-2025**: Upgrade to closed loop or traffic adaptive when V/C >1.0	**2010-2020**: Upgrade to traffic adaptive when V/C >0.90
Traveler Information	**2010-2030**: V/C >1.05 (511 + DOT web site)	**2010-2025**: V/C >1.0 (511 + DOT web site + DOT-sponsored personalized info)	**2010-2020**: V/C >0.90 (More aggressive, superseded as VII is enabled)
Vehicle Infrastructure Integration (VII)[b]	50 percent of light-duty vehicles equipped by 2025, 100 percent by 2040	50 percent of light-duty vehicles equipped by 2020, 100 percent by 2030	50 percent of light-duty vehicles equipped by 2015, 100 percent by 2020

[b] VII deployment is based on the deployment curve in Volpe VII BCA Report (http://www.intellidriveusa.org/documents/vii-benefits-cost-analysi-(Draft).pdf) (Chart 3.1: Projected Phase-In of VII Equipped Vehicles in the U.S. Fleet). The "More Aggressive" scenario uses these forecasts and they are adjusted for "Current Practice" and "Maximum Effort" scenarios.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Bottleneck Relief and Capacity Expansion Strategies			
Bottleneck Relief	Improve 25 percent of top 200 bottlenecks to level of service "E" by 2030	Improve 50 percent of top 200 bottlenecks to Level of Service E by 2030	Improve all top 200 bottlenecks to level of service "D" by 2020 using pricing, system management, enhanced alternatives and capacity expansion in the mix best supported by cost/benefit analysis that accounts for indirect, secondary and cumulative impacts and costs.
Capacity Expansion	25 percent of the economically justified investments increased over current funding levels.	50 percent of the economically justified investments increased over current funding levels.	100 percent of the economically justified investments increased over current funding levels.
Multimodal Freight Strategies			
Freight Strategies – Modal Diversion			
Rail Capacity Improvements	**2025**: Address choke points in rail system for carload and double-stack service so that currently expected 2025 capacity restrictions are reduced by 20 percent.	**2020**: Address choke points in rail system for carload and double-stack service so that currently expected 2025 capacity restrictions are reduced by 30 percent.	**2020**: Address choke points in rail system for carload and double-stack service so that currently expected 2025 capacity restrictions are reduced by 50 percent.
Marine Transportation System Maintenance and Improvement	2010: Maintain the current state of the system for channel depth, lock and dam conditions, harbor channels and terminals, and similar system elements for inland waterways, intracoastal waterways, the Great Lakes, and marine coastal shipping.	As per Scenario A and: 2025: Restore major components of the system to a state of good repair with all system elements fully functional.	As per Scenarios A and B and: 2010-2020: Restore the entire system to a state of good repair with all system elements fully functional.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Freight Strategies – Mode Optimization			
Overweight Load Permits for Trucks Carrying Shipping Containers	**2025**: [All Regions] Allow indivisible load permits for trucks carrying shipping containers at GVWs up to 110,000 pounds for distances up to 250 miles. Permit fees would cover all resulting pavement cost. Would increase efficiency of access hauls between interior origins and destinations and rail intermodal facilities, and also access hauls between ports and nearby origins and destinations. 250-mile limit would prevent use of these permits from diverting current intermodal movements to/from ports to all-truck movements.	**2020**: [All Regions] Allow indivisible load permits for trucks carrying shipping containers at GVWs up to 110,000 pounds for distances up to 250 miles.	**2015**: [All Regions] Allow indivisible load permits for trucks carrying shipping containers at GVWs up to 110,000 pounds for distances up to 250 miles.
Overweight Load Permits for Longer Combination Vehicles (LCV)	**2025**: [All Regions] Allow divisible load permits for LCVs carrying natural resources on designated non-IS truck routes at weights up to 105,500 pounds Eligible truck routes would be limited to routes meeting appropriate structural and geometric criteria for accommodating these vehicles. Permit fees would cover all resulting costs of upgrading and maintaining these roads. Limitation to non-IS roads (and to carriage of natural resources) would limit resulting diversion from rail.	**2020**: [All Regions] Allow divisible load permits for LCVs carrying natural resources on designated non-IS truck routes at weights up to 129,000 pounds	**2015**: [All Regions] Allow divisible load permits for B-Train LCVs carrying natural resources on designated non-IS truck routes at weights up to 129,000 pounds and up to 138,000 pounds for eight-axle B-Trains.
WIM Screening	**2025:** Mainline Weigh-in-motion (WIM) systems installed at all 24-hour truck weigh stations and used to allow all vehicles with transponders to bypass static scales.	**2020:** Mainline WIM installed at all 24-hour truck weigh stations and used to allow all vehicles with transponders to bypass static scales.	**2015:** Mainline WIM installed at all truck weigh stations and used to allow all vehicles with transponders to bypass static scales.

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Use of Electronic Credentialing to Allow Vehicles to Bypass Weigh Stations and Safety Inspections	**2025:** Expand the PrePass and NORPASS electronic credentialing systems so that they cover all 49 mainland states and both systems are recognized at all weigh stations and inspection sites in these states. Also implement an equivalent system in Hawaii.	**2020:** Expand the PrePass and NORPASS electronic credentialing systems so that they cover all 49 mainland states and both systems are recognized at all weigh stations and inspection sites in these states. Also implement an equivalent system in Hawaii.	**2010-2015:** Expand the PrePass and NORPASS electronic credentialing systems so that they cover all 49 mainland states and both systems are recognized at all weigh stations and inspection sites in these states. Also implement an equivalent system in Hawaii.
Truck Stop Electrification	**2025**: Increase the number of truck stops that allow trucks to plug in to local power to 1,500 (out of 5,000).	**2020**: Increase the number of truck stops that allow trucks to plug in to local power to 3,000.	**2015**: Allow trucks to plug in to local power at all truck stops.
Heating and Cooling Systems for Sleeper Cabs	**2025**: Require the installation of battery-operated heating and/or cooling systems in all sleeper cabs.	**2020**: Require the installation of battery-operated heating and/or cooling systems in all sleeper cabs.	**2015**: Require the installation of battery-operated heating and/or cooling systems in all sleeper cabs.
Truck-Only Toll Lane Networks	Start implementation in 2010, complete by 2025. Apply to 10 percent of interstate VMT in Large/High density urban areas.	Start implementation in 2010, complete by 20-25. Apply to 25 percent of interstate VMT in Large/High density urban areas.	Start implementation in 2010, complete by 2025. Apply to 40 percent of interstate VMT in Large/High density urban areas. Plus, start implementation in 2015, complete by 2030 applied to 10 percent of interstate VMT in large/low-density urban areas.
Freight Strategies – Logistics			
Urban Consolidation Centers and Limitations on Pickup and Delivery (PUD) Service in Dense Urban Areas	2025: [LH] Consolidation Centers would be established on the periphery of large urbanized areas. Time-of-Day restrictions would be instituted on most deliveries to the CBD, and all LTL and parcel deliveries to the CBD would be subject to a permitting system that would result in consolidation of shipments to nearby destinations.	2020: [LH] 2020[LL] Consolidation Centers would be established on the periphery of large urbanized areas. Time-of-Day restrictions would be instituted on most deliveries to the CBD, and all LTL and parcel deliveries to the CBD would be subject to a permitting system that would result in consolidation of shipments to nearby destinations.	2010-2015: [LH] 2015-2020[LL, MH] Consolidation Centers would be established on the periphery of large urbanized areas. Time-of-Day restrictions would be instituted on most deliveries to the CBD, and all LTL and parcel deliveries to the CBD would be subject to a permitting system that would result in consolidation of shipments to nearby destinations.

Appendix B

Assumptions and Methodology Used in Moving Cooler Effectiveness Analysis

Assumptions and Methodology Used in *Moving Cooler* Effectiveness Analysis

This Appendix provides background information regarding the major assumptions, data sources, and analytic approaches used to assess the effectiveness of individual strategies and strategy bundles in reducing greenhouse gas (GHG) emissions.

Section I – Baseline Assumptions*:* Section I presents the major assumptions about overall baseline and trend conditions that are used throughout the analysis regarding growth in vehicle miles traveled (VMT), fuel prices, and fuel efficiency.

Section II – Strategy-Specific Assumptions and Methodology*:* Section II presents the specific assumptions, data and analytic methodologies applied in the assessment of measures in each of the nine strategy groups.

Section III – Sensitivity Analysis Assumptions and Methodology*:* Section III presents the methodological approaches and assumptions for developing different National on-road transportation GHG emission baselines, and the related impact on individual strategy effectiveness results.

Section IV – Bundles and Interaction Assumptions and Methodology*:* Section IV presents the method supporting the bundle development process, GHG emissions accounting and assumptions on accounting for strategy interactions.

Section V – Induced Demand Assumptions and Methodology: Section V presents the assumptions and method of accounting for the impact of induced demand in the assessment of the effectiveness of strategies in reducing GHG emissions.

I. Baseline Assumptions

The starting point for the analysis of GHG reductions is referred to as the study "baseline." Estimates of the GHG reductions from individual strategies and from bundles of strategies are reflected as changes from the study baseline. The study baseline is represented by annual forecasts through 2050 of national on-road vehicle-miles traveled, gasoline equivalent average on-road fuel economy, and average on-road vehicle GHG emissions per mile. In the baseline forecast, long-term average growth rates are used, and it is recognized that the baseline does not include shorter-term fluctuations that occur due to fuel price changes and economic cycles.

■ Vehicle Miles of Travel (VMT)

Consistent with AASHTO's recent Bottom Line analyses, *Moving Cooler* uses a long-term base case forecast growth rate of 1.4 percent per year in highway vehicle miles of travel.[1] The long-term growth rate forecast should not be confused with shorter-term fluctuations, which occur due to fuel price changes and economic cycles. The effects of a more modest or aggressive VMT growth rate are incorporated in the sensitivity tests, described in Section III.

Sources supportive of a 1.4 percent baseline growth rate include the following:

- AASHTO's 2009 Bottom Line report forecasts a base case of 1.4 percent long-term VMT growth per year through 2031, primarily based on a review of recent years of VMT growth.
- Steve Polzin of the Center for Urban Transportation Research (CUTR) at the University of South Florida has developed a VMT forecasting spreadsheet model, which when input with moderately progressive land use policies, Census forecasts of population, and a moderate rate of growth for incomes yields 1.4 percent per year growth in VMT through 2035.
- In the 2008 Annual Energy Outlook (AEO) of the U.S. DOE Energy Information Administration (EIA), the high price case results in a 1.4 percent per year growth rate

---

[1] *Bottom Line Technical Report: Highway and Public Transportation National and State Investment Needs*. American Association of State Highway and Transportation Officials (AASHTO), March 2009. http://bottomline.transportation.org/FullBottomLineReport.pdf.

of light duty vehicle VMT through 2030. The updated 2008 AEO numbers are referenced here as they were the most recent EIA numbers available during development of the *Moving Cooler* baseline. As a comparison, the 2009 AEO reference case for light duty vehicle annual VMT growth is 1.49 percent. The 2009 AEO high price case is 1.22 percent.

It also is assumed that highway freight traffic grows at the same rate of 1.4 percent per year. For the 2009 Bottom Line report and for this study, Cambridge Systematics investigated the historical trends of VMT growth, compared to forecasts of VMT growth. This investigation provided the basis for recommendations that VMT growth forecasts be moderated downward from the 1.8 percent per year in HPMS.

Both total highway VMT and highway freight VMT were included in this investigation. Historical trends of highway freight VMT were compiled from VM-1 table of Highway Statistics, the same source used to track all other national VMT trends. The evaluation focused on the last six years and the last 10 years. VM-1 is available for all years on the FHWA web site (http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.cfm).

From 2000 to 2006, VM-1 shows the following percentage growth in VMT:

- Passenger cars and other two-axle four-tire vehicles: 9.73 percent;
- Combination trucks: 5.55 percent; and
- All trucks of two-axle six or more tires and larger: 8.38 percent.

From 1995 to 2006 VM-1 percentage growth rates were:

- Passenger cars and other two-axle four-tire vehicles: 24.4 percent;
- Combination trucks: 23.6 percent; and
- All trucks: 25.2 percent.

Thus, in no period has freight VMT grown faster than passenger VMT. In choosing to moderate the baseline VMT forecasts, we chose to moderate both categories, rather than to moderate only the light-duty vehicle category, which has been growing faster over the last six years. All trucks of two or more axles and six or more tires accounted for 7.40 percent of VMT in 2006, according to VM-1.

The public transportation base case growth in ridership of 2.4 percent is the growth rate between 1995 and 2007 from the National Transit Database. Ridership grew more rapidly in 2008, but the 2.4 percent growth rate is used for the long-term trend and is consistent with 2009 Bottom Line analyses.

Refer to the Bottom Line report, Section 2.6, for further details on vehicle miles of travel and public transportation passenger trends and forecasts.

Fuel Cost

The baseline fuel price is assumed to begin at $3.70 in 2009 and then to increase annually at 1.2 percent. This price growth rate is based on the EIA AEO 2008. Although short-term market volatility will likely continue, this is not assumed to effect long-term trends or results.

Sensitivity analysis related to fuel prices is discussed in Section III.

Fuel Economy

Light-Duty Fuel Economy

Moving Cooler analysis uses a gasoline-equivalent average car and light-duty truck on-road fleet fuel economy of 20.3 miles per gallon (mpg) (0.46 kg CO_2e/mile) based on the EIA Annual Energy Outlook (AEO) 2008. This serves as the starting value for estimating future on-road light-duty vehicle fuel economy through 2050.

AEO 2008 reflects new light-duty CAFE fuel economy standards established through the Energy Independence and Security Act (EISA) in December 2007.[2] The "low" sensitivity test annual fuel economy growth rate (1.61 percent) represents the AEO 2008 forecast through 2030, while the "baseline" (1.91 percent) and "high" (2.75 percent) annual fuel economy growth rates reflect the potential effects of higher fuel prices and/or additional technology or fuel improvements from the AEO forecast.

The baseline growth rate reflects updates to vehicle technology and the carbon content of fuels as a result of CAFE and renewable fuel programs and is overall consistent with a 0.6 long-run price elasticity of fuel economy with respect to fuel price. This elasticity is the middle of the range of 0.3 to 0.9 referenced by the Congressional Budget Office (CBO) in a 2003 report.[3] Although this number is higher than a number of more recent estimates, those studies were conducted during a period of historically low real fuel prices.

The *Moving Cooler* baseline subsumes technology driven improvements in vehicle technology and fuels into overall on-road vehicle fuel economy assumptions. Using the 0.6 elasticity applied to the difference in *Moving Cooler* forecasts of low fuel prices (assumes a 0.7 percent annual increase) versus baseline fuel prices (1.2 percent annual

---

2 Energy Information Administration. "Annual Energy Outlook 2008" Report #: DOE/EIA-0383 (2008), Table 49. http://www.eia.doe.gov/oiaf/aeo/supplement/index.html.

3 Congressional Budget Office. "The Economic Costs of Fuel Economy Standards Versus a Gasoline Tax" December 2003. http://www.cbo.gov/doc.cfm?index=4917.

increase), approximately results in the baseline annual 1.91 percent fuel economy growth rate.

The high growth rate reflects a tripling of on-road fuel economy by 2050; this rate was selected to provide sufficient difference for sensitivity analysis and is consistent with many aspirational goals. This approach results in a fleet average on-road baseline fuel economy in 2050 of 43.3 mpg (0.21 kg CO_2e/mile) and high fuel economy of 60.1 mpg (Table 1).

The long-range forecasts used in *Moving Cooler* for the fuel economy of the U.S. light-duty fleet exceed the fuel economy of the current fleets of other nations with high fuel prices. The EMBARQ study by Lee Schipper[4] was considered by Cambridge Systematics because it covers the subject of changes in fuel economy from a comprehensive and international perspective. Figure 1 (page 5) of the EMBARQ report shows comparisons of on-road fuel economy for the U.S. light-duty fleet versus other nations. Of particular interest is that the United States improved the most since 1970, however is still below 12 L/100 km whereas the other nations are grouped from 7 to 8 L/100 km. – which is 50 percent or better on-road fuel economy. Figure 1 also indicates that the other nations have not continued to make major gains in fuel economy, but rather, progress that is more modest. Figures 8 and 9 (page 13) show fuel price versus thousands of km per capita and fuel price versus fleet average fuel efficiency. These figures demonstrate strong correlations between fuel price and fuel economy as well as between fuel price and travel per capita.

It is noteworthy that the highest fuel prices in the study – Italy at better than three times the United States – are associated with fuel economy gains of about 60 percent compared to the United States. The study also identifies the differences between on-road and tested fuel efficiency, which is an issue in all nations. On-road fuel consumption figures for new fleets must always be factored down from the results of new fleet test procedures. From this study, it is clear that there is significant room for improvement in U.S. light-duty fuel economy and that higher fuel prices are associated with significant gains in fuel economy.

In addition to the high-end fuel economy estimates which will be covered in the sensitivity analysis, other technological changes such as alternative fueled vehicles and zero emission vehicles have been analyzed in other studies and such potential changes are referenced to place the findings of this study into context. It is likely that these and future technologies will be very important contributors to reductions in greenhouse gas emissions within the transportation sector and other sectors.

Medium- and Heavy-Duty Truck Fuel Economy

The on-road combined medium- and heavy-duty truck fleet annual fuel economy growth rate for the low sensitivity test reflects estimates from AEO 2008. The 2010 estimate is 6.0

---

[4] Schipper, Lee, "Automobile fuel; Economy and CO2 Emissions in Industrialized Countries: Troubling Trends through 2005/6", EMBARQ, Washington D.C. 2007.

mpg (1.75 kg CO_2e/mile), with a forecast annual growth rate of 0.61 percent.[5] The *Moving Cooler* baseline sensitivity test estimated a 0.63 percent annual growth rate, the high a 0.91 percent annual growth rate. The baseline growth rate reflects updates to vehicle technology and is overall consistent with a 0.3 long-run price elasticity of fuel economy with respect to fuel price. This elasticity is the low point of the CBO range considered for light-duty vehicles. The lower elasticity reflects the influence of other more prevalent factors guiding private trucking company fleet decisions. The percent difference between the baseline to the high represents the same percent difference between the baseline and high cases for light-duty fuel economy.

Transit Bus Fuel Economy

For buses, the annual percent increase in fuel economy is generated as a result of the estimated increase in the share of diesel-hybrid buses in the nations transit bus fleet. In 2006, 1.65 percent of the national fleet is diesel-hybrid, as estimated in APTA's 2007 Public Transportation Factbook. Diesel-hybrid buses were 18 percent of total bus orders in 2006[6] and 30 percent of total orders in 2007.[7] An annual fuel economy growth rate of 1.27 percent is based on a 15-year bus life cycle and an assumption that from 2007 to 2030, the share of new buses entering fleets that are diesel-hybrid technology (or a similar technology in terms of fuel economy) will increase from the 30 percent observed in 2007 to a maximum of 90 percent of total orders by 2038. This will result in a low fleet estimate in 2050 that is 79 percent diesel-hybrid with an average fuel economy of 6.6 mpg (Table 1).

The baseline sensitivity test is a 1.50 percent annual growth rate, representing the same ratio of change as between the low and baseline case for the light-duty fleet. This baseline reflects both the transition to diesel-hybrid technology as well as the impact of lighter chassis, drive-train performance, alternative fuels and other technologies. The high sensitivity test is a 2.16 percent annual growth rate. The percent difference between the baseline to the high represents the same percent difference between the baseline and high cases for light-duty fuel economy.

Summary

Table 1 summarizes annual percent change, average on-road fuel economy in "snapshot" years and total percent change from 2010 to 2050. The on-road light-duty fleet fuel economy recommended for *Moving Cooler* analysis has a consistent start year value of 20.3

5 Energy Information Administration. "Annual Energy Outlook 2008" Report #: DOE/EIA-0383 (2008), Table 57. http://www.eia.doe.gov/oiaf/aeo/supplement/index.html.

6 Federal Transit Administration, "Analysis of Electric Drive Technologies For Transit Applications: Battery Hybrid-Electric, and Fuel Cells Final Report" August 2005. http://www.fta.dot.gov/documents/Electric_Drive_Bus_Analysis.pdf.

7 American Public Transportation Association, 2007 Transit Vehicle Database.

mpg in 2010 across the Low, Baseline, and High sensitivity tests, with annual growth rates of 1.61 percent (AEO forecast), 1.91 percent (based on price elasticity) and 2.75 percent (tripling of fuel economy by 2050). The total percent change for the light-duty Baseline is 113 percent – exceeding forecast Baseline changes for the on-road heavy-duty fleet (29 percent) and the transit bus fleet (82 percent).

Table 1. *Moving Cooler* Fuel Economy Summary

	Annual Percent Increase	2010	2030	2050	Change (2010-2050)
On-Road Light-Duty Fleet					
Low	1.61%	20.3	27.9	38.5	89%
Baseline	1.91%	20.3	29.6	43.3	113%
High	2.75%	20.3	34.9	60.1	196%
On-Road Medium/Heavy-Duty Truck Fleet					
Low	0.61%	6.0	6.8	7.7	28%
Baseline	0.63%	6.0	6.8	7.8	29%
High	0.91%	6.0	7.2	8.7	44%
On-Road Transit Bus Fleet					
Low	1.27%	3.7	4.7	6.1	65
Baseline	1.50%	3.7	4.9	6.7	82%
High	2.16%	3.7	5.6	8.6	135%

Greenhouse Gas/VMT Ratio

Moving Cooler assumes a 1:1 ratio in percent GHG reduction to percent VMT reduction. Congestion and induced demand effects may affect this and are included as part of the bundling phase when congestion effects can be estimated more accurately. Illustrative GHG emissions used are 0.43 million metric tonnes per billion light-duty VMT for 2010 and 0.31 for 2030 (due to improving fuel economy). Of course, some measures also reduce GHGs in supplement to or independent of their VMT reduction (e.g., congestion pricing, a gas/carbon tax, speed limit reductions, freight technologies). For these measures, the fuel economy GHG effect and VMT effect have been aggregated.

II. Strategy-Specific Assumptions and Methodology

The following sections outline the analytic approach and specific assumptions applied to each of the nine strategy groups. These groups are:

1. Pricing strategies;
2. Land use and smart growth strategies;
3. Nonmotorized transportation strategies;
4. Public transportation improvement strategies;
5. Regional ride-sharing, car-sharing and commuting strategies;
6. Regulatory strategies;
7. Operational and intelligent transportation system (ITS) strategies;
8. Bottleneck relief and capacity expansion strategies; and
9. Multimodal freight strategies.

1.0 Pricing Strategies

1.1 Parking Pricing

There are three different parking pricing related strategies evaluated in *Moving Cooler*. The method for analyzing the GHG emissions reduction of each individually, is presented below. Level A refers to "expanded current practice," Level B refers to "more aggressive" and Level C refers to "maximum effort."

Strategy Description: Begin pricing all CBD/employment center/retail center on-street parking; price to encourage "park once" behavior; complete over eight years (Level A), six years (Level B), four years (Level C).

Analysis is based on the assumption that one-quarter of all person trips are commute based trips, and of commute trips, approximately 15 percent are trips to the CBD or regional activity centers.[8] Based on data from a Wagner University study, Table 1.1 presents the share of CBD/activity center public parking that is on-street.

Table 1.1 Share of CBD Public Parking On-Street

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
58%	58%	60%	70%	65%	75%

Source: The Dynamics of On-Street Parking in Large Central Cities, http://wagner.nyu.edu//transportation/files/street.pdf.

For this measure, a 25 percent increase in on-street parking fees is assumed to be the starting point sufficient to reduce affected VMT. This increase is applied across all urban area types and converted to a VMT reduction through use of ranges of elasticities from a Victoria Transportation Policy Institute study. The study summarizes research on trip

[8] Commuting in America III: The Third National Report on Commuting Patterns and Trends. Transportation Research Board, 2006. Executive summary at: http://onlinepubs.trb.org/onlinepubs/nchrp/CIAIII.pdf.

sensitivity for changes in parking prices at various CBD locations.[9] Two locations were evaluated: Preferred CBD and Less Preferred CBD. For preferred CBD, the elasticity was (-0.47) and for less preferred CBD (-0.15). For this analysis, the preferred CBD elasticity is used for all high-density regions, while the less preferred CBD elasticity is used for all low-density regions.

Deployment of the on-street parking strategy and thus the associated VMT reduction is assumed to be phased in linearly over the eight-, six- and four-year period's dependant on urban area type and start year as identified in Appendix A.

Table 1.2 Annual Percent VMT Reduction for On-Street Parking Strategy

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
1.02%	0.33%	1.06%	0.39%	1.14%	0.42%

Strategy Description: Introduce tax/higher tax on free CBD private parking lots with >100 spaces (Level B) and with >50 spaces (Level C).

This strategy is applied in CBDs and activity centers to all VMT. The percent of all VMT to and from CBDs and activity centers is estimated to be 15 percent, which is comparable to statistics within Commuting in America III. The percentage of free parking spaces in metropolitan areas was estimated from an inventory of parking spaces in Seattle. That survey did not indicate if lots were free or pay parking, so an adjustment was made. The estimated parking spaces in a CBD and/or activity center that are free and greater than 100 spaces total by urban area are shown in Table 1.3.

---

[9] Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior. Victoria Transport Policy Institute, July 2008. www.vtpi.org.

Table 1.3 Percentage of Free Spaces
CBD/Activity Center Private Parking Lots with Greater Than 100 Spaces

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
10%	6%	6%	4%	4%	2%

The costs of the added parking fee are set at $1.20 per trip, or $2.40 per round trip, sufficient to reduce trips by 15 percent based on a cost of $4 per trip and a -0.45 price elasticity.

The 15 percent reduction applied to the percentage of VMT to affected lots results in the VMT reduction shown in Table 1.4.

Table 1.4 Annual Percent VMT Reduction
Aggressive Deployment

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
0.15%	0.09%	0.09%	0.06%	0.06%	0.03%

Maximum (Level C) deployment is applied to lots greater than 50 spaces. The broadening of the applicability to more lots is assumed to increase the VMT reductions as shown in Table 2.4.

Table 1.5 Annual Percent VMT Reduction
Maximum Deployment

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
0.23%	0.14%	0.14%	0.09%	0.09%	0.05%

Strategy Description: Require residential parking permits for on-street parking in residential areas: minimum cost: $200 biannually for Level B ($100 annually) and $400 biannually for Level C ($200 annually).

This strategy is assumed to impact home-based trips, which according to the National Household Travel Survey represent approximately 60 percent of all urban trips. There is no data on the percentage of residents with free on-street parking but it is expected to vary by urban density and size. The assumptions are shown in Table 1.6.

Existing residential parking permit fees can run as high as $76 a year per vehicle (San Francisco) or over $100 for the year (Toronto, Canada). Some places structure fees so that second and third permits for a household are more expensive. For example, in Alexandria, Virginia, residential parking permits cost $15 for the first vehicle, $20 for the second vehicle, and $50 for each additional vehicle.

Table 1.6 Households with Free On-Street Parking

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
15%	20%	20%	30%	30%	20%

From the NHTS the number of trips per household is assumed to be eight per day. A fee of $200/biannual at @ 300 days per year amounts to $.33/day, which at 4.8 home-based trips per day amounts to approximately $.07/trip. At $4 per trip, $.07 is an increase of 1.75 percent per trip. Based on a price elasticity of -0.45 this would result in a reduction in VMT of 0.79 percent. To account for uncertainties, this is assumed to be 1 percent. Applying a 1 percent reduction to 60 percent of household VMT for the households estimated in Table 1.6 results in the annual percentage reductions in Table 1.7.

Table 1.7 Annual Percent VMT Reduction
Aggressive Deployment

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
0.09%	0.12%	0.12%	0.18%	0.18%	0.12%

Maximum deployment increases the residential parking fee to $400/biannually. The increase in parking fee effectively doubles the VMT reduction from those shown in Table 1.8.

Table 1.8 Annual Percent VMT Reduction
Maximum Deployment

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
0.18%	0.24%	0.24%	0.36%	0.36%	0.24%

1.2 Cordon Pricing

Cordon pricing was assumed to be applied only to CBDs. An estimate was made of the proportion of urban area roads and urban VMT, which would be subject to cordon pricing under each level of implementation. A combined long- and short-run elasticity estimate was applied of a -0.45 percent change in volume for each 1.0 percent change in trip cost. Pricing was assumed to be applied to all cordon highways and roads. An average of 3 percent of regional VMT is assumed to cross the CBD cordon.

The price fee applied for both cordon and congestion pricing was derived from methodologies developed in NCHRP Project 8-36, Congestion Pricing and Investment Requirements, to estimate responses to congestion prices.[10] Based on Texas Transportation Institute (TTI) congestion index and the price responsiveness in HERS procedures, an estimate was made that on average it was necessary to reduce peak period VMT by 20 percent on congested facilities in order to achieve the target levels of service. A reduction of VMT of 20 percent was estimated to require an average 65 cents per mile congestion price applied to all congested VMT. It is necessary to apply pricing to all facilities of course. Otherwise, congestion is simply diverted among facilities. Smaller reductions in the percentage of travel under congestion could of course be achieved at lower prices. The prices estimated were comparable to the results of recent studies in the Washington, D.C. and Seattle metropolitan areas.

Revenues and VMT changes were calculated year by year based on the assumed implementation schedules. Since the assumptions for cordon pricing were intended to be

[10] http://www.trb.org/NotesDocs/NCHRP08-36(85)_FR.pdf.

consistent with those for congestion pricing, only the impacted VMT differed for cordon pricing versus congestion pricing. In addition, no delay reduction impacts were included in cordon pricing, since VMT diverted around or away from the priced area would potentially cause increased delay on other roads.

1.3 Congestion Pricing

Congestion pricing was assumed to be applied for all highways and roads, which were congested, based on v/c ratios. An estimate was made of the proportion of all urban area road centerline miles and VMT and rural road centerline miles and VMT, which would be subject to congestion pricing under each level of implementation. Pricing was assumed to be applied to all of the congested highways and roads. Rural roads were only included under Level C deployment. The proportions which were estimated to be congested were derived from HPMS and HERS runs performed by FHWA for recent pricing analyses supporting updates to the 2006 Conditions and Performance Report. These values were 29 percent of VMT for urban facilities and 7 percent of VMT for rural. HERS runs showed that the percentage congested did not vary greatly over the investment period, although the degree of congestion is likely to be ever increasing. A combined long- and short-run elasticity estimate was applied of a -0.45 percent change in volume for each 1.0 percent change in trip cost. An average peak hour per mile price of $0.65 on congested segments is assumed in Level B and Level C deployment in order to reduce enough volume to obtain LOS D conditions.

A delay reduction impact was calculated in addition to the impacts of reduced VMT. The delay reduction calculation is based on relationships between delay and fuel consumption which also are applied to the categories of operations and highway capacity expansion. Each reduction in hours of delay per 1,000 VMT affected results in a 1.65 percent decrease in fuel lost in delay. The resulting percent fuel saved per priced VMT ranges from 5.1 percent in 2020 to 5.3 percent in 2050.

1.4 Intercity Tolls, PAYD Insurance, VMT Fee, Gas Tax/Carbon Price

A combined short- and long-run price elasticity of driving -0.45 was used for these pricing measures, consistent with the price elasticities used in the AASHTO Bottom Line Report. This was used in conjunction with a baseline price of driving of $0.69 per mile (which was varied appropriately over time due to changes in fuel economy and fuel prices). Since that figure includes the price of insurance (approximately $0.066 per mile), a baseline price of $0.624 per mile was used for pay-as-you-drive (PAYD).

Intercity tolls were applied of two, three, and five cents per mile under Levels A, B, and C, respectively to all rural interstate highways. These tolls were applied to all rural interstate VMT, assumed to be 25 percent of all rural VMT (consistent with FHWA's 2006 Highway Statistics). The average toll rate per mile nationally on existing tolled facilities is 10 cents per mile.

Sources for Pay-As-You-Drive (PAYD) insurance costs (per mile) and corresponding reduction in VMT were compiled. All provide a national cost per mile estimate with some providing a break out of cost per mile by state. The per-mile insurance premium and reduction in VMT range varies according to state. In states where insurance premiums are high (New Jersey, Hawaii), the insurance cost per mile is highest and therefore the reduction in VMT is greatest. The average cost per mile used for *Moving Cooler* is a national cost of 6.6 cents, consistent with Bordoff and Noel study for Brooking's Institution in 2008.[11] According to the recent Brookings Institution report, presumably, the first 2 percent of customers signing up for PAYD policies will be the low-risk, low-mileage drivers that have a financial incentive to do so. The *Moving Cooler* assumption is that each PAYD insurance policy results in a 10 percent VMT reduction as based on research estimates from both the Brookings Institution report and Victoria Transportation Policy Institute.[12]

The VMT and gas/carbon tax applied fees of 1, 3, and 12 cents per mile under Levels A, B, and C, respectively in current dollars. The 12 cent per mile fee was intended to represent the increment needed to represent West European motor fuel tax levels, and was derived based on an additional tax of approximately $4 per gallon on an approximate average on road 33 mpg.

For the gas/carbon tax, the effect this measure would have on fuel economy was modeled using a combined short and long run elasticity of fuel economy with respect to fuel price of 0.4. The first 0.1 was applied immediately to reflect driver behavior changes such as speed reduction, vehicle selection in multi-vehicle households, etc.; this number is consistent with a 2008 CBO report on the effects of gasoline prices on driving behavior and vehicle markets.[13] The remaining 0.3 was phased in using a VMT by model year weighted basis over 15 years, when full penetration was reached. For the gas/carbon tax, the -0.45 VMT elasticity was then applied to the reduced vehicle operating costs from this fuel economy improvement. The GHG reduction from the improved fuel economy was then applied to the remaining VMT.

---

11 *Pay-As-You-Drive Auto Insurance: A Simple Way to Reduce Driving-Related Harms and Increase Equity*. Bordoff and Noel, The Brookings Institution. July 2008. http://www.brookings.edu/papers/2008/07_payd_bordoffnoel.aspx.

12 http://www.vtpi.org/tdm/tdm79.htm.

13 *Effect of Gasoline Prices on Driving Behavior and Vehicle Markets*. U.S. Congressional Budget Office, 2008. http://www.cbo.gov/ftpdocs/88xx/doc8893/01-14-GasolinePrices.pdf.

2.0 Land Use and Smart Growth Strategies

■ Strategy Definition

Level A – All MPOs (or another regional agency designated by the MPO) develop a regional transportation and land use plan meeting-defined criteria for process and content. Plans collectively provide for at least 60 percent of new development in attached or small-lot detached units, in pedestrian- and bicycle-friendly neighborhoods (e.g., sidewalks, bicycle facilities, good connectivity) with mixed-use commercial districts and high-quality transit. The majority (72 percent) of communities adopt zoning and planning standards allowing for sufficient densities and requiring pedestrian-friendly design in these areas. State, regional, and local agencies work collaboratively on other implementation policies identified through these efforts. The net nationwide effect is that 43 percent of new metropolitan development occurs in compact, walkable neighborhoods, compared to 34 percent under the baseline.[14]

Provide Federal and state transportation funding incentives/set-asides for: a) regional comprehensive planning activities; and b) local planning and implementation (infrastructure) activities that support land use objectives as described above.

Level B – Metropolitan land use plans call for at least 70 percent of new development in neighborhoods as described under [A]. Local plan/zoning code compliance is higher than under [A] (about 90 percent) as a result of stronger funding incentives.

All states adopt comprehensive planning laws similar to Washington State's Growth Management Act, requiring local comprehensive plans meeting-defined objectives, designation of urban growth/priority funding areas, and interagency plan review. Require comprehensive plan adoption and revision of zoning and other municipal codes for consistency by 2020. Require consistency with regional plans in metro areas (see above).

---

[14] Thirty-four percent is optimistic in describing the current state of practice, but is not unreasonable as a 2030 or 2050 baseline given changes in market trends (see the discussion of market trends at the end of this section). The issue of importance here is the *additional increment* of compact development that is induced by policy actions, which is conservatively estimated under the Level A Deployment Level to be 9 percent. Forty-three percent also corresponds to the amount of population residing in higher-density census tracts as of 2000.

Federal and state housing, community development, and economic development programs include requirements for consistency with regional plan and smart growth objectives. State, regional, and local governments work collaboratively on other implementation strategies.

Level C – Collectively provide for at least 90 percent of new development in neighborhoods as described under [A]. Local plan/zoning code compliance is 100 percent.

Density minimums are established inside urban growth boundaries. Requirements are established for minimum fractions of new jobs and housing to be located within walking distance of high-frequency transit service.

MPOs have authority to disapprove local land use plans and ordinances if not consistent with regional plan; enforced through withholding of funding for transportation projects.

■ Calculation Method

This analysis considers potential GHG reductions from fewer personal (noncommercial) VMT as a result of a shift toward more compact development patterns. The analysis relies on estimates of per capita VMT by Census tract population density range, from Polzin et al.'s CUTR VMT forecasting model (2007). The CUTR model is based on analysis of 2001 Nationwide Household Travel Survey (NHTS) data. The model provides estimates of per capita VMT for five density ranges. The model is currently set up for years 2005, 2035, and 2055; for this analysis, results were interpolated for 2030 and 2050. The CUTR VMT forecasts for the United States as a whole, with default inputs for the other model parameters (e.g., income), are shown in Table 2.1.

Table 2.1 CUTR VMT Forecasts by Census Tract Density (Annual VMT per Capita)
2007

Tract Density Range (Persons Per Square Mile) (ppsm)	2005	Delta Versus <500 ppsm	2035	Delta Versus <500 ppsm	2055r	Delta Versus <500 ppsm
0-499	11,422	0.0%	13,798	0.0%	16,191	0.0%
500-1,999	10,083	-11.7%	12,196	-11.6%	14,359	-11.3%
2,000-3,999	9,345	-18.2%	11,345	-17.8%	13,406	-17.2%
4,000-9,999	7,986	-30.1%	9,782	-29.1%	11,651	-28.0%
10,000+	4,437	-61.2%	5,651	-59.0%	5,940	-63.3%

The observed relationship between per capita VMT and population density is a rough proxy for the effects of "smart growth" development. Higher levels of population density are associated with overall shorter trips because destinations are closer together. In addition, areas with higher population densities are more likely to have pedestrian-friendly design (e.g., walkability and mixed-use development) and to support transit service.

The specific method used to estimate GHG benefits of smart growth land use strategies is as follows:

1. Total U.S. metro area population in the year 2000 is identified by five Census tract density ranges as defined in the CUTR model: fewer than 500, 500–1,999, 2,000–3,999, 4,000–9,999, and 10,000 or more persons per square mile (ppsm). These density ranges can be very roughly described as representing the following conditions (assuming 50 percent of land in residential use, and 2.5 persons/household):

   – <500 ppsm (<0.6 DU/acre): Rural.

   – 500-1,999 (0.6-2.5 DU/acre): Low-density suburban; small towns/villages.

   – 2,000-3,999 (2.5-5.0 DU/acre): Moderate-density suburban; still auto-oriented.

   – 4,000-9,999 (5.0-12.5 DU/acre): Urban with reasonable transit service and some neighborhood walkability; or high-density suburban. First category with reasonable travel options available for many trips.

   – >10,000 (>12.5 DU/acre): Urban with strong transit service and walkability.

The change in population from 1990 to 2000, and associated share of change by density range, is identified from Census data. For the baseline scenario, new population growth between 2000 and the end analysis year (2050) is allocated to tract density ranges based on the share of growth in the 1990–2000 timeframe.

2. The proportion of existing housing stock (population) that would be redeveloped over the analysis period is estimated at 10 percent per decade. This redevelopment allocated to tract density ranges based on the 1990–2000 share of population growth.[15] As can be seen from Table 2.2, 14 percent of the population in 2030 is "new"

---

[15] Housing stock turnover is estimated at 6 percent per decade in the 2007 Growing Cooler report Section 1.7.3, citing analysis of Census data by Nelson [2006]. Commercial building stock turnover is estimated by Nelson to be 20 percent per decade. While the current analysis method is population-based, a method was needed to account for the faster turnover rates in the commercial versus residential sector. An overall stock turnover rate of 10 percent was, therefore, applied in this analysis, which results in 64 percent of total development between 2015 and 2050 being new or redevelopment. In comparison, Growing Cooler estimated this figure to be 67 percent for a slightly longer period (2010 through 2050). The redevelopment parameter in this study was primarily chosen to obtain an overall level of turnover (and therefore, the share of development that could be directed into "compact development" areas) consistent with the Growing Cooler study.

(compared to 2015) and 13 percent is "redeveloped" for a total of 27 percent that is reallocated towards more Smart Growth patterns.[16]

Table 2.2 Population Forecast Comparison

Population Comparisons	Total	Percent of 2030
Total Population, 2000	172,185,305	
Total Population, 2015	206,389,040	
Total Population, 2030	240,592,775	100%
New, 2015-2030	34,203,735	14%
Redeveloped, 2015-2030	30,958,356	13%
Existing, Not Redeveloped	175,430,684	73%

3. For the *Moving Cooler* scenarios, a significant shift in the proportion of new development and relocated redevelopment is assumed to take place, with higher-density tracts (>4,000 persons per square mile) receiving greater amounts of new development. The specific shifts are shown below in Table 2.3. The shifts apply only to new population added between 2015 and the analysis year, assuming that policy implementation begins in 2015. Total population by tract density under each Deployment Level in the analysis year is then calculated. As an example, Table 2.3 shows that as of 2000, 43 percent of the U.S. metro population lived in tracts with a density of at least 4,000 ppsm. Under the baseline scenario 34 percent of growth is forecast to occur in tracts with a density of at least 4,000 ppsm (based on 1990-2000 trends), while under Implementation Level A, 43 percent of growth is forecast to occur in these tracts.

[16] Although data are not shown here, the corresponding figure for 2050 is that 55 percent of all population will be in "new" or "redeveloped" locations.

Table 2.3 Growth Allocation Assumptions
2015-2030

Tract Density Range (ppsm)	Percent Population 2000	Percent Growth by Category: 1990-2000 and Base	Percent Growth by Category: Level A	Percent Growth by Category: Level B	Percent Growth by Category: Level C	Cumulative Percent Growth in Category or Higher Density: 1990-2000 and BAU	Cumulative Percent Growth in Category or Higher Density: Level A	Cumulative Percent Growth in Category or Higher Density: Level B	Cumulative Percent Growth in Category or Higher Density: Level C
0-499	14%	20%	17%	10%	4%	100%	100%	100%	100%
500-1,999	22%	27%	24%	17%	3%	80%	83%	90%	96%
2,000-3,999	20%	20%	17%	10%	4%	54%	60%	74%	94%
4,000-9,999	25%	21%	26%	31%	49%	34%	43%	64%	90%
10,000+	18%	13%	17%	33%	41%	13%	17%	33%	40%

4. Total personal-travel VMT is calculated based on VMT per capita (from the CUTR model) and total 2030 or 2050 population by tract density range, and the percent reduction in personal-travel VMT is calculated.

The shifts shown in Table 2.3 are based on the Deployment Level descriptions which include targets for the percentage of new development in attached or small-lot detached units, in pedestrian- and bicycle-friendly neighborhoods (e.g., sidewalks, bicycle facilities, good connectivity) with mixed-use commercial districts and high-quality transit. Such neighborhoods are assumed to correspond to the two highest tract density ranges (>4,000 ppsm). The descriptions include targets for the percent of new urban development in such neighborhoods (as specified in metropolitan plans), discounted by a "compliance" factor which assumes that the incentives will not be sufficient to encourage all jurisdictions to adopt locally consistent plans.[17] The metropolitan targets and compliance levels currently assumed are:

- Level A = 60 percent of new development planned in compact, walkable neighborhoods; 72 percent compliance (43 percent overall new growth in 4,000+ ppsm tracts).
- Level B = 70 percent of new development planned in compact, walkable neighborhoods; 90 percent compliance (64 percent overall new growth in 4,000+ ppsm tracts).

---

[17] For comparison, jurisdictions representing over 85 percent of the Denver region's population have signed on to the Mile High Compact.

- Level C = 90 percent of new development planned in compact, walkable neighborhoods; 100 percent compliance (90 percent overall new growth in 4,000+ ppsm tracts).

Implementation

The analysis assumes that 2015 is the beginning year for implementation of all policy measures. Implementation is assumed to occur linearly between the start year (2015) and end year of the analysis (2050). Essentially, the assumption is that implementation affects all new development, and that growth is occurring in a linear fashion over this timeframe.

Comparison with Growing Cooler Analysis

An attempt was made to compare the assumptions and results of this analysis with the Growing Cooler analysis. Growing Cooler examined a horizon year of 2050 and estimated that total transportation GHG could be reduced by 7-10 percent, which equates to a reduction in urban light-duty VMT of 12 to 18 percent.[18]

One of the key factors is the reduction in VMT for "compact" versus "sprawl" development. Growing Cooler estimates this reduction to be 30 percent (although the study appears to have applied this factor in a way that the 30 percent actually means a reduction for "compact" versus "all" development, i.e., the implicit assumption is that that with no action, all future development is sprawl). The corresponding reduction for *Moving Cooler*, based on VMT by census tract density range, is shown in Table 2.4. This comparison assumes that densities of more than 4,000 ppsm correspond to "compact" development while densities less than 4,000 ppsm correspond to "sprawl" development. The reduction shown is 35 percent for compact versus sprawl, or 23 percent for compact versus all, given the baseline distribution of population growth by density.

---

[18] Based on the study's assumed factors of 80 percent of VMT in urbanized areas, 80 percent of transportation GHG from motor vehicles, and a 90 percent ratio of CO_2 to VMT reductions.

Table 2.4 VMT Reduction for Compact Development

Population Density	*Moving Cooler* VMT/Capita, 2030	Growing Cooler
0-3,999 ("Sprawl")	12,297	
4,000 + ("Compact")	8,054	
All Densities (Average)	10,452	
Percent Reduction		
Compact versus Sprawl	-35%	30%
Compact versus All	-23%	

Table 2.5 compares the various assumptions made either explicitly or implicitly in the two studies. The *Moving Cooler* market share assumptions are more conservative than Growing Cooler, ranging from 43 to 90 percent of new development in compact areas, compared with 60 to 90 percent in Growing Cooler. This reflects a professional judgment about what is realistic. The reduction in VMT per capita for compact development also is more conservative, but as explained above, this is because the BAU mix of development is assumed to include some amount of compact development, which was not assumed in the Growing Cooler study. The increment of new/redevelopment relative to the baseline was adjusted to be consistent with the Growing Cooler study, accounting for the slightly longer timeframe of that study (64 versus 67 percent in 2050).

The net effect of taking Growing Cooler's "high" finding of 18 percent reduction in VMT and multiplying it by the ratio of the Level C parameters (90/90 * 23/30 * 64/67) is a 13.8 percent reduction in VMT, which is close to the *Moving Cooler* estimate.

Table 2.5 Comparison of *Moving Cooler* and Growing Cooler Parameters and Results

Factor	*Moving Cooler*				Growing Cooler	
	Baseline	A	B	C	Low	High
Market share of compact development	34%	43%	63%	90%	60%	90%
Reduction in VMT per capita with compact development versus base			23%		30%	
Increment of new/redevelopment relative to base			64%		67%	
Overall reduction in urban light-duty VMT (2050)		-1.7%	-7.7%	-12.6%	-12%	-18%

Market Trends Supporting Compact Development

Nelson (2006), cited in Growing Cooler, provides the following projections of housing demand and density in 2025 as shown in Table 2.6. Table 2.6 shows that current demand for development that could be "compact" in nature (attached and small-lot detached) is estimated at 46 percent of the market, compared to 60 percent in 2025, as a result of changing demographics and lifestyle preferences. The 60 percent figure roughly corresponds to the *Moving Cooler* Level B scenario. This does not mean that all of this development will be "smart growth," (walkable, mixed-use, transit-accessible, etc.) but it does suggest that market forces could be supportive of policies that work to achieve at least a Level B target for compact development. In addition, 55 percent of respondents to poll said that they would prefer to walk more throughout the day rather than drive everywhere.[19]

Table 2.6 Housing Demand and Density

Type	Density (Units Per Net Acre)	Percent	
		2003 Units	2025 Units
Attached	20	25%	31%
Small-Lot Detached	7	21%	29%
Large-Lot Detached	2	54%	40%

[19] Belden Russonello & Stewart 2003 as cited in Growing Cooler.

3.0 Nonmotorized Transportation Strategies

3.1 Combined Pedestrian Strategies

Strategy Definitions

Level A – By 2015, all new developments have buffered sidewalks on both sides of the street, marked/signalized pedestrian crossings at intersections on collector and arterial streets, lighting. New or fully reconstructed streets in denser neighborhoods (>4,000 persons/square mile and business districts) incorporate traffic calming measures such as bulb-outs and median refuges to shorten street-crossing distances. "Complete streets" policies adopted by state and local transportation agencies, requiring appropriate pedestrian accommodations on all roadways.

By 2025, existing streets within one-quarter mile of transit stations, schools, and business districts are audited for pedestrian accessibility and retrofitted with curb ramps, sidewalks, and crosswalks.

Level B – Same as Level A, plus by 2020 existing streets within one-half mile of transit stations, schools, and business districts audited for pedestrian accessibility and retrofitted with curb ramps, sidewalks, crosswalks, and limited traffic calming measures as appropriate to improve pedestrian accessibility.

Level C – Same as Level B, but with more extensive traffic calming.

Calculation Method

It is very difficult to distinguish the effects of pedestrian improvements/design factors apart from the effects of a mixed-use environment and higher density on travel behavior. The literature does suggest that the willingness to walk is most heavily influenced by proximity to generators – i.e., a trip has to be short enough to be competitive with alternatives. This is a function of the density of development, mix of uses, and connectivity of the street/pedestrian network. Nevertheless, there does appear to be some influence of design factors (availability of sidewalks, safe street crossings, etc.), while holding the built environment constant. This analysis is directed at determining the impacts of pedestrian improvements alone, within a fixed land use context.

The basic method is to apply an elasticity of VMT with respect to a Pedestrian Environment Factor (PEF). Elasticities from the Ewing and Cervero synthesis (Travel and the Built Environment, 2001)[20] and Smart Growth INDEX model documentation (also cited in Growing Cooler) are applied to hypothetical changes in the PEF as a result of the implementation-level pedestrian improvements. Three PEF change levels were run – Levels A and B (basic sidewalk and pedestrian crossing improvements – the area over which they are applied differs between A and B), and Level C (enhanced improvements with more traffic calming measures). These are shown in Table 3.1. Two different elasticities were tested – Ewing's "synthesis" elasticity from the Smart Growth INDEX model (-0.03)[21] and the elasticity cited from the 1993 PBQD analysis for Portland (-0.19)[22]. As Table 3.1 shows, VMT changes range from -1.5 percent to -12.7 percent in suburban areas (where it is assumed that a greater relative level of pedestrian improvement could be implemented) and -0.5 percent to -3.8 percent in urban areas. The high-elasticity scenario (PBQD) seems to produce rather high results, considering especially that walk trips are short compared to the average trip. Therefore, the second, more conservative, scenario using Ewing & Cervero's -0.03 elasticity is used.

Table 3.1 Application of Pedestrian Environment Factor (PEF) Elasticities to VMT

Portland PEF Factors		Suburban			Urban		
		Base	A, B	C	Base	A, B	C
Sidewalk Availability		1	3	3	2	3	3
Ease of Street Crossing		1	2	3	2	2.5	3
Connectivity of Street/Sidewalk System		1	1	1	3	3	3
Terrain		3	3	3	3	3	3
PEF Score		6	9	10	10	11.5	12
Percent Change in PEF			50%	67%		15%	20%
Percent Change in VMT:							
PBQD's Portland PEF Elasticity:	-0.19		-9.5%	-12.7%		-2.9%	-3.8%
Ewing's SGI PEF Elasticity:	-0.03		-1.5%	-2.0%		-0.5%	-0.6%

---

20 Ewing, R. and R. Cervero (2001) Travel and the Built Environment. Transportation Research Record 1780, 87-114. Available at http://www.ce.berkeley.edu/~yuli/ce259/reader/Ewing%20and%20Cervero%20TOD.pdf.

21 In the original analysis this was erroneously cited as -0.05, which is the elasticity of *vehicle-trips* (not VMT) with respect to design.

22 1,000 Friends of Oregon. *Making the Land Use Transportation Air Quality Connection: Volume 4A, The Pedestrian Environment*. Portland, OR, 1993. Available at http://www.teleport.com/~friends/Lutraq2/Docs.htm.

The "suburban" percentage VMT reduction is applied to density ranges 1-3 (<4,000 ppsm), the urban reduction to range 5 (<10,000 ppsm), and a midpoint reduction (1.4 percent) applied to range 4. The VMT change was not applied to all population; instead it was applied to an estimate of the population affected by the relevant pedestrian improvements. This estimate varies by census tract density range, based on the estimated land area covered by the improvements (Table 3.3). The pedestrian strategy assumes pedestrian improvements only in certain areas, such as transit stations, school zones, and business districts, as it would probably be cost-prohibitive and not very effective to make such improvements to all neighborhoods, everywhere. The following assumptions are made about the number of each type of area:

- **Schools –** 91,516 total K-12 schools in U.S. (National Center for Educational Statistics, 2005-2006) * 5/6 of U.S. population (schools) in metro areas ~= 75,000 schools. These were distributed across all density ranges, based on population.

- **Transit Stations:** Fifty cities with fixed-guideway transit (2030) * 30 stations each = 1,500 transit stations. These were distributed across the three highest density ranges, based on population.

- **Business Districts –** Estimated at 20,000. Multiple estimation methods used: 1) one for each of the 18,000 cities, towns, and villages in the United States; 2) one per 15,000 people (approximately the market area for a grocery store) yields 17,000 districts; and 3) one per 5,000 people (market area for a convenience store), considering only urban population in areas w/>4,000 ppsm, yields 20,000 districts. These were distributed across the four highest density ranges, based on population.

In Table 3.2, the percentage of total land area affected is calculated based on improvements within a one-quarter-mile radius for Level A, and within a one-half-mile radius for Levels B and C.

Table 3.2 Percent Population Living in Area with Pedestrian Improvements
2030

Population/ Square Mile	Total Improved Areas			Percent of Total Area Affected	
	Schools	**Transit**	**Business Districts**	**One-Quarter Mile (A)**	**One-Half Mile (B, C)**
0-499	10,561			1%	6%
500-1,999	16,006		4,968	9%	40%
2,000-3,999	13,459	417	4,177	22%	99%
4,000-9,999	19,505	604	6,054	61%	100%
10,000+	15,469	479	4,801	100%	100%
Total	**75,000**	**1,500**	**20,000**		

Implementation

Implementation of pedestrian improvements is assumed to begin in 2010 and continue with full deployment of improvements by 2020. The short timeframe for starting implementation reflects the fact that many cities already are implementing pedestrian improvements and most already require pedestrian facilities in new development. In addition, the policy framework already exists to do so in many situations (e.g., the Safe Routes to School program). However, it should be noted that full deployment by 2020 is an aggressive schedule, especially for more capital-intensive infrastructure improvements.

3.2 Combined Bicycle Strategies

Strategy Definition

Level A – By 2015, primary central business districts have a "bike station" that provides services, including parking, rentals, repair, changing facilities, and information. By 2025, citywide and/or regional plans developed and implemented for on-street bicycle accommodations to create a continuous network of routes. The network includes bicycle lanes at 1-mile intervals, and other facilities (shared-use markings, signed routes using neighborhood streets) at 1-mile intervals, for a combined network density of one-half mile, implemented in areas with population density >2,000 persons per square mile.

Level B – By 2020, bicycle accommodations provided to create a continuous network of routes with approximately one-half-mile spacing. The bicycle network consists of a combination of bicycle lanes, bicycle boulevards, and shared-use paths provided at combined one-half-mile spacing (half bicycle lanes and one-quarter each bicycle boulevards and shared-use paths), implemented in areas with population density >2,000 persons per square mile. Bicycle boulevards (on residential streets) include traffic diverters to limit automobile traffic on these routes.

Level C – By 2015 "Bike stations" are located at all major activity centers and transit hubs as well as in the CBD. Level B plus by 2025, the bicycle network consists of a combination of bicycle lanes, bicycle boulevards, and shared-use paths provided at combined one-quarter-mile spacing (half bicycle lanes and one-quarter each bicycle boulevards and shared-use paths), implemented in areas with population density >2,000 persons per square mile.

Calculation Method

The bicycle analysis was conducted using population density data by the five density ranges used in the Level A, B, and C land use analysis. The increase in bicycling mode share as a result of bicycle-supportive infrastructure and policies varies by density range, with greater effects for the higher density ranges (<4,000 ppsm) where bicycling is likely to be more competitive. Therefore, the results for each Implementation Level "pivot" off the land use strategy levels, which result in (incrementally) different amounts of future population by density range for each Implementation Level.

The baseline bicycle trips per capita per week for all except recreational trips was estimated from 2001 NHTS data. This ranges from 0.07 for the lowest density range to 0.19 for the highest range. There is little variation across the three lowest density ranges.[23]

To estimate VMT reduced, the average bicycle trip length was assumed to be 1.94 miles, constant across density ranges, based on the NHTS. The "prior driver" mode share (percent of new bicycle trips formerly taken by drivers) was estimated by taking the personal vehicle mode share by density range from the NHTS, and dividing by the national average of 1.6 persons per vehicle. The prior driver mode share ranges from 56 percent in the lowest three density ranges to 40 percent in the highest range.

To estimate the increase in bicycling that might take place under each level of implementation, a simple model was developed based on data in a paper by Dill & Carr (2003) examining bicycle commuting and facilities deployment in 42 U.S. cities. Their analysis found that "for more typical U.S. cities with at least 250,000 population, each additional mile of Type 2 bicycle lanes per square mile is associated with a 1 percent increase in bicycle commuting."[24] This 1 percent increase was applied to a baseline commuting percentage of 1.1 percent across their sample and 0.34 miles of lanes per square mile, with the following bicycle lane network spacing:

- Implementation Level A – One-mile spacing (two miles bicycle lanes per square mile);
- Implementation Level B – One-half-mile spacing (four miles bicycle lanes, boulevards, or paths per square mile); and
- Implementation Level C – One-quarter-mile spacing (eight miles bicycle lanes, boulevards, or paths per square mile).

The result was an increase in bicycle commuting of 258 percent, 449 percent, and 830 percent for Levels A, B, and C, respectively. (The percentage increase was calculated so it could be applied to all trip types, not just commuting.) The baseline number of bicycle trips per capita per week was then multiplied by the percentage increase for each level, and multiplied by 52 (weeks/year) * average bicycle trip length (mile) * prior drive mode

---

[23] This estimate could be refined – the NHTS "social/recreational" trips include some trips where the bicycle was used to get somewhere, as opposed to purely recreational trips that start and end at home and which are excluded from this analysis; some judgmental smoothing was made to account for this factor.

[24] *Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them – Another Look*. Dill, J., and T. Carr (2003). Transportation Research Record No. 1828, National Academy of Sciences, Washington, D.C.

share (percent) to get the total annual VMT savings. This was then multiplied by the population in each density range in the analysis year.

The impacts of bicycle infrastructure should depend strongly on fuel prices (not to mention a host of other factors that could not be considered). Therefore, different estimates were produced for each fuel price sensitivity scenario (see Section III). It is assumed that the estimates described above are consistent with the "low" fuel price scenario, since Dill & Carr's data was collected when gas prices were still less than $2/gallon. The baseline (medium) fuel price scenario and high fuel price scenario pivot off the low scenario results. It is assumed that bicycling doubles under the medium scenario compared to the low scenario, and triples under the high scenario. The results in terms of mode shares for all three fuel price scenarios are shown in Table 3.4.

Table 3.4 Urban Area Bicycle Mode Shares by Fuel Price and Implementation Level

Tract Population Density	Baseline	Low Fuel			Baseline Fuel			High Fuel		
		A	B	C	A	B	C	A	B	C
0 to 500	0.3%	0.8%	1.3%	2.5%	1.5%	2.7%	5.0%	2.3%	4.0%	7.5%
500 to 2K	0.3%	0.8%	1.3%	2.5%	1.5%	2.7%	5.0%	2.3%	4.0%	7.5%
2K to 4K	0.3%	0.8%	1.3%	2.5%	1.5%	2.7%	5.0%	2.3%	4.0%	7.5%
4K to 10K	0.4%	1.1%	1.9%	3.4%	2.1%	3.7%	6.8%	3.2%	5.6%	10.3%
>10K	0.8%	2.2%	3.8%	7.0%	4.4%	7.6%	14.0%	6.6%	11.4%	21.1%
All	**0.4%**	**1.1%**	**2.0%**	**3.7%**	**2.2%**	**3.9%**	**7.4%**	**3.3%**	**5.9%**	**11.1%**

Note: These shares assume the development patterns as identified in the *Moving Cooler* land use analysis for Level A, B, and C.

In addition, bicycle trips were adjusted downward by a 50 percent seasonality factor to account for the fact that in most areas, daily or seasonal variations in weather (cold/snow, high heat, rain, etc.) can reduce the number of bicycle trips made compared to favorable weather conditions.

Since there are many judgments and assumptions underlying this analysis, a "reality check" was performed to compare the resulting estimates of bicycle trip-making to actual bicycle mode share data from cities with a well-developed cycling infrastructure. The weekly current NHTS trip rates shown above roughly correspond to baseline bicycle mode shares (for utilitarian trips) of 0.3 percent in the lowest three density ranges, 0.4 percent in the fourth range (4,000-9,999 ppsm), and 0.8 percent in the highest range (>10,000 ppsm). When factored by the assumed percent increases, the mode shares in the highest two density ranges under the "high" fuel price scenario can be compared to bicycle mode shares in European cities and countries. The low-end European countries, including the United Kingdom and France, have mode shares of 2-3 percent, increasing to 9-10 percent for Germany and Sweden, 18 percent for Denmark, and 27 percent for the Netherlands, which has a particularly extensive cycling infrastructure. We estimate 2-3 percent as about the maximum level of bicycling estimated for the moderate-density tracts under Implementation Level A, while 10-20 percent is roughly the maximum range for the highest two tract density ranges under Implementation Level C (before seasonality factor adjustments). Another comparison can be made by examining data collected by John Pucher (2007) on rates of cycling in German cities in the 1970s (before major cycling infrastructure improvements) and the 1990s/early 2000s (after improvements). The 1970s rates in four midsize and large cities (Stuttgart, Nuremburg, Munich, and Cologne) range from 2 to 6 percent, while late-1990s rates range from 6 to 13 percent. The best cities (Freiburg, Bremen, Muenster), range around 20 percent or more. Again, this range appears consistent with the range of results obtained for the two highest density tract ranges under the high fuel price scenario.

Implementation

Implementation is assumed to begin in 2015 (to allow time for plan development and revision of design standards) and continue with full deployment of improvements by 2025. Some substrategies (such as bicycle racks and bicycle stations) can be implemented more quickly than this. However, the network changes will take at least 10 years (more likely at least 15, unless extremely aggressive action is taken) and the network changes are assumed to be the most important component of this strategy in terms of inducing mode shift.

4.0 Public Transportation Improvement Strategies

4.1 Fare Measures

Price elasticities were used to estimate the increase in ridership due to fare reductions. These elasticities[25] varied by level of fare reduction, as follows:

- **Deployment Level (A):** -0.15 price elasticity for lowering fares 25 percent (3.75 percent transit trip increase)
- **Deployment Level (B):** -0.2 price elasticity for lowering fares 33 percent (6.6 percent transit trip increase)
- **Deployment Level (C):** -0.3 price elasticity for lowering fares 50 percent (15 percent transit trip increase)

The following constants were used in the analysis:

- **Average Vehicle Occupancy: 1.43 persons –** Average vehicle occupancy by trip type is obtained from the 2001 NHTS, NPTS Trip Purposes data. The 2007 APTA Public Transportation Factbook indicates 59.2 percent of all transit trips are work related. Work related trips from NPTS show an average occupancy of 1.14, while nonwork is 1.84.
- **Vehicle Miles Traveled per Trip: 5.12 miles –** This is based on the weighted average trip length by total trips by mode of all fixed-route transit trips in the 2006 National Transit Database. It does not incorporate the length of drive to a park-and-ride lot, as that portion of a converted trip would still be auto based and therefore not contribute to any GHG emission reductions.

[25] "Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior", 26 July 2008, Victoria Transport Policy Institute.

4.2 Level of Service (LOS) Measures

This section describes the assumptions applied for various Level of Service measures. For all Level of Service measures, the same constants for Average Vehicle Occupancy and Vehicle Miles Traveled were used for analysis, consistent with the constants applied for Fare Measures, discussed in Section 4.1. These are:

- Average Vehicle Occupancy: 1.43
- Vehicle Miles Traveled per Trip: 5.12

LOS Measures: Frequency

An elasticity of 0.5 was used to estimate ridership increases due to increased frequency of service (decreased headways):

- **Deployment Level (A):** 0.5 headway elasticity (a 1.50 percent increase in annual transit trips for the assumed 3 percent increase in service);
- **Deployment Level (B):** 0.5 headway elasticity (a 1.75 percent increase in annual transit trips for the assumed 3.5 percent increase in service); and
- **Deployment Level (C):** 0.5 headway elasticity (a 2.30 percent increase in annual transit trips for the assumed 4.67 percent increase in service).[26]

Level of Service (LOS) Measures: Speed/Reliability

Speed elasticities[27] were used to estimate ridership increases due to increased operational speed for transit vehicles, resulting from measures such as signal prioritization, limited stop service, signal synchronization, intersection reconfiguration, and automated vehicle location (AVL). Deployment Level C also assumes an increase in reliability resulting from the measures implemented at that deployment level, and thus uses a higher speed elasticity to capture the added ridership attracted by the increased reliability:

- **Deployment Level (A) –** Speed elasticity of 0.4 for each 1 percent travel speed increase (4 percent increase in annual transit trips for the assumed 10 percent increase in travel speeds);

---

[26] "Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior", 26 July 2008, Victoria Transport Policy Institute.

27 Ibid.

- **Deployment Level (B) –** Speed elasticity of 0.4 for each 1 percent travel speed increase (6 percent increase in annual transit trips for the assumed 15 percent increase in travel speeds); and

- **Deployment Level (C) –** Speed elasticity of 0.5 for each 1 percent travel speed increase (15 percent increase in annual transit trips for the assumed 30 percent increase in travel speeds and 40 percent boost in reliability).

LOS Measures: Service Extent

The service extent measure evaluates the GHG reductions from expanded geographic coverage of urban/rural fixed route transit services. This strategy is specifically evaluating the reductions attributed to fixed route bus service expansion.

- **Implementation Level (A) –** Expand fixed-route bus service by 1.5 times the average revenue-miles growth rate;

- **Implementation Level (B)** – Expand fixed-route bus service by two times the average revenue-miles growth rate; and

- **Implementation Level (C)** – Expand fixed-route bus service by four times the average revenue-miles growth rate.

The emission reductions are calculated as follows:

1. Annual bus revenue mile growth rates per urban area and rural, 1997 to 2006 are determined from National Transit Database across each urban region type and nonurban (range from 1.1 percent to 3.7 percent for urban areas, 2.5 percent for nonurban).

2. Revenue mile growth rates are increased by 50 percent in Level A, 100 percent in Level B and 200 percent in Level C. These new rates are applied to develop forecasts of fixed-route bus transit revenue miles by region type through 2050.

3. Revenue miles through 2050 are converted to passenger miles based on average passenger loads (passenger miles/revenue miles). Average loads, based on the 2006 National Transit Database range from 12.4 passengers for Large/High-Density regions to 2.1 passengers for Small/Low-Density regions. It is assumed that average load factors are held constant through the duration of the study period (this reflects a balance of start-up revenue miles experiencing lower average load factors in early years of operation, with potentially higher load factors once new routes/systems mature). Passenger miles are converted to reduced VMT based on an average vehicle occupancy of 1.43.

4.3 Urban Transit Expansion

2007 GHG Reduction from Transit

The baseline starting value of 9.95 billion unlinked transit trips in 2007 from the National Transit Database is used to build future ridership forecasts.

An analysis of current GHG reductions from the existing national transit system was conducted as a point of comparison for the assessment of reduction estimates in Level A, B, and C. The direct effect on GHG emission reductions from transit in 2007 is 14.2 mmt CO_2e. This figure represents the effect of the substitution of public transit passenger miles with private automobile travel (without accounting for emissions from new transit services). The calculation assumes the following:

- An average auto occupancy of diverted trips of 1.43, which is lower than the 1.63 average for all trips from the 2001 NHTS. The 1.43 value assumes that 60 percent of transit trips are home-based work with an average occupancy of 1.14 and the remaining nonwork trips have an average occupancy of 1.84 (NHTS, 2001).
- The current auto based person miles of travel share for all trip types (88.2 percent auto based according to NHTS 2001). Therefore, the substitution assumes that 88.2 percent of transit passenger miles are saved vehicle miles traveled.

In other words, urbanized transit systems in 2007 removed 32.0 billion vehicle miles traveled from the nation's roadways. This represents 1.6 percent of urban area vehicle miles traveled according to FHWA Highway Statistics 2007.

The secondary or indirect effects of transit expansion include long-term land use changes that redistribute growth focused on fixed-guideway transit stations. *The Broader Connection between Public Transportation, Energy Conservation and Greenhouse Gas Reduction t*ransit and land use analysis (Transit Cooperative Research Program Project J-11) estimated the average reduction of VMT per household by level of transit availability based on household trip survey data from the 2001 National Household Travel Survey. The model estimation from this study resulted in an average daily reduction of VMT per household of 2.2 for households with access to transit.

The combined GHG reduction of direct and indirect effects, accounting for emissions from public transit, in 2007 results in a total emissions reduction of 39.0 mmt CO_2e.

2010-2050 GHG Reductions from the 2.4 percent Growth Baseline

The 2009 Bottom Line Report explores three possible scenarios for future ridership growth: a continued 2.4 percent increase; a 3.5 percent increase, which represents a doubling of transit ridership in 20 years, and would require aggressive strategies to grow ridership; and an aspirational growth rate of 4.6 percent.[28] Transit trip growth rates of 2.4 percent (Base), 3 percent (Level A), 3.5 percent (Level B) and 4.6 percent (Level C) are applied to the baseline figure to estimate total trips through 2050.

The ridership difference between the baseline growth rate and the growth rates in Level A, B, and C are converted to VMT through dividing the difference by the average vehicle occupancy and multiplying by average transit trip length (see section 4.1). The VMT is then converted to annual million metric tons of GHG emissions through applying the annual estimate of baseline light-duty fuel economy and GHG emission factors. This estimates the direct benefit of transit expansion.

To account for the secondary or indirect effects of transit expansion from 2010 to 2050, the same relationship used to calculate the 2007 GHG reduction from urban transit systems is used. The average daily reduction of VMT per household remain 2.2 for households with access to transit. The factor that changes in the future is household accessibility to transit. The TCRP J-11 project calculates a transit availability for rail and bus based on the NHTS survey data. For the 2001 NHTS sample households, the average rail availability is 9 percent, the average bus availability is 37 percent. These same values are used in the 2007 calculation.

To determine rail and bus availability from 2010 to 2050, the following assumptions are made:

1. On average bus availability for urban area households will remain constant through 2050.

2. Average rail availability for urban area households will increase slightly, as a result of future system expansion. Based on FTA New Starts data from 1990 to 2006, the 2009 Bottom Line report assumed that 43 percent of total transit investment need is capital expansion. To grow accessibility to rail through 2030, the 43 percent is applied to the 2001 estimate of rail accessibility from TCRP Project J-11 (9 percent) to obtain a 2050 accessibility of 12.9 percent.

Section 4.6 includes details on the calculation of transit based GHG emissions.

---

[28] The maximum deployment level growth rate assumes a variety of potential factors that could cause public transportation ridership to grow more rapidly, including higher energy prices, implementation of policies to promote development around public transportation services, increased concern for the impacts of climate change, and stronger emphasis on the relationships between land use and transportation.

4.4 Intercity Passenger Rail

Estimates for automobile VMT displaced by increasing intercity passenger rail service above the baseline are derived from simple calculations. Historical intercity passenger rail ridership on Amtrak is obtained from the Bureau of Transportation Statistics' National Transportation Statistics publication.[29] Ridership for 10 years from 1996 to 2005 is used to create a linear trend and project baseline ridership into the future. The percentages above baseline specified in deployment levels A-C are applied to the baseline ridership to calculate new intercity rail passenger-miles (see Figure 4.1). These passenger miles are divided by a vehicle occupancy of 1.63 passenger per vehicle[30] to obtain the automobile VMT displaced by additional investment in intercity passenger rail. Further research is being conducted to reflect the displacement to traditional intercity rail by diversion from aviation rather than highway vehicles.

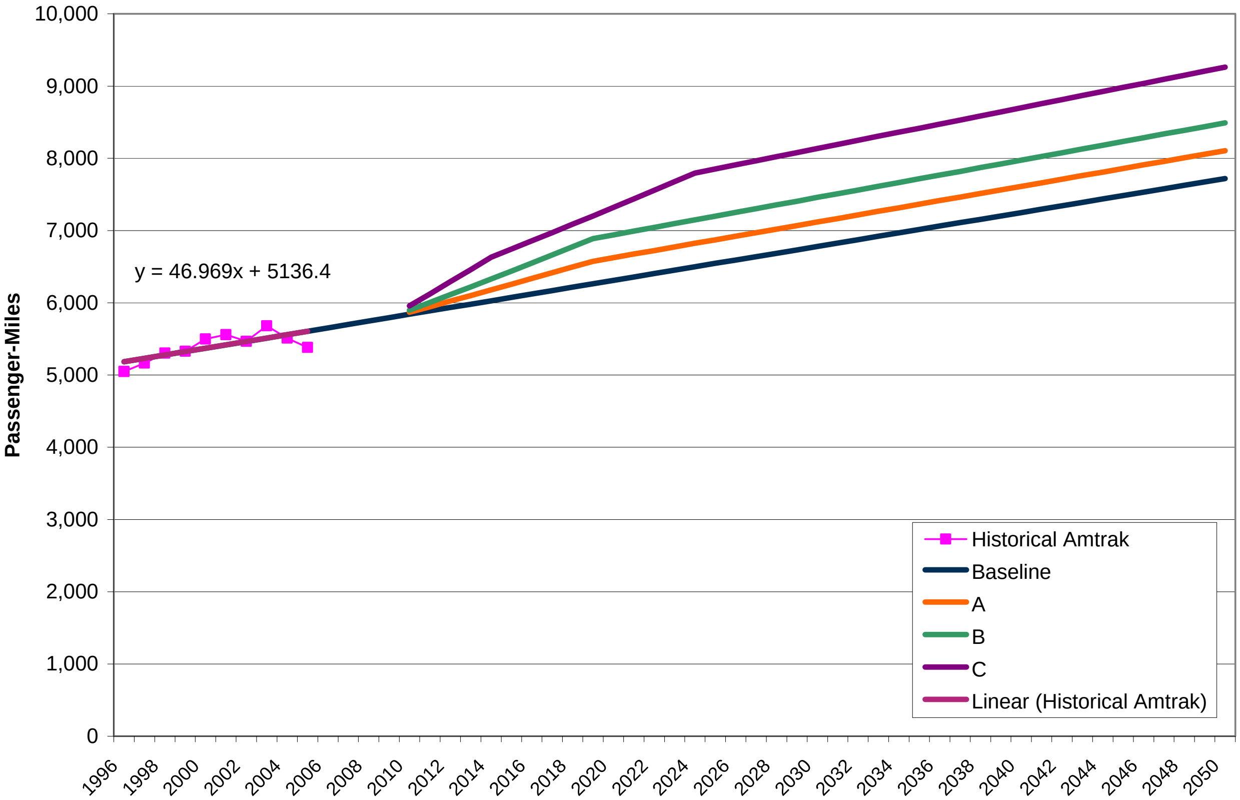
In addition, for this measure emissions reduced as a result of VMT decrease are offset to some degree in our analysis by increased transit vehicle emissions. See Section 4.6 for an explanation of the offset methodology.

---

[29] Bureau of Transportation Statistics. National Transportation Statistics. Table 1-37. http://www.bts.gov/publications/national_transportation_statistics/.

[30] Federal Highway Administration. National Household Travel Survey 2001. Table A-14. http://nhts.ornl.gov/.

Figure 4.1 Historical and Projected Intercity Rail Passenger Miles



■ 4.5 High-Speed Rail

Estimates for the displacement VMT due to the introduction of intercity high-speed passenger rail were derived from a report entitled "High-Speed Rail and Greenhouse Gas Emissions in the United States."[31] This report studied all Federally designated high-speed rail corridors and included estimates of passenger-miles.[32]

For *Moving Cooler*, corridors were placed in order from the largest auto vehicle miles traveled displacement to the smallest and then grouped by the number of corridors specified by each *Moving Cooler* implementation level (Table 4.1). The total GHG

---

[31] Center for Clean Air Policy and Center for Neighborhood Policy. High Speed Rail and Greenhouse Gas Emissions in the U.S. January 2006. http://www.cnt.org/repository/HighSpeedRailEmissions.pdf.

32 Federally Designated High-Speed Rail Corridors (Source: Federal Railroad Administration, http://www.fra.dot.gov/us/content/203).

emissions reduction includes benefits as a result of diversion from auto, intercity bus and rail and air modes.

In addition, for this measure emissions reduced as a result of VMT decrease and other modal diversions are offset by increased high-speed rail emissions. See Section 4.6 for an explanation of the offset methodology.

Table 4.1 Automobile VMT Displacement by Corridor and Level of Implementation

Corridor	Auto VMT Displaced (2025)	Corridor Number
California	3,313,553,642	1
Midwest	587,177,970	2
Gulf Coast	291,431,462	3
Southeast	216,118,270	4
Florida	201,814,650	5
South Central	180,400,000	6
Empire	138,907,196	7
Pacific Northwest	130,874,585	8
Northern New England	90,813,754	9
Northeast	59,830,000	10
Ohio	59,590,346	11
Keystone	5,156,250	12
Level A	**4,610,095,994**	**1-5**
Level B	**4,929,403,190**	**1-7**
Level C	**5,275,668,125**	**1-12**

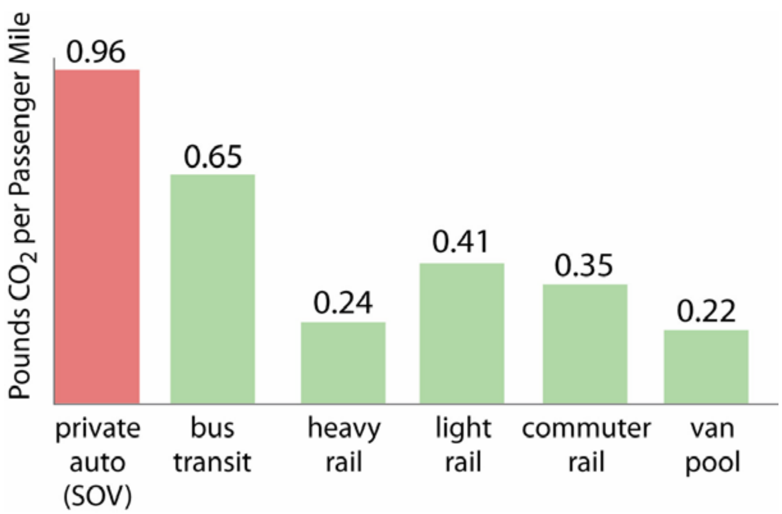
4.6 Transit Greenhouse Gas Emissions Methodology

Improvement of existing transit services and expansion of infrastructure results in added emissions from the transit sector. The magnitude of this addition is dependant on GHG emission factors, distribution of services by mode and fuel type and total new unlinked trips on the system.

Fixed Guideway and Bus Transit

Emission reductions are a result of the lower than average emissions per passenger-mile for transit versus private vehicles. In 2006, based on fuel consumption data from the National Transit Database, the average greenhouse gas emissions rate for urbanized area transit systems (excluding demand response services) is 0.48 pounds CO_2e per passenger-mile.[33] With an average on-road fuel economy of 20.3 mpg, a single-occupant vehicle releases 0.96 pounds CO_2e per passenger-mile; at the average occupancy for all trips of 1.63 passengers per vehicle (based on the 2001 NHTS), personal vehicle travel releases 0.62 pounds CO_2e per passenger-mile. Transit emissions vary by mode, however, with rail emissions lower than bus emissions on the average. As shown in Figure 4.2, FTA calculates that bus transit averaged 0.65 pounds CO_2e per passenger-mile, compared to 0.41 for light rail, 0.35 for commuter rail, and 0.24 for heavy rail (FTA 2009). These figures reflect differences in loading for different systems as well as inherent differences in vehicle efficiency and emissions characteristics for electric versus diesel vehicles.

Figure 4.2 Average CO_2 Emission Rates by Mode



Source: FTA (2009).

The data on average GHG emissions by mode were used to estimate the GHG reductions that are achieved through the transit services in place today. Based on data from the National Transit Database, total GHG emissions from public transit vehicle operations in 2007 are estimated to be 11.8 mmt CO_2e.

[33] Based on emission factors of 10.15 kilograms CO_2 per gallon for diesel fuel and 1.185 pounds CO_2 per kilowatt-hour for electricity (EPA 2006).

CO_2 emission factors are shown in Table 4.2A. The values represent default values obtained through USEPA or The Climate Registry General Reporting Protocol. Note that the emission factors for biodiesel and ethanol assumes 100 percent B100 and E100 fuel types. Table 4.2B presents CO_2 emission factors for the electricity generation sector, powering all operations for heavy rail and light rail and a significant portion of commuter rail vehicle miles. The emission rates vary by mode as a result of using USEPA 2006 eGRID subregion data. Total powerplant CO_2 emissions to support KWH usage for propulsion are calculated for each transit system individually based on specific emission rates for each subregion. From this data an average emission factor by mode is determined.

Table 4.2A CO_2 Emission Factors
Fuels

Fuel Type	Efac (Pounds CO_2/Gallon
Gasoline	19.42
Diesel	22.38
Biodiesel (B100)	20.86
CNG	16.14
Ethanol (E85)	12.26
Kerosene	21.52
LNG	9.83
LPG	12.76
Methanol	9.04
Propane	12.65

Source: The Climate Registry, General Reporting Protocol, May 2008. Table 13.1. http://www.theclimateregistry.org/downloads/GRP.pdf.

Table 4.2B CO_2 Emission Factors
Electricity Generation

Transit Mode	2006 EFac (Pounds CO_2/kwh)
Heavy Rail	1.050
Light Rail	1.134
Commuter Rail	1.185

Source: USEPA, Emissions and Generation Resource Integrated Database, October 2008. http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

The CO_2 emission factors in Table 4.2A and B represent 95 percent of total GHG emissions according to USEPA, except in the case of natural gas based fuels (liquefied natural gas, compressed natural gas and methanol) which have significantly higher methane emissions compared to CO_2. Other transportation-relevant GHG emission factors are shown in Table 4.3.

Table 4.3 Other GHG Emission Factors

Fuel/Energy Type	EFac	Units	Source
Electricity Generation	.092	Pounds N_2O/kwh	EIA
Electricity Generation	.012	Pounds CH_4/kwh	EIA
CNG/LNG	.175	Pounds N_2O/mi	EIA
	1.97	Pounds CH_4/mi	

Source: USEPA, 2005 (http://www.epa.gov/otaq/climate/420f05001.htm), EIA Simplified Emissions Inventory Tool, 2006 (http://www.eia.doe.gov/oiaf/1605/Forms.html).

GHG emission factors in Tables 4.2 and 4.3 are applied to total transit energy consumption and divided by total passenger miles to obtain 1997 and 2006 GHG emissions per passenger mile (Table 4.4).

Table 4.4 Baseline GHG Emissions per Passenger-Mile[a]

Emissions (Pounds/Pax-Mile)	Commuter Rail	Heavy Rail	Light Rail	Bus	Other[b]
GHG/Pax-Mile (1997)	0.36	0.31	0.35	0.72	0.92
GHG/Pax-Mile (2006)	0.36	0.28	0.40	0.71	0.80

[a] NTD energy consumption data is only reported for direct operated service.

[b] Other includes: automated guideway, cable car, ferry, incline, trolley bus and vanpool.

To calculate future year GHG emissions:

1. Calculate total annual transit unlinked trips (applying Deployment Level A, B, and C growth rates)

2. Calculate mode share (of each transit mode) of total transit trips (Table 4.5). The mode share among each of the five modes is multiplied by total unlinked trips to obtain mode-specific unlinked trips for each year through 2050.

Table 4.5 Transit Mode Share

Year	Commuter Rail	Heavy Rail	Light Rail	Bus	Other
1997	4.1%	31.9%	3.4%	58.2%	2.4%
2006	4.6%	33.9%	4.6%	54.8%	2.1%
2050	6.8%	39.0%	9.9%	43.6%	0.6%

3. Calculate mode-specific passenger miles per unlinked trip (Table 4.6) – The passenger miles per trip by mode is multiplied by mode-specific total unlinked transit trips to obtain total passenger miles. "Other" is held constant through 2050 as it only represents.6 percent of all passenger trips.

Table 4.6 Passenger Miles per Unlinked Trip

Year	Commuter Rail	Heavy Rail	Light Rail	Bus	Other
1997	22.5	4.9	4.0	3.7	3.7
2006	22.8	5.0	4.6	3.7	5.2
2050	24.1	5.4	7.5	3.8	5.2

4. GHG Emissions per Passenger Mile – The rate of change from 1997 to 2006 is used to forecast annual GHG emissions per passenger mile by mode through 2050. This value is multiplied by passenger miles to obtain annual GHG emissions by mode.

The 1997 to 2006 trends obtained from NTD inform projections of future transit mode shares and passenger miles per trip (Note: 2007 NTD data was not available at the start of *Moving Cooler* analysis, therefore 2006 data is the most recent). Translating this data into future estimates of GHG emissions per passenger mile requires modifications to account for new strategies and technologies that significantly will affect future emissions. In *Moving Cooler*, three primary changes are considered: improved transit load factors across all modes, decreased emissions from the transit bus fleet as a result of new technology and decreased power plant emissions used to power electric transit systems.

Bus Fleet Technology Improvements

For buses, greenhouse gas emission factors are assumed to decline from 0.71 pounds GHG per passenger mile in 2006 to 0.44 pounds GHG per passenger mile in 2050. The decrease over time represents two assumptions. Assumption one is based on an increase in the share of diesel-hybrid buses in the national bus fleet from 1.65 percent as estimated in APTA's 2007 Public Transportation Factbook to 79 percent in 2050. This growth is based on a 15-year replacement cycle and an assumption that from 2007 to 2030, the share of new buses entering fleets that are diesel-hybrid will increase from 30 percent observed in 2007 to a maximum of 90 percent of total orders by 2038. For reference, diesel-hybrids were 18 percent of total bus orders in 2006[34] and 30 percent of total orders in 2007.[35] Assumption two is based on forecast increases in transit bus fuel economy as a result of increased utilization of alternative fuels and new technologies. The effect of assumption one is a 1.27 percent annual fuel economy growth rate, while the effect of assumption two is a.23 percent annual growth rate.

Power Generation Emission Standards

For electric powered transit systems, eGRID subregion data from 1997 and 2006 support calculation of mode-specific CO_2 emission factors and can inform determination of a trend for emission factors through 2050. In 1997, heavy rail, light rail and commuter rail average CO_2 emission factors were 1.144, 1.005, and 1.221 pounds CO_2 per kwh, respectively. The 2006 factors presented in table 4.2B are 8.2 percent lower for heavy rail, 12.8 percent higher for light rail and 2.9 percent lower for commuter rail. Using these trends to extrapolate emission rates through 2050 was considered unrealistic given state and regional guidelines recently developed or under development delineating the role the power sector plays with regard to decreasing CO_2 emissions. There are a number of examples of regional and state goals for reducing CO_2 emissions; for the purposes of this study, the Regional Greenhouse Gas Initiative (RGGI), which sets targets for reducing the CO_2 emissions from the power sector for 10 Northeast and Mid-Atlantic states was selected as the most realistic national set of guidelines in the future. These states represent 75 percent of heavy rail passenger miles and 75 percent of commuter rail passenger miles in 2006. If California transit systems are considered, a State which has equally, or more ambitious CO_2 emission reduction goals, 84 percent of heavy rail and 57 percent of light rail passenger miles are covered.

RGGI sets a goal of stabilizing emissions from 2009 to 2014 and decreasing emissions by 10 percent by 2018. *Moving Cooler* applies this goal at a national level starting 2015 through 2050 (equivalent to a 2.5 percent reduction in the emission factor per year).

Improved Transit Load Factors

Transit load factors from NTD 1991 to 2006 data reflect slight decreases in load factors for commuter rail and bus, while heavy rail, light rail and other show marginal increases (Table 4.7).

---

[34] Federal Transit Administration, "Analysis of Electric Drive Technologies for Transit Applications: Battery Hybrid-Electric, and Fuel Cells Final Report" August 2005. http://www.fta.dot.gov/documents/Electric_Drive_Bus_Analysis.pdf.

[35] American Public Transportation Association, 2007 Transit Vehicle Database.

Table 4.7 Transit Load Factors
Passengers per Vehicle

Year	Commuter Rail	Heavy Rail	Light Rail	Bus	Other[a]
1991	37.3	20.6	24.9	11.7	28.9
1999	36.0	23.0	25.2	10.9	27.5
2006	36.1	23.2	25.6	10.7	31.7

[a] Other includes: automated guideway, cable car, ferry, incline and trolley bus.

Assumptions regarding the future number of riders per transit vehicle have a significant impact on GHG emissions per passenger mile. Table 4.8 displays forecast GHG/passenger-mile based on NTD energy consumption trends, transit mode shares, transit trip lengths, improved bus technology and decreased power generation emissions. The results assume that transit load factors remain constant. This represents the "Baseline" (2.4 percent annual ridership growth scenario).

Table 4.8 Baseline GHG Emissions per Passenger-Mile[a]

Emissions (Pounds/Pax-Mile)	Commuter Rail	Heavy Rail	Light Rail	Bus	Other[b]
GHG/Pax-Mile (2006)	0.36	0.28	0.40	0.71	0.80
GHG/Pax-Mile (2050)	0.19	0.10	0.18	0.54	0.60

[a] NTD energy consumption data is only reported for direct operated service.

[b] Other includes: automated guideway, cable car, ferry, incline, trolley bus and vanpool.

FTA's Transit Economic Requirements Model (TERM) is used to forecast future transit funding needs to assist in preparation of U.S. DOTs Conditions and Performance Report. For *Moving Cooler*, TERM is utilized to forecast future transit investment needs by mode required to meet annual ridership growth rate targets of 3, 3.5, and 4.67 percent. A primary input supporting TERM calculations are assumptions about seating capacity utilization of transit services.

The method TERM uses to support the *Moving Cooler* analysis is to add capacity to a system only when load factors on the existing system are above a specific threshold. The thresholds selected are the average utilization rates from 2006 NTD data. These are: 33.2 percent for commuter rail, 44 percent for heavy rail, 40.2 percent for light rail and 26.4 percent for bus. For each year through 2026 (TERMs model timeframe), capacity is only added to systems which currently exceed the mode-specific threshold. For these systems, enough capacity is added in order to maintain the same utilization rate. For systems under the threshold, capacity is not added until the threshold is met in future years as a result of ridership increases. A good example is Metropolitan Transit Authority (MTA) New York which currently has the highest utilization for a bus system nationally at 34 percent. The model will add enough capacity annually in each ridership growth scenario to maintain the existing utilization rate. The result of this analysis are in Table 4.9

Table 4.9 Transit Load Factor Forecast
Passengers per Vehicle

Year	Commuter Rail	Heavy Rail	Light Rail	Bus	Other[a]
2006	36.2	23.2	25.6	10.7	31.7
2050 – Level A	39.0	26.7	30.0	12.4	33.6
2050 – Level B	39.4	26.8	29.3	12.2	34.0
2050 – Level C	39.1	27.0	29.3	12.1	34.1

[a] Other includes: automated guideway, cable car, ferry, incline and trolley bus.

The resulting GHG per passenger mile estimates for 2050 as a result of adjustments to the 1997-2006 NTD trends for commuter rail, heavy rail, light rail and bus are presented in Table 4.10. These results are applied to GHG emissions for deployment levels A, B, and C.

Table 4.10 Scenario GHG Emissions per Passenger-Mile[a]

Emissions (Pounds/Pax-Mile)	Commuter Rail	Heavy Rail	Light Rail	Bus	Other[b]
2006	0.36	0.28	0.40	0.71	0.80
2050 (Level A)	0.33	0.24	0.33	0.58	0.75
2050 (Level B)	0.33	0.24	0.34	0.59	0.74
2050 (Level C)	0.33	0.23	0.34	0.60	0.74

[a] NTD energy consumption data is only reported for direct operated service.

[b] Other includes: automated guideway, cable car, ferry, incline, trolley bus and vanpool.

Intercity and High-Speed Rail

For intercity rail service, GHG emissions pivot off current estimates in AEO 2008. These reflect total energy consumption in terms of both kwh of electricity and gallons of diesel. In 2010, the resulting baseline emissions rate per passenger mile is 0.49 pounds GHG per passenger mile. According to AEO projections this will decrease to.26 pounds GHG per passenger mile by 2050. This rate is adjusted for Level A, B, and C to reflect the expansion of the use of regenerative braking systems in intercity rail trains through 2050. A recent BritRail study estimated that regenerative braking saves 20 percent of the energy of stopping a train. Regenerative braking is similar to the system in gas-electric hybrid vehicles. In the case of trains, braking energy from electric-powered trains is captured and sent back into power lines to boost the acceleration of trains as they depart stations. *Moving Cooler* increases the penetration of this technology in intercity rail service starting in 2011 and assumes by 2030 that 100 percent of passenger miles on electric-powered intercity rail service will use regenerative braking. This assumption results in a GHG per passenger mile estimate in 2050 of 0.20 pounds GHG per passenger mile.

For high-speed rail, the total emissions calculated by the CCAP 2006 study referred to above in Section 4.5 are applied. This study presents all its results in terms of emissions in the year 2025. The *Moving Cooler* methodology assumes total emissions to increase linearly from the start year to complete year (varies by implementation level) to the build out estimate from CCAP. Beyond the complete year, total emissions are assumed to increase in the same trend as total VMT (1.4 percent annually). Eleven of the 12 corridors studied are assumed to use the "IC-3" diesel fuel train system which is most similar to present day Amtrak Acela service. Only the California corridor is assumed to use France's "TGV" technology which runs at maximum speeds of 300 km/hour with lower emissions factor than the IC-3 technology.

5.0 HOV Lanes, Car-Sharing, and Commuter Strategies

5.1 High-Occupancy Vehicle Lanes

Information about the center line miles of urban expressways by urban area that are three or more lanes in each direction is not readily available. The national average is inferred from the division of the reported number of lanes miles by the number of center line miles. The percentage of miles by urban area in Table 5.1 is based on professional judgment. Due to the assumed implementation year and phase in period for this strategy and the fact that the HOV lanes will be taken from existing lanes, the implementation of new HOV lanes was assumed to all be in contra-flow lanes as a take-a-lane with movable barriers (i.e., similar to Boston's I-93 SE Expressway "Zipper Lane"). It is recognized that only radial expressways are suitable for contraflow operation and the percentages in Table 5.1 also include an adjustment based on professional judgment to account for nonapplicability to urban expressways where the directional split in the off-peak direction is more than 40 percent.

It was decided that barrier separated HOV lanes implemented in the magnitude and with the deployment dates outlined in *Moving Cooler* was an unrealistic and not cost-effective GHG emissions reduction approach. Thus deployment of "Quickchange Moveable Barriers" was the chosen implementation approach.

The costs for the barriers were not specific for the Hawaiian system but were taken from a review of such systems which was published in support of the Hawaii deployment (this included the Boston moveable barrier system). If QMB are not used and new lanes and ramps are constructed, the costs go up by several orders of magnitudes and the regulatory requirements for implementation become inconsistent with the schedules outlined in *Moving Cooler*. For these reasons, the study team decided to stick with the cost estimates and GHG reduction estimates for the QMB type HOV deployment.

Table 5.1 Percentage of Expressways with 3+ Lanes per Direction Suitable for HOV Lanes

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
70%	70%	60%	60%	50%	50%

Strategy 5.1.1 is the implementation of HOV lanes where the general purpose lanes are operating at LOS F. From the Texas Transportation Institute's report on Urban Mobility, the center line miles of the facilities at LOS are estimated to be those in Table 5.2.

Table 5.2 Urban Expressways at LOS F

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
40%	40%	30%	30%	20%	20%

From USEPAs COMMUTER model, the percent reduction in fuel consumption from a shift from SOV to HOV (either to carpool or transit) due to a one-minute savings varies by the size and density of the urban area as is expected to be as shown in Table 5.3.

Table 5.3 Reduction in Fuel Consumption per One Minute of Time Savings

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
0.6%	0.3%	0.3%	0.2%	0.3%	0.2%

The average travel time savings for a 10 minute trip in minutes for large urban areas is taken from the 1999 Los Angeles HOV lane network evaluation (0.5 min/mile * 10 miles) (Evaluation of regional HOV network in SF Bay Area found 1.7 minute average time savings for 10-mile trip) The travel time saving for medium and small urban areas are assumed similar, since analysis is based on percent miles at LOS F.

The net reduction in fuel consumption is based on the product of the values in Tables 5.1, 5.2, and 5.3 applied to a five-minute savings is as shown in Table 5.4

Table 5.4 Percent Reduction in Fuel Consumption for Five-Minute Savings
Strategy 5.1.1

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
0.80%	0.36%	0.28%	0.19%	0.13%	0.10%

For Strategy 5.1.2, the HOV lanes are to be implemented when the LOS is LOS D. The percent of applicable miles based on TTI's Urban Mobility is assumed to be changed to those shown in Table 5.5 and the net reduction in fuel consumption is changed to those in Table 5.6

Table 5.5 Urban Expressways at LOS D or Greater

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
50%	50%	40%	40%	30%	309%

Table 5.6 Percent Reduction in Fuel Consumption for Five-Minute Savings
Strategy 5.1.2

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
1.00%	0.45%	0.37%	0.25%	0.20%	0.15%

For Strategy 5.1.3, the HOV lanes are to be implemented on all facilities which results in a net reduction in fuel consumption as shown in Table 5.7.

Table 5.7 Percent Reduction in Fuel Consumption for Five-Minute Saving
Strategy 5.1.3

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
2.01%	0.90%	0.93%	0.63%	0.67%	0.51%

5.2 High-Occupancy Vehicle Lanes to 24/7 Operation

The implementation of new HOV lanes was assumed to all be in contra-flow lanes as a take-a-lane with movable barriers (i.e., similar to Boston's I-93 SE Expressway "Zipper Lane"). Contra flow or reversible HOV lanes are not suitable for 24/7 operations. (Contraflow cannot be offered 24/7 because the capacity is only available off-peak. Reversible lanes by definition cannot be operated in both directions 24/7. The center line miles (CLM) of existing concurrent flow lanes which might be operated 24/7 represent only 4 percent of the CLM of urban expressways. Of those facilities 50 percent already are operated 24/7. Therefore, 2 percent (50 percent of 4 percent) of the urban expressway might be expected to be impacted by this strategy. From the COMMUTER model, the percentage reduction in fuel consumption from a shift from SOV to HOV (either to carpool or transit) due to a one-minute savings varies by the size and density of the urban area as is expected to be as shown in Table 5.8.

Table 5.8 Percentage Reduction in Fuel Consumption per One Minute of Time Savings

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
0.6%	0.3%	0.3%	0.2%	0.3%	0.2%

The average time savings in fuel for a 10-minute trip during the off–peak hours is, as adjusted from research cited in Strategy 5.1.1 based on professional judgment is shown in Table 5.9.

Table 5.9 Average Savings in Time

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
2.0%	2.0%	1.5%	1.5%	1.0%	1.0%

The net savings in fuel consumption is the product of the two percent of eligible facilities, the fuel consumption savings per minute of time reduction in Table 5.8 and the time savings in Table 5.9 and is shown in Table 5.10.

Table 5.10 Percent Reduction in Fuel Consumption for Five-Minute Savings
Strategy 5.1.4

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
0.02%	0.01%	0.01%	0.01%	0.01%	0.00%

Strategy 5.1.5 changes the year of implementation and phase in period but does not otherwise change the reductions.

■ 5.3 Car-Sharing

This strategy set goals in aggressive deployment of one car per 2,000 inhabitants of medium and 1,000 inhabitants of high-density census tracts. The population by urban area for 2030 was taken from metro area projections as shown in Table 5.11

Table 5.11 2030 Population by Urban Group

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
165,663,145	37,381,749	12,405,022	39,851,632	4,142,127	37,513,092

Medium-density areas, those with 4,000 to 10,000 persons per square mile are assumed to constitute 26 percent of all urban areas, based on analysis of projected 2030 land use plans. High-density areas, those with greater than 10,000 persons per square mile are assumed to constitute 20 percent of all urban areas. Applying the goals by density to the percentage of population of the urban areas, results in the number of shared cars shown in Table 5.12.

Table 5.12 Shared Cars

LH – Large High Density	LL – Large Low Density	MH – Medium High Density	ML – Medium Low Density	SH – Small High Density	SL – Small Low Density
54,669	12,336	4,094	13,151	1,367	12,379

The values in Table 5.12 are multiplied by 20, an assumption for the number of members per shared car, to determine the number of equivalent cars that this represents. This number is divided by the population, where it is assumed that one car is otherwise available per person. Finally the percentage reduction in VMT per equivalent car is assumed to be 50 percent, recognizing that those members without a car would drive more than before, but those members who had previously owned a car would drive less than before. The net reduction in VMT is equivalent to 0.33 percent for all urban areas.

Level C changes the year of implementation, phase in period and sets more aggressive goals of one car per 1,000 inhabitants in medium density and one car per 500 inhabitants in high density. Strategy 5.2.1, which sets no specific goals, is assumed to result in one-half of the reductions of 5.2.2, which would amount to 0.17 percent of regional VMT.

5.4 Employer Based Commute Strategies

The commuter measures analysis was performed in two basic steps:

1. Run the COMMUTER Model to get percent VMT reduction impacts per affected employee for a variety of commuter measures.

2. Apply assumptions about the percentage of affected employment for each of the strategies defined for the *Moving Cooler* analysis.

These two steps are described below.

1. Run COMMUTER Model

The COMMUTER Model was set up with baseline work-trip mode shares and trip distances which varied by the six metro area classes.[36] It was then run for units of 1,000 employees and for unit measures (e.g., $1/day parking cost). The unit measures that were run include:

- **Employer Support Programs –** Employers offer transit, ridesharing, and nonmotorized support programs at "Level 3" as described in the model. Level 3 is described as follows: Carpooling includes in-house carpool matching and information services plus preferential (reserved, inside, and/or especially convenient) parking for carpools, a policy of flexible work schedules to accommodate carpools, and a half-time transportation coordinator. Vanpooling also includes vanpool development and operating assistance, including financial assistance, such as vanpool purchase loan guarantees, consolidated purchase of insurance, and a startup subsidy. Bicycling includes secure bicycle parking and shower and locker facilities.[37]

- **Transit Fare Subsidies –** A decrease in costs of $1 per day for transit mode.

- **Parking Cash-Out –** A subsidy of $1/day for all nondrivers (carpoolers: $0.50/day).

---

[36] The COMMUTER Model analyzes time and cost strategies using a "pivot-point" logit mode choice model, which uses the mode choice coefficients from regional travel models and applies a change in time and/or cost to "pivot" off of a baseline starting mode share to achieve a final mode share (hence the pivot-point name). Baseline mode shares vary by Metro group and therefore impacts do as well. For "soft" strategies such as employer outreach, the COMMUTER Model uses look-up tables that were developed based on professional judgment reviewing the known impacts of such strategies on commuting behavior. Assumptions about CWW and telecommuting participation were manually input, since the defaults in the COMMUTER model on these strategies are rather old.

[37] The bicycling program was set at Level 2 in the COMMUTER Model since Level 3 includes supportive infrastructure, which is beyond the scope of the employment site.

- **Parking Charges –** An increase in parking costs of $1/day per vehicle ($0.50 per vehicle for carpools, free for vanpools).
- **Compressed Work Week (CWW) –** An additional 1 percent of employees participate in a 4/40 or a 9/80 compressed workweek.
- **Telecommuting –** An additional 1 percent of employees telecommute on average 1.5 days per week.

The resulting unit impacts are shown in Table 5.13. Alternative Work Schedule impacts reflect a discounting of 25 percent to account for the "rebound" effect (i.e., travel for other purposes on the day on which the employee is working at home or not working).

Table 5.13 Commuter Measures Unit Impacts

		Percent Change in Commuting VMT					
Strategy	**COMMUTER Model Description**	**LH**	**LL**	**MH**	**ML**	**SH**	**SL**
Support Programs							
Employer Support – High	Employers promote alternative modes @ high level (3)	5.2%	5.2%	5.4%	5.4%	6.2%	6.2%
Financial Incentives							
Transit Fare Subsidies	Subsidy of $1/day	7.0%	1.6%	2.6%	0.7%	1.8%	0.6%
Parking Cash-Out	Subsidy of $1/day for all nondrivers (carpoolers: $0.50/day)	7.7%	3.7%	4.5%	3.0%	4.0%	3.0%
Parking Charges	Parking charge of $1/day ($0.50 for carpools, free for vanpools)	6.9%	0.9%	1.8%	0.5%	1.3%	0.5%
Alternative Work Schedules							
CWW 4/40	1% of employees	0.15%	0.15%	0.15%	0.15%	0.15%	0.15%
CWW 9/80	1% of employees	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%
Telecommute	1% of employees @ 1.5 days/week	0.22%	0.22%	0.22%	0.22%	0.22%	0.22%

2. Apply Assumptions About Percentage of Affected Employment

The next step was to apply assumptions about the percentage of affected employment under each of the *Moving Cooler* strategies. A baseline (current) percentage also was assumed, to account for the fact that some employers already offer commute benefits and alternative work schedules.[38] For support programs and financial incentives, the

[38] Baseline assumptions include: five percent of employers offering a "high" level of alternative mode support as well as transit subsidies at $2/day; four percent of employees (one-half of CBD

(Footnote continued on next page...)

percentage of affected employment was based on the percentage employment in establishments by size of the establishment (number of employees). TDM requirements and/or outreach programs are generally targeted at larger businesses, although smaller businesses may take advantage of regional TDM resources as well on a voluntary basis. Based on national data from 2006 County Business Patterns, 55 percent of workers are in an establishment with at least 50 employees, and 42 percent are in an establishment with at least 100 employees.[39]

Alternative work schedule measures were applied differently to the public versus private sectors, since the public sector has the power to require alternative work schedule participation. National data show that about 86 of employment is in the private sector and 14 percent in the public sector (not counting self-employment). Since the VMT reduction results need to be expressed as a percentage of all commute trips, the private sector VMT reductions for telecommuting were multiplied by 0.86 and the public sector reductions by 0.14.

Table 5.14 includes a description of each strategy and the key assumptions about its impacts. (The strategy numbering skips because some of the strategies originally listed were combined with others.) Strategies were combined based on two criteria: 1) the policies contained in the strategy are highly complementary and therefore effects cannot easily be distinguished; and 2) the policies contained in the strategy have a similar implementation approach and feasibility. Implementation Levels B and C combine the alternative work schedules and other strategies, since they are implemented through a combination of trip reduction requirements and tax incentives which should affect all types of commute alternatives. Within each of the implementation levels, the strategies shown in Table 5.14 should be considered additive.

Table 5.14 Commuter Strategies and Assumed Impacts

Strategy	Description	Level	Assumed Impacts
6.1.1	Provide employer goals and tax incentives for the offering and adoption of telecommuting and compressed work week targets. Provide technical assistance for starting a telecommuting program. Provide public funding or subsidies for the private provision of regional telework centers and shared satellite offices. Require elimination of telecommuting barriers in state and local tax codes (e.g., double taxation).	A	Increase CWW from 4 percent to 8 percent – equally split between 4/40 and 9/80, Increase TC from 8 percent to 12 percent, Private sector employment only Total = 20 percent w/alt work schedules.

workers) paying for parking; four percent working compressed work weeks; and eight percent telecommuting.

39 http://www.census.gov/econ/cbp/index.html.

Strategy	Description	Level	Assumed Impacts
6.1.2	All government agencies allow option of telecommuting and compressed work week for eligible employees.	A	Increase CWW from 8 percent to 12 percent – equally split between 4/40 and 9/80, Increase TC from 8 percent to 12 percent, Public sector employment only Total = 24 percent w/alt work schedules.
6.2.1	MPO or other designated agencies (such as TMAs) implement aggressive outreach program to inform major employers (100+ employees) of alternative travel options, assist with providing information and incentives to employees. Contact is made annually. States and/or MPOs provide on-line ridematching and vanpool services and guaranteed ride home program for all areas where services already are not provided by TDM service providers. Transit agencies make monthly passes available through employers at discounted rates.	A	50 percent of all employers w/100+ employees and 25 percent w/ <100 employees offer "aggressive" level of alt. mode support (net = 41 percent). Of these employers, half provide some sort of financial subsidy (40 percent provide transit subsidy ($2/day) and 10 percent provide parking cash-out ($2/day) to all nondrivers). Net effect is that 20 percent of all employees are offered a financial incentive.
6.1.5	All government agencies require four-day work weeks.	B	Increase total public sector AWS participation from 16 percent to 80 percent (68 percent 4/40, 12 percent TC).
6.2.4	Establish requirements for employers w/50+ employees to develop and implement plans to reduce SOV trips by 10 percent compared to baseline levels; offer technical assistance to employers for these plans; provide Federal tax incentives/disincentives for compliance. Value of parking benefits is taxed; value of cash-out or transit benefits is not. Continues regional ridematching, vanpool, GRH, and transit discount services.	B	80 percent of employers w/50+ employees implement aggressive level of alt. mode support; 25 percent of other employers do so (net = 66 percent). Of these employers, 40 percent provide transit subsidy ($2/day) and 10 percent provide parking cash-out ($2/day) to all nondrivers. Telecommuting increases from 8 percent to 16 percent and CWW from 4 percent to 8 percent (split equally between 4/40 and 9/80) – Total of 24 percent AWS. Number of CBD commuters with paid parking increases from 50 percent to 75 percent.
6.2.7	Federal/state tax levied on all commercial parking spaces ($5/space/weekday); employers required to pass along this cost to employees; proceeds used to provide free transit passes for employees and other TDM activities (e.g., transit shuttles). Continues regional ridematching, vanpool, GRH, transit discount, and employer outreach programs.	C	Increased parking cost of $5/day for all commuters. Added to TC/CWW shift from Level B and employer support shift from Level A (no TDM plan requirement).

Strategy 6.2.7 raises numerous concerns regarding both its political and administrative feasibility, including how to ensure that parking costs are passed on to employees on a per-trip basis so that travel behavior is affected. One alternative variation might be a $5 tax on all SOV trips, which would provide a more direct incentive for the employer to reduce trips, but would be extremely difficult to monitor and enforce.

Discussion of Telecommuting/Alternative Work Schedule Assumptions

A Cambridge Systematics review of national studies conducted in 2007 for the New York City Department of Transportation suggest the existing rate of telecommuting is about 8 percent, with 1.5 days per week being a typical average. Data from Phoenix (where trip reduction ordinances have been implemented) found that 13 percent of nonhome-based commuters use a compressed work weeks (CWW), with 2 percent operating 9/80 (nine days and 80 hours every two weeks), 8 percent operating 4/40, and 3 percent (many police and fire) operating 3/12.

A range of estimates can be made for future participation rates in alternative work schedules. Data from various national studies suggest that roughly 50 percent of the workforce could potentially participate (based on job requirements) and 50 percent of workers offered the option to do so would take advantage of it – for a net of 25 percent of the workforce. This probably represents an upper bound on CWW participation short of additional strong motivating factors, such as high fuel prices, traffic gridlock, or mandates. One study in Phoenix, AZ found that 31 percent of employers currently offer telecommuting as an option, while an additional 13 percent were considered likely to do so; assuming that 25 percent of these workers both could and chose to take advantage of the option, the rate of telecommuting would increase from 7.75 percent (31 percent offering * 50 percent able * 50 percent interested) to 11 percent. Applying similar assumptions to a study of employers in Arlington County, Virginia the result is that an estimated 13.8 percent of workers currently telecommute, and 16.3 percent might ultimately do so. However, these studies were conducted before the most recent rise in gas prices, and it is possible that sustained high fuel prices will sustain the potential for telecommuting. The potential for further adoption of CWW schedules also is unknown, but appears to be a subject of growing interest.

Potential Future Refinements

The following refinements could be made:

- Conduct a more thorough review of existing commute options program evaluation data (e.g., from Arizona and Washington State) to validate and possibly develop better estimates of baseline and Level A participation rates. Provide a more solid justification of the participation assumptions made, based on this review. [This review would require additional resources.]

- Vary Alternative Work Schedule participation by fuel price.

6.0 Regulatory Strategies

6.1 Urban Nonmotorized Zones

This measure assumes that over a period of 10 years, a percentage of Central Business District (CBD) and other major activity center roadway miles are converted to transit malls, linear parks or other nonmotorized zones.

The analysis makes use of the following assumptions:

- The effectiveness rate for light-duty vehicle trip reduction to/from the nonmotorized zone is assumed to be 5.00 percent
- A VMT/trip reduction factor of 66.67 percent was used to account for longer trips being less likely to be diverted than shorter ones
- The percentage of CBD or activity center roadway centerline miles converted to nonmotorized zones is 2.0 percent (Level A), 4.0 percent (Level B), and 6.0 percent (Level C).
- Applicable VMT for trips to CBDs and other major retail/employment activity centers was assumed to be 15 percent of total metropolitan area VMT.
- We assumed a linear rate of implementation for a 10-year startup period. The maximum percentage annual VMT reduction of CBD/activity center VMT at full implementation is.07 percent for Level A,.13 percent for Level B and.2 percent for Level C (.01 percent,.02 percent and.03 percent, respectively of total metropolitan VMT).

6.2 Urban Parking Restrictions

This measure implements a parking freeze on new parking supply, capping the absolute number of commuter spaces in CBDs and regional employment and retail centers. Exceptions may be made for carpool-designated spaces. The measure is implemented over a 10-year period from 2015 to 2025 for Deployment Level A, a 10-year period from 2010 to 2020 for Level B, and a 5-year period from 2010 to 2015 for Level C.

The analysis makes use of the following assumptions:

- The effectiveness rate for trip reduction in the parking freeze area is 40-60 percent; this applies only to new trips (due to VMT growth) above the cap plus buffer.
- A VMT/trip reduction factor of 66.67 percent was used to account for longer trips being less likely to be diverted than shorter ones.
- The percentage of CBD/activity center covered by the parking freeze is 67 percent for Deployment Level A, and 83 percent for Level B and 100 percent for Level C.
- Applicable VMT for trips to CBDs and other major retail/employment activity centers was assumed to be 15 percent of total metropolitan area VMT.
- A cap buffer of 10 percent for Deployment Levels A and B is assumed, while a cap buffer of 0 percent is used for Deployment Level C.

6.3 Speed Limit Reductions

This strategy involves a combination of the phasing in of decreased speed limits to 65, 60 then 55 mph, beginning on non-urban expressways and then on urban expressways. It also includes provision for tightening enforcement through personnel and speed cameras/electronic means.

The following assumptions and method were used to assess the effectiveness of speed reductions in achieving GHG reductions:

- Estimate percent of current VMT operating in various 5 mph speed blocks, for the Interstate System and for Other Freeways and Expressways, for three area types (large/medium urbanized, small urbanized, and other) by time of day from HERS section output for 2006. For all sections, assume that traffic is split 20 percent peak period, peak direction; 10 percent peak period opposite direction; and 70 percent off-peak.
- For each system, combine above to produce distribution of VMT by 5 mph speed block, as depicted in Table 6.1 below.

Table 6.1 Share of Total VMT Operating in Speed Ranges

	Speed Range (mph)	Percent of VMT
Rural VMT		
	75+	48.8%
	70-75	36.22%
	65-70	5.93%
	60-65	4.98%
	55-60	1.49%
	<55	2.53%
Large/Medium Urban Area VMT		
	75+	10.3%
	70-75	25.6%
	65-70	14.1%
	60-65	21.5%
	55-60	9.0%
	<55	19.5%
Small Urban Area VMT		
	75+	17.6%
	70-75	28.0%
	65-70	12.1%
	60-65	24.7%
	55-60	5.2%
	<55	12.4%

- For each speed block above the new speed limit, estimate increased mpg from mpg for midpoint of speed block and mpg for new speed limit. Fuel economy improvements were calculated using mechanical engineering equations for different vehicles when operating at steady speeds. It was assumed that 75 percent of the combined urban/non-urban VMT at the high speeds affected by the speed limits would be conducted at approximately steady speeds.

- For each (pre-policy) speed block, estimate net reduction in VMT as a result of increased travel-time costs (due to reduced speed) and decreased fuel costs using HERS value of total elasticity (-0.45) and inferred shares for travel-time costs and fuel costs (by highway system).

7.0 Operational and Intelligent Transportation System (ITS) Strategies

■ 7.1 Eco-Driving

The eco-driving strategy, through driver education and training and proper vehicle maintenance, can help reduce fuel consumption and GHG emissions. According to the U.S. EPA, this type of smart driving can improve fuel economy by up to 33%.[40]

In the Netherlands and Sweden, eco-driving training programs have been in place since the late 1990s. These programs aim to alter driving behavior such as avoiding rapid acceleration and braking, avoiding speeding, proper gear shifting, and cruise control usage. Another component of eco-driving is encouraging proper vehicle maintenance, such as proper tire inflation, lower rolling resistance tires, and lower viscosity motor oil, through public awareness campaigns, new driver education, and working with tire industry, oil change shops, and refueling stations.

The *OECD Observer* noted "the EU Commission's European Climate Change Programme estimated in 2001 that adoption of ecodriving across the then 15 EU countries had the potential to remove 50 million tons of CO2 per year from their total road traffic emissions." It summarized the experience with eco-driving in the Netherlands: ."".. the country that has done the most to promote ecodriving is the Netherlands, and the results serve as an interesting model for others. The Dutch programme, which stemmed directly from the 1997 Kyoto protocol to reduce greenhouse gases, is a 10-year campaign that began in 1999 and cost 35 million euros.

Latest available figures from yearly evaluations of the Dutch programme show that in 2006 the ecodriving campaign was directly responsible for slashing 0.3 million tons of CO2 from road traffic emissions. The target is that by 2010, ecodriving will account for a yearly reduction of 1.5 million tons of CO2 emissions. If that ambition is achieved, the Dutch government estimates the cost of the 10-year programme (principally a

---

[40] EcoDriver's Manual**:** A Guide to Increasing Your Mileage and Reducing Your Carbon Footprint.

communications campaign) will have been equivalent to less than 10 euros per ton of CO2 saved." [41]

In a 2007 presentation at an eco-driving workshop, the Ministry of Transport, Public Works and Water Management reported 0.6 million tons of CO2 were avoided in 2006 because of eco-driving in the Netherlands. The cost-effectiveness works out to be €7 / ton CO2 emission avoidance. The early results of the program in the Netherlands were promising that policy makers decided to spend additional money for the program and noted that changing 'driver' behavior is cheap compared to investments in wind and solar.

The implementation of eco-driving in the Netherlands involved a communication campaign on TV and radio in additional to the use of a coalition of groups to help disseminate the principles of eco-driving. Overall 67 percent of the population knows about eco-driving and 35% uses the new driving style. In 2008 eco-driving is part of the driving license exam.[42]

Eco-driving in Sweden also started in the late 1990s with the establishment of the first head instructor courses for passenger cars in 1999 and for heavy vehicles in 2000. By 2005 an association of fuel-efficiency coaches was established. The number of drivers in Sweden educated in eco-driving is 27,000 for light duty vehicles to 18,000 for heavy duty vehicles. The expected annual reduction in fuel consumption is 37.7 million litres, at a cost savings of €38.7 million/year. This equates to a reduction of CO2 emissions of 95,000 tonnes/year. New rules were enacted in 2006 making eco-driving mandatory in all levels of driver education in phases. In April 2007 eco-driving was included in the taxi driver license. In December 2007 eco-driving became part of the driver education course for a private passenger car license and in 2008 eco-driving will be launched at all levels.[43]

Table 7.1 presents the strategy definition and assumed constants for the GHG reduction calculation. In 2050, this results in a nationwide 3.3 percent reduction in fuel use (Level A), 4.9 percent reduction (Level B) and 5.9 percent reduction (Level C).

---

[41] http://www.oecdobserver.org/news/fullstory.php/aid/2596/Ecodriving:_More_than_a_drop_in_the_ocean_.htm.

[42] "Evaluation and monitoring as an instrument for policy-decision-making" by Henk Wardenaar, Ministry of Transport, Public Works and Water Management, Netherlands.

[43] "Great savings every kilometre" by Gugge Häglund and Anna Gudmundsson of the Swedish Road Administration.

Table 7.1 Eco-Driving Strategy Definition

Eco-Driving Strategy	Individual Fuel Use Reduction		Percent of Population Reached			Of Those Reached, Percent that Implement	Net Percent Adoption		
	Range	Middle	Level A	Level B	Level C		Level A	Level B	Level C
General (All Strategies)	10-25%	17.5%	50%	75%	90%	38%	19%	28%	34%
Eco-Driver Training	5-33%	19.0%	10%	20%	50%	50%	5%	10%	25%
Vehicle Maintenance	1-24%	12.5%	10%	30%	50%	25%	3%	8%	13%

7.2 Operations Strategies

The deployment of operations strategies mirrors the procedures used in FHWA's HERS Operations Preprocessor. The analysis starts by merging ITS Deployment Tracking data from RITA with HPMS data (2006 in this case) so that current levels of deployment are known for each HPMS segment. Congestion levels (as determined by the V/C ratio) are calculated, the data are sorted, and the worst segments that do not have the strategy already present are selected for deployment. Delay with and without the new deployment is calculated using the current procedures in the HERS model and the fuel saved is calculated using a relationship developed for FHWA.[44] The delay reduction factors for each strategy are shown in Table 8.2; these have been compiled from a number of sources, including the ITS Deployment Analysis System and the ITS Benefits Database maintained by RITA.

As a starting point, the thresholds in Table 7.2 were used; these are based on recent runs of the Operations Preprocessor for FHWA, AASHTO, and the I-95 Corridor Coalition. However, for the sensitivity analysis of different VMT growth rates, using V/C ratios as the "trigger" for deployment will result in more deployment under the higher VMT growth rate sensitivity scenarios because more facilities will be congested. It was decided to hold the amount of deployment constant for each of the three VMT growth rate sensitivity scenarios. This was accomplished by making several iterative runs of the model to observe how many miles of deployment approximated the rules in Table 7.3.

[44] SAIC and Cambridge Systematics, Inc., *Speed Determination Models for the Highway Performance Monitoring System*, prepared for FHWA, October 31, 1993.

The analysis makes use of the following assumptions and methodology:

- Results reflect the cumulative effect of making the improvements, so the effect of an early year improvement is carried forward.
- Trucks are accounted for in the fuel consumption relationship.
- Different congestion thresholds are used to get distinction in the VMT growth rate sensitivity scenarios.
- Deployment of strategies, except for VII, is assumed to occur continuously throughout the analysis period.
- VII deployment is based on the deployment curve in Volpe VII Benefit Cost Analysis Report (Chart 3.1: Projected Phase-In of VII Equipped Vehicles in the U.S. Fleet). Deployment Level B uses these forecasts, and they are adjusted appropriately for Levels A and C.
- Delay reductions for the strategies are based on those used in the HERS Operations Preprocessor and the ITS Deployment Analysis System.

Table 7.2 Initial Assumptions for Deployment of Operations Strategies

Operations Component	Level A	Level B	Level C
Freeway Management			
Ramp Metering (Centrally Controlled)	Large urban + V/C >1.05	Large/medium + V/C >1.0	All locations where V/C >0.90
Electronic Roadway Monitoring	Added with ramp meters, VMS, or incident management		
VMS	V/C >1.05	V/C >1.0	V/C >0.90
Active Traffic Management	Not deployed	Large/medium + V/C >1.0 (speed harmonization + lane control + queue warning)	All locations where V/C >0.90 (speed harmonization + lane control + queue warning + hard shoulder running)
Integrated Corridor Management	Not deployed	Large/medium + V/C >1.0	All locations where V/C >0.90
Incident Management			
Detection Algor/Free Cell Call	V/C >1.05	V/C >1.0	V/C >0.90
Closed Circuit TV Cameras	V/C >1.05	V/C >1.0	V/C >0.90
On-Call Service Patrols; TMC	V/C >1.05	V/C >1.0	V/C >0.90 (aggressive on-scene management, similar to Europe)

Operations Component	Level A	Level B	Level C
Road Weather Management (snow/ice/fog; freeways)	Fully deployed on freeways by 2030	Fully deployed on freeways by 2025	Fully deployed on freeways by 2020
TMC Deployment	Accompanies incident management or ramp metering deployments		
Arterial Management			
Signal Control Level	Upgrade to closed loop or traffic adaptive when V/C >1.0	Upgrade to closed loop or traffic adaptive when V/C >1.0	Upgrade to traffic adaptive when V/C >0.90
VMS	Not deployed	Assumed when ICM is deployed	
Traveler Information	V/C >1.05 (511 + DOT web site)	V/C >1.0 (511 + DOT web site + DOT-sponsored personalized info)	V/C >0.90 (More aggressive, superseded as VII is enabled)
Vehicle Infrastructure Integration	50 percent of light-duty vehicles equipped by 2025; 100 percent by 2040	50 percent of light-duty vehicles equipped by 2020; 100 percent by 2030	50 percent of light-duty vehicles equipped by 2015; 100 percent by 2020

Table 7.3 Operations Strategies Relationships

	Impact Category		
ITS Component	**Congestion/Delay**	**Event Characteristics**	**Safety**[45]
Arterial Management			
Signal Control	Standard HERS relationships		
VII-Enabled			-3.8% total signalized arterial crashes[46]
Electronic Roadway Monitoring	Supporting deployment for corridor signal control (2 highest levels) and Traveler Info		
EM Vehicle Signal Preemption			
VMS	-0.5% incident delay[47]		

[45] Not used in this effort.

[46] VII BCA Report states 28 percent of 178,000 target signalized intersection crashes can be reduced; total traffic signal-related = 1,308,000 (NHTSA Traffic Safety Facts).

[47] IDAS value.

ITS Component	Impact Category		
	Congestion/Delay	**Event Characteristics**	**Safety**[45]
Freeway Management			
Ramp Metering – Preset Ramp Metering – Traffic Actuated	New delay = ((1-0.13)(original delay)) + 0.16 hours per 1,000 VMT[48]		-3% number of injuries and PDO accidents[3]
Electronic Roadway Monitoring	Supporting deployment for ramp metering and Traveler Info		
VMS	-0.5% incident delay[2]		
Active Traffic Management (Speed Harmonization + Lane Control + Queue Warning)	-10% total delay[49]		-15% total crashes
Integrated Corridor Management			
Deployed with ramp meters and RTTAC signal control	-10% total delay (assumed to be incurred on freeways)[50]		
VII-enabled	-5% total delay (additional; on top of base ICM)		
Automated Vehicle Control Systems (including VII)[51]	Special sensitivity runs: +10%, +25%, +50% increase in capacity; not currently assumed to occur with VII, so not handled with Preprocessor		-2.2% total crashes[52], all freeways and signalized arterials
Incident Management		All factors based on IDAS relationships	
Detection Algor/Free Cell		-4.5% incident duration	-5% fatalities
Surveillance Cameras		-4.5% incident duration	-5% fatalities

48 Based on analysis of data collected for Minneapolis Ramp Meter Evaluation.

49 Based on three to five percent increase in throughput for speed harmonization alone in The Netherlands (Active Traffic Management: The Next Step in Congestion Management); also total crash reduction is from The Netherlands.

50 ITS Benefits Database (Glasgow).

51 Not included in Operations Preprocessor; must be analyzed offline.

52 VII BCA Report states 133,000 rear end crashes reduced (5,973,000 total crashes); "brake light warning".

	Impact Category		
ITS Component	**Congestion/Delay**	**Event Characteristics**	**Safety**[45]
On-Call Service Patrols		-25% incident duration (typical)	-10% fatalities
All Combined		Multiplicative reduction	-10% fatalities
Road Weather Management			
Faster snow/ice control	3% total delay in northern states (snow/ice covered highways)	-	
Active Traffic Management (Speed Harmonization + Lane Control + Queue Warning)	-10% total delay		-15% total crashes
Integrated Corridor Management			
Deployed with ramp meters and RTTAC signal control	-10% total delay (assumed to be incurred on freeways)[53]		
VII-enabled	-5% total delay (additional; on top of base ICM)		
Automated Vehicle Control Systems (including VII)[54]	Special sensitivity runs: +10%, +25%, +50% increase in capacity; not currently assumed to occur with VII, so not handled with Preprocessor		-2.2% total crashes[55], all freeways and signalized arterials

[53] ITS Benefits Database (Glasgow).

[54] Not included in Operations Preprocessor; must be analyzed offline.

[55] VII BCA Report states 133,000 rear end crashes reduced (5,973,000 total crashes); "brake light warning".

8.0 Bottleneck Relief and Capacity Expansion Strategies

8.1 Bottleneck Relief Strategies

The bottleneck analysis is based on previous work done for the American Highway Users Alliance (AHUA)[56] and FHWA.[57] These studies compiled a list of national bottlenecks, almost exclusively freeway-to-freeway interchanges, where the majority of delay occurs in urban areas. These locations were then identified in the 2006 HPMS data. Delay with and without improvements to the target levels of service were calculated using the procedure in FHWA's STEAM model.[58] The following deployment levels were used in the analysis:

- **Deployment Level A) –** Improve 100 of top 200 bottlenecks to Level of Service "E" by 2030;
- **Deployment Level B) –** Improve all top 200 bottlenecks to Level of Service "E" by 2030; and
- **Deployment Level C) –** Improve all top 200 bottlenecks to Level of Service "D" by 2020 using pricing, system management, enhanced alternatives and capacity expansion in the mix best supported by cost/benefit analysis that accounts for indirection, secondary and cumulative impacts.

The analysis makes use of the following assumptions and methodology:

- Potential bottlenecks compiled from a list of 388 locations used in previous studies conducted for American Highway Users Alliance (AHUA) and FHWA.
- Updated data for locations using 2006 HPMS data.

---

[56] AHUA, *Unclogging America's Arteries: Effective Relief for Highway Bottlenecks*, 2004, http://www.highways.org.

[57] Battelle Memorial Institute and Cambridge Systematics, Inc., An Initial Assessment of Freight Bottlenecks on Highways, prepared for Federal Highway Administration, Office of Transportation Policy Studies, October 2005.

[58] http://www.fhwa.dot.gov/steam/.

- Estimated total delay at the locations using the methodology used in the AHUA and FHWA methodology used in Conditions and Performance (C&P) reports; this is based on the delay equations in FHWA's Highway Economic Requirements System.
- The C&P reports methodology is also used to project the effects of bottleneck relief on future VMT. This methodology addresses induced demand and diverted travel and also assumes that increased user fees will pay for bottleneck relief projects. More detail on this approach is included in Section V of this Appendix.
- Ranked locations by total delay; select top bottlenecks for improvement in each year – the number improved depends on the scenario used.
- Carried forward a location's delay and fuel savings throughout the remainder of the analysis period.

Note: The bottleneck relief and capacity expansion strategies are included in three of the six bundles evaluated in the study (Long-Term/Maximum Results, System and Driver Efficiency, and Facility Pricing). Each of these bundles include facility pricing strategies (cordon pricing, congestion pricing and/or intercity tolls) that to a degree offset the assumption that user fees will pay for bottleneck relief/capacity expansion projects (because assumptions regarding the specific application of revenues are not included in the *Moving Cooler* analysis, this interaction warrants further exploration). When the C&P methodology is applied absent the user fee assumption, the estimated GHG produced by these individual strategies increase cumulatively to 440-560 mmt (less than 1 percent of the study baseline).

8.2 Capacity Expansion Strategies

The impacts of capacity expansions are based on speed-fuel consumption relationships. The analysis of GHG reductions from system efficiency strategies was performed by estimating a reduction in delay per 1,000 VMT from each strategy, and then calculating the reduction in fuel consumption per hour of delay reduced. This calculation was based on relationships developed for FHWA by SAIC,[59] adjusted for acceleration and deceleration effects. The SAIC formulas indicate a fuel savings of 0.62 gallons per hour of delay reduced for passenger cars, 1.607 gallons per hour for single-unit trucks, and 1.934 gallons per hour for combination trucks, for a weighted value of 0.71 gallons per hour across all vehicles. However, the formulas probably underestimate the fuel savings of delay reduction because they do not consider the effects of reduced acceleration and deceleration. Correction factors were developed by evaluating relationships between average speed and fuel efficiency embedded in FHWA's ITS Deployment and Analysis

[59] SAIC (1993). *Speed Determination Models for the Highway Performance Monitoring System.* Prepared for FHWA by Science Applications International Corporation.

System (IDAS) model and the U.S. Environmental Protection Agency's new draft MOVES model. Evaluation of the speed-fuel consumption curves suggests that within the speed ranges where most congestion reductions would occur (20-45 mph), the change in fuel consumption per hour of delay reduced is about 40 percent higher than from the SAIC equations (based on IDAS) or 30 percent higher (based on MOVES). For this analysis, the SAIC delay-fuel consumption relationships were increased by 30 percent, the lower of these adjustments.

Capacity expansion strategies were estimated using the results of HERS runs for maximum economic investment and for current funding. The two runs give a picture of highway system performance over time with maximum justified investment compared to current funding levels. The HERS runs show differences in future years for the two key factors which determine GHG as a result of investments: changes in delay and changes in induced VMT compared to levels forecast with current levels of investment. HERS provides estimates of delay and of changes in hours of delay per 1,000 VMT. Using estimates and equations developed by Harry Cohen for the impact of delay on fuel consumption, percentage reductions in fuel consumption for each future year due to investments were calculated in relation to reductions in delay for full investment versus current levels of investment.

The method is consistent with the approach used for the bottleneck relief strategy described in Section 8.1. The C&P reports methodology is used to project the effects of bottleneck relief on future VMT. This methodology addresses induced demand and diverted travel and also assumes that increased user fees will pay for bottleneck relief projects. [See note regarding the user fee assumption and its inclusion in the bundle analysis at the end of Section 8.1.]

A time stream of differences in year-by-year percentage fuel consumption for maximum economic investment versus existing funding was estimated. An estimate also was made of the changes in induced travel for maximum economic investment versus current investment, which can be taken directly from HERS. Reductions in fuel consumption due to reduced delay are added to increases in fuel consumption due to induced VMT, giving a net impact from highway investment.

The results show greenhouse gas reductions through 2030, eventually offset by increases in induced travel, which occur with a time lag. More detail on this approach is included in Section V of this Appendix.

9.0 Multimodal Freight Strategies

9.1 Address Rail System Bottlenecks

This measure addresses choke points in the rail system for carload and double-stack service so expected 2025 capacity restrictions are reduced by 20 percent, 30 percent, and 60 percent for Deployment Levels A, B, and C, respectively.

The analysis used the following input data, assumptions, and methodology:

- Billion Rail Ton-Miles (TM): 2007
  - Class I = 1.771 (from American Association of Railroads (AAR) – 2007)
  - All = 1.838 (Scaled using TM ratio from 2005 (AAR))
- Growth Factor: 1.47 (2005 to 2030)
- TM potential rail traffic in 2030: 2.702
- Assume 25 percent diverted to truck due to choke points:
  - B TM diverted to truck in 2030 if no rail investment = 675.4
  - B TM diverted back to rail under Level A (20 percent) = 135.1
  - B TM diverted back to rail under Level A (30 percent) = 202.5
  - B TM diverted back to rail under Level A (60 percent) = 337.5
  - RR TM/gallon = 413
  - Truck TM/gallon = 155

9.2 Restore Major Elements of Marine Transport System

For this measure, it is assumed that Deployment Level A maintains the current state of the marine transport system (rather than allowing further decline). Level B restores major components of the system to a state of good repair with all system elements fully functional, and Level C restores the entire system to a state of good repair with all system elements fully functional.

The analysis used the following input data, assumptions, and methodology:

- 1987 Billion Ton-Miles: Lakewise = 50.1, Internal = 257.3 (Waterborne Commerce Statistics);
- 2006 Billion Ton-Miles: Lakewise = 53.1, Internal = 279.8 (Waterborne Commerce Statistics);
- Internal Tons (million) = 627.6 (Waterborne Commerce Statistics);
- Average Length of Haul = 446 miles (Internal);
- 2025 Total Forecast at 1987-2006 Growth Rate = 360.5 billion ton-miles; and
- Ratio of inland water miles to rail miles: 1.20 (Congressional Budget Office, Table A-16).

9.3 Overweight Load Permits for Trucks Carrying Shipping Containers

This measure implements indivisible load permits (i.e., overweight load permits) for trucks carrying shipping containers at gross vehicle weights (GVW) up to 110,000 pounds for distances up to 250 miles. This is implemented over 15 years for Deployment Level A, 10 years for Level B, and 5 years for Level C.

The analysis used the following input data, assumptions, and methodology:

- Empty VMT (Billion) = 0.794 (2002 VIUS)
- Loaded Billion VMT 2002 (@ 80% loaded) = 3.18
- Loaded Billion VMT 2006 (1.4% annual growth rate) = 3.36
- Percent VMT in states with weight limit for containers: 50%
- Percent weight-limited and eligible for permits: 40%
- Average weight of affected containers current (pounds):
  - 80K limit = 50,000, 90K limit = 58500
- Average weight of affected containers future (pounds):
  - 80K limit = 65,000, 90K limit = 65000
- Affected 2006 VMT: 80K limit =.67, 90K limit =.67
- VMT if permits were available: 80K limit =.52, 90K limit =.60
- Reduction in VMT: 80K limit =.155, 90K limit =.067

- Fuel Economy (2008):
  - 80K = 5.75 mpg
  - 90K = 5.48 mpg

9.4 Overweight Load Permits for Longer Combinations Vehicles (LCV) Carrying Natural Resources

This measure implements divisible load permits (e.g., overweight load permits) for longer combination vehicles (LCV) carrying natural resources on designated non-interstate truck routes at weights up to 105,500 pounds for Deployment Level A and 129,000 pounds for Level B. For Level C, divisible load permits are allowed for B-Train LCVs carrying natural resources on designated non-interstate truck routes at weights up to 129,000 pounds and up to 138,000 pounds for eight-axle B-Trains.

The analysis used the following input data, assumptions, and methodology:

- VMT (2002) = 6.21 B (2002 VIUS – grains, fertilizers, coal, crushed stone, sand, and minerals);
- VMT (2006) = 6.57 B (1.4% annual growth rate);
- Percent of ton-miles operating under permit = 25%;
- Affected 2006 VMT = 1.64 B; and
- Current Fuel used = 170.1 (m gallons).

Table 9.1 Higher Weight Limits for Haulers of Natural Resources

Scenarios	Base	Level A	Level B	Level C
Weight Limits	78K	105.5K	129K	138K
Payload	53,400	73,800	88,700	97,700
VMT with Permits		1.19	.99	.90
Reduction in VMT		**.454**	**.653**	**.745**
2008 MPG	9.65	8.24	7.35	6.88

9.5 Weigh-in-Motion Screening at Weigh Stations

Under this measure, weigh-in-motion (WIM) systems are installed at all 24-hour truck weigh stations and used to allow clearly underweight vehicles to bypass static scales. This is implemented over 15 years for Deployment Level A, 10 years for Level B, and 5 years for Level C.

WIM systems are useful where vehicles are being checked for weight violations but not for safety violations. This analysis therefore assumes that the number of locations at which this approach can be used equals half the number at which electronic credentialing can be used (see below). Potential fuel savings equals half that of electronic credentialing.

9.6 Electronic Credentialing to Bypass Weigh Stations

For this measure, the PrePass and NORPASS electronic credentialing systems are expanded so they cover all 49 mainland states and both systems are recognized at all weigh stations and inspection sites in these states, with an equivalent system implemented in Hawaii. Deployment Level A assumes a 15-year implementation, Level B a 10-year implementation, and Level C a 5-year implementation.

The analysis used the following input data, assumptions, and methodology:

- Potential additional bypasses in Oregon: 500,000 per year;[60]
- Oregon VMT/National VMT: 0.0127;
- Assumed national potential: 39,373,347 per year; and
- Fuel saving per bypass: 0.10 gallon.

9.7 Truck Stop Electrification

This measure increases the number of truck stops that allow trucks to plug in to local power to 1,500 (out of 5,000) for Deployment Level A; 3,000 for Level B, and all 5,000 truck stops for Level C.

[60] Oregon Department of Transportation, "*Green Light* Emissions Testing Project". 2008.

The analysis used the following input data, assumptions, and methodology:

- Current number of electrified truck stops = 136 (as of October 9, 2008 from DOE's EERE Info. Center);
- Average number of spaces per truck stop = 40;[61]
- Average utilization per day = 30% (Perrot, Table 1);[62]
- Number of hours per use = 8;
- Fuel saved per truck per hour = 1 gallon;
- Average power per truck = 3.8 kW;
- GHG per gallon of diesel fuel = 22.2 pounds; and
- GHG per kw hour = 1.40 pounds.

9.8 Auxiliary Power Units (APU)/Heating and Cooling Systems for Sleeper Cabs

This measure requires the installation of battery-operated heating and/or cooling systems in all sleeper cabs. A 15-year implementation is assumed for Deployment Level A, 10 years for Level B, and 5 years for Level C. These rates of implementation are compared to a baseline growth rate in current usage of 3.6 percent annually, which is consistent with the high growth rate for fuel prices. (The high growth rate is chosen as it is assumed fuel prices alone will not lead to increases in APU use. This also may occur through public or private initiatives or incentives.)

The analysis used the following input data, assumptions, and methodology:

- Sleeper-cab VMT as percent of combination truck VMT = 50.2% (2002 VIUS);
- Ratio of sleeper cabs to total annual million VMT of combination trucks = 5.95;
- Use of alternative power: 1,830 hours/cab/year (ShurePoint Presentation, Kim, May 2006);
- Current usage = 12%;[63]

---

[61] The Climate Trust. http://www.climatetrust.org/offset_truckstop.php.

[62] http://www.epa.gov/smartway/documents/dewitt-study.pdf.

- Fuel Consumption per Hour (gallons):
  - Engine = 1.0 (Perrot, Table 1);
  - APU = 0.3 (Navistar, July 2008); and
  - Battery = 0.05 (Bergstrom/Firefly, January 2008).
- Assumed split between APU and battery = 50%.

9.9 Truck-Only Toll Lanes

This measure assumes that truck-only toll lanes are implemented starting in 2010, with a completed system in 2025. Deployment Level A assumes that this applies to 10 percent of interstate VMT in Large/High-density urban areas; Level B assumes that it applies to 25 percent of interstate VMT in Large/High-density urban areas; and Level C applies it to 40 percent of interstate VMT in Large/High-density urban areas. In addition, for Level C they are applied to 10 percent of interstate VMT in large/low-density urban areas, with implementation starting in 2015 and completed in 2030.

The calculation for the amount of fuel saved by implementing truck-only lanes is largely based upon a study of truck-only lanes (TOL) in the Atlanta metropolitan area conducted by the Georgia Department of Transportation (GDOT).[64]

The analysis used the following input data, assumptions, and methodology:

- Average daily vehicle speeds – Table 45 of the GDOT TOL report;
- Automobile and truck fuel efficiency by speed – Derived from EMFAC model; and
- Total VMT – Table 42 of the GDOT TOL report.

Table 9.2 VMT Breakdown

Corridor Share		Trucks in GP versus TOL	
Percent Automobile	63.6%	Percent Trucks in GP	38.9%
Percent Truck	36.4%	Percent Truck in TOL	61.1%

---

[63] http://www.westcoastdiesel.org/files/sector-trucking/fleet-preferences-survey.pdf.

[64] Georgia Department of Transportation. Statewide Truck Lanes Needs Identification Study. Technical Memorandum 3: Truck-Only Lane Needs Analysis and Engineering Assessment. April 2008.

Table 9.3 Calculation of Fuel Savings from Truck-Only Lanes

Description	No Project		With TOL Project	
	GP Lanes	TO Lanes	GP Lanes	TO Lanes
Speed (mph)	26	NA	36	47
Auto Fuel Efficiency (Miles/Gallon)	23.80	NA	29.35	31.12
Truck Fuel Efficiency (Miles/Gallon)	5.00	NA	5.57	5.98
Total Daily VMT (Millions)	25.64	NA	25.64	
Auto Daily VMT (Millions)	16.30	NA	16.30	NA
Truck Daily VMT (Millions)	9.34	NA	3.63	5.71
Gallons Gasoline (Millions)	0.68	NA	0.56	NA
Gallons Diesel (Millions)	1.87	NA	0.65	0.95
Gallons Gasoline Saved (Millions)				0.13
Gallons Diesel Saved (Millions)				0.26
Atlanta Regional Interstate Daily VMT (Millions) 2006				42.84
Atlanta Regional Interstate Daily VMT (Millions) 2035				64.12
Gallons Gasoline Saved Per Million VMT (Regional Interstate)				2,018.13
Gallons Diesel Saved Per Million VMT (Regional Interstate)				4,079.66

9.10 Urban Consolidation Centers

This measure assumes that urban consolidation centers are implemented starting in 2010, with a completed system in 2025. Deployment Level A assumes that this applies to 10 percent of interstate VMT in Large/High-density urban areas; Level B assumes that it applies to 25 percent of interstate VMT in Large/High-density urban areas; and Level C applies it to 40 percent of interstate VMT in Large/High-density urban areas. In addition, for Level C they are applied to 10 percent of interstate VMT in large/low-density urban areas, with implementation starting in 2015 and completed in 2030.

The analysis used the following input data, assumptions, and methodology:

- Percent of truck-miles operated by LTL carriers (large/medium urban areas) = 8.6%;
- Percent of truck-miles operated by LTL carriers (small urban areas) =.46%;
- Percent for which consolidation is practical = 50% large urban, 40% medium urban, 50% small urban; and
- Percent reduction in VMT = 10% large urban, 6% medium urban, 10% small urban.

III. Sensitivity Analysis Assumptions and Methodology

We will conduct a sensitivity analysis on our results from the scenario bundling analysis. Discussions at Steering Committee meetings have centered around sensitivity to VMT growth rates and to fuel prices. Because these are related factors, for the purposes of our analysis, fuel price are regarded as a major driver of VMT growth. Therefore, we propose performing sensitivity analyses for the following scenarios:

- **High fuel price, low VMT –** This assumes that fuel prices are higher than baseline, resulting in lower VMT growth over time and a market shift toward vehicles with better fuel economy.

- **Low fuel price, high VMT –** This assumes that fuel prices are lower than baseline, resulting in higher VMT growth over time and market shift toward vehicles with lower fuel economy.

- **High-technology/fuel economy, high VMT –** This assumes that technology (including fuel economy and noncarbon fuels) progresses rapidly, reducing the variable cost of driving (and possibly fuel prices) and resulting in higher VMT growth but with lower GHG emission impacts.

This sensitivity analysis will warrant some examination of fuel price trends and projections. Between 2002 and 2007, gasoline prices were growing at an average of 15.5 percent per year, indicating that price levels would hit $3.79 in 2009. For our base case, we propose to assume no change (from $3.70) in 2009 and then some more modest rate of growth. The AEO high price case growth rate was 1.2 percent per year for gasoline prices and 1.4 percent per year for diesel prices. Fuel prices have clearly demonstrated great volatility in recent months; our analysis will focus on long-term trends and projections.

IV. Bundles and Interaction Assumptions and Methodology

General Approach to Combining Strategies Within Bundles

- Use multiplicative application to eliminate double-counting (e.g., represent two strategies with 10 percent effectiveness as 0.9 * 0.9 = 0.81 or a 19 percent reduction, rather than 0.10 + 0.10 = 20 percent reduction)
- Synergistic effects - Effectiveness of Nonmotorized Travel, Car Sharing, and Urban Public Transportation are dependent on the densities (on a Census tract level) determined by the Land Use strategy
- Synergistic effects - Interaction of Pricing with Land Use, Transit, Non-SOV Travel and Other Modes was suggested for being analyzed using a sensitivity analysis of +20 percent and -20 percent, but with the concurrence of the Steering Committee, was not conducted.

General Approach to Combining Strategies Within Bundles

A significant issue that arises with the analysis is the extent to which various strategies overlap one another, and thus are counting the same change in behavior twice. For example, some pricing strategies may encourage commuters to take non-SOV modes of travel. This general approach addresses the issue of double-counting of the effects of individual strategies when implemented together, for example within a bundle. Within each bundle, the effects of individual strategies are combined using a multiplicative approach to avoid "double-counting" of benefits. For example, if Strategy A results in a 10 percent GHG reduction, and Strategy B results in a 10 percent GHG reduction, the combined effect will be (1-0.10) * (1-0.10) = 0.90 * 0.90 = 0.81, or a 19 percent combined reduction, rather than a 20 percent reduction if they were simply added. This approach is especially important when combining many strategies; 10 strategies at 10 percent effectiveness each would mean a 100 percent reduction if simply added, but a 65 percent reduction using this multiplicative approach.

This part of our approach does not account for synergies among particular strategies, only for the double-counting. For example, it may be possible that if Strategy A and B are complementary, their combined effect will be greater than the sum of the individual effects (for example, if A & B = 21 percent because of synergistic effects).

Synergistic Effects

For a number of individual strategies, synergistic effects already are included in the strategy analysis, and therefore already are reflected in the bundles. In particular, Land Use interactions with Nonmotorized Travel have had the synergistic effects between individual strategies accounted for. This was done by making nonmotorized travel contingent upon the population living at each of several different density levels, and then varying the respective amounts of future population by density for each Level of Implementation, consistent with the same Level of Implementation from the Land Use analysis. The additional GHG reductions resulting from Land Use interactions with Car Sharing and Urban Public Transportation are calculated in the Bundle analysis.

Increased share of development in dense, compact census tracts as assumed in the combined land use strategy is presented in Table 4.1. The shares shown in Table 4.1 are based on the Deployment Level descriptions. The metropolitan targets and compliance levels assumed are:

- Level A = 60 percent of new development planned in compact, walkable neighborhoods; 72 percent compliance (43 percent overall new growth in 4,000+ ppsm tracts).
- Level B = 70 percent of new development planned in compact, walkable neighborhoods; 90 percent compliance (64 percent overall new growth in 4,000+ ppsm tracts).
- Level C = 90 percent of new development planned in compact, walkable neighborhoods; 100 percent compliance (90 percent overall new growth in 4,000+ ppsm tracts).

Table 4.1 Population by Census Tract Density
2030

	Population Shares, 2030			
Tract Density Range (ppsm)	**BAU**	**Level A**	**Level B**	**Level C**
0-499	16%	16%	14%	12%
500-1,999	23%	23%	21%	17%

2,000-3,999	20%	19%	17%	16%
4,000-9,999	24%	25%	26%	31%
10,000+	17%	17%	21%	24%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**

The changes in population distribution by census tract density range directly affect results for pedestrian, bicycling and car-sharing strategy GHG reduction methodologies, all which rely on population distribution by census tract density ranges.

Combined Pedestrian Strategy

The methodology for the combined pedestrian strategy uses percent VMT reductions as presented in Table 4.2 applied to an estimate of affected populations in census tract density ranges. The interaction is applied through the increase in population in the densest census tracts in the land use strategy Deployment Levels A, B, and C. Therefore, because of accelerated population growth in dense, compact developments, there are higher VMT reductions from pedestrian strategies.

Table 4.2 Application of Pedestrian Environment Factor (PEF) Elasticities to VMT

	Suburban			Urban		
Portland PEF Factors	**Base**	**A, B**	**C**	**Base**	**A, B**	**C**
PEF score (sidewalk availability, street crossing, connectivity, terrain)	6	9	10	10	11.5	12
Percent change in PEF		50%	67%		15%	20%
Percent change in VMT:						
PBQD's Portland PEF elasticity: -0.19		-9.5%	-12.7%		-2.9%	-3.8%
Ewing's SGI PEF elasticity: -0.03		-1.5%	-2.0%		-0.5%	-0.6%

The "suburban" percentage VMT reduction is applied to density ranges 1-3 (<4,000 ppsm), the urban reduction to range 5 (<10,000 ppsm), and a midpoint reduction (1.4 percent) applied to range 4. The VMT change was applied to an estimate of the population affected by the relevant pedestrian improvements. This percentage was about 100 percent for the three highest-density tract ranges, but less for the lower-density areas because fewer people would live within one-half mile of schools, transit stations, or business districts.

Combined Bicycle Strategy

The methodology for the combined bicycle strategy uses population density data by the five density ranges used in the land use analysis. The increase in bicycling mode share as a result of bicycle-supportive infrastructure and policies varies by density range, with greater effects for the higher density ranges (<4,000 ppsm) where bicycling is likely to be more competitive. Therefore, the results for each Deployment Level "pivot" off of the land use strategy levels, which result in (incrementally) different amounts of future population by density range for each Deployment Level.

Car-Sharing Strategy

The methodology for the car-sharing strategy uses population density data by the five density ranges used in the land use analysis to assign total cars available per capita. Deployment Level B and C set goals of one car per 2,000 inhabitants of medium and 1,000 inhabitants of high-density census tracts. Medium-density areas, those with 4,000 to 10,000 persons per square mile, are assumed to constitute 26 percent of all urban areas, based on baseline analysis of projected 2030 land use plans. High-density areas, those with greater than 10,000 persons per square mile are assumed to constitute 20 percent of all urban areas. Applying the goals by density results in the number of shared cars. With greater population growth in the densest census tracts as projected in land use strategy Levels B and C, the total shared cars increase.

Table 4.3 Shared Cars

	Density					
	Large High	**Large Low**	**Medium High**	**Medium Low**	**Small High**	**Small Low**
Base	48,042	10,841	3,597	11,557	1,201	10,879
Level B Land Use	54,669	12,336	4,094	13,151	1,367	12,379
Level C Land Use	78,038	16,584	5,575	17,573	1,863	16,657

The values in Table 4.3 are multiplied by 20, the number of members per shared car, to determine the number of equivalent cars that this represents. This number is divided by the population, where it is assumed that one car is otherwise available per person. Finally the percentage reduction in VMT per equivalent car is assumed to be 50 percent, recognizing that those members without a car would drive more than before, but those members who had previously owned a car would drive less than before. The calculation results in 20 to 25 percent increase in VMT reduced as a result of the Land Use/Car-Sharing interaction.

Urban Transit Expansion

Increased population growth in dense census tracts has a direct interaction with transit ridership. Population growth in line with current trends, combined with expansion of urban transit systems will result in total household accessibility to transit in urban areas by 2050 of:

- Level B – 26 percent for rail transit modes and 72 percent for bus; and
- Level C – 30 percent for rail transit modes and 80 percent for bus.

As a result of densifying urban areas as estimated through the *Moving Cooler* maximum deployment combined land use strategy, the share of population with accessibility to transit increases. We assume that the population redistribution will only affect accessibility to rail transit. The new accessibility figures:

- Level B – 32 percent for rail transit modes and 72 percent for bus; and
- Level C – 47 percent for rail transit modes and 80 percent for bus.

TCRP Project J-11, *The Broader Connection between Public Transportation, Energy Conservation and Greenhouse Gas Reduction*, estimated the average reduction of VMT per household by level of transit availability based on household trip survey data from the 2001 National Household Travel Survey.[65] The model estimation from this study resulted in an average daily reduction of VMT per household of 2.2 for households with access to transit. This reduction is applied to new estimates of total households with transit accessibility to obtain increased estimates of VMT reduction for this strategy.

The impact of the accounting for this interaction for the urban public transportation strategy is cumulatively through 2050 a 2.7 to 3 times increase in VMT reduction.

Pricing Interactions

One other set of strategies was identified as "high-priority" for synergistic effects by the research team and *Moving Cooler* Steering Committee: **Pricing interactions with Land Use, Transit, Non-SOV Travel and Other Modes**. For example, it would be expected that areas with the availability of multiple high-quality modes of transportation and dense land use would experience a greater response to pricing strategies, since travelers in these areas have more alternatives available to them. Research suggests that regions with lower quality transit and more sprawling land uses are less sensitive to fuel tax increases than denser urban areas with high-quality multiple modes available. This also is consistent with travel demand theory, which shows flatter (more responsive) demand patterns when multiple measures are implemented.

---

[65] http://www.apta.com/research/info/online/documents/land_use.pdf.

Unfortunately, there are few studies that have produced directly applicable quantitative data about interactive effects, for example, by examining individual strategies versus combinations of strategies. The existing research includes regional modeling studies conducted in Seattle (PSRC), Sacramento (Johnston et al.), San Francisco Bay Area (MTC), and the cities of Dortmund and Naples in Europe. These studies used modeling to compare the results of various combinations of land use, transit, and pricing strategies on a regional basis. Some inferences may be drawn about interactive effects by comparing results for separate versus combined strategies. These studies have not yielded conclusive evidence about the potentially advantageous effects of synergies (higher responsiveness, or elasticities) and overlap (the multiplicative effect described above), as model runs that have combined strategies imply that the "synergy/overlap effect" may vary between -20 percent and +20 percent compared to the impact of individual strategies when combined directly additively.[66] The Steering Committee decided that this sensitivity analysis would not be worthwhile.

[66] "Synergy effect" is defined here as the percent change in *effect* when strategies are modeled in combination vs. when their individual results are added together. For example, if the benefits of A = 10 percent, B = 10 percent, C = 10 percent, the combined overlap effect without any synergy would be approximately 18.8 percent. (=(1-0.10)*(1-0.10) *(1-0.10)), or a reduction of 6 percent from direct additive effects. If the benefit of the combined strategies is found to be 22.5 percent, the "synergy effect" would be (0.225 – 0.188)/0.188 = 19.7 percent above the overlap effect.

V. Induced Demand Assumptions and Methodology

Induced demand is a form of the basic economic concept that if an activity is made less costly (monetarily or, e.g., through time expenditure) then more people will partake in it. In transportation, the term generally recognizes that improvements in level of service (in any mode) will result in an increase in demand, although this can take form in many ways.

There are two basic types of transportation GHG reduction measures that can result in induced demand: 1) system efficiency improvements that reduce congestion and delay, thereby improving travel times (as well as reducing fuel consumption and GHG); and 2) travel behavior strategies that reduce VMT. For example, policies that cause shorter trips, fewer SOV highway trips, or diversion to transit reduce highway congestion and thereby reduce highway travel times, making highway travel more attractive to travelers who, in turn, increase somewhat the number and/or length of their highway trips. Travel behavior strategies will result in induced demand to the extent that they reduce VMT during congested travel periods, and therefore reduce delay and decrease travel times. This is sometimes referred to as a "rebound effect." This effect occurs when travel that has been reduced from the network results in a short-term improvement in travel conditions, thus inducing additional traffic back to the network. Note, vehicle efficiency strategies would also lead to increases in travel as a result of lower travel costs, however the induced effect from these strategies are not included in *Moving Cooler*.

Strategies that reduce VMT by making highway travel more expensive in a way that self-equilibrates to a constant flow rate (e.g., congestion, cordon, gas or carbon prices that adjust to achieve a given flow VMT rate) do not produce a separate rebound effect, since the initial estimate of the effect of such policies on VMT is a net estimate; that is, it is a collective estimate of the reduced VMT resulting from the policy (e.g., the tax) and the increased VMT resulting from the reduction in congestion.

The offsetting effects of induced demand apply to any VMT or congestion/delay-related metric such as fuel consumption or criteria pollutant emissions. The magnitude of these effects depends upon the elasticity of travel demand with respect to a change in travel time or travel cost – i.e., the percent change in travel for a given percent change in time/cost. Both short-term (about one year) and long-term (multi-year) elasticities have been estimated, since rebound effects can be greater over the long term as people make more significant changes to their travel habits such as living further from work.

The offsetting effects from diversion were deemed too uncertain to be incorporated. There is significantly lower fuel economy generally associated with the low speeds and much higher signalization on minor arterials and lower classification roads. Regional four-step models and the literature provide mixed results on what the effects, including potentially increased travel distance, are on total fuel consumption from diversion to or from major arterials and urban expressways. Effects on expressway access/egress from diversion have not been studied sufficiently to yield any reliable results. Based on the lack of evidence, we therefore could not find a basis to estimate an effect from diversion to or from higher classification facilities.

■ Travel Behavior/VMT Reduction Strategies

Available, well-proven analytic procedures do not readily produce highly accurate estimates of the extent of the reduction in GHG benefits from induced demand. However, it is possible to use analyses performed with the Highway Economic Requirements System (HERS)[67] to obtain some approximations to these reductions. For this purpose, three HERS runs that were previously made for the American Association of State Highway and Transportation Officials (AASHTO) Bottom Line Report were used to infer the extent to which VMT reduction measures that improve alternatives to auto travel may result in offsetting the reduced VMT – a "rebound effect."

HERS accounts for induced demand using an elasticity that allows feedback to generate an estimate of this rebound effect. The three HERS runs were made using a 25-year forecast period and a total long-term elasticity of VMT with respect to total user costs of -0.6 (i.e., a 1 percent decrease in user costs results in a 0.6 percent increase in VMT). Total user costs for HERS are comprised of travel time, fuel costs, oil, tires, vehicle maintenance and repair, and other out-of-pocket expenses. In order to be consistent with the most recent FHWA findings and HERS runs, provided by Ross Crichton, this -0.6 elasticity (and its component parts) that was used within the Bottom Line HERS runs used here was then scaled up by one-third to match the -0.8 currently used by FHWA with HERS. When applying the induced demand effects in this analysis, half of the effects (a -0.4 short-run elasticity) was applied immediately, and an additional -0.4 elasticity (to reach the total long-run elasticity of -0.8) was applied after a 5-year delay.

The three runs differed in their assumptions about available budgets for highway improvements (resulting in different capacities on congested roads) and/or their assumptions about future growth in demand for auto travel (as would occur as a result of policies designed to make alternative modes more attractive). The results of the HERS runs indicate that the systemwide rebound effects, averaged over the entire United States, are 18.1 percent. That is, for any measure that would reduce national VMT by making shorter trips or other modes more attractive, the initially estimated reduction in VMT

---

[67] HERS is a national model of the U.S. highway system. The model was developed by the Federal Highway Administration (FHWA) to examine the relationship between national investment levels and the condition and performance of the nation's highway system.

should be reduced by (at most) 18.1 percent to reflect the rebound effect.[68] Because the HERS model already incorporates equilibration in generating this 18.1 percent estimate, further equilibration from this point would have been inappropriate.

For the analysis of induced demand for *Moving Cooler*, this rebound is applied to all VMT reduction measures except three appropriate pricing measures (congestion, cordon, and intercity pricing) and to the speed limit strategy. There is no rebound effect for speed limits because there is no congestion when you are going 75 mph, even though there is a minor VMT reduction (mode shift, combined trips) from this measure.

The measures it was applied to include the land use, nonmotorized, public transportation, HOV/carpool/vanpool/commuter measures, and some regulatory measures (nonmotorized zones and urban parking restrictions). GHG benefits were reduced individually by 18.1 percent for each strategy, before combining the strategy benefits to the estimate bundled benefits as described above.

System Efficiency Strategies

The analysis of system efficiency measures is somewhat more complicated. For measures that reduce congestion, the increase in VMT from induced demand can be analyzed in a manner similar to travel behavior strategies – i.e., through the use of elasticities. However, the only GHG benefit from system efficiency strategies is from reduced delay and reduced inefficient, low level of service operation – not from VMT reduction. To estimate the net reduction in fuel consumption and GHG from system efficiency measures is a two-step process. First, the fuel-efficiency benefits of reduced congestion are estimated; and second, induced VMT and the corresponding increase in fuel consumption is estimated. The two estimates are then combined to produce an estimate of the net change in fuel consumption and in GHG.

In this study, the analysis of GHG reductions from system efficiency strategies – not accounting for induced demand – was performed by estimating a reduction in delay per 1,000 VMT from each strategy, and then calculating the reduction in fuel consumption per hour of delay reduced. This calculation was based on formulas developed for FHWA (SAIC et al., 1993), adjusted for acceleration and deceleration effects. The SAIC formulas

[68] The estimates developed from HERS and shown here reflect the effects of all forms of induced VMT, including VMT that, in concept, has been diverted to the improved alternative(s) to auto travel and then diverted back again. Since the original analysis of the effects of the alternative(s) is assumed to produce an estimate of the *net* diversion from auto travel, there is some double counting of induced VMT that should be subtracted from the estimates of induced VMT produced using these percentages. For example, for a strategy that increased transit ridership by providing incentives for using transit, the induced demand would be assumed to come from other modes, new trips, etc. but not from transit.

indicate a fuel savings of 0.62 gallons per hour of delay reduced for passenger cars, 1.607 gallons per hour for single-unit trucks, and 1.934 gallons per hour for combination trucks, for a weighted value of 0.71 gallons per hour across all vehicles. However, based on more recent research, we believe the 1993 SAIC formulas underestimate the fuel savings of delay reduction because they do not consider the effects of reduced acceleration and deceleration. We developed correction factors for this by evaluating relationships between average speed and fuel efficiency embedded in FHWA's IDAS model and EPA's new draft MOVES model. Evaluation of the speed-fuel consumption curves suggests that within the speed ranges where most congestion reductions would occur (20-45 mph), the change in fuel consumption per hour of delay reduced is about 40 percent higher than from the SAIC equations (based on IDAS) or 30 percent higher (based on MOVES). We ultimately increased the SAIC delay-fuel consumption relationships by 30 percent, the lower of these adjustments. Using the higher adjustment would result in added fuel savings and GHG reductions.

To estimate the offsetting increase in GHG as a result of increased VMT, some approximations can again be made using the HERS model at a national scale. HERS model runs indicate that a systemwide average reduction in delay of one hour per 1,000 VMT in the absence of induced demand results in a systemwide increase in VMT of 2.13 percent. This increase in VMT results in a proportionate increase in fuel consumption and GHG emissions. This is a long-run increase, and short-run increases will be somewhat less (one-half of long-run elasticities in the HERS model), consistent with the lower nature of short-run response. For this analysis, we have adjusted GHG from increased VMT in the initial year of strategy deployment by (2.13 percent * 0.5), ramping up this increase to the full 2.13 percent after 10 years.

Appendix C

Assumptions and Methodology Used in Moving Cooler Cost Analysis

Assumptions and Methodology Used in *Moving Cooler* Cost Analysis

This Appendix provides background information regarding the major assumptions, data sources, and analytic approach used to assess the costs and cost-effectiveness of individual strategies and measures in reducing greenhouse gases (GHG).

Section I: General Cost-Effectiveness Methodology – Section I presents details behind the methodology, and what costs are and are not included in the determination of cost-effectiveness across the range of measures in *Moving Cooler*.

Section II: Fuel and Vehicle Operating Cost Assumptions – Section II presents the major assumptions about overall trend fuel and vehicle operating costs that are used in the analysis to determine cost savings associated with reductions in vehicle miles traveled (VMT) or fuel consumption.

Section III: Strategy-Specific Cost Assumptions – Section III presents the specific assumptions, data and analytic methodologies applied in developing costs of measures in each of the nine strategy groups.

I. General Cost-Effectiveness Methodology

The primary focus of the cost-effectiveness analysis is in determining readily quantifiable social costs and benefits of each measure and calculating a net present value (NPV) for various time horizons. The methodology does not represent a comprehensive measure of social welfare associated with each strategy. The NPV is divided by the total tonnes of CO_2e reduced during the same time period to estimate cost-effectiveness in terms of cost per tonne. The primary elements of costs and benefits considered in *Moving Cooler*:

- Implementation Costs
  - Direct capital, annual operating, and maintenance costs
  - Administrative or other program costs;
- Vehicle Costs
  - Fuel costs (savings) due to reduced VMT or improved traffic flow; and
  - Vehicle costs (savings) (other than fuel) due to reduced VMT.

Externalities and benefits that are not direct monetary savings (value of time saved, safety benefits, and air quality improvements) are not included in the cost-effectiveness (CE) analysis.

The primary assumptions that apply to the *Moving Cooler* cost-effectiveness methodology are described below:

- **Calculation of Cost-Effectiveness –** CE will be calculated by dividing cumulative discounted net costs (net present value of total implementation costs minus vehicle costs) by cumulative GHG reductions over the same time period.

- **Discount Rate –** A discount rate of four percent will be applied to future investments and vehicle costs. (The McKinsey report[69] used a seven percent discount rate, but many agencies such as state DOTs utilize a four percent or lower discount rate. If the same methodology were used as was used in the 1992 Office of Management and

[69] McKinsey & Company, Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost? U.S. Greenhouse Gas Abatement Mapping Initiative, Executive Report. (Washington, D.C.: McKinsey & Company, 2007).

Budget (OMB) directive[70], which specified a seven percent discount rate at that time, a discount rate of around three percent would now be used.)

Emission reductions are not discounted. This is consistent with the standard approach to calculating cost-effectiveness of emission reductions (as in the McKinsey report and the Center for Climate Strategies (CCS) methodology for more than a dozen states). The approach recognizes that although the value of money lessens over time, GHG emissions effectively do not due to their long lifetimes (50- to 200-year lifetime for CO_2).

- **Taxes, Tolls, Subsidies, and Other Transfers –** Taxes, tolls, subsidies, and other fees or incentives do not change the total societal cost of a given GHG reduction strategy, but rather affect the costs to individual actors – effectively, they are transfers from one actor to another. Therefore, these are not included in the cost-effectiveness estimates. They are highlighted in the *Moving Cooler* report Section 4.13 and in the equity appendix because they are very important to each group involved in the transfer.

[70] OMB Circular A-94, Guidelines and Discount Rates for Benefit–Cost Analysis of Federal Programs (October 29, 1992) and OMB Circular A-130, Management of Federal Information Resources

II. Fuel and Vehicle Operating Cost Assumptions

These are the costs to private and commerical vehicle operators (excluding taxes and fees, which are regarded as a transfer payment). These include fuel costs, vehicle maintenance, and vehicle ownership costs. These costs are an important component of net societal costs and are generally included in agency cost/benefit calculations, but do not appear on the balance sheet of public agencies and the private sector when it comes to raising sufficient funds for project implementation. The following vehicle costs are included in the *Moving Cooler* cost-effectiveness analysis:

- Fuel cost savings due to reduced VMT or improved traffic flow; and
- Vehicle operating cost savings due to reduced VMT.

Depending on specific strategy definitions, each strategy incorporates either fuel cost savings due to VMT and/or improved traffic flow and vehicle operating cost savings.

Fuel Cost Savings from Reduced VMT

Annual reductions in VMT by strategy are multiplied by baseline fuel economy forecasts and baseline fuel costs per gallon to obtain total fuel cost savings. Cordon pricing, congestion pricing and speed limits which impact both light-duty vehicle and truck VMT use a VMT weighted average fuel economy to determine fuel savings and average fuel cost (diesel and gasoline) to determine total cost savings. In researching the Energy Information Administration (EIA) average fuel price data, from 1994 to present, diesel retail prices averaged three percent higher than gasoline retail prices. The Annual Energy Outlook (AEO) 2009[71] price projections indicate approximately the same relationship. *Moving Cooler* is not analyzing fuel types. For the purposes of *Moving Cooler* analysis, diesel and gasoline prices are assumed to be the same.

Fuel economy forecasts for the on-road light-duty vehicle and truck fleets are the 1.91 percent and 0.63 percent annual growth rates detailed in Appendix B.

---

[71] Energy Information Administration. Annual Energy Outlook 2009. http://www.eia.doe.gov/oiaf/aeo/index.html.

The baseline fuel price is assumed to begin at $3.70 in 2009 and then to increase annually at 1.2 percent. This price growth rate is based on the EIA AEO 2008. Although short-term market volatility will likely continue, this is not assumed to effect long-term trends or results. Fuel prices have fluctuated since this forecast assumption was made.

Fuel Cost Savings from Improved Traffic Flow

Annual reductions of fuel consumption result from improved traffic flow (Cordon & Congestion Pricing, VMT/Gas/Carbon Tax, HOV, Speed Limits, Operations, Bottleneck Relief and Capacity Expansion strategies), improved freight load factors (longer combination vehicle and shipping container permits) and reduced idling for some freight strategies (weigh station bypasses, truck stop electrification and heating and cooling systems for sleeper cabs). Total annual reduction in fuel consumption is multiplied by average annual fuel cost per gallon to obtain total savings. These were calculated based on relationships between fuel consumption rates and changes in hours of delay per 1,000 VMT as estimated through FHWA HERS model runs completed for *Moving Cooler*.

Operating Cost Savings from Reduced VMT

Operating cost savings include all costs attributed to operating a vehicle. Thus, the cost of operating a vehicle on a given section is a function of costs for oil, tires, maintenance and repair, and mileage-related depreciation. For strategies affecting both passenger car and freight VMT (cordon pricing, congestion pricing, intercity tolls, and speed limits), the passenger vehicle and truck combined VMT weighted operating costs are used. The cost per mile for light-duty vehicles and trucks through 2050 are obtained from IRS data for light-duty vehicles (58.5 cents in 2008, adjusted for higher fuel prices to 60 cents per mile, and further adjusted for all vehicles based on cost ratios between light-duty and all vehicles from the Highway Economic Requirements System (HERS) model.[72]) This data is presented in Table 1.

[72] The Highway Economic Requirements System (HERS) model was developed by the Federal Highway Administration (FHWA) to examine the relationship between national investment levels and the condition and performance of the nation's highway system. FHWA uses the model to estimate future investment required to either maintain or improve the nation's highway system. http://www.fhwa.dot.gov/infrastructure/asstmgmt/.

Table 1. Average Vehicle Operating Costs

Operating Costs/Vehicle Type	Dollars/Mile		
	2010	**2030**	**2050**
Passenger Vehicles Only	$0.60	$0.59	$0.59
Passenger Vehicles and Trucks	$0.68	$0.68	$0.68

Truck operating cost savings for freight-specific strategies are discussed within each strategy methodology as they vary depending on strategy definition (see Section III, 9.0 Freight Strategies).

III. Strategy-Specific Cost Assumptions

The following sections outline the analytic approach and specific cost assumptions applied to each of the nine strategy groups defined by the report. These groups are:

1. Pricing strategies;
2. Land use and smart growth strategies;
3. Nonmotorized transportation strategies;
4. Public transportation improvement strategies;
5. Regional ride-sharing, car-sharing and commuting strategies;
6. Regulatory strategies;
7. Operational and intelligent transportation system (ITS) strategies;
8. Bottleneck relief and capacity expansion strategies; and
9. Multimodal freight strategies.

1.0 Pricing Strategies

1.1 Parking Pricing

There are three individual measures qualified as parking pricing strategies, all with consistent cost assumptions (GHG reduction methodologies do vary by measure). These are:

1. Central Business District (CBD)/Activity Center on-street parking pricing to encourage "park-once" behavior (Level A – complete over eight years, Level B – complete over six years, Level C – complete over four years);

2. Introduce tax/higher tax on free private parking lots (Level B >100 spaces, Level C >50 spaces); and

3. Require residential parking permit of on-street parking in residential areas (Level B = $200 biennially, Level C= $400 biennially, plus multi-zone permits for delivery vehicles).

For all measures, the primary implementation mechanisms are new parking regulations and enforcement. While there is a transfer cost for those paying the taxes, permits and/or fees to a public or private entity, there is insufficient information to determine from which socioeconomic groups these transfer revenues would be collected and how these transfer revenues would be used. The public costs of implementing these measures are minimal and comparatively less than transfer revenues. The CBD/Activity Center on-street parking pricing measure includes some implementation cost for purchasing new meters or updating existing meters to reflect new prices as well as administrative costs to monitor and set appropriate fee levels. For consistency among measures and the recognition that any implementation and enforcement costs would presumably be deducted from the revenues raised by these strategies, the implementation costs are assumed to be zero.

1.2 Cordon Pricing

Cordon pricing was applied for all vehicle travel to central business districts. An estimate was made of the proportion of urban VMT (3 percent) which would be subject to cordon pricing. Thus, the cost estimate for cordon pricing is assumed to be proportional to the cost estimate for congestion pricing, which utilizes similar technology for implementation. Congestion pricing applies to 29 percent of urban VMT.

1.3 Congestion Pricing

Congestion pricing is applied for all highways and roads which are congested based on volume/capacity (V/C) ratio thresholds (maintain level of service (LOS) D for roads currently LOS F). An estimate was made of the proportion of all urban and rural roads and VMT, which would be subject to congestion pricing under each level of implementation. The proportions were derived from the Highway Performance Monitoring System (HPMS)[73] and HERS runs performed by FHWA for recent system pricing analyses. A value of 29 percent of congested VMT was utilized for urban areas and 7 percent for rural areas based on the FHWA information.

Initial capital costs include the on-board units (OBU) and installation, enforcement requirements and central system development. According to a 2008 study by the Puget Sound Regional Council (PSRC),[74] the total capital startup cost for the Seattle region is $748.5 million. The same PSRC study estimated annual system costs, which include OBU repair, enforcement and data communications needs at $287.7 million annually in 2008 dollars. These costs are expanded on a per capita basis (based on 2006 census population of the Seattle region, 3.3 million) to cover deployment to all urban areas within each of the six urban area classes. Deployment starts in 2015 in large areas (>1 million population), 2020 in medium areas and 2025 in small areas and rural.

As VMT grows at a forecasted rate of 1.4 percent annually (see Appendix B), annual operations costs will increase proportionally.

Table 1.1 Total Implementation Costs – Congestion Pricing
2010-2050

	Total Cost (Billions (2008 Dollars)	
Deployment Level	**2010-2030**	**2010-2050**
Level A	$133.00	$233.90
Level B	$179.24	$348.99
Level C	$206.62	$380.31

[73] The Highway Performance Monitoring System (HPMS) is a national level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the nation's highways. http://www.fhwa.dot.gov/policy/ohpi/hpms/abouthpms.cfm.

[74] Puget Sound Regional Council. 2008. Traffic Choices Study. http://psrc.org/projects/trafficchoices.

1.4 Intercity Tolls

The same assumptions used for congestion pricing in terms of implementation and annual costs are applied for intercity tolls. This strategy tolls all intercity interstates at varying per mile rates in Levels A, B, and C. The rural system needs as estimated through the congestion pricing analysis (7 percent congested VMT) is applied at an expanded scale (all currently non-tolled rural interstates) to determine total cost for this strategy.

Table 1.2 Total Implementation Costs – Intercity Tolls
2010-2050

	Total Cost (Billions (2008 Dollars)	
Deployment Level	**2010-2030**	**2010-2050**
Level A	$15.96	$33.56
Level B	$25.82	$44.69
Level C	$38.28	$58.51

1.5 Pay-As-You-Drive Insurance and VMT Fees

The costs for these measures are assumed identical because they both measure vehicle miles traveled. Thus if both pay-as-you-drive insurance (PAYD) and VMT fees are being implemented the total costs are split evenly across measures to reflect this implementation overlap. It is assumed that pay-as-you-drive insurance at the scale considered here would be implemented as a government supported program, thus there are associated public costs. Currently most costs of pay-as-you-drive insurance are borne by the insurance provider or the vehicle owner.

The basis of cost assumptions for these strategies in *Moving Cooler* come from a 2008 Cambridge Systematics white paper completed for FHWA on Estimating the Cost of Systemwide Road Pricing.

The PAYD and/or VMT fee system uses an on-board radio frequency (RF) transmitter connected either to existing vehicle odometers or to electronic hub odometers. Most discussions of vehicle infrastructure integration (VII) deployment assume a price closer to $100 per unit for on-board communications units. A recent paper on Toll Collection

Technology Considerations estimated the price of GPS OBUs at $200 to $400.[75] *Moving Cooler* uses a cost of $400 per unit, including start up costs and installation.

Transceivers would be located at gas stations to record mileage information between fill-ups. The estimate for roadside units from the VII Benefit Cost Analysis is used as a proxy for this type of unit.[76] Roadside equipment designed for installation in locations with access to communications is estimated to cost about $1,000, with an additional $4,800 for installation. For number of gas stations, the number of nationwide establishments from the 2002 Economic Census[77] (130,515) was used.

Assuming that the system is deployed as described above, costs for electronic hub odometers, on-board units, and gas station RF receivers are presented in Table 1.3. Additional operating costs are approximated at 10 percent of the field equipment cost. Annual administrative costs are estimated at 5 percent of revenue.

Costs are identical across deployment levels through 2050, however revenue will vary as per mile rates for VMT fees increase from Level A through Level C. Annual operating costs increase by 1.4 percent per year, consistent with *Moving Cooler* forecasts for annual VMT growth. Total implementation costs through 2050 in 2008 dollars are $166.48 billion.

Table 1.3 PAYD and VMT Fee Implementation Costs

Item	Units	Cost per Unit	Cost Extended
Hub Odometers (Electronic) and Start Up	275 million	$400	$110 billion
OBU RF Transmitters	250 million	$100	$25 billion
RF Receivers at Gas Stations	130,515	$5,800	$0.75 billion
Total Deployment Cost			$135.75 billion
Annual Operating and Administrative Costs			$1.715 billion

[75] *Toll Collection Technology Considerations, Opportunities, and Risks*, Background Paper No. 8, Washington State Comprehensive Tolling Study, September 20, 2006 (IBI Group with Cambridge Systematics, Inc.).

[76] *VII Initiative Benefit/Cost Analysis: Pre-Testing Estimates*, Draft Report, Sean Peirce and Ronald Mauri, John A. Volpe National Transportation Systems Center, Cambridge, Massachusetts, March 30, 2007.

[77] Economic Census 2002 Reports. http://www.census.gov/econ/census02/.

■ 1.6 Gas Tax/Carbon Price

It is assumed for *Moving Cooler* that a carbon price related to transportation would be assessed through the same or parallel procedures as are now used for motor fuel taxes. Existing motor fuel taxes are extremely cost-effective, because their costs of administration and compliance are very low. Increases in motor fuel taxes could be accomplished without incurring additional costs for administration or compliance. It also is assumed that a carbon price would be collected much like a motor fuel tax, primarily from the large energy producers at the top of the chain. Thus, a carbon price would have low administrative and compliance costs and high cost-effectiveness.

2.0 Land Use and Smart Growth Strategies

Administrative Costs

These are defined as the program costs of developing and implementing "smart growth"[78] land use planning and coordination mechanisms at the state, regional, and local levels. Costs include public agency staff time as well as external expenses for data acquisition, analysis, public involvement, etc.

Administrative cost estimates are based on experience from recent regional visioning efforts, as well as program requirements for states that already have implemented comprehensive planning requirements (Florida, New Jersey, Oregon, and Washington). The following are examples of regional visioning efforts for which costs have been documented:

- **California Blueprint Program –** Provided $5 million each in 2005-2006 and 2006-2007 for "seed money" for regional blueprint programs. In the first year, 11 applications were submitted, requesting $7 million. First-year grant amounts were $1.2 million (Los Angeles/Southern California Association of Governments), $500,000 (Metropolitan Transportation Commission/Association of Bay Area Governments), and $200,000 to $400,000 for other metropolitan planning organizations (MPO).[79] Second-year applications were of similar magnitude.
- **Envision Utah –** This was about $6 million in the first five to six years, now up to $9-10+ million since 1996.[80]
- **Myregion (Orlando, Florida) –** Cost: (Total in "low millions," public/private mix) Over $1 million dollars was spent by myregion.org in research and development, including private sources.[81]

---

[78] Smart Growth America defines smart growth according to its outcomes: neighborhood livability; better access, less traffic; thriving cities, suburbs and towns; shared benefits; lower costs and taxes; and keeping open space open.

[79] California Regional Blueprint Planning Program: Report to Joint Legislative Budget Committee, December 2006, http://calblueprint.dot.ca.gov/index_files/BP_Report_final.pdf.

[80] The History of Envision Utah. http://www.envisionutah.org/historyenvisonutahv5p1.pdf.

- **Lansing, Michigan** – Approximately $1.5 million for regional growth concept development. Additional ongoing funding for implementation activities.[82]

- **Charlottesville, Virginia –** Jefferson Area Eastern Planning Initiative 2050 – $500,000 grant from FHWA TCSP program to develop plan, plus additional local and in-kind. Ongoing implementation activities.[83]

- **Sacramento, California Blueprint –** Cost: "in the low millions," Public/Private, Federal dollars through Sacramento Area Council of Governments, state agencies, and private donors.[84]

- **Austin, Envision Central Texas –** Cost: Public/Private, wide variety of private contributors, with substantial support from the Capital Metropolitan Transportation Authority and participating cities and counties. Phase 1 cost upwards of $2 million.[85]

Based on experience, the following cost estimates are applied for regional-level planning/ visioning, and applied to all metro areas:

- **Large Metro Areas –** $1 million a year for 10 years (5 years planning, and 5 years implementation), then continuing at $300,000 a year for three full-time equivalents (FTE) indefinitely for ongoing outreach, technical assistance, local plan review, plan updates, etc.

- **Medium Metro Areas –** $500,000 a year for 10 years, then continuing at $200,000 a year (two FTEs) indefinitely.

- **Small Metro Areas –** $200,000 a year for 10 years, then continuing at $100,000 a year (one FTE) indefinitely.

For state growth management programs, the average level of effort per state is estimated at $500,000 annually for Level A (5 FTEs), $1 million annually for Level B (10 FTEs), and $1.5 million annually for Level C (15 FTEs). This includes policy development and analysis in the first few years, then ongoing implementation work, including local outreach, technical assistance, local plan review, state plan updates, etc. It does not include grants for local planning, which are covered under municipal planning costs

---

[81] How Shall We Grow? A Shared Vision for Central Florida. 2007. http://www.myregion.org/Portals/0/HSWG/HSWG_final.pdf.

[82] Regional Growth: Choices for our Future. Tri-County Regional Planning Commission. http://www.mitcrpc.org/tricounty_website/1_overview.htm.

[83] Jefferson Area Eastern Planning Initiative. http://www.tjpdc.org/community/epi.asp.

[84] http://www.sacregionblueprint.org/sacregionblueprint/home.cfm.

[85] http://envisioncentraltexas.org.

(below) without the source of these costs being specified. The increasing costs correspond to increasing levels of state involvement in planning oversight, technical assistance, etc.

For local plan and code updates, an average cost of $100,000 per municipality is estimated for Levels A and B ($150,000 for Level C), with approximately 21,000 municipalities (counties, cities, and towns – based on Census data) in the United States updating their plans to comply with regional and state planning objectives. The cost may be considerably greater than this for larger jurisdictions; however, many jurisdictions probably would have performed updates anyway during the course of the implementation period and so this may not necessarily represent a significant additional cost. Many rural jurisdictions that currently do not have comprehensive plans and/or zoning also may need to expend additional resources.

Costs and Cost Savings Not Included in the Analysis

These include cost savings for roadways and water/sewer lines resulting from more compact development patterns.

The primary data source for infrastructure cost savings is the work of Robert Burchell and colleagues, as documented in TCRP Report 74, The Costs of Sprawl – 2000 (2002)[86] and Sprawl Costs: Economic Impacts of Unchecked Development (2005).[87]

Roadway Infrastructure – Burchell et al. (2002) developed a statistical model of the relationship between road density and population density at the county level in the United States, and then applied typical costs per mile for "developed" and "undeveloped" rural, suburban, and urban areas (Table 8.2, page 248).

Municipal Services – Burchell et al. (2002) estimate savings in municipal services based on population density, based on aggregate analysis of municipal revenues and expenditures, but the magnitude of these savings ($64 per residential unit and $3 per job) is quite small compared to the magnitude of the infrastructure cost savings shown above. In addition, there is some disagreement in the literature about whether higher-density development results in lower services costs when examined across all services. Lacking any strong evidence or data showing a larger impact to municipal services, this category of costs was therefore ignored. (Municipal service cost savings from Kentucky and Rhode

---

[86] Burchell, R., et al. (2002). TCRP Report 74, Costs of Sprawl – 2000. http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_74-a.pdf.

[87] Burchell, R., et al. (2005). Sprawl Costs: Economic Impacts of Unchecked Development. Island Press.

Island studies referenced in Brookings (2004) could be reviewed to see if there is any further relevant information on this topic.)[88]

Real Estate Development – Burchell et al. (2002) also estimate real estate development cost savings from compact versus sprawl development, with the cost savings based primarily on smaller lot sizes (reduced land costs) and smaller building sizes in multifamily development. They estimate a reduction of $13,000 per unit (8 percent) for residential development and $865 per unit (1 percent) for commercial development. These cost savings were not accounted for in this study for two primary reasons. First, the savings resulting from smaller unit sizes may represent a welfare loss to consumers (although Burchell justifies ignoring this by stating that market trends are favoring smaller units anyway). Second, it is possible that more urban-style development requires additional public amenity costs (such as sidewalks, public space, etc.) that are not accounted for elsewhere in this analysis. Such cost differences, however, have not been well-documented. Finally, there is evidence that some types of growth policies (such as growth boundaries) may increase land prices (in fact, this is an important mechanism for achieving higher densities), meaning that land costs may not be lower taken together.

Transit Infrastructure and Services – One might argue that the additional cost of transit infrastructure and services should be considered, if reduced road costs are considered. Transit costs are considered separately, under the transit strategy category, and therefore it would be double-counting to also consider them here.

Utilities (Water, Sewer, Gas, Electric) – It is likely that compact development would realize savings from utilities due to shorter infrastructure connection requirements. Burchell et al. (2005) provide estimates of water and sewer costs per residential unit for different types of development. Gas and electric cost savings were estimated in an analysis of regional growth alternatives for northern Utah by Envision Utah.

Demonstration Grants and Catalyst Funding – A number of state and metropolitan area planning initiatives have include a significant program of demonstration grants, catalyst project funding, etc. in the implementation phase. Such costs are not included in this analysis for three reasons. First, it is assumed that these are largely infrastructure and development funds that are redirected from other uses – e.g., funds for pedestrian improvements in transit villages are reallocated from pedestrian (or other) infrastructure improvements that might have been implemented in other locations not identified as target growth areas. Second, "smart growth" practices are by now well-established so there is less need to learn how to do something particularly new or innovative. Finally, it is very difficult to say how much (if any) catalyst or demonstration funding might be required to achieve an ultimate desired plan outcome; if sufficient requirements and other policy levers (e.g., strings attached to Federal transportation funding) are part of the

[88] Muro, M. and R. Puentes. 2004. Investing In a Better Future: A Review of the Fiscal and Competitive Advantages of Smarter Growth Development Patterns. The Brookings Institution Center on Urban and Metropolitan Policy.

policy package, additional implementation funds (as incentives for local communities or developers) may not be necessary at all.

Land Preservation – While land preservation programs play a role in regional planning and land use, targeted land preservation is primarily a conservation strategy, not a compact growth/growth management strategy. While land protection can be accomplished through acquisition of development rights, it also may be accomplished through regulations at no cost. Therefore, it is difficult to make blanket assumptions about the magnitude of investment needed for land preservation to support regional growth strategies.

Overall Affordability – Some researchers have suggested that overall regional housing costs may increase because of growth boundaries or other regulations that restrict the location and form of development. The evidence on this point is limited, however, and there is dispute over the extent to which housing costs in (say) the Portland, Oregon region are a result of growth controls versus market factors. As noted above, there also are potential cost savings in the form of reduced real estate costs (from smaller-footprint buildings) that are not taken into account in this analysis.

Brownfields Cleanup – Some level of additional funding for brownfields cleanup may be required in order achieve greater levels of infill development than would otherwise occur. A 2006 survey by the U.S. Conference of Mayors, cited in a recent paper by Paull,[89] found that 82 respondent cities identified a capacity for new housing for a total of 2.8 million people on brownfields sites in these cities. A 1999 CUED study (also cited in Paull) found that the median remediation cost per acre of Brownfields was $57,000.

Results

Table 2.1 presents total administrative costs in 2008 dollars, which are the same for each implementation level. Much of the initial administrative costs take place in the early years but the benefits are compounded over time.

Table 2.1 Summary of Land Use Costs
Billions 2008 Dollars

	Level A/B/C	
	2010-2030	2010-2050
Total Costs	**$1.27**	**$1.51**

[89] Evans Paull, The Environmental and Economic Impacts of Brownfields Redevelopment. Northeast-Midwest Institute, July 2008.

3.0 Nonmotorized Transportation Strategies

3.1 Pedestrian Strategies

Costs of the pedestrian strategies are calculated using a bottom-up approach that takes unit costs of various types of pedestrian facilities (sidewalks, marked/signalized crossings, etc.) multiplied by assumptions about the quantity that will be required for each Deployment Level. Pedestrian improvements are assumed to be made in three types of areas – schools (K-12), transit station areas (fixed-guideway), and business districts.

The following assumptions are made about the **nature and quantity of new pedestrian facilities** in each type of area:

- **Sidewalks –** New sidewalk within 0.25 (Level A) or 0.5 (Levels B and C) mile radius along arterial or major collector, both sides of street; one-quarter of all areas currently are missing sidewalks. This yields 0.5 mile new sidewalk for 0.25-mile radius, or 1.0 mile for 0.5-mile radius. Applied to all six urban area types.

- **Pedestrian Crossings/Traffic Calming –** Four new painted/signed crosswalks for one-quarter-mile radius (Level A) of schools and transit stations (one per major directional approach); doubled for business districts since these are a larger area, not a point destination. Two of these locations are retrofitted with bulb-outs or median refuge islands. One location is retrofitted with a two-corner pedestrian signal. Quantities are doubled for one-half-mile radius (Level B). Quantities are doubled again for Level C implementation to reflect greater implementation of traffic calming measures.

The following assumptions are made about unit costs:

- **Sidewalks –** A literature review for NCHRP 20-24(63)[90] suggested a range of costs of $200,000 to $800,000 per mile for new sidewalks. A number close to the low end of this range ($250,000) was selected, assuming that in most cases where sidewalks already do not exist, a four- or five-foot sidewalk would be installed, and applications that are more expensive avoided.

---

[90] Porter, C., et al. (2008). NCHRP 20-24 (63). Partnership Approaches to Identify, Promote, and Implement Congestion Management Strategies. http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/20-24(63)_FR.pdf.

- **Pedestrian Crossings/Traffic Calming –** A literature review for NCHRP 20-24(63) found that marked and signed crossings cost less than $1,000. The Bicycle Transportation Alliance (2008) reports that bulb-outs cost $10,000 to $19,000 each, and refuge islands $8,000 to $15,000.[91]

The analysis was supported by a "top-down" review of various cities' pedestrian plans, to compare proposed expenditures on pedestrian facilities with what is contained in the plans. Three cities were located with pedestrian plans and cost estimates, as shown in Table 3.1. As can be seen, costs varied widely. However, the range of $100 to $200 per person for Oakland and Portland is fairly consistent with the Level B and C costs of $133 and $185 per person, respectively, in this analysis. These cities' plans included improvements that extended beyond just the pedestrian areas (schools, transit stations, and business districts) analyzed in this analysis, and therefore costs would be expected to be higher.

Table 3.1 Pedestrian Master Plans and Cost Estimates

City	Population	Cost/Person	Comments
Sacramento	475,000	$ 1,684	Estimated cost of all sidewalk and crosswalk improvements – not fully funded
Oakland	501,000	$100	Twenty-year priorities for streetscape projects (median improvements, street restriping, sidewalk/curb repair, traffic signal improvements, etc.)
Portland	568,000	$211	Twenty-year project list; includes $26 million for "Pedestrian District" and "Main Street Pedestrian Design" projects (includes widened sidewalks, curb extensions, street lighting and signing) and $24 million for sidewalk improvements
Average (Three Cities)		**$504**	

It was assumed that these capital investment costs would be spread over a 15-year timeframe, starting in 2010. It was further assumed that after this initial 15-year period, maintenance costs would continue at the level of 10 percent of initial annual capital costs. The results of the pedestrian cost analysis are shown in Table 3.2.

[91] Bicycle Transportation Alliance. Bicycle Boulevard Toolkit. http://www.bta4bikes.org/at_work/bikeboulevards.php.

Table 3.2 Pedestrian Strategy Costs

		Cost per Area			Total Cost, All UZAs (Millions Dollars)		
Area Type	**Total Number**	**A – One-Quarter Mile**	**B – One-Half Mile**	**C – One-Half Mile with More Traffic Calming**	**A – One-Quarter Mile**	**B – One-Half Mile**	**C – One-Half Mile with More Traffic Calming**
Schools	75,000	$191,000	$382,000	$514,000	$14,325	$28,650	$38,550
Transit Stations	1,500	$191,000	$382,000	$514,000	$287	$573	$771
Business Districts	20,000	$257,000	$514,000	$778,000	$5,140	$10,280	$15,560
			Total 15-Year Capital (Millions Dollars)		**$19,752**	**$39,503**	**$54,881**
			Cost per UZA (Millions Dollars)		$54.4	$108.8	$151.2
			Cost per Person (Dollars)		$67	$133	$185
			Cost per Year, 2010-2024		$1,317	$2,634	$3,659
			Cost per Year, 2025+		$132	$263	$366

3.2 Bicycle Strategies

Costs of the bicycle strategies were calculated using a bottom-up approach that applied unit costs of various types of bicycle facilities (lanes, paths, racks, etc.) multiplied by assumptions about the quantity that will be required for each metro area size category and Deployment Level. These costs estimates were validated and refined based on a top-down review of various North American cities' bicycle plans. The review focused on plans that are directed at achieving an extensive bicycle infrastructure as described in the scenarios for this strategy.

For bicycle facilities (lanes, shared-use paths, and bicycle boulevards), assumptions were made about the network spacing at each level of implementation, which was then expressed in terms of miles of facility per square mile. The network density was then multiplied by the total land area within census tracts of population density of at least 2,000 persons per square mile (as obtained from the Land Use strategy analysis). This corresponds to moderate-density suburban areas and higher-density urban neighborhoods. It was assumed that these areas would have the most significant potential for bicycling, and therefore would represent the most cost-effective extension of the bicycle network. Simple bicycle improvements lanes and signage could be implemented in many lower-density areas at relatively low cost, but would be expected to have only a minor impact on mode shares.

Cost data for bicycle facilities and parking were taken from a number of sources, including the NCHRP-developed *Benefit/Cost Analysis of Bicycle Facilities* tool (http://www.bicyclinginfo.org/bikecost/); the Bicycle Transportation Alliance web site (http://www.bta4bikes.org/at_work/bikeboulevards.php); and various cities' bicycle master plans. In some cases, professional judgment was used to reconcile estimates that varied significantly among different sources.

Table 3.3 shows the various assumptions that were made in determining the overall costs of the bicycle strategies. The bottom of this table also shows some summary statistics such as miles of bikeway per capita, cost per person, and cost per mile, that are compared with findings from North American bicycle plans. Overall, the cost per person for Level C of $198 compares with $211 for five cities with aggressive bicycle plans, and the miles of facility per person of 727 compares with the average of 681 from three of these cities' plans.

Table 3.3 Bicycle Facility Assumptions

Item	Unit Cost/ Quantity	Level A	Level B	Level C	Comments
Signed Bicycle Routes					
Cost per Mile	$1,000				
Miles per Square Mile		2	0		
Total Miles		54,000	-	-	
Cost (Millions Dollars)		$54	-	-	
Bicycle Lanes					
Cost per Mile	$25,000				NCHRP reports $5K/mile for signing/striping; assume some roads require reconfiguration of all lanes, more expensive (Columbus $12-93K; Toronto $40K)
Miles per Square Mile		2	2	4	Two miles/square mile = 1 mile spacing; 4 miles/square mile = one-half-mile spacing
Total Miles		54,000	54,000	108,000	
Cost (Millions Dollars)		$1,350	$1,350	$2,700	
Shared Use or Off-Street Path					
Cost per Mile	$750,000				Columbus – $707,000; Toronto; $675,000 CDN. Includes bridges
Miles per Square Mile		0	1	2	One mile/square mile = 2-mile spacing; 2 miles/square mile = 1-mile spacing
Total Miles		-	27,000	54,000	
Cost (Millions Dollars)		-	$20,250	$40,500	~$1-1.5 trillion/year; compare to $1 trillion total from 1991-1997 in the United States

Item	Unit Cost/ Quantity	Level A	Level B	Level C	Comments
Bicycle Boulevard Conversions					
Cost per Mile	$200,000				Splits the cost of Columbus ($50K/mile), Bicycle Trans Alliance ($250-500K), and Berkeley ($375K); includes bicycle signals, 1/mile
Miles per Square Mile		0	1	2	1 mile/square mile = 2-mile spacing; 2 mile/square mile = 1-mile spacing
Total Miles		-	27,000	54,000	
Cost (Millions Dollars)		-	$5,400	$10,800	
Bicycle Racks					
Cost per Unit (Inverted U)	$200				NCHRP Guidebook
Quantity per 1,000 Residents	50				Portland: 15 short-term and 41 long-term per 1,000 population in Bike Plan
Total Racks (Millions)		7.5	7.8	8.0	
Cost (Millions Dollars)		$1,500	$1,550	$1,600	
Bus Bicycle Racks					
Cost per Unit	$600				NCHRP Guidebook
Number of Buses	106,700				
Total Racks (Millions)		106,700	106,700	106,700	
Cost (Millions Dollars)		$64	$64	$64	
Bicycle Station					
Cost per Unit	$200,000				NCHRP Guidebook
Number per UZA		1	1	2	
Cost (Millions Dollars)		$59	$59	$118	
Cycling Skills Course (K-12)					
Cost per Class	$1,000				
Students per Class	25				
Total Number of Students (Millions/Year)	4.58				53.8 million K-12 students in 2006
Number of Years	15				
Cost (Millions Dollars)		$2,750	$2,750	$2,750	
Total Cost, First 15 Years (Millions)		**$5,723**	**$31,423**	**$58,710**	
Cost per Metro (Millions)		$19.3	$106.2	$198.3	
Cost per Person		$19	$106	$198	Compare with $211 average from five cities
Cost per Mile of Facility		$105,986	$290,956	$271,806	Compare with $217,000 average from three cities
Miles/Million Persons		182	364	727	Compare with 681 average from three cities
Annual Costs (Billions)					
Infrastructure, 2015-2029		$0.20	$1.91	$3.73	
Infrastructure, 2015-2030+		$0.02	$0.19	$0.37	
Skills Course		$0.18	$0.18	$0.18	

To annualize costs (also shown in Table 3.3), it was assumed that initial capital investment costs would be spread over a 15-year timeframe (2015-2029). Beyond this point, it was assumed that maintenance costs would be incurred at 10 percent of the annual capital investment cost. The skills course is assumed to continue into the future.

The costs estimates are most heavily driven by the assumptions regarding the quantity and cost of major investments, including shared-use/off-road paths and bicycle boulevards. Bicycle lanes and the cycling skills course also represent significant expenses. The overall costs and costs per facility-mile will depend upon the assumed mix of facilities, and this analysis is somewhat simplified in the sense that it does not consider strategies such as widening existing pavement to create bicycle lanes or shoulders.

4.0 Public Transportation Improvement Strategies

4.1 Fare Measures

This strategy is defined as offering lower fares or discount passes. In Level A, the average fare decrease is 25 percent, in Level B 33 percent and in Level C 50 percent. It is assumed that minimal administrative costs are required to manage these reductions and zero capital costs. If fare reductions are combined with smart card systems, there are costs associated with the purchase of new or upgraded equipment as well as lifetime operations and maintenance costs of the system. *Moving Cooler* assumes zero cost for this strategy.

There are significant transfer costs associated with this strategy. While lower fares would result in a cost savings to existing transit users and for new transit users who switch modes as a result of travel cost savings, the revenue lost by transit agencies would need to be offset by new revenue from other sources (increased local taxes, impact fees, etc.). These issues are addressed in the multi-attribute table in the final report.

4.2 Increased Level of Service and Speed Strategies

For the purposes of *Moving Cooler* cost-effectiveness analysis, the three individual strategies within this category are grouped together to determine total costs and cost-effectiveness. This includes increased frequency, improved operations and speed and expanded urban/rural fixed route bus service.

Moving Cooler uses costs estimated for the Bottom Line transit analysis[92] to obtain capital and operations/maintenance costs through 2050. The total costs are the marginal additional investments required above needed costs for an annual 2.4 percent ridership growth rate.

---

[92] American Association of State Highway and Transportation Officials (AASHTO). 2009. Transportation: Are We There Yet?: Bottom Line Report. Washington, D.C.

Capital Costs

The Bottom Line cost model is extended from 2026 through 2050, using the 20-year trend for urban transit systems. Total capital costs for the headway and level of service strategies use Bottom Line costs for the difference in annual costs between "maintain" transit service performance and "improve" transit service performance scenarios from Bottom Line. For the bus expansion strategy, the vehicle replacement model developed for Bottom Line is utilized to determine total vehicles required to support transit ridership increases resulting from system expansion.

The "improve" service performance scenario assumes that added investments are made to improve the speed of systems where the average speed falls below the national average. For the baseline ridership growth scenario, Bottom Line estimates that on average an additional investment of $7.3 billion annually (a 21 percent increase from "maintain") is required to improve performance. This difference from the base plus rural capital investment forecasts for the 3 percent, 3.5 percent, and 4.6 percent ridership growth rates are the total capital costs for Level A, B, and C.

For the extent measure, the strategy definition for Level A, B, and C identifies annual growth rates for bus revenue miles of 50 percent, 100 percent and 200 percent above baseline growth from 1997 to 2006. This results in annual ridership growth of 2.7 percent, 3.7 percent, and 6.0 percent. These growth rates are applied to the Bottom Line vehicle replacement model to determine annual costs for fleet expansion and replacement/rehabilitation to support ridership growth.

The total capital costs are decreased based on forecasts used in *Moving Cooler* for increases in transit load factors. Based on results from the Federal Transit Administration's Transit Economic Requirements Model (TERM)[93] run (see Appendix B), the trip weighted load factor increase in 2050 for Level A is 15.9 percent, Level B 9.4 percent, Level C 8.9 percent. The trip weighted load factor adjustment is calculated by multiplying the forecasted 2050 mode shares among transit modes by the forecasted load factor increase from TERM. The load factor increase and related reduction in costs is phased in incrementally over the first 20 years (2010-2030). Refer to Table 4.1 for details.

[93] FTA TERM Model, http://wwwcf.fhwa.dot.gov/policy/2006cpr/appc.htm.

Table 4.1 Transit Load Factor Adjustment

Mode	Trip Share		2050 Load Factor Increase		
	2010	2050	Level A	Level B	Level C
CR	5%	7%	8%	9%	8%
HRT	24%	39%	15%	15%	16%
LRT	5%	10%	17%	15%	15%
Bus	54%	44%	18%	16%	15%
Other	2%	<1%	6%	7%	7%
Trip Weighted Load Factor Increase			**15.9%**	**9.4%**	**8.9%**

Operating Costs

Using data from the American Public Transportation Association's (APTA) 2007 Public Transportation Factbook,[94] the estimate for operating costs per unlinked transit trip in 2006 is $2.50 (excluding paratransit services and nonvehicle facility maintenance costs). From 1995 to 2006, this number has increased from $1.84 per trip, a 36 percent increase or 2.6 percent increase annually. This growth rate is in line with Consumer Price Index (CPI) increases from 1996 to 2006 (32.3 percent increase) and is not indicative of any decrease in the operating efficiency of transit. For reference, Table 4.2 presents general transit operating cost trends from the 2007 Public Transportation Factbook.

Table 4.2 Operating Cost per Transit Trip
Excluding Paratransit

Year	Bus	Rail (CR, HR, LR)	All Modes
1995	$2.13	$2.33	$2.20
2000	$2.28	$2.15	$2.25
2006	$3.02	$2.68	$2.93

[94] American Public Transportation Association. 2007. Public Transportation Fact Book. http://www.apta.com/resources/statistics/Documents/FactBook/APTA_2007_Fact_Book.pdf.

In *Moving Cooler*, the 2006 operating cost per trip is multiplied by the total annual marginal trip increase (i.e., Level A trips – Base trips) to obtain total annual operating costs. Total annual operating costs are then decreased by the trip weighted load factor increase (see Table 9).

Results

Average annual implementation costs and total costs for Level A, B, and C are presented in Tables 4.3 and 4.4.

Table 4.3 Annual Implementation Costs (2010-2050)
Billions Increase over Baseline

	Average Annual Cost (Billions 2008 Dollars)		
Deployment Level	**Capital**	**Operations**	**Total**
Level A	$0.42	$0.94	$1.36
Level B	$0.83	$1.82	$2.65
Level C	$1.95	$4.38	$6.32

Table 4.4 Total Implementation Costs
Billions Increase over Baseline

	Total Cost (Billions (2008 Dollars)	
Deployment Level	**2010-2030**	**2010-2050**
Level A	$19.48	$52.48
Level B	$37.55	$102.61
Level C	$83.55	$243.77

■ 4.3 Urban Transit Expansion

This measure focuses on expansion of all transit modes in urbanized areas to meet annual ridership growth rates as identified in the Bottom Line report.

Moving Cooler uses costs estimated for the Bottom Line to obtain capital and operations/maintenance costs through 2050. The total costs are the marginal additional investments required above needed costs for an annual 2.4 percent ridership growth rate.

Capital Costs

The Bottom Line cost model is extended from 2026 through 2050, using the 20-year trend for urban transit systems. Total capital costs for this strategy use Bottom Line difference in annual costs for the "maintain/maintain" scenario between the base, Level A, Level B, and Level C ridership growth rates.

The total capital costs are decreased based on forecasts used in *Moving Cooler* for increases in transit load factors. Based on results from the TERM model run (see Appendix B), the trip weighted load factor increase in 2050 for Level A is 15.9 percent, Level B 15.2 percent, Level C 14.9 percent. Using the Bottom Line assumption that approximately 64 percent of expansion costs go to fixed guideway transit (i.e., New Starts projects), this allows calculation of a cost weighted load factor increase. This results in a 14 percent reduction in total capital costs per year (assume this reduction is phased in linearly over the first 20 years). The cost weighted load factor is used for this strategy to reflect the proportionally higher expense for expanding rail-based transit.

Table 4.5 Transit Load Factor Adjustment

	Trip Share		2050 Load Factor Increase		
Mode	**2010**	**2050**	**Level A**	**Level B**	**Level C**
CR	5%	7%	8%	9%	8%
HRT	24%	39%	15%	15%	16%
LRT	5%	10%	17%	15%	15%
Bus	54%	44%	18%	16%	15%
Other	2%	<1%	6%	7%	7%
Cost Weighted Load Factor Increase			14.6%	14.2%	14.0%

Operating Costs

Using data from APTA's 2007 Public Transportation Factbook, the estimate for operating costs per unlinked transit trip in 2006 is $2.80 (excluding paratransit services only). From 1995 to 2006, this number has increased from $2.07 per trip, a 35 percent increase or 2.5 percent increase annually. This growth rate is in line with Consumer Price Index increases from 1996 to 2006 (32.3 percent increase) and is not indicative of any decrease in the operating efficiency of transit.

In *Moving Cooler*, the 2006 operating cost per trip is multiplied by the total annual marginal trip increase (i.e., Level A trips – Base trips) to obtain total annual operating costs. Total annual operating costs are then decreased by the trip weighted load factor increase.

Results

Average annual implementation costs and total costs for Level A, B, and C are presented in Tables 4.6 and 4.7. All costs are presented in constant 2008 dollars.

Table 4.6 Annual Implementation Costs (2010-2050)
Billions Increase over Baseline

	Average Annual Cost (Billions 2008 Dollars)		
Deployment Level	**Capital**	**Operations**	**Total**
Level A	$3.84	$2.91	$6.75
Level B	$7.57	$5.76	$13.33
Level C	$17.73	$14.12	$31.85

Table 4.7 Total Implementation Costs
Billions Increase over Baseline

	Total Cost (Billions (2008 Dollars)	
Deployment Level	**2010-2030**	**2010-2050**
Level A	$111.55	$255.03
Level B	$218.34	$502.97
Level C	$489.39	$1,197.29

■ 4.4 Intercity Rail

Capital Costs

The total capital cost estimate for maintaining and expanding the national intercity passenger rail network between 2008 and 2050 is $357.2 billion in 2007 dollars, an annualized cost of $8.1 billion.[95] Total capital costs above the National Surface Transportation Policy and Revenue Study Commission (NSTPRSC) recommended investment are based on an average cost per diverted vehicle mile. This is obtained from estimates of Federal capital assistance and diverted vehicle miles in the National Passenger Rail Working Group report for NSTPRSC in 2008. The results are:

- Level A (additional 5 percent passenger mile growth) – $13.6 billion above base;
- Level B (additional 10 percent passenger mile growth) – $27.1 billion above base; and
- Level C (additional 20 percent passenger mile growth) – $49.9 billion above base.

The added capital costs plus baseline NSTPRSC annual costs are averaged over 25 years for Level A, 20 years for Level B and 15 years for Level C. No additional capital costs are assumed beyond these timeframes (such as replacement vehicle purchases or rehabilitation).

Operating Costs

According to Amtrak financial reporting[96] for January to September 31, 2008, there were 6.159 billion passenger miles with total operating costs of $914.1 million (operations, fuel, utilities, facilities, materials and communications). This results in an average operating cost of $0.15 per passenger mile. Average operating cost per passenger mile is applied to total new passenger mile forecasts compared to the base for each level through 2050.

---

[95] National Surface Transportation Policy and Revenue Study Commission, *U.S Intercity Passenger Rail Network Through 2050*, December 2007.

[96] Amtrak. Annual Reports & Consolidated Financial Statements. http://www.amtrak.com/pdf/AmtrakAnnualReport_2008.pdf.

Results

Table 4.8 Annual Implementation Costs (2010-2050)
Billions Increase over Baseline

Deployment Level	Average Annual Cost (Billions 2008 Dollars) Capital	Operations	Total
Level A	$0.433	$0.038	$0.471
Level B	$0.799	$0.072	$0.870
Level C	$1.698	$0.163	$1.861

Table 4.9 Total Implementation Costs
Billions Increase over Baseline

Deployment Level	Total Cost (Billions (2008 Dollars) 2010-2030	2010-2050
Level A	$17.04	$19.26
Level B	$31.13	$35.58
Level C	$64.94	$76.05

■ 4.5 High-Speed Rail

Capital Costs

Total costs are from a variety of sources, including Federal Railroad Administration (FRA) studies, project-level environmental impact study (EIS) documents and project web sites. These are used to determine an average capital cost per passenger mile. The strategy considers up to 10 corridors as identified by FRA. When looking at available cost data for these corridors, capital costs range from $4.75 per passenger mile for corridors 1-5 to $4.08 per passenger mile for all 12 corridors. Using these ranges, the resulting total costs are: Level A $80.26 billion, Level B $83.01 billion, Level C $103.91 billion. For Level A, the total costs are split evenly over 25 years, 20 years for Level B, 15 years for Level C and then discounted to 2008 dollars. Costs in Level A, B, and C do not represent marginal costs over a forecasted baseline investment for this strategy.

Operating Costs

Annual operating costs are assumed to be 2.5 percent of total capital costs. This represents a total capital cost weighted average of available information from three high-speed rail corridors: California (2 percent), Midwest (6 percent) and Southeast (2.9 percent). Annual operating costs reach maximum when system construction is complete (assumes 10-year linear increase during implementation).

Results

Table 4.10 Annual Implementation Costs
2010-2050

	Average Annual Cost (Billions (2008 Dollars)		
Deployment Level	**Capital**	**Operations**	**Total**
Level A	$1.958	$0.571	$2.529
Level B	$2.025	$0.743	$2.768
Level C	$2.534	$1.189	$3.724

Table 4.11 Total Implementation Costs

	Total Cost (Billions (2008 Dollars)	
Deployment Level	**2010-2030**	**2010-2050**
Level A	$69.74	$99.55
Level B	$90.64	$108.15
Level C	$117.53	$144.20

5.0 High-Occupancy Vehicle (HOV) Lanes, Regional Car-Sharing and Commuting Strategies

5.1 HOV Strategies

A distinction is made between new HOV facilities and increased hours of operation of existing HOV facilities. It is assumed that the new HOV lanes are Quickchange Moveable Barriers™ (QMB) which would create an HOV lane from the off-peak direction of existing urban expressways. The costs were based on information on a study of a "Zipper Lane" in Honolulu.[97] From that study, a capital cost of $1,000,000 and $100,000 annual operating costs, in year 2000 dollars, per lane mile was obtained. The projects implemented in *Moving Cooler* are assumed to be a single additional lane in each direction. The center line miles of new HOV lanes was assumed to be the percent of the urban expressways to be implemented by deployment level multiplied by the miles of urban expressway in each *Moving Cooler* urban group (estimated as equal to a percent of the VMT in that group as determined from the parameter table estimated from Highway Statistics table HM-71 applied to the CLM of 224,348 miles of urban expressways from that same table). Based on the level of implementation it is estimated that:

- For Level A: 51,648 miles of QMB HOV lanes are created;
- For Level B: 66,150 miles of QMB HOV lanes are created; and
- For Level C: 145,015 miles of QMB HOV lanes are created.

---

[97] Papacostas, C S, Honolulu's Zipper Lane: A Moveable Barrier HOV Application, Compendium of Papers, Institute of Transportation Engineers 2000, District 6 Annual Meeting.

Table 5.1 New HOV Lane Annual Costs

Strategy	HOV CLM	Capital Cost	Life (Years)	Annualized Capital Cost	Annual Operating Cost	Total Annual Cost
Level A	51,648	$103.3 billion	20	$7.6 billion	$5.2 billion	$12.8 billion
Level B	66,150	$132.3 billion	20	$9.7 billion	$ 6.6 billion	$16.3 billion
Level C	145,015	$290.0 billion	20	$21.3 billion	$ 14.5 billion	$35.8 billion

Capital costs are only expended through 2030, defined as the completion date of the system for each level.

The HOV capital costs used in the final iteration of *Moving Cooler* results have not been changed per input from the Moving Cooler stakeholder committee. HOV costs and implementation schedule vary significantly depending on the infrastructure approach chosen.

Many stakeholder comments noted that "Zipper Lanes" represent an outdated HOV strategy. While the intent to illustrate how "Quickchange Moveable Barriers" (QMB) could utilize existing infrastructure to obtain more HOV lanes is a more cost-effective approach, recent experience indicates that state DOTs are moving away from this approach and investing in at-grade or grade separated HOV facilities since there are fewer distinct directional flows during the peak periods (congestion is seen in both directions during peak flows).

The study team notes that it is probably unrealistic to assume that HOV lanes could be implemented in the magnitude and with the deployment dates outlined in *Moving Cooler* without QMB. The costs for the barriers were not specific for the Hawaiian system but were taken from a review of such systems which was published in support of the Hawaii deployment (this included the Boston moveable barrier system). If QMB are not used and new lanes and ramps are constructed, the costs go up by several orders of magnitudes and the regulatory requirements for implementation become inconsistent with the schedules outlined in *Moving Cooler*. For these reasons, the study team decided to stick with the cost estimates for the QMB type HOV deployment.

Annual operations costs continue through 2050. For the 24/7 operation of existing HOV lanes, it is assumed that there are minimal regulatory and enforcement costs, therefore costs are assumed at zero.

5.2 Car-Sharing Strategies

The implementation costs of car-sharing strategies are equal to the cost of the number of cars acquired; assumed to be at a cost of $15,000 per car. The method for determining the number of cars acquired is detailed in Section 5.0, Table 5.12 of Appendix B. Level A represents current practice and expanded start-up of car-sharing organizations through 2020, while Level B and C set targets of number of residents per car through 2015.

It is assumed that members would be responsible for the fuel and operating maintenance costs and those costs are not included in this estimate. It also is likely that the subsidy would cover only some of the depreciation costs of the vehicles with the remaining depreciation costs assigned to the members. Since the percentage of the depreciation costs that would be assigned to the members was not established, the entire annualized capital costs are included below.

The description of the strategy suggests that only a start-up subsidy would be provided. It is therefore assumed that the capital costs of replacing the vehicles would be borne by the members and no costs would incur beyond the start up period. From an accounting perspective, it may be appropriate to assign the total capital costs as a one time cost in the first year of implementation rather than annualizing the costs over the life of the cars. Finally, there is no basis on which to determine the socioeconomic groups that would become members due to this strategy and therefore no basis to assign this subsidy to any socioeconomic group.

Table 5.2 Car-Sharing Costs

Strategy	Cars	Capital Cost	Years	Annualized Capital Cost	Annual Operating Cost	Total Annual Cost
Level A	49,000	$735 million	10	$91 million	$ 0	$91 million
Level B	98,000	$1.47 billion	5	$330 million	$ 0	$330 million
Level C	196,000	$2.94 billion	5	$660 million	$ 0	$660 million

5.3 Employer-Based Commute Strategies

Cost estimates were built up from general assumptions about the major inputs to commuter programs. Fare subsidies or other financial incentives to commuters are not included because these represent a transfer, rather than a net social cost. Therefore, the cost to the public sector and/or businesses of these programs is likely to be greater than the estimates shown here – offset by cost savings to the commuting public.

Costs were built up for the following five types of program expenses:

- Regional vanpool;
- Regional rideshare (including guaranteed ride home);
- Employer outreach;
- Administration and enforcement of transportation demand management (TDM) requirements; and
- Telework.

Annual costs were determined per metro area for large, medium, and small metro areas, and then aggregated across all areas. Capital costs were annualized based on an assumed average lifetime of the equipment. Key assumptions are discussed below.

- **General Parameters –** Administrative staff costs (salaries and overhead) of $100,000 per full-time equivalent (FTE).

- **Regional Vanpool –** Administrative staff varying from 0.5 to 2 FTEs by metro area size; $25,000 cost per van; 12-year lifetime; total number of vans corresponding to a roughly 0.5 percent vanpool mode share (1,000 in large metro areas).[98]

- **Regional Rideshare** – Administrative staff varying from 0.5 to 2 FTEs by metro area size; $100,000 software/setup cost lasting five years; guaranteed ride home (GRH) program costing $2/year per participant at 10 percent workforce participation.[99]

- **Employer Outreach –** Two hundred and fifty employers covered by each program staff (one day of outreach time per employer per year); total establishments vary by whether employers with >50 or >100 employees are covered by the program.

- **TDM Requirement Administration and Enforcement –** Two hundred and fifty employers covered by each program staff (same as for employer outreach only – essentially, a doubling of effort if requirements are added).

- **Telework –** Cost per new teleworker of $1,000/year to cover additional hardware and software, communications equipment, etc. This cost is assumed the same for both home-teleworkers and remote-office/telework center teleworkers.[100]

---

[98] For comparison, the San Diego Association of Governments' Ridelink program had 572 participating vanpools as of late 2007.

[99] http://www.vtpi.org/tdm/tdm18.htm.

Costs that are not included include:

- **Compressed Work Week (CWW) –** No costs are assumed to be associated with this strategy, aside from administrative costs of outreach/promotion programs as already described.
- **Vanpool Operating Costs –** In all likelihood, vanpool users will experience a net cost savings because of reduced automobile operating costs.
- **Additional Transit Operating Costs –** For large-scale travel shifts to transit, it may be necessary to account for additional transit service operating costs. This will be revisited in coordination with the Transit strategy cost estimates.

Discussion of Telework Costs

Telework cost estimates vary widely, depending upon assumptions such as what equipment the worker already has versus what is provided at additional cost, as well as the specific types of equipment provided. Furthermore, telework costs are likely to continue to decline in the future as technologies such as high-speed Internet access become ubiquitous and costs continue to decline. Therefore, the telework cost estimates should be viewed as highly uncertain. This is a particular problem since, as is shown below, the telework cost estimates are quite high.

Some studies have found business cost savings as a result of increased productivity. However, productivity impacts vary widely by worker and may be negative for some workers. Since it is likely that workers with the greatest interest in telework already are doing so, no further productivity benefits were assumed for programs that lead to additional telework penetration. In addition, it was assumed that most workers will still work in the office most of the week and retain their own office or desk space, and therefore there are no significant savings in office space from teleworking.

Results

Table 22 shows the resulting annual costs across all metro areas, by program category. This provides an indication of which parameters are most important in determining the overall cost estimates, and which are essentially negligible. Overall, telework costs are the highest (see discussion below). Employer outreach and TDM requirements are next-

---

[100] A 2006 GSA survey found an estimated total annual telework cost per employee ranging from $310 to $5,420 across 18 organizations interviewed, with a mean of $1,920 and a median of $1,088. See: http://www.teleworkexchange.com/ppts/Current-Telework-Costs-2.ppt#0. A Federal telework program run from 1999-2001 found an annual user cost per teleworker of $1,000 to $2,000 for remote teleworkers; see http://www.telework.gov/Reports_and_Studies/tw_rpt01/Dec01con.aspx.

highest, because of the significant labor involved in implementing meaningful outreach and enforcement programs. Capital costs for vanpools also are significant. Administrative costs for the regional rideshare and vanpool programs, as well as the GRH program, are small.

Table 5.3 Commuter Program Costs

Program	Element	Total Annual Cost, All Metro Areas (Millions)
Regional Vanpool	Administration	$27.7
	Capital (Vans)	$179.8
Regional Rideshare	Administration	$27.7
	Capital	$5.9
	Guaranteed Ride Home	$29.7
Employer Outreach	Admin – Employers >100 Workers	$215.7
	Admin – Employers >50 Workers	$367.7
TDM Requirements	Admin – Employers >50 Workers	$367.7
Telework	Additional 4% Telework	$5,940.0
	Additional 4% Public Sector Telework	$831.6

Table 5.4 shows the resulting cost for each strategy, in annual terms as well as over the analysis period. Some key assumptions in Table 23 need to be noted:

- Because they are both so large and yet so uncertain, telework costs are not included in the costs of Strategies 6.2.1, 6.2.4, and 6.2.7. It is likely that these strategies, which are general strategies to encourage alternative mode/commute patterns, will result in some shifting to telework. However, it also might be assumed that if these strategies are so expensive, that less costly strategies would be employed instead. Of course, telework may actually end up being a lower-cost and more attractive strategy for some workers compared to the time and other welfare costs of shifting to other modes of travel. Since such costs are not being included in this analysis, however, this comparison cannot be made.

- Strategy 6.1.5 is a four-day workweek for all government employees. It is likely that this will result in some cost savings to public agencies in building energy costs. On the other hand, energy costs at home may increase on the day off. The net effect is assumed to be zero. Administrative costs also are assumed to be zero.

- Strategy 6.2.7 includes a required parking fee on commercial parking. The costs in administering this fee will likely not be insignificant. However, because substantial mode shifts may be induced, the required effort for TDM requirements and outreach will probably be considerably lower. Therefore, the cost for this strategy is assumed to be the same as for Strategy 6.2.4.

Table 5.4 Commuter Strategy Costs
Millions

Strategy	Brief Description	Annual	2015-2030	2031-2050
6.1.1	Telecommuting and CWW goals and incentives	$5,940	$89,100	$118,800
6.1.2	Government agencies provide telecommuting and CWW option	$832	$12,474	$16,632
6.1.5	Required four-day workweek for government employees	$0	$0	$0
6.2.1	Outreach to employers >100, regional ridesharing and vanpooling	$486	$7,296	$9,728
6.2.4	TDM requirements for employers >100; outreach expanded to employers >50	$1,006	$15,094	$20,125
6.2.7	Tax on all commercial parking spaces, plus continuation of TDM requirements and outreach programs	$1,006	$15,094	$20,125

6.0 Regulatory Strategies

6.1 Nonmotorized Zones

This strategy is defined as converting a share of CBD and Activity Center streets to transit malls, linear parks or other nonmotorized zones. For all deployment levels, the timing of implementation is over 10 years, starting in 2010 in high-density regions and 2015 or 2020 in lower density regions.

The 16th Street Mall in Denver, Colorado is selected as the example on which cost estimates are based. This mall was opened in 1982 over 16 blocks for a total cost of $29.5 million. In 2008 dollars, this would equate to $4.88 million per block converted.

The average length of a nonmotorized zone is five blocks according to data from a 1992 survey of pedestrian malls completed in the United States in the 1970s.[101] Using this as a guidance, Level A assumes 25 percent of urbanized areas build at least one, five block nonmotorized zone. Level B assumes 75 percent of urbanized areas build at least one, five block nonmotorized zone. Level C assumes 100 percent of urbanized areas build at least two, five5 block nonmotorized zones. Implementation costs include capital construction costs only. Operations costs for transit using these zones are not included.

Table 6.1 Total Implementation Costs

	Total Cost (Billions (2008 Dollars)	
Deployment Level	**2010-2030**	**2010-2050**
Level A	$1.05	$1.39
Level B	$4.23	$4.23
Level C	$8.47	$8.47

[101] Rubenstein, H. (1992). *Pedestrian Malls, Streetscapes and Urban Spaces*. John Wiley & Sons, Inc.

6.2 Urban Parking Restrictions

Urban parking freezes, similar to those implemented in Boston and San Francisco, set caps for the total number of commuter parking spaces in central business districts and employment centers. For *Moving Cooler*, it is assumed that there is zero cost for implementing this strategy. As part of a discussion of co-benefits of this strategy, it is recognized that urban parking restrictions lead to employers developing more expansive travel demand management programs for their employees to offset the impact of fewer parking spaces. While there may be some cost to the private sector in this case, it also is likely that there are significant savings resulting from leasing fewer parking spaces.

6.3 Reduced Speed Limits

Reduced speed limit measures result in comprehensive reductions to 65 mph overall by 2020 for Level A, 60 mph overall by 2020 for Level B and 55 mph overall by 2015 for Level C. Using information on maximum posted speed limits for interstates by urban and rural areas from the Insurance Institute for Highway Safety[102] combined with data from the 2006 Highway Statistics publication,[103] total centerline miles by state at different maximum posted speed limits is determined.

To decrease all posted speed limits to a maximum of 65 mph would affect 25,317 centerline miles of interstates (61.4 percent of the national system). To decrease all posted speed limits to a maximum of 60 mph would affect 40,476 centerline miles of interstates (98.1 percent of the national system). The mileage estimates are multiplied by capital, maintenance, and administrative costs associated with enforcement.

Estimates from Saving Oil in a Hurry analysis of the potential of speed limit reductions, indicate an average cost of $26,000 per camera and estimates the need of one camera per direction every 6.2 miles.[104] Camera maintenance costs per site are estimated at $3,000 per year.[105] Annual operating and administration costs are obtained from a 2003 study of

[102] Insurance Institute for Highway Safety. Maximum posted speed limits; see http://www.iihs.org/laws/speedlimits.aspx.

[103] Office of Highway Policy Information. Federal Highway Administration. 2006 Highway Statistics; see http://www.fhwa.dot.gov/policy/ohim/hs06/index.htm.

[104] International Energy Agency. *Saving Oil in a Hurry*. 2005.

[105] http://www.itscosts.its.dot.gov/its/benecost.nsf/.

speed enforcement systems in the United Kingdom.[106] The results of this study indicate a 2008 cost of approximately $25,000 per camerar per year.

Table 6.2 Total Implementation Costs

Deployment Level	Total Cost (Billions 2008 Dollars) 2010-2030	2010-2050
Level A	$2.51	$4.06
Level B	$4.01	$6.50
Level C	$4.90	$7.46

[106]http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ID/07D81D8AB57059AE85256F430051A633?OpenDocument&Query=CApp

7.0 Operational and Intelligent Transportation System (ITS) Strategies

7.1 Eco-Driving

The strategy assumes no public sector costs for this analysis. It is recognized that implementation of eco-driving education programs will incur a public cost. Eco-driving programs could be included as part of drivers-education programs.

Sources for the costs for direct eco-driver training programs include details on a similar program in the Netherlands, which required an investment of 2 million Euros to train 6,500 driving instructors(Wilbers et al., 2006).[107]

7.2 Operations Strategies

The deployment of operations strategies mirrors the procedures used in FHWA's HERS Operations Preprocessor. The analysis starts by merging intelligent transportation systems (ITS) Deployment Tracking data from the Research and Innovative Technology Administration (RITA) with HPMS data (2006 in this case) so that current levels of deployment are known for each HPMS segment. Congestion levels (as determined by the V/C ratio) are calculated, the data are sorted, and the worst segments that do not have the strategy already present are selected for deployment.

As a starting point, the thresholds in Table 7.1 from Appendix B were used to determine the scope of each deployment level.

[107] http://www.iapsc.org.uk/presentations/0606_Kroon_combined.pdf.

The analysis makes use of the following assumptions and methodology:

- Deployment of strategies, except for Vehicle Infrastructure Integration (VII), is assumed to occur continuously throughout the analysis period.

- VII deployment and costs are based on the deployment curve in Volpe VII Benefit/Cost Analysis Report[108] (Chart 3.1: Projected Phase-In of VII Equipped Vehicles in the U.S. Fleet). Deployment Level B uses these forecasts, and they are adjusted appropriately for Levels A and C. Costs are the same for all scenarios because it is assumed that the public investment is the same; only penetration rate of vehicles varies.

- Cost per centerline mile for the strategies are based on those used in the HERS Operations Preprocessor.

Table 7.1 Operations Strategies Implementation Costs per Mile

Strategy	Capital Cost per Mile	Annual Operations and Maintenance Cost per Mile
Traveler Information	$100,000	$10,000
Ramp Metering	$51,000	$1,000
VMS	$50,000	$2,000
Signal Management	$25,000	$15,000
Automated Traffic Management	$100,000	$50,000
Integrated Corridor Management	$100,000	$50,000
Weather Management	$100,000	$10,000
Incident Management	$65,000	$18,000

[108] Volpe National Transportation Systems Center. 2008. Vehicle-Infrastructure Integration (VII) Initiative Benefit/Cost Analysis Version 2.3.

8.0 Bottleneck Relief and Capacity Expansion Strategies

8.1 Bottleneck Relief Strategies

The bottleneck analysis is based on previous work done for the American Highway Users Alliance (AHUA)[109] and FHWA.[110] These studies compiled a list of national bottlenecks, almost exclusively freeway-to-freeway interchanges, where the majority of delay occurs in urban areas. The following deployment levels were used in the analysis:

- **Deployment Level A) –** Improve 100 of top 200 bottlenecks to Level of Service "E" by 2030;
- **Deployment Level B) –** Improve all top 200 bottlenecks to Level of Service "E" by 2030; and
- **Deployment Level C) –** Improve all top 200 bottlenecks to Level of Service "D" by 2020 using pricing, system management, enhanced alternatives and capacity expansion in the mix best supported by cost/benefit analysis that accounts for indirection, secondary and cumulative impacts.

The analysis makes use of the following assumptions and methodology:

- Potential bottlenecks compiled from a list of 388 locations used in previous studies conducted for American Highway Users Alliance (AHUA) and FHWA.
- Updated data for locations using 2006 HPMS data.
- Estimated total delay at the locations using the methodology used in the AHUA and FHWA studies; this is based on the delay equations in FHWA's HERS model.

---

[109] AHUA, Unclogging America's Arteries: Effective Relief for Highway Bottlenecks, 2004, http://www.highways.org.

[110] Battelle Memorial Institute and Cambridge Systematics, Inc., *An Initial Assessment of Freight Bottlenecks on Highways*, prepared for Federal Highway Administration, Office of Transportation Policy Studies, October 2005.

- Ranked locations by total delay; select top bottlenecks for improvement in each year – the number improved depends on the scenario used.
- Deployment of strategies is assumed to occur continuously throughout the analysis period.
- Average cost per bottleneck to achieve LOS D conditions assumed at 750 million.

■ 8.2 Capacity Expansion Strategies

Capacity expansion strategies were estimated using the difference in results of HERS runs for maximum economic investment and constrained current funding. The two runs give a picture of highway system performance over time with maximum justified investment compared to current funding levels.

9.0 Freight Strategies

9.1 Rail Bottleneck Strategies

This measure addresses choke points in the rail system for carload and double-stack service so expected 2025 capacity restrictions are reduced by 20 percent, 30 percent, and 60 percent for Deployment Levels A, B, and C, respectively.

The cost savings analysis used the following assumptions:

- Assume 25 percent diverted to truck due to choke points:
  - Billion ton miles (B TM) diverted to truck in 2030 if no rail investment = 675.4;
  - B TM diverted back to rail under Level A (20 percent) = 135.1;
  - B TM diverted back to rail under Level B (30 percent) = 202.5;
  - B TM diverted back to rail under Level C (60 percent) = 337.5;
  - RR TM/gallon = 413, rail cost per ton-mile = $0.063; and
  - Truck TM/gallon = 155, truck cost per ton-mile = $0.097.

Corresponding capital investment levels are derived from National Surface Transportation Policy and Revenue Study Commission, Transportation for Tomorrow, December 2007, Volume 2, Exhibit 4-16).

9.2 Marine Strategies

Vehicle Costs: The Level B analysis estimated benefits that would result from investment in the waterway system that would allow water traffic to grow by 50 percent between 2006 and 2025,[111] rather than the reduced annual rate of 0.42 percent[112] that has resulted from underfunding of waterway improvements in recent years. The Level A and C

[111] Based on a forecast from Cambridge Systematics, Inc., *Waterborne Freight Transportation Bottom Line,* prepared for AASHTO, April 2006, page 4-6.

[112] Derived from U.S. Army Corps of Engineers, *Waterborne Commerce of the United States,* Calendar Year 2006, Part 5, Table 1-11, data for 1987 and 2006.

analyses assumed growth of 33.3 percent and 75 percent, respectively. These assumptions, combined with 2006 data for lakewise and internal movements,[113] produced estimates of increased waterway freight movements of 92.6, 138.9, and 208.3 billion ton-miles for the three analyses.

Reduced use of rail was estimating by dividing the above values by a relative circuity factor of 1.2,[114] and truck access hauls to/from ports were assumed to average 10 miles per movement. Changes in fuel consumption were then estimated by using fuel efficiency factors (in ton-miles per gallon) of 576 for water transport, 413 for rail, and 155 for truck.[115]

Implementation Costs: The total construction backlog for Corps of Engineers navigation projects was estimated to be $10 billion in 2003.[116] Based on this information, capital costs in 2008 dollars for the Level A, B, and C analyses were assumed to be $3, $6, and $12 billion. Annual maintenance costs were assumed to be five percent of the capital costs.

9.3 Truck Size and Weight Permits

Natural Resources

Vehicle Costs: Under this strategy, the 80,000 pound cap on gross vehicle weights (GVW) would be replaced by higher caps for longer combination vehicles (LCV) carrying natural resources for distances of up to 250 miles and operating under permit. Eligible commodities would include grain, fertilizer, coal, crushed stone, sand and other nonmetallic minerals. The new limits would be: 105,500 pounds for Level A; 129,000 pounds for Level B; and, for Level C, 138,000 pounds for eight-axle B Trains (and 129,000 pounds for other LCVs). These higher caps would apply on an appropriate set of truck roads that would include the Interstate System. The minimum distance of 250 miles is assumed as part of the strategy in order to minimize any reduction in the use of rail transport of these commodities, since rail is more fuel efficient than truck.

The VMT of trucks carrying the above commodities was 6.21 billion in 2002.[117] Applying our assumed growth rate of 1.4 percent annually produces an estimate of 6.57 billion VMT

---

[113] *Ibid.,* Table 1-4.

[114] Derived from Congressional Budget Office, *Energy Use in Freight Transportation,* 1982, Table A-16.

[115] Texas Transportation Institute, *A Modal Comparison of Domestic Freight Transportation Effects on the General Public,* prepared for the U.S. Department of Transportation, Maritime Administration, and the National Waterways Foundation, November 2007, Table 12.

[116] Robert F. Vining, *The U.S. Army Corps Budget: The Challenge to Meet Navigation Needs,* presentation to the National Waterways Conference, Waterways Rally and Budget Summit, March 6, 2003.

[117] U.S. Census Bureau, *2002 Vehicle Inventory and Use Survey,* December 2004, Table 8.

for these trucks in 2006. It is assumed that, under this strategy, shipments accounting for 25 percent of this VMT would be diverted from 80,000 pound trucks to LCVs operating at the above weight limits.

Fuel consumption rates for transport in hopper-bottom trailers operating in these configurations in 1995 at loaded weights of 80,000, 105,500, 129,000, and 138,000 pounds and operating empty 50 percent of the time were forecast in 1991 to be 9.65, 8.24, 7.35, and 6.88 mpg, respectively.[118] There does not appear to have been an increase in mpg for combination trucks between 1995 and 2006,[119] so these fuel consumption rates were used without adjustment. This information indicates that the strategy would save between 26.0 (Level A) and 39.6 (Level C) million gallons of diesel fuel in 2006.

Implementation Costs: Estimates of increased pavement and bridge costs were developed from cost responsibility data for the various configurations and operating weights presented in the 1997 Federal Highway Cost Responsibility Study.[120] These costs were converted to 2006 dollars using the FHWA Comparative Price Index for Highway Construction, and then to 2008 dollars using the Bureau of Labor Statistics Producer Price Index (PPI) for Highway Construction. Estimates of reduced driver costs and vehicle operating costs were developed from The Effect of Size and Weight Limits on Truck Costs[121] and converted to 1992 dollars using the Consumer Price Index (CPI-U), to 2003 dollars using the PPI for Trucking except Local (PDU4213), and to 2008 dollars using the PPI for Truck Transportation (PCU484). In addition, savings in costs for overseas shipment of containers were estimated using an assumed average charge of $2,000 per container shipped (in 2008 dollars).

Containers

Vehicle Costs: The Vehicle Inventory and Use Survey (VIUS)[122] contains no information on the VMT of trucks carrying loaded shipping containers, but it does indicate that the VMT of trucks carrying empty shipping containers was 794 million in 2002. It has been estimated that the percentage of combination-truck-miles operated empty on the Interstate

---

[118] Derived from data in Jack Faucett Associates, *The Effect of Size and Weight Limits on Truck Costs,* prepared for FHWA, revised October 1991.

[119] Actually, data in FHWA, *Highway Statistics,* Tables VM-201A, 1995 and VM-1, 2006 show a decline in average mpg from 5.9 to 5.1, though this is dues, at least in part, to increases in truck weight.

[120] FHWA, *Federal Highway Cost Responsibility Study,* 1997, Tables V-6, V-10, V-15, V-20, and V-27.

[121] Jack Faucett Associates, *op,cit.*

[122] U.S. Census Bureau, *2002 Vehicle Inventory and Use Survey,* December 2004, Table 8.

System (IS) is about 20 percent.[123] Applying this percentage to the estimate of empty operation and applying our assumed growth rate of 1.4 percent annually produces an estimate of 3.36 billion loaded VMT for trucks carrying shipping containers in 2006. It was assumed that half of this VMT currently is carried by five-axle combinations under the 80,000-pound weight limit, and half is carried under permit in six-axle combinations at weights of 90,000 pounds.

Under this strategy, loaded shipping containers could be carried under permit on the IS and on most other roads by eight-axle combinations (4S4s) for distances of up to 250 miles at weights of up to 110,000 pounds. (The minimum distance of 250 miles is assumed as part of the strategy in order to minimize any reduction in the use of rail transport of containers, since rail is more fuel efficient than truck.) It is assumed that, under this strategy, 80 percent of the freight currently carried in containers that are transported by truck would be carried in more heavily loaded containers having an average weight of 100,000 pounds, with half of the affected traffic currently being subject to the 80,000 pound weight limit and half currently being subject to the 90,000 pound limit.

Fuel consumption rates for transport in these configurations in 1995 at loaded weights of 80,000, 90,000 and 100,000 pounds were forecast in 1991 to be 5.75, 5.48, and 5.23 mpg, respectively.[124] There does not appear to have been an increase in mpg for combination trucks between 1995 and 2006,[125] so these fuel consumption rates were used without adjustment. After allowing for the higher fuel consumption rates of empty eight-axle combinations (relative to empty five- and six-axle combinations), the above information indicates that the strategy would save 23.7 million gallons of diesel fuel in 2006.

Implementation Costs: Estimates of increased pavement and bridge costs were developed from cost responsibility data for the various configurations and operating weights presented in the 1997 Federal Highway Cost Responsibility Study.[126] These costs were converted to 2006 dollars using the FHWA Comparative Price Index for Highway Construction, and then to 2008 dollars using the Bureau of Labor Statistics Producer Price Index (PPI) for Highway Construction. Estimates of reduced driver costs and vehicle operating costs were developed from The Effect of Size and Weight Limits on Truck Costs[127] and converted to 1992 dollars using the Consumer Price Index (CPI-U), to 2003 dollars using the PPI for Trucking except Local (PDU4213), and to 2008 dollars using the

---

[123] Interstate Commerce Commission, Empty/Loaded Truck Miles on Interstate Highways During 1976, April 1977, Table 1.

[124] Derived from data in Jack Faucett Associates, *The Effect of Size and Weight Limits on Truck Costs,* prepared for FHWA, revised October 1991.

[125] Actually, data in FHWA, *Highway Statistics,* Tables VM-201A, 1995 and VM-1, 2006 show a decline in average mpg from 5.9 to 5.1, though this is due, at least in part, to increases in truck weight.

[126] FHWA, *Federal Highway Cost Responsibility Study,* 1997, Tables V-6, V-10, V-15, V-20, and V-27.

[127] Jack Faucett Associates, *op,cit.*

PPI for Truck Transportation (PCU484). In addition, savings in costs for overseas shipment of containers were estimated using an assumed average charge of $2,000 per container shipped (in 2008 dollars).

9.4 Weigh Station Bypasses and Weigh-in-Motion (WIM)

Vehicle Costs: There currently are two major weigh station bypass systems, PrePass and NorPass, plus the Green Light system used in Oregon. A major limitation on the benefits of these systems results from a restriction that PrePass transponders not be used to communicate with non-PrePass systems. To achieve the maximum benefits of weigh station bypass, a single system should be implemented throughout the country allowing all transponder-equipped trucks to communicate with all weigh stations.

It has been estimated that the interoperability restriction prevents 500,000 bypasses per year in Oregon alone.[128] Comparing truck VMT in Oregon to National VMT suggests that, a single national bypass system would allow the annual number of bypasses to increase by about 39.4 million. One evaluation of the benefits of bypass systems[129] summarizes the range of estimates of time and fuel saved per bypass. The midpoints of these two ranges are approximately three minutes saved and 0.1 gallon of diesel fuel saved.

High-speed WIM screening without checking of electronic credentials is primarily of value at weigh stations where safety inspections are not conducted. It was assumed that the number of such sites is half the number at which electronic credentialing is used, and that the benefits are half those for full weigh station bypass systems.

Implementation Costs: Currently, eight of the contiguous states do not have bypass systems, most of which are relatively small. Assuming that an average of 10 weigh stations per state would require installation of a new system, the number of new systems required would be 80. Implementation costs for new systems are estimated to be $150,000 per weigh station, with annual operating and administrative costs of $10,000 per weigh station plus $15,000 per state.[130] Costs for modifying existing bypass systems to eliminate interoperability restrictions were not considered.

---

[128] Oregon DOT, "Green Light" Emission Testing Project, August 2008, page 3.

[129] Carolyn J. Rodier, Susan A. Shaheen and Ellen Cavanaugh, *Virtual Commercial Vehicle Compliance Stations: A Review of Legal and Institutional Issues,* University of California Davis, Institute of Transportation Studies, 2005, page 8.

[130] Estimates were obtained from a review of U.S. data by Tri-Global Solutions Group and IBI Group, *Cost Benefit Study of Electronic Clearance and Roadside Inspection for Canada,* prepared for Transport Canada, June 2003, Chapter 3, page 9.

The value of time saved was estimated by multiplying total time saved by the current HERS estimate of the average value of time for combination trucks of $36.05.[131] The value of fuel saved was estimated by multiplying total fuel saved by the price of diesel fuel.

9.5 Truck Stop Electrification

Vehicle Costs: There are about 5,000 truck stops in the country. As of October 2008, 136 of these had been electrified.[132] For the Truck Stop Electrification strategy, it was assumed that varying numbers of the remaining truck stops would be electrified by 2025, 2020, or 2015.

The average number of spaces to be electrified per truck stop was taken to be 40 (based on data from a proposed electrification project for Oregon and Washington.[133]) On average, 30 percent of available electrified spaces are estimated to be used in any 24-hour period, with the average period of utilization being 8 hours, and with one gallon of diesel fuel saved per hour of use and 3.8 kW of electricity used during this time.[134]

Implementation Costs: Capital and operating and maintenance (O&M) costs were estimated using data for two truck stops in New York,[135] and converting from 2004 dollars to 2008 dollars by multiplying by 1.119, as indicated by the GDP deflator. In 2004 dollars, the source indicated that capital costs were $10,000 per space, and O&M costs per space were $100 for maintenance, $25 for insurance, and $1,314 for overhead labor. The capital-cost estimate of an average of $10,000 per space was assumed to apply to all spaces constructed under Level A assumptions. Level B and C implementations were assumed to include electrification of some truck stops where capital costs would be higher. Accordingly, average capital costs were assumed to be 10 percent higher for Level B and 20 percent higher for Level C.

---

[131] FHWA, *Highway Economic Requirements System.*

[132] U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center, http://www.afdc.energy.gov/afdc/vehicles/idle_reduction_stations.html, accessed October 9, 2008.

[133] The Climate Trust, Truck Stop Electrification, http://www.climatetrust.org/offset_truckstop.php, accessed October 9, 2008.

[134] Thomas L. Perrot, et al., "Truck Stop Electrification as a Long-Haul Tractor Idling Alternative", TRB 2004 Annual Meeting CD-ROM, December 2003.

[135] Antares Group, Inc., *Summary of Operations: Truck Stop Electrification Facilities on the New York State Freeway,* prepared for the New York State Energy Research and Development Authority, January 2005, Section 5.

Reduced costs of energy were derived from the above estimates of electricity requirements and diesel fuel saved and from estimated 2008 prices of $3.90 per gallon for diesel fuel and $0.202 per KWhr for electricity.

9.6 Truck APUs and HVAC Systems

Vehicle Costs: Sleeper cabs are estimated to idle 2,400 hours per year[136] and to use one gallon of diesel fuel per hour when idling.[137] Auxiliary power units (APU) are estimated to use 0.3 gallons of diesel fuel per hour,[138] and battery-operated heating and cooling systems are estimated to require between 0.03 and 0.06 gallons of diesel fuel for battery recharging per hour of battery operation.[139] In addition, the ratio of numbers of sleeper cabs to total VMT of all combination trucks is 5.95 per million VMT.[140]

Estimates of the benefits of APUs and battery-operated heating and cooling systems per million VMT of combinations trucks were developed using the above information and assuming that: 90 percent of sleeper cabs already do not have APUs or battery-operated heating and cooling systems; there will be a 50/50 split between the two technologies for future implementation; and the average fuel consumption of battery-operated heating and cooling systems is 0.05 gallons of diesel fuel per hour.

Implementation Costs: There were 666,300 sleeper cabs in 2002.[141] For purposes of analysis, the above assumptions indicate that 10 percent of these already are equipped with APUs or battery-operated heating and cooling systems, 45 percent will be equipped with APUs in the future, and 45 percent will be equipped with battery-operated heating and cooling systems in the future.

---

[136] *Bulk Transporter,* "Thermo-King Discusses Idle Reduction", http://bulktransporter.com/fleet/, October 1, 2007, accessed October 14, 2008.

[137] Thomas L. Perrot, et al., "Truck Stop Electrification as a Long-Haul Tractor Idling Alternative", TRB 2004 Annual Meeting CD-ROM, December 2003.

[138] Business Wire, "Navistar's Fleetrite Auxiliary Power Unit To Help Fleet Truck Fuel Consumption", July 31 2008.

[139] Business Wire, "Bergstrom, Firefly Energy Agree to Test, Co-Market NITE™ Sleeper Cab Cooling System Powered by Oasis™ Group 31 Battery", January 29, 2008.

[140] U.S. Census Bureau, *2002 Vehicle Inventory and Use Survey,* December 2004.

[141] *Ibid.*

APUs cost $9,000[142] and battery systems cost $3,500.[143] It is assumed that both types of system require replacement, on average, after 10 years, either because the system wears out or because the sleeper cab is scrapped. In addition, it is assumed that battery packs have to be replaced every two years, at a cost of $100. In addition, it is assumed that all states will provide appropriate weight allowances for APUs and battery packs, so that these devices have no effect on the maximum payload that can be carried. Finally, for simplicity, the small increase in fuel consumption due to increased vehicle weight is ignored.

9.7 Truck-Only Toll Lanes

Vehicle Costs: Annual fuel consumption savings for commercial vehicles using truck-only toll lanes is multiplied by forecast diesel fuel prices to obtain estimates of cost savings.

Implementation Costs: The Georgia Department of Transportation (GDOT) completed a Statewide Truck Lanes Needs Identification Study in April 2008.[144] Table 22 of this report presented total implementation cost estimates and annual operations and maintenance cost estimates. Phase I of the Atlanta system, which covered 25 percent of interstate VMT in the Atlanta region cost $7.479 billion. Phase II covered 44 percent of interstate VMT at a total cost of $13.209 billion. These figures were translated into implementation cost per vehicle mile traveled with all LH (large, high-density regions) implementing systems similar to Atlanta Phase II ($0.61/VMT) and all LL (large, low-density regions) implementing systems similar to Atlanta Phase I ($0.20/VMT).

9.8 Urban Consolidation Centers

Vehicle Costs: A small number of Urban Consolidation Centers (UCC) have been implemented in Europe and Asia, but none in the United States. The literature contains effectiveness information from six of these centers,[145],[146] including one that was

[142] *Bulk Transporter, op.cit.*

[143] California Air Resources Board, "Alternatives to Primary Engine Idling", undated.

[144] www.dot.state.ga.us/INFORMATIONCENTER/PROGRAMS/studies/trucklanestudy.

[145] Michael Brown, et al., *Urban Freight Consolidation Centres,* Final Report, University of Westminster, prepared for the (British) Department for Transport, November 2, 2005.

[146] Kristof Carlier, Developments in Urban Transport Since the 2001 White Paper, Annex XVI of *Assessment of the Contribution of the TEN and Other Transport Policy Measures to the Mid-Term*

(Footnote continued on next page...)

unsuccessful and has been closed, and one, at Heathrow Airport, that serves only the airport and not an entire urban area. Estimates of reductions in truck VMT and in fuel consumption are fairly limited; however, it has been estimated that the UCC in Bremen, Germany, results in monthly savings of about 6,000 truck-miles of travel and 250 gallons of diesel fuel.[147] Unfortunately, the source does not relate these figures to total truck VMT or truck fuel consumption.

In the United States, 8.6 percent of the VMT of combination trucks is operated by Less-Than-Truckload (LTL) carriers.[148] For purposes of analysis, it was conservatively assumed that, in large urbanized areas half of this VMT represents operations that could be served by a UCC, and that use of such centers would reduce the VMT of affected operations by 10 percent in large high-density areas and by eight percent in large low-density areas. Similarly, it was conservatively assumed that, in medium-sized high-density urbanized areas, 40 percent of LTL operations could be served by a UCC, resulting in a six percent reduction in the VMT of affected operations. It was assumed that only large high-density urbanized areas would be served by UCCs under a Level A implementation, but that all three of these area types would be served under a Level C implementation.

Implementation Costs: The literature contains no information on the cost of building UCCs. However, these costs are clearly related to the size (population) of the area that they are designed to serve. For purposes of analysis, development costs were assumed to be $5 million per million persons in the area.

Implementation of the White Paper on European Transport Policy for 2010, Final Report, DG TREN, European Commission, October 28, 2005.

[147] *Ibid.*, page 12.

[148] U.S. Census Bureau, *2002 Vehicle Inventory and Use Survey,* December 2004.

Appendix D

Moving Cooler Data Tables

Table D.1 Annual Reductions (Level A, B, and C)
Short-Term: 2015, 2020

Annual Reductions (Short Term)	**Expanded Current Practice GHG Reduction (mmt)**		**More Aggressive GHG Reduction (mmt)**		**Maximum GHG Reduction (mmt)**	
Strategy Description	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**
Pricing						
CBD/Activity Center on-street parking	0.00	0.45	0.69	1.14	0.97	1.21
Tax/higher tax on free private parking	N/A	N/A	0.00	0.00	0.00	0.98
Residential parking permits	N/A	N/A	0.00	0.00	0.00	1.30
Cordon Pricing	0.00	0.63	0.00	0.63	0.65	1.33
Congestion Pricing	0.00	5.45	0.00	10.54	0.00	18.01
Intercity Tolls	0.00	0.00	0.00	1.71	2.92	2.84
PAYD Insurance	20.49	20.14	20.37	39.43	20.37	56.29
VMT fee	0.00	8.42	0.00	25.25	0.00	101.01
Carbon Pricing (VMT impact)[b]	-	10.62	-	32.15	-	135.88
Carbon Pricing (Fuel economy impact)	-	24.36	-	70.30	-	236.27
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	0.00	0.97	0.00	6.69	0.00	11.48
Combined Pedestrian	0.94	2.07	2.17	4.76	2.88	6.32
Combined Bicycle	0.00	0.86	0.00	1.49	0.00	2.47
Public Transportation Strategies						
Transit Fare Measures	0.45	0.50	0.79	0.89	2.09	2.04
Transit Frequency/LOS/Extent	0.28	0.66	0.76	1.11	1.86	2.46
Urban Transit Expansion	1.24	2.03	2.50	4.04	4.93	7.99
Intercity Passenger Rail	1.36	1.30	1.37	1.32	1.39	1.56
High-Speed Passenger Rail	0.00	0.60	0.00	0.92	0.96	2.15
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	0.55	1.26	0.87	1.76	3.46	4.06
HOV Lanes (24-hour applicability)	0.00	0.00	0.00	0.04	0.05	0.04
Car-Sharing	0.49	0.84	0.97	2.30	3.46	4.59
Employer-Based Commute Strategies	0.00	7.48	0.00	14.99	0.00	35.49

Note: the term "Annual Reductions" refers to snapshot GHG reductions for specific horizon years.

Table D.1 Annual Reductions (Level A, B, and C) (continued)
Short-Term: 2015, 2020

Annual Reductions (Short Term)	Expanded Current Practice GHG Reduction (mmt)		More Aggressive GHG Reduction (mmt)		Maximum GHG Reduction (mmt)	
Strategy Description	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**
Regulatory Strategies						
Nonmotorized Zones	0.00	0.01	0.02	0.07	0.04	0.10
Urban Parking Restrictions	0.00	0.00	0.00	0.50	0.99	3.45
Speed Limit Reductions	0.00	12.44	13.00	40.31	21.42	50.65
System Operations and Management Strategies						
EcoDriving	3.45	7.57	6.90	15.13	17.24	37.84
Ramp Metering	0.16	0.07	0.22	0.10	0.23	0.18
Variable Message Signs	0.01	0.01	0.02	0.02	0.02	0.02
Active Traffic Management	N/A	N/A	0.39	0.12	0.48	0.10
Integrated Corridor Management	N/A	N/A	0.39	0.12	0.48	0.10
Incident Management	0.35	0.13	0.60	0.12	0.72	0.08
Road Weather Management	0.01	0.00	0.02	0.01	0.06	0.03
Signal Control Management	0.02	0.01	0.04	0.02	0.07	0.04
Traveler Information	0.02	0.01	0.04	0.01	0.05	0.01
Vehicle Infrastructure Integration	0.16	0.20	0.24	0.30	0.48	0.48
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	0.58	0.91	1.13	1.77	2.48	3.88
Capacity Expansion [c]	0.86	1.35	1.68	2.63	3.36	5.25
Multimodal Freight Strategies						
Rail Capacity Improvements	0.12	0.50	0.18	0.75	0.37	1.50
Marine System Improvements	0.04	0.10	0.06	0.15	0.08	0.22
Shipping Container Permits	0.05	0.14	0.08	0.22	0.19	0.25
LCV Permits	0.06	0.16	0.13	0.33	0.32	0.42
WIM Screening	0.00	0.01	0.01	0.02	0.02	0.02
Weigh Station Bypass	0.01	0.02	0.01	0.04	0.03	0.04
Truck Stop Electrification	0.08	0.21	0.26	0.68	0.99	1.30
Truck APUs	0.31	2.79	0.46	3.66	0.77	5.05
Truck-Only Toll Lanes	0.00	0.25	0.00	0.63	0.00	1.01
Urban Consolidation Centers	0.03	0.09	0.05	0.14	0.12	0.16

Table D.2 Annual Reductions (Level A, B, and C)
Long-Term: 2030, 2040, 2050

Annual Reductions (Long-Term) Strategy Description	Expanded Current Practice GHG Reduction (mmt)			More Aggressive GHG Reduction (mmt)			Maximum GHG Reduction (mmt)		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Pricing									
CBD/Activity Center on-street parking	1.15	1.10	1.04	1.15	1.10	1.04	1.15	1.10	1.04
Tax/higher tax on free private parking	N/A	N/A	N/A	0.67	0.64	0.61	0.93	0.89	0.84
Residential parking permits	N/A	N/A	N/A	0.77	0.73	0.70	1.54	1.47	1.39
Cordon Pricing	1.44	2.90	2.90	2.29	3.04	2.90	3.04	3.04	2.90
Congestion Pricing	18.18	18.56	17.69	34.72	36.61	35.04	42.86	40.88	39.13
Intercity Tolls	1.08	1.03	0.98	1.62	1.54	1.47	2.70	2.57	2.45
PAYD Insurance	19.39	19.37	18.61	47.23	46.66	44.37	62.98	62.21	59.16
VMT fee	8.09	7.78	7.46	24.28	23.33	22.39	97.13	93.32	89.58
Carbon Pricing (VMT impact)[b]	10.14	9.66	9.20	31.94	29.59	28.28	135.72	134.01	132.25
Carbon Pricing (Fuel economy impact)	36.74	37.94	38.63	103.90	105.83	106.38	322.54	325.48	325.41
Land Use and Smart Growth Strategies/Nonmotorized Strategies									
Combined Land Use	3.23	6.65	9.87	22.27	34.36	45.01	38.20	57.06	73.44
Combined Pedestrian	2.18	2.08	1.97	5.03	4.78	4.55	6.68	6.36	6.04
Combined Bicycle	2.04	1.94	1.84	2.08	2.00	1.69	6.11	5.81	5.53
Public Transportation Strategies									
Transit Fare Measures	0.50	0.47	0.45	0.87	0.83	0.79	1.94	1.85	1.76
Transit Frequency/LOS/Extent	1.13	1.53	2.03	1.68	2.35	3.36	3.56	5.35	9.10
Urban Transit Expansion	3.57	5.05	6.57	7.00	9.77	12.33	14.09	20.16	26.14
Intercity Passenger Rail	1.16	1.03	0.90	1.20	1.05	0.92	2.29	2.13	1.97
High-Speed Passenger Rail	1.93	2.88	3.52	2.92	3.64	4.44	3.93	4.88	5.98
HOV/Carpool/Vanpool/Commute Strategies									
HOV Lanes	1.44	1.38	1.31	1.83	1.74	1.66	3.86	3.67	3.50
HOV Lanes (24-hour applicability)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Car-Sharing	1.09	1.04	0.99	2.18	2.08	1.97	4.37	4.15	3.95
Employer-Based Commute Strategies	7.40	7.03	6.69	14.26	13.56	12.90	33.76	32.10	30.53
Regulatory Strategies									
Nonmotorized Zones	0.05	0.06	0.06	0.13	0.13	0.12	0.19	0.19	0.18
Urban Parking Restrictions	1.03	3.66	6.61	3.57	8.20	13.05	8.93	13.78	18.13
Speed Limit Reductions	43.75	42.31	40.97	75.38	73.20	71.36	76.04	73.90	72.11

Note: the term “Annual Reductions” refers to snapshot GHG reductions for specific horizon years.

Table D.2 Annual Reductions (Level A, B, and C) (continued)
Long-Term: 2030, 2040, 2050

Annual Reductions (Long-Term)	Expanded Current Practice GHG Reduction (mmt)			More Aggressive GHG Reduction (mmt)			Maximum GHG Reduction (mmt)		
Strategy Description	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
System Operations and Management Strategies									
EcoDriving	17.92	27.54	36.17	29.44	42.62	54.25	49.91	57.96	65.10
Ramp Metering	0.21	1.09	2.42	0.11	3.57	6.57	0.11	3.87	7.23
Variable Message Signs	0.01	0.07	0.17	0.02	0.10	0.23	0.02	0.10	0.24
Active Traffic Management	N/A	N/A	N/A	0.38	1.83	4.13	0.25	3.40	6.93
Integrated Corridor Management	N/A	N/A	N/A	0.38	1.83	4.13	0.25	3.40	6.93
Incident Management	0.43	2.29	5.25	0.52	2.83	6.69	0.52	3.20	7.40
Road Weather Management	0.02	0.02	0.02	0.04	0.03	0.04	0.07	0.05	0.06
Signal Control Management	0.03	0.12	0.26	0.06	0.87	1.39	0.08	1.83	2.52
Traveler Information	0.03	0.16	0.38	0.05	1.42	2.34	0.04	1.48	2.42
Vehicle Infrastructure Integration	0.10	3.57	6.13	0.14	0.54	2.23	0.11	0.49	0.71
Bottleneck Relief and Capacity Expansion Strategies									
Bottleneck Relief [c]	0.99	(0.50)	(3.79)	2.87	(0.98)	(4.97)	4.24	(2.14)	(10.00)
Capacity Expansion [c]	1.47	(0.74)	(2.15)	1.93	(1.45)	(7.37)	5.74	(2.90)	(12.74)
Multimodal Freight Strategies									
Rail Capacity Improvements	1.50	1.54	1.50	2.25	2.32	2.25	4.51	4.63	4.50
Marine System Improvements	0.17	0.17	0.17	0.26	0.26	0.26	0.39	0.39	0.39
Shipping Container Permits	0.24	0.23	0.23	0.24	0.23	0.23	0.24	0.23	0.23
LCV Permits	0.27	0.26	0.25	0.36	0.35	0.34	0.41	0.39	0.38
WIM Screening	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Weigh Station Bypass	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Truck Stop Electrification	0.35	0.34	0.33	0.74	0.72	0.70	1.26	1.23	1.19
Truck APUs	5.01	4.77	4.23	5.01	4.77	4.23	5.01	4.77	4.23
Truck-Only Toll Lanes	0.74	0.85	0.97	1.84	2.12	2.43	3.33	3.88	4.46
Urban Consolidation Centers	0.17	0.19	0.20	0.24	0.27	0.30	0.26	0.28	0.31

Table D.3 Percent Annual Reductions from Baseline (Level A, B, and C)
Short-Term: 2015, 2020

Annual Percent Reductions from Baseline (Short Term)	Expanded Current Practice Annual Percent Reduction		More Aggressive Annual Percent Reduction		Maximum Annual Percent Reduction	
Strategy Description	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**
Pricing						
CBD/Activity Center on-street parking	0.00%	0.03%	0.04%	0.07%	0.06%	0.07%
Tax/higher tax on free private parking	N/A	N/A	0.00%	0.00%	0.00%	0.06%
Residential parking permits	N/A	N/A	0.00%	0.00%	0.00%	0.08%
Cordon Pricing	0.00%	0.04%	0.00%	0.04%	0.04%	0.08%
Congestion Pricing	0.00%	0.32%	0.00%	0.62%	0.00%	1.05%
Intercity Tolls	0.00%	0.00%	0.00%	0.10%	0.17%	0.17%
PAYD Insurance	1.18%	1.18%	1.17%	2.30%	1.17%	3.29%
VMT fee	0.00%	0.49%	0.00%	1.47%	0.00%	5.90%
Carbon Pricing (VMT impact)[b]	-	0.62%	-	1.88%	-	7.94%
Carbon Pricing (Fuel economy impact)	-	1.42%	-	4.11%	-	13.80%
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	0.00%	0.06%	0.00%	0.39%	0.00%	0.67%
Combined Pedestrian	0.05%	0.12%	0.13%	0.28%	0.17%	0.37%
Combined Bicycle	0.00%	0.05%	0.00%	0.09%	0.00%	0.14%
Public Transportation Strategies						
Transit Fare Measures	0.03%	0.03%	0.05%	0.05%	0.12%	0.12%
Transit Frequency/LOS/Extent	0.02%	0.04%	0.04%	0.06%	0.11%	0.14%
Urban Transit Expansion	0.07%	0.12%	0.14%	0.24%	0.28%	0.47%
Intercity Passenger Rail	0.08%	0.08%	0.08%	0.08%	0.08%	0.09%
High-Speed Passenger Rail	0.00%	0.04%	0.00%	0.05%	0.06%	0.13%
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	0.03%	0.07%	0.05%	0.10%	0.20%	0.24%
HOV Lanes (24-hour applicability)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Car-Sharing	0.03%	0.05%	0.06%	0.13%	0.20%	0.27%
Employer-Based Commute Strategies	0.00%	0.44%	0.00%	0.88%	0.00%	2.07%
Regulatory Strategies						
Nonmotorized Zones	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
Urban Parking Restrictions	0.00%	0.00%	0.00%	0.03%	0.06%	0.20%
Speed Limit Reductions	0.00%	0.73%	0.75%	2.35%	1.24%	2.96%

Note: the term "Annual Reductions" refers to snapshot GHG reductions for specific horizon years.

Table D.3 Percent Annual Reductions from Baseline (Level A, B, and C) (continued)
Short-Term: 2015, 2020

Annual Percent Reductions from Baseline (Short Term) Strategy Description	Expanded Current Practice Annual Percent Reduction 2015	2020	More Aggressive Annual Percent Reduction 2015	2020	Maximum Annual Percent Reduction 2015	2020
System Operations and Management Strategies						
EcoDriving	0.20%	0.44%	0.40%	0.88%	0.99%	2.21%
Ramp Metering	0.01%	0.00%	0.01%	0.01%	0.01%	0.01%
Variable Message Signs	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Active Traffic Management	N/A	N/A	0.02%	0.01%	0.03%	0.01%
Integrated Corridor Management	N/A	N/A	0.02%	0.01%	0.03%	0.01%
Incident Management	0.02%	0.01%	0.03%	0.01%	0.04%	0.00%
Road Weather Management	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Signal Control Management	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Traveler Information	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Vehicle Infrastructure Integration	0.01%	0.01%	0.01%	0.02%	0.03%	0.03%
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	0.03%	0.05%	0.07%	0.10%	0.14%	0.23%
Capacity Expansion [c]	0.05%	0.08%	0.10%	0.15%	0.19%	0.31%
Multimodal Freight Strategies						
Rail Capacity Improvements	0.01%	0.03%	0.01%	0.04%	0.02%	0.09%
Marine System Improvements	0.00%	0.01%	0.00%	0.01%	0.00%	0.01%
Shipping Container Permits	0.00%	0.01%	0.00%	0.01%	0.01%	0.01%
LCV Permits	0.00%	0.01%	0.01%	0.02%	0.02%	0.02%
WIM Screening	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Weigh Station Bypass	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Truck Stop Electrification	0.00%	0.01%	0.01%	0.04%	0.06%	0.08%
Truck APUs	0.02%	0.10%	0.03%	0.16%	0.04%	0.30%
Truck-Only Toll Lanes	0.00%	0.01%	0.00%	0.04%	0.00%	0.06%
Urban Consolidation Centers	0.00%	0.01%	0.00%	0.01%	0.01%	0.01%

Table D.4 Percent Annual Reductions from Baseline (Level A, B, and C)
Long-Term: 2030, 2040, 2050

Annual Percent Reductions from Baseline (Long-Term)	Expanded Current Practice Annual Percent Reduction			More Aggressive Annual Percent Reduction			Maximum Annual Percent Reduction		
Strategy Description	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Pricing									
CBD/Activity Center on-street parking	0.07%	0.07%	0.06%	0.07%	0.07%	0.06%	0.07%	0.07%	0.06%
Tax/higher tax on free private parking	N/A	N/A	N/A	0.04%	0.04%	0.04%	0.06%	0.05%	0.05%
Residential parking permits	N/A	N/A	N/A	0.05%	0.04%	0.04%	0.09%	0.09%	0.08%
Cordon Pricing	0.09%	0.17%	0.18%	0.14%	0.18%	0.18%	0.18%	0.18%	0.18%
Congestion Pricing	1.08%	1.11%	1.07%	2.06%	2.19%	2.12%	2.54%	2.45%	2.37%
Intercity Tolls	0.06%	0.06%	0.06%	0.10%	0.09%	0.09%	0.16%	0.15%	0.15%
PAYD Insurance	1.15%	1.16%	1.13%	2.80%	2.80%	2.68%	3.73%	3.73%	3.58%
VMT fee	0.48%	0.47%	0.45%	1.44%	1.40%	1.35%	5.75%	5.59%	5.42%
Carbon Pricing (VMT impact)[b]	0.60%	0.58%	0.56%	1.83%	1.77%	1.71%	8.16%	8.09%	8.00%
Carbon Pricing (Fuel economy impact)	2.18%	2.27%	2.34%	6.15%	6.40%	6.56%	19.10%	19.51%	19.68%
Land Use and Smart Growth Strategies/Nonmotorized Strategies									
Combined Land Use	0.19%	0.40%	0.60%	1.32%	2.06%	2.72%	2.26%	3.42%	4.44%
Combined Pedestrian	0.13%	0.12%	0.12%	0.30%	0.29%	0.28%	0.40%	0.38%	0.37%
Combined Bicycle	0.12%	0.12%	0.11%	0.12%	0.12%	0.10%	0.36%	0.35%	0.33%
Public Transportation Strategies									
Transit Fare Measures	0.03%	0.03%	0.03%	0.05%	0.05%	0.05%	0.12%	0.11%	0.11%
Transit Frequency/LOS/Extent	0.07%	0.09%	0.12%	0.10%	0.14%	0.20%	0.21%	0.32%	0.55%
Urban Transit Expansion	0.21%	0.30%	0.40%	0.41%	0.59%	0.75%	0.83%	1.21%	1.58%
Intercity Passenger Rail	0.07%	0.06%	0.05%	0.07%	0.06%	0.06%	0.14%	0.13%	0.12%
High-Speed Passenger Rail	0.11%	0.17%	0.21%	0.17%	0.22%	0.27%	0.23%	0.29%	0.36%
HOV/Carpool/Vanpool/Commute Strategies									
HOV Lanes	0.09%	0.08%	0.08%	0.11%	0.10%	0.10%	0.23%	0.22%	0.21%
HOV Lanes (24-hour applicability)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Car-Sharing	0.06%	0.06%	0.06%	0.13%	0.12%	0.12%	0.26%	0.25%	0.24%
Employer-Based Commute Strategies	0.44%	0.42%	0.40%	0.84%	0.81%	0.78%	2.00%	1.92%	1.85%

Note: the term "Annual Reductions" refers to snapshot GHG reductions for specific horizon years.

Table D.4 Percent Annual Reductions from Baseline (Level A, B, and C) (continued)
Long-Term: 2030, 2040, 2050

Annual Percent Reductions from Baseline (Long-Term) Strategy Description	Expanded Current Practice Annual Percent Reduction 2030	2040	2050	More Aggressive Annual Percent Reduction 2030	2040	2050	Maximum Annual Percent Reduction 2030	2040	2050
Regulatory Strategies									
Nonmotorized Zones	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
Urban Parking Restrictions	0.06%	0.22%	0.40%	0.21%	0.49%	0.79%	0.53%	0.83%	1.10%
Speed Limit Reductions	2.59%	2.54%	2.48%	4.46%	4.39%	4.32%	4.50%	4.43%	4.36%
System Operations and Management Strategies									
EcoDriving	1.06%	1.65%	2.19%	1.74%	2.55%	3.28%	2.96%	3.47%	3.94%
Ramp Metering	0.01%	0.07%	0.15%	0.01%	0.21%	0.40%	0.01%	0.23%	0.44%
Variable Message Signs	0.00%	0.00%	0.01%	0.00%	0.01%	0.01%	0.00%	0.01%	0.01%
Active Traffic Management	N/A	N/A	N/A	0.02%	0.11%	0.25%	0.02%	0.20%	0.42%
Integrated Corridor Management	N/A	N/A	N/A	0.02%	0.11%	0.25%	0.02%	0.20%	0.42%
Incident Management	0.03%	0.14%	0.32%	0.03%	0.17%	0.40%	0.03%	0.19%	0.45%
Road Weather Management	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Signal Control Management	0.00%	0.01%	0.02%	0.00%	0.05%	0.08%	0.00%	0.11%	0.15%
Traveler Information	0.00%	0.01%	0.02%	0.00%	0.08%	0.14%	0.00%	0.09%	0.15%
Vehicle Infrastructure Integration	0.01%	0.21%	0.37%	0.01%	0.03%	0.13%	0.01%	0.03%	0.04%
Bottleneck Relief and Capacity Expansion Strategies									
Bottleneck Relief [c]	0.06%	-0.03%	-0.17%	0.11%	-0.06%	-0.30%	0.25%	-0.13%	-0.66%
Capacity Expansion [c]	0.09%	-0.04%	-0.25%	0.17%	-0.09%	-0.45%	0.34%	-0.17%	-0.89%
Multimodal Freight Strategies									
Rail Capacity Improvements	0.09%	0.09%	0.09%	0.13%	0.14%	0.14%	0.27%	0.28%	0.27%
Marine System Improvements	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
Shipping Container Permits	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
LCV Permits	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
WIM Screening	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Weigh Station Bypass	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Truck Stop Electrification	0.02%	0.02%	0.02%	0.04%	0.04%	0.04%	0.07%	0.07%	0.07%
Truck APUs	0.30%	0.29%	0.26%	0.30%	0.29%	0.26%	0.30%	0.29%	0.26%
Truck-Only Toll Lanes	0.04%	0.05%	0.06%	0.11%	0.13%	0.15%	0.20%	0.23%	0.27%
Urban Consolidation Centers	0.01%	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%

Table D.5 Percent Annual Reductions from 2005 (Level A, B, and C)
Short-Term: 2015, 2020

Annual Percent Reductions from 2005 (Short Term) Strategy Description	Expanded Current Practice Annual Percent Reduction 2015	2020	More Aggressive Annual Percent Reduction 2015	2020	Maximum Annual Percent Reduction 2015	2020
Pricing						
CBD/Activity Center on-street parking	0.00%	0.03%	0.04%	0.07%	0.06%	0.07%
Tax/higher tax on free private parking	N/A	N/A	0.00%	0.00%	0.00%	0.06%
Residential parking permits	N/A	N/A	0.00%	0.00%	0.00%	0.08%
Cordon Pricing	0.00%	0.04%	0.00%	0.04%	0.04%	0.08%
Congestion Pricing	0.00%	0.33%	0.00%	0.64%	0.00%	1.09%
Intercity Tolls	0.00%	0.00%	0.00%	0.10%	0.18%	0.17%
PAYD Insurance	1.24%	1.22%	1.24%	2.39%	1.24%	3.42%
VMT fee	0.00%	0.51%	0.00%	1.53%	0.00%	6.13%
Carbon Pricing (VMT impact)[b]	-	0.64%	-	1.95%	-	8.25%
Carbon Pricing (Fuel economy impact)	-	1.48%	-	4.27%	-	14.34%
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	0.00%	0.06%	0.00%	0.41%	0.00%	0.70%
Combined Pedestrian	0.06%	0.13%	0.13%	0.29%	0.17%	0.38%
Combined Bicycle	0.00%	0.05%	0.00%	0.09%	0.00%	0.15%
Public Transportation Strategies						
Transit Fare Measures	0.03%	0.03%	0.05%	0.05%	0.13%	0.12%
Transit Frequency/LOS/Extent	0.02%	0.04%	0.05%	0.07%	0.11%	0.15%
Urban Transit Expansion	0.08%	0.12%	0.15%	0.24%	0.30%	0.48%
Intercity Passenger Rail	0.08%	0.08%	0.08%	0.08%	0.08%	0.09%
High-Speed Passenger Rail	0.00%	0.04%	0.00%	0.06%	0.06%	0.13%
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	0.03%	0.08%	0.05%	0.11%	0.21%	0.25%
HOV Lanes (24-hour applicability)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Car-Sharing	0.03%	0.05%	0.06%	0.14%	0.21%	0.28%
Employer-Based Commute Strategies	0.00%	0.45%	0.00%	0.91%	0.00%	2.15%
Regulatory Strategies						
Nonmotorized Zones	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
Urban Parking Restrictions	0.00%	0.00%	0.00%	0.03%	0.06%	0.21%
Speed Limit Reductions	0.00%	0.76%	0.79%	2.45%	1.30%	3.08%

Note: the term "Annual Reductions" refers to snapshot GHG reductions for specific horizon years.

Table D.5 Percent Annual Reductions from 2005 (Level A, B, and C) (continued)
Short-Term: 2015, 2020

Annual Percent Reductions from 2005 (Short Term)	Expanded Current Practice Annual Percent Reduction		More Aggressive Annual Percent Reduction		Maximum Annual Percent Reduction	
Strategy Description	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**
System Operations and Management Strategies						
EcoDriving	0.21%	0.46%	0.42%	0.92%	1.05%	2.30%
Ramp Metering	0.01%	0.00%	0.01%	0.01%	0.01%	0.01%
Variable Message Signs	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Active Traffic Management	N/A	N/A	0.02%	0.01%	0.03%	0.01%
Integrated Corridor Management	N/A	N/A	0.02%	0.01%	0.03%	0.01%
Incident Management	0.02%	0.01%	0.04%	0.01%	0.04%	0.01%
Road Weather Management	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Signal Control Management	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Traveler Information	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Vehicle Infrastructure Integration	0.01%	0.01%	0.01%	0.02%	0.03%	0.03%
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	0.04%	0.06%	0.07%	0.11%	0.15%	0.24%
Capacity Expansion [c]	0.05%	0.08%	0.10%	0.16%	0.20%	0.32%
Multimodal Freight Strategies						
Rail Capacity Improvements	0.01%	0.03%	0.01%	0.05%	0.02%	0.09%
Marine System Improvements	0.00%	0.01%	0.00%	0.01%	0.01%	0.01%
Shipping Container Permits	0.00%	0.01%	0.01%	0.01%	0.01%	0.02%
LCV Permits	0.00%	0.01%	0.01%	0.02%	0.02%	0.03%
WIM Screening	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Weigh Station Bypass	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Truck Stop Electrification	0.00%	0.01%	0.02%	0.04%	0.06%	0.08%
Truck APUs	0.02%	0.11%	0.03%	0.16%	0.05%	0.31%
Truck-Only Toll Lanes	0.00%	0.02%	0.00%	0.04%	0.00%	0.06%
Urban Consolidation Centers	0.00%	0.01%	0.00%	0.01%	0.01%	0.01%

Table D.6 Percent Annual Reductions from 2005 (Level A, B, and C)
Long-Term: 2030, 2040, 2050

Annual Percent Reductions from 2005 (Long-Term)	Expanded Current Practice Annual Percent Reduction			More Aggressive Annual Percent Reduction			Maximum Annual Percent Reduction		
Strategy Description	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Pricing									
CBD/Activity Center on-street parking	0.07%	0.07%	0.06%	0.07%	0.07%	0.06%	0.07%	0.07%	0.06%
Tax/higher tax on free private parking	N/A	N/A	N/A	0.04%	0.04%	0.04%	0.06%	0.05%	0.05%
Residential parking permits	N/A	N/A	N/A	0.05%	0.04%	0.04%	0.09%	0.09%	0.08%
Cordon Pricing	0.09%	0.18%	0.18%	0.14%	0.18%	0.18%	0.18%	0.18%	0.18%
Congestion Pricing	1.10%	1.13%	1.07%	2.11%	2.22%	2.13%	2.60%	2.48%	2.38%
Intercity Tolls	0.07%	0.06%	0.06%	0.10%	0.09%	0.09%	0.16%	0.16%	0.15%
PAYD Insurance	1.18%	1.18%	1.13%	2.87%	2.83%	2.69%	3.82%	3.78%	3.59%
VMT fee	0.49%	0.47%	0.45%	1.47%	1.42%	1.36%	5.90%	5.67%	5.44%
Carbon Pricing (VMT impact)[b]	0.60%	0.57%	0.54%	1.83%	1.75%	1.67%	8.14%	7.98%	7.82%
Carbon Pricing (Fuel economy impact)	2.17%	2.24%	2.28%	6.14%	6.31%	6.41%	19.07%	19.24%	19.24%
Land Use and Smart Growth Strategies/Nonmotorized Strategies									
Combined Land Use	0.20%	0.40%	0.60%	1.35%	2.09%	2.73%	2.32%	3.46%	4.46%
Combined Pedestrian	0.13%	0.13%	0.12%	0.31%	0.29%	0.28%	0.41%	0.39%	0.37%
Combined Bicycle	0.12%	0.12%	0.11%	0.13%	0.12%	0.10%	0.37%	0.35%	0.34%
Public Transportation Strategies									
Transit Fare Measures	0.03%	0.03%	0.03%	0.05%	0.05%	0.05%	0.12%	0.11%	0.11%
Transit Frequency/LOS/Extent	0.07%	0.09%	0.12%	0.10%	0.14%	0.20%	0.22%	0.32%	0.55%
Urban Transit Expansion	0.22%	0.31%	0.40%	0.42%	0.59%	0.75%	0.86%	1.22%	1.59%
Intercity Passenger Rail	0.07%	0.06%	0.05%	0.07%	0.06%	0.06%	0.14%	0.13%	0.12%
High-Speed Passenger Rail	0.12%	0.18%	0.21%	0.18%	0.22%	0.27%	0.24%	0.30%	0.36%
HOV/Carpool/Vanpool/Commute Strategies									
HOV Lanes	0.09%	0.08%	0.08%	0.11%	0.11%	0.10%	0.23%	0.22%	0.21%
HOV Lanes (24-hour applicability)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Car-Sharing	0.07%	0.06%	0.06%	0.13%	0.13%	0.12%	0.27%	0.25%	0.24%
Employer-Based Commute Strategies	0.45%	0.43%	0.41%	0.87%	0.82%	0.78%	2.05%	1.95%	1.85%

Note: the term "Annual Reductions" refers to snapshot GHG reductions for specific horizon years.

Table D.6 Percent Annual Reductions from 2005 (Level A, B, and C) (continued)

Long-Term: 2030, 2040, 2050

Annual Percent Reductions from 2005 (Long-Term)	Expanded Current Practice Annual Percent Reduction			More Aggressive Annual Percent Reduction			Maximum Annual Percent Reduction		
Strategy Description	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Regulatory Strategies									
Nonmotorized Zones	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
Urban Parking Restrictions	0.06%	0.22%	0.40%	0.22%	0.50%	0.79%	0.54%	0.84%	1.10%
Speed Limit Reductions	2.66%	2.57%	2.49%	4.58%	4.44%	4.33%	4.62%	4.49%	4.38%
System Operations and Management Strategies									
EcoDriving	1.09%	1.67%	2.20%	1.79%	2.59%	3.29%	3.03%	3.52%	3.95%
Ramp Metering	0.01%	0.07%	0.15%	0.01%	0.22%	0.40%	0.01%	0.24%	0.44%
Variable Message Signs	0.00%	0.00%	0.01%	0.00%	0.01%	0.01%	0.00%	0.01%	0.01%
Active Traffic Management	N/A	N/A	N/A	0.02%	0.11%	0.25%	0.02%	0.21%	0.42%
Integrated Corridor Management	N/A	N/A	N/A	0.02%	0.11%	0.25%	0.02%	0.21%	0.42%
Incident Management	0.03%	0.14%	0.32%	0.03%	0.17%	0.41%	0.03%	0.19%	0.45%
Road Weather Management	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Signal Control Management	0.00%	0.01%	0.02%	0.00%	0.05%	0.08%	0.01%	0.11%	0.15%
Traveler Information	0.00%	0.01%	0.02%	0.00%	0.09%	0.14%	0.00%	0.09%	0.15%
Vehicle Infrastructure Integration	0.01%	0.22%	0.37%	0.01%	0.03%	0.14%	0.01%	0.03%	0.04%
Bottleneck Relief and Capacity Expansion Strategies									
Bottleneck Relief [c]	0.06%	-0.03%	-0.17%	0.12%	-0.06%	-0.30%	0.26%	-0.13%	-0.66%
Capacity Expansion [c]	0.09%	-0.05%	-0.25%	0.17%	-0.09%	-0.45%	0.35%	-0.18%	-0.90%
Multimodal Freight Strategies									
Rail Capacity Improvements	0.09%	0.09%	0.09%	0.14%	0.14%	0.14%	0.27%	0.28%	0.27%
Marine System Improvements	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
Shipping Container Permits	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
LCV Permits	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
WIM Screening	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Weigh Station Bypass	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Truck Stop Electrification	0.02%	0.02%	0.02%	0.05%	0.04%	0.04%	0.08%	0.07%	0.07%
Truck APUs	0.30%	0.29%	0.26%	0.30%	0.29%	0.26%	0.30%	0.29%	0.26%
Truck-Only Toll Lanes	0.04%	0.05%	0.06%	0.11%	0.13%	0.15%	0.20%	0.24%	0.27%
Urban Consolidation Centers	0.01%	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%

Table D.7 Cumulative Reductions (Level A, B, and C)
2020, 2030, 2050

Cumulative GHG Reduction Strategy Description	Expanded Current Practice Cumulative GHG Reduction (mmt)			More Aggressive Cumulative GHG Reduction (mmt)			Maximum Cumulative GHG Reduction (mmt)		
	2010-2020	**2010-2030**	**2010-2050**	**2010-2020**	**2010-2030**	**2010-2050**	**2010-2020**	**2010-2030**	**2010-2050**
Pricing									
CBD/Activity Center on-street parking	1.36	11.04	32.92	7.32	19.07	40.95	8.52	20.31	42.19
Tax/higher tax on free private parking	N/A	N/A	N/A	0.00	5.68	18.38	3.95	13.48	31.17
Residential parking permits	N/A	N/A	N/A	0.00	5.54	20.17	3.26	19.03	48.30
Cordon Pricing	1.91	13.94	66.41	1.91	17.11	75.69	7.27	30.85	91.61
Congestion Pricing	13.68	139.16	509.64	26.51	297.08	1020.74	58.08	425.33	1241.40
Intercity Tolls	0.00	9.94	30.47	6.88	23.48	54.28	26.12	53.79	105.13
PAYD Insurance	204.55	401.89	788.52	286.74	745.38	1676.54	370.35	990.05	2231.60
VMT fee	42.39	124.81	280.05	127.17	374.43	840.14	508.69	1497.73	3360.55
Carbon Pricing (VMT impact)[b]	53.58	157.16	349.98	161.60	476.66	1067.24	670.08	2046.31	4744.04
Carbon Pricing (Fuel economy impact)	92.93	421.62	1180.55	270.32	1205.98	3342.51	950.54	3935.99	10442.29
Land Use and Smart Growth Strategies/Nonmotorized Strategies									
Combined Land Use	2.44	24.78	159.96	16.81	170.74	865.17	28.83	292.82	1445.08
Combined Pedestrian	10.47	32.80	74.25	24.11	75.55	170.99	32.04	100.40	227.24
Combined Bicycle	2.15	19.82	58.51	4.31	39.65	117.02	6.46	59.47	175.53
Public Transportation Strategies									
Transit Fare Measures	4.82	9.89	19.31	8.48	17.41	33.98	20.89	40.76	77.63
Transit Frequency/LOS/Extent	3.37	12.84	44.29	7.31	21.65	70.60	17.14	47.57	167.72
Urban Transit Expansion	13.20	42.04	144.24	26.49	83.28	280.59	52.35	165.82	574.73
Intercity Passenger Rail	13.54	25.80	46.26	13.64	26.18	47.12	13.88	27.11	49.51
High-Speed Passenger Rail	1.61	14.91	72.67	2.47	22.65	96.45	10.75	43.86	143.01
HOV/Carpool/Vanpool/Commute Strategies									
HOV Lanes	6.26	20.56	48.05	9.59	27.81	62.63	27.65	67.17	140.52
HOV Lanes (24-hour applicability)	0.00	0.39	1.20	0.18	0.62	1.42	0.41	0.85	1.66
Car-Sharing	5.41	16.05	36.77	12.97	35.30	76.75	35.89	80.55	163.44
Employer-Based Commute Strategies	35.47	111.13	251.53	69.31	215.15	485.79	179.26	524.56	1165.31

Table D.7 Cumulative Reductions (Level A, B, and C) (continued)
2020, 2030, 2050

Cumulative GHG Reduction	Expanded Current Practice Cumulative GHG Reduction (mmt)			More Aggressive Cumulative GHG Reduction (mmt)			Maximum Cumulative GHG Reduction (mmt)		
Strategy Description	**2010-2020**	**2010-2030**	**2010-2050**	**2010-2020**	**2010-2030**	**2010-2050**	**2010-2020**	**2010-2030**	**2010-2050**
Regulatory Strategies									
Nonmotorized Zones	0.03	0.38	1.61	0.31	1.40	3.91	0.46	2.09	5.86
Urban Parking Restrictions	0.00	3.71	80.36	0.64	19.59	189.09	14.47	80.01	358.53
Speed Limit Reductions	31.28	390.94	1236.07	180.86	856.47	2319.69	247.13	950.72	2428.06
System Operations and Management Strategies									
EcoDriving	38.35	170.45	727.01	76.70	309.47	1169.60	191.74	651.05	1814.76
Ramp Metering	0.97	2.07	27.14	1.00	1.01	77.48	0.73	0.50	83.41
Variable Message Signs	0.06	0.13	1.80	0.09	0.17	2.49	0.10	0.18	2.54
Active Traffic Management	N/A	N/A	N/A	2.22	4.22	46.43	2.58	3.83	79.56
Integrated Corridor Management	N/A	N/A	N/A	2.22	4.22	46.43	2.58	3.83	79.56
Incident Management	2.13	4.41	57.51	3.19	5.60	71.76	3.63	5.88	80.23
Road Weather Management	0.08	0.19	0.58	0.14	0.34	1.02	0.36	0.73	1.76
Signal Control Management	0.10	0.25	2.93	0.23	0.57	18.32	0.42	0.92	37.21
Traveler Information	0.14	0.32	4.08	0.23	0.45	29.82	0.27	0.47	31.16
Vehicle Infrastructure Integration	-0.32	-1.41	65.42	-0.56	-2.29	15.69	-1.27	-4.36	7.93
Bottleneck Relief and Capacity Expansion Strategies									
Bottleneck Relief [c]	5.52	13.90	-3.05	10.76	27.10	-4.91	23.61	59.48	-10.77
Capacity Expansion [c]	8.19	20.62	-4.07	15.97	40.22	-7.28	31.93	80.43	-14.57
Multimodal Freight Strategies									
Rail Capacity Improvements	1.88	12.96	43.77	2.82	19.44	65.66	5.64	38.90	131.38
Marine System Improvements	0.44	1.98	5.42	0.66	2.97	8.13	1.00	4.45	12.20
Shipping Container Permits	0.64	2.83	7.51	1.00	3.45	8.14	1.63	4.08	8.77
LCV Permits	0.71	3.11	8.26	1.51	5.21	12.27	2.73	6.84	14.69
WIM Screening	0.05	0.24	0.63	0.08	0.29	0.68	0.14	0.34	0.73
Weigh Station Bypass	0.11	0.47	1.25	0.17	0.57	1.35	0.27	0.68	1.46
Truck Stop Electrification	0.94	4.14	11.00	3.08	10.61	25.02	8.52	21.31	45.78
Truck APUs	6.39	40.97	133.05	9.48	54.82	148.90	17.68	68.11	162.19
Truck-Only Toll Lanes	0.62	6.52	23.63	1.54	16.30	59.07	2.49	28.08	106.49
Urban Consolidation Centers	0.40	1.88	5.64	0.63	2.63	8.13	1.02	3.27	8.96

Table D.8 Percent Cumulative Reductions from Baseline (Level A, B, and C)

2020, 2030, 2050

Percent Cumulative GHG Reduction from Baseline	Expanded Current Practice Percent Cumulative GHG Reduction			More Aggressive Percent Cumulative GHG Reduction			Maximum Percent Cumulative GHG Reduction		
Strategy Description	**2010-2020**	**2010-2030**	**2010-2050**	**2010-2020**	**2010-2030**	**2010-2050**	**2010-2020**	**2010-2030**	**2010-2050**
Pricing									
CBD/Activity Center on-street parking	0.01%	0.03%	0.05%	0.04%	0.06%	0.06%	0.05%	0.06%	0.06%
Tax/higher tax on free private parking	N/A	N/A	N/A	0.00%	0.02%	0.03%	0.02%	0.04%	0.05%
Residential parking permits	N/A	N/A	N/A	0.00%	0.02%	0.03%	0.02%	0.06%	0.07%
Cordon Pricing	0.01%	0.04%	0.10%	0.01%	0.05%	0.11%	0.04%	0.09%	0.14%
Congestion Pricing	0.08%	0.41%	0.75%	0.15%	0.87%	1.51%	0.34%	1.24%	1.83%
Intercity Tolls	0.00%	0.03%	0.05%	0.04%	0.07%	0.08%	0.15%	0.16%	0.16%
PAYD Insurance	1.18%	1.17%	1.17%	1.66%	2.17%	2.48%	2.14%	2.89%	3.30%
VMT fee	0.24%	0.36%	0.41%	0.73%	1.09%	1.24%	2.94%	4.37%	4.97%
Carbon Pricing (VMT impact)[b]	-	0.46%	-	0.93%	-	1.58%	3.87%	5.97%	7.01%
Carbon Pricing (Fuel economy impact)	-	1.23%	-	1.56%	-	4.94%	5.49%	11.48%	15.43%
Land Use and Smart Growth Strategies/Nonmotorized Strategies									
Combined Land Use	0.01%	0.07%	0.24%	0.10%	0.50%	1.28%	0.17%	0.85%	2.14%
Combined Pedestrian	0.06%	0.10%	0.11%	0.14%	0.22%	0.25%	0.19%	0.29%	0.34%
Combined Bicycle	0.01%	0.06%	0.09%	0.02%	0.12%	0.17%	0.04%	0.17%	0.26%
Public Transportation Strategies									
Transit Fare Measures	0.03%	0.03%	0.03%	0.05%	0.05%	0.05%	0.12%	0.12%	0.11%
Transit Frequency/LOS/Extent	0.02%	0.04%	0.07%	0.04%	0.06%	0.10%	0.10%	0.14%	0.24%
Urban Transit Expansion	0.08%	0.12%	0.21%	0.15%	0.24%	0.41%	0.30%	0.48%	0.85%
Intercity Passenger Rail	0.08%	0.08%	0.07%	0.08%	0.08%	0.07%	0.08%	0.08%	0.07%
High-Speed Passenger Rail	0.01%	0.04%	0.11%	0.01%	0.07%	0.14%	0.06%	0.13%	0.21%
HOV/Carpool/Vanpool/Commute Strategies									
HOV Lanes	0.04%	0.06%	0.07%	0.06%	0.08%	0.09%	0.16%	0.20%	0.21%
HOV Lanes (24-hour applicability)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Car-Sharing	0.03%	0.05%	0.05%	0.07%	0.10%	0.11%	0.21%	0.23%	0.24%
Employer-Based Commute Strategies	0.20%	0.32%	0.37%	0.40%	0.63%	0.72%	1.04%	1.53%	1.72%

Table D.8 Percent Cumulative Reductions from Baseline (continued) (Level A, B, and C)

2020, 2030, 2050

Percent Cumulative GHG Reduction from Baseline Strategy Description	Expanded Current Practice Percent Cumulative GHG Reduction 2010-2020	2010-2030	2010-2050	More Aggressive Percent Cumulative GHG Reduction 2010-2020	2010-2030	2010-2050	Maximum Percent Cumulative GHG Reduction 2010-2020	2010-2030	2010-2050
Regulatory Strategies									
Nonmotorized Zones	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.01%
Urban Parking Restrictions	0.00%	0.01%	0.12%	0.00%	0.06%	0.28%	0.08%	0.23%	0.53%
Speed Limit Reductions	0.18%	1.14%	1.83%	1.04%	2.50%	3.43%	1.43%	2.77%	3.59%
System Operations and Management Strategies									
EcoDriving	0.22%	0.50%	1.07%	0.44%	0.90%	1.73%	1.11%	1.90%	2.68%
Ramp Metering	0.01%	0.01%	0.04%	0.01%	0.00%	0.11%	0.00%	0.00%	0.12%
Variable Message Signs	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Active Traffic Management	N/A	N/A	N/A	0.01%	0.01%	0.07%	0.01%	0.01%	0.12%
Integrated Corridor Management	N/A	N/A	N/A	0.01%	0.01%	0.07%	0.01%	0.01%	0.12%
Incident Management	0.01%	0.01%	0.08%	0.02%	0.02%	0.11%	0.02%	0.02%	0.12%
Road Weather Management	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Signal Control Management	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.00%	0.00%	0.05%
Traveler Information	0.00%	0.00%	0.01%	0.00%	0.00%	0.04%	0.00%	0.00%	0.05%
Vehicle Infrastructure Integration	0.00%	0.00%	0.10%	0.00%	-0.01%	0.02%	-0.01%	-0.01%	0.01%
Bottleneck Relief and Capacity Expansion Strategies									
Bottleneck Relief [c]	0.03%	0.04%	-0.0074%	0.06%	0.08%	-0.0073%	0.14%	0.17%	-0.0159%
Capacity Expansion [c]	0.05%	0.06%	-0.0109%	0.09%	0.12%	-0.0108%	0.18%	0.23%	-0.0215%
Multimodal Freight Strategies									
Rail Capacity Improvements	0.01%	0.04%	0.06%	0.02%	0.06%	0.10%	0.03%	0.11%	0.19%
Marine System Improvements	0.00%	0.01%	0.01%	0.00%	0.01%	0.01%	0.01%	0.01%	0.02%
Shipping Container Permits	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
LCV Permits	0.00%	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%
WIM Screening	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Weigh Station Bypass	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Truck Stop Electrification	0.01%	0.01%	0.02%	0.02%	0.03%	0.04%	0.05%	0.06%	0.07%
Truck APUs	0.04%	0.12%	0.20%	0.05%	0.16%	0.22%	0.10%	0.20%	0.24%
Truck-Only Toll Lanes	0.00%	0.02%	0.03%	0.01%	0.05%	0.09%	0.01%	0.08%	0.16%
Urban Consolidation Centers	0.00%	0.01%	0.01%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%

Table D.9 Annual Costs and Savings (Level A, B, and C)
2015

Included Costs and Vehicle Cost Savings (2015)	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
Pricing						
CBD/Activity Center on-street parking	$0.00	$0.00	$0.00	$0.87	$0.00	$1.22
Tax/higher tax on free private parking	N/A	N/A	$0.00	$0.00	$0.00	$0.00
Residential parking permits	N/A	N/A	$0.00	$0.00	$0.00	$0.00
Cordon Pricing	$0.00	$0.00	$0.00	$0.00	$0.00	$1.05
Congestion Pricing	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Intercity Tolls	$0.00	$0.00	$0.00	$0.00	$1.91	$4.07
PAYD Insurance	$1.43	$29.70	$1.43	$29.54	$1.43	$29.54
VMT fee	$1.43	$0.00	$1.43	$0.00	$1.43	$0.00
Carbon Pricing (VMT impact)[b]	-	$0.00	-	$0.00	-	$0.00
Carbon Pricing (Fuel economy impact)	-	$0.00	-	$0.00	-	$0.00
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	$0.11	$0.00	$0.11	$0.00	$0.11	$0.00
Combined Pedestrian	$1.04	$1.18	$2.08	$2.71	$2.89	$3.61
Combined Bicycle	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Public Transportation Strategies						
Transit Fare Measures	$0.00	$0.56	$0.00	$0.99	$0.00	$2.62
Transit Frequency/LOS/Extent	$0.70	$0.44	$1.33	$1.18	$2.81	$2.83
Urban Transit Expansion	$5.23	$1.81	$10.00	$3.69	$21.22	$7.39
Intercity Passenger Rail	$0.69	$1.77	$1.38	$1.85	$2.75	$2.02
High-Speed Passenger Rail	$3.21	$0.00	$4.15	$0.00	$6.93	$0.53
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	$5.76	$0.18	$7.92	$0.29	$23.27	$1.15
HOV Lanes (24-hour applicability)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.02
Car-Sharing	$0.03	$0.61	$0.06	$1.22	$0.01	$4.33
Employer-Based Commute Strategies	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Regulatory Strategies						
Nonmotorized Zones	$0.00	$0.00	$0.05	$0.03	$0.09	$0.04
Urban Parking Restrictions	$0.00	$0.00	$0.00	$0.00	$0.00	$1.24
Speed Limit Reductions	$0.11	$0.00	$0.18	$7.53	$0.36	$12.26

Table D.9 Annual Costs and Savings (Level A, B, and C) (continued)

2015

Included Costs and Vehicle Cost Savings (2015)	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
System Operations and Management Strategies						
EcoDriving	$0.00	$1.14	$0.00	$2.29	$0.00	$5.72
Ramp Metering	$0.07	$0.05	$0.16	$0.07	$0.39	$0.08
Variable Message Signs	$0.04	$0.00	$0.10	$0.01	$0.25	$0.01
Active Traffic Management	N/A	N/A	$0.30	$0.13	$0.71	$0.16
Integrated Corridor Management	N/A	N/A	$0.30	$0.13	$0.71	$0.16
Incident Management	$0.08	$0.12	$0.19	$0.20	$0.46	$0.24
Road Weather Management	$0.09	$0.00	$0.22	$0.01	$0.52	$0.02
Signal Control Management	$0.06	$0.01	$0.16	$0.01	$0.43	$0.02
Traveler Information	$0.09	$0.01	$0.22	$0.01	$0.52	$0.02
Vehicle Infrastructure Integration	$1.94	$0.05	$1.94	$0.08	$1.94	$0.16
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	$1.19	$6.62	$2.96	$11.62	$5.93	$25.48
Capacity Expansion [c]	$14.60	$9.31	$27.03	$17.24	$54.06	$34.46
Multimodal Freight Strategies						
Rail Capacity Improvements	$0.58	$0.09	$0.95	$0.13	$1.41	$0.27
Marine System Improvements	$0.19	$0.01	$0.38	$0.02	$1.14	$0.02
Shipping Container Permits	$0.00	$0.02	$0.00	$0.03	$0.00	$0.06
LCV Permits	$0.00	$0.13	$0.00	$0.28	$0.00	$0.55
WIM Screening	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Weigh Station Bypass	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Truck Stop Electrification	$0.01	$0.03	$0.02	$0.07	$0.03	$0.12
Truck APUs	$0.01	$0.45	$0.01	$0.67	$0.03	$1.27
Truck-Only Toll Lanes	$2.47	$0.00	$6.17	$0.00	$10.35	$0.00
Urban Consolidation Centers	$0.03	$0.01	$0.03	$0.02	$0.03	$0.05

Table D.10 Annual Costs and Savings (Level A, B, and C)
2020

Included Costs and Vehicle Cost Savings (2020)	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
Pricing						
CBD/Activity Center on-street parking	$0.00	$0.50	$0.00	$1.27	$0.00	$1.35
Tax/higher tax on free private parking	N/A	N/A	$0.00	$0.00	$0.00	$1.09
Residential parking permits	N/A	N/A	$0.00	$0.00	$0.00	$1.45
Cordon Pricing	$0.87	$0.92	$0.87	$0.92	$1.12	$1.92
Congestion Pricing	$8.39	$7.90	$8.39	$11.85	$10.87	$21.50
Intercity Tolls	$0.00	$0.00	$1.57	$2.13	$1.68	$3.55
PAYD Insurance	$1.26	$26.07	$1.26	$51.43	$1.26	$72.86
VMT fee	$1.26	$9.71	$1.57	$29.12	$1.26	$116.48
Carbon Pricing (VMT impact)[b]	-	$12.25	-	$37.07	-	$156.69
Carbon Pricing (Fuel economy impact)	-	$7.05	-	$20.36	-	$68.43
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	$0.09	$1.08	$0.09	$7.47	$0.09	$12.82
Combined Pedestrian	$0.86	$2.31	$1.71	$5.32	$2.38	$7.06
Combined Bicycle	$0.25	$0.96	$1.36	$1.91	$2.54	$2.87
Public Transportation Strategies						
Transit Fare Measures	$0.00	$0.56	$0.00	$0.99	$0.00	$2.28
Transit Frequency/LOS/Extent	$1.00	$0.90	$1.91	$1.77	$4.18	$4.07
Urban Transit Expansion	$5.76	$2.61	$11.22	$5.35	$24.85	$10.90
Intercity Passenger Rail	$1.18	$1.56	$1.76	$1.64	$3.53	$1.85
High-Speed Passenger Rail	$3.47	$0.32	$4.51	$0.45	$7.60	$1.03
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	$6.46	$0.36	$8.86	$0.51	$20.67	$1.18
HOV Lanes (24-hour applicability)	$0.00	$0.00	$0.00	$0.01	$0.00	$0.01
Car-Sharing	$0.00	$0.94	$0.00	$2.56	$0.00	$5.13
Employer-Based Commute Strategies	$4.71	$8.69	$0.65	$16.75	$0.65	$39.65

Table D.10 Annual Costs and Savings (Level A, B, and C) (continued)

2020

Included Costs and Vehicle Cost Savings (2020)	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
Regulatory Strategies						
Nonmotorized Zones	$0.02	$0.01	$0.19	$0.08	$0.38	$0.12
Urban Parking Restrictions	$0.00	$0.00	$0.00	$0.45	$0.00	$3.96
Speed Limit Reductions	$0.17	$6.05	$0.27	$18.83	$0.25	$23.98
System Operations and Management Strategies						
EcoDriving	$0.00	$2.19	$0.00	$4.38	$0.00	$10.96
Ramp Metering	$0.05	$0.02	$0.12	-$0.01	$0.29	-$0.03
Variable Message Signs	$0.03	$0.00	$0.07	$0.00	$0.17	$0.00
Active Traffic Management	N/A	N/A	$0.29	$0.03	$0.70	$0.03
Integrated Corridor Management	N/A	N/A	$0.29	$0.03	$0.70	$0.03
Incident Management	$0.07	$0.04	$0.16	$0.03	$0.39	$0.02
Road Weather Management	$0.06	$0.00	$0.16	$0.00	$0.39	$0.01
Signal Control Management	$0.06	$0.00	$0.16	$0.01	$0.45	$0.01
Traveler Information	$0.06	$0.00	$0.16	$0.00	$0.39	$0.00
Vehicle Infrastructure Integration	$1.44	-$0.06	$1.44	-$0.09	$1.44	-$0.18
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	$0.97	$6.12	$2.44	$10.74	$4.87	$23.57
Capacity Expansion [c]	$12.00	$8.60	$22.22	$15.93	$44.44	$31.88
Multimodal Freight Strategies						
Rail Capacity Improvements	$0.75	$0.32	$1.23	$0.47	$1.83	$0.95
Marine System Improvements	$0.19	$0.02	$0.38	$0.04	$1.13	$0.06
Shipping Container Permits	$0.00	$0.04	$0.00	$0.06	$0.00	$0.07
LCV Permits	$0.00	$0.25	$0.00	$0.56	$0.00	$0.61
WIM Screening	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Weigh Station Bypass	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Truck Stop Electrification	$0.02	$0.08	$0.04	$0.17	$0.06	$0.28
Truck APUs	$0.01	$0.79	$0.02	$1.18	$0.01	$1.34
Truck-Only Toll Lanes	$0.06	$0.08	$0.15	$0.19	$0.26	$0.30
Urban Consolidation Centers	$0.02	$0.04	$0.02	$0.06	$0.02	$0.07

Table D.11 Annual Costs and Savings (Level A, B, and C)
2030

Included Costs and Vehicle Cost Savings (2030)	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
Pricing						
CBD/Activity Center on-street parking	$0.00	$1.03	$0.00	$1.03	$0.00	$1.03
Tax/higher tax on free private parking	N/A	N/A	$0.00	$0.60	$0.00	$0.83
Residential parking permits	N/A	N/A	$0.00	$0.69	$0.00	$1.38
Cordon Pricing	$0.67	$1.67	$1.13	$2.66	$1.16	$3.53
Congestion Pricing	$6.51	$21.07	$10.96	$29.97	$11.21	$38.99
Intercity Tolls	$1.14	$1.08	$1.22	$1.62	$1.31	$2.71
PAYD Insurance	$0.98	$20.12	$0.98	$49.01	$0.98	$65.35
VMT fee	$0.98	$7.54	$0.98	$22.61	$0.98	$90.43
Carbon Pricing (VMT impact)[b]	-	$9.44	-	$28.80	-	$128.22
Carbon Pricing (Fuel economy impact)	-	$8.10	-	$22.90	-	$71.10
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	$0.02	$2.89	$0.02	$19.94	$0.02	$34.20
Combined Pedestrian	$0.06	$1.96	$0.12	$4.50	$0.16	$5.98
Combined Bicycle	$0.17	$1.82	$0.92	$3.65	$1.72	$5.47
Public Transportation Strategies						
Transit Fare Measures	$0.00	$0.44	$0.00	$0.78	$0.00	$1.74
Transit Frequency/LOS/Extent	$1.45	$1.32	$2.84	$2.60	$6.64	$6.26
Urban Transit Expansion	$6.86	$3.69	$13.80	$7.62	$32.96	$16.15
Intercity Passenger Rail	$0.85	$1.12	$1.71	$1.22	$4.27	$1.52
High-Speed Passenger Rail	$3.83	$0.84	$5.00	$1.19	$1.33	$1.38
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	$5.31	$0.32	$7.04	$0.40	$16.58	$0.85
HOV Lanes (24-hour applicability)	$0.00	$0.01	$0.00	$0.01	$0.00	$0.01
Car-Sharing	$0.00	$0.98	$0.00	$1.96	$0.00	$3.91
Employer-Based Commute Strategies	$3.19	$6.62	$0.44	$12.77	$0.44	$30.23

Table D.11 Annual Costs and Savings (Level A, B, and C) (continued)
2030

Included Costs and Vehicle Cost Savings (2030)	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
Regulatory Strategies						
Nonmotorized Zones	$0.12	$0.05	$0.19	$0.12	$0.38	$0.17
Urban Parking Restrictions	$0.00	$0.92	$0.00	$3.19	$0.00	$8.00
Speed Limit Reductions	$0.11	$15.59	$0.18	$26.52	$0.17	$26.70
System Operations and Management Strategies						
EcoDriving	$0.00	$3.95	$0.00	$6.53	$0.00	$11.00
Ramp Metering	$0.02	$0.05	$0.06	$0.02	$0.14	$0.02
Variable Message Signs	$0.02	$0.00	$0.04	$0.00	$0.10	$0.00
Active Traffic Management	N/A	N/A	$0.29	$0.08	$0.68	$0.06
Integrated Corridor Management	N/A	N/A	$0.29	$0.08	$0.68	$0.06
Incident Management	$0.05	$0.09	$0.14	$0.11	$0.33	$0.11
Road Weather Management	$0.04	$0.00	$0.11	$0.01	$0.26	$0.01
Signal Control Management	$0.07	$0.01	$0.16	$0.01	$0.45	$0.02
Traveler Information	$0.04	$0.01	$0.11	$0.01	$0.26	$0.01
Vehicle Infrastructure Integration	$1.17	$0.02	$1.17	$0.03	$1.17	$0.02
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	$0.66	$3.71	$1.65	$6.52	$3.29	$14.35
Capacity Expansion [c]	$8.11	$5.22	$15.01	$9.67	$30.02	$19.40
Multimodal Freight Strategies						
Rail Capacity Improvements	$0.52	$0.72	$0.85	$1.08	$1.27	$2.17
Marine System Improvements	$0.07	$0.03	$0.13	$0.05	$0.26	$0.07
Shipping Container Permits	$0.00	$0.05	$0.00	$0.05	$0.00	$0.05
LCV Permits	$0.00	$0.32	$0.00	$0.48	$0.00	$0.47
WIM Screening	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Weigh Station Bypass	$0.00	$0.01	$0.00	$0.01	$0.00	$0.01
Truck Stop Electrification	$0.02	$0.10	$0.04	$0.22	$0.08	$0.37
Truck APUs	$0.01	$1.00	$0.01	$1.00	$0.01	$1.00
Truck-Only Toll Lanes	$0.04	$0.17	$0.10	$0.42	$0.17	$0.76
Urban Consolidation Centers	$0.00	$0.06	$0.00	$0.08	$0.00	$0.09

Table D.12 Annual Costs and Savings (Level A, B, and C)
2050

Included Costs and Vehicle Cost Savings (2050)	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
Pricing						
CBD/Activity Center on-street parking	$0.00	$0.60	$0.00	$0.60	$0.00	$0.60
Tax/higher tax on free private parking	N/A	N/A	$0.00	$0.35	$0.00	$0.49
Residential parking permits	N/A	N/A	$0.00	$0.40	$0.00	$0.81
Cordon Pricing	$0.41	$2.18	$0.68	$2.18	$0.70	$2.18
Congestion Pricing	$3.92	$13.16	$6.60	$20.09	$6.76	$23.13
Intercity Tolls	$0.68	$0.63	$0.73	$0.95	$0.79	$1.59
PAYD Insurance	$0.59	$12.01	$0.59	$28.64	$0.59	$38.19
VMT fee	$0.59	$4.54	$0.59	$13.63	$0.59	$54.50
Carbon Pricing (VMT impact)[b]	-	$5.60	-	$17.21	-	$80.46
Carbon Pricing (Fuel economy impact)	-	$4.93	-	$13.84	-	$41.56
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	$0.01	$5.71	$0.01	$26.04	$0.01	$42.49
Combined Pedestrian	$0.03	$1.14	$0.05	$2.63	$0.07	$3.50
Combined Bicycle	$0.04	$1.07	$0.08	$2.13	$0.11	$3.20
Public Transportation Strategies						
Transit Fare Measures	$0.00	$0.26	$0.00	$0.46	$0.00	$1.02
Transit Frequency/LOS/Extent	$1.72	$1.65	$3.50	$3.86	$9.05	$12.83
Urban Transit Expansion	$7.00	$4.48	$14.46	$9.52	$37.59	$22.45
Intercity Passenger Rail	$0.05	$0.56	$0.11	$0.61	$0.27	$0.77
High-Speed Passenger Rail	$0.70	$0.70	$0.88	$0.74	$1.33	$0.81
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	$2.51	$0.17	$3.41	$0.21	$8.42	$0.45
HOV Lanes (24-hour applicability)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Car-Sharing	$0.00	$0.57	$0.00	$1.14	$0.00	$2.29
Employer-Based Commute Strategies	$1.45	$3.87	$0.20	$7.46	$0.20	$17.67
Regulatory Strategies						
Nonmotorized Zones	$0.00	$0.03	$0.00	$0.07	$0.00	$0.10
Urban Parking Restrictions	$0.00	$3.83	$0.00	$7.55	$0.00	$10.49
Speed Limit Reductions	$0.05	$8.57	$0.08	$14.70	$0.08	$14.82

Table D.12 Annual Costs and Savings (Level A, B, and C) (continued)
2050

Included Costs and Vehicle Cost Savings (2050)	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
System Operations and Management Strategies						
EcoDriving	$0.00	$4.62	$0.00	$6.93	$0.00	$8.31
Ramp Metering	$0.00	$0.31	$0.01	$0.84	$0.02	$0.92
Variable Message Signs	$0.01	$0.02	$0.01	$0.03	$0.03	$0.03
Active Traffic Management	N/A	N/A	$0.21	$0.53	$0.50	$0.89
Integrated Corridor Management	N/A	N/A	$0.21	$0.53	$0.50	$0.89
Incident Management	$0.03	$0.67	$0.08	$0.85	$0.19	$0.95
Road Weather Management	$0.02	$0.00	$0.05	$0.01	$0.12	$0.01
Signal Control Management	$0.05	$0.03	$0.13	$0.18	$0.34	$0.32
Traveler Information	$0.02	$0.05	$0.05	$0.30	$0.12	$0.31
Vehicle Infrastructure Integration	$0.61	$0.78	$0.61	$0.28	$0.61	$0.09
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	$0.30	-$0.04	$0.75	-$0.06	$1.50	-$0.14
Capacity Expansion [c]	$3.70	-$0.05	$6.85	-$0.09	$13.70	-$0.19
Multimodal Freight Strategies						
Rail Capacity Improvements	$0.24	$0.42	$0.39	$0.63	$0.58	$1.26
Marine System Improvements	$0.03	$0.02	$0.06	$0.03	$0.12	$0.04
Shipping Container Permits	$0.00	$0.03	$0.00	$0.03	$0.00	$0.03
LCV Permits	$0.00	$0.19	$0.00	$0.29	$0.00	$0.28
WIM Screening	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Weigh Station Bypass	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Truck Stop Electrification	$0.01	$0.06	$0.02	$0.12	$0.04	$0.20
Truck APUs	$0.00	$0.46	$0.00	$0.46	$0.00	$0.46
Truck-Only Toll Lanes	$0.02	$0.13	$0.05	$0.32	$0.08	$0.59
Urban Consolidation Centers	$0.00	$0.04	$0.00	$0.05	$0.00	$0.06

Table D.13 Cumulative Costs and Savings (Level A, B, and C)
2015

Cumulative 2015	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Costs (2010- 2015)**	**Vehicle Cost Savings (2010-2015)**	**Implementation Costs (2010- 2015)**	**Vehicle Cost Savings (2010-2015)**	**Implementation Costs (2010- 2015)**	**Vehicle Cost Savings (2010-2015)**
Pricing						
CBD/Activity Center on-street parking	$0.00	$0.00	$0.00	$2.71	$0.00	$3.79
Tax/higher tax on free private parking	N/A	N/A	$0.00	$0.00	$0.00	$0.00
Residential parking permits	N/A	N/A	$0.00	$0.00	$0.00	$0.00
Cordon Pricing	$0.00	$0.00	$0.00	$0.00	$0.00	$3.27
Congestion Pricing	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Intercity Tolls	$0.00	$0.00	$0.00	$0.00	$14.77	$16.99
PAYD Insurance	$133.05	$156.70	$133.05	$156.29	$133.05	$156.29
VMT fee	$133.05	$0.00	$133.05	$0.00	$133.05	$0.00
Carbon Pricing (VMT impact)[b]	-	$0.00	-	$0.00	-	$0.00
Carbon Pricing (Fuel economy impact)	-	$0.00	-	$0.00	-	$0.00
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	$0.58	$0.00	$0.58	$0.00	$0.58	$0.00
Combined Pedestrian	$5.64	$3.03	$11.27	$6.98	$15.66	$9.27
Combined Bicycle	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Public Transportation Strategies						
Transit Fare Measures	$0.00	$2.99	$0.00	$5.25	$0.00	$13.87
Transit Frequency/LOS/Extent	$2.46	$0.44	$4.66	$1.18	$9.73	$2.83
Urban Transit Expansion	$20.21	$7.07	$38.43	$14.39	$80.44	$28.66
Intercity Passenger Rail	$2.16	$9.29	$4.31	$9.56	$8.62	$10.09
High-Speed Passenger Rail	$16.05	$0.00	$20.75	$0.00	$34.64	$1.35
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	$26.48	$0.47	$35.32	$0.74	$92.79	$2.97
HOV Lanes (24-hour applicability)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.06
Car-Sharing	$0.16	$2.21	$0.32	$4.43	$0.08	$18.06
Employer-Based Commute Strategies	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Table D.13 Cumulative Costs and Savings (Level A, B, and C) (continued)

2015

Cumulative 2015	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	Implementation Costs (2010- 2015)	Vehicle Cost Savings (2010-2015)	Implementation Costs (2010- 2015)	Vehicle Cost Savings (2010-2015)	Implementation Costs (2010- 2015)	Vehicle Cost Savings (2010-2015)
Regulatory Strategies						
Nonmotorized Zones	$0.00	$0.00	$0.25	$0.08	$0.50	$0.11
Urban Parking Restrictions	$0.00	$0.00	$0.00	$0.00	$0.00	$3.19
Speed Limit Reductions	$0.39	$0.00	$0.62	$19.44	$1.27	$29.96
System Operations and Management Strategies						
EcoDriving	$0.00	$2.96	$0.00	$5.91	$0.00	$14.79
Ramp Metering	$0.38	$0.16	$0.95	$0.26	$2.27	$0.29
Variable Message Signs	$0.22	$0.01	$0.55	$0.02	$1.31	$0.02
Active Traffic Management	N/A	N/A	$1.38	$0.42	$3.32	$0.54
Integrated Corridor Management	N/A	N/A	$1.38	$0.42	$3.32	$0.54
Incident Management	$0.38	$0.38	$0.95	$0.67	$2.27	$0.84
Road Weather Management	$0.45	$0.01	$1.13	$0.03	$2.72	$0.07
Signal Control Management	$0.29	$0.02	$0.72	$0.04	$1.99	$0.07
Traveler Information	$0.45	$0.02	$1.13	$0.04	$2.72	$0.06
Vehicle Infrastructure Integration	$6.54	$0.14	$6.54	$0.22	$6.54	$0.44
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	$6.42	$16.97	$16.05	$29.78	$32.10	$65.33
Capacity Expansion [c]	$61.99	$23.86	$114.79	$44.18	$229.58	$88.35
Multimodal Freight Strategies						
Rail Capacity Improvements	$2.47	$0.17	$4.05	$0.25	$6.00	$0.50
Marine System Improvements	$0.75	$0.02	$1.51	$0.03	$4.52	$0.05
Shipping Container Permits	$0.00	$0.05	$0.00	$0.08	$0.00	$0.16
LCV Permits	$0.00	$0.32	$0.00	$0.72	$0.00	$1.41
WIM Screening	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Weigh Station Bypass	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Truck Stop Electrification	$0.02	$0.07	$0.04	$0.15	$0.07	$0.25
Truck APUs	$0.03	$1.42	$0.04	$2.11	$0.10	$3.88
Truck-Only Toll Lanes	$13.37	$0.00	$33.43	$0.00	$56.06	$0.00
Urban Consolidation Centers	$0.12	$0.03	$0.12	$0.04	$0.12	$0.09

Table D.14 Cumulative Costs and Savings (Level A, B, and C) *2020*

Cumulative 2020	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Costs (2010- 2020)**	**Vehicle Cost Savings (2010-2020)**	**Implementation Costs (2010- 2020)**	**Vehicle Cost Savings (2010-2020)**	**Implementation Costs (2010- 2020)**	**Vehicle Cost Savings (2010-2020)**
Pricing						
CBD/Activity Center on-street parking	$0.00	$1.57	$0.00	$8.79	$0.00	$10.31
Tax/higher tax on free private parking	N/A	N/A	$0.00	$0.00	$0.00	$4.56
Residential parking permits	N/A	N/A	$0.00	$0.00	$0.00	$3.72
Cordon Pricing	$6.19	$2.85	$6.19	$2.85	$7.92	$11.25
Congestion Pricing	$59.82	$20.31	$59.82	$30.47	$76.55	$73.96
Intercity Tolls	$0.00	$0.00	$12.14	$8.87	$23.62	$35.73
PAYD Insurance	$139.70	$294.06	$139.70	$404.88	$139.70	$518.15
VMT fee	$139.70	$51.09	$139.70	$153.27	$139.70	$613.06
Carbon Pricing (VMT impact)[b]	-	$64.57	-	$194.74	-	$807.06
Carbon Pricing (Fuel economy impact)	-	$28.20	-	$82.04	-	$288.85
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	$1.05	$2.79	$1.05	$19.21	$1.05	$32.95
Combined Pedestrian	$10.27	$12.44	$20.54	$28.66	$28.53	$38.09
Combined Bicycle	$1.34	$2.46	$7.37	$4.92	$13.77	$7.38
Public Transportation Strategies						
Transit Fare Measures	$0.00	$5.96	$0.00	$10.48	$0.00	$25.93
Transit Frequency/LOS/Extent	$6.85	$4.91	$13.04	$11.34	$27.82	$26.73
Urban Transit Expansion	$48.08	$18.61	$92.33	$37.98	$197.87	$76.39
Intercity Passenger Rail	$7.13	$17.52	$12.42	$18.16	$24.84	$19.68
High-Speed Passenger Rail	$32.78	$0.81	$42.44	$1.15	$71.03	$5.56
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	$57.61	$1.95	$78.92	$3.00	$201.15	$8.75
HOV Lanes (24-hour applicability)	$0.00	$0.00	$0.00	$0.05	$0.00	$0.13
Car-Sharing	$0.16	$6.51	$0.32	$15.49	$0.08	$43.65
Employer-Based Commute Strategies	$25.54	$41.27	$3.54	$80.69	$3.54	$209.59
Regulatory Strategies						
Nonmotorized Zones	$0.06	$0.03	$1.29	$0.36	$2.58	$0.55
Urban Parking Restrictions	$0.00	$0.00	$0.00	$0.72	$0.00	$17.04
Speed Limit Reductions	$1.13	$15.62	$1.81	$93.02	$2.65	$129.21

Table D.14 Cumulative Costs and Savings (Level A, B, and C) (continued)
2020

Cumulative 2020	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Costs (2010- 2020)**	**Vehicle Cost Savings (2010-2020)**	**Implementation Costs (2010- 2020)**	**Vehicle Cost Savings (2010-2020)**	**Implementation Costs (2010- 2020)**	**Vehicle Cost Savings (2010-2020)**
System Operations and Management Strategies						
EcoDriving	$0.00	$11.97	$0.00	$23.95	$0.00	$59.87
Ramp Metering	$0.66	$0.32	$1.65	$0.34	$3.95	$0.26
Variable Message Signs	$0.38	$0.02	$0.95	$0.03	$2.27	$0.03
Active Traffic Management	N/A	N/A	$2.82	$0.73	$6.77	$0.86
Integrated Corridor Management	N/A	N/A	$2.82	$0.73	$6.77	$0.86
Incident Management	$0.73	$0.70	$1.82	$1.06	$4.36	$1.22
Road Weather Management	$0.81	$0.02	$2.01	$0.05	$4.83	$0.12
Signal Control Management	$0.60	$0.03	$1.51	$0.07	$4.16	$0.14
Traveler Information	$0.81	$0.04	$2.01	$0.08	$4.83	$0.09
Vehicle Infrastructure Integration	$14.27	-$0.08	$14.27	-$0.14	$14.27	-$0.34
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	$11.70	$52.36	$29.25	$91.85	$58.49	$201.57
Capacity Expansion [c]	$126.97	$73.60	$235.13	$136.29	$470.26	$272.59
Multimodal Freight Strategies						
Rail Capacity Improvements	$5.93	$1.26	$9.72	$1.89	$14.41	$3.78
Marine System Improvements	$1.70	$0.12	$3.40	$0.18	$10.20	$0.27
Shipping Container Permits	$0.00	$0.22	$0.00	$0.32	$0.00	$0.51
LCV Permits	$0.00	$1.33	$0.00	$2.98	$0.00	$4.60
WIM Screening	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
Weigh Station Bypass	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
Truck Stop Electrification	$0.08	$0.38	$0.18	$0.81	$0.31	$1.37
Truck APUs	$0.09	$4.75	$0.11	$7.07	$0.16	$10.98
Truck-Only Toll Lanes	$16.03	$0.19	$40.07	$0.48	$67.20	$0.77
Urban Consolidation Centers	$0.24	$0.17	$0.24	$0.27	$0.24	$0.45

Table D.15 Cumulative Costs and Savings (Level A, B, and C)
2030

Cumulative 2030	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Costs (2010- 2030)**	**Vehicle Cost Savings (2010-2030)**	**Implementation Costs (2010- 2030)**	**Vehicle Cost Savings (2010-2030)**	**Implementation Costs (2010- 2030)**	**Vehicle Cost Savings (2010-2030)**
Pricing						
CBD/Activity Center on-street parking	$0.00	$11.05	$0.00	$20.44	$0.00	$22.00
Tax/higher tax on free private parking	N/A	N/A	$0.00	$5.55	$0.00	$14.02
Residential parking permits	N/A	N/A	$0.00	$5.36	$0.00	$19.37
Cordon Pricing	$13.76	$18.09	$18.54	$21.94	$21.37	$41.13
Congestion Pricing	$133.00	$178.50	$179.24	$276.83	$206.62	$429.01
Intercity Tolls	$15.96	$10.88	$25.82	$27.27	$38.28	$66.39
PAYD Insurance	$150.71	$520.80	$150.71	$929.98	$150.71	$1,228.35
VMT fee	$150.71	$135.76	$150.71	$407.29	$150.71	$1,629.16
Carbon Pricing (VMT impact)[b]	-	$171.01	-	$518.41	-	$2,219.71
Carbon Pricing (Fuel economy impact)	-	$109.72	-	$314.20	-	$1,030.96
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	$1.27	$24.52	$1.27	$168.94	$1.27	$289.73
Combined Pedestrian	$14.39	$34.59	$28.78	$79.67	$39.98	$105.88
Combined Bicycle	$3.35	$19.77	$18.41	$39.53	$34.39	$59.30
Public Transportation Strategies						
Transit Fare Measures	$0.00	$10.99	$0.00	$19.34	$0.00	$45.63
Transit Frequency/LOS/Extent	$19.48	$16.74	$37.55	$33.92	$83.55	$79.35
Urban Transit Expansion	$111.55	$51.18	$218.34	$104.98	$489.39	$215.91
Intercity Passenger Rail	$17.04	$30.57	$31.13	$32.27	$64.94	$36.34
High-Speed Passenger Rail	$69.74	$7.15	$90.64	$10.08	$117.53	$19.14
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	$116.65	$5.53	$157.01	$7.55	$384.26	$18.65
HOV Lanes (24-hour applicability)	$0.00	$0.10	$0.00	$0.16	$0.00	$0.24
Car-Sharing	$0.16	$17.02	$0.32	$37.64	$0.08	$87.96
Employer-Based Commute Strategies	$63.78	$116.31	$8.84	$225.34	$8.84	$552.06
Regulatory Strategies						
Nonmotorized Zones	$1.05	$0.37	$4.23	$1.43	$8.47	$2.15
Urban Parking Restrictions	$0.00	$3.47	$0.00	$18.90	$0.00	$81.02
Speed Limit Reductions	$2.51	$158.67	$4.01	$359.29	$4.90	$407.85

Table D.15 Cumulative Costs and Savings (Level A, B, and C) (continued)
2030

Cumulative 2030	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Costs (2010- 2030)**	**Vehicle Cost Savings (2010-2030)**	**Implementation Costs (2010- 2030)**	**Vehicle Cost Savings (2010-2030)**	**Implementation Costs (2010- 2030)**	**Vehicle Cost Savings (2010-2030)**
System Operations and Management Strategies						
EcoDriving	$0.00	$44.40	$0.00	$81.34	$0.00	$174.20
Ramp Metering	$1.01	$0.58	$2.51	$0.33	$6.04	$0.19
Variable Message Signs	$0.60	$0.04	$1.51	$0.05	$3.62	$0.05
Active Traffic Management	N/A	N/A	$5.78	$1.21	$13.87	$1.16
Integrated Corridor Management	N/A	N/A	$5.78	$1.21	$13.87	$1.16
Incident Management	$1.32	$1.25	$3.30	$1.64	$7.92	$1.75
Road Weather Management	$1.35	$0.05	$3.37	$0.09	$8.10	$0.21
Signal Control Management	$1.28	$0.07	$3.19	$0.16	$8.78	$0.26
Traveler Information	$1.35	$0.09	$3.37	$0.13	$8.10	$0.14
Vehicle Infrastructure Integration	$26.15	-$0.37	$26.15	-$0.60	$26.15	-$1.15
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	$19.60	$94.50	$49.00	$165.78	$98.01	$364.14
Capacity Expansion [c]	$224.28	$132.84	$415.33	$245.99	$830.67	$492.44
Multimodal Freight Strategies						
Rail Capacity Improvements	$12.84	$7.18	$21.01	$10.77	$31.19	$21.55
Marine System Improvements	$3.08	$0.45	$6.17	$0.68	$14.11	$1.02
Shipping Container Permits	$0.00	$0.74	$0.00	$0.91	$0.00	$1.10
LCV Permits	$0.00	$4.56	$0.00	$8.38	$0.00	$9.89
WIM Screening	$0.01	$0.04	$0.01	$0.04	$0.01	$0.04
Weigh Station Bypass	$0.02	$0.08	$0.02	$0.08	$0.02	$0.08
Truck Stop Electrification	$0.30	$1.43	$0.63	$2.99	$1.08	$5.09
Truck APUs	$0.19	$14.80	$0.20	$18.55	$0.24	$22.46
Truck-Only Toll Lanes	$16.52	$1.69	$41.31	$4.22	$69.27	$7.25
Urban Consolidation Centers	$0.36	$0.71	$0.36	$1.00	$0.36	$1.29

Table D.16 Cumulative Costs and Savings (Level A, B, and C)

2050

Cumulative 2050	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	Implementation Costs (2010- 2050)	Vehicle Cost Savings (2010-2050)	Implementation Costs (2010- 2050)	Vehicle Cost Savings (2010-2050)	Implementation Costs (2010- 2050)	Vehicle Cost Savings (2010-2050)
Pricing						
CBD/Activity Center on-street parking	-	$26.80	-	$36.20	-	$37.75
Tax/higher tax on free private parking	N/A	N/A	-	$14.70	-	$26.75
Residential parking permits	N/A	N/A	-	$15.90	-	$40.44
Cordon Pricing	$24.20	$66.01	$36.10	$76.30	$39.34	$97.90
Congestion Pricing	$233.90	$522.77	$348.99	$792.92	$380.31	$1,033.76
Intercity Tolls	$33.56	$27.44	$44.69	$52.11	$58.51	$107.79
PAYD Insurance	$165.90	$831.16	$165.90	$1,678.04	$165.90	$2,225.77
VMT fee	$165.90	$252.53	$165.90	$757.60	$165.90	$3,030.38
Carbon Pricing (VMT impact)[b]	-	$316.13	-	$962.80	-	$4,246.18
Carbon Pricing (Fuel economy impact)	-	$236.66	-	$671.68	-	$2,121.06
Land Use and Smart Growth Strategies/Nonmotorized Strategies						
Combined Land Use	$1.51	$117.99	$1.51	$655.51	$1.51	$1,098.49
Combined Pedestrian	$15.18	$64.43	$30.35	$148.40	$42.17	$197.21
Combined Bicycle	$4.56	$47.62	$20.64	$95.24	$37.71	$142.86
Public Transportation Strategies						
Transit Fare Measures	-	$17.77	-	$31.27	-	$72.18
Transit Frequency/LOS/Extent	$52.48	$46.98	$102.61	$99.27	$243.77	$265.42
Urban Transit Expansion	$255.03	$135.47	$502.97	$281.67	$1,197.29	$611.55
Intercity Passenger Rail	$19.26	$46.47	$35.58	$49.61	$76.05	$58.02
High-Speed Passenger Rail	$99.55	$24.70	$108.15	$29.53	$144.20	$40.17
HOV/Carpool/Vanpool/Commute Strategies						
HOV Lanes	$171.78	$10.15	$231.92	$13.41	$569.08	$30.99
HOV Lanes (24-hour applicability)	$0.00	$0.23	$0.00	$0.30	$0.00	$0.38
Car-Sharing	$0.16	$31.94	$0.32	$67.48	$0.08	$147.64
Employer-Based Commute Strategies	$107.06	$217.40	$14.84	$420.20	$14.84	$1,013.42
Regulatory Strategies						
Nonmotorized Zones	$1.39	$1.26	$4.23	$3.24	$8.47	$4.86
Urban Parking Restrictions	$0.00	$55.48	$0.00	$135.57	$0.00	$276.08
Speed Limit Reductions	$4.06	$389.76	$6.50	$753.64	$7.46	$805.12

Table D.16 Cumulative Costs and Savings (Level A, B, and C) (continued)

2050

Cumulative 2050	Expanded Current Practice Billion Dollars		More Aggressive Billion Dollars		Maximum Billion Dollars	
Strategy Description	**Implementation Costs (2010- 2050)**	**Vehicle Cost Savings (2010-2050)**	**Implementation Costs (2010- 2050)**	**Vehicle Cost Savings (2010-2050)**	**Implementation Costs (2010- 2050)**	**Vehicle Cost Savings (2010-2050)**
System Operations and Management Strategies						
EcoDriving	$0.00	$134.91	$0.00	$221.76	$0.00	$366.91
Ramp Metering	$1.25	$4.46	$3.11	$12.33	$7.47	$13.17
Variable Message Signs	$0.81	$0.29	$2.02	$0.41	$4.84	$0.42
Active Traffic Management	N/A	N/A	$10.80	$7.74	$25.93	$12.96
Integrated Corridor Management	N/A	N/A	$10.80	$7.74	$25.93	$12.96
Incident Management	$2.15	$9.43	$5.37	$11.82	$12.88	$13.22
Road Weather Management	$1.97	$0.12	$4.91	$0.21	$11.79	$0.38
Signal Control Management	$2.46	$0.48	$6.14	$2.97	$16.88	$6.08
Traveler Information	$1.97	$0.67	$4.91	$4.77	$11.79	$5.00
Vehicle Infrastructure Integration	$42.62	$9.91	$42.62	$2.16	$42.62	$0.82
Bottleneck Relief and Capacity Expansion Strategies						
Bottleneck Relief [c]	$28.55	$124.81	$71.37	$218.97	$142.74	$481.62
Capacity Expansion [c]	$334.43	$175.45	$619.32	$324.92	$1,238.64	$651.30
Multimodal Freight Strategies						
Rail Capacity Improvements	$19.93	$18.49	$32.62	$27.73	$48.46	$55.49
Marine System Improvements	$3.98	$0.96	$7.96	$1.43	$17.69	$2.15
Shipping Container Permits	$0.00	$1.55	$0.00	$1.72	$0.00	$1.90
LCV Permits	$0.00	$9.56	$0.00	$15.82	$0.00	$17.17
WIM Screening	$0.02	$0.10	$0.02	$0.10	$0.02	$0.10
Weigh Station Bypass	$0.03	$0.19	$0.03	$0.19	$0.03	$0.19
Truck Stop Electrification	$0.61	$2.94	$1.28	$6.18	$2.19	$10.50
Truck APUs	$0.30	$28.82	$0.31	$32.57	$0.35	$36.48
Truck-Only Toll Lanes	$17.08	$4.62	$42.70	$11.54	$71.61	$20.67
Urban Consolidation Centers	$0.36	$1.62	$0.36	$2.33	$0.36	$2.66

Table D.17 Annual Reductions (Aggressive and Maximum)
Short-Term: 2015, 2020

Annual Reductions (Short Term)	Aggressive Deployment GHG Reduction (mmt)		Maximum Deployment GHG Reduction (mmt)	
Bundle	**2015**	**2020**	**2015**	**2020**
Near Term/Early Results	56.22	116.73	110.36	196.78
Long Term/Max Results	38.75	117.52	76.04	206.28
Land Use/Transit/Nonmotorized	19.37	55.27	37.60	97.20
System/Driver Efficiency	24.09	78.30	52.49	129.02
Facility Pricing	5.92	19.20	11.48	36.09
Low Cost	30.61	102.46	59.40	171.85

Table D.18 Annual Reductions (Aggressive and Maximum)
Long-Term: 2030, 2040, 2050

Annual Reductions (Long-Term)	Aggressive Deployment GHG Reduction (mmt)			Maximum Deployment GHG Reduction (mmt)		
Bundle	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Near Term/Early Results	199.41	233.04	269.46	257.36	284.45	317.00
Long Term/Max Results	218.73	256.91	308.55	308.62	344.15	411.95
Land Use/Transit/Nonmotorized	105.93	130.82	150.78	175.20	214.74	246.02
System/Driver Efficiency	147.61	163.12	194.45	175.54	174.24	250.84
Facility Pricing	46.01	43.52	54.69	57.94	45.02	69.93
Low Cost	213.06	260.53	305.76	278.35	323.32	369.72

Table D.19 Percent Annual Reductions from Baseline (Aggressive and Maximum)
Short-Term: 2015, 2020

Annual % Reductions from Baseline (Short Term)	Aggressive Deployment Annual Percent Reduction		Maximum Deployment Annual Percent Reduction	
Bundle	**2015**	**2020**	**2015**	**2020**
Near Term/Early Results	3.24%	6.82%	6.36%	11.49%
Long Term/Max Results	2.23%	6.86%	4.38%	12.05%
Land Use/Transit/Nonmotorized	1.12%	3.23%	2.17%	5.68%
System/Driver Efficiency	1.39%	4.57%	3.03%	7.53%
Facility Pricing	0.34%	1.12%	0.66%	2.11%
Low Cost	1.76%	4.98%	3.42%	8.04%

Table D 20 Percent Annual Reductions from Baseline (Aggressive and Maximum)
Long-Term: 2030, 2040, 2050

Annual Percent Reductions from Baseline (Long-Term)	Aggressive Deployment Annual Percent Reduction			Maximum Deployment Annual Percent Reduction		
Bundle	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Near Term/Early Results	11.8%	14.0%	14.3%	15.2%	17.0%	17.4%
Long Term/Max Results	13.0%	15.4%	18.7%	18.3%	20.6%	24.9%
Land Use/Transit/Nonmotorized	6.3%	7.8%	9.1%	10.4%	12.9%	14.9%
System/Driver Efficiency	8.7%	9.8%	10.8%	10.4%	10.4%	12.2%
Facility Pricing	2.7%	2.6%	3.3%	3.4%	2.7%	4.2%
Low Cost	10.9%	15.6%	15.5%	14.4%	19.4%	18.4%

Table D.21 Percent Annual Reductions from 2005 (Aggressive and Maximum)
Short-Term: 2015, 2020

Annual Percent Reductions from 2005 (Short Term)	Aggressive Deployment Annual Percent Reduction		Maximum Deployment Annual Percent Reduction	
Bundle	**2015**	**2020**	**2015**	**2020**
Near Term/Early Results	3.4%	2.0%	6.7%	8.1%
Long Term/Max Results	2.4%	3.1%	4.6%	9.0%
Land Use/Transit/Nonmotorized	1.2%	-1.0%	2.3%	2.5%
System/Driver Efficiency	1.5%	1.3%	3.2%	4.4%
Facility Pricing	0.4%	-3.2%	0.7%	-2.2%
Low Cost	1.9%	2.2%	3.6%	6.2%

Table D.22 Percent Annual Reductions from 2005 (Aggressive and Maximum)

Long-Term: 2030, 2040, 2050

Annual Percent Reductions from 2005 (Long-Term)	Aggressive Deployment Annual Percent Reduction			Maximum Deployment Annual Percent Reduction		
Bundle	2030	2040	2050	2030	2040	2050
Near Term/Early Results	9.1%	14.1%	14.4%	12.3%	17.3%	17.4%
Long Term/Max Results	11.3%	15.6%	18.3%	16.7%	20.9%	24.0%
Land Use/Transit/Nonmotorized	4.4%	7.9%	9.2%	7.6%	13.0%	14.4%
System/Driver Efficiency	6.0%	9.9%	11.8%	7.7%	10.6%	12.2%
Facility Pricing	0.2%	1.6%	3.3%	1.5%	2.7%	4.2%
Low Cost	8.9%	12.3%	15.8%	11.9%	15.6%	18.4%

Table D.23 Cumulative Reductions (Aggressive and Maximum)

2020, 2030, 2050

Cumulative GHG Reduction	Aggressive Deployment Cumulative GHG Reduction (mmt)			Maximum Deployment Cumulative GHG Reduction (mmt)		
Bundle	2010-2020	2010-2030	2010-2050	2010-2020	2010-2030	2010-2050
Near Term/Early Results	635.61	2,348.48	7,056.11	1,144.45	3,535.89	9,273.58
Long Term/Max Results	564.14	2,410.20	7,630.16	1,061.46	3,818.18	10,835.60
Land Use/Transit/Nonmotorized	284.80	1,132.23	3,759.68	524.59	1,972.78	6,280.38
System/Driver Efficiency	353.74	1,620.82	4,950.81	652.14	2,302.26	6,011.65
Facility Pricing	90.53	464.14	1,365.43	180.89	708.78	1,697.94
Low Cost	458.48	2,199.51	7,453.12	822.02	3,241.02	9,762.23

Table D.24 Percent Cumulative Reductions from Baseline (Aggressive and Maximum)

2020, 2030, 2050

Percent Cumulative GHG Reduction from Baseline	Aggressive Deployment Percent Cumulative GHG Reduction			Maximum Deployment Percent Cumulative GHG Reduction		
Bundle	**2010-2020**	**2010-2030**	**2010-2050**	**2010-2020**	**2010-2030**	**2010-2050**
Near Term/Early Results	3.7%	6.9%	10.4%	6.6%	10.3%	13.7%
Long Term/Max Results	3.3%	7.0%	11.3%	6.1%	11.1%	16.0%
Land Use/Transit/Nonmotorized	1.6%	3.3%	5.6%	3.0%	5.8%	9.3%
System/Driver Efficiency	2.0%	4.7%	7.3%	3.8%	6.7%	8.9%
Facility Pricing	0.5%	1.4%	2.0%	1.0%	2.1%	2.5%
Low Cost	2.6%	6.4%	11.0%	4.7%	9.5%	14.4%

Table D.25 Annual Costs and Savings (Aggressive and Maximum)

2015

Included Costs and Vehicle Cost Savings (2015)	Aggressive Deployment Billion Dollars		Maximum Deployment Billion Dollars	
Bundle	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
Near Term/Early Results	$13.43	$53.64	$22.34	$107.42
Long Term/Max Results	$79.17	$26.96	$165.24	$52.34
Land Use/Transit/Nonmotorized	$25.09	$24.07	$45.14	$47.32
System/Driver Efficiency	$60.40	$4.47	$127.48	$7.63
Facility Pricing	$71.01	-$3.89	$138.75	-$7.76
Low Cost	$4.64	$16.70	$7.63	$35.58

Table D.26 Annual Costs and Savings (Aggressive and Maximum)

2020

Included Costs and Vehicle Cost Savings (2020)	Aggressive Deployment Billion Dollars		Maximum Deployment Billion Dollars	
Bundle	**Implementation Cost**	**Vehicle Cost (Savings)**	**Implementation Cost**	**Vehicle Cost (Savings)**
Near Term/Early Results	$17.34	$85.73	$25.79	$148.58
Long Term/Max Results	$80.71	$97.17	$156.93	$172.86
Land Use/Transit/Nonmotorized	$42.48	$65.37	$66.27	$117.24
System/Driver Efficiency	$60.92	$43.55	$110.88	$66.19
Facility Pricing	$69.62	$9.55	$133.86	$20.11
Low Cost	$17.18	$67.39	$20.68	$121.52

Table D.27 Annual Costs and Savings (Aggressive and Maximum) *2030*

Included Costs and Vehicle Cost Savings (2030)	Aggressive Deployment Billion Dollars		Maximum Deployment Billion Dollars	
Bundle	Implementation Cost	Vehicle Cost (Savings)	Implementation Cost	Vehicle Cost (Savings)
Near Term/Early Results	$17.64	$98.67	$23.57	$139.59
Long Term/Max Results	$70.57	$154.28	$129.69	$236.89
Land Use/Transit/Nonmotorized	$44.15	$101.66	$66.45	$174.67
System/Driver Efficiency	$48.02	$77.17	$82.16	$93.40
Facility Pricing	$64.53	$40.99	$113.13	$56.62
Low Cost	$17.84	$115.00	$17.55	$163.81

Table D.28 Annual Costs and Savings (Aggressive and Maximum) *2050*

Included Costs and Vehicle Cost Savings (2050)	Aggressive Deployment Billion Dollars		Maximum Deployment Billion Dollars	
Bundle	Implementation Cost	Vehicle Cost (Savings)	Implementation Cost	Vehicle Cost (Savings)
Near Term/Early Results	$12.35	$71.69	$19.24	$94.13
Long Term/Max Results	$42.33	$139.51	$89.24	$215.19
Land Use/Transit/Nonmotorized	$29.71	$97.48	$58.99	$171.09
System/Driver Efficiency	$24.17	$57.55	$41.00	$66.20
Facility Pricing	$39.59	$35.90	$81.27	$59.44
Low Cost	$10.11	$99.53	$9.93	$133.43

Table D.29 Cumulative Costs and Savings (Aggressive and Maximum) *2020*

Included Costs and Vehicle Cost	Aggressive Deployment Billion Dollars		Maximum Deployment Billion Dollars	
Savings Cumulative 2010-2020 Bundle	Implementation Cost (2010-2020)	Vehicle Cost Savings (2010-2020)	Implementation Cost (2010-2020)	Vehicle Cost Savings (2010-2020)
Near Term/Early Results	$183.47	$548.20	$275.59	$1,007.88
Long Term/Max Results	$833.07	$475.85	$1,648.55	$919.32
Land Use/Transit/Nonmotorized	$335.41	$348.17	$530.34	$652.42
System/Driver Efficiency	$655.39	$168.33	$1,265.58	$278.34
Facility Pricing	$734.22	$10.99	$1,411.87	$39.06
Low Cost	$127.03	$296.96	$167.87	$584.50

Table D.30 Cumulative Costs and Savings (Aggressive and Maximum) *2030*

Included Costs and Vehicle Cost	Aggressive Deployment Billion Dollars		Maximum Deployment Billion Dollars	
Savings Cumulative 2010-2030 Bundle	Implementation Cost (2010-2030)	Vehicle Cost Savings (2010-2030)	Implementation Cost (2010-2030)	Vehicle Cost Savings (2010-2030)
Near Term/Early Results	$382.41	$1,531.62	$521.67	$2,496.10
Long Term/Max Results	$1,604.58	$1,853.72	$3,083.81	$3,112.97
Land Use/Transit/Nonmotorized	$793.32	$1,232.21	$1,218.99	$2,213.55
System/Driver Efficiency	$1,211.36	$856.89	$2,226.55	$1,162.79
Facility Pricing	$1,433.85	$325.41	$2,651.64	$491.99
Low Cost	$331.93	$1,319.92	$375.99	$2,126.33

Table D.31 Cumulative Costs and Savings (Aggressive and Maximum) *2050*

Included Costs and Vehicle Cost	Aggressive Deployment Billion Dollars		Maximum Deployment Billion Dollars	
Savings Cumulative 2010-2050 Bundle	Implementation Cost (2010-2050)	Vehicle Cost Savings (2010-2050)	Implementation Cost (2010-2050)	Vehicle Cost Savings (2010-2050)
Near Term/Early Results	$676.31	$3,211.42	$945.24	$4,779.30
Long Term/Max Results	$2,611.31	$4,846.04	$5,104.62	$7,667.75
Land Use/Transit/Nonmotorized	$1,438.97	$3,269.58	$2,389.73	$5,740.16
System/Driver Efficiency	$1,869.94	$2,213.63	$3,337.93	$2,736.52
Facility Pricing	$2,371.22	$1,121.27	$4,483.58	$1,656.42
Low Cost	$599.32	$3,499.01	$634.30	$5,102.68

Appendix E

Equity

1.0 Introduction

1.1 Overview

Moving Cooler provides an analysis of the role that mobility-related strategies can play in helping reduce greenhouse (GHG) emissions from transportation. It identifies the effectiveness and cost effectiveness of a wide range of strategies and combinations, or "bundles," of strategies and discusses how implementation of different types of strategies work together to achieve not only GHG reductions but also other societal goals.

This equity analysis identifies the equity issues associated with implementing these different strategies as well as some of the actions needed to resolve them. The primary focus of the equity analysis is on determining the distribution of the costs and benefits of strategies and bundles among income groups. The likelihood of equity issues differs very greatly across strategies and bundles. For most strategies, equity is not a serious issue and already is being adequately addressed in the transportation planning and decision-making process.

The *Moving Cooler* study examines strategies specifically intended to reduce GHG emissions in nine major categories: pricing; land use and smart growth; non motorized transport; public transportation; regional ride sharing and car sharing and employer-based commute programs; regulatory approaches; systems operations and management; bottleneck relief and capacity expansion; and multimodal freight improvements.

Many of the strategies and bundles of strategies considered in *Moving Cooler* do not raise great equity concerns. For example, the benefits of comprehensive programs for operations, commuter ride sharing, transit investment, highway investment, and other strategies are typically spread across most or at least many groups. The equity of such investments can be determined by the mix of investments within each such category. These types of programs are not inherently equitable or inequitable. Rather, equity for all categories of strategies with the exception of pricing can be addressed by distributing the services and investments so as to impact equitably on various groups. Only for the pricing measures is equity an inherent issue which cannot be remedied as readily. Pricing has inherently different equity impacts on different groups, and equity issues arising from pricing need to be addressed through other compensatory measures outside pricing. In addition, equity for low-income groups also may involve assuring that there are alternatives to automobile travel, and thus transit investments and services will be an important contributor to equity.

The *Moving Cooler* study shows that pricing strategies, including congestion pricing, motor fuel taxes, and carbon taxes can yield substantial reductions of GHG emissions.

However, analysis of the equity of potential measures demonstrates that there are significant issues associated with these pricing strategies on low-income populations. While the quantitative equity analysis provided in this memorandum focuses on congestion pricing, motor fuel, and carbon taxes, the results are applicable to all strategies that impact upon price, including vehicle miles of travel (VMT) fees and tolls.

It also is important to note that these pricing strategies have important benefits beyond GHG reductions that can help offset equity issues. For example, the pricing strategies are able to generate substantial revenues that will help pay for the implementation of other effective strategies, such as transit and highway capital and operating investments which reduce delay. Furthermore, the improvements that then accrue to system operations as a result of the implementation of the pricing strategies and the other strategies that are now affordable also can relieve equity issues. Investments in these other strategies also can provide strong economic returns, with benefits exceeding costs by ratios of from 2-1 to 3-1. In other words, the benefits begin to multiply. The reinvestment of the revenues from pricing measures into other strategies both resolves the primary equity issues and makes further contributions to reducing GHG emissions over and above the reductions that occur as a direct result of the pricing or motor fuel tax or carbon tax measures.

Although this analysis focuses on the equity implications of the *strategies* for GHG reductions that are considered as part of the *Moving Cooler* study, the equity of GHG reductions themselves is not addressed, although it is a major concern. GHGs are assumed to impact on all parties, but their impacts may be greater upon areas that are more vulnerable to the impacts of climate change, such as low lying areas. In addition, lower-income persons are less likely to have the resources to adapt to global climate change, by moving to less vulnerable locations, for instance.

■ 1.2 Definitions of Equity in Transportation

Rosenbloom (2009) notes that "Equity… is a multidimensional concept, difficult to define, evaluate, or create." The term equity has both a descriptive (positive) and normative use. A wide range of terms and concepts are used in discussing equity, as evidenced by the list below:

- Opportunity, or process, equity – fair access to the planning and decision-making process (fairness).
- Horizontal equity – treatment of individuals within a class.
- Vertical equity – treatment of different classes.
- Spatial, or territorial, equity – benefits and costs are distributed equally over space (Viegas, 2001).

- Longitudinal, or temporal, equity – compares the past, present, and future (Viegas, 2001).
- Market equity, or the benefit principle – the benefit received is proportional to the price paid (Figure 1.1).
- Social equity – allocation is proportionate to need (Jones, 2003).
- Outcome, or result, equity – just consequences of a decision (justice).

Most equity concerns are determined by those who are a party to the action, which is how a change affects users. But many changes affect non-users. These changes are considered externalities. Levinson (2002) identifies two types of externalities in transportation:

1. Technical Externalities – the classic external costs of air pollution, noise pollution, and carbon emissions, borne by those who do not directly benefit from the travel (neither the traveler nor the road agency).
2. Mobility Externalities – transportation projects benefit some parties but worsen conditions for other travelers. Intermodal mobility externalities are illustrated by a quote from Ivan Illich: "Motorized vehicles create remoteness which they alone can shrink. They create distances for all and shrink them for only a few." (Illich, 1974). Mobility externalities can occur within a mode as well, as when a freeway interrupts a local grid of streets, or traffic calming reduces traffic on some streets to the detriment of others. Inequity is endemic in transportation, as noted in Levinson (2005), which examines the "micro-foundations of congestion and pricing" and illustrates using game theory for a very simple case that road pricing on a facility where travelers can adjust travel times (with associated schedule delay penalties) may have Nash equilibria that are inequitable. Some travel costs are borne directly by the user while different costs are borne by other users (Nash, 2001).

Ramjerdi (2006) summarizes a number of potential measures of inequality (mean, range, variance, coefficient of variation, relative mean deviation, logarithmic variance, variance of logarithms, Theil's entropy, Gini coefficient, Atkinson measure, and Kolm measure), and finds none which are both scale invariant and translationally invariant. There is no consensus measure among researchers, and each defines equity differently.

1.3 Current Practice in Equity Analysis

The current state of the art of addressing equity in transportation investments for different income groups has been primarily through analyses of the equity of transportation programs at the metropolitan level. Studies of equity have addressed overall equity and environmental justice concerns. Environmental justice specifically focuses on whether programs and investments are fairly beneficial to disadvantaged groups in relation to other groups. The analysis presented in *Moving Cooler* makes use of the findings of these metropolitan studies of equity.

The type of analysis done by metropolitan planning organizations (MPO) spans the issues which are sometimes termed "environmental justice." We are always concerned about equity when it comes to introducing changes to the existing system, because of perceptions of fairness and government's role in increasing, or at least not diminishing, social welfare. However, there also are legal considerations of equity that have collectively come to be known as the transportation-related field of Environmental Justice, defined as the following:[149]

- To avoid, minimize, or mitigate disproportionately high and adverse human health or environmental effects, including social and economic effects, on minority populations and low-income populations;
- To ensure the full and fair participation by all potentially affected communities in the transportation decision-making process; and
- To prevent the denial of, reduction in, or significant delay in the receipt of benefits by minority populations and low-income populations.

These are issues that are required to be addressed in regional and project-level plans. As articulated by a publication from the Institute for Transportation Studies at the University of California at Berkeley, equity and fairness issues most frequently arise when:[150]

- Some communities get the benefits of improved accessibility, faster trips, and congestion relief, while others experience fewer benefits;
- Some communities suffer disproportionately from transportation programs' negative impacts, like air pollution;
- Some communities have to pay higher transportation taxes or higher fares than others in relation to the services that they receive; or
- Some communities are less represented than others when policy-making bodies debate and decide what should be done with transportation resources.

---

[149] Federal Highway Administration. Questions and Answers on Environmental Justice and Title VI. April 2008. Available on-line at: www.fhwa.dot.gov/environment/ejustice/facts/index.htm.

[150] Cairns, Shannon; Greig, Jessica; and Wachs, Martin. Environmental Justice and Transportation: A Citizen's Handbook, Institute of Transportation Studies, University of California at Berkeley, January 2003, http://www.its.berkeley.edu/publications/ejhandbook/ejhandbook.html, accessed October 9, 2005.

These issues are addressed now through analyses by MPOs which determine the distribution of impacts on communities and groups from both the existing transportation system and from the planned future improvements to the system. MPOs show the current levels of accessibility for various communities, as measured by jobs within a certain travel time via highway or via public transportation, utilizing their travel modeling systems, and then forecast the impacts of their long-range plan on these measures for those communities. They assess potential negative impacts on low-income groups and on communities for both services and environmental impacts.

Equity is addressed in this report primarily in relation to income groups, and also, where applicable, in terms of users of different modes or of different types of vehicles (such as personal vehicles versus freight vehicles). There are other equity issues which already are addressed regularly, although not necessarily resolved. Two of the more regularly discussed include:

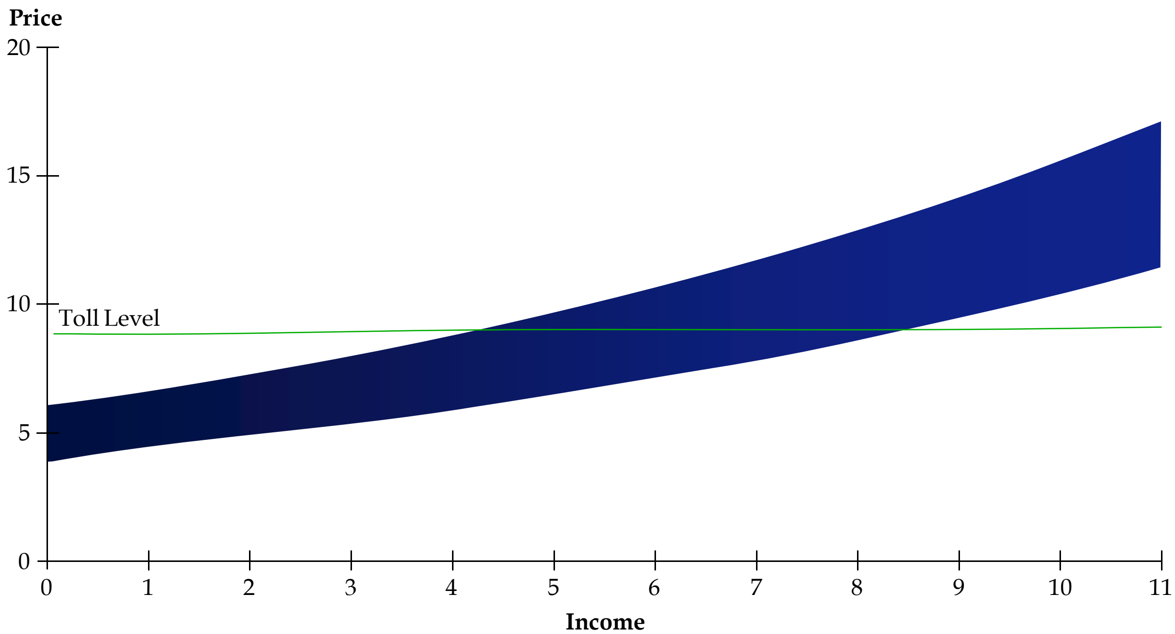
1. The equity of highway expenditures and highway fees across vehicle classes. Equity studies such as highway cost allocation studies specifically address whether road users of particular types are paying their appropriate share of road expenditures. Highway cost allocation studies generally address whether total shares of revenue payments by truckers and by auto users are relatively fair in relation to the costs each class of vehicle imposes on the highway system. Highway cost allocation studies are supported by an array of modeling procedures which are used to calculate the shares of costs and shares of revenues which are attributed to each vehicle type. Highway cost allocation is a well established mechanism to deal with the equity of expenditure programs versus revenues in relation to types of vehicles.
2. The spatial equity of transportation expenditure allocations in relation to where transportation fees and revenues that fund these allocations are generated. A great deal of attention at the Federal level also is addressed to the equity concern that the share of Federal highway expenditures allocated to each state is close to the share of Federal highway taxes calculated to be collected within each state. The Federal Highway Administration maintains models that attribute Federal highway user revenues to each state and which estimate the distribution of revenues to each state. In contrast, in distributing expenditures within a state, state legislatures have not historically pushed for returns of shares of attributed fees to those parts of the state in proportion to where the fees are generated. Virtually all states spend a much greater share of state highway user revenues on rural roads than the share that is generated by travel on those roads. They tend to do this to help ensure equity in relation to outcomes; specifically, rural road users, like their urban counterparts, should have mobility and connectivity even though user fees from the rural areas are not sufficient to fund the roads in those areas. However, some regional transit agencies allocate expenditures to services for the jurisdictions which they serve in relation to the revenues from those jurisdictions, and some do not.

1.4 Structure of this Appendix

This appendix provides a summary of the results of the *Moving Cooler* equity analysis, and documents the assumptions, data sources, and analytic approaches which have been used to assess the equity of strategies and bundles which are designed to reduce greenhouse gases (GHG) in transportation. The results of *Moving Cooler* and this supplemental equity analysis will provide critical input to national and state deliberations about the environmental and economic policies for transportation.

- Section 2.0 presents a comprehensive equity policy discussion and a review of the literature on equity, with a focus on pricing.
- Section 3.0 presents the results of the equity analysis, including a summary of equity impacts of each GHG reduction measure and a quantitative analysis of the equity of pricing strategies, including congestion pricing, motor fuel taxes, and carbon taxes. In addition, it outlines some of the options for reducing inequity by reinvesting revenues which these fees will generate.
- Section 4.0 provides a summary and conclusions.
- Section 5.0 provides a list of references cited in this appendix.

Figure 1.1 Willingness to Pay for Road Pricing by Income versus Price



Note: As income rises, willingness to pay increases, for low-income individuals, price always exceeds willingness to pay, while for very high income individuals, the opposite occurs, in the middle, travelers will sometimes pay.

2.0 Literature Review of Equity Issues in Transportation

This section provides a review of the literature on equity concerns in transportation strategies that can be used for GHG reduction. As shown in this literature review, the greatest volume of literature is to be found in investigations of the equity impacts of pricing or taxing strategies, reflecting concerns about the monetary impacts that can be imposed by these strategies on lower-income travelers.

Section 2.1 provides an in-depth treatment of pricing and taxing strategies on equity, reflecting the volume of literature on that topic, and the relative importance it is given in equity discussions in transportation. Sections 2.2 – 2.6 review the literature on equity in land use, non-motorized strategies, public transport, commuter strategies, and operations strategies.

2.1 Equity in Pricing Measures

Equity issues are of greatest importance for those *Moving Cooler* strategies that impact upon pricing, because lower-income individuals may have lesser ability to absorb the impacts of changes in pricing. This is supported by extensive equity literature examined in this section. Since income distributions determine people's ability to pay, those measures that impose higher or new prices as a means to reduce GHG emissions raise the most important equity concerns.

Additional quantitative results are found in equity studies conducted by MPOs, sometimes in conjunction with environmental justice analysis. These equity analyses look at the impacts on income groups of the investments proposed in regional transportation plans. Combining the results of these two types of quantitative studies produces a fairly exact parallel to the *Moving Cooler* bundles of interest with regard to equity. Those bundles are comprised of pricing strategies combined with the investment of the resulting revenues. As demonstrated by this equity analysis, pricing alone without consideration for how revenues are used has significant equity problems. Only reinvestment or redistribution of the pricing revenues can address the equity issues created by this category of strategies.

Pricing seeks to recover the social costs of driving not previously charged for, resulting in revenue gains to government. Until assumptions are made about what would be done with this revenue, it is difficult to determine whether individual groups, or society as a whole, would be better off. Distribution of revenue is an age-old political issue, and it would be no different with congestion pricing. For the sake of fairness and gaining political support, there would be a strong temptation to use the revenue to overcompensate the losers or to spread benefits around to all groups. In all circumstances, an underlying purpose of redistributing revenue would be to make a positive contribution to society in some way. Some approaches to achieve this include:

- Investing in transit improvements in the affected area;
- Investing in highway improvements (e.g., parallel arterials);
- Rebating pricing fees (or perhaps motor fuel taxes);
- Reducing general taxes such as income, property, or sales taxes;
- Awarding unspecified grants to the affected communities; and/or,
- Devising a system whereby users during peak times pay a price, and those who travel during off-peak get a credit. Credits might be used for travel on another day or on transit.

It is important to note, however, that these uses of revenue contrast with more traditional public ideas of how traditional toll revenues should be used. "Lessons Learned" from the FHWA's Value Pricing Pilot Program suggest that people support the use of tolls to benefit corridor-level improvements, including the transit system; or that toll revenue should only be spent for the benefit of those paying the toll, in particular, through investments in the highway being tolled. This is the traditional political justification for financing roads, bridges, and tunnels with tolls.

An interesting treatment of this topic by University of California planners King, Manville, and Shoup suggests using congestion pricing revenue to compensate communities directly.[151] Their argument is that those people perceiving themselves as losers under congestion pricing are likely to form strong political resistance to the idea. As a result, one mechanism to gain support would be to target the distribution of revenue to create more groups that perceive themselves as winners, and thus, would be more likely to be supportive. These payments could include highway, transit, or other types of investments examined in *Moving Cooler* which have added positive impacts on GHG reductions.

2.1.1 Why is Pricing Studied?

Alternatives to the gas tax to pay for roads are motivated by numerous factors:

---

[151] David King, Michael Manville, Donald Shoup, *The Political Calculus of Congestion Pricing*, January 2007.

- First, there is a trend toward higher-mileage cars and ultimately away from gasoline as the fuel of choice for both environmental and economic reasons.

- Second, there is a desire to better tie road charges to road use, in particular to be specific by time of day and location to address congestion issues.

- Third, there is a need to raise additional revenues for transportation, both to maintain and replace aging infrastructure, and to expand transportation networks to serve growing demand.

- Fourth, there is an environmental interest in directly internalizing the non-congestion externalities of road use, and the fuel tax can only do so indirectly (though gasoline consumption is a good proxy for carbon emissions, it ties less perfectly with other pollutants, and more importantly is not correlated with the health damages which depend on where the fuel is burned and the rate of intake of those pollutants).

- Fifth, there is political advantage to shift the burden of payment. Levinson (2000, 2001) examined the issue of using tolls as a form of tax exporting. By placing tolls at boundaries, jurisdictions can ensure that out-of-jurisdiction (e.g., out-of-state) residents pay for their use of the road, and perhaps more than their fair share, in contrast to a system of gas taxes where out-of-jurisdiction residents may never pay their costs (if they buy gas where they live rather than where they drive) and would instead free ride on the road system.

The free rider problem identified in the last point exemplifies certain types of equity issues. The first is the spatial equity problem. Roads are provided locally, but used by both local and non local users. For large jurisdictions, this is a minor issue as most travel is local, but for small jurisdictions, the likelihood of non local travelers increases. This explains why tolls are more common on the east coast of the United States where jurisdictions are small and ınterstate travel is a relatively large share of all travel compared with the big states in the western United States. The second is the benefit principle, where those who benefit should pay in proportion to their benefit rather than in proportion to the cost imposed (which may be related). If non residents free-ride they violate the benefit principle. In contrast, with tolls, if non residents pay more than their use, cross-subsidizing local travelers, the benefit principle is violated in the opposite direction. King et al. (2007) extends Levinson (2001) to identify subunits of government as potential recipients of recycled revenue (as opposed to being the unit which tolls roads) to create a class of beneficiaries from road pricing, and thereby shift the political calculus.

Ramjerdi (2006) writes: "Sen (1992) states that every normative social theory that has stood the test of time demands equality along some dimension that is regarded as particularly important in that theory. Sen also suggests that demanding equality in one space implies inequality in some other space." Within road pricing there are three decisions that affect equity: allocating the burden of charges, spending the revenue, and distributing the externalities (Langmyhr, 1997), while with ramp metering there is no revenue to spend, the burden of delay is distributed to different parties. Rietveld (2003) argues equity plays two roles in transport: inequity may be a side effect of attempts to address efficiency and environmental issues, and equity may be the target of policies such as building infrastructure in undeveloped areas.

(Flynn, n.d.) Reviews the literature and identifies steps necessary to implement pricing in New York, he cites (Jones, 2002) that inequity can be mitigated through the following parameters:

- "The basis of charging (e.g., point charges, cordon or area charges, and trip length charges);
- The area covered by the charge;
- The time period covered;
- Discounts or exemptions; and
- Linkages to other transport charges, such as reduced public transit fares."

The first three items are questions of the design of the system. The latter two are questions of what to do with the revenue that is collected.

On the topic of road pricing and ramp metering, which are at the intersection of engineering and economics, equity arises as a central feature in effectiveness, acceptability, and implementability. Foster (1974, 1975) was perhaps the first to argue that road pricing discriminates against the poor. Depending on circumstances, this may be true if revenues are not recycled (i.e., used in a way that benefits the lower-income group). The marginal utility of money may be higher among the poor, leading to difficulties in analyzing the welfare effects of pricing if money is assumed equally valuable (Brekke, 1997; Brekke et al., 1996; Medin et al., 2001).

Any change will create winners and losers, and though there is always a search for Pareto Efficient solutions (at Pareto Optimality no one can gain without someone losing), in practice these solutions are hard to come by, especially if it is desired that the losers actually be compensated (Pareto Efficiency only requires that compensation could theoretically be made, not that it actually take place). The Dalton Principle says that transfer of income to a lower-income individual from a higher-income individual, so long as it keeps the rankings of individuals unchanged, improves equity (Ramjerdi, 2006; Rietveld, 2003).

The equity issues associated with road pricing has not escaped academic attention; a brief review (almost certainly incomplete) has turned up more than one-hundred papers on the topic. The findings of the important contributions are summarized below.

2.1.2 Types of Road Pricing

Figure 2.1, in the form of a three-dimensional matrix, organizes the major dimensions of road pricing: the spatial resolution (which set of links are priced), the pricing objective, and the temporal resolution of how quickly prices shift. This matrix implies 6 * 5 * 3 = 90 different types of road pricing. And while incomplete, this considers much of the literature and likely policy directions. This does not directly address a number of other parameters (e.g., ownership, regulatory regime, duration of pricing period, relationship to other road charges, differentiation between cars and trucks).

The current U.S. situation, where gas taxes applied uniformly over states, is best described as the upper left cell of the front page of the matrix: general pricing with uniform links, with average cost prices, that are coarse (unvarying over time). The theoretical ideal from an economic efficiency point-of-view is in the bottom right of the last page of the matrix, general pricing with differentiated links (not all links have the same price), using first, best marginal cost prices which vary dynamically over time.[152,153]

[152] The development of first-best pricing is generally credited to (Pigou, 1912), who argues that resources can be most efficiently allocated by setting the price equal to the social marginal cost. This argument depends on a number of assumptions, many of which either do not hold or are difficult to ensure in practice, leading to the development of second-best pricing strategies.

[153] Pigou did not deal with dynamics of charging across a period of time, which awaited the development of Vickrey's bottleneck model (Arnott et al., 2003; Vickrey, 1965). Xin and Levinson (2006) distinguishes between *omniscient pricing* (where the toll operator knows both schedule delay penalties and desired arrival times) and *observable pricing* (where the toll operator can observe only delay).

Figure 2.1 Types of Road Pricing Strategies

Dynamic	Average Cost	Profit-Maximizing	Regulated (Price-Capped) Profit Maximizing	Second-best	Marginal Cost

Time-Varying	Average Cost	Profit-Maximizing	Regulated (Price-Capped) Profit Maximizing	Second-best	Marginal Cost

Coarse (Fixed)	Average Cost	Profit-Maximizing	Regulated (Price-Capped) Profit Maximizing	Second-best	Marginal Cost
General with Uniform Links					
Facility-Specific					
HOT Lanes					
Area-Based					
Cordon					
General with Differentiated Links					

Note: Each row indicates a different spatial type, each column a different pricing objective, and each page a different temporal resolution on the pricing strategy

2.1.3 Assessing Winners and Losers from Road Pricing

Winners and losers can be identified from road pricing schemes, and the literature has identified some classes, e.g., Gomez-Ibanez (1992); Hau (2005); Kitchen (2008); Langmyhr (1997), and Lo et al. (1996) developd a taxonomy of effects by System Users (stratified by income, mode, gender, geography, trip purpose, and cause (those who cause congestion)), Transportation Service Providers, and Society. There are other groups who win or lose, most notably the agency collecting the revenue, and those who might benefit from recycled revenue.

Often categories must be considered simultaneously, e.g., the effects of income may be ambiguous depending on auto ownership. Many low-income travelers do not own a car, and thus won't pay user charges (and may benefit from revenue recycling if the money is invested in transit modes), while those low-income travelers who do use a car spend an above average share of income on travel (Metz, 2008).

2.1.4 Empirical Findings

Urban Road Pricing

Singapore had the first road pricing deployment with its Area Licensing Scheme. It was later upgraded to Electronic Road Pricing. Olszewski and Xie (2005) argues the Singapore experience is evidence that road pricing is effective in controlling congestion. Wilson (1988) found that while the Singapore Area Licensing Scheme reduced peak-hour traffic by 65 percent, and bus ridership increased from 35.9 to 43.9 percent; more travelers (44.1 percent) saw longer travel time and fewer (36.1 percent) saw a reduction as slower (and now more crowded) buses substituted for faster cars. While congestion management as in Singapore may lower welfare for some users, investing in grade-separated alternative modes (in Singapore Mass Rapid Transit (MRT) and Light Rail Transit (LRT)) can mitigate the effects of the road charge (Goh, 2002).

Norway had an early implementation of congestion pricing using toll rings, where prices varied by time of day to manage congestion. Langmyhr (1997) uses the Norwegian case to understand equity considerations, developing a thorough framework of different equity concerns. Ramjerdi (2006) argues, after testing scenarios with various types of revenue recycling for a proposed charge in Oslo, Norway, no single equity measure is appropriate to use, and different measures lead to different policy conclusions; therefore multiple measures should be considered.

Banister (2002), writing just before the opening of the London Congestion Charging Scheme, notes there is almost no empirical literature on the effect of road pricing on land use, and whether it will lead to centralization or decentralization of activities. He argues that while "the impact of road pricing on all travelers is progressive," and bus users will benefit from both the speeds and the use of road pricing revenues, "the impact on low-income car owners is regressive" (Banister, 1994). The issue of boundary effects also arises, especially important with cordon pricing schemes as the cost of driving to areas just inside a boundary will be significantly higher than staying just outside. (One might note that spillover parking issues also arise naturally in such a case, especially if parking is uncharged or undercharged. Similarly, under cordon pricing, one would expect that parking charges would drop as road pricing increased, since demand for parking is lowered and parking is fixed, thereby mitigating the effectiveness of the cordon charge on locally destined traffic). The nature of the land use effects depends on the nature of the road pricing, and whether it is limited or extensive. If the price of travel increases generally, one expects a denser urban form as people try to reduce travel costs. However if the price of travel only increases locally, there may be substitution effects as people avoid the area with higher travel costs *ceteris paribus*.

Ison (1998) discusses the issues of implementing road pricing, and presents evidence that without revenue recycling, pricing is generally considered unacceptable, and the preferred way in the UK to allocate revenues raised from pricing was to public transport locally, and to local roads secondarily.

Ison and Rye (2005) notes how equity in the London congestion charging scheme can be achieved by providing exemptions from the charge for certain groups, e.g., "alternative fuel vehicles; vehicles driven by or carrying disabled people who have registered for a 100 percent discount; emergency vehicles; vehicles with nine or more seats; motorbikes and mopeds; black cabs and London-licensed mini-cabs; and residents within the charging zone (who get a 90 percent discount)." "[T]he key in terms of acceptance is to keep the inequity to a minimum."

Eliasson and Mattsson (2006) examines the then proposed Stockholm road pricing case for equity consequences. The two key issues they argue for equity are who is affected by the charge and how the revenue is used, which are much more important than any other issues such as value of time. In the case of Stockholm, it is argued that men, the wealthy, and those living in the center city, are affected most by the charge, while the revenue spending on public transport benefits women, and those with lower incomes, thus the scheme is progressive.

U.S. High-Occupancy Toll Lane Projects

Looking at the equity concerns associated with proposed HOT lane projects, which have been derided as "Lexus Lanes," Weinstein and Sciara (2006) notes that equity may arise as an issue at any stage of project development, and is not something can simply be addressed beforehand, but instead continuous monitoring of the equity implications projects is required both before and after opening.[154] Planners would be wise to engage the issue proactively. HOT lanes are generally coupled with parallel free lanes, where the free lanes may be left for equity reasons (Verhoef et al., 1996).

---

[154] The origin of the term "Lexus lane" is unclear, but a brief article on the subject can be found at Toll Road News: http://www.tollroadsnews.com/node/2143, attributing the term to Seattle-based HOV advocate Heidi Stamm.

Parkany (2005) identifies the equity issues associated with transponder ownership. Acquiring a transponder is a barrier to entry for many who wish to use roads metered by electronic tolls, and it turns out that many low-income households do not have either credit cards, or bank accounts that are often necessary prerequisites to transponder ownership. Examination of SR 91 and Pennsylvania Turnpike data shows wealthier individuals are both more likely to own transponders, and use electronic toll lanes more often given they own transponders. For routes like HOT lanes, where transponder ownership is mandatory to access the system, this may pose an additional equity issue, while when there are alternatives such as manual payment, the effect is not as severe.

A study of SR 91 by Sullivan (2000) found lower-income drivers approved of the lanes almost as much as wealthier drivers, though wealthier drivers did make more use of the facility.

Examining the I-15 HOT lanes in San Diego, Supernak et al. (2002) states "Equity issues did not emerge despite the fact that FasTrak users came from the highest-income groups." Users perceived the system as fair, as it was seen that travel-time benefits went to those who paid.

Smirti et al. (2007) summarizes literature and interviews a number of players for various congestion charging proposals in California. There was consensus that to achieve political acceptability, excess revenues should remain within the project corridor, and especially be allocated for transit.

The QuickRide system is a high-occupancy toll lane along the Katy Freeway in Houston (Burris and Appiah 2004). Burris and Hannay (2003) found that while usage among enrollees did not vary by income, the decision to enroll was correlated with income, with high-income travelers more likely to enroll in the system than those with lower incomes. Further the system is more widely used by long-distance than short-distance travelers, and by commuters more than travelers engaged in non-work trip purposes.

In Minnesota on the I-394 MnPASS lanes, while support was largely independent of income, it is clear that higher income individuals use the system more frequently, in part because of its location serving high-income communities, but even after controlling for location there is an income effect (Patterson and Levinson, n.d.). In the corridor though, income was not related to willingness to pay to save time Tilahun and Levinson (n.d.). Few individuals in the corridor cited social equity as a concern with the conversion of the carpool lanes to HOT lanes (Douma et al., n.d.).

2.1.5 Simulated Findings

There have been far more road pricing proposals than actual implementations. Thus many of the results about road pricing are based on computer simulations of the expected effects of road pricing rather than measurements of actual effects. While actual measurements are to be preferred where available, the relative dearth of road pricing implementations leads us to depend on simulations for some of our evidence. This section summarizes the results from simulations of particular proposed cases.

Urban Road Pricing

Europe and Japan

Mitchell (2005) considered the environmental justice effects of road pricing in Leeds, looking at the effects of changes on pollution by income category using a modeling approach. For the base case there is an association between economic deprivation and pollution levels. For the case with road pricing, the pollution reduction associated with pricing benefits the most deprived quartile more than the highest-income quartile. The exact changes depend on the specifics of the scenario. Further, the author argues that pricing addresses pollution inequity more effectively than Low Emission Zones (LEZ). Bonsall and Kelly (2005) also study the effects of the proposed road pricing scheme in Leeds, concluding road user charging will increase social exclusion for some drivers, especially for low-income, car-captive travelers.

Santos and Rojey (2004) shows that whether road pricing is regressive or progressive depends on circumstances, and tests via traffic simulation for proposed cordon toll scheme in three UK towns (Cambridge, Northampton, and Bedford), even before redistribution, because of the mix of incomes and mix of transit passengers, pedestrians, bicyclists, and drivers.

Raj´e et al. (2004) describes potential exemptions for the proposed Edinburgh congestion charge. It also considers the problems of boundary effects, especially the issue of spillover parking as people park on street at the edge of the congestion charge zone to avoid payment. Exemptions are a strategy to ameliorate some of the equity impacts and make projects more acceptable.

Fridström et al. (2000) tested a number of first-best and second-best pricing strategies for three scenarios: Edinburgh, Helsinki, and Oslo. Prior to revenue recycling, consumers were worse off, but there were positive welfare gains overall as the operator's gains exceeded consumers' losses. In the long-term pricing could reverse urban sprawl, and by increasing density make urban public transport more economically viable with increased economies of scale and increased ridership as travelers switch away from auto. A poll transfer of excess revenue (returning the money equally to all individuals) benefits the poor more than the wealthy, and not all money need be reimbursed in order to ensure a Pareto-improving scenario, just enough so that the poorest group is better off, leaving additional revenue which can be used in other ways. Looking at the question of spatial accessibility, pricing diminishes accessibility by car (using generalized cost, clearly if it improves travel time, time-based accessibility should increase), but increases accessibility by public transit (Fridström et al., 2000).

Teubel (2000) examines the effect of introducing road pricing on commuters in Dresden, Germany. As is commonly found, in the absence of revenue recycling "All measures indicate that the welfare is distributed more unequally after the introduction of road pricing than before. Both components of the welfare changes analyzed before contribute to this effect. The tolls itself as well as the travel time gains separately enlarge inequality." Revenue recycling can remedy the inequity provided the toll collection costs are not too high.

Maruyama and Sumalee (2007) compares cordon and area pricing schemes, (where a cordon toll requires payment each crossing, while an area-based toll requires payment once per day) testing the cases on a simulation of Utsunomiya, Japan, with a finding that while the area scheme has greater welfare than a cordon (and a higher optimal toll), it also has greater inequity. Larger coverage of either system increased welfare and greater tolls decreased equity.

United States

Anderson and Mohring (1997) finds from a transportation network model, that while a hypothetical comprehensive road pricing system in the Twin Cities would improve system efficiency, it will make most travelers worse off unless revenue is recycled. Mohring (1999) extended the analysis to consider difference by income category. Without revenue recycling under severe congestion, incomes needed to exceed $80,000 for travelers to experience welfare increases.

Johnston and Rodier (1999) running simulation experiments on the Sacramento, California region, found from a user welfare measure that pricing would have a detrimental effect on low-income households but positive for middle- and high-income categories in the absence of revenue recycling. Some strategies for investing the revenue in transit could produce positive benefits for all groups.

Testing a proposal to combine day-of-week rationing with tolls to buy out of the rationing, Nakamura and Kockelman (2002) state it will be "very difficult to provide a Pareto-improving policy for [the San Francisco-Oakland Bay Bridge] via pricing and rationing," and without revenue recycling, as had been theoretically proposed by Daganzo (1995) because the travel-time savings needed to be much greater than the simulation found. From an equity perspective, the scheme was most beneficial under pure rationing, with mixed rationing and pricing harming the lowest income group.

Road pricing of various kinds is being seriously considered in the Seattle region because the high-congestion levels due to topology and economic growth. Tolling across bridges to pay for their reconstruction, and more systematic approaches have been debated. Dill and Weinstein (2007) reports that "A poll of Washington State residents found that more people felt that tolls were fairer than increasing the gas tax if more funds were needed. Respondents who were specifically asked about fairness to lower-income groups felt even more strongly, with 52 percent indicating that tolls were fairer than increased gas taxes (27 percent) (Lawrence, 2006)."

Franklin (2006) focuses on the issue of vertical equity, distribution between groups. He simulates in a stylized way proposed charges on the Washington State Route 520 Bridge, connecting Seattle to Bellevue, assuming alternatives also are tolled, and testing the tolls for the morning peak period so that most trips are work-related, leaving mode as the primary substitution effect. The repressiveness of tolling will tend to be understated when excluding the income effect, but even without redistribution a toll may be Pareto-improving because the wealthy have a higher value of time.

Kitchen (2008) describes a pilot experiment conducted in the Puget Sound region using 400 in-vehicle, GPS-based tolling, where tolls would be assessed across the network (not on every street, but on major streets and highways). The households were all given a travel endowment, which would be drawn upon to pay tolls, and for which the remainder would remain with the household. They found value of time rose with wage rate, from about $10 per hour for the lowest-income group to $60 per hour for households making $150,000 per year or more. The study estimated the region would be able to raise about $3 billion per year, which compares with $500 million per year from gas taxes at current rates (though clearly annual administrative costs would be much higher from one percent for gas taxes, up to eight percent for network tolling, excluding initial capital expenditures). The study suggests the large revenue collected could be used to ensure fairness.

Safirova et al. (2004) considers short-run distributional effects from three pricing scenarios for Washington D.C.: HOT lanes, limited congestion pricing (on all freeway segments that have HOV lanes), and comprehensive congestion pricing (on all freeway segments) modeled in their START model. HOT lanes are most equitable, with benefits accruing to all income groups even before recycling, while achieving between 77 and 83 percent of the efficiency benefits associated with comprehensive road pricing, writing "HOV lanes, which have disappointed their many advocates, may end up being a Trojan horse for congestion tolls."

Safirova et al. (2006) considers longer term responses to policy, such as changes in land use and the location of jobs and residences. Urban economic theory assuming a mono-centric city predicts that long-run effects of comprehensive congestion pricing reduce the physical size of the city (i.e., increasing density). However more sophisticated models suggest that industry may leave the central core, and thus pricing might have a decentralizing effect. While workers may select commutes with shorter travel times in response to congestion charges, there is no guarantee that either workers or firms move toward the center. Safirova et al. (2006) models cordon tolls in Washington, D.C. extending their START model with the LUSTRE model. When considering land use effects, optimal (welfare maximizing) tolls are higher then when considering only transportation effects. However, as noted by Parry and Bento (2001), pricing without appropriate revenue recycling leads to higher wages but higher unemployment. Unlike that paper, the authors still found welfare gains even with lump-sum redistribution.

Looking a bit farther afield, some theoretical studies have examined hypothetical networks of private roads, and compared those with a scenario of publicly owned roads This is important to consider what might occur should road privatization become more widespread, as evidence suggests this is gaining additional credence with many new toll roads being privately owned and some states (e.g., Indiana) selling, or considering selling (e.g., Pennsylvania, New Jersey) their turnpike systems. Zhang and Levinson (2005*b*) find that under private autonomous links, the disparity in accessibility is much greater than under centralized control. Zhang et al. (2008) uses coupled agent-based travel demand

and link investment models to examine the effects of product differentiation in a network of private roads. Generally (and assuming no recycling as these are private roads), "users with lowest value of time harvest the least benefit (or suffer the most loss) from road pricing and investment decisions."

National Road Pricing

Steininger et al. (2007, n.d.) use a computable general equilibrium (CGE) approach to model private transportation in Austria with road pricing. Their model suggests that road pricing is in fact progressive, poorer households would bear a smaller burden than wealthier households. This is because poorer households spend less money on transportation in general, and use public transport more. It is noted that to be effective, redistribution of revenue needs to be independent of use, or it negates the benefits of road pricing.

The proposed national road user charge in England has been examined (Glaister and Graham, 2005, 2006), finding that if revenues are recycled through a reduction in the fuel tax, benefits accrue to rural more than urban residents, in contrast with the current situation in England (with its high fuel tax) where rural residents overpay compared with urban residents.

Bonsall et al. (2007) considers the proposed UK national road pricing scheme. The system is a national, largely distance-based charge. Concerns arise because of the prospective complexity of the scheme (which may raise difficulties for travelers without the ability to appropriately deal with the complexity and who find such complexity frustrating). It is especially pertinent as drivers are often unaware of the distances they travel, leading to charges perhaps being perceived as surprises. Further if charges are higher as well in certain areas (congestion charging), the exact formula may be difficult to discern.

Whitty and Imholt (2005) describes the proposed Oregon distance-based road user fee, extending some of the pioneering methods developed in Oregon from charging trucks (Oregon also was the first state to impose the gas tax). A distance-based charge is more equitable than existing gas taxes according to the benefit principle, costs are tied to benefits received, though of course as with any disruption will create winners and losers.

Forkenbrock (2005) advocates a move toward mileage-based road user charges, ultimately a national scheme for the United States. Forkenbrock, (2006) is critical of using electronic tolls on selected arterials and highways, noting the equity issue of double payment, as those tolls may be in addition to already collected motor fuel taxes. Further if tolls only collected on part of the system pay for the entire system, horizontal inequity may result.

2.1.6 Comparative Equity between Vehicle Classes

Gillen (1997) notes the inequity of the current transportation system, where all modes are subsidized to one degree or another. (If one includes local streets, the highway system is highly subsidized from general revenue (usually property taxes pay for local streets), if one includes only major roads, those direct costs are largely paid for with a gas tax, excluding external costs). He argues for a multipart tariff to pay for roads, an access charge (e.g., a motor vehicle license fee) to pay for fixed costs per user, a mileage fee for cars (perhaps as a fuel tax) to pay for infrastructure costs that are proportional to use, especially on uncongested roads, and congestion and environmental externality charges to optimize use of the system, and for trucks a weight-distance charge, as is used in Oregon, to replace the diesel fuel tax.

The 1997 Federal Highway Cost Allocation Study found that because heavy vehicles impose road damage disproportionate to their fuel taxes, they underpay compared to other classes of vehicles, and are thus cross subsidized (Forkenbrock, 2005).

Doll (n.d.) considers the issue of joint costs: infrastructure is shared between different classes of users (e.g., cars and trucks) and how much to toll each class is especially important, as many highway financing equity debates center on the problem of cost allocation. This especially became important in Germany with the implementation of TollCollect on Heavy Goods Vehicles (HGV). In the U.S. an incremental approach to costs is used, where infrastructure required by a class (and all heavier classes) (e.g., thicker pavement) is charged to those classes. In Austria, a statistical approach allocating costs is used. Each approach creates a different set of winners and losers, and thus there will be contention between the different user groups. Doll tries to find Shapley values derived from game theory for classes of users.

2.1.7 Road Pricing versus Other Revenue Mechanisms

Arnott (1994) examining the likelihood of implementing road pricing, and noting its difficulty, considers alternatives. While in favor of pricing in principle, he argues tolling only some streets (or tolling freeways while leaving streets untolled) can worsen congestion by displacing cars from facilities that are better able to tolerate congestion to those with less capacity. Parking is seen as an opportunity, as the cost of parking is higher in many urban areas than the rest of the cost of the trip. A number of second-best strategies are required in the absence of pricing.

As the gas tax continues to shrink its share of the transportation funding pie, alternatives must be considered. Road pricing and general funds are two possible sources, local option sales taxes are a third. Schweitzer and Taylor (2006) find local option sales taxes, which are popular in California as a mechanism for transportation financing to be more regressive than congestion charging. "The fuel tax is regressive with respect to income, but progressive with respect to highway use" since users of highways with more expensive (and less fuel-efficient) vehicles pay more. Sales taxes in particular penalize non-users.

2.1.8 Acceptability

Studies of acceptability have been widespread in the field of road pricing, as it is the political concerns, rather than their economic efficacy that have held back implementation

(Jaensirisak et al., 2005; Link and Polak, 2003; Marini and Marcucci, 2003; Odeck and Bråthen, 1997; Pädam and Wijkmark, n.d.; Schade and Schlag, 2003; Truelove, 1998; Whittles, 2003). Ungemah (2007) provides a practical set of questions to consider when examining the equity implications of various road pricing projects that may further acceptability. Dill and Weinstein (2007) summarizing results from a number of surveys suggest "Support for pricing options was not clearly related to income or ethnicity, as might be expected based upon the debates over equity" because the alternatives such as sales taxes are clearly less equitable. Lyons et al. (2004) survey a wide span of international evidence on the acceptability of road pricing finds acceptance rises when the "when the revenues are hypothecated to the development of transport generally."

In a survey of Sweden, Japan, and Taiwan about perceptions of pricing, perceived fairness was higher in Japan and Taiwan than Sweden, and acceptance depends on perceived fairness, which was the most important factor (Fujii et al., 2004). Different cultures respond differently to the social dilemma that congestion poses, a decision that is selfishly rational may be detrimental to society.

Rajé (2003) conducted a series of focus groups analyzing a potential road pricing scheme in Bristol, England, interviewing groups that are potentially socially excluded (ethnic minorities, non-English speakers, elderly, and young). The author concludes "[P]ublic acceptability of road user charging will be directly related to its perceived effects on local residents." Recycling the revenue to local transport initiatives would be important in addressing issues of fairness of the system to socially at-risk groups and thereby promoting social inclusion, but car-based transport will still be important for many members of these groups, and taxi and paratransit should be considered as possible recipients of recycled revenues.

2.1.9 Recycling the Revenue

Many strategies have been proposed to use the revenue raised from congestion pricing. The first cost is paying for the implementation of the system, which is much costlier than gas taxes (Levinson and Odlyzko, 2008). The remaining funds may be used for general revenue, additional road investments (either near where the tolls were collected or otherwise), or additional transit investments, to help encourage modal shift (both through the higher monetary cost of road travel and the better service provided by alternatives (which in the case of bus transport can take advantage of the faster road speeds as well), or returned to users in some other fashion.

Newbery and Santos (1999) argue in favor earmarking (hypothecating) fuel tax revenue for use in the road sector, as is done in the U.S. with the Highway Trust Fund. Currently in England, fuel taxes go into the general fund (and are high enough to account for 10 percent of total tax revenue, far exceeding the amount spent on roads). They call for a three-way allocation of road taxes: one part of road user charges dedicated to paying for roads, a second part paying for environmental damages, and a third part which revenue is raising. They write: "The political attractions of green taxes are obvious they are likely to command more support than other kinds of taxes, as they cloak the painful process of extracting revenue in a mantle of virtue and provide a salve for guilt. The main economic advantage of taxes that reflect the marginal damage is that they leave the user to decide how best to respond, rather than forcing him or her to make one particular kind of decision." Distinguishing green taxes is important, but difficult as accounting for the full costs of transportation, including determining the capital value of infrastructure (which is historically valued at less than replacement cost, potentially leading to under investment), has not generally been performed in a systematic way. Just as fuel taxes might be hypothecated to the road sector, the same argument can be made for road tolls.

Oberholzer-Gee and Weck-Hannemann (2002) address the question raised by Lave (1994) "Why is the world reluctant to do the obvious?" Arguing that "marginal cost pricing does not prevail throughout the economy, the information cost of determining Pigouvian taxes are likely to be considerable, and there is ample evidence that policy-makers do not maximize social welfare," the authors warn that prices can crowd out "intrinsic motivation" so that people who were previously doing good because they wanted to be responsible instead become selfish. Unfortunately the public tends to overestimate the effectiveness of many behaviors that result from intrinsic motivation (e.g., rewards for carpooling or using public transportation). Charges should avoid displacing people's underlying motives. The paper also argues that effective compensation should be in same dimension as the perceived losses from the charge. Thus if people lose the ability to travel in the peak, they should be compensated by easier travel at other times. Implicitly this argument is in favor of pricing credits of some kind.

2.1.10 Building Winning Coalitions

Button (2006) looks at alternative uses of the money raised by pricing with the hope of finding a winning coalition of supporters for such a change. Goodwin (1989) came up with the rule of three, allocating revenue to roads, transit, and reduced taxes, though not necessarily in equal shares, and Small (1992) makes a similar point. The question of earmarking arises as a way to help ensure support and show taxpayers that the money raised will be spent on something they desire, but which may not be economically efficient.

Small (1983) in an early simulated analysis of the effects of road pricing by income class uses a queuing model and a logit mode choice model to understand distributional effects. The highest-income group benefitted most from road pricing as while they paid more tolls, they had a higher value of time and saved more time. However once revenue was recycled, every income group benefitted, assuming congestion was sufficiently severe.

Mayeres and Proost (2002) use the idea of Pareto-frontier to tradeoff efficiency against equity in road pricing, and only consider changes to financing acceptable when they are Pareto-improving. This requires comparison of absolute utility levels across individuals, which is a theoretical difficulty. On the Pareto Equity-Efficiency Frontier, it is impossible to improve one individual's utility without worsening another's. The authors use Computable General Equilibrium (CGE) model of Belgium to argue that revenue recycling is required to achieve equity across income groups when a marginal social cost pricing regime is instituted.

2.1.11 Solving Societal Problems

To address broader social equity concerns (that is, to use transport policies to address societal inequities, not just transportation inequities or the marginal inequities associated with a change in transport policy), Nash (2003) argues for use of distributive weighting systems making use of Ramsey pricing (Ramsey, 1927) while retaining marginal social cost pricing as a starting point, following the ideas laid out in (Feldstein, 1972). This however may not fully recover costs.[155]

Parry and Bento (2001) considers the issue of how road pricing affects labor force participation. Theory suggests higher commuting costs will discourage the marginal commuter (the cost of the toll exceeds the benefit of congestion reduction for most travelers), and in most of the authors' numerical simulations, the welfare gains from road pricing (internalizing congestion costs) is less than the efficiency cost in the labor market. The authors suggest recycling the revenue to reduce labor taxes, offsetting the penalty associated with road prices, and that this is more effective than providing transit subsidies or providing a lump-sum payment to households (which does not encourage labor force participation).

Lindsey (2003), citing (Nix, 2001) notes that the Maritime provinces have resisted tolls because of spatial equity and double taxation rationales. He further identifies the issue of spillover effects on customers of firms that have located based on a particular assumption about the costs of freight, which post-tolling would see their cost structure change, citing (Lake et al., 1999).

Levine and Garb (2002) argues that traditional congestion pricing policies are mobility based, and thus may lead to spatial deconcentration as prices discourage driving to congested areas. The authors suggest tolls be redistributed to enhance accessibility (the ability to reach places) rather than mobility (the ability to move on the network).

Evans (1992) notes the redistribution aspects of road pricing may drown the efficiency gains. (This is similar to the case with ramp metering, discussed below, which serves foremost to transfer delay, and secondarily to improve system efficiency.)

Minimizing congestion and minimizing emissions can be at odds (Rilett and Benedek, 1994). First-best marginal social cost congestion pricing do not necessarily reduce emissions, but there is a toll pattern which does (Yin and Lawphongpanich, 2006).

---

[155] Ramsey pricing charges users in proportion to willingness to pay, using price discrimination to differentiate customers by their elasticity of demand, constrained to recover some amount of money.

2.1.12 Summary of Issues Regarding the Tradeoff Between Efficiency and Equity

The tradeoff between efficiency and equity emerges naturally as systems mature, as users compete over the allocation of scarce resources rather than growing the resource base. Issues of both process and outcome equity arise. In order to achieve process equity, transparency in the decision-making process, in addition to allowing input from all potentially affected individuals or groups representing them, is required.

Because of past experience, citizens will remain skeptical of claims about road pricing and ramp metering projects. The Pareto maxim, that so long as the losers could theoretically be compensated by the winners, the project is worthwhile, cannot be used as a political rustication, actual compensation is required. In the absence of such compensation, political opposition will continue to rise, and new construction will continue to be more and more difficult. Viegas (2001) posits that the reluctance of politicians to adopt road pricing despite receiving ideas along these lines suggest they are "seeing dimensions of the problem that the economists are not considering."

The perception of equity is highly subjective. A project that may appear equitable to an analyst across one set of dimensions may not to individuals affected by the project. Achieving consensus on decisions (thereby ensuring people believe the decision was equitable) may involve departure from objective "engineering" rationality, moving into the realm of politics. The issue is further complicated because equity concerns may mask opposition motivated by other reasons (Giuliano, 1994).

Resolving the equity versus efficiency problem requires a recognition that in complex, politically driven, mature systems like transportation, *equity is efficiency*. Without satisfying potential constituent groups, nothing can be accomplished. Logrolling, as described by Buchanan and Tullock (1962), recognizes the political efficiency under representative democracies for satisfying multiple groups. Side payments of cash or as an in-kind subsidy, bargaining, bundling of projects, and buying-off losing groups, or in the language of road pricing, revenue recycling, may be necessary to achieve consensus about acceptability, achieving a package that is considered win/win by the relevant players.[156]

From an equity perspective, HOT lanes are the pricing strategy least likely to raise public concerns, especially if it involves conversion of underutilized HOV lanes, or construction of new lanes without taking new right-of-way. While there is a slight bias in use towards wealthier individuals, all travelers benefit from the additional usable capacity, and the revenue can be recycled to benefit transit users in the corridor. However these are not as effective as more extreme pricing that is more comprehensive at the urban or national level. More comprehensive pricing is not optional in the same way as HOT lanes with

[156] Bundling ensures that not only is there a net benefit (when all projects are considered together), the number of winners exceeds the number of losers by a significant amount.

parallel free lanes are. Thus it raises more equity issues as to avoid the toll, drivers must switch modes, destinations, or time of day.

2.2 Land Use Strategies

More compact growth patterns have been cited as having a number of co-benefits. These include improved mobility/accessibility for populations without access to an automobile, and potentially safety benefits related to lower travel speeds and therefore less severe crashes. One study found that U.S. metropolitan areas with high levels of “sprawl” have higher traffic fatality rates than “non-sprawling” regions (Ewing, Pendall, and Chen, 2003). Another focused on Hawaii found that higher population densities were associated with lower crash rates (Kim & Yamashita, 2002). On the other hand, while overall emissions of air pollutant will decrease because of VMT reductions, concentrated land use has the effect of concentrating air and water pollutants in areas of potentially greater population exposure.

To the extent that growth management policies constrain the supply of land, consumers and businesses may experience higher land costs and therefore higher housing and floor space rents. Some have argued that growth management laws have had significant impacts on affordability. For example, Staley and Gilroy (2002) conclude that Florida’s Growth Management Act (GMA) may have contributed to a 15 percent decline in affordability between 1994 and 2000, and that Washington State’s GMA may have added about 0.7 percentage points to the housing inflation rate for each year the county had a comprehensive plan in place. Other studies, however, have found that growth management effects are minor after controlling for other factors. For example, an analysis of the urban growth boundary in Portland, Oregon found that the boundary has created upward pressure on housing prices, but the effect is relatively small in magnitude, contributing no more than $10,000 compared to an overall cost appreciation of $144,000 over their study period (Phillips and Goodstein 2000). A broader literature review concluded that market factors, including increased housing demand, increased employment, and rising incomes are much more significant influences; and furthermore, that policy changes to allow increased densities and smaller units have mitigated any affordability impacts by allowing housing supply to be increased within the growth boundary (Nelson et al. 2002).

A variety of both social benefits and ills have been assigned to “sprawl” versus “compact” land use patterns (Burchell et al. 1997). For example, some have argued that land use controls could reduce consumer welfare by constraining consumer choice (e.g., requiring smaller dwelling units and/or yards). To the extent that land use policy changes simply *accommodate* latent market trends for more compact development, this should not be a concern. However, more aggressive policy changes that restrict where people live could potentially lead to welfare losses. The factors that influence residential and neighborhood quality are complex and there is not a consensus on the extent to which compact land use may increase or decrease overall social welfare or benefit particular income groups.

2.3 Non-Motorized Strategies

Bicycle and pedestrian strategies can improve mobility by providing people with increased travel options, at a lower cost. Bicycle and pedestrian improvements and programs also should increase safety for non-motorized travelers, many of whom are lower income. Non motorized improvements will provide increased opportunities for, and will encourage, recreational activity as well as non-motorized transportation, thereby increasing physical activity and improving public health. The evidence from many studies on walking and bicycling demonstrate that regular participation in these activities provides a health benefit for people of all ages, genders, and races (Dunn et al., 1999).

2.4 Public Transportation Strategies

A major co-benefit associated with transit is its ability to reduce the relative degree that non-drivers are disadvantaged compared with motorists (VTPI 2008). Transit increases economic and social opportunities for people who are disadvantaged, and helps achieve equity objectives, such as helping physically and economically disadvantaged people access public services, education, and employment. The equity benefits of transit improvements will depend, to some extent, on the type of service provided, and the neighborhoods and employment opportunities served. For example, bus commuters tend to be lower income than light- and heavy-rail commuters, who similarly have lower incomes than commuter-rail users. Service improvements in low income and minority neighborhoods will have greater equity benefits than improvements serving wealthier areas. However, suburban transit service can be important for providing "reverse-commute" options for car-less central city residents to suburban jobs.

The numerical equity analysis in Section 3.2 illustrates that public transportation services may be relatively more used by lower-income groups than by all groups, and thus the benefits of public transportation investments may occur with higher proportionality towards lower-income groups. This is of course dependent on the specific services and investments.

2.5 Commuter Strategies

Like transit, commuter measures that improve the availability and quality or reduce the cost of travel for commuters, as well as those that provide information about alternatives, can improve equity by increasing mobility for lower-income commuters. Examples of strategies that may improve equity include additional transit service (e.g., shuttles), transit subsidies, and expanded ridesharing and vanpooling options. Strategies such as parking cash-out will particularly benefit lower-income commuters who may place a higher relative value on the cash benefit received (compared to higher-income commuters), if they choose not to drive. Similarly, ridesharing and vanpooling produce benefits through reduced vehicle operating costs which may be more meaningful to lower-income commuters. For example, at a round-trip length of 24 miles and a cost of $0.55 per mile per current Internal Revenue Service (IRS) guidance (as of January 2009), the typical commuter could theoretically save about $13 per day (although the actual savings may be less as this includes some fixed costs such as insurance).

Strategies that are implemented by increasing costs or providing other disincentives may have a negative equity impact. For example, increasing parking costs will represent a relatively greater hardship for lower-income commuters than for higher-income commuters. They will either need to pay a greater share of their income for parking costs, or make use of travel alternatives that may be less convenient.

Strategies that provide expanded work hour options, including telecommuting and compressed work weeks, can provide a social benefit by providing employees more flexibility in scheduling work and personal commitments. This could lead to increased job satisfaction, reduced stress, shorter commute time, and more free time during non-weekend periods for employees. Employees may use this time to become more engaged in their families and communities, leading to stronger family support and a deeper level of civic engagement. However, not all employees will prefer longer work days or working at home, or have compatible personal schedules. Therefore, if telecommuting or compressed work weeks are made mandatory, some employees are likely to be made better off while others are worse off.

2.6 Operations Strategies

On the whole, operations strategies do not have significant equity impacts. The one exception is ramp metering, which decreases travel time delays for one group of users (those starting farthest from the ramp metering zone) while increasing delays for the other users. The most significant empirical studies of ramp metering's real efficiency and equity effects were conducted in the Twin Cities during fall of 2000, when the metropolitan area's meters were turned off for eight weeks so that an assessment of their effectiveness could be made. While the primary assessment focused on the efficiency of the system, considering mobility and safety particularly (Cambridge Systematics, 2001), a transportation equity analysis of the delay distribution across space also was conducted. Levinson and Zhang (2006) fully describes the methodology. The latter paper considered equity for a number of corridors that had sufficient data. The authors found that, for instance on Route 169, a suburb-to-suburb limited access highway, connecting the North and South legs of the region's beltway, with ramp metering, the average travel speed (taking ramp delay into account) of the highway increases from 37 km/h to 62 km/h; travel delay per mile decreases from 136 seconds to 112.5 seconds, and the average travel time for one trip decreased from 610 seconds to 330 seconds. The shortest trips actually are hurt in mobility terms by ramp metering, while the longest trips, benefit the most. As is expected, metering redistributes delay. Moreover, metering makes the system less equitable overall, when considering the Gini coefficient, removing metering improved the equity of trip speed, running speed, and travel delay per km. Alternative ramp control strategies can improve equity, but the theoretically most efficient system (metering ramps closest to bottlenecks) is likely to be the least equitable (as delay is borne by a minimum number of ramps) (Kotsialos and Papageorgiou, 2004; Zhang and Levinson, 2005*a*, 2002), showing the real tradeoff between these two distinct objectives.

Unlike road pricing, there is no excess revenue to be recycled with ramp metering, so there is no direct way to compensate the losers in such a system. So long as the losses appear to be small, complaints may be minimal, but when delays get large, as was the case in the Twin Cities prior to 2000, a reaction may take place, leading to equity becoming a more significant constraint. In the Twin Cities ramp delays were capped at four minutes following the ramp meter shut down. As a consequence the efficiency of the system is degraded.

3.0 Analysis of Equity in Moving Cooler

Section 3.1 discusses the equity implications of each of the *Moving Cooler* GHG reduction strategies. Section 3.2 provides a more detailed analysis of the pricing strategies and Section 3.3 does the same for the motor fuel and carbon taxing strategies. Section 3.4 discusses some of the options for remedying the inequities generated by these strategies.

3.1 Equity Implications of Strategies in *Moving Cooler*

Travel behavior strategies may have consumer welfare, economic, and equity impacts that are either positive or negative, depending upon the specific strategy and how it is applied. Essentially, strategies that rely on measures such as improved service or financial incentives to induce voluntary behavior changes will, by definition, result in increased consumer welfare, through time savings, vehicle operating cost savings, and/or other benefits such as increased comfort and convenience. On the other hand, strategies that are implemented through disincentives (such as price increases) or requirements will make some people worse off.

Strategies that improve the availability and quality or reduce the cost of travel alternatives, as well as those that provide information about alternatives, can provide increased mobility to travelers and improve equity. The mobility benefit is particularly acute for low-income people for whom an automobile may be a financial hardship, as well as for children, seniors, and those with disabilities that make driving impossible.

Table 3.1 provides an assessment of equity impacts by strategy. The subsections below discuss each of the strategy groups shown in that table.

Pricing Strategies – Strategies in the pricing group require intensive analysis and consideration of additional measures to remedy equity concerns. This is, of course, reflects the monetary costs of driving and parking fees on low-income groups, for whom the costs may be more important than benefits (such as time savings) gained. These issues are explored in greater depth in Section 3.2, but a brief summary is provided here.

Modest to strong negative equity impacts on low-income groups are projected for the pricing strategies. For instance, congestion pricing has greater benefits for higher income than for lower income single occupant (drive alone) work trips, although both groups will see lower benefits from pricing itself than the costs of the tolls they will pay. Equity concerns with motor fuel taxes and carbon taxes are similar to those for other pricing strategies or fees, in their effect in increasing financial burdens on low-income groups. Carbon taxes, it should be noted, also will impact other fuel costs besides motor fuel costs. The one exception to these equity concerns is pay-as-you-drive insurance, which essentially turns existing fixed insurance costs into a per-mile insurance cost. Since the overall cost does not change, the equity effects are minimized. It is estimated that approximately two-thirds of drivers will experience cost savings under a fully implemented pay-as-you-drive regime, and low-income groups may benefit to the extent that they are not high-mileage drivers.[157] Pay-as-you-drive does create a difference in impacts between low-mileage and high-mileage drivers, as does any mileage-based fee. In addition, it should be noted that equity issues for lower-income groups created by congestion pricing or by higher fuel costs could be addressed through reinvestment in highways, public transportation, system operations, and commuter and ridesharing programs, as discussed in Section 3.2.

Land Use and Smart Growth Strategies – Modest to strong positive equity impacts on both low-income and inner-area (i.e., located near urban cores) groups are expected from the land-use and smart-growth strategies analyzed in *Moving Cooler*. More compact development patterns benefit these groups by bringing jobs, retail, and health care closer. This reduces travel times and costs, particularly for individuals who may not have reliable access to private automobiles. These policies also could increase housing costs, presenting an offsetting negative externality. As discussed in the literature review, however, particularly when offset by policies allowing increased densities and smaller units these effects have been shown to have a relatively small influence on overall household housing costs.

Non-Motorized Transport Strategies – Positive equity impacts also are shown for non-motorized transport, reflecting the improved mobility and access, and decreased cost of travel for low-income groups and inner-area groups. The gains may not apply equally to all within low-income and inner-area groups; those with disabilities or the infirm may not be able to take advantage of non motorized strategies as easily.

Public Transportation Improvement Strategies – Because low-income groups utilize public transportation more than average, investments in public transportation can potentially target a larger percentage of benefits to low-income groups. The fare measures, level of service improvements, and expanded route miles will all greatly benefit low-income and inner-area groups by decreasing monetary travel costs on existing routes (e.g., decreased fares), decreasing travel times, and expanding the destinations that can be reached via transit. These equity benefits are not experienced for intercity public transportation, however. The *Moving Cooler* strategy emphasizes intercity rail, which is not disproportionately used by low-income groups. High-speed rail travel in particular will likely not benefit low-income travelers due to the cost of service.

---

[157] Bordoff, Jason and Pascal J. Noel. "*Pay-As-You-Drive Auto Insurance: A Simple Way to Reduce Driving-Related Harms and Increase Equity*." The Brookings Institution, Washington D.C., 2008.

Regional Ride Sharing, Car Sharing, and Commuting Strategies – Car sharing, which is most successful in denser areas, would – like transit – be a particular boon to inner area groups who may not own private vehicles, whether because of affordibility or choice. Employer commute strategies in general would have positive equity impacts on low-income groups, by increasing access to jobs (through shared ride or shuttle options). However, charging for employer parking would represent a negative equity impact for low-income groups, who would be less able to afford the fees. They also would be less likely to benefit from telework strategies, which often are not readily applied to lower-income positions.

Regulatory Measures – These strategies have mixed equity impacts. Urban non motorized zones and urban parking restrictions will have negative equity impacts on inner-area groups and to some extent on low-income groups, who are more likely to live in those areas. Speed limit reductions could have negative equity impacts on rural drivers, who are more likely to be driving longer distances on highways operating in free flow conditions (and thus be constrained by the lower speed limits). Eco-driving will not have significant equity impacts.

Operations and Intelligent Transportation System (ITS) Strategies – Almost all of the operations and ITS strategies analyzed in *Moving Cooler* do not have significant equity effects. They primarily serve to smooth traffic flows and increasing operating speeds on existing roadways throughout both urban and rural areas. The exception is ramp metering, which reduces travel times in the aggregate but also redistributes some of the delay to inner-area drivers. It favors drivers starting at the edge of urban areas – i.e., drivers who enter the highway at non metered ramps – who drivers benefit from the increased operating speeds of the roadway for the longest distances, without even experiencing the delays at metered ramps (in one direction, at least).

Bottleneck Relief and Capacity Expansion Strategies – These strategies have strong positive equity impacts. Improved highway transportation is an important source of mobility for low-income persons. Despite their proportionately larger transit ridership than other socioeconomic groups, nationally low-income groups still rely primarily on highways for their mobility. Improved mobility gives these groups better access to jobs, healthcare, and retail.

Multimodal Freight Strategies - These strategies do not have significant socioeconomic equity impacts. It is possible that implementation costs could be passed onto customers in the form of higher prices for goods (which would affect low-income groups, who spend a greater share of their income on food and other necessities than other groups), but this is not likely to be significant for the strategies analyzed, and in many cases, savings may be generated instead. However, rail and marine improvement strategies do favor those modes at the expense of trucking.

Table 3.1 Equity Impacts of Greenhouse Gas Emission Reduction Strategies

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Pricing Strategies			
Parking pricing (combine with land use, transit, operations, equity analysis)	Modest negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Moderate negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Strong negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.
Cordon pricing (combine with land use, transit, highway investment, operations, equity analysis)	Modest negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Moderate negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Strong negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.
Congestion pricing	Modest negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Moderate negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Strong negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.
Intercity tolls	Modest negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Moderate negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Strong negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.
Pay-as-you-drive (PAYD) insurance	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
VMT tax	Modest negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Moderate negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Strong negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.

Table 3.1 Equity Impacts of Greenhouse Gas Emission Reduction Strategies *(continued)*

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Pricing Strategies (continued)			
Gas tax and carbon tax	Modest negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Moderate negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.	Strong negative equity impacts on low-income groups – reduced access to jobs, health care, education, and retail.
Land Use and Smart Growth Strategies			
Combined strategies	Modest positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Strong positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.
Non-Motorized Transport Strategies			
Combined strategies – pedestrian	Modest positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Strong positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.
Combined strategies – bicycling	Modest positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Strong positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.

Table 3.1 Equity Impacts of Greenhouse Gas Emission Reduction Strategies *(continued)*

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Public Transportation Improvement Strategies			
Fare measures	Modest positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Strong positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.
Increased levels of service/improved travel times	Modest positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Strong positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.
Expanded urbanized area public transportation	Modest positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Strong positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.
Intercity Bus and Rail/High speed rail	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Regional Ride Sharing, Car-Sharing and Commuting Strategies			
HOV lanes	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Car-sharing	Modest positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.	Strong positive equity impacts on low-income and inner area groups – increased access to jobs, health care, education, and retail.

Table 3.1 Equity Impacts of Greenhouse Gas Emission Reduction Strategies *(continued)*

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Regional Ride Sharing, Car-Sharing and Commuting Strategies (Continued)			
Employer-based telework and compressed work week programs: private sector	Modest positive equity impacts on low-income and inner area groups – increased access to jobs.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs.	Strong positive equity impacts on low-income and inner area groups – increased access to jobs.
Employer-based telework and compressed work week programs: public sector	Modest positive equity impacts on low-income and inner area groups – increased access to jobs.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs.	Strong positive equity impacts on low-income and inner area groups – increased access to jobs.
Employer-based TDM requirements, outreach, and support	Modest positive equity impacts on low-income and inner area groups – increased access to jobs.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs.	Moderate positive equity impacts on low-income and inner area groups – increased access to jobs, offset by parking charges.
Regulatory Measures			
Urban non-motorized zones	Modest negative equity impacts on low-income groups.	Moderate negative equity impacts on low-income groups.	Strong negative equity impacts on low-income groups.
Urban parking restrictions	Modest negative equity impacts on low-income groups.	Moderate negative equity impacts on low-income groups.	Strong negative equity impacts on low-income groups.
Speed limit reductions and/or auto governors	No significant equity impacts by-income level, but substantial negative impacts on rural mobility.	No significant equity impacts by-income level, but substantial negative impacts on rural mobility.	No significant equity impacts by-income level, but substantial negative impacts on rural mobility.
Ecodriving	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.

Table 3.1 Equity Impacts of Greenhouse Gas Emission Reduction Strategies *(continued)*

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Operations and Intelligent Transportation System (ITS) Strategies			
Ramp metering (centrally-controlled)	Modest negative equity impacts on inner area groups.	Moderate negative equity impacts on inner area groups.	Strong negative equity impacts on inner area groups.
Electronic roadway monitoring	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
VMS	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Active traffic management	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Integrated corridor management	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Detection algor/free cell call	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Closed circuit TV cameras	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
On-call service patrols; tmc integration/coordination	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Road weather management (snow/ice/fog; freeways**)**	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
TMC deployment	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Signal control level	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
VMS	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Traveler information	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Vehicle Infrastructure Integration (VII)	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.

Note: VII deployment is based on the deployment curve in Volpe VII BCA Report (Chart 3.1: Projected Phase-In of VII Equipped Vehicles in the US Fleet). The "More Aggressive" scenario uses these forecasts and they are adjusted for "Current Practice" and "Maximum Effort" scenarios

Table 3.1 Equity Impacts of Greenhouse Gas Emission Reduction Strategies *(continued)*

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Bottleneck Relief and Capacity Expansion Strategies			
Bottleneck relief	Modest positive equity impacts on low-income and inner-area groups – increased access to jobs, health care, education, and retail.	Moderate positive equity impacts on low-income and inner-area groups – increased access to jobs, health care, education, and retail.	Strong positive equity impacts on low-income and inner-area groups – increased access to jobs, health care, education, and retail.
Capacity expansion	Modest positive equity impacts on low-income and inner-area groups – increased access to jobs, health care, education, and retail.	Moderate positive equity impacts on low-income and inner-area groups – increased access to jobs, health care, education, and retail.	Strong positive equity impacts on low-income and inner-area groups – increased access to jobs, health care, education, and retail.
Freight Strategies – Modal Diversion			
Rail capacity improvements	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Marine transportation system maintenance and improvement	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Overweight load permits for trucks carrying shipping containers	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Overweight load permits for longer combination vehicles (LCV)	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Low-speed WIM screening at weigh stations	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Truck stop electrification	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Truck-only toll lane networks	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.

Table 3.1 Equity Impacts of Greenhouse Gas Emission Reduction Strategies (continued)

GHG Reduction Strategy	A. Expanded Best Practice	B. More Aggressive	C. Maximum Effort
Freight Strategies – Mode Optimization (continued)			
Use of electronic credentialing to allow vehicles to bypass weigh stations and safety inspections	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Heating and cooling systems for sleeper cabs	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.
Freight Strategies – Logistics			
Urban consolidation centers and limitations on pickup and delivery (pud) service in dense urban areas	No significant equity impacts.	No significant equity impacts.	No significant equity impacts.

3.2 Quantitative Equity Analysis of Pricing Strategies in *Moving Cooler*

While the literature on equity in pricing is very rich, as demonstrated in Section 2.0, the quantitative analyses conducted to date of equity are very limited. It is necessary to combine the results of several prior analyses in order to develop useful numerical estimates of the equity implications of individual strategies and of packages. The concept of equity is intrinsic to the concept of bundles of strategies, because it is only through bundling of strategies that the equity issues arising from pricing can reasonably be addressed.

Equity in Pricing Itself – Differences in Impacts By Income Group

A very useful evaluation of congestion pricing by the Puget Sound Regional Council (PSRC) "Traffic Choices Study: Findings From a Road Pricing Experiment (2008)" provides evidence of the equity consequences of pricing. PSRC tested congestion pricing using a sample of households whose responses to road pricing were monitored. The PSRC study is particularly useful for quantitative equity analysis because it measures impacts on different income groups, and also because it measures whether congestion pricing produces net benefits prior to reinvestment of the revenues. The study involved charging a sample of users different fees for use of the roadways at various times of day. Because only a sample was charged congestion pricing fees, the responses were extrapolated to regional totals. However, the responses of specific different income groups, and the benefits they received from pricing, were measured by PSRC.

The PSRC study applied tolls during weekdays and measured the responses of different user groups. The toll rates per mile examined in the PSRC region are shown in Table 3.2. The toll rates are illustrative and are obviously not set for each particular roadway segment, which would presumably be done in a comprehensive application of congestion pricing. Also, although it may be the case that toll rates should be set higher on non-freeways than on freeways due to the greater impact of an additional vehicle on congestion on non freeways, the PSRC sets freeway toll rates higher than non freeway toll rates. This is a common problem with other studies of pricing. Tolls ideally should be set by segment and time of day.

Table 3.2 Weekday Toll Rates: PSRC Pricing Study

Time Period	Toll Rates Per Mile For Freeways	Toll Rates Per Mile For Non Freeways
6 a.m. to 9 a.m.	$0.40	$0.20
9 a.m. to 4 p.m.	$0.15	$0.08
4 p.m. to 7 p.m.	$0.50	$0.25
7 p.m. to 10 p.m.	$0.10	$0.05
10 p.m. to 6 a.m.	$0.00	$0.00

Table 3.3 shows PSRC's results in terms of the savings, by type, for the different classes of users. Results for work trips based on income levels were reported, providing important information for evaluating the equity of pricing applications.

PSRC's definitions of user groups and vehicle types presents results by income level for the drive alone work trips, and aggregate results for all income groups for the other user groups. It is likely that if the results also were compiled for non-work trips, the same equity results for income groups would also be demonstrated.

Of greatest interest are the comparisons among income groups, which PSRC compiled for single occupant auto work trips. For other trips with higher occupancies, the PSRC study did not report on income levels, perhaps because that is somewhat ambiguous for multi-occupant travel. Trucks show very high time savings, and very high unreliability cost savings, due to congestion pricing.

Table 3.3 PSRC Daily User Benefits From Tolling Application
(Dollars in Thousands)

User Group	Time Savings	Operating Cost Savings	Unreliability Cost Savings	Total of All Savings
Drive Alone Home Based Work				
Low-Income	(0.4)	2.9	0.0	2.5
Low-Middle-Income	48.7	12.0	(4.0)	56.7
High-Middle-Income	299.6	29.8	15.7	345.1
High-Income	865.2	46.8	68.8	980.8
Drive Alone Non Work	548.0	121.6	68.9	739.4
Carpool and Vanpool	339.4	65.7	41.6	446.7
Public Transportation	156.1	0.0	0.0	156.1
Light Truck	1,524.1	131.4	260.2	1,914.7
Medium Truck	557.6	65.0	70.5	693.1
Heavy Truck	648.4	50.2	71.5	770.1
Totals For All Groups	$4,983.7	$525.4	$593.2	$6,102.3

Table 3.4 shows total savings versus tolls paid and the ratio of savings to tolls paid for each group. The most important column is the fourth column which shows the percentage of the benefits in comparison to the tolls paid for each user group. It is very interesting that, before the use of the revenues to generate offsetting benefits, all groups are worse off, some far more than others. An important equity lesson is that pricing has disbenefits for all user groups except transit users, *until* revenues are reinvested. Transit

vehicles were exempted from tolls in the PSRC demonstration. The lowest-income users are the worst off, consistent with a wide range of similar findings reported in the Section 2.0 literature review.

As can be seen, although low-income drive alone auto users have very low benefits, also they pay a small portion of the tolls. For drive alone work trips, the share of benefits is greater than the share of tolls paid only for the high-income group. In the PSRC estimates, truck users receive higher portions of benefits than of tolls paid. This is primarily due to the estimated benefits to them from time savings and reliability savings, which make the benefits to truck users higher than the benefits to other users.

Table 3.4 PSRC Daily User Benefits Versus Tolls From Tolling Application
(Dollars in Thousands)

User Group	Total of All Savings	Tolls Paid by Group	Ratio Percent of Benefits per Dollar of Tolls	Percent of Total Tolls Paid	Percent of Total Savings (Benefits)
Drive Alone Home-Based Work					
Low-Income	$2.5	$111.5	2.24%	0.84%	0.04%
Low-Middle-Income	$56.7	$391.6	14.48%	2.97%	.93%
High-Middle-Income	$345.1	$1,054.1	32.74%	7.99%	5.66%
High-Income	$980.8	$1,745.2	56.20%	13.22%	16.07%
Drive Alone Nonwork	$739.4	$4,203.8	17.59%	31.85%	12.12%
Carpool and Vanpool	$446.7	$1,978.3	22.58%	14.99%	7.32%
Public Transportation	$156.1	$0.0	N/A	0.00%	2.56%
Light Truck	$1,914.7	$2,147.5	89.21%	16.27%	31.39%
Medium Truck	$693.1	$707.3	97.99%	5.36%	11.36%
Heavy Truck	$770.1	$861.1	89.43%	5.52%	12.62%
Totals For All Groups	$6,102.3	$13,200.3	46.23%	100.00%	100.00%

The PSRC study did not provide a basis for estimating the impacts on groups due to the reinvestment of revenues. This would have to be accomplished through parallel analyses, which has been estimated here using investment models.

To evaluate the combined impact of including the reinvestment of revenues, a Cambridge Systematics (CS) analysis of the user benefits of highway investments also has been added to the PSRC equity results for congestion pricing itself. The CS analysis was conducted as part of the recent Bottom Line technical report on National and State Investment Needs for Highways and Public Transportation, under NCHRP Project 20-24(54)G.

Combined Equity in Pricing Plus Equity in Investments

To estimate the total equity of pricing, it is necessary to estimate the equity implications of reinvestments using the revenues generated by pricing. Two methods are used to illustrate the impacts of the reinvestments of revenues on various user groups. The first is a CS analysis of the net return on investment of the added user benefits associated with increasing national highway capital investment levels by funding all projects that pass a benefit-cost criterion. The second is an analysis by the San Francisco area's Metropolitan Transportation Commission of the equity of its adopted program of future investments on low-income households.

Highway and Transit Investments – Equity and Return on Investment

The Highway Economic Requirements System (HERS) model calculates highway needs based upon the maximum economic return, which is defined as implementing projects whose benefits exceed their costs. The results of the recent NCHRP analysis of highway needs were a justified level of highway capital investment of $166 billion per year, which is $98 billion per year higher than current investment levels. This is a large increase in investments, but it will generate an even larger increase in additional net user benefits. The NCHRP analysis and a parallel Transit Cooperative Research Program (TCRP) analysis also calculated comparable public transportation capital investment needs, with a mid range of $48 billion in investment needs versus a current level of $13 billion. Thus, a comparable figure for the incremental needs for public transportation over and above current levels is about $35 billion per year.

Increasing investments in mobility without any limit is clearly not necessary or desirable. It is important to estimate what maximum level of additional transportation reinvestment would generate net benefits capable of offsetting equity issues resulting from pricing or other user fees. Considering that many *Moving Cooler* strategies are less costly to implement than highway and public transportation, a very reasonable estimate is that over $150 billion per year generated by pricing measures and then reinvested in the other *Moving Cooler* mobility measures will have very high economic returns to society, and could remedy the equity issues created by pricing while also contributing to further GHG emission reductions.

This rough estimate of a $150 billion per year of additional economically justified investment in mobility measures would be equivalent to a $1.00 per gallon of motor fuel tax, or an average of five cents per vehicle mile of travel. This figure is only cited to illustrate that desirable reinvestments with positive economic returns can be made for a very large amount of any new revenues generated by any of the pricing measures. All the equity analysis is done on a dollar-for-dollar basis, comparing payments to net benefits for each group. Thus the same conclusions are applicable across all levels of investment in these measures.

For the full economic needs scenario and the existing funding scenario in recent NCHRP research for project 20-24(49)G, a comparative calculation was performed of the net present value of the increase in user benefits from the higher investment versus the costs of the increase in capital investment itself. The higher level of economically justified investment, over the 20 years covered in the NCHRP study, would yield $2.13 trillion more in net benefits after subtracting out the higher investment costs, which were about $2 billion more investment over 20 years compared to current levels. To put another way, the failure to increase investment to an economically justified level will cost the economy $2.13 trillion dollars in losses. A rational society would not fail to make these investments.

When averaged across the years in the equity analysis for the *Moving Cooler* study, which expanded on the NCHRP work, the added user cost benefits as calculated for reinvestment in highways will be 1.95 times as great as the added costs of the higher investment in highway infrastructure.

Public transportation returns on capital investment are comparable. A previous estimate for APTA in "*Public Transportation and the Nation's Economy: A Quantitative Analysis of Public Transportation's Economic Impact*" also showed a positive yield for public transportation investments, with a return on investment of 3 to 1. This estimate was for a broader measure of benefits, and is the ratio of the net increase in business sales per dollar of increase in public transportation investments. The highway and public transportation benefits per dollar of additional investment may be fairly equal, perhaps 2 to1 when just user benefits are considered and 3 to 1 when broader benefit measures are used. Thus, reinvestment in both highway and public transportation programs can produce very large net benefits.

The benefits from reinvestment are additive to the equity results from pricing alone. To estimate the overall value of pricing plus reinvestment, the benefits of the reinvestment would be added to the impacts of pricing by user group. Each user group would have at least $1.95 in benefits from reinvestment for every dollar paid, based upon a long-term comparison of the costs of higher levels of investment to the associated higher level of benefits to the users.

Table 3.5 shows the illustrative results of the numerical equity analysis for congestion pricing, utilizing the PSRC Traffic Choices Study results for estimating the pricing responses and using the CS Bottom Line and *Moving Cooler* analysis results for estimating the benefits of the reinvestment of the pricing revenues.

Table 3.5 Equity Analysis: Return on Investment by User Group: From Pricing Alone, From Reinvestment of Revenues, and From Combined Pricing and Reinvestment

User Group	From Pricing Alone: Dollars of Benefit Per Dollars of Tolls Paid	From Reinvestment Alone: Dollars of Benefit Per Dollars Reinvested	Combined: Dollars of Benefit Per Dollars Paid and Reinvested
Low-Income SOV Work Trips	$.02	$1.95	$1.97
Low-Middle-Income SOV Work Trips	$.14	$1.95	$2.09
High-Middle-Income SOV Work Trips	$.33	$1.95	$2.28
High-Income SOV Work Trips	$.56	$1.95	$2.51
Drive Alone Nonwork	$.19	$1.95	$2.14
Carpool and Vanpool	$.23	$1.95	$2.18
Heavy Trucks	$.89	$1.95	$2.84
All Vehicle Classes Combined	$.46	$1.95	$2.41

Sources: Puget Sound Regional Council Traffic Choices Study and CS Analysis for *Moving Cooler* Report and Bottom Line Report. All returns from the reinvestment are shown as the same for each group on a per mile basis of vehicle miles of travel. Transit investments are estimated to return $3 for each dollar invested, in a CS and Economic Development Research Group study, which includes all economic benefits (user and non-user). This table includes only user benefits, and overall economic benefits are likely to be higher for each group with highways as well as with transit.

Further Addressing Low-Income Equity Issues With Public Transportation Investments

Another useful source of quantitative results is the San Francisco Metropolitan Transportation Commission's *MTC Transportation 2035 Equity Analysis Report*. The report estimates the equity impacts of the region's proposed long-range transportation plan on income groups in the Bay area. As with other equity analyses, it focuses on the equity of expenditures among the various income groups, and compares the expenditures that may benefit low-income households to the expenditures that benefit all households. This comparison of expenditures defines the current state of the art in equity analysis for regional plans. Other measures considered include whether accessibility increases more for target groups than for all groups.

The ultimate impact on different income groups, however, is heavily influenced by how the revenue from congestion pricing or any other revenue is spent. Revenue reinvestment is widely acknowledged by economists and policy-makers to be a solution to inequitable-income effects, by redistributing benefits to specifically targeted recipients, through tax policy changes, or to the public in general, through infrastructure and transit investments.

Table 3.6 shows the San Francisco area's calculation of expenditures per household for low-income households versus all households.[158] The MTC concluded that their planned investments were equitable to low-income groups based on the average expenditure they calculated for low-income households versus other households.

Table 3.6 Quantitative Equity of San Francisco Long-Range Plan (T2035) Expenditures

	All Households	Low-Income Households	All Other Households
Share of Transit Usage	100.0%	26.7%	73.3%
Share of Roadway Usage	100.0%	2.4%	97.6%
T2035 Transit Expenditures (Dollars in Billions)	$148.9	$ 39.7	$109.1
T2035 Highway Expenditures (Dollars in Billions)	$76.4	$ 1.8	$ 74.6
Total Expenditures	$225.3	$ 41.6	$183.7
Households (in 2006)	2,468,024	436,554	2,031,470
Expenditures Per Household (Dollars in Thousands	$91.3	$95.2	$90.4

The MTC long-range plan has very high investments in public transportation relative to investments in highways. Because low-income groups receive 27 percent of the benefits from public transportation versus 2 percent of the benefits from highways, the MTC's investment mix, which is oriented to transit, will tend to provide very strong returns for low-income households. The MTC example shows that adding significant public transportation investments into the reinvestment mix could potentially strengthen the already good returns on investment that would occur for lower-income groups from only highway reinvestments.

[158] The study includes detailed tables for transit operations, transit capital, highway operations, highway capital, etc. However, since all the expenditures were assigned by percentage of users, these tables do not provide more information about the equity of specific categories of expenditures.

Regardless, the primary lesson is very positive: either highway or public transportation investments or a mix can provide solutions to the equity issues of pricing impacts on low-income groups. In addition, the *Moving Cooler* effectiveness analysis shows that these reinvestments contribute to further reductions in GHG emissions. This conclusion can be extended to other strategies that are less capital intensive than reinvestment. Operations improvements, for example, have very high user benefits per dollar invested, also while contributing to reductions in GHG emissions.

3.3 Equity Analysis of Motor Fuel Taxes and Carbon Taxes

Table 3.7 shows the Consumer Expenditure Survey information on incomes, transportation expenditures, motor fuel expenditures, and percentages of income paid by income quintile for 2007. Each income quintile represents the average of one-fifth of the households in the U.S., ranked by income from the lowest one-fifth of households to the highest one-fifth of households. This information is commonly used to track expenditures by income group, and the distribution and magnitude of consumer expenditures by income group.

Table 3.7 Equity Analysis by Quintile of Income: Motor Fuel Expenses

Parameters	Lowest One-Fifth	Second One-Fifth	Middle One-Fifth	Fourth One-Fifth	Highest One-Fifth	Average
Income After Tax	$10,534	$27,419	$45,179	$70,050	$150,927	$60,858
Transportation Expenditures	$3,242	$5,717	$7,926	$11,058	$15,831	$8,758
Air and Public Transportation	$171	$242	$362	$506	$1,406	$538
Private Transportation	$3,071	$5,475	$7,564	$10,552	$14,425	$8,220
Percent on Private Transportation	29.2%	20.0%	16.7%	15.1%	9.6%	13.5%
Gas and Oil Expenditures	$1,046	$1,768	$2,418	$2,988	$3,696	$2,384
Percent on Gas and Oil	9.9%	6.5%	5.4%	4.3%	2.5%	3.9%

The last row of Table 3.7 shows how much each income group now spends on motor fuel and oil in comparison to its income. Virtually all these expenditures are on motor fuel itself. The lowest-income group spent nearly 10 percent of after tax income on motor fuel in 2007, which compares to about one-fourth the percentage of income which the highest income group spent on motor fuel. Although fuel was at a historically high price in 2007, the price in 2007 was less than the even higher average price in 2008. Since the end of 2008, motor fuel prices have declined.

The equity implications of increases in fuel user fees are parallel to those of congestion pricing fees. Comparable impacts on different user groups from incremental motor fuel fees have not been estimated in the same manner as was done by PSRC for pricing fees.

The analysis for the Bottom Line report utilized the HERS model system with its "self financing feature," e.g., the user fees in the analysis were set equal to the levels of investment which were generated in the analysis. Therefore, all the impacts of the higher fuel prices needed to fund the investments and generate the benefits shown in Table 3.8 below, already are considered in the parameters that are used in forecasting vehicle miles of travel and other parameters. This means that the results of the HERS already runs include the motor fuel taxes and the expenditures together. What they may be missing are additional fees necessary to fund the motor fuel tax portion of higher transit investments. Table 3.8 shows the motor fuel tax return on investment by income group.

Table 3.8 Equity Analysis: Return On Investment By User Group: From Fuel Taxes and Reinvestment of Revenues

User Group	Dollars of Benefits Per Dollar Reinvested
Low-Income SOV Work Trips	$1.95
Low-Middle-Income SOV Work Trips	$1.95
High-Middle-Income SOV Work Trips	$1.95
High-Income	$1.95
Drive Alone Non Work	$1.95
Carpool and Vanpool	$1.95
Heavy Trucks	$1.95
All Vehicle Classes Combined	$1.95

Although lower-income groups and all groups would receive net benefits, the incidence of added motor fuel user fees on the household budgets of lower-income groups is still of concern. As with the congestion fees, the types of additional equity repayments suggested by other researchers for lower-income groups include potential reductions in income taxes, payroll tax rebates, increased earned income tax payments, increases in social security and supplemental security income benefits, increases to food stamp benefits, and others.

A very useful quantitative analysis of equity is included in a study by the MIT Joint Program on the Science and Policy of Global Climate Change "Analysis of U.S.

Greenhouse Gas Tax Proposals" Report No. 160, April 2008. MIT uses its Emissions Prediction and Policy Analysis (EPPA) Model to evaluate the economic consequences of GHG and energy tax proposals. The model includes an evaluation of the welfare consequences (gain or loss of effective income) for various income groups under different GHG tax and rebate proposals. The model predicts the impacts on fuel prices and welfare for the alternative legislative proposals, and relates the CO_2 prices to anticipated prices of fuel. For example, they estimate that a $27 per ton CO_2 price would cause a $0.26 increase in the price of regular gasoline, as well as changes in price for other energy sources. The model forecasts potential revenues for alternative legislative proposals through 2050. Tax revenue for three selected proposals ranges from $69 billion to $126 billion per year in 2015, growing to a range of $141 billion to $1,031 billion per year by 2050. For comparison purposes, also they estimate the percentage of CO_2 revenues to overall Federal revenues. These range from 4 percent to 7 percent of Federal revenues in 2015 to from 3 percent to 21 percent of Federal revenues in 2050. These are very substantial revenue streams.

The model utilizes an input/output model and consumer expenditure survey data from 2003 (similar data to table 3.8) to estimate the increase in costs by household. An example analysis for a $15 per ton CO_2 equivalent tax estimated price increases for various energy sources and other purchased products. The carbon tax calculated as a percentage of income, which constitutes an income loss, ranged from 3.7 percent of income for the lowest 10 percent to only 0.8 percent of income for the highest income 10 percent of the population. Their analysis also estimated the impacts of a "lump sum" rebate of all carbon revenues to all households, as the means to address equity issues. Rebating all revenues as a common lump sum would result in a 5.6 percent income gain for the lowest 10 percent of households to a 0.6 percent gain for the highest 10 percent of households. The results are shown in Table 3.9.

Table 3.9 Distributional Impacts of Carbon Tax and Lump Sum Rebate

Income Decile	Carbon Tax as Percent of Income (Income Loss)	Lump Sum Rebate as Percent of Income (Income Gain)	Net Impact
1	-3.7	5.6	1.9
2	-3.0	4.0	1.0
3	-2.3	3.1	0.8
4	-2.0	2.4	0.4
5	-1.7	2.1	0.4
6	-1.5	1.6	0.1
7	-1.3	1.3	0.0
8	-1.2	1.2	0.0
9	-1.0	0.9	-0.1
10	-0.8	0.6	-0.2

Thus, a full rebate in equal amounts to all households, of the proceeds of carbon taxes can eliminate the equity impacts on the lowest-income groups. However, the rebate of all these fees misses the net additional benefits that can be achieved for all groups from reinvesting some portion of these revenues in transportation GHG reduction measures. Perhaps a mix of uses of carbon taxes, with some portiongoing to transportation programs, could both remedy the equity issues of the taxes and contribute further to reducing GHG emissions.

3.4 Addressing Equity with Revenue Distribution

The analysis presented in *Moving Cooler* showed that economy-wide pricing strategies have the potential to generate reductions in GHG emissions greater than those of many other individual strategies. By the same token, pricing strategies also present the most significant equity issues for lower-income groups and rural residents. According to the U.S. Bureau of Labor Statistics data, the lowest-income group spends four times the percentage of their income on motor fuel, when compared to the highest-income group. Given this fact, any strategy that increases the price of travel will have a disproportionate effect on lower-income populations.

Table 3.10 shows the incomes, transportation expenditures, motor fuel expenditures, and the percentages of income paid by income quintiles for 2007. Each income quintile represents the average of one-fifth of the households in the U.S., ranked by income level from the lowest one-fifth of households to the highest one-fifth of households.

The last row of the table shows how much each income group now spends on motor fuel and oil, in comparison to its income. Virtually all these expenditures are on motor fuel itself. While the lowest-income group spent nearly 10 percent of its after-tax income on motor fuel in 2007, the highest-income quintile spent about 2.5 percent of income.

Approaches for addressing potential equity effects of higher prices need to first identify how those prices affect different populations. Planning organizations are increasingly analyzing overall equity effects as part of their planning processes. For example, the analyses performed by such MPOs as the San Francisco Metropolitan Transportation Commission explicitly estimate how planned transportation expenditures are allocated to lower-income households, as compared to all other households. This type of analysis will be central to first understanding and then mitigating equity effects of pricing strategies to reduce GHGs

The revenues generated by the pricing strategies can be a significant part of the response to mitigate inequities through the reinvestment of those revenues in other transportation services. There can be three basic ways of mitigating equity effects with these revenues. First, revenues created by the pricing strategies could be transferred to affected groups. Second, these revenues could be reinvested in the transportation system to benefit all groups. Third, transportation investments could be further focused on those portions of the transportation system, such as public transportation, that are used more extensively by lower-income populations.

Table 3.10 Equity Analysis by Quintile of Income: Motor Fuel Expenses as a Percent of Income of U.S. Households
2007

Parameters	Lowest One-Fifth	Second One-Fifth	Middle One-Fifth	Fourth One-Fifth	Highest One-Fifth	Average
Income After Tax	\$10,534	\$27,419	\$45,179	\$70,050	\$150,927	\$60,858
Transportation Expenditures	\$3,242	\$5,717	\$7,926	\$11,058	\$15,831	\$8,758
Air and Public Transportation	\$171	\$242	\$362	\$506	\$1,406	\$538
Private Transportation	\$3,071	\$5,475	\$7,564	\$10,552	\$14,425	\$8,220
Percent Spent on Private Transportation	29.2%	20.0%	16.7%	15.1%	9.6%	13.5%
Gas and Oil Expenditures	\$1,046	\$1,768	\$2,418	\$2,988	\$3,696	\$2,384
Percent Spent on Gas and Oil	9.9%	6.5%	5.4%	4.3%	2.5%	3.9%

Source: 2007 United States Bureau of Labor Statistics Consumer Expenditure Survey.

Addressing Equity Through Rebates

As one example of how revenue transfers might be used to address inequities, an MIT study evaluated the economic consequences - that is the gain or loss of income - of GHG and energy tax proposals. In its examination of a carbon tax equivalent to a \$27 per ton CO_2 price or a \$0.26 increase in the price of regular gasoline, MIT estimated that the revenues generated would total from 3 to 21 percent of Federal revenues in 2050. The carbon pricing revenues evaluated by MIT would apply to all sectors of the economy, not just to transportation. MIT also estimated that the monetary impacts of a carbon tax on households - constituting an income loss - ranged from 3.7 percent of the income for the lowest 10 percent to only 0.8 percent of the income for the highest 10 percent of households. To address this inequitable effect, MIT estimated the effects of a "lump sum" rebate of all carbon revenues to all households. Rebating all revenues as a common lump sum would result in a 5.6 percent income gain for the lowest 10 percent of households to a 0.6 percent gain for the highest 10 percent of households. The net equity results generated by MIT are shown in Table 3.11. It is conceivable that rebates of general carbon taxes might use just a portion of the total revenues generated, rather than reimburse households the full amounts that are generated. This allocation would allow some proceeds to be used for transportation investments that could provide benefits to all income groups.

Table 3.11 Distributional Impacts of Carbon Tax and Lump Sum Rebate

Income Decile	Carbon Tax as Percent of Income (Income Loss) (pPercent)	Lump Sum Rebate as Percent of Income (Income Gain) (percent)	Net Impact (percent)
1 (lowest)	-3.7	5.6	1.9
2	-3.0	4.0	1.0
3	-2.3	3.1	0.8
4	-2.0	2.4	0.4
5	-1.7	2.1	0.4
6	-1.5	1.6	0.1
7	-1.3	1.3	0.0
8	-1.2	1.2	0.0
9	-1.0	0.9	-0.1
10	-0.8	0.6	-0.2

Source: Analysis *of U.S. Greenhouse Gas Tax Proposals,* Report No.160, (Boston: MIT Joint Program on the Science and Policy of Global Climate Change, Massachusetts Institute of Technology, April 2008).

Addressing Equity Through Highway Reinvestment

Revenue reinvestment is widely acknowledged by economists and policy-makers to be an effective response to inequitable income effects of user fees, by redistributing benefits through transit, highway, or other investments. Using pricing revenues to reinvest in the transportation system is therefore another way to address potential inequities. A highway investment analysis conducted for AASHTO's Bottom Line report estimated the net user cost savings of higher levels of investment that would be economically justified, compared to current investment levels.[159] The analysis showed that the increased user benefits were two times greater than the increased investments needed. All of the projects implemented

[159] American Association of State Highway and Transportation Officials, *Transportation: Are We There Yet?: Bottom Line* Report, (Washington, D.C.: AASHTO, 2009).

in this analysis return benefits that are greater than their costs. These net benefits are proportional for each income group's use of the roads, as are the motor fuel taxes paid by each group. Given this positive return, investments will provide a benefit to all groups, which will help offset the higher price of travel. Operations improvements have been shown to have even higher net returns on investments than the average for other types of highway investments.

Addressing Equity Through Targeted Public Transportation Investments

Focusing reinvestment of the pricing revenues on public transportation improvements is another way to address equity. Also, like the highway investment above, it also returns significant economic benefits. Because public transportation is used disproportionately by lower-income users, by other disadvantaged groups such as the disabled, and by those too young or too old to drive, providing more services would benefit those groups and offset the effect of higher prices of travel by automobile.

A Cambridge Systematics report for APTA, "*Public Transportation and the Economy*" (2000, and 2009 Update),[160] found returns on investment of 3-1 or more for public transportation capital improvements. The average returns for the largest urban areas are 6-1. These returns on investment were calculated using a much broader measure of benefits than in the highway benefit calculations, so the results of these studies do not directly compare the return on investment for public transportation and for highway investments.

[160] American Public Transportation Association, "*Public Transportation and the Economy*" (Washington, D.C.: APTA, 2000, and updated 2009).

4.0 Moving Cooler Final Report Summary of Equity Issues

The potential equity issues that might occur with the implementation of differing types of *Moving Cooler* strategies and opportunities to address them are summarized below.

- **Pricing strategies.** All pricing strategies (including carbon taxes or the effects of cap-and-trade on the prices of fuels), unless mitigated, would adversely impact lower-income groups more than those with higher incomes. The poorest users get fewer benefits from congestion pricing, VMT fees, or other fees, because they spend a higher proportion of their income on transportation, are less able to afford to pay higher fees, and may be priced off these services altogether. Lower-income groups pay four times as high a percentage of their income for motor fuels as the highest-income groups, and would receive even more inequitable effects from pricing strategies that increase their traveling costs. Rural or exurban users, because of lower incomes and fewer transit and carpool options, will also have equity issues from pricing that may be even harder to remedy. To mitigate these adverse equity effects, the revenues generated by the pricing strategies could be used to invest in other transportation services, or to fund income transfers among those affected by the strategies.
- **Land Use and Smart Growth.** Land use and smart growth can improve accessibility and mobility for those without access to autos, and enable individuals in all income groups to avoid the increased costs of travel that would occur with other GHG reduction strategies, thereby providing an option to mitigate the adverse effects of those strategies. While there are potential concerns with the effects on property values, these may be offset by decreased transportation costs. Gains and losses to property owners in more or less centrally located areas from the changes in land use regulation are a secondary concern, but should be noted.
- **Nonmotorized.** Investment in nonmotorized modes can have substantial positive equity effects by increasing mobility for lower-income groups and all those without significant access to vehicles (youth, the elderly, disabled persons, or others unwilling or unable to obtain a driver's permit).[161] These

[161] According to U.S. Census 2007 estimates, 15 percent of the age-eligible U.S. population does not hold a driver's licenses. When accounting for the elderly, those unable to afford a car, and multi-

(Footnote continued on next page...)

new modes would enhance their access to jobs, medical care, education, retail services, and other needed services.

- **Public Transportation.** Public transportation services provide access to employment opportunities, health care, education, retail services, and other services. Because lower-income people rely more on public transportation than other groups, public transportation improvements can potentially channel higher percentages of benefits to lower-income people and those without other mode choices, such as people who reside in rural areas. As with nonmotorized transportation, these benefits also should apply to many in the driving-age population without daily access to an automobile. Public transportation improvements can thus remedy part of any mobility loss due to pricing measures. Reduced fares also can make transit more affordable for lower-income groups.
- **Commuter, HOV, Carpool, and Vanpool.** Commuter, HOV, carpool, and vanpool measures can improve equity by providing low-cost mobility and access to jobs, medical care, education, retail, and other needed services for lower-income, disabled, and other users who are most in need of sharing the costs or tasks of travel. These strategies, along with investments in public transportation services, may be particularly helpful in rural settings to mitigate other inequities. These equity benefits would also apply to many others who are unable to drive a vehicle.
- **Regulatory.** Lower speed limits will impose significant travel time penalties on all groups, and perhaps more on rural users. Lower speeds improve safety, reducing fatalities and injury incidents.
- **System Operations and Management.** System operations measures have no significant equity issues, except for ramp metering, which may have negative effects on drivers who must access the metered roadway from locations closer to urban centers than other drivers.
- **Capacity Expansion and Bottleneck Relief.** Highway improvements provide significant mobility and accessibility benefits to all highway users. Economy-wide pricing, by providing a source of funding to make investments in capacity expansion and bottleneck relief, can mitigate the equity issues caused by higher per mile costs from the pricing measures. These strategies can thus provide improved access to employment opportunities, health care, education, retail services, and other services for highway users.
- **Multimodal Freight Strategies.** Freight strategies, while potentially having some redistributive effects across freight modes, should have no negative equity implications for other users and may decrease congestion. They can

driver and single-vehicle (or similar) households, a significantly larger portion of the U.S. population does not have daily access to a personal vehicle.

enhance delivery of various goods and services to businesses and consumers.

All of these factors will influence the design of national and local strategies to reduce GHGs from transportation. There are significant opportunities to build win-win solutions through integrated approaches that improve the nation's transportation network and enhance mobility, in addition to creating the benefits of the reductions in GHG emissions. However, the investment costs of some of these strategies are considerable and the potential for negative equity effects from some of the pricing strategies are high, absent strong policy intervention.

Many negative effects - mobility losses and the potential burdens placed on lower-income and rural travelers - could be addressed by using the revenues from fees and taxes to provide substantial benefits, for example, through highway, ride-share, transit, or other improvements or through financial reimbursements to lower-income and other low-mobility groups. These reinvestment strategies could help ensure that lower-income and other low-mobility groups do not have their travel restricted as a result of increased costs because of pricing or other measures. Morever, equity-based reinvestment is economically justified. Analyses of highway and public transportation strategies in *Moving Cooler* and the results of the cost-benefit studies cited above conclude that these investments provide economic returns on these investments ranging from 2-1 or 3-1 or more, in terms of their benefits in relation to costs. However, equitable reinvestment is a key policy decision and will not happen automatically.

- Carbon taxes on all fuels or the effects of cap-and-trade on the prices of all fuels also will increase other non-transportation fuel costs for lower-income groups.

5.0 References

Adler, J. and Cetin, M. (2001), "A Direct Redistribution Model of Congestion Pricing," *Transportation Research Part B,* Vol. 35(5), Elsevier, pages 447-460.

Anderson, D. and Mohring, H. (1997), "Congestion costs and congestion pricing," *The Full Costs and Benefits of Transportation: Contributions to Theory, Method and Measurement,* Springer.

Arnott, R. (1994), Alleviating Traffic Congestion: Alternatives to Road Pricing, *in* "Proceedings of the TRED Conference on Alternative Strategies for Managing Externalities."

Arnott, R., de Palma, A. and Lindsey, R. (2003), "A Structural Model of Peak-Period Congestion: A Traffic Bottleneck with Elastic Demand," *International Library of Critical Writings in Economics,* Vol. 164, Edward Elgar Publishing Ltd., pages 364-382.

Banister, D. (1994), "Equity and Acceptability Questions in Internalizing the Social Costs of Transport," *Internalizing the Social Costs of Transport,* OECD (Organization for Economic Co-Operation & Dev), pages 153-175.

Banister, D. (2002), "The Integration of Road Pricing with Land Use Planning," *Exposé présenté á un atelier du Réseau thématique imprint, Bruxelles,* Vol. 14, pages 14-15.

Bonsall, P. and Kelly, C. (2005), "Road User Charging and Social Exclusion: The Impact of Congestion Charges on At-Risk Groups," *Transport Policy,* Vol. 12(5), Elsevier, pages 406-418.

Bonsall, P., Shires, J., Maule, J., Matthews, B. and Beale, J. (2007), "Responses to Complex Pricing Signals: Theory, Evidence, and Implications for Road Pricing," *Transportation Research Part A,* Vol. 41(7), Elsevier, pages 672-683.

Brekke, K. (1997), "The Numéraire Matters in Cost-Benefit Analysis," *Journal of Public Economics,* Vol. 64(1), Elsevier, pages 117–123.

Brekke, K., Lurå, H. and Nyborg, K. (1996), "Allowing Disagreement in Evaluations of Social Welfare," *Journal of Economics,* Vol. 63(3), Springer, pages 303-324.

Buchanan, J. and Tullock, G. (1962), *The Calculus of Consent*, University of Michigan.

Burchardt, T., Le Grand, J. and Piachaud, D. (1999), "Social Exclusion in Britain 1991-1995," *Social Policy and Administration,* Vol. 33(3), Blackwell Synergy, pages 227-244.

Burris, M. and Appiah, J. (2004), "Examination of Houston's QuickRide Participants by Frequency of QuickRide Usage," *Transportation Research Record,* Vol. 1864, Trans Res Board, pages 22-30.

Burris, M. and Hannay, R. (2003), "Equity Analysis of the Houston, Texas, QuickRide Project," *Transportation Research Record,* Vol. 1859, Trans Res Board, pages 87-92.

Button, K. (2006), "How Should the Revenues from Congestion Pricing is Spent," *Street Smart: Competition, Entrepreneurship, and the Future of Roads,* pages 225-242.

Cambridge Systematics (2001), "MnDOT Ramp Metering Study Final Report," http://www.dot.state.mn.us/rampmeterstudy.

Daganzo, C. (1995), "A Pareto Optimum Congestion Reduction Scheme," *Transportation Research Part B,* Vol. 29(2), Elsevier, pages 139-154.

De Corla-Souza, P. et al. (2005), "Fair Highway Networks: A New Approach to Eliminate Congestion on Metropolitan Freeways," *Public Works Management & Policy,* Vol. 9(3), page 196.

DeCorla-Souza, P. and Barker, W. (2005), "Innovative Public-Private Partnership Models for Road Pricing/BRT Initiatives," *Journal of Public Transportation,* Vol. 8(1), page 78.

Dial, R. (1999), "Minimal-Revenue Congestion Pricing Part I: A Fast Algorithm for the Single-Origin Case," *Transportation Research Part B,* Vol. 33(3), Elsevier, pages 189-202.

Dill, J. and Weinstein, A. (2007), "How to Pay for Transportation? A Survey of Public Preferences in California," *Transport Policy,* Vol. 14(4), Elsevier, pages 346-356.

Doll, C. (n.d.), Fair and Economically Sustainable Changes for the Use of Motorway Infrastructure, Technical report, Working Paper, 2003.

Douma, F., Zmud, J. and Patterson, T. (n.d.), "Pricing Comes to Minnesota: Attitudinal Evaluation of I-394 HOT Lane Project."

Eliasson, J. and Mattsson, L. (2006), "Equity Effects of Congestion Pricing Quantitative Methodology, and a Case Study for Stockholm," *Transportation Research Part A,* Vol. 40(7), Elsevier, pages 602-620.

Environmental Protection Agency: Office of Solid Waste and Emergency Response (1994), "Executive order 12898 about environmental justice," http://www.epa.gov/swerosps/ej/aboutej.htm.

Evans, A. (1992), "Road Congestion Pricing: When is it a Good Policy?" *Journal of Transport Economics and Policy,* Vol. 26, pages 213-213.

Feldstein, M. (1972), "Distributional Equity and the Optimal Structure of Public Prices," *American Economic Review,* Vol. 62(1), pages 32-36.

Flynn, M. (n.d.), "Moving It Forward: A Blueprint for Making Road Pricing a Reality in New York City."

Forkenbrock, D. (2005), "Implementing a Mileage-Based Road User Charge," *Public Works Management & Policy,* Vol. 10(2), page 87.

Forkenbrock, D. (2006), "Financing Local Roads: Current Problems and New Paradigm," *Transportation Research Record,* Vol. 1960, Trans Res Board, pages 8-14.

Forkenbrock, D. and Schweitzer, L. (1999), "Environmental Justice in Transportation Planning," *Journal of the American Planning Association,* Vol. 65(1), Routledge, pages 96-112.

Foster, C. (1974), "The Repressiveness of Road Pricing," *International Journal of Transport Economics,* Vol. 1(2), pages 133-141.

Foster, C. (1975), "A Note on the Distributional Effects of Road Pricing: A Comment," *Journal of Transport Economics and Policy,* Vol. 9, pages 186-187.

Franklin, J. (2006), The Equity Effects of Roadway Tolls: An Application of Hicksian Welfare Measures with Income Effects, *in* 'Conference on Travel Behaviour Research', Vol. 1.

Fridstrom, L., Minken, H., Moilanen, P., Shepherd, S., and Vold, A. (2000), "Economic and Equity Effects of Marginal Cost Pricing in Transport," *AFFORD Deliverable 2A. VATT Research Reports.*

Fujii, S., Garling, T., Jakobsson, C., and Jou, R. (2004), "A Cross-Country Study of Fairness and Infringement on Freedom as Determinants of Car Owners' Acceptance of Road Pricing," *Transportation,* Vol. 31(3), Springer, pages 285-295.

Gillen, D. (1997), "Efficient Use and Provision of Transportation Infrastructure with Imperfect Pricing: Second Best Rules," *The Full Costs and Benefits of Transportation: Contributions to Theory, Method and Measurement,* Springer.

Giuliano, G. (1994), "Equity and Fairness Considerations of Congestion Pricing. Curbing Gridlock, Peak-Period Fees to Relieve Traffic Congestion," *Transportation Research Board Special Report,* Vol. 242, pages 250-279.

Glaister, S. and Graham, D. (2005), "An Evaluation of National Road User Charging in England," *Transportation Research Part A,* Vol. 39(7-9), Elsevier, pages 632-650.

Glaister, S. and Graham, D. (2006), "Road Pricing in Great Britain: Winners and Losers."

Goh, M. (2002), "Congestion Management and Electronic Road Pricing in Singapore," *Journal of Transport Geography,* Vol. 10(1), Elsevier, pages 29-38.

Gomez-Ibanez, J. (1992), "The Political Economy of Highway Tolls and Congestion Pricing," *Transportation Quarterly,* Vol. 46(3), pages 343-360.

Goodwin, P. (1989), "The 'Rule of Three': A Possible Solution to the Political Problem of Competing Objectives for Road Pricing," *Traffic engineering and control,* Vol. 30(10), Hemming, pages 495-497.

Hau, T. (2005), "Economic Fundamentals of Road Pricing: A Diagrammatic Analysis, Part I–Fundamentals," *Transportmetrica, 2005a,* Vol. 1, pages 81-117.

Illich, I. (1974), *Energy and Equity*, Calder & Boyars London.

Ison, S. (1998), "The Saleability of Urban Road Pricing," *Economic Affairs,* Vol. 18(4), Blackwell Synergy, pages 21-25.

Ison, S. and Rye, T. (2005), "Implementing Road User Charging: The Lessons Learned from Hong Kong, Cambridge and Central London," *Transport Reviews,* Vol. 25(4), Taylor and Francis, pages 451-465.

Jaensirisak, S., Wardman, M. and May, A. (2005), "Explaining variations in public acceptability of road pricing schemes," *Journal of Transport Economics and Policy,* Vol. 39(2), pages 127-153.

Johnston, R. and Rodier, C. (1999), "Synergisms Among Land Use, Transit, and Travel Pricing Policies," *Transportation Research Record,* Vol. 1670, Trans Res Board, pages 3-7.

Jones, P. (2002), Addressing Equity Concerns in Relation to Road User Charging, *in* "Conference on Acceptability of Transport Pricing Strategies, Dresden, Germany."

Jones, P. (2001, April). Addressing Equity Concerns in Relation to Road User Charging. Paper presented at the CUPID-PROGRESS Workshop, Trondheim, Norway.

Jones, P. (2003), "Acceptability of Transport Pricing Strategies: Meeting the Challenge," *Acceptability of Transport Pricing Strategies,* pages 27-62.

King, D., Manville, M. and Shoup, D. (2007), "The Political Calculus of Congestion Pricing," *Transport Policy,* Vol. 14(2), Elsevier, pages 111-123.

Kitchen, M. (2008), "Traffic Choices Study: Summary Report."

Kockelman, K. and Kalmanje, S. (2005), "Credit-Based Congestion Pricing: A Policy Proposal and the Public Response," *Transportation Research Part A,* Vol. 39(7-9), Elsevier, pages 671-690.

Kotsialos, A. and Papageorgiou, M. (2004), "Efficiency and Equity Properties of Freeway Network-Wide Ramp Metering with AMOC," *Transportation Research Part C,* Vol. 12(6), Elsevier, pages 401-420.

Lake, R., Hirshtorn, R., Barton, R., Schwier, C., Tardif, L.-P., and Hackston, D. (1999), "Road Pricing and Climate Change. Phase I: Needs assessment."

Langmyhr, T. (1997), "Managing equity The case of road pricing," *Transport Policy,* Vol. 4(1), Elsevier, pages 25-39.

Lave, C. (1994), "The Demand Curve Under Road Pricing and the Problem of Political Feasibility," *Transportation research. Part A, Policy and practice,* Vol. 28(2), Elsevier, pages 83-91.

Lawrence, G. (2006), "A Two-Phase Study of Attitudes of Washington State Voters Toward Transportation Issues. 2006."

Levine, J. and Garb, Y. (2002), "Congestion Pricing's Conditional Promise: Promotion of Accessibility or Mobility?," *Transport Policy,* Vol. 9(3), Elsevier, pages 179-188.

Levinson, D. (2000), "Revenue Choice on a Serial Network," *Journal of Transport Economics and Policy,* Vol. 34(1), pages 69-98.

Levinson, D. (2001), "Why States Toll: An Empirical Model of Finance Choice," *Journal of Transport Economics and Policy,* Vol. 35(2), pages 223-238.

Levinson, D. (2002), "Identifying Winners and Losers in Transportation," *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 1812, National Research Council, pages 179-185.

Levinson, D. (2005), "Micro-Foundations of Congestion and Pricing: A Game Theory Perspective," *Transportation Research Part A,* Vol. 39(7-9), Elsevier, pages 691-704.

Levinson, D. and Odlyzko, A. (2008), "Too Expensive to Meter: The Influence of Transaction Costs in TRansportation and Communication," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* Vol. 366(1872), The Royal Society, pages 2033-2046.

Levinson, D. and Rafferty, P. (2004), "Delayer Pays Principle: Examining Congestion Pricing With Compensation," *International Journal of Transport Economics,* Vol. 31(3), pages 295-311.

Levinson, D. and Zhang, L. (2006), "Ramp Meters on Trial: Evidence from the Twin Cities Metering Holiday," *Transportation Research Part A,* Vol. 40(10), Elsevier, pages 810-828.

Lindsey, R. (2003), Road Pricing Issue and Experiences in the U.S. and Canada.

Link, H. and Polak, J. (2003), "Acceptability of Transport Pricing Measures Among Public and Professionals in Europe," *Transportation Research Record,* Vol. 1839, Trans Res Board, pages 34-44.

Lo, H., Hickman, M., Walstad, M., California, of Transportation Studies, I., of California, B. U., for Advanced Transit, P., (Calif, H. and of Transportation, D. (1996), *An Evaluation Taxonomy for Congestion Pricing*, California PATH Program, Institute of Transportation Studies, University of California at Berkeley.

Lyons, G., Dudley, G., Slater, E., and Parkhurst, G. (2004), "Evidence-base review: Attitudes to road pricing," *Final report to the Department for Transport, UK.*

Marini, M. and Marcucci, E. (2003), "Political Acceptability of Road Pricing Policies Under Individual Specific Uncertainty," *Acceptability of Transport Pricing Strategies. Elsevier Science,* pages 279-297.

Maruyama, T. and Sumalee, A. (2007), "Efficiency and Equity Comparison of Cordon- and Area-Based Road Pricing Schemes Using a Trip-Chain Equilibrium Model," *Transportation Research Part A,* Vol. 41(7), Elsevier, pages 655-671.

Mayeres, I. and Proost, S. (2002), "Reforming Transport Pricing: An Economist's Perspective on Equity, Efficiency, and Acceptability," *Center for Economic Studies–KU Leuven.*

Medin, H., Nyborg, K. and Bateman, I. (2001), "The Assumption of Equal Marginal Utility of Income: How Much Does it Matter?" *Ecological Economics,* Vol. 36(3), Elsevier, pages 397-411.

Metz, D. (2008), "National Road Pricing: A Critique and an Alternative," *Transport,* Vol. 161(3), Thomas Telford, pages 167-174.

Mitchell, G. (2005), "Forecasting Environmental Equity: Air Quality Responses to Road User CHarging in Leeds, UK," *Journal of Environmental Management,* Vol. 77(3), Elsevier, pages 212-226.

Mohring, H. (1999), "Congestion. Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer eds J. Gomez-Ibanez, WB Tye, C. Winston."

Nakamura, K. and Kockelman, K. (2002), "Congestion Pricing and Roadspace Rationing: An Application to the San Francisco Bay Bridge Corridor," *Transportation Research Part A,* Vol. 36(5), Elsevier, pages 403-417.

Nash, C. (2001), "Equity Versus Efficiency in Transport Systems," *Handbook of Transport Systems and Traffic Control,* Pergamon, pages 33-45.

Nash, C. (2003), "Marginal Cost and Other Pricing Principles For User Charging in Transport: A Comment," *Transport Policy,* Vol. 10(4), Elsevier, pages 345-348.

Newbery, D. and Santos, G. (1999), "Road Taxes, Road User Charges, and Earmarking," *Fiscal Studies,* Vol. 20(2), Blackwell Synergy, pages 103-132.

Newman, L., Dunnet, A. and Meis, G. J. (1969), "Freeway Ramp Control: What it Can and Cannot Do."

Nix, F. (2001), "Alternative Road Financing Arrangements," *research conducted for the Canadian Transportation Act Review, (http://www.reviewctaexamenltc.gc.ca/CTAReview/CTAReview/english/reports/nix. pdf), accessed July,* Vol. 11, page 2,006.

Oberholzer-Gee, F. and Weck-Hannemann, H. (2002), "Pricing Road Use: Politico-Economic and Fairness Considerations," *Transportation Research Part D,* Vol. 7(5), Elsevier, pages 357-371.

Odeck, J. and *Bråthen*, S. (1997), "On Public Attitudes Toward Implementation of Toll Roads the Case of Oslo Toll Ring," *Transport Policy,* Vol. 4(2), Elsevier, pages 73-83.

Olszewski, P. and Xie, L. (2005), "Modeling the Effects of Road Pricing on Traffic in Singapore," *Transportation Research Part A,* Vol. 39(7-9), Elsevier, pages 755-772.

Pädam, S. and Wijkmark, B. (n.d.), "Ways and Means to Increase the Acceptance of Urban Road Pricing."

Parkany, E. (2005), "Environmental Justice Issues Related to Transponder Ownership and Road Pricing," *Transportation Research Record,* Vol. 1932, Trans Res Board, pages 97-108.

Parry, I. and Bento, A. (2001), "Revenue Recycling and the Welfare Effects of Road Pricing," *Scandinavian Journal of Economics,* Vol. 103(4), Blackwell Synergy, pages 645-671.

Patterson, T. and Levinson, D. (n.d.), "Lexus Lanes or Corolla Lanes? Spatial Use and Equity Patterns on the I-394 MnPASS Lanes."

Pigou, A. (1912), "The Economics of Welfare. 1920, Reprint ed. London, 1952," *Wealth and Welfare.*

Piotrowicz, G. and Robinsons, J. (1995), "Ramp Metering Status in North America."

Rajé, F. (2003), "The Impact of Transport on Social Exclusion Processes with Specific Emphasis on Road User Charging," *Transport Policy,* Vol. 10(4), Elsevier, pages 321-338.

Rajé, F., Grieco, M. and McQuaid, R. (2004), *Edinburgh, Road Pricing and the Boundary Problem: Issues of Equity and Efficiency*, scotecon. net.

Ramjerdi, F. (2006), "Equity Measures and Their Performance in Transportation," *Transportation Research Record,* Vol. 1983, Trans Res Board, pages 67-74.

Ramsey, F. (1927), "A Contribution to the Theory of Taxation," *Economic Journal,* Vol. 37(145), JSTOR, pages 47-61.

Rietveld, P. (2003), "Winners and Losers in Transport Policy: On Efficiency, Equity, and Compensation," *Handbook of transport and the environment,* pages 585-602.

Rilett, L. and Benedek, C. (1994), "Traffic Assignment Under Environmental and Equity Objectives," *Transportation Research Record,* National Academy of Sciences, pages 92-92.

Rosenbloom, S. (2009), "The Equity Implications of Financing the Nation's Surface Transportation System," *TR News*, Transportation Research Board, Vol. 261 (March-April), pages 3-9.

Safirova, E., Gillingham, K., Perry, I., Nelson, P., Harrington, W., and Mason, D. (2004), "Welfare and Distributional Effects of Road Pricing Schemes for Metropolitan Washington, D.C.," *Road Pricing: Theory and Evidence,* pages 179-206.

Safirova, E., Houde, S., Lipman, D., Harrington, W., and Baglino, A. (2006), Congestion Pricing: Long-Term Economic and Land use Effects, Technical report, Discussion paper 06-37. Washington, D.C.: Resources for the Future.

Santos, G. and Rojey, L. (2004), "Distributional Impacts of Road Pricing: The Truth Behind the Myth," *Transportation,* Vol. 31(1), Springer, pages 21-42.

Schade, J. and Schlag, B. (2003), "Acceptability of Urban Transport Pricing Strategies," *Transportation Research Part F: Psychology and Behaviour,* Vol. 6(1), Elsevier, pages 45-61.

Schweitzer, L. and Taylor, B. (2006), "Just Pricing: Comparing the Effects of Congestion Pricing and Transportation Sales Taxes on Low-Income Households," *Transportation Research Board. Transportation Research Board,* pages 1-27.

Sen, A. (1992), *Inequality Reexamined*, Oxford University Press.

Small, K. (1983), "The Incidence of Congestion Tolls on Urban Highways," *Journal of Urban Economics,* Vol. 13(1), pages 90-111.

Small, K. (1992), "Using the Revenues From Congestion Pricing," *Transportation,* Vol. 19(4), Springer, pages 359-381.

Smirti, M., Evans, A., Gougherty, M. and Morris, E. (2007), "Politics, Public Opinion, and Project Design in California Road Pricing," *Transportation Research Record,* Vol. 1996, Trans Res Board, pages 41-48.

Steininger, K., Friedl, B. and Gebetsroither, B. (2007), "Sustainability Impacts of Car Road Pricing: A Computable General Equilibrium Analysis for Austria," *Ecological Economics,* Vol. 63(1), Elsevier, pages 59-69.

Steininger, K., Friedl, B., and Gebetsroither, B. (n.d.), "Distributional Impacts of Nationwide Car Road Pricing: A CGE Analysis for Austria."

Sullivan, E. (2000), "Continuation Study to Evaluate the Impacts of the SR 91 Value-Priced Express Lanes: Final Report," *Submitted to State of California Department of Transportation Traffic Operations Program HOV Systems Branch, Sacramento CA,* Vol. 94273.

Supernak, J., Golob, J., Golob, T., Kaschade, C., Kazimi, C., Schreffler, E., and Steffey, D. (2002), "San Diego's Interstate 15 Congestion Pricing Project: Attitudinal, Behavioral, and Institutional Issues," *Transportation Research Record,* Vol. 1812, Trans Res Board, pages 78-86.

Teubel, U. (2000), "The Welfare Effects and Distributional Impact of Road User Charges on Commuters: An Empirical Analysis of Dresden," *International Journal of Transport Economics,* Vol. 27(2), Rivista Internazionale DI, pages 231-256.

Tilahun, N. and Levinson, D. (n.d.), "Value of Time Comparisons in the Presence of Unexpected Delay," *Presented at the Third International Conference on Transport Network Reliability in Delft, Netherlands, July 2007.*

Truelove, P. (1998), "The Political Feasibility of Road Pricing," *Economic Affairs,* Vol. 18(4), Blackwell Synergy, pages 15-20.

Ungemah, D. (2007), "This Land Is Your Land, This Land Is My Land: Addressing Equity and Fairness in Tolling and Pricing," *Transportation Research Record,* Vol. 2013, Trans Res Board, pages 13-20.

Verhoef, E., Nijkamp, P., and Rietveld, P. (1996), "Second-Best Congestion Pricing: The Case of an Untolled Alternative," *Journal of Urban Economics,* Vol. 40(3), Elsevier, pages 279-302.

Verhoef, E., Niskanen, E., Proost, S., and Rouwendal, J. (2003), "Phasing and Packaging of Pricing Reform."

Vickrey, W. (1965), "Pricing as a Tool in Coordination of Local Transportation."

Viegas, J. (2001), "Making Urban Road Pricing Acceptable and Effective: Searching for Quality and Equity in Urban Mobility," *Transport Policy,* Vol. 8(4), Elsevier, pages 289-294.

Weinstein, A. and Sciara, G. (2006), "Unraveling Equity in HOT Lane Planning: A View from Practice," *Journal of Planning Education and Research,* Vol. 26(2), ACSP, page 174.

Whittles, M. (2003), *Urban Road Pricing: Public and Political Acceptability*, Ashgate Publishing, Ltd.

Whitty, J. and Imholt, B. (2005), *Oregons Mileage Fee Concept and Road User Fee Pilot Program: Report to the 73rd Oregon Legislative Assembly On proposed alternatives to the current system of taxing highway use through motor vehicle fuel taxes*, Vol. 73.

Wilson, P. (1988), "Welfare Effects of Congestion Pricing in Singapore," *Transportation,* Vol. 15(3), Springer, pages 191-210.

Xin, W. and Levinson, D. (2006), Stochastic congestion and pricing model with endogenous departure time selection and heterogeneous travelers, *in* "Proceedings of 11th International Conference for Hong Kong Society of Transportation Studies, December."

Yin, Y. and Lawphongpanich, S. (2006), "Internalizing Emission Externality on Road Networks," *Transportation Research Part D,* Vol. 11(4), Elsevier, pages 292-301.

Zhang, L. and Levinson, D. (2005*a*), "Balancing Efficiency and Equity of Ramp Meters."

Zhang, L. and Levinson, D. (2005*b*), "Road Pricing with Autonomous Links," *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 1932, Trans Res Board, pages 147-155.

Zhang, L. and Levinson, D. M. (2002), "Optimal Freeway Ramp Control Without Origin-Destination Information."

Zhang, L., Levinson, D., and Zhu, S. (2008), "Agent-Based Model of Price Competition, Capacity Choice, and Product Differentiation on Congested Networks," *Journal of Transport Economics and Policy*, Vol. 42(3), pages 435-461.