Synthesis of Congestion Pricing-Related Environmental Impact Analyses

Final Report

Prepared for
United States Department of Transportation
Federal Highway Administration (FHWA)
Office of Operations
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Washington, DC 20590

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October 18, 2010

QUALITY ASSURANCE STATEMENT

Technical Report Documentation Page

1. Report No. FHWA-HOP-11-008	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Synthesis of Congestion Pricing-Related Environmental Impact Analyses – Final Report		5. Report Date October 18, 2010
		6. Performing Organization Code
7. Author(s) Matt Burt and Garnell Sowell, Battelle; Jason Crawford and Todd Carlson, Texas Transportation Institute.		8. Performing Organization Report No.
9. Performing Organization Name and Address Battelle 505 King Avenue Columbus, OH 43201		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFH61-06-D-00007 – Task T10001
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Highway Administration Federal Transit Administration 1200 New Jersey Avenue, S.E. Washington, DC 20590		13. Type of Report and Period Covered
		14. Sponsoring Agency Code HRT
15. Supplementary Notes Gene McHale, COTM		

16. Abstract

This report summarizes the state-of-the-practice and presents a recommended framework for before-after evaluations of the environmental impacts of congestion pricing projects, such as high-occupancy toll (HOT) lanes and cordon or area pricing schemes. The report focuses on the three environmental impact areas that have been most commonly examined in such evaluations: air quality, noise, and environmental justice (sometimes referred to as equity). Since environmental impacts are a function of the travel impacts of congestion pricing projects, this report also examines state-of-the-practice regarding evaluation of travel impacts such as traffic, transit and travel behavior. The state-of-the-practice results are based primarily on a review of the published literature associated with eight congestion pricing study projects from around the world. A number of gaps in existing practice and understanding are identified and recommendations are provided to address those gaps.

17. Key Word Congestion pricing, road user charges, environmental impacts	18. Distribution Statement No restrictions. This document is available to the public.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 96	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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LIST OF ABBREVIATIONS

CARB	California Air Resources Board
CO	carbon monoxide
CO_2	carbon dioxide
CRD	Congestion Reduction Demonstration
CURACAO	Coordination of Urban Road User Charging Organisational Issues.
DSRC	dedicated short-range communication
EAs	environmental assessments
EISs	environmental impact statements
EMFAC	EMission FACtors
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GPS	global positioning system
HOT	high occupancy toll
HOV	high-occupancy vehicle
I-15	Interstate-15
IM	inspection and maintenance
MSATS	mobile source air toxics
Mn/DOT	Minnesota Department of Transportation
NEPA	National Environmental Policy Act of 1969
NO_x	nitrogen oxides
OBU	on-board unit
$PM_{2.5}$	fine particulate matter
PM_{10}	particulate matter
ppm	parts per million
PSRC	Puget Sound Regional Council
RTMC	Regional Transportation Management Center
SDSU	San Diego State University
U.S. DOT	United States Department of Transportation
UPA	Urban Partnership Agreement
VMT	vehicle miles traveled
VOCs	volatile organic compounds

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EXECUTIVE SUMMARY

This report presents the results of the United States Department of Transportation (U.S. DOT) Federal Highway Administration (FHWA) study of methods for before-after measurement of the travel and environmental impacts resulting from congestion pricing projects. Congestion pricing encompasses a variety of strategies which feature roadway facility charges to reduce traffic congestion, such as high occupancy toll (HOT) lanes which allow vehicles with fewer occupants to pay a charge to access lanes available to vehicles with more occupants at no charge or at a reduced charge. Other congestion pricing strategies include zone-based pricing where vehicles are charged to enter or drive within a specific geographic area and full roadway pricing in which a toll is imposed upon a previously un-tolled roadway.

This report presents a summary and analysis of current practices as well as a set of recommended practices for conducting before-after evaluations of congestion pricing projects. This study focuses on the environmental impact areas most commonly considered in the literature: air quality, noise, and environmental justice—sometimes termed “equity”—which considers how impacts distribute across different types of people, especially low income and minority groups. Since environmental impacts are driven by the broader travel impacts of congestion pricing projects, this study also investigated state-of-the-practice and assessed gaps in travel evaluation methodologies, including traffic, transit and traveler behavior.

Published literature providing detailed environmental evaluation methodology information is not plentiful and there are very few critical assessments of the state-of-the-art, limitations and best practices. This study is intended to address that gap and provide recommendations that will inform U.S. DOT congestion pricing evaluations such as the approximately $1B Urban Partnership Agreement and Congestion Reduction Demonstration (UPA/CRD) program and other future projects.

Study Process

A sample of eight projects from among the more than 70 projects that were identified worldwide was selected for analysis. The sample included only before-after evaluations, a variety of project/study types, and several high-visibility, frequently cited projects which have not been investigated from an environmental evaluation methodology perspective. The eight study projects are:

- Oregon Mileage Fee Concept and Road User Fee Pilot Program
- Puget Sound Traffic Choices Study
- Commute Atlanta Mileage-Based Value Pricing Demonstration
- Minnesota Interstate 394 MnPASS HOT Lanes
- San Diego Interstate 15 HOT Lanes
- The Stockholm Trial
- Central London Congestion Charging
- Singapore Area Pricing.

The findings presented in this report are based on a review of the published literature associated with these eight study projects as well as some of the relatively scarce congestion pricing

synthesis reports. These include reports from the Federal Highway Administration Value Pricing Pilot Program and the European Commission's "Coordination of Urban Road User Charging Organisational Issues" (CURACAO) reports.

State-of-the-Practice Findings

State-of-the practice and knowledge gaps and limitations are presented separately below for travel and environmental impacts.

Travel Impact Prevailing Practice

- The most common impact areas considered include *traffic* (either describing the usage of a roadway, such as traffic volumes, or the performance of a roadway, such as average speeds), *transit* (either describing usage, such as ridership, or performance, such as schedule adherence), and *traveler behavior,* e.g., route, mode, and time of travel.
- The most common traffic impact performance measures, used in nearly every study project, are: traffic volumes, vehicle miles traveled (VMT) and average speeds. Travel time is also frequently considered.
- Most data for traffic performance measures are objective data, that is, data collected in the field using a wide variety of mostly automated techniques. One important area, vehicle occupancy (key to mode share and other person trip considerations), is often collected manually through visual observation. Probe vehicles, whether driven by evaluators or general public volunteers, are becoming increasingly common for traffic data collection.
- There is less variation and fewer performance measures in the area of transit impacts. The most common measure, included in most evaluations that examine anything other than traffic impacts, is transit ridership, which is often collected automatically using on-board sensors. Bus travel times, schedule adherence, and rider perceptions are less common.
- Consideration of traveler behavior impacts is common, but it is not included in all evaluations. Most evaluations that consider traveler behavior impacts use similar measures, including time of travel, route, mode, origin and destination, and collect the data using traveler surveys.
- Traveler behavior data are usually collected through panel (or "longitudinal") surveys in which the same people participate in the before and after surveys. More robust evaluations survey all adult travelers within a household; other surveys include only one traveler from a household. More robust evaluations survey both general traveler behavior (i.e., focusing on "typical" travel) and collect detailed trip information for one to three specific days using travel diaries. Across evaluations in general, travel diaries are not common. Coupling travel diaries with instruments in the respondents' vehicles to record actual mileage and other data is rare.

Travel Impact Knowledge Gaps and Limitations

Table ES-1 identifies those areas where the current understanding of the travel impacts of congestion pricing projects is stronger as well as the areas where there are gaps and limitations.

Table ES-1. Travel Impact Knowledge Gaps

Better Understood Impacts (Knowledge)	Less Understood Impacts (Knowledge Gaps)
Short-term impacts (from a few months up to a year after deployment)	Long term impacts
Localized impacts	Regional impacts
Cumulative impacts (projects plus exogenous factors)	Project-attributable impacts
Individual travel behavior changes	Household travel behavior changes
Vehicle volumes	Person trips
Average speeds	Vehicle speed fluctuations (driving cycle)
Average performance	Variability in performance (reliability)
Transit ridership changes	Transit crowding implications

Most of the gaps and limitations have implications for environmental impact evaluation. Long term impacts refers to the understanding of land use changes such as changes in home or work locations that will only fully manifest over time periods far beyond typical project evaluation timeframes. In the case of regional impacts, it is not that most evaluations are failing to consider expected regional impacts but rather that there has not been enough analysis to understand even whether such impacts are likely. The failure to fully understand the influence of exogenous factors is a pervasive problem. Few evaluations understand those influences well enough to quantitatively adjust observed impacts to reflect only the pricing project. Of significance to air quality is the fact that there is a poor understanding of how congestion pricing projects impact traffic flow in ways that significantly impact vehicle driving cycles.

Environmental Impact Prevailing Practice

- Most evaluations do consider environmental impacts; most commonly air quality, noise and environmental justice.
- There is little variation in air quality or noise impact evaluation methodologies among evaluations.
- Air quality analyses consider project-related vehicle emissions and/or ambient pollution concentrations; the former are always calculated and the latter are always measured using roadside monitors. Calculation of emissions is more common than monitoring, which normally does not allow differentiation of project-attributable changes.
- There is little variation in methods used to calculate vehicle emissions. Emission rates (or "factors") expressing emissions of various pollutants in grams per mile at various average speeds are derived using models and applied to roadway link-specific, observed VMT at various speeds (usually observed speeds) to determine emissions. Total emissions are determined by summing all of the study roadway links.
- In the U.S., vehicle emission rates have been developed using the Environmental Protection Agency (EPA) MOBILE model or, if the project is in California, using the similar California Air Resources Board EMission FACtors (EMFAC) model. These models require region-specific inputs on temperature, vehicle fleets, fuel types and

vehicle inspection and maintenance programs. These models provide little ability to examine impacts of vehicle driving cycle (proportion of travel under acceleration, deceleration, cruise and idle) impacts.

- Like air quality impacts, noise impacts are examined by calculating noise levels—often with the FHWA Traffic Noise Model—or by roadside monitoring of ambient noise levels. No examples of project-attributable, significant noise impacts were found in the literature. Most evaluations show no perceptible changes in noise levels.

Environmental Impacts Knowledge Gaps and Limitations

Table ES-2 shows those areas where the current understanding of the air quality impacts of congestion pricing projects is stronger as well as the areas where there are gaps and limitations. Some of the gaps, such as uncertainty regarding project-attributable changes in VMT and speeds and lack of driving cycle changes—flow directly from limitations in traffic impact evaluation. Others, such as under-consideration of hourly variations in VMT and speeds are less about a lack of traffic data and more about the choice of air quality impact methodology.

Table ES-2. Air Quality Knowledge Gaps

Better Understood Components of Congestion Pricing Vehicle Emission Changes	Less Understood Components of Congestion Pricing Vehicle Emission Changes
Cumulative impacts (VMT, speed)	Project-attributable impacts (VMT, speed)
Localized impacts	Regional impacts
Average daily impacts	Hourly variation (VMT, speed)
	Driving cycle changes (traffic flow change)
	Vehicle mix

It is unlikely that most congestion pricing projects will demonstrate the magnitude of traffic volume or speed changes necessary to produce perceptible changes in noise levels. The smallest noise level change perceptible to most people—about 3dBA—requires a doubling or halving of traffic volume.

Gaps and limitations regarding environmental justice are somewhat less clear, but generally include the following:

- The need for more results overall to support development of more standardized approaches and to solidify knowledge.
- The need to more fully explore geographic location and other “horizontal equity” issues (issues unrelated to income levels and ability to pay) and focus less exclusively on the “vertical equity” issue of the varying incomes and abilities to pay of different stakeholder groups.
- Greater investigation of long-term impacts.
- More research into how the uses of pricing revenues impact perceived and actual equity.

Recommended Evaluation Framework

Air Quality

Key air quality evaluation recommendations include the following:

- Calculate vehicle emissions (ambient monitoring can also be performed if resources permit but the priority should be on emission calculations).
- In those unusual cases where a congestion pricing project is likely to significantly increase localized traffic congestion, especially near sensitive land uses such as nursing homes or schools, consider using a dispersion model such as the EPA CAL3QHCR carbon monoxide model to estimate project-attributable pollutant levels.
- Always use a "project-level" analysis that considers project VMT and speed impacts on individual roadway links.
- Select pollutants for analysis based on local air quality attainment status and issues. Common pollutants of interest include the criteria pollutants carbon monoxide, nitrogen oxides (ozone precursors), volatile organic compounds, and particulate matter; the greenhouse gas-related pollutants carbon dioxide and methane; and the mobile source air toxic benzene.
- The geographic area of analysis should include as many of the roadway links as possible that are expected to be significantly impacted (e.g., a ±5 mile per hour change in average speed) as possible. Include at least all freeways and major arterials within the priced zone and the parallel routes that may experience significant traffic diversion.
- Collect at least a couple of months of VMT and speed data and a full year's worth if possible. Longer data collection time frames allow seasonal variation to be controlled and exploration of changes as travelers "settle into" their responses to the pricing project.
- To the extent possible, utilize VMT and average speed data that reflect only project-attributable changes by controlling for exogenous factors. Methods for determining whether and how much exogenous factors have impacted observed traffic data include:
    - Comparisons to control roadways/corridors/areas
    - Statistical modeling that can remove or control for the effect of exogenous factors by including such variables in multivariate equations
    - Utilization of household survey data (travel diary data being ideal) to understand the causes behind reported changes in travel behavior
    - Tracking fuel prices and employment levels
    - Elimination of traffic data from times and locations within the study area characterized by severe weather, significant traffic incidents, and significant roadway construction
    - Collecting before and after tracking data for the same month(s) of the year
    - Examination of historic traffic trends.
- Calculate total daily emissions by summing calculated hourly emissions based on hourly VMT and average speed data; as opposed to calculating daily emissions based on 24-hour VMT and average speeds.

- Test for possible driving cycle changes and if present, collect observed driving cycle data using "floating car" test vehicle procedures (in which vehicles are equipped with Global Positioning Systems and drive train sensor) and use the new EPA MOVES model (Motor Vehicle Emission Simulator) to calculate emissions, as MOBILE and EMFAC provide little to no consideration of driving cycle changes.
- Understand and carefully consider the inputs and default variables and methods utilized in the emission rate (e.g., EMFAC or MOBILE) or emissions model (e.g., MOVES) utilized as they can have significant impacts on calculated emissions. Reflect all local, user-specified inputs as accurately as possible.
- Test for before-after changes in vehicle mix (the proportion of different vehicle types) and if present, vary VMT-by-vehicle type breakdown accordingly when calculating emissions.

Noise

Congestion pricing project evaluations have not shown significant, project-attributable noise impacts and since few congestion pricing projects are likely to produce the dramatic increases in traffic volumes necessary to produce perceptible changes in noise levels, noise analysis is not recommended as a standard component of project evaluation. The recommended framework therefore focuses on air quality and environmental justice.

Environmental Justice

Key environmental justice recommendations include the following:

- Include the common tools and techniques which provide a solid foundation for understanding environmental justice impacts:
    - Regional geographic information systems to map the locations of low-income and minority populations within the likely impact area.
    - Attitudinal surveys, interviews and focus groups of the general public, corridor travelers and specific types of residents and travelers to gather attitude and perception as well as general travel behavior data.
    - Travel diary surveys to gather detailed, specific travel behavior data of various groups of interest.
- Consider broadly how the congestion pricing project impacts different types of people across a wide range of dimensions, not just income and minority status. Other important factors include access to transit, access to private vehicle, and residential and work locations.
- Integrate the collection of demographic data as fully as possible into the overall evaluation data collection plan. Such data can and should be collected in any and all surveys, but also consider how other data of environmental justice importance can be collected in other ways, such as origin-destination information via license plate recognition technology.
- Explicitly consider the transportation environmental justice implications of how congestion pricing project revenues are reinvested.

1.0 INTRODUCTION

This report presents the results of the United States Department of Transportation (U.S. DOT) Federal Highway Administration (FHWA) study of methods for before-after measurement of the travel and environmental impacts resulting from congestion pricing projects. Congestion pricing encompasses a variety of strategies which feature transportation facility charges to reduce demand during congested periods, such as high occupancy toll (HOT) lanes which allow vehicles with fewer occupants to pay a charge to access lanes available to vehicles with more occupants at no charge or at a reduced charge.

This report presents a summary and analysis of current before-after practices as well as a set of recommended practices for evaluating the environmental impacts of deployed congestion pricing projects. The summary of current practice is based primarily on a review of published literature pertaining to eight congestion pricing projects from around the world.

The remainder of this introductory chapter provides background information, elaborates on the purpose of this study and summarizes the study methodology. Chapter 2.0 presents narrative summaries of each of the eight study projects describing, for each project, the congestion pricing project, the travel and environmental impact evaluation methodologies, and the reported impacts. Chapter 3.0 draws upon the information presented in Chapter 2.0 to summarize the state-of-the-practice and presents a critical assessment of the strengths and weaknesses. Chapter 4.0 presents the recommended framework for before-after evaluations of the environmental impacts of congestion pricing projects.

1.1 Background and Purpose

Traffic congestion has proven to be a persistent, challenging problem throughout the world. Very significant levels of traffic congestion have persisted and, typically, have continued to increase in many urban areas over the last several decades. The Texas Transportation Institute analyzes traffic congestion data from agencies throughout the United States and publishes results in Urban Mobility Monitoring Reports. The latest available report[1], published in 2009 and based on 2007 data, show the following congestion increases between 1982 and 2007:

- 162 percent increase in annual congestion delay per traveler
- 427 percent increase in total delay
- 462 percent increase in total fuel wasted
- 422 percent increase in the total cost of congestion.

Although advances in transportation facilities and operations practices have proven useful in the effort to manage traffic congestion, to date, no cost-feasible and politically and environmentally acceptable "solutions" to traffic congestion have been identified. In approximately the last decade, the search for additional strategies to reduce traffic congestion has led to a heightened focus on congestion pricing. Interest in congestion pricing strategies is also, to some degree, a function of increasing interest in roadway revenue collection and financing options—the two strategies can be closely linked. Table 1-1 identifies various types of congestion pricing projects

[1] Schrank, David and Lomax, Tim, "Urban Mobility Monitoring Report 2009," University Transportation Center for Mobility, Texas Transportation Institute, July 2009.

and some examples of deployed projects and studies. The categories of congestion pricing projects used in Table 1-1 are those used by the FHWA in their Value Pricing Pilot Program.[2]

Table 1-1. Types of Congestion Pricing Projects

Type of Congestion Pricing	Summary Description	Project or Study Examples
HOT Lanes (Partial Facility Pricing)	Conversion of high-occupancy vehicle (HOV) lanes into priced lanes called HOT lanes. Vehicles not meeting HOV occupancy requirements can pay a fee to use the HOT lane.	• I-15 in San Diego, California • I-394 and I-35W in Minneapolis, Minnesota • I-25 in Denver, Colorado • I-95 in Miami, Florida • I-10 and US 290 in Houston, Texas • SR 167 in Seattle Washington • I-495 in Virginia • I-15 in Salt Lake City, Utah • I-85 in Atlanta, Georgia
Express Toll Lanes (Partial Facility Pricing)	Introduction of new roadway capacity that can be accessed only by paying a toll.	• SR 91 in Orange County, California
Full Roadway Facility Pricing	Introduction of variable tolls on roads, bridges or tunnels that were formerly free, or making currently flat tolls variable.	• San Joaquin Hills Toll Road in Orange County, California • Midpoint and Cape Coral Bridges in Lee County, Florida • New Jersey Turnpike • New York-New Jersey Interstate toll crossings • SR 520 Bridge in Seattle, Washington
Zone-based Pricing, including Cordon and Area Pricing	Variable or fixed charges to drive within or into a congested area within an urban region. Involves placing new tolls on multiple existing roads.	• Central London Congestion Charging • The Stockholm Trial, Sweden • Milan, Italy "EcoPass" • Rome, Italy
Regionwide Pricing	Pricing at several locations within a region, including new and existing lanes or entire facilities.	• Singapore
Making Vehicle Use Costs Variable	Conversion of fixed costs such as vehicle taxes and fees, auto insurance and lease costs, into costs that vary vehicle miles driven and/or time of day.	• Oregon Mileage Fee Concept and Road User Fee Pilot Program • Puget Sound Traffic Choices Study • Commute Atlanta Mileage Based Value Pricing Demonstration • Minnesota Mileage-based User Fee Demonstration
Parking Pricing and Other Market-Based Strategies	Various parking and other market-based strategies (see examples at right).	• Dynamically Priced Car Sharing in Tampa, Florida • New York City On-Street Parking Pricing • San Francisco Car Sharing • Los Angeles ExpressPark Variable Parking Pricing • San Francisco Downtown Parking Pricing

[2] United States Department of Transportation, Federal Highway Administration, "Report on the Value Pricing Pilot Program Through May 2009," September 17, 2009.

An important manifestation of the increasing focus on congestion pricing in the United States is the U.S. DOT Urban Partnership Agreement (UPA) and Congestion Reduction Demonstration program. Under the UPA/CRD, U.S. DOT has provided a total of approximately $1B shared among six metropolitan areas (Atlanta, Los Angeles, Miami, Minneapolis, San Francisco and Seattle) to deploy integrated sets of congestion reduction strategies that feature various forms of congestion pricing coupled with supporting travel demand management, transit, and technology-based strategies. Table 1-2 summarizes the UPA/CRD deployments, with the congestion pricing strategies shown in bold type. An important part of the UPA/CRD program is the U.S. DOT evaluation of the impacts of each deployment. Comprehensive assessments of the impacts of the various strategies used at each site are critical both to inform U.S. Federal transportation policy and programs but also to provide guidance to operating agencies who may implement similar strategies.

As congestion pricing projects are becoming more common there is a growing volume of literature describing the projects and their effects. However, there is little published literature on the strengths and weaknesses of prevailing congestion pricing evaluation methodologies. This study is intended to address that deficiency; to summarize current practice and recommend a framework that can inform the UPA/CRD evaluations that are currently in progress and which may also help guide future U.S. DOT or other evaluations.

The primary focus of this study is on the environmental impacts of congestion pricing, including air quality, noise and environmental justice. However, environmental impacts are typically a direct result of travel impacts of projects, such as changes in traffic volumes and roadway speeds. As such, it was clear that this study must also consider how the travel impacts which underlie environmental impacts have been and can best be evaluated.

1.2 Study Process

The study process consisted of the following steps:

- A scan of published literature on congestion pricing projects
- Selection of study projects for detailed literature review
- Detailed review of published literature on the study projects
- Review of several general (not evaluation methodology-focused) congestion pricing references for possible information on evaluation
- Development of the state-of-the-practice summary and recommended framework.

The initial scan of published literature utilized extensive Internet-based literature searches as well as some searches of university library and technical journal databases. The initial scan was intended to provide a sketch-level understanding of the number and general nature of congestion pricing projects and studies of those projects worldwide. That understanding also informed the selection of a manageable number of study projects.

Table 1-2. Summary of UPA/CRD Strategies by Site[3]

UPA/CRD Strategies	Site					
	MN	SF	Sea	Mia	LA	Atl
Convert HOV lanes to dynamically priced high-occupancy tolling (HOT) lanes and/or new HOT lanes	X			X	X	X
Priced dynamic shoulder lanes	X					
Variably priced parking and/or loading zones		X			X	
Variably priced roadways or bridges (partial cordon)			X			
Increase park-and-ride capacity (expand existing or add new)	X		X	X	X	X
Expand or enhance bus service	X		X	X		X
Implement new, or expand existing, Bus Rapid Transit	X			X	X	
Transit on special runningways (e.g., contraflow lanes, shoulders)	X			X		
New and/or enhanced transit stops/stations	X		X	X	X	
Transit traveler information systems (bus arrival times, parking availability)	X	X	X			
Transit lane keeping/lane guidance	X					
Transit traffic signal priority	X			X	X	
Arterial street traffic signal improvements to improve transit travel times	X					
Ferry service improvements		X	X			
Improved transit travel forecasting techniques		X				
Pedestrian improvements				X	X	
"Results Only Work Environment" employer-based techniques	X					
Work to increase use of telecommuting	X	X	X	X		
Work to increase flexible scheduling	X		X	X		
Work to increase alternative commute programs, including car and van pools	X	X	X	X	X	X
Vehicle infrastructure integration test bed		X				
Active traffic management	X		X			
Regional multi-modal traveler information (e.g., 511)	X	X	X			
Freeway management (ramp meters, travel time signs, enhanced monitoring)	X			X		
Enhanced traffic signal operations	X					
Parking management system		X			X	
Integrated electronic payment for parking and transit		X				
Automated enforcement of HOV and toll violations						X

Note: Strategies shown in bold type are congestion pricing strategies.

[3] United States Department of Transportation, Federal Highway Administration and Federal Transit Administration, "Atlanta Congestion Reduction Demonstration National Evaluation Plan – Draft," prepared by Battelle, May 2010.

A number of conclusions were drawn based on the initial scan:

- A large number of congestion pricing projects was found—about 70, too many to study in-depth as part of this study, and therefore a down-selection of study projects was necessary.
- There was significant variation in congestion pricing projects in terms of the type of pricing (HOT lane, cordon, area, etc.), geographic location (there are many U.S. and international projects), deployment status (proposed/planned vs. operating), and consideration of environmental impacts.
- There was a limited amount of literature focusing on the before-after evaluation of the environmental impacts (including the precipitating travel impacts) of congestion pricing projects. The authors of a 2008 FHWA evaluation of their Value Pricing Pilot Program[4] reached the same conclusions.

The following compiled lists of congestion pricing projects include the projects considered in the initial scan conducted for this study and are available on-line:

- A list compiled by Mark W. Burris, Ph.D., P.E. of the Texas Transportation Institute: https://ceprofs.civil.tamu.edu/mburris/pricing.htm
- A list of Federal Highway Administration Value Pricing Pilot Program Projects: http://ops.fhwa.dot.gov/tolling_pricing/value_pricing/projects/allprojects.htm
- A list of case studies examined through the Coordination of Urban Road User Charging Organisational Issues (CURACAO) program (see "Case Studies" list): http://www.curacaoproject.eu/downloads.php.

Following the initial scan, a subset of congestion pricing projects was selected for detailed literature review based on consideration of the following factors:

- A focus on analyses of *deployed, operational* congestion pricing projects (whether a short-term demonstration with simulated congestion charges or long-term, full deployment with real charges)—which is consistent with the fundamental study objective to inform the evaluation of the UPA/CRD field deployments.
- The apparent extent to which environmental impacts were considered.
- The desirability of including several highly visible, frequently cited pricing and/or revenue collection projects like the London, Singapore and Stockholm area pricing schemes and the Puget Sound and Oregon field studies.
- A mix of pricing projects reflecting a variety of pricing strategies.
- A mix of projects from throughout the United States and around the world.

[4] United States Department of Transportation, Federal Highway Administration, "Value Pricing Pilot Program: Lessons Learned Final Report." Prepared by K.T. Analytics and Cambridge Systematics, Inc. August 2008.

Based on these factors, along with practical considerations encountered over the course of the research—namely difficulties in finding sufficient documentation for certain projects—the following eight study projects were selected.

- Oregon Mileage Fee Concept and Road User Fee Pilot Program
- Puget Sound Traffic Choices Study
- Commute Atlanta Mileage Based Value Pricing Demonstration
- Minnesota I-394 MnPASS HOT Lanes
- San Diego I-15 HOT Lanes
- The Stockholm Trial
- Central London Congestion Charging
- Singapore Area Pricing.

Three of these projects—the Oregon, Puget Sound and Atlanta projects—consisted of before-after (or "with/without") evaluations of short-term field demonstrations of congestion pricing/revenue collection schemes featuring simulated pricing charges. The other projects all consisted of before vs. after evaluations of fully-deployed congestion pricing schemes with real pricing charges. The eight study projects and associated evaluation methodology and pricing impact results information gleaned from the literature review are described in Chapter 2.0.

After selecting the eight study projects, a second on-line literature search was conducted to obtain as many relevant project documents as possible. In addition to reports focusing on specific congestion pricing projects, this second search identified a small number of congestion pricing synthesis reports, including the following:

- FHWA, Value Pricing Pilot Program Lessons Learned, Final Report (August 2008)
- CURACAO reports (State of the Art Review, May 2009; Final Report, June 2009)
- FHWA, Lessons Learned from International Experience in Congestion Pricing (December 2008).

All of this project-specific and synthesis literature was analyzed and provides the basis for Chapters 2.0 and 3.0 of this report, and informs the recommendations presented in Chapter 4.0.

2.0 PROJECT SUMMARIES

This chapter describes the eight congestion pricing projects that were examined as part of this study. For each project, the overall objectives are summarized, along with the travel and environmental analysis methodologies and findings. The information presented in this chapter is strictly descriptive, that is, a summary of information contained in the reviewed literature. As such, the "findings" discussion within each project summary presents the findings reported in the literature, including any reported observations or conclusions pertaining to the strengths and weaknesses of the methodologies. Chapter 3.0 compiles the key project findings presented in this chapter and synthesizes the state-of-the-practice, including an assessment of collective strengths, weaknesses and gaps associated with those practices.

The *methodologies* used in before-after evaluations of congestion pricing projects are the focus of this study, rather than the *impacts* themselves. However, the project summaries that follow as well as some of the summary information in Chapter 3.0 include findings (impact) information because the information was generally readily available from the same literature that was reviewed for methodologies.

Table 2-1 presents basic characteristics of each of study project. Additional information on each project is presented in the summaries that follow.

Table 2-1. Study Project Key Characteristics

Study/Project	Study/Project Type	Study Timeframe	Travel Impacts Analyzed?	Environmental Impacts Analyzed?
Oregon Mileage Fee Concept and Road User Fee Pilot Program	Simulated Pricing Field Demonstration	2006-2007	Yes	No
Puget Sound Traffic Choices Study	Simulated Pricing Field Demonstration	2005-2007	Yes	No
Commute Atlanta Mileage Based Value Pricing Demonstration	Simulated Pricing Field Demonstration	2003-2006	Yes	No
Minnesota I-394 MnPASS HOT Lanes	Before-After Evaluation of an HOV to HOT Lane Conversion	2003-2006	Yes	Yes
San Diego I-15 HOT Lanes	Before-After Evaluation of an HOV to HOT Lane Conversion	1997-2000	Yes	Yes
The Stockholm Trial	Before-After Evaluation of Cordon Pricing	2003-2006	Yes	Yes
Central London Congestion Charging	Before-After Evaluation of Cordon Pricing	2002-Present	Yes	Yes
Singapore Area Pricing	Before-After Evaluation of Area Pricing	1975-Present	Yes	Yes

2.1 Oregon Mileage Fee Concept and Road User Fee Pilot Program

This project summary is based primarily on a 2007 report prepared by the project sponsor, the Oregon Department of Transportation.[5]

The Congestion Pricing Strategy and Objectives

The Oregon Department of Transportation conducted a simulated field demonstration of a time-of-day and area-based congestion pricing scheme. The congestion pricing investigation, the "Road User Fee Pilot Test," was part of a broader project—the Oregon Mileage Fee Concept—which examined the general notion of mileage-based charges in lieu of traditional gas taxes.

The congestion pricing demonstration was conducted in 2006-2007 and involved providing volunteer (general public) drivers of instrumented vehicles feedback on how much they would have paid for their travel under the traditional gas tax approach versus under a per-mile charging scheme in which charges were higher for travel during peak periods and within congested zones (within the Portland region). The drivers did not actually pay the congestion charges but were asked to make their travel decisions as if they were actually being charged. Feedback on what the mileage fee charges would have been was provided to drivers when they refueled at special, participating gas stations. Drivers were also updated monthly by program administrators as to the status of their charges.

This project was concerned only with understanding travel behavior changes and did not assess how those behaviors translated into traffic congestion or transit ridership changes. This project did not assess any environmental impacts.

Methodology

This project examined the following congestion pricing-related travel performance measures:

- Changes in total vehicle miles traveled (VMT)
- Time-of-day changes in vehicle miles traveled, e.g., shifts from the peaks (higher charge) to off-peaks (lower charge)
- Mode shifts from driving to transit or bicycling
- Route changes, e.g., taking routes that avoided the congestion pricing zone
- Number of trips, e.g., foregoing trips that would have been made lacking the pricing.

Changes in total VMT, time-of-day changes, and route changes were collected using the in-vehicle global positioning system (GPS) devices. Mode shifts were assessed qualitatively via traditional (non-travel diary) surveys of participants.

The project included both a baseline (no pricing) and experimental phase. During the experimental phase, drivers were broken into three groups, a control group where no mileage-based or congestion pricing elements were introduced, a "VMT group" where flat, per-mile (not congestion) pricing was introduced, and a third group where time-of-day and area pricing was

[5] Whitty, James M., "Oregon's Mileage Fee Concept and Road User Fee Pilot Program: Final Report," Oregon Department of Transportation, November 2007.

introduced. Changes in the performance measures were determined by comparing among the various phases and experimental groups: the baseline phase (no pricing), the experimental phase control group (no pricing), the experimental phase VMT group, and the experimental phase time-of-day/area pricing group.

Findings

Analysts concluded that the premium charged in the peak periods motivated participants to change the timing of their trips, seek alternate routes outside the congested zone, or use transit more. Participants in the time-of-day/area pricing group reduced their total VMT by 10 percent relative to the baseline (no pricing, pre-deployment) condition, with a peak hour VMT reduction of 13 percent. Study data also showed that the congestion pricing charges could impact mode choice during peak hours, with distance to transit influencing the extent of impact. Those who live closer to transit stops were more likely to use it during peak periods as an alternative to driving.

2.2 Puget Sound Traffic Choices Study

This project summary is based primarily on a 2008 report prepared by the project sponsor, the Puget Sound Regional Council.[6]

The Congestion Pricing Strategy and Objectives

In 2002, the Puget Sound Regional Council (PSRC) received a grant from FHWA to conduct a pilot project to see how travelers change their travel behavior in response to variable charges for road use (variable or congestion-based tolling). Global positioning system tolling meters were placed in the vehicles of about 275 volunteer households. From July 2005 until February 2007, the project observed participant driving patterns before and after hypothetical tolls were charged for the use of all the major freeways and arterials in the Seattle metropolitan area.

The primary aims of the Traffic Choices Study were to:

1. Accurately describe the behavioral response to the congestion-tolling of roadways
2. Better understand issues of policy related to the implementation of road network tolling
3. Test an integrated system of technical solutions to the problem of tolling a large network of roads without deploying substantial physical hardware on the roadside
4. Familiarize the public and policy makers with road network tolling
5. Generate price response data for use in other modeling and analysis
6. Develop an understanding of technological applications and standards
7. Better define a set of policy issues to be addressed in actual program design.

This study considered only travel behavior changes. It did not examine how travel behavior changes may translate into traffic or environmental impacts.

[6] Puget Sound Regional Council, "Traffic Choices Study–Summary Report," April 2008.

The study recruited a sample of volunteers and, after establishing their baseline "before-tolling" driving routine, began imposing hypothetical charges (levied against an endowment account as a financial incentive) for access to selected roadway facilities at particular time periods in the day. The study monitored driving behavior of participants for an average of approximately 18 months per household.

Methods

The study goal was to determine how travel behavior (distance, timing, and number of vehicle trips) was affected by a range of other factors (e.g., household income, size, location; number of vehicles; availability of transit; day or time of travel; congestion price charged). The study formulated statistical models to explain how measures of travel demand, across households, vehicles, and workers (the dependent variables) are affected by changes in the generalized costs of travel (tolls, out-of-pocket costs and time costs), while controlling for household demographics (income and number of drivers), seasonal factors, and a measure of transit viability (the independent, explanatory variables). The study estimated the *elasticities* of travel demand with respect to changes in the price of travel (tolls).

Characteristics of the study included:

- Over 275 households; over 400 vehicles
- Randomly selected from a pool of potential participant households
- Each household was provided a unique travel endowment account, based on their baseline travel behavior
- Hypothetical tolls were levied against the endowment account
- 450 on-board unit (OBU) installations and removals
- System fully operational for over 18 months
- Up to 18 months of trip data per household
- Over 750,000 individual trip records
- Household surveys and focus groups conducted.

The billing system provided detailed physical and financial information on trip activity:

- Tolls paid, VMT by link type, travel time, speeds
- GPS provided information for reconstructing paths, trip ends, and times of travel.

Trip purpose and traveler demographic attributes were appended to trip information:

- Trip purpose had to be inferred using employment and land use records
- Driving tours were constructed from trip data
- Household income was both reported and inferred.

GPS tolling meters were placed in vehicles of 275 volunteer households:

- Established baseline “before tolling” driving routine
- Monitored “after tolling” driver response to pricing on all major freeways and arterials for 18 months.

Findings

The Traffic Choices study resulted in a number of changes in aggregate travel demand. Under the tolling policy established for the study, the changes included:

- 7 percent reduction in all vehicle trips per week
- 12 percent reduction in VMT per week
- 8 percent reduction in travel time per week
- 6 percent reduction in trip segments per week)
- 13 percent reduction in miles driven on tolled roads (tolled miles per week).

The participating households altered the nature and amount of vehicle use in response to hypothetical tolls that increased the costs of travel but did not result in improved travel times.

Many households made notable changes in their travel practices. Households that modified their travel did so in many different ways: taking fewer and shorter vehicle trips, choosing alternate routes and times of travel, or linking trips together to reduce vehicle use altogether. Some households altered their routine travel practices. On the other hand, other households had very limited opportunities to avoid using high demand roads during peak travel times.

The results were consistent with the study team’s expectations. Researchers concluded “paying tolls that reflected the costs of congestion caused many travelers to change aspects of travel behavior, some more than others, depending on the usefulness and convenience of the opportunity for change.”

A conservative analysis of the benefits of network tolling in the Puget Sound region indicates that the present value (2008) of net benefits would be $33.6 billion over a 30-year period. The implementation and operating cost of the system in present value was estimated at $5.5 billion. This provides a benefit/cost ratio of 6.1 for a variable toll network in the region.

Not all aspects of a road network tolling system were fully demonstrated, but the core technology for satellite-based (and whole road network) toll systems were mature and reliable. The tolling system performed as expected and met basic system operating requirements. Further work on system refinement and design of enforcement and billing systems would be required prior to any full system deployment.

2.3 Commute Atlanta Mileage Based Value Pricing Demonstration

The Congestion Pricing Strategy and Objectives

"Commute Atlanta" refers to a multi-faceted, multi-phase program. The portion of the program of interest to this study is a field study of mileage-based value pricing that was carried out between 2004 and 2006. Participants in the overall Commute Atlanta Program include FHWA, the Georgia Department of Transportation and the Georgia Institute of Technology.

The mileage-based value pricing strategy evaluated the effectiveness of a cash incentive to reduce the vehicle miles traveled by volunteer households. For each household, an incentive account was established based on the household's actual number of miles traveled in the equivalent quarter of the previous, baseline year.[7] The amount of the account varied quarterly and was determined by multiplying a dollar amount (which varied from quarter to quarter over the study period, starting at $0.05 per mile and concluding at $0.15 per mile) by the number of miles traveled in the baseline quarter. During the nine-month experiment, households were eligible for a payment from their account each quarter, with the amount of each payment dependent on how many miles they had driven. In the first quarter, $0.05 per mile driven was deducted from the payment. So, if a household had traveled 1,000 miles in the first quarter of the baseline year, and 900 miles in the first quarter of the experimental period, their total *potential* payment would have been $50 (1,000 miles x $0.05) but their *actual* payment would have been $5 ($50 – [900 miles x $0.05]). Households that traveled as many or more miles than in the baseline period received no payments.

The evaluation of the mileage-based value pricing strategy used a before (no incentive) versus after (with incentive) methodology and focused strictly on household travel behavior. No investigation of environmental impacts was performed. However, as part of a separate study of the potential for congestion pricing in the Metropolitan Atlanta Area, an air quality evaluation framework was proposed and that proposed approach is summarized here.

Methods

The evaluation of the mileage-based value pricing component of Commute Atlanta considered the following travel-related performance measures and variables:

- Household travel behavior
    - Vehicle miles driven
    - Number of trips (trip making rates)
    - Trip lengths
    - Durations
    - Intra- versus extra-regional travel activity.
- Household demographic data, including: home location, work status, household structure, income, schools attended, and vehicle ownership.[8]

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[7] Georgia Institute of Technology, Commute Atlanta Study webpage, accessed July 2010: http://commuteatlanta.ce.gatech.edu/.

[8] Xu, Zuyeva, Kall, Elango, Guensler, "Mileage Based Value Pricing: Phase II Case Study Implications of the Commute Atlanta Project." Transportation Research Board 2009 Annual Meeting.

Household travel behavior data were collected using volunteers' vehicles instrumented with GPS and data loggers which monitored travel parameters (position, speed, etc.) from which data could be accessed remotely. These data were collected from 95 households that constitute a subset of a much larger group of households who have participated in other aspects of the overall Commute Atlanta program data collection over a number of years.[9]

The collection of household socio-economic data was performed using longitudinal (panel) surveys and supported a detailed, case study analysis of each of the 95 households to understand the relationship between demographic changes over the course of the study and their impact on travel behavior. Participating households were surveyed monthly over the course of the study on household demographic parameters. It is important to note that although the household surveys included measurement of parameters that are believed to be closely linked to travel behavior, such as work status changes, the surveys do not appear to have specifically queried participants on the motivations behind travel decisions and changes.

The overall Commute Atlanta program included additional data collection, including two-day travel diaries and surveys focusing on employer commute incentives, but it does not appear that those data were used in the analysis of the mileage-based value pricing demonstration.

The air quality impacts of the Commute Atlanta mileage-based value pricing demonstration were not investigated. However, as part of a separate study of the potential for congestion pricing in the Metropolitan Atlanta Area,[10] an air quality evaluation framework was proposed that focuses on two air quality performance measures:

- Total vehicle emissions of: carbon monoxide (CO), particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$) and ozone
- Localized CO levels (CO "hotspot" modeling).

Had vehicle emissions been studied, the plan was to calculate them using emission rates (grams per mile) from the EPA MOBILE emission factor model multiplied by observed link vehicle miles traveled. Localized CO levels were to be calculated using the EPA CALINE4 model, which utilizes user supplied traffic, meteorological, and topographic inputs coupled with EPA CO emission rates to estimate CO concentrations at specific modeled locations associated with roadway intersections.

Findings

The data collection associated with the mileage-based value pricing demonstration included trip lengths, trip durations and other performance measures. However, the literature that was reviewed included only findings related to vehicle miles driven and the influence of household demographic factors on miles driven. The later findings are especially important as this study delved deeply into these particular exogenous factors (changes in household demographics) and

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[9] Xu, Zuyeva, Kall, Elango, Guensler. 2009

[10] Ross, Guensler, et al. 2008. "Final Report – Congestion Pricing Response: Study for Potential Implementation in the Metropolitan Atlanta Area." Prepared for the Georgia Department of Transportation by the Center for Quality Growth and Regional Development & School of Civil and Environmental Engineering at the Georgia Institute of Technology.

represents the most critical examination of these considerations that was found in the literature. In the case of this study, the findings related to exogenous factors are more significant than the travel impacts.

It was reported that more than half of the mileage-based value pricing households reduced their travel and that, overall, vehicle miles driven was reduced by 3 percent relative to the baseline (no incentive) period. However, researchers concluded that the VMT reduction was not significant given the significant variability in before-after household travel changes among households.[11]

The researchers concluded that changes in household demographics over the course of their study had a significant impact on observed VMT changes and more of an impact than other exogenous factors. They found that of the 95 households in the case study, only 28 households remained stable with respect to all six major demographic characteristics: home location, work status, household structure, income, school(s) attended, and vehicle ownership. The most common change was vehicle ownership (40 percent), followed by work status (34 percent). The researchers concluded that among the demographic changes, the impact of work status change was most evident, but that home location and household structure changes were also important influences on VMT. Given the small sample size, they were not able to form conclusions about how the other demographic parameters affect travel.

Based on these findings, the researchers identified a number of methodology enhancements that are necessary in order to form valid conclusions regarding the household travel impacts of congestion pricing projects. These recommendations focus on larger sample sizes and collection of more detailed information from participants to better understand the reasons behind the reported travel behavior. The researchers recommend using "case study" approaches such as theirs in which the impact of changes in household demographics are thoroughly explored at the individual household level. They also suggest that home interviews and focus groups would be helpful in understanding travel behavior changes.

Finally, the researchers cast some degree of doubt on the results of other congestion pricing studies that may not have adequately controlled for household demographic changes (including two studies discussed in this report: Oregon and Puget Sound). Specifically, they state that: "…the findings of similar studies that have been conducted should be eyed with caution and researchers need to be careful in drawing any conclusions on the impact of pricing incentives from these studies."[12]

2.4 Minnesota I-394 MnPASS HOT Lanes

The Congestion Pricing Strategy and Objectives

In May 2005, the Minnesota Department of Transportation (Mn/DOT) started operation of the State's first high occupancy toll facility on a segment of the I-394 corridor in the Minneapolis/ St. Paul region. The system, known locally as MnPASS, was the first deployment of HOT lane strategies in Minnesota and the second in the United States that dynamically adjusts pricing

[11] Xu, Zuyeva, Kall, Elango, Guensler. 2009.

[12] Xu, Zuyeva, Kall, Elango, Guensler. 2009.

levels in response to varying traffic conditions. The travel behavior/traffic objective of the congestion pricing was to adjust tolls so as to meter use of the HOT lane to levels that would provide consistent free-flow speeds.

Mn/DOT conducted a comprehensive monitoring and evaluation effort to assess the I-394 MnPASS system, including investigation of traffic impacts (using both pre- and post-deployment data); traveler behavior changes, including mode choice; and environmental impacts.

Methods

Travel related performance measures utilized by Mn/DOT in their evaluation included the following:

- Reported travel behavior, including mode choice and vehicle occupancy
- Traffic volumes
- Speeds
- Travel times.

Reported travel behavior was collected through three waves of panel surveys of project corridor residents and, as a control group, users of HOV lanes in a different corridor, I-35W. Between 800 and 900 residents participated in each wave. The first wave of surveying was conducted prior to HOT lane deployment and the second and third waves were conducted post-deployment. The survey effort included telephone surveys, mailed questionnaires, and travel logs. The travel logs included a travel diary for a single day and general travel behavior information for one week.

Traffic volumes, speeds and travel times were collected directly, or derived, from Mn/DOT Regional Transportation Management Center (RTMC) detectors. The detectors provided a nearly continuous source of data on vehicle volumes for a period between January 2003 (pre-deployment) and July 2006 (post-deployment). Data were collected from all detectors located within the roadway project section. Data from selected stations upstream and downstream of I-394 were also collected to monitor vehicle volumes at adjacent bottleneck locations. Vehicle speed data, as derived from detector density data, were analyzed separately for the general purpose and MnPASS lanes based on the recorded influencing factors. Baseline detector data were compiled for all available days and time periods between July 2003 and May 2005. Similar data were compiled for the technical evaluation from the opening date through July 2006 to represent the after conditions.[13]

Environmental performance measures consisted of:

- Noise levels
- CO levels (the project was located within a CO non-attainment area)
- Environmental justice (variation in survey responses for various demographics).

[13] Cambridge Systematics, Inc., Short-Elliott-Hendrickson, Inc., and LJR, Inc. "I-394 MnPASS Technical Evaluation-Final Report." Minnesota Department of Transportation and the Metropolitan Council, Minneapolis, Minnesota. November 2006.

Before and after data on CO levels were collected with emissions sensing stations deployed at several strategic locations near the roadway. Pre-implementation data were supplemented by historical emissions data from existing sensor stations located in the corridor. One-hour CO averages were recorded for the a.m. and p.m. peak hours for the pre- and post-implementation lane operation. Each hour of data collected, plus the previous seven hours collected, were averaged to calculate the eight-hour CO average.[14] The one-hour CO averages were compared for a.m. and p.m. peak hours, for pre- and post-MnPASS lane operation for the same dates that noise monitoring was conducted and traffic counts were taken.

Before and after data on roadway noise levels were collected from field sensors temporarily deployed at several strategic locations adjacent to the roadway. The noise data were collected in close coordination with several detailed vehicle counts, documenting the number and type of vehicles using the roadway. These data were collected prior to the opening of the MnPASS lanes to provide an assessment of pre-implementation noise levels. Field noise data was again collected after implementation.[15]

To evaluate and explain specific noise level changes in the a.m. and p.m. peak hours, the MINNOISE model was used. The MINNOISE model uses geography, traffic, and vehicle speeds as input parameters for the program and is based on the FHWA Traffic Noise Model. Sound level differences between measured after and before, and modeled sound level differences between after and before were compared and tested for statistically significant changes in noise level.[16]

Environmental justice was examined through the same survey effort that collected data on traveler behavior and attitudes. Demographic data including income, education, employment status, gender, age and ethnicity were collected. These data allowed researchers to compare survey responses pertaining to social equity, traveling experiences, use of the HOT lanes and attitudes about MnPASS tolling operations across various demographics.

Findings

Findings related to traffic measures consisted of the following:[17]

- Corridor throughput increased during the peak hour by up to 5 percent. This increase occurred while regional volumes in other non-MnPASS corridors observed a decrease.
- General purpose lane travel speeds were observed to increase at all study locations by an average of approximately 6 percent. Travel speeds in the MnPASS lanes either remained the same or increased slightly.
- Average person travel time in the corridor decreased.

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[14] Jordahl-Larson, Marilyn, et. al. "MnPASS Air & Noise Analysis—Final Draft." Environmental Modeling and Testing Unit, Office of Environmental Services, Minnesota Department of Transportation, Minneapolis, Minnesota. October 2005.

[15] Jordahl-Larson, Marilyn, et. al., 2005.

[16] Jordahl-Larson, Marilyn, et. al., 2005.

[17] Cambridge Systematics, Inc., Short-Elliott-Hendrickson, Inc., and LJR, Inc. 2006.

- Significant decreases in the numbers and mode shares of carpools were observed on I-394; however, a significant (yet tempered) decrease in carpool usage was similarly observed on I-35W, which was not equipped with MnPASS during the same time period, suggesting a regional shift in carpool usage. The snapshot nature of the available auto occupancy data, significant variations in the day-to-day usage of the lane by HOV users, and the change in operating hours between the pre-MnPASS and post-deployment periods all served to complicate the precise identification of carpool impacts. Therefore, it can neither be confidently proven nor refuted that the decrease on carpool usage on I-394 is directly attributable to the deployment of MnPASS as the observed decrease is within the margin of error of the analysis. Additionally, user survey results from the separately conducted I-394 MnPASS Attitudinal Evaluation did not reveal any changes in mode choice reported by corridor carpoolers.

Findings related to travel behavior performance measures and travelers' attitudes and opinions consisted of the following:[18]

- Support for the idea of allowing single drivers to use carpool lanes by paying a fee remained high one year after implementation.
- Satisfaction with toll operations remained strong, with minimal levels of dissatisfaction voiced by all MnPASS lane users.
- Traveling experiences of I-394 users have improved since fall 2004 – 71 percent reported no congestion delays on their reference trip compared to 62 percent in Wave 1 and 61 percent of I-35W respondents.
- The dynamic pricing formula was adjusted in January 2006 resulting in a higher average price for peak period users. The formula adjustment also resulted in less price fluctuations and more predictability. However, there was subsequently a slight decrease in the percentage of MnPASS subscribers who considered the MnPASS toll a good value – decreased from 71 percent to 61 percent.
- The implementation of MnPASS did not have a negative impact on carpooling on I-394, nor on traveling experiences in the corridor. The current mode share of I-394 panelists was comparable to that captured in the Wave 1 survey: 81 percent drive alone and 19 percent carpool.

In regard to air quality, a 0.20 parts per million (ppm) CO one-hour average increase was found in the a.m. peak hours at the north monitoring site, with a 0.03 ppm CO decrease in the p.m. peak hours. At the south monitoring site a one-hour average increase of 0.29 ppm CO was found during a.m. peak hours and a 0.01 ppm increase during the p.m. peak hours. The increases in the one-hour average CO levels were considered minimal, and the CO concentrations remained well below the 30 ppm one-hour CO air quality standard for the State of Minnesota. It was concluded that the operation of the MnPASS lane did not result in a substantial impact on the air quality due to any changes in traffic patterns in the project area.[19]

[18] Zmud, Johanna. "MnPASS Evaluation Attitudinal Panel Survey Wave 3—Final Report." Humphrey Institute of Public Affairs, University of Minnesota; NuStats, Austin, Texas. August 2006.

[19] Jordahl-Larson, Marilyn, et. al., 2005.

In regard to noise levels, taking all sites into account and averaging the a.m. and p.m. noise level measurements, it was found that there was not a statistically significant change in the average neighborhood sound pressure level, during the peak hours. The analysis showed instances where noise level changes were confidently attributed to changes in traffic patterns due to the MnPASS lane; nevertheless, there was not a statistically significant change in average neighborhood sound pressure level.[20]

In regard to environmental justice, the evaluation did not identify any significant correlation between demographics and project benefits. It was noted that beneficiaries of the HOT lane include a diverse population across all income, age, race/ethnicity, employment, and mode usage groups.

2.5 San Diego Interstate-15 HOT Lanes

The Congestion Pricing Strategy and Objectives

Eight miles of HOV lanes on Interstate-15 (I-15) were converted to HOT lanes (opened to paying single occupant vehicles) in December 1996. The I-15 HOT lane facility—"FasTrak Lanes"—uses a dynamic, real-time tolling structure in which tolls vary with the level of congestion in order to maintain free-flow traffic conditions. Fees can vary in 25-cent increments as often as every six minutes. All transactions are electronic; overhead antennas read a transponder affixed to the inside of a vehicle's windshield and deduct the toll electronically from the driver's prepaid account.[21] Pricing is based on maintaining a Level of Service "C" in the HOT lanes.

Methods

San Diego State University (SDSU) researchers conducted an independent, multi-element, three-year (1997-2000) evaluation to assess HOT lane impacts on the I-15 corridor and the San Diego region. The research team studied changes in I-15 corridor traffic, travel behavior, and attitudes toward the project throughout its duration. A control corridor (a portion of Interstate 8) was used for traffic-related analyses in order to help differentiate project-related changes from exogenous factors.[22]

The evaluation was conducted in a series of periodic waves, which generally occurred in the spring and fall of each year to avoid interference from the typical seasonal changes in traffic patterns. For most of the studies, SDSU conducted five waves of data collection between fall 1997 and fall 1999.

[20] Jordahl-Larson, Marilyn, et. al. 2005.

[21] K.T. Analytics and Cambridge Systematics, Inc., 2008.

[22] Supernak, Janusz, et. al. "San Diego's I-15 Congestion Pricing Project: Traffic-Related Issues." Transportation Research Record, No. 1812, Paper No. 02-4169. Transportation Research Board, National Academies, Washington, D.C., 43-52. 2002.

Travel related performance measures consisted of the following:

- Macroscopic (aggregate), for both study and control corridors
  - Distribution of traffic volumes by lane group during peak periods
  - Speeds
  - Travel time
  - Traffic incidents
  - Toll violations
  - Vehicle classification (type of vehicle, e.g., passenger versus heavy truck)
  - Vehicle occupancy.
- Microscopic (disaggregate) data on individual travel behavior
  - Demographic characteristics
  - FasTrak use
  - Mode choice
  - Departure time
  - Time savings.

Before-and-after traffic volume, speed, travel time, toll violations, and vehicle classification data were collected from various roadway detectors, including those associated with the HOT lane electronic toll collection system. The data on vehicle occupancy were objective—as opposed to estimated or modeled—but the specific data collection method was not identified in the literature that was reviewed. The source of incident data is unknown.

Post-deployment travel behavior data were collected through a 5-wave panel survey of three groups: HOT lane users, I-15 general purpose lane users (both solo drivers and carpoolers), and I-8 (control corridor) travelers. Surveys were conducted between 1997 and 1999.

Environmental performance measures were restricted to total emissions of volatile organic compounds (VOCs), nitrogen oxides (NO_x), PM_{10}, and CO.

Total emissions of each pollutant were calculated as the product of emission factors—derived using the California Air Resources Board (CARB) EMission FACtors model (EMFAC)—multiplied by the number of vehicles and by the length of the corridor segment. Total emissions for each peak period along the corridor were determined by aggregating emissions over all I-15 segments in the corridor for all time periods and all vehicle types.

Findings

Travel Behavior

Overall (all lanes) traffic volume increases along the I-15 corridor were attributed to the substantial volume increases in the I-15 express lanes (48 percent) during the 3-year study period. The I-15 pricing project alleviated congestion on the I-15 main lanes by redirecting an increasing share of volume onto the I-15 express lanes. The study team concluded the increases in total I-15 corridor volume reflected more the pressures of population and employment growth in the travel corridor.[23]

In the monitoring period, the I-15 corridor experienced a substantial increase in SOV volume and a corresponding decrease in HOV volume during the a.m. peak period. The increase in SOV volume along the I-15 express lanes was attributed to scheduled program expansion, but could also have been a result of strong demographic and socioeconomic pressures in the corridor because of relatively high rates of commercial and residential development.[24]

A decline in HOV main lane volume along I-15 contrasted sharply with an observed rise in HOV volume along the I-8 control corridor from 1997 to 1999. The results strongly suggested corridor-specific factors, including the I-15 pricing project, were responsible for these differences. Unrewarded carpooling on the express lanes may have played a role plus limited access to the lanes in the study period, with only one entrance and one exit.[25]

LOS C, required by law to be maintained at all times on the express lanes, was sustained at virtually all times. There was a decrease in variance of volume distribution from fall 1996 to fall 1997 in the a.m. peak period and a subsequent general increasing trend through fall 1999 in the variance of peak-period volume distributions in both a.m. and p.m. peak periods. This result strongly suggested that the dynamic pricing structure was able to create desirable redistribution of a portion of express-lane traffic from the middle of the peak to the shoulders. Researchers were unable to find a sufficient explanation for the HOV portion of the shift to shoulder periods.[26]

Researchers noted a significant increase in express lane use from spring 1998 to spring 1999. They concluded that it may have reflected the effectiveness of the shoulder pricing policy (further decreased toll prices in the off-peak hours) introduced in August 1998 to distribute traffic more evenly throughout the peak period away from the peak hour.[27]

The dynamic pricing influenced the times at which people traveled. FasTrak customers exhibited later departure times than did other I-15 users in all survey waves except for one. Researchers also found that 76 percent of FasTrak customers would leave at a different time in the morning if there were no FasTrak. The majority of those would leave earlier for work to account for the longer and highly unreliable travel times without FasTrak.[28]

Air Quality

The SDSU evaluation team reported that data from the fall study waves from 1997 to 1999 demonstrated that the FasTrak program moderated emission levels along the I-15 corridor during a period in which emission levels increased substantially along the I-8 corridor. The average relative increases along I-8 were three times larger than the average relative increases along the

[23] Supernak, Janusz, et. al. 2002.

[24] Supernak, Janusz, et. al. 2002.

[25]Supermak, Janusz, et. al. 2002.

[26]Supermak, Janusz, et. al. 2002.

[27]Supermak, Janusz, et. al. 2002.

[28]Supernak, Janusz, et. al. 2002.

I-15 corridor in the a.m. peak period. In the p.m. peak period, this difference was even greater (five times larger). The changes in average emission levels along the I-15 main lanes and express lanes over the same period reflected the influence of the FasTrak program in displacing traffic from the main lanes to the express lanes. Average emission levels of all four pollutants on the express lanes increased substantially from fall 1997 to fall 1999 in both peak periods.[29]

Since the study was observational in nature, and other potentially influential factors could not be controlled or measured precisely, the team could not definitively attribute all observed differences in I-15 and I-8 emission profiles to the HOT lane program. However, the effects of the corridor-specific factors were more pronounced along I-15 than I-8 and could be expected to have increased emission levels along the I-15 corridor. No factors, other than the FasTrak program, were identified that could have reduced or mitigated increases in I-15 emission levels.[30]

2.6 The Stockholm Trial

The Congestion Pricing Strategy and Objectives

In January of 2006, the City of Stockholm implemented a cordon/area congestion pricing project spanning seven months, known as The Stockholm Trial. The stated goals of the trial were:[31]

- A 10-15 per cent reduction in the number of vehicles that cross the Inner City segment during morning and afternoon rush hours.
- Improved access on the busiest roads in Stockholm traffic.
- Reduced emissions of carbon dioxide (CO_2), NO_x and particles in inner city air.
- Better street-level environment perceived by people in the inner city.

The congestion pricing component of the trial was to charge motorists a tax whenever they entered Inner City Stockholm. Inner City Stockholm borders or boundaries were defined, and were equipped with control points around the charging zone to monitor vehicles entering and exiting the zone; the vehicles were identified through photographing the license plates or via onboard units. Reducing traffic to improve traffic flow and manage congestion were clear expectations of this project.

An extensive evaluation of the Stockholm Trial was performed using a wide variety of before-after data.

Methods

The evaluation of the Stockholm Trial included the following travel performance measures:

- Traffic volumes
- Vehicle kilometers traveled

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[29] Supernak, Janusz, et. al. 2002.

[30] Supernak, Janusz, et. al. 2002.

[31] Stockholmsforsoket. "Facts and Results from the Stockholm Trials." December 2006.

- Journey (travel) times
- Vehicle queue lengths at intersections
- Individual traveler behavior (demographics, number of trips, origins-destinations, mode, time of travel, travel time)
- Transit ridership
- Bus travel times
- Transit rider perceptions.

Traffic volumes were collected in the field using various data collection methods. Vehicle kilometers traveled were estimated using traffic models. Traffic queue lengths were measured with instrumented test vehicles. Journey times data were collected using two methods: 1) Instrumented vehicles driven by volunteers (50 commuters), and 2) License plate reader vehicle matching.

Individual traveler behavior data were collected through a travel diary (one day) panel study. The panel study included three waves of data collection—two before the pricing project and one after pricing began. More than 30,000 individuals participated in the panel study.

Transit ridership and travel times were collected using automated on-board detectors, with the exception of ridership on underground rail which was collected manually. Transit rider perceptions of the pricing project were gathered through on-board surveys.

The evaluation of the Stockholm Trial included the following environmental performance measures:

- Total vehicle emissions
- Pollutant levels
- Noise levels
- Environmental justice (equity)
    - Origins and destinations
    - Travel times
    - Congestion charges paid
    - Travel adaptation costs
    - Pricing revenue redistribution impacts.

Vehicle emissions of PM_{10}, NO_x, NO_2, CO_2, CO, and VOCs were calculated using observed traffic data (vehicle kilometers traveled) and model-derived emission factors. Ambient pollutant levels were measured using roadside monitors. Estimates of exposure to vehicle-generated emissions were made using air quality dispersion models. Noise levels were measured using roadside monitors.

The environmental justice impacts of the Stockholm Trial were evaluated using traveler origin-destination data collected through a panel travel diary study conducted in two waves which included approximately 24,000 participants, coupled with a regional travel demand model. The travel-diary derived information on trip making was fed into a regional travel demand model and the model was used to estimate the travel times, congestion charges paid, and adaptation costs (e.g., switching to transit) associated with the observed (travel diary) trips under both "with pricing" and "without pricing" scenarios. The travel diary-derived trip data were also used to calculate the impacts of three hypothetical pricing revenue redistribution scenarios: 1) Revenues distributed evenly to all county residents, 2) Reduction of transit fares, and 3) Reductions to income tax.

Findings

Evaluators concluded that the Stockholm Trial was able to manage congestion and increase flow and accessibility. The traffic volume in Inner City Stockholm decreased 16 percent in the morning and 24 percent in the afternoon and early evening. The sum of distances traveled by all motor vehicles (vehicle kilometers traveled) declined 14 percent within the charging zone from 2005 to 2006. Journey times decreased by 3 percent. Data on average queue lengths did not illuminate clear project impacts. Public transport utilization increased by 6 percent overall and by as much as 10 percent during peak hours. Transit customer satisfaction varied by route. Satisfaction among passengers on existing routes dropped slightly, from 66 percent to 61 percent, while 87 percent of passengers on new routes were satisfied[32].

Travel behavior findings included the following:

- Exogenous factors, including season differences between the before and after travel diary data collection and increases in fuel prices preclude a definitive accounting of person trip changes. However, car trips across the pricing zone decreased 20 percent and use of public transportation has increased.
- No project-attributable changes in pedestrian or bicycle travel or telecommuting or car pooling can be attributed to the pricing projects.
- Trips to and from work and school across the pricing zone did not decrease.
- The coordination of carrying out several objectives in a travel chain may have increased slightly.
- A majority of the "cancelled" work and school car trips across the zone have shifted to transit.

Evaluators concluded that decreases in traffic volume and increases in traffic flow from the Stockholm Trial impacted air quality and noise. Reductions in VOC, CO, NO_X, CO_2, and PM_{10} ranged from 8.5 percent to 14 percent. Monitored noise levels showed minor declines.

Major findings of the environmental justice evaluation consisted of the following:

- A few drivers pay the majority of the congestion tax—but the majority pays sometimes.
- There is great variation in how much congestion tax different people pay.
- Wealthy men in the inner city pay the most.

[32] Stockholmsforsoket. December 2006.

- Residents of the inner city and Lidingo experience the greatest net loss per person when taking into account direct traffic effects (travel time, congestion tax and adaptation costs).
- High income earners are affected more than low income earners.
- The key to total cost-benefit effects is how charging revenues are redistributed.
- Commercial traffic and business trips are "net winners" even before charging revenue redistribution is taken into consideration.

Researchers identified a number of exogenous factors that probably significantly impacted evaluation findings, including increases in fuel prices, seasonal variation, weather conditions which impacted monitored air quality, and other transportation projects. These factors could not be controlled; however, when possible the evaluators attempted to isolate the effect of exogenous factors by comparing different monitoring occasions and different areas.[33]

2.7 Central London Congestion Charging

The Congestion Pricing Strategy and Objectives

London launched a cordon road pricing project focusing on Central London in February 2003 and the charging zone has since been expanded—the "Western Extension." The objective of this project was to reduce traffic, improve the speed of buses, create revenue, and improve quality of life.[34] Motorists pay a standard, flat rate to drive cars within the congestion charging zone. The rates did not vary per location and after paying the vehicles can exit and enter as many times as desired. Charges are applied on weekdays from 7:00 a.m. to 6:30 p.m. Congestion charges are paid in advance or on the day of travel by telephone, regular mail, Internet or at retail outlets. There are no toll booths or other roadside payment infrastructure. To enforce and monitor the payments the system made use of networked video cameras (automatic license plate recognition) to record license plate numbers, then matched the license plate numbers to a paid list.[35] Over the years, many aspects of the charging program have been modified, including increases in the daily charge.

The London congestion charging projects have been rather extensively studied. These studies have included before-after evaluations of a variety of travel and environmental impacts.

Methods

The organization Transport for London has conducted a long-term and on-going evaluation of the London congestion charging initiative. Six annual reports on the monitoring efforts have been published to date, with the first report in 2003 describing baseline (pre-pricing) conditions.[36] Although many evaluation methods have remained the same over time and as the

[33] Stockholmforsoket. "Evaluation of the Effects of the Stockholm Trial on Road Traffic." June 2006.

[34] United States Department of Transportation, Federal Highway Administration. "Lessons Learned from International Experience in Congestion Pricing." Prepared by K.T. Analytics. August 2008.

[35] Litman, Todd. "London Congestion Pricing: Implications for Other Cities." Victoria Transport Policy Institute. January 2006.

[36] Transport for London, "Central London Congestion Charging – Impacts Monitoring, First Annual Report," Mayor of London, 2003.

pricing was extended westward, some methods have evolved over time or have been applied only to the central London or Western Extension studies. Of course, different findings have emerged from the various studies. This summary endeavors to present a composite view of all of the travel and environmental impact evaluation methodologies that have been applied.

Travel Impacts

The London congestion pricing evaluations have included before and after measurement of the following travel-related performance measures:

- Congestion (the "excess delay" or "lost travel time" defined as the difference between average network travel rates in uncongested versus congested conditions)
- Average network speeds (vehicle kilometers divided by vehicle hours)
- Average network travel rate (vehicle minutes divided by vehicle kilometers)
- Speed distributions (the proportion of time spent driving within various speed bands)
- Traffic density (number of vehicles per kilometer)
- Number of vehicle trips
- Journey (travel) times
- Traffic volumes
- Vehicle kilometers driven
- Vehicle minutes driven
- Average vehicle occupancy
- Transit ridership
- Average bus journey speeds
- Mode of travel
- Road traffic accidents
- Parking and pedestrian activity
- Number and type of roadway crashes
- Bus reliability – passengers excess waiting time (difference between scheduled and actual bus arrival)
- Bus reliability – operated mileage versus scheduled mileage (congestion can result in a bus covering fewer miles, completing fewer runs than scheduled).

Over the years, a wide variety of data collection methods have been used to collect these various performance measures, with multiple data collection methods often used to collect the same performance measures. The vast majority of data for travel-related performance measures has been collected directly, either in the field using various detectors and manual methods or with surveys and interviews with travelers and other stakeholders. Although travel demand modeling has been used to complement observed traffic data, very few of the travel-related performance measures have been derived solely through modeling or simulation.

Data collection methods utilized for travel-related performance measures have included the following:

- Instrumented floating car runs, license plate matching, and commercially purchased satellite vehicle tracking to collect vehicle speed/travel rate data
- Volunteer, general public driver panels (100 participants) to collect journey time and route choice data
- Various manual and automatic counting methods for traffic volume data
- Visual observation to collect vehicle occupancy data
- Calculation of vehicle kilometers traveled using traffic volumes and roadway lengths
- Automated vehicle location systems for bus travel speeds and times
- Bus station manual schedule adherence observations
- Bus operating statistics to determine the amount of service delivered
- Manual, on-board monitoring to collect bus delay data
- Manual counts and fare collection data for transit ridership
- Case studies with parking authorities to collect parking data
- Manual counting of pedestrian volumes
- Accident reports for data on the type and number of crashes.

In addition, a wide variety of surveys, interviews and focus groups have been conducted to collect attitudinal, general travel behavior, and detailed (travel diary) travel behavior. Evaluation of the London congestion pricing scheme has featured the most extensive and sophisticated use of surveys, interviews and focus groups of all of the projects that have been reviewed as part of this study. These efforts are distinguished in the following respects:

- The sheer *number* of different types of surveys, interviews and focus groups—both at any one time and cumulatively over the course of more than five years.
- The *variety of methods* that have been used, including household as well as individual surveys; in-person as well as telephone survey administration; roadside recruitment as well as use of various databases and “snowball” sampling recruitment of hard to reach populations through coordination with “trusted organizations;” and general travel behavior/attitudinal surveys as well as *detailed travel diaries*.
- An emphasis on the *household as the unit of analysis* and extensive use of household surveys—in which each adult member of the household participates—as a means to pick up on travel changes and trade-offs within households, such the question of how a vehicle is used that was formerly used by someone in the household to drive who is now, because of the congestion charge, taking transit.

- The extensive use of longitudinal, or *panel surveys* which survey the same specific people in successive waves before and after project implementation.
- The extent of special, *targeted efforts to reach traditionally under-represented or unrepresented populations* such as disabled individuals, pedestrians, bicyclists and shift workers.

Specific survey, interview and focus group activities used to collect travel behavior and attitudinal travel-related performance measures have included:

- Household panel surveys of up to 2,300 households
- Panel surveys of up to 2,400 individual travelers
- En-route (at the destination stop) transit surveys to gauge attitudes (e.g., satisfaction) and general travel behavior (e.g., reason for mode choice)
- Roadside traveler interviews with 15,000 or more participants
- Focus groups, typically part of "special inquiries" targeting populations that are typically under-represented in general traveler or household surveys.

Environmental Impacts

Evaluations of Central London Congestion Charging have included before and after measurement of the following environmental impacts:

- Total vehicle emissions (one component of a regional, all-source/all-pollutants inventory) of NO_2, NO_x, PM_{10}, and CO_2
- Pollutant levels (monitored)
- Noise levels
- Environmental justice (within a broader investigation of "social impacts").

Many data collection and analysis methods have changed over time, but cumulatively, the following methods have been used:

- Calculation (estimation) of vehicle emissions using observed roadway link-level traffic data (volumes, speeds, vehicle types) multiplied by model-derived emission rates
- Roadside monitoring of ambient pollutant levels
- Roadside monitoring of ambient noise levels
- Assessment of impacts and attitudes among various socio-economic groups (environmental justice) using surveys, interviews and focus groups.

The methodology used to calculate emissions was compatible with the approach used in the Mayor of London's Air Quality Strategy.[37] The emissions estimation approach included breaking down vehicle emissions by specific traffic variable, e.g., traffic volume, speed changes

[37] Transport for London. 2003.

and emission rates (reflecting changes in vehicle fleet mix and emissions technology changes). This approach was not evidenced in any of the other study projects. From the beginning, monitored pollutant levels were not expected to reveal impacts that could be traced specifically to the congestion charging scheme, but were performed regardless.

Original plans included both modeling and monitoring noise levels. Noise modeling was planned to utilize travel flow, composition, and speed to produce noise mapping and generate noise predictions. However, no results of any modeling efforts were located in the literature, which may indicate that only monitoring was performed.

The consideration of environmental justice issues was conducted within the broader assessment of “social impacts”—the comprehensive assessment of the impact of the pricing on people’s attitudes, perceptions, and abilities. This analysis did consider differences among different income groups but income and race were not as central of a focus as is sometimes found in U.S. studies. Rather, the London analysis has focused on user groups defined by other criteria, such as transit users, people living outside the charging zone, the disabled, people lacking automobiles, and shift workers. Most of the data pertaining to these issues were collected through surveys, interviews and focus groups. Although general traveler/household surveys included demographic data allowing results to be sorted by various characteristics relevant to environmental justice, a number of special surveys and focus groups were conducted focusing specifically on user groups of interest.

Findings

A tremendous volume of evaluation results has been published over the course of six annual monitoring reports and numerous additional studies. Overall, the latest annual report (published in July 2008) concludes that congestion charging continues to meet its fundamental traffic and transport objectives and that the scheme continues to deliver congestion reduction generally equal to the 30 percent reduction achieved in the first year.[38] The same report cites results from the Fifth Annual Report stating that, given the influence of many non-project related factors, it can be misleading to compare recent congestion levels (2006 data) to pre-charging levels but that nevertheless, such a comparison shows 2006 congestion levels to be 8 percent lower than pre-charging levels. The Fifth Annual Report (published in 2007) elaborates that charging has accentuated positive trends such as reduced accidents and emissions while mitigating negative trends like increasing congestion.[39]

Additional specific travel findings as well as environmental findings are summarized below. The specific findings that follow are adapted primarily from the two most recent annual reports—the fifth and sixth.

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[38] Transport for London, “Central London Congestion Charging – Impacts Monitoring, Sixth Annual Report,” Mayor of London, July 2008.

[39] Transport for London, “Central London Congestion Charging – Impacts Monitoring, Fifth Annual Report,” Mayor of London, July 2007.

Travel Impacts

After the first year of the project in the Central London charging zone, VKT decreased by 15 percent for vehicles with four wheels or more and the number of vehicles entering the zone declined by 18 percent. A 14 percent decrease occurred in journey times. The average network speeds in 2003 were 14 kilometers per hour (9 miles per hour), which increased to 17 kilometers per hour (11 miles per hour) in 2006.[40] Research found that in the beginning of the congestion pricing project the traffic volume reductions were significant and as the congestion pricing continued the reductions in traffic volume also continued, but at a slower rate. Overall, the charging zones that began in 2003 and continued through 2006 led to 21 percent less traffic entering the zones.

In the Western Extension zone traffic volume decreased by 14 percent compared with pre-charging conditions in 2005-2006. Also an 11 percent decrease in VKT for vehicles with four wheels or more was reported. Average network speeds and journey time results for the Western Extension were not clearly represented. The volume of commuter trips increased 33 to 38 percent.[41]

Examinations of mode split—the percentage of trips made by the various modes, including driving, public transportation and elimination of the trip entirely—were conducted in support of the second annual monitoring report which reported the first post-deployment year findings related to the central charging zone, and the sixth annual monitoring report, which reported results pertaining to the Western Extension of the pricing zone. Overall, the results suggest that the charging scheme has prompted significant shifting from driving to alternate modes, primarily bus transit.

The early results for the central zone showed that 65,000 to 70,000 car trips no longer cross into the charging zone and estimated the displacement of those trips as follows:[42]

- 50-60 percent shifted to public transportation (slightly more to rail than to bus)
- 20-30 percent kept driving but diverted around the charging zone
- 8-10 percent shifted to bicycle, motorcycle, walking or taxi
- Less than 1 percent (less than 5,000 trips) shifted their car trips to outside of the charging hours
- Less than 1 percent (less than 5,000 trips) eliminated trips (reduced travel frequency).

[40] Transport for London, 2007.

[41] Transport for London, 2008.

[42] Transport for London, 2003.

The results for the Western Extension show that 32 percent of sampled drivers changed their behavior in response to the charge.[43] Among that group that changed their behavior, the breakdown of specific changes was as follows:

- 38 percent changed to an alternative mode
- 28 percent chose not to make the trip at all
- 34 percent made other choices, such as changing the time, route or destination of trip.

Examples of findings related to public transportation usage include the following:

- Passengers entering the central charging zone by bus increased 37 percent during charging hours during the first year of charging; up to half of that increase was attributed to pricing.
- Bus service reliability improved on routes in and around the charging zone; excess wait time fell by 30 percent the first year and an additional 18 percent the second year.
- Bus kilometers not operated because of traffic congestion fell by 20 percent the first year.

Environmental Impacts

As anticipated, it has not been possible to distinguish project impacts from the impacts of exogenous factors in the monitored air quality results. However, results of the emissions calculations indicate that the project has contributed to emissions reductions. In Central London the overall traffic emissions change between 2002 and 2003 included a decrease in NO_x of 13.4 percent, a decrease in PM_{10} of 15.5 percent, and a decrease in CO_2 of 16.4 percent. The Western Extension results comparing 2006 to 2007 also showed a decrease of 2.5 percent in NO_x, a decrease of 4.2 percent in PM_{10}, and a decrease of 6.5 percent in CO_2 based on combined traffic volumes and composition change.[44]

Early noise results—changes from the baseline (2002) observed in the first year of post-deployment (2003) were small and considered imperceptible in typical urban conditions. No project-related impacts on noise were identified. The fourth annual report noted that "Limited sample surveys of ambient noise in and around the charging zone continue to suggest the absence of a detectable congestion charging impact." Later reports do not contain any additional new noise findings.

The various results related to environmental justice issues—the impact of the charging scheme on various types of people—do not identify broad, significant adverse impacts but do note some concerns. Explicit, prominent identification of "winners" and "losers" are not at all prominent in the Transport for London annual reports. This passage from the sixth annual report which focuses on the Western Extension is typical of the sorts of summations found in the Transport for London annual reports:

[43] Transport for London, 2008.

[44] Transport for London, 2007.

> "Overall, the evidence suggests that most London residents have been able to adapt to the introduction of charging in the Western Extension without any detriment to their quality of life, although some concerns remain about the impact of charging on the social interaction of vulnerable groups."[45]

Examples of specific reported findings include the following:

- Actual impacts of the scheme on individuals were generally less than expected by the same respondents.
- Transportation issues that respondents felt most negatively about, such as a lack of parking spaces, were generally not related to the pricing scheme.
- The majority of all respondents felt that the charge was affordable, although—despite the discount they received—more residents inside the charging zone found it difficult to afford.

2.8 Singapore Area Pricing

The Congestion Pricing Strategy and Objectives

Singapore first implemented cordon congestion pricing in 1975 in order to better manage traffic and to reduce vehicle emissions. The initial pricing project was an Area Licensing Scheme in which vehicles were charged a fee for entering a 2.0-mile square central business area during the a.m. commute period. Vehicles entering the priced zone along any of 28 entry points were required to display a pre-purchased daily or monthly windshield license. Transit buses, motorcycles and vehicles carrying more than 4 people (high occupancy vehicle [HOV] 4+) were excluded from the charge. That initial scheme evolved through the late 1990's, including extension of the charging periods, increases in the charges, and, by virtue of expansion of price points to roadways outside the central business area, evolution to an area-wide pricing scheme. In 1998, the system was converted to a fully automated, electronic system whereby charges are collected using vehicle transponders with smart cards, dedicated short-range communication (DSRC), and readers mounted on overhead gantries.

Methodology

No detailed information on evaluation methods was found in the published literature. Although general in nature, the bulk of the best information is found in the FHWA report "Lessons Learned from International Experience in Congestion Pricing."[46] That report summarizes various evaluations of the Singapore congestion pricing activities and indicates that the following travel performance measures have been investigated:

- Traffic volumes
- Mode share (HOV 4+, vehicles less than HOV 4+, bus)
- Trip departure times
- Routes

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[45] Transport for London, 2008. Pg. 7.

[46] K.T. Analytics, 2008.

- Average speeds
- Crashes.

There is no specific information available on data collection, but based on the discussion of impacts, it appears that most of the performance measures were analyzed based on objective, observed data, e.g., traffic volumes and speeds derived from various detector data and traffic crashes based on police reports. It appears that at least some of the data, especially mode share information, were collected via traveler surveys.

Environmental impacts considered in the Singapore evaluations include:

- Vehicle emissions (CO, NO_x, and smoke/haze)
- Pedestrian safety
- Equity.

Analysis of vehicle emissions has included both roadside monitoring as well as calculation of emissions based on travel impacts. Perceived pedestrian safety was evidently assessed through the use of surveys. Equity implications were assessed via a modeling analysis and surveys of travelers. It appears that the modeling analysis utilized the geographic distribution of various travel impacts coupled with geographic socioeconomic data to infer how travel impacts distributed across various impact groups. In addition, equity implications—specifically, various types of travelers' perceptions of and responses to congestion pricing—were assessed through surveys.

Although published literature does not explicitly identify how exogenous factors were considered in the various evaluations of the Singapore congestion pricing projects, various summaries of project impacts include references to several types of exogenous factors. These factors include auto ownership and employment.

Findings

Overall, the Singapore congestion pricing projects have been effective in reducing congestion and vehicle emissions and are generally not believed to have significantly and disproportionately negatively impacted lower income populations. The initial system introduced in 1975 reduced traffic volumes entering the priced zone by 44 percent; the share of HOV 4+ trips increased from 8 to 19 percent and bus share increased from 33 to 46 percent; a.m. peak speeds inside the priced zone increased by 20 percent or more; and speeds increased 10 percent on inbound roadways leading to the priced zone.[47] Other travel responses to the initial system included motorists shifting their trips to just before or after the priced time periods and diversion of trips to alternate, non-priced routes.[48]

Immediately following the introduction of the initial pricing project, measured CO levels in the morning peak period within the priced zone declined to below pre-project levels and monthly average NO_x levels also decreased. These reductions were attributed to the large reduction in

[47] K.T. Analytics, 2008.

[48] Toh, Rex S. (2003), "Road Congestion Pricing in Singapore: 1975 to 2003." Transportation Journal, March 22, 2004.

automobile travel. Measurements of smoke and haze also showed declines but those declines could not be fully attributed to the pricing project.[49]

Reported equity impacts include the following:[50]

- "Losers" associated with the initial project included those who switched from cars to buses or switched to non-priced travel time periods, those who encountered congestion on non-priced routes, and those for whom the cost of the charge is not fully offset by improved travel times.
- After some initial crowding, transit riders enjoyed better service as service was expanded over time.
- HOV 4+, motorists and pedestrians benefitted.
- Car drivers and passengers perceived the initial project as mildly unfavorable; middle income travelers felt adversely effected; pedestrians, taxi riders and residents outside of the priced zone viewed the initial project as neural or negatively; travelers and residents within the priced zone viewed the initial project positively.
- Shifts to transit were fairly uniform across income groups.
- There was no evidence that any given income groups was more or less impacted by travel time changes.

[49] K.T. Analytics, 2008.

[50] K.T. Analytics, 2008.

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3.0 SYNTHESIS OF THE STATE OF THE PRACTICE

This chapter summarizes the state of the practice for evaluating the travel and environmental impacts of congestion pricing projects. The findings presented here are drawn primarily from a review of published literature associated with the eight study projects described in Chapter 2.0. This chapter is divided into three sections. The first highlights some of the fundamental differences and similarities in the evaluation approaches among the eight study projects. The second section focuses on travel impacts. The final section focuses on environmental impacts.

3.1 Basic Similarities and Differences between Study Projects

All eight of the study projects include before-after (or "with/without") evaluations of deployed congestion pricing schemes: either short-term demonstrations with simulated congestion charges or long-term deployments with real charges. The Oregon, Puget Sound and Commute Atlanta mileage-based value pricing investigation are examples of the former (short-term, simulated) and the other five projects are of the latter type (long-term, non-simulated).

Two of the projects—London and Singapore—have been evaluated in an on-going manner over many years, encompassing a number of expansions and other changes in the congestion pricing programs. Those projects, to varying extents, have produced a series of results reports which include comparisons and which draw conclusions based on many years of post-deployment data. The six other projects generally focus on shorter, finite, post-deployment evaluation periods of between a few months and, in the case of I-15, up to three years. Although the Minnesota I-394 HOT lanes project is subject to on-going monitoring, the comprehensive evaluation effort was, essentially, a one-time effort.

London demonstrates the most extensive evaluation effort among the study projects in terms of evaluation period (over five years) and the breadth of impacts, performance measures and data sources. The next most extensively studied projects are Stockholm and Singapore.

The simulated pricing field deployment projects—Oregon, Puget Sound and Commute Atlanta—focused more narrowly on individual traveler behavior than the other projects, that is, they did not consider the traffic or environmental ramifications of changes in travel behavior. Further, to varying degrees (Commute Atlanta less so), those three projects focused more narrowly on driving behavior and associated measures and less on other modes than did the other study projects.

3.2 Assessing Travel Impacts

This section contains two parts. The first summarizes travel impacts, performance measures and data collection methods and the second part summarizes travel findings and study limitations.

3.2.1 Impacts, Performance Measures and Data Collection Methods

Table 3-1 compiles the travel impacts, performance measures and associated data collection methods for each of the eight study projects. Among those projects, three broad types of travel impacts were found most commonly:

- **Traffic impacts** – the impact on roadway usage, e.g., traffic volumes, and/or roadway performance, e.g., speeds and collisions.
- **Transit impacts** – the impact on transit system usage, e.g., ridership and/or transit performance, e.g., schedule adherence.
- **Traveler behavior impacts** – the impact on the behavior of travelers, e.g., routes, modes, time of trip.

The travel impact most commonly considered in the eight study projects is traffic. Transit and traveler behavior impacts are less common, but far from unusual. Few study projects examined safety impacts.

Table 3-1. Travel Impacts, Measures and Data Collection Methods

Study/Project	Impacts Analyzed	Associated Performance Measures	Data Collection Method
Simulated Pricing Field Demonstrations			
Oregon Mileage Fee Concept and Road User Fee Pilot Program	Traveler behavior (individual)	• Vehicle miles traveled • Vehicle miles traveled by time-of-day (peak vs. off-peak) • Route choice • Number of trips • Demographics	• Instrumented vehicles (GPS) driven by volunteer, general public travelers
		• Mode choice – stated inclination to use alternate modes (transit, bicycle)	• Traveler surveys (attitudinal)
Puget Sound Traffic Choices Study	Traveler behavior (individual)	• Vehicle miles traveled by road type • Vehicle hours of travel • Number of trips • Route choice • Trip purpose • Demographics	• Instrumented vehicles (GPS) driven by volunteer, general public travelers
Commute Atlanta Mileage Based Value Pricing Demonstration	Traveler behavior (household)	• Number of trips • Trip lengths • Trip duration • Intra- vs. extra-regional trip making • Demographics	• Instrumented vehicles driven by general public travelers • Panel survey of the participating travelers
	Traffic	• Total vehicle miles traveled	• Instrumented vehicles driven by volunteer general public travelers

Table 3-1. Travel Impacts, Measures and Data Collection Methods (Continued)

Study/Project	Impacts Analyzed	Associated Performance Measures	Data Collection Method
Before-After Project Evaluations – U.S.			
Minnesota I-394 MnPASS HOT Lanes	Traffic	• Hourly traffic volumes by lane • Average vehicle speed by lane group (general purpose and HOT) • Travel time	• Permanent roadway detectors
	Traveler behavior (individual)	• Vehicle occupancy • Number of carpools • Mode choice (transit use) • Demographics	• Traveler surveys (attitudinal) – panel – 800-900 per wave • Travel diaries (1-day) with general travel behavior questions – 800-900 participants
San Diego I-15 HOT Lanes	Traffic	• Traffic volumes • Time-of-peak distribution • Average speed • Vehicle classification	• Roadway detectors
		• Vehicle occupancy	• Unknown
	Safety	• Incidents	• Unknown
	Traveler behavior (individual)	• Mode split	• Traveler surveys (attitudinal) – panel – 1,500 respondents per wave

Table 3-1. Travel Impacts, Measures and Data Collection Methods (Continued)

Study/Project	Impacts Analyzed	Associated Performance Measures	Data Collection Method
Before-After Project Evaluations – International			
The Stockholm Trial	Traffic	• Traffic volumes	• Objective data collection in the field (various methods used)
		• Vehicle kilometers traveled	• Estimated using traffic models
		• Journey (travel) times	• Instrumented vehicles (GPS) • Roadside detectors (traffic cameras used to match vehicle images at various points)
		• Vehicle queue lengths at intersections	• Instrumented vehicle field data collection
	Traveler behavior (individual)	• Demographics • Number of trips • Origin-destination • Mode • Time of travel • Travel time	• (Stockholm County residents) Travel diaries (1 day) – panel study in 3 waves (2 pre- and 1 post) – 30,000+ participants • (Commuters into pricing zone) – subset of County residents survey – 2,200 participants
		• Demographics • Number of trips • Mode choice • Potentially other measures unspecified in literature	• (Other County Residents) 875 participants – study methodology unknown
	Transit	• Ridership	• Detectors
		• Travel times	
		• Rider perceptions	• On-board surveys

Table 3-1. Travel Impacts, Measures and Data Collection Methods (Continued)

Study/Project	Impacts Analyzed	Associated Performance Measures	Data Collection Method
Before-After Project Evaluations – International (Continued)			
Central London Congestion Pricing	Traffic	• Congestion (the "excess delay" or "lost travel time" as defined as the difference between average network travel rates in uncongested versus congested conditions)	• Calculated from other data
		• Average network speeds (vehicle kilometers divided by vehicle hours)	• Instrumented floating car runs • Automated license plate matching (cameras) • Commercially purchased satellite vehicle tracking
		• Average network travel rate (vehicle minutes divided by vehicle kilometers)	
		• Speed distributions (the proportion of time spent driving within various speed bands)	
		• Traffic density (number of vehicles per kilometer)	• Derived from traffic volume data
		• Number of vehicle trips	• Derived from traffic volume data (may also have been measured through traveler surveys)
		• Journey (travel) times	• Volunteer, general public driver panels (manual recording of times)
		• Traffic volumes	• Various manual and automated (roadway detectors) methods
		• Vehicle kilometers driven	• Derived from traffic volumes
		• Vehicle minutes driven	• Derived from traffic volume and congestion data
		• Average vehicle occupancy	• Visual observation
		• Parking and pedestrian activity	• Manual counts

Table 3-1. Travel Impacts, Measures and Data Collection Methods (Continued)

Study/Project	Impacts Analyzed	Associated Performance Measures	Data Collection Method
Before-After Project Evaluations – International (Continued)			
Central London Congestion Pricing (Cont.)	Transit	• Transit ridership	• Manual counts • Fare collection data
		• Average bus journey speeds	• Automatic vehicle location systems
		• Bus reliability – passengers excess waiting time (difference between scheduled and actual bus arrival)	• Manual schedule adherence monitoring at bus stops/stations
		• Bus reliability – operated mileage versus scheduled mileage (congestion can result in a bus covering fewer miles, completing fewer runs than scheduled)	• Transit agency databases
	Traveler behavior (household)	• General travel behavior (modes, routes, times, etc.)	• Panel surveys of up to 2,300 households
		• Detailed travel behavior (modes, routes, times, etc.)	• Panel surveys of up to 2,300 households with 1-day travel diaries
	Traveler behavior (individual)	• General travel behavior (modes, routes, times, etc.)	• Panel surveys of up to 2,400 individuals • En-route transit rider surveys • Roadside interviews with up to 15,000 travelers (driving, cycling, walking) • Focus groups (generally targeting subpopulations like disabled people or shift workers)
		• Detailed travel behavior (modes, routes, times, etc.)	• Panel surveys of up to 2,400 individuals with 1-day travel diaries
	Safety	• Number and type of roadway crashes	• Accident reports
Singapore Area Pricing	Traffic	• Traffic volumes • Trip departure time • Average speed	• Unknown, but likely that most data were objective data, e.g., traffic counts
	Traveler behavior	• Routes • Modes	• Unknown
	Safety	• Number of crashes	• Unknown, likely accident reports

Tables 3-2 through 3-4 summarize the state-of-the-practice for travel impacts in terms of the relative prevalence of various performance measures and associated data collection methods. This information is based primarily on the eight study projects. Greater variety was found in the area of traffic impacts than in transit and traveler behavior and therefore Table 3-2 uses three categories to assess prevalence and Tables 3-3 and 3-4 use only two. Assessments of the relative rarity of various measures are subjective and there are a few close calls. For example, categorizing travel times and speeds as "very common" versus "common." Assessments for the performance measures are absolute in the sense that they reflect how commonly each measure appears in the evaluation reports that were reviewed. Assessments of methods are relative in the sense that they do not describe how often a particular data collection method appears in the literature overall, but rather, how frequently that method is used among those projects that include the associated performance measure. For example, a "very common" data collection method for an "uncommon" measure means that, in the literature overall, that data collection method is not common.

Table 3-2. Traffic Impact Performance Measures and Data Collection Methods

Performance Measures	Associated Data Collection Methods (by prevalence)		
	Very Common	Common	Less Common
Very Common			
Traffic volumes	• Permanent vehicle detectors (loops, radar, cameras, etc.)	• Temporary vehicle detectors (radar, cameras, etc.)	• Manual counts (visual observation) • Probe vehicles driven by travelers (e.g., toll tag-equipped)
Vehicle miles traveled	• Derived from traffic volumes and roadway segment lengths		• Probe vehicles driven by travelers
Average speeds	• Permanent vehicle detectors (loops, radar, cameras, etc.)	• Temporary vehicle detectors (radar, cameras, etc.)	• Probe vehicles driven by travelers • Probe vehicles driven by evaluators (i.e., "floating car")
Common			
Travel time	• Probe vehicles driven by evaluators (i.e., "floating car")	• Vehicle detectors (loops, radar, cameras, etc.)	• Probe vehicles driven by travelers
Vehicle classification[1]	• Permanent vehicle detectors (loops, radar, cameras, etc.)	• Temporary vehicle detectors (radar, cameras, etc.)	• Manual counts (visual observation)

Table 3-2. Traffic Impact Performance Measures and Data Collection Methods (Continued)

Performance Measures	Associated Data Collection Methods (by prevalence)		
	Very Common	Common	Less Common
Less Common			
Vehicle occupancy	• Manual counts (visual observation)		
Mode split[2]	• Derived from traffic counts coupled with average vehicle occupancy; transit passenger counts & other mode (bike, walk)		
Travel rate (distance per hour or minute)	• Derived from other data, namely volumes, speeds, roadway link lengths		
Traffic density	• Derived from traffic volume data		
Vehicle minutes or hours driven	• Derived from vehicle miles driven and speeds		
Number of accidents or accident rates	• Accident reports/databases		
Traveler and/or system operator perceptions of safety	• Surveys, interviews or focus groups		

Notes:

[1] Rare as an end measure, commonly collected to support environmental analysis (an input to emission rates)

[2] This measure appears both as a traffic impact measure as well as a traveler behavior impact measure (Table 3-4) to reflect the two different approaches to collecting these data (counts for traffic vs. surveys for travel behavior) and the different focus in traffic analysis (impact, e.g., person throughput, on roadways) versus travel behavior (impact on people).

Table 3-3. Transit Performance Measures and Data Collection Methods

Performance Measures	Associated Data Collection Methods (by prevalence) — More Common	Associated Data Collection Methods (by prevalence) — Less Common
Common		
Ridership	• Automated passenger counters • Manual passenger counters	
Less Common		
Travel time	• Automatic vehicle location systems	
Rider attitudes & perceptions	• En-route surveys	
Bus speeds	• Automatic vehicle location systems	
Bus schedule adherence: on-time performance	• Automatic vehicle location systems	• Visual observation in the field
Bus schedule adherence – operated mileage	• Transit agency vehicle operations database	

Table 3-4. Traveler Behavior Impact Performance Measures and Data Collection Methods

Performance Measures	Associated Data Collection Methods (by prevalence) — More Common	Associated Data Collection Methods (by prevalence) — Less Common
Common		
Individual, general travel behavior (typical routes, modes, time of trip, etc.) Individual traveler attitudes & perceptions	• Panel surveys (same sample before-after)	• Cross-sectional surveys (different samples before-after)
Less Common		
Individual, specific travel behavior (routes, modes, etc. on specific sample day[s]) Household, specific travel behavior (routes, modes, etc. on specific sample day[s])	• Panel travel diary (same people before-after)	• Cross-sectional travel diary (different people before-after)
Household, general traveler behavior (typical routes, modes, time of trip, etc.)	• Panel surveys (same people before-after)	• Cross-sectional surveys (different people before-after)
Mode choice/mode split	• Derived from household or individual travel diary data	• Derived from household or individual general travel survey data

As indicated in Tables 3-2 through 3-4, and as one would expect with evaluations of deployed projects, all of the traffic and transit measures utilize objective data rather than modeling, simulation or other estimated or derived sources. In contrast, travel behavior measures always rely on travelers' self reports of their behavior, although in the case of travel diaries—where travelers are asked to very accurately and specifically record the details of individual trips using paper or electronic forms—reported behavior is expected to be a fairly accurate reflection of actual behavior.

Overall, explicit consideration of mode choice changes and the change in mode splits or shares—the percentage of person trips made by various modes—is not extremely rare, but is far from standard. Although some evaluations do not consider mode changes at all, most of them do, with the smaller, less comprehensive studies often inferring some mode change effects based on changes in traffic volumes and transit ridership. The most comprehensive evaluations, such as London, do explicitly consider mode changes and attempt a complete accounting, e.g., of the X number of car trips that were eliminated, Y percent went to transit, etc. However, even among the more robust evaluations, comprehensive treatments which capture both the total change in *person trips* and trace all of the mode-to-mode changes are very uncommon. In London, the disposition of the car trips that were eliminated was examined, but a complete accounting of total person trips before and after by mode was not performed.

Within the area of traveler behavior surveys, variations can be observed based on the following major variables:

- Pre- and post-deployment surveying (before and after) versus pre-only or after-only.
- Panel (longitudinal) samples (the same people participate in the before and after survey) versus cross-sectional samples (different people participate in the before and after survey).
- Household surveys, in which each adult in the household is surveyed, versus surveys of only a single traveler.
- General travel behavior information, where travelers describe their typical behavior, versus detailed and specific travel behavior information in which travelers record travel details for one or more specific days in a diary.
- Travel diaries alone, versus travel diaries in conjunction with in-vehicle data collection.

The state-of-the-practice in regard to these parameters can be summarized from the eight study projects as follows:

- Pre- and post-deployment surveying is standard.
- Panel (longitudinal) studies are typical.
- The largest, most comprehensive and robust evaluations of large-scale pricing schemes (e.g., London and Stockholm) use both household and individual surveys. The less comprehensive evaluations and evaluations of smaller-scale pricing projects tend to use one or the other, with individual traveler surveys being somewhat more common.
- Large, comprehensive evaluations utilize surveys gauging both general traveler behavior as well as specific travel behavior collected through diaries.
- Use of instrumented vehicles in general is common, but instrumentation of vehicles driven by volunteers who are also maintaining travel diaries is uncommon.

Considering the full range of travel impacts (traffic, transit, traveler behavior, safety) the state of the practice in regard to instrumented vehicles, including traffic probes, can be summarized as follows:

- Overall, instrumented vehicle data collection is common.
- Collection of speed and/or travel time data from GPS-equipped buses and cars is common and transit ridership is often collected using on-board passenger counters.
- For average roadway speeds and travel times, in the cases where instrumented vehicles are used, the most common approach is for the evaluators to perform a set number of data collection runs themselves. It is less common to recruit public volunteers or to purchase commercial data derived from various inputs, including traffic probes.
- Instrumented vehicles for collecting detailed and specific traveler behavior are common in simulated congestion pricing field demonstrations. All three study projects of that type used instrumented vehicles driven by public volunteers. This is probably because data were collected over much longer periods than is possible using a travel diary and/or because a pricing changes were dynamic and a high degree of accuracy was needed, for example in the Puget Sound study.

3.2.2 Reported Findings and Study Limitations

Appendix A includes a table summarizing the main travel related findings of the eight study projects. Results indicate that a variety of congestion pricing projects have been shown to be effective in reducing traffic congestion. Highlights of reported findings include the following:

- Significant reductions in vehicle travel (VMT or VKT) on the order of 10 percent are common.
- Vehicle trips have been reduced by between 7 and 20 percent.
- Travel reductions between 3 and 14 percent.
- Speed increases between 6 and 21 percent.
- Mode shift from driving to transit, with transit ridership increases between 6 and 37 percent.

In reviewing the findings of congestion pricing evaluations, the emphasis in this study was to understand how the evaluation methodologies and challenges impacted the ability of researchers to draw definitive conclusions. The table in Appendix A includes a column that summarizes major caveats or limitations relevant to specific findings reported for the eight study projects. These caveats and limitations can be summarized as follows:

- Although some references to study limitations are common, detailed discussions of how various aspects of the evaluation methodology or context may impact conclusions are not common in the published literature.
- Many evaluators acknowledge that exogenous factors have impacted their findings but it is very rare to quantitatively adjust results to eliminate variance related to exogenous factors.

- Commonly cited exogenous factors include fuel price changes, other transportation projects, seasonal variations, survey samples that do not accurately represent the population, and background traffic growth related to land development.
- Few concerns are noted about the fundamental accuracy of objective data such as traffic volumes, speeds and travel times.
- Some evaluations utilize control groups, but many do not.
- Challenges in reconciling travel diary data with objective transit and traffic data as well challenges in collecting comprehensive carpooling, telecommuting, bicycle and pedestrian data make it very difficult to perform a comprehensive accounting of mode choice changes.

3.3 Assessing Environmental Impacts

This section contains two parts. The first part summarizes environmental impacts, performance measures and data collection methods and the second part summarizes environmental findings and study limitations.

3.3.1 Impacts, Performance Measures and Data Collection Methods

A 2008 FHWA lessons-learned report on their Value Pricing Pilot Program noted that congestion pricing evaluations have paid less attention to equity and environmental impacts than traffic impacts, project operations, and public and customer satisfaction.[51] That is also generally the case among the eight study projects.

Table 3-5 identifies the environmental impacts, performance measures and associated data collection methods for each of the eight study projects. Among those projects, three broad types of environmental impacts were common:

- **Air Quality –** the impact on pollutant levels.
- **Noise –** the impact on traffic noise levels.
- **Environmental Justice –** the extent to which positive and negative impacts are disproportionate among people of different races and income levels, including the delay of benefits and/or a disproportionate share of adverse impact accruing to minority and low-income populations.

[51] K.T. Analytics and Cambridge Systematics, Inc., 2008.

Table 3-5. Environmental Impacts, Measures and Data Collection Methods

Study/Project	Impacts Analyzed	Associated Performance Measures	Data Collection Method
Simulated Pricing Field Demonstrations			
Oregon Mileage Fee Concept and Road User Fee Pilot Program	No Environmental Analysis Performed		
Puget Sound Traffic Choices Study			
Commute Atlanta Mileage Based Value Pricing Demonstration	Air Quality (cumulative vehicle emissions) – *methodology identified but analysis was not performed*	• CO, $PM_{2.5}$, PM_{10} and ozone emissions	• Calculated (estimated) based on objective traffic data and regional emission rates
	Air Quality (CO hotspot microscale) – *methodology identified but analysis was not performed*	• Localized CO levels	• Calculated (estimated) using EPA CALINE4 microscale model
Before-After Project Evaluations – U.S.			
Minnesota I-394 MnPASS HOT Lanes	Air quality (cumulative vehicle emissions)	• CO levels	• Roadside monitors
	Noise	• Sound levels	• Roadside monitors
			• MINNOISE model (based on FHWA Traffic Noise Model)
	Environmental justice	• Surveyed perceptions among different socio-demographics	• Traveler surveys (attitudinal) – panel – 800-900 per wave • Travel diaries (1-day) with general travel behavior questions – 800-900 participants
San Diego I-15 HOT Lanes	Air quality (cumulative vehicle emissions)	• VOC, NO_x, PM_{10} and CO emissions.	• Calculated (estimated) based on objective traffic data and regional emission rates
	Noise	• Monitored sound levels	• Roadside monitors

Table 3-5. Environmental Impacts, Measures and Data Collection Methods (Continued)

Study/Project	Impacts Analyzed	Associated Performance Measures	Data Collection Method
Before-After Project Evaluations – International			
The Stockholm Trial	Air quality (cumulative vehicle emissions)	• Emissions of PM_{10}, NO_x, CO_2, CO, and VOC	• Estimated using the European Union "ARTEMIS" model, utilizing both monitored and estimated traffic inputs
		• Pollutant levels	• Roadside monitors
		• Vehicle emission exposure levels	• Dispersion models utilizing objective traffic data coupled with emission rate and meteorological inputs
	Noise	• Sound levels	• Roadside monitors
	Environmental justice (equity)	• Origins and destinations • Travel times • Congestion charges paid • Travel adaptation costs • Pricing revenue redistribution impacts	• Travel diaries (1 day) – two waves – 24,000 participants • Regional travel demand modeling of with and without pricing conditions using travel-diary derived specific travel behavior
London Congestion Pricing	Air quality (cumulative vehicle emissions)	• Emissions of PM_{10}, NO_x, and CO_2	• Roadside monitors to collect total concentrations (for reference; not expected to be conclusive)
			• Calculated (estimated) emissions to better understand project contributions to changes in emissions; used observed traffic impacts and regional emissions rates
	Noise	• Sound levels	• Roadside monitors
	Environmental justice	• Perceptions of various types of travelers (varying by income, mode use, residence location, vehicle ownership, physical ability/disability, shift workers, etc.)	• Individual traveler and household panel surveys • Roadside interviews • Focus groups

Table 3-5. Environmental Impacts, Measures and Data Collection Methods (Continued)

Study/Project	Impacts Analyzed	Associated Performance Measures	Data Collection Method
Before-After Project Evaluations – International (Continued)			
Singapore Area Pricing	Air quality (cumulative vehicle emissions)	• Emissions of CO, NO_x and smoke/haze	• Calculated (estimated) based on objective traffic data and regional emission rates • Roadside monitors
	Pedestrian safety (perceived)	• Pedestrian perceptions of safety	• Uncertain, but seemingly via interviews
	Environmental justice	• Geographic distribution of traffic impacts	• Travel modeling analysis (comparing travel impacts to geographic distributions of various income and other socio-economic variables)
		• Attitudes and perceptions of various types of travelers	• Surveys

Pre-deployment estimation of the environmental impacts of congestion pricing projects—such as environmental assessments (EAs) and environmental impact statements (EISs) developed in the U.S. in compliance with the National Environmental Policy Act of 1969 (NEPA)—do consider a much wider range of potential impacts, including land use. However, the present study focuses on measurement of the actual, post-deployment impacts of congestion pricing and, with one exception, there were no examples of those other types of environmental impacts among the study projects. The one exception—the one other environmental impact that was found in the study projects (London and Stockholm)—is the impact of congestion pricing on business and the economy. However, in neither London nor Stockholm were these impacts included within the "environmental" impact category. This state of the practice summary focuses on the more common impacts: air quality, noise and environmental justice.

Some of the eight congestion pricing study projects—the simulated pricing field demonstrations in Oregon, the Puget Sound region, and Atlanta—did not consider any environmental impacts whatsoever. However, with the exception of the seeming omission of noise and the addition of pedestrians perceptions of safety in Singapore, all of the other study projects considered air quality, noise and—although under various names and varying emphases—environmental justice. In several cases, "environmental justice" impacts were termed "equity" impacts or were part of broader investigations such as "social impacts."

In regard to performance measures and data collection methods, air quality and noise environmental impact analyses show less variation from study to study and fewer measures and methods overall than do travel impact analyses. The most common air quality performance measure—used in each air quality analysis that was reviewed—is the volume of pollutant emissions from roadway traffic. The only other performance measure that was found, and which is much less commonly considered, is ambient pollutant concentrations. Only one data collection method was found for vehicular pollutant emissions: calculating emissions by multiplying project-attributable changes in vehicle miles traveled on roadway links by model-derived emission factors (e.g., grams emitted per mile) corresponding to the observed speeds on the roadway links. Likewise, there was only one data collection method found for ambient pollutant concentrations: roadside pollution sensors. None of the study projects included in-depth considerations of greenhouse gases. Rather, when greenhouse gases are addressed at all, it is typically done by including the precursor CO_2 among the calculated vehicle emissions. No examples of the sort of atmospheric modeling necessary to actually estimate green house gases were found.

There is even less variation in evaluation practices related to noise impacts. Noise impacts in all of the study projects were measured in terms of ambient sound levels, in decibels, and in all cases roadside noise monitors were used to collect the data.

Pedestrian safety was only considered as an environmental impact and evaluated in Singapore. Pedestrian safety was measured in terms of pedestrians' perceptions which were gathered through surveys, interviews or focus groups.

In contrast to air quality and noise, analyses of environmental justice or equity impacts vary more from project to project. This may be because environmental justice analyses typically include more qualitative or subjective elements and, therefore, or more of an art than a science, or it may be that as a relatively new area of interest, fewer standardized approaches have thus far emerged. Although specific approaches vary, environmental justice analyses generally focus on two main areas. The first is to examine how travel impacts distribute geographically and, using geographic socioeconomic databases, infer whether projects differentially impact (both benefits and disbenefits) areas with concentrations of low income and/or minority populations. The second element employs public surveys and or focus groups to gauge the perceptions of low income and/or minority populations.

3.3.2 Reported Findings and Study Limitations

Appendix B includes a table summarizing the main environmental impact findings of the eight study projects. Highlights of reported findings include the following:

- Reductions in calculated vehicle emissions of various pollutants of up to 16 percent.
- No project-attributable changes in monitored air quality levels.
- No significant project-attributable changes in modeled noise levels.
- No project-attributable changes in monitored noise levels.

- Benefits and costs of congestion pricing do impact different types of people differently, but negative impacts to lower income earners have generally been less than anticipated and generally not disproportional.
- Horizontal equity considerations such as residential and work locations and access to travel alternatives play as much or more of a role than vertical equity considerations (namely ability to pay the pricing charge) in explaining differential impacts among various types of people.
- How pricing revenues are spent can have a significant impact on the net costs and benefits for different people.

Caveats and limitations associated with environmental impacts focus largely on the inability to differentiate project contributions from exogenous factor influences on monitored air quality impacts. Although some state-of-the-practice reviews have identified the failure to test for air quality implications of possible changes in traffic flow (e.g., more cruising and less stop and go) as a weakness, this issue is rarely noted by the evaluators of specific projects. There are limited discussions of caveats and study limitations in regard to environmental justice. When discussed, limitations sometimes focus on measurement issues such as survey sample limitations and the inherently subjective and "less scientific" nature of perception data.

3.4 Knowledge Gaps

This section identifies gaps in the understanding of the travel and environmental impacts of congestion pricing.

3.4.1 Travel Impacts

Table 3-6 summarizes the aspects of travel impacts that have generally been well established through before-after evaluations as well as those areas where understanding is less complete. Each of these gaps is discussed following Table 3-6.

Table 3-6. Travel Impact Knowledge Gaps

Better Understood Impacts (Knowledge)	Less Understood Impacts (Knowledge Gaps)
Short-term impacts (from a few months up to a year after deployment)	Long term impacts
Localized impacts	Regional impacts
Cumulative impacts (projects plus exogenous factors)	Project-attributable impacts
Individual travel behavior changes	Household travel behavior changes
Vehicle volumes	Person trips
Average speeds	Vehicle speed fluctuations (driving cycle)
Average performance	Variability in performance (reliability)
Transit ridership changes	Transit crowding implications

Long Term Impacts

Long-term impacts are not well understood because there have been relatively few long-term evaluations. Although the Singapore and London evaluations have continued over many years, the ability to draw conclusions is still limited by the fact that not all analyses have been continued and because over these longer periods the masking influence of exogenous factors has made isolation of project impacts especially challenging. In particular, there is not a good understanding of the long-term traveler behavior associated with congestion pricing, e.g., will travelers who, in the short term, are willing to continue driving and pay charges switch to other modes or make other changes, such as moving, switching jobs or telecommuting, over the long term? Conversely, will travelers who initially shift to transit or make other changes to avoid the charge eventually drift back to driving—and if so, how many of them and why? Even when long-term traffic and transit ridership data have been studied, only the aggregate change is usually considered and the components of the change are unclear. For example it is unclear whether static mode shares over time mean that travel behavior changes in response to pricing have ended or whether changes continue but off-set one another, e.g., drivers continue to switch to transit but as transit becomes crowded other travelers switch to driving. This area of uncertainty includes a lack of information on long-term impacts on auto ownership.

Regional Impacts

Another gap concerns the regional impacts of congestion pricing. Although some evaluations have considered travel impacts over a fairly large area (e.g., London and Stockholm), many evaluations have focused on the priced facilities/zone and the immediately adjacent portions of the transportation system. Of course, it is resource intensive to study larger areas, and most evaluations have focused their attention on the areas where the most significant impacts are expected, which is a logical strategy given constrained resources. Unfortunately, this has created something of a self-perpetuating cycle: evaluators do not examine regional impacts in part because there is not strong evidence that there will be regional impacts but the reason there is no strong evidence is not because evaluations have found few impacts but simply because those impacts are very seldom assessed.

Project-Attributable Impacts

Another significant gap in the understanding of travel impacts concerns the specific influence of the pricing project in observed changes. The combined or cumulative impact of pricing projects—the impact of the project coupled with the influence of a wide range of exogenous factors—has been relatively well established in many evaluations. However, most evaluations are not able to accurately isolate the discrete impact of the project. Most evaluations acknowledge one or two exogenous factors that may be relevant, e.g., gas prices or other transportation system changes, and some go as far as to describe the changes in those exogenous factors and qualitatively consider the potential general impact of those factors as they draw conclusions about the project impacts. But rarely are the impacts of the exogenous factors addressed quantitatively. The 2008 FHWA Value Pricing Pilot Program Lessons Learned Final Report came to similar conclusions, noting that:

- Attempts to distinguish the effects of pricing from outside influences such as gas prices or economic swings have been modest at best.
- Use of controls is limited.
- Opportunities for improvement include attention to controls and statistical tests to insure valid results and to rule out influences of ongoing swings in gasoline prices and economic conditions.

Even in the few cases where evaluators have estimated the quantitative impact of certain exogenous factors, results have sometimes been challenged. For example, different researchers disagree about the how much of the traffic reductions were due to fuel increases.[52]

Use of household travel diaries in conjunction with conventional surveys which focus on the influences on travel behavior can be a powerful means for improved understanding of exogenous factors. However, as the evaluators of the Commute Atlanta mileage-based value pricing program evaluation found, use of household travel diaries is not effective unless changes in households between the before and after periods are carefully considered and unless sample sizes are large enough to balance significant demographic variation among households. The Commute Atlanta researchers concluded that the several well known and frequently cited U.S. congestion pricing evaluations have not sufficiently controlled for such factors.

Household Travel Behavior Changes

Use of household traveler surveys and travel diaries is not rare, but it is far from commonplace. Also, when household travel behavior has been investigated, there is often insufficient focus on shifts and trade-offs within the households, such as how a vehicle is used by family member X which was formerly driven by family member Y who has shifted to transit in response to pricing. Likewise, there has been little to no significant investigation of how total household travel budgets—in terms of time and money—factor into these intra-household changes and the connection to specific pricing strategies. As a result, the understanding of household impacts of congestion pricing projects is not complete.

Person Trips

The understanding of the impact on congestion pricing projects on person trips, especially person throughput and overall mode shares is incomplete. Many evaluations focus foremost on traffic impacts, or vehicle trips. Many of those evaluations that have included consideration of other modes have focused on transit ridership. Some of the largest and most robust evaluations, like London, have tracked person trip shifts to some degree—e.g., tracing X number of curtailed driving trips into the pricing zone—but those analyses have not included a truly comprehensive accounting of all person trips and their shifts. There has also been very limited consideration of person throughput. Challenges in cost-effectively collecting average vehicle occupancy data and data from travelers who telecommute, forego trips, bicycle, or walk likely contribute to the under consideration of person trip impacts.

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[52] Coordination of Urban Road User Charging Organisational Issues (CURACAO), "Deliverable D2: State of the Art Review (FINAL). Prepared by the Institute for Transport Studies, University of Leeds. May 2009.

Vehicle Speed Fluctuations (Driving Cycle)

Most evaluations focus on the before-after changes in the *average* speeds on specific roadway links or across roadway networks and these changes are relatively well understood. However, there is not yet a sufficient understanding of impacts on vehicle driving cycle (proportion of vehicle operation in acceleration, deceleration, idle and cruising modes) that are related to changes in traffic flow characteristics and which may not be accompanied by significant changes in average speeds. A roadway that shows little to no change in average speed may in fact demonstrate improved flow and a significantly different driving cycle profile. For example, pre-pricing, a road may have an average speed of 30 miles per hour (mph) that reflects brief bursts of 45 mph travel punctuated by frequent stops (idle). After pricing, the average speed may still be 30 mph but it may reflect a steady, 30 mph flow with no stops and starts. To date, evaluations have neither clearly identified the significance of traffic flow improvements on driving cycle and emissions nor eliminated the possibility that they may be as or more important than reductions in traffic volumes.[53]

Variability in Performance (Reliability)

Most evaluations focus on average or typical transportation system performance. There has been far less attention paid to the variability in transportation performance, that is, reliability. Gaps in this area include both objective quantification of reliability as well as thorough understanding of traveler attitudes and responses to varying levels of reliability.

Transit Crowding Implications

In so much as one objective of many pricing strategies is to shift some travel from driving to public transportation, transit services and capacity play a key role in congestion pricing success. Although evaluations often document the net changes to transit ridership, the implications of transit capacity and crowding are not well understood. As many transit agencies across the U.S. are implementing or considering service cut-backs, understanding these issues is especially important now.

3.4.2 Environmental Impacts

This section discusses gaps in the understanding of the air quality, noise, and environmental justice (equity) impacts of congestion pricing projects.

Air Quality

What is currently understood regarding the impact of congestion pricing projects on air quality is based on the analyses that have calculated vehicle emissions. As noted in Section 3.2, roadside monitoring of before and after air quality has not enhanced that understanding.

Overall, the calculated vehicle emissions analyses that have been done have provided an understanding of the approximate or partial air quality impacts of congestion pricing projects. Inaccuracies and incompleteness stem from a failure to accurately specify all of the key input parameters—both traffic and emission rate-related.

[53] Institute for Transport Studies, University of Leeds, 2009.

Table 3-7 identifies those determinants of congestion pricing project vehicle emission impact that are usually well represented in analyses as well as those that are not. It is the latter that underlie the gaps or uncertainties in the current understanding of the air quality impacts of congestion pricing projects.

Table 3-7. Air Quality Knowledge Gaps

Better Understood Components of Congestion Pricing Vehicle Emission Changes	Less Understood Components of Congestion Pricing Vehicle Emission Change
Cumulative impacts (VMT, speed)	Project-attributable impacts (VMT, speed)
Localized impacts	Regional impacts
Average daily impacts	Hourly variation
	Driving cycle changes (traffic flow change)
	Vehicle mix

Project-Attributable VMT. As discussed in Section 3.3.1, most analyses acknowledge a number of exogenous factors impacting observed, before-after changes in traffic volumes and average speeds, but very rarely are the traffic inputs to emissions volume quantitatively adjusted to eliminate the portion of variation attributable to exogenous factors. Indeed, analysts very seldom understand (or agree on) exactly how much of the observed variation is due to factors such as fuel price changes or employment changes.

Regional VMT and Speed Changes. Also as noted in Section 3.3.1, the analysis of the traffic impacts of congestion pricing projects typically focus on the priced facility/area and, somewhat less typically, may also include the immediately adjacent roadways. Examinations of potential impacts farther away, throughout the region, are rare. Correspondingly, emissions analyses have been unable to capture any of more distant impacts that may be created.

Hourly Variation. Many congestion pricing projects can be expected to have significantly different impacts during different times of day. It does not appear that hourly variations in VMT and or link speeds are standard considerations in congestion pricing project air quality analysis, and thus the understanding of these impacts is incomplete.

Driving Cycle Changes (Traffic Flow Change). The “grams per mile” emission rates (“factors”) used in emission calculations are almost always derived from emission factor models such as the U.S. Environmental Protection Agency (EPA) MOBILE6 model or the California Air Resources Board EMFAC model. Those models utilize assumptions—which, to varying degrees, can be manipulated by users—regarding the “driving cycles” of vehicles. Driving cycle refers to the proportion of a vehicle’s travel (VMT) under acceleration, deceleration, idle, and cruise (constant speed). Evaluations of congestion pricing project emissions impacts seldom include adjustments to reflect driving cycle assumptions in the emission factor models based on project-attributable impacts to driving cycles. The likely reasons for omitting such potentially important probably changes include: 1) It is usually unclear whether a project has impacted vehicle driving cycles (most traffic analysis look only at net changes in average roadway link speeds), and 2) Some analysts do not understand the significance of driving cycle in the emission factor estimation process, which is opaque in so much as it occurs internal to the emission factor model.

Vehicle Mix. Vehicle emission rates—grams per mile or grams per hour (idle)—vary significantly by vehicle type. The traffic analyses within most evaluations of congestion pricing projects do not appear to explicitly study project impacts on vehicle mix and, as a result, these changes are usually not included in the air quality analysis. That is, the breakdown of total observed link VMT for the before and after scenarios utilize the same vehicle mix. To the extent that congestion pricing projects do not differentially impact different vehicle types, it is of course appropriate to use the same mix, but to the extent that projects do impact this area, these impacts are seldom reflected in the emissions analyses.

Noise

There are no gaps, per se, in the understanding of the noise impacts of congestion pricing. This is because, even allowing for the likely inaccuracies in calculated (modeled) noise levels and, in the case of monitored noise levels, the inability to differentiate project impacts from exogenous impacts, congestion pricing projects have not been shown to, and are unlikely to, generate the magnitude of traffic changes needed to produce a change in noise levels that is perceptible to most people. Hearing sensitivity among humans is non-linear in that very large increases in the noise-generating activity are necessary to produce even the smallest perceptible changes in noise levels. In the case of traffic, at least a doubling (or halving) of traffic volume will be necessary to produce a change in noise levels that is noticeable to most people.[54] Unless a congestion pricing project is expected to increase or decrease traffic levels by 50 percent or more, and/or noise is an extremely significant concern in a community, there is little value in even attempting to gauge the noise impacts of congestion pricing projects.

Environmental Justice

Overall, review of the published literature associated with the eight study projects as well as other documents assessing congestion pricing project effects and evaluation methods yielded fewer insights into knowledge gaps in the area of environmental justice than in the areas of travel impacts and air quality. That may be due in part to the fact that, although there is considerable information on environmental justice (or "equity" as it is often termed), there has been somewhat less focus on this topic than on travel impacts, a conclusion shared by a recent report on lessons learned from the FHWA Value Pricing Pilot Program.[55] It may also be a function of the fact that much of the focus on environmental justice topics has been on predicting the impacts as part the design of the scheme so as to maximize public acceptance rather than solely on measuring the impacts of deployed projects. Predicting impacts has been a particular focus among European congestion pricing researchers.

[54] Institute for Transport Studies, University of Leeds, 2009.

[55] K.T. Analytics and Cambridge Systematics, Inc., 2008.

Although there is not extensive information identifying gaps in the environmental justice knowledgebase, four specific areas can be identified:

- The need for more results, overall, and the importance of considering environmental justice issues in all evaluations.
- The need for particular focus on "horizontal equity" issues, which pertain to those aspects of equity or environmental justice that pertain to issues other than income (vertical equity), including geographic locations and auto access.
- Greater investigation into the long-term equity implications of congestion pricing projects, including on land use and population.
- Greater emphasis on how the uses of congestion charging revenues can impact both the perceived and actual equity of pricing projects.

The importance of continued examination of horizontal equity issues is based in part on evaluation findings that have shown that the vertical equity issues associated with congestion pricing projects may not be as great, or at least not as singular of a focus as had been expected.[56] The need to gather more information on the long-term environmental justice impacts of congestion pricing reflects a concern common to essentially all impact areas. The importance of an improved understanding of the impacts of pricing revenue redistribution has been cited by several researchers, including the 2008 FHWA Value Pricing Pilot Program lessons learned report, the CURACAO study and a 2009 study by the RAND Corporation.[57]

[56] K.T. Analytics and Cambridge Systematics, Inc., 2008.

[57] Ecola, Lissa and Light, Thomas, "Technical Report – Equity and Congestion Pricing, A Review of the Evidence," RAND Corporation, 2009.

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4.0 RECOMMENDED EVALUATION FRAMEWORK

This chapter presents a recommended framework for before-after evaluations of the air quality and environmental justice impacts of congestion pricing projects. The recommendations presented here represent a general framework that provides the foundation for the development of project specific evaluation approaches. This framework is intended to stimulate, rather than replace, explicit project-specific evaluation methodology development processes that will include a wide range of stakeholders and which will carefully consider local conditions, project objectives and potential impacts, evaluation objectives, and evaluation resources.

The framework recommended here is consistent with the evaluation methodologies being utilized in the U.S. DOT evaluation of the Urban Partnership Agreement and Congestion Reduction Demonstration deployments. The general evaluation approaches are presented in the UPA/CRD National Evaluation Framework (http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/14446.htm). The detailed evaluation methods are described in a series of test plan documents that are being developed for each UPA/CRD. Test plans for the Minneapolis UPA site are currently available, and plans for the other sites will be made available as they are completed, on the U.S. DOT UPA/CRD "Publications, Legislation and Guidance" webpage: http://www.upa.dot.gov/pub.htm.

In keeping with this study's interest in travel impacts in so much as they relate to environmental impact evaluation, recommendations for assessing travel impacts in and of themselves are not presented here. Rather, those travel impacts that are directly relevant given the recommended evaluation methodologies are discussed within the context of the environmental impact framework.

Congestion pricing projects rarely can be expected to produce significant noise impacts and therefore noise analysis is not recommended as part of a standard analysis framework. Consideration of other impacts which may or may not be universally categorized as "environmental impacts," such as impacts on business and the economy may be appropriate for many congestion pricing projects but were not considered in this study.

Table 4-1 summarizes the overall recommended framework. Recommendations are elaborated in the text that follows (Section 4.1 and 4.2). The recommendations presented in Section 4.1 and 4.2, generally describe recommended best practice without regard to project-specific resource availability. Table 4.1 includes recommendations for cost-savings when resources are especially constrained.

Table 4-1. Summary of Recommended Environmental Impact Evaluation Framework

Evaluation Consideration	Recommended Approach	Options for Limiting Costs
Air Quality		
Ambient Monitoring versus Calculated Vehicle Emissions	• Calculate project-related vehicle emissions rather than trying to discern them within monitored ambient pollutant levels	• None (vehicle emission calculation is not resource intensive)
Dispersion Modeling	• Only perform if significant increases in local traffic delay are expected, especially near sensitive land uses	• Will not be needed for most evaluations
Vehicle Emission Calculation Procedures	• Use a project-level analysis that sums emissions among individual study roadway links under before (without project) and after	• None
Pollutants	• Consult with state/local and Federal agencies within the analysis region • Typically include criteria pollutants (CO, NO_x, VOC and PM), greenhouse gas related pollutants (CO_2, methane) and mobile source air toxics (benzene)	• None (very little cost implication for calculating one versus several pollutants)
Geographic Area of Analysis	• As many impacted roadway links (+ 5 percent project-attributable traffic volume change) as possible; at least all major roadways in the priced zone and all major, adjacent alternate routes	• Focus on only the most significantly impacted roadway links and caveat conclusions appropriately
Traffic Data Collection Timeframe	• More data is better—a minimum of several months with a full year being best, so as to control for seasonal and other cyclical changes	• Limit to a few days or weeks of data collection, making sure to control for seasonal and other cyclical changes impacted before-after data.
Traffic Inputs and their Derivation	• Use observed rather than modeled data • At a minimum, include roadway link-specific VMT and average speeds; include driving cycle data when impacts are present and if resources permit collection of observed data • Use any of various, proven speed data collection methods including probe vehicles or various roadway detectors (e.g., license plate readers, inductive loops, microwave, magnetic, Bluetooth, etc.) • Calculate VMT based on actual link lengths and observed traffic volumes collected using any of various proven, specific data collection methods, e.g., inductive loops, microwave, Bluetooth, etc.	• Eliminate driving cycle data and caveat findings appropriately • Minimize or eliminate special data collection on less important links (rely mostly or entirely on existing detector data)

Table 4-1. Summary of Recommended Environmental Impact Evaluation Framework (Continued)

Evaluation Consideration	Recommended Approach	Options for Limiting Costs
Project-Attributable Traffic Changes	• Base the vehicle calculations on project-attributable rather than cumulative or total observed before-after changes • Consider and apply a wide range of techniques to control for exogenous factors, including use of controls, statistical modeling, household travel diary data, etc.	• Use cumulative, observed changes but qualitatively assess the potential influence of exogenous factors and caveat findings appropriately
Hourly Emission Estimates	• Calculate total daily emissions as the sum of calculated hour-by-hour emissions	• Assuming traffic data is available, there are limited cost implications of calculating by hour
Vehicle Mix	• Break link VMT into VMT by major vehicle types and apply appropriate vehicle type-specific emission factors if project has impacted vehicle mix	• Assume no project change in vehicle mix and use a single all-vehicle VMT figure
Emission Rates	• Derive using an emission rate model selected based on local preference and familiarity • If observed vehicle driving cycle data is available, utilize EPA MOVES model • Carefully review and understand all model inputs, including default values	• If MOVES not used, there are few cost implications because emission factors are often available from regional air quality agencies and/or can be fairly easily developed • Collection of observed driving cycle data and use of MOVES should only be eliminated if no significant driving cycle changes are present and if resources preclude MOVES modeling
Noise		
Inclusion in the Environmental Analysis	• Not recommended as a “standard” practice because most congestion pricing projects will have little or no discernable impact • Include only if it is a key local issue	• If included at all, either monitor or model, but not both

Table 4-1. Summary of Recommended Environmental Impact Evaluation Framework (Continued)

Evaluation Consideration	Recommended Approach	Options for Limiting Costs
Environmental Justice		
Use of Prevailing, Fundamental Tools	• Prevailing methods and tools provide a solid foundation and should be utilized in most analyses; tools/techniques include mapping of travel impacts in relation to minority and low income populations, attitudinal surveys and focus groups with various populations, and travel diaries completed by various populations	• GIS mapping is more powerful, but simpler manual overlays may be substituted • Panel surveys are best but cross-sectional surveys may be substitute • Travel diaries are best but general stated behavior surveys may be substituted
Travel Impacts to Consider	• Consider the potential environmental justice implications of any and all documented travel impacts (see text for recommended measures)	• When household travel diaries/surveys are cost-prohibitive, may use individual travel diaries/surveys • Eliminate travel diaries completely if resources preclude them and rely more on general stated behavior (from surveys and/or focus groups) • Leverage existing system-based data collection and cut back on “special” data collection as resources dictate • When resources dictate “picking and choosing” of impacts to consider, focus on those that are expected to be most significant and which can be most accurately measured, such as traffic volumes and speeds and transit ridership
Populations to Consider	• Consider as many different populations as possible (see text), including those based on socio-economic, transportation mode, employment type, and trip purpose factors	• If resources require “picking and choosing,” focus on socio-economic factors, especially income and race
Charging Revenues	• Explicitly consider how charging revenues will be reinvested and relationship between who pays charges and who benefits from sharing revenue investments	• In most cases, the scope and scale of the consideration of reinvestment will be much less extensive than the consideration of the direct travel impacts of the congestion pricing project itself and may be subjective
Sources of Demographic Data	• Build in as much demographic data collection as possible into all manner of travel and other evaluation data collection; not just surveys	• When resource constraints dictate, surveys or even zip code data can be used as a minimum

4.1 Air Quality Analysis Framework

This section presents a general recommended framework for evaluating the air quality impacts of deployed congestion pricing projects such as the U.S. DOT Urban Partnership Agreement deployments.

4.1.1 Ambient Monitoring versus Calculated Vehicle Emissions

Experience from other congestion pricing evaluations indicates that roadside monitoring of ambient air quality levels is not an effective approach to gauging project impacts; it is simply impossible to differentiate project-related impacts from other, exogenous factors. As such, the first and most fundamental recommendation is that the air quality impacts of congestion pricing projects be evaluated using the one method that allows direct estimation of project-attributable air quality impacts: by comparing before (without pricing) and after (with pricing) *calculated* vehicle emissions.

4.1.2 Dispersion Modeling

Dispersion models, or hot spot models, estimate the localized ambient concentrations of vehicle emissions, as compared to the "calculated vehicle emissions" discussed above which calculate the volume of pollutants being emitted directly from vehicles. Dispersion modeling takes into account atmospheric and site topography considerations to estimate roadside concentrations of pollutants emitted from all traffic. No examples of dispersion modeling for before-after congestion pricing projects were found among the eight study projects or in the general literature.

It is recommended that dispersion modeling only be performed if the traffic analysis indicates that the congestion pricing project has created significant increases in localized traffic delay, especially near sensitive land uses such as nursing homes, parks, or schools. Such impacts may be possible with some congestion pricing projects, such as those that may divert significant traffic away from a priced facility onto one or two already congested parallel routes. If dispersion modeling is appropriate selection of a model and specific methodologies should be based on local considerations and should reflect an interagency consultation including state and local air quality and traffic agencies and regional U.S. DOT representatives. Examples of dispersion models include the EPA CAL3QHCR or CARB CALINE4 carbon monoxide dispersion models.

4.1.3 Calculation of Vehicle Emissions

This section presents the recommended framework for what will, in most cases, constitute the air quality evaluation: calculation of before and after vehicle emissions. The recommended framework is as follows:

- **Project-level Analysis –** vehicle emission calculations for deployed congestion pricing projects should, logically, use a project-level analysis. A project-level approach calculates project-related changes in traffic volumes and speeds on specific affected roadway links and calculates total vehicle emissions as the sum of calculated emissions for each link.

- **Pollutants –** the selection of pollutants for consideration in the air quality analysis will be driven by local air quality issues. The selection of pollutants should be made via an interagency consultation including state and local air quality and traffic agencies and regional U.S. DOT representatives. Many analyses will likely focus on all or some of the following pollutants associated with vehicle activity:
    - Some criteria pollutants (pollutants associated with National Ambient Air Quality Standards): carbon monoxide, ozone precursors nitrogen oxides, volatile organic compounds, and particulate matter
    - Greenhouse gas related pollutants: carbon dioxide and methane
    - Mobile source air toxics (MSATS): benzene.
- **Geographic Area of Analysis –** The geographic area of analysis should include as many of the roadway links as possible that are expected to be affected by the project, a determination that will be made in the traffic analysis that precedes the air quality analysis. Generally, at a minimum, the air quality analysis should include the major roadways (highway and major arterials) within the priced zone as well as the major likely alternate routes to those roadways. It has been suggested that "affected" roadways could be defined as those links where the average annual daily traffic is expected to change by more than $\pm$5 percent as a result of the project.[58] Experience has shown that traffic diversion can be significant: in pre-deployment surveys for the Seattle region UPA congestion pricing deployment, 40 percent of respondents indicated that they will take an alternative, non-priced route;[59] in London, it was estimated that 20-30 percent of car trips no longer made into the priced zone are now made on non-priced roads.[60]
- **Data Collection Timeframe –** A minimum of several months of before and after data is recommended and up to a full year of data pre- and post-pricing project implementation is better. Collection of a full year of before and after data allows for seasonal variation to be controlled for or explicitly evaluated, allows random variations to be averaged out, and allows examination of both the immediate (first few weeks/months) as well as somewhat more mature (one year) impacts of the pricing project be investigated. If using only a few months of data, it is important to compare before and after data that are from the same season or month to control for seasonal variation.
- **Traffic Impacts and their Derivation –** At a minimum, observed rather than modeled roadway link-specific VMT and average speeds should be utilized. Link speeds can be collected using any of various, proven speed data collection methods including probe vehicles (e.g., floating cars operated by the evaluators, GPS-equipped vehicles operated by public volunteers, or toll-tag equipped vehicles operated by the general public) or various roadway detector types such as license plate readers, inductive loops, Bluetooth, microwave, infrared, acoustic, etc. Link VMT should be calculated based on actual link

[58] Claggett, Michael and Miller, Terry, "A Methodology for Evaluating the Mobile Source Air Toxic Emissions Among Project Alternatives," May 2006.

[59] Washington State Department of Transportation, "SR 520 Bridge Tolling *Good to Go!* Baseline Survey – Telephone Survey Report, Draft," prepared by Pacific Rim Resources, Inc. May 2010.

[60] Transport for London "Central London Congestion Charging Impacts Monitoring Second Annual Report," April 2004. http://www.tfl.gov.uk/assets/downloads/Impacts-monitoring-report-2.pdf

lengths and observed traffic volumes. Traffic volumes should be collected using any of various proven, specific data collection methods, e.g., inductive loops, microwave, etc. If the project has been shown by the traffic analysis to have significantly impacted traffic flow (i.e., driving cycle), observed driving cycle data should be collected and used in the calculation of vehicle emissions (see discussion of Emission Rates, below).

- **Project-Attributable Traffic Changes –** Emission calculations should utilize project-attributable changes in link speeds, VMT (and, if applicable, driving cycle) rather than total observed changes in these metrics. That is, ideally, the influence of exogenous factors should be controlled in such a way that observed traffic data can be quantitatively adjusted to eliminate the non-project related portion of total before-after variability. If exogenous factors such as fuel price changes, employment changes, and other transportation projects and programs are believed to have exerted little or no influence on travel in the study area, then observed post-deployment VMT and speeds can be used directly. However, if—based on thorough tracking from the pre-deployment through the post-deployment data collection period—there is reason to believe that exogenous factors have significantly impacted observed post-deployment traffic data, efforts should be made to adjust the post-deployment traffic data to eliminate the influence of exogenous factors. If that is not possible, the results of the emissions calculations should caveat the results appropriately. The influence of exogenous factors on driving cycle is especially problematic. If it is determined that exogenous factors have significantly impacted traffic conditions, in many cases consideration of driving cycle impacts may need to be eliminated. This is because it is much harder to quantitatively adjust driving cycle data than volume or average speed data—if possible at all it would require resource-intensive traffic simulation. Further, even if adjustments can be made, the resulting estimates may be so uncertain as to eliminate the fundamental value in considering driving cycle data at all. Recommended methods for determining whether and how much exogenous factors have influenced traffic volume and speed changes include:
  - Comparisons to control roadways/corridors/areas
  - Statistical modeling that can remove or control for the effect of exogenous factors by including such variables in multivariate equations
  - Utilization of household survey data (travel diary data being ideal) to understand the causes behind reported changes in travel behavior, including the following considerations:
    - Using adequate sample sizes given intra and inter-household changes over the analysis period.
    - Collection of detailed information from participants to better understand the reasons behind the reported travel behavior.
    - Consideration of case study approaches in which the impact of changes in household demographics are thoroughly explored at the individual household level, potentially including home interviews and focus groups.

    - Tracking fuel prices and employment levels
    - Elimination of traffic data from times and locations within the study area characterized by severe weather, significant traffic incidents, and significant roadway construction
    - Collecting before and after tracking data for the same month(s) of the year
    - Examination of historic traffic trends.

- **Hourly Emission Estimates –** It is recommended that total daily vehicle emissions for both the before and after periods be developed by summing hourly emission estimates. Those hourly estimates should use hourly VMT and speed data.
- **Vehicle Mix –** Traffic analyses of congestion pricing projects should test for before-after changes in vehicle mix and any changes should be reflected in the air quality analysis by breaking VMT down by vehicle type.
- **Emission Rates (Factors) –** Emission factors should be derived from an emission model such as the EPA MOBILE6, MOVES or California Air Resources Board EMFAC models. Selection of the model will be driven by local preference and familiarity (that is, using a model that is accepted and well adapted to the analysis region) as well as the approach taken to driving cycle.
    - Resources permitting and assuming that a traffic analysis has shown that driving cycle impacts (changes in flow—the pattern of acceleration, deceleration, idling and cruising on study roadway links) are likely, these impacts should be explicitly considered in the air quality analysis. That will require collection of before and after driving cycle data using instrumented test vehicles performing floating car runs on all of the study roadways and during all of the time periods of interest. Multiple runs will be required on each link at different times of the day, made by at least a couple of different types of vehicles. When observed driving cycle data are available, it will be important to utilize the EPA MOVES model to derive emissions factors because the MOVES model provides by far the most effective means for taking driving cycle changes into account.
    - Collection of observed driving cycle data can be expensive. For example, as part of the preliminary planning for the U.S. DOT evaluation of the Seattle-Lake Washington Corridor Urban Partnership Agreement, it was estimated that collection of driving cycle data for that analysis would cost between $50,000 and $100,000.[61] In those cases where resources do not permit the collection of driving cycle data, the selection of the emission factor model should be based on local considerations.
    - Regardless of which emission factor model is selected for a specific analysis, evaluators should carefully review and understand the model inputs and default and user-defined inputs and options. Local inputs such as fleet registration and fuel-type distributions, vehicle emission inspection and maintenance (IM) programs, and vehicle fuel programs should be accurately reflected in the model.

[61] Unpublished technical memorandum, "Decision Support Information for UPA/CRD Environmental Analysis Approach," prepared by Battelle for the United States Department of Transportation, November 2009.

4.2 Environmental Justice Analysis Framework

This section presents recommendations for evaluating the environmental justice impacts of congestion pricing projects. Perhaps more so than any other areas of evaluation, the specific issues to be considered in the environmental justice evaluation should be driven by local, site-specific issues and objectives. However, there are several principles that will be widely applicable.

4.2.1 The Prevailing, Fundamental Tools and Techniques Provide a Solid Foundation

In addition to the recommended enhancements noted below, the fundamental tools and techniques that currently constitute state of the practice for investigating environmental justice are useful and should continue to be utilized. These methods include:

- Using regional geographic information systems to map the locations of low-income and minority populations within the likely impact area.
- Using attitudinal surveys, interviews and focus groups of the general public, corridor travelers and specific types of residents and travelers to gather attitude and perception as well as general travel behavior data.
- Using travel diary surveys to gather detailed, specific travel behavior data of various groups of interest.

4.2.2 Travel Impacts

The specification of travel impacts relevant to an environmental justice analysis is more complex than the specification of traffic impacts relevant to an air quality analysis. In the case of air quality, only a few "bottom line" traffic impacts (VMT, speeds and driving cycle) manifest directly in terms of air quality. Consideration of other travel impacts (e.g., mode choice) is irrelevant because such changes either ultimately translate to changes in VMT, speed and/or driving cycle or they are totally unrelated to air quality. In the case of environmental justice, it is not the case that only certain travel impacts are relevant, although certainly some, such as charges paid by socio-economic category, are more relevant. Rather, an environmental justice analysis seeks to understand a particular dimension (differential impacts among populations) of essentially *any and all* significant travel impacts.

As such, the first and most fundamental consideration in regard to assessing environmental justice impacts is to start with a comprehensive travel impacts evaluation that assesses as many potentially significant project-related travel changes as possible. These impacts will vary according to the type of project and its regional setting, but generally, a comprehensive travel impacts analysis (and one which will support a robust environmental justice evaluation) will consider the following impacts:

- Traffic volumes
- Vehicle miles traveled
- Average speeds
- Person and vehicle throughput

- Travel times, including some “indexed” measure such as the travel time index utilized by the Texas Transportation Institute in their urban traffic monitoring program for U.S. DOT
- Travel time reliability, such as represented by a “buffer index” or “planning index”, both of which capture the extra increment of time travelers need to plan for given observed variability in travel conditions
- Geographic and temporal extent of congestion, e.g., hours of congestion and miles of congested roadway
- Vehicle classification/vehicle mix
- Average vehicle occupancy
- Mode choice/mode split
- Accident rates and contributing factors
- System operator and/or traveler (all modes) perceptions of safety and congestion
- Transit ridership
- Transit travel time
- Transit schedule adherence/on-time performance
- Household traveler behavior (travel diaries completed by each member of the household documenting routes, modes, foregone trips, times of travel, etc. with accompanying attitudinal surveys)
- Congestion pricing charges paid

An environmental justice analysis should consider how each of these travel impacts associated with the project in question impacts different populations (see Section 4.2.3). For example, what types of people use the roads where traffic volumes decreased and increased? What types of people made what sorts of mode choice changes and how did those changes impact the quality of their travel experience? Which types of people paid various amounts of congestion charging fees?

Note that depending on the project, it may be useful to collect additional travel impacts—what could be considered first order impacts—that improve the understanding of the project impact (and exogenous factor impact) on the “bottom line,” or second order, impacts. Consider the example of a congestion pricing project that is accompanied by supporting transit improvements including park-and-ride lot enhancements. In that case, collecting data on park-and-ride lot utilization in addition to transit ridership will help explain whether it was the project (in this case the park-and-ride lot enhancements) or other factors (e.g., fuel prices) that drove any ridership changes.

4.2.3 Consider Broadly How Impacts Differ Among a Wide Range of Users

One of the primary recommendations is that evaluations of environmental justice should focus more broadly on understanding how impacts will vary for a wide range of users rather than only on how impacts may vary based on income and minority status. Income and minority status are certainly very important categories to consider. However, the investigation of differential impacts in those areas should be part of a broader area of enquiry that permeates many different individual evaluation analyses (e.g., traffic, travel behavior) and which seeks to understand all of the ways in which some people may be impacted differently than other people by the project. Depending on the project, the types of differential impacts which should be considered for investigation include:

- People of varying income and education levels
- People of various racial groups
- People with various employment status, including full-time, part-time and unemployed
- Users of different transportation modes, including drive alone, rideshare, telecommuters, bicyclists, users of various transit services, and pedestrians
- People with varying travel origins and destinations (namely residential and work locations)
- Users with varying degrees of flexibility in changing their time, route or mode of travel
- Different trip purposes
- Travel during different days of the week and time of day
- Frequent travelers versus occasional travelers
- People with disabilities
- People with differential access to various travel modes, including transit and private auto
- New residents versus long-term residents
- Visitors versus permanent residents.

Understanding which of these sorts of distinctions are going to be important will have significant implications on the development of the evaluation plan, as the data needs associated with these distinctions will impact various data collection areas across the evaluation. Surveys will of course be significantly impacted, where it will be important to categorize the respondent according to all of the demographic and other characteristics of interest, but so will the collection of objective data such as traffic data. For example, understanding how impacts differ between carpoolers and single occupant vehicles could mean that collecting average vehicle occupancy data is important.

4.2.4 Explicitly Consider the Uses of Charging Revenues

Evaluations should endeavor to take into consideration how any public revenues raised by the congestion pricing scheme will be reinvested in any transportation programs or projects and the potential implications of those investments on the net environmental justice impacts of the pricing project. Reinvestment can significantly impact net equity effects.

4.2.5 Collect Demographic and other User Data Wherever Possible

Key to understanding environmental justice impacts of congestion pricing projects is the ability to associate specific impacts, e.g., changes in traffic volumes and speeds, with various user groups (demographics), including those that vary by income, minority status, access to transit, access to private auto, residential location, work location, etc. Therefore, it is important build in as much demographic data collection as possible into all manner of travel and environmental data collection throughout the evaluation. This includes the obvious example of including demographic questions in all surveys. But other opportunities should also be investigated, for example, objective traffic data collected using license plate readers may—if supportable under applicable state and local privacy laws—also provide some understanding, through vehicle registration data, of the residential locations associated with the vehicles. That information in turn could provide some understanding of origin-destination.

APPENDIX A
Summary of Study Project Reported Travel Findings

Study/Project	Results	Conclusion	Major Caveats/Limitations
Simulated Pricing Field Demonstrations			
Oregon Mileage Fee Concept and Road User Fee Pilot Program	• 10% reduction in total VMT • 13% reduction in peak hour VMT • Peak hour mode choice influenced by the pricing	• Mileage price incentives can be expected to impact travelers' total amount of driving, the timing of their trip making, and, potentially, their mode of travel	• None reported
Puget Sound Traffic Choices Study	• 7% reduction in total weekly vehicle trips • 12% reduction in weekly VMT • 8% reduction in total weekly travel time • 13% reduction in weekly VMT on tolled roads	• Motorists made small-scale adjustments in travel that, in aggregate, would have a major impact on transportation system performance • Households that modified their travel did so in many different ways: fewer and shorter vehicle trips, alternate routes and times of travel, or linking trips together to reduce vehicle use altogether	• Responses to congestion charging may be underestimated in so much as some households who may have been inclined to avoid the peak period charges did not have the flexibility to do so
Commute Atlanta Mileage Based Value Pricing Demonstration	• 3% reduction in total VMT	• Little if any project impact. Observed VMT reduction thought to be a function of non-project related changes in travel behavior	• Inter- and intra-household variability and demographic instability obscured any project impact • Higher income respondents were somewhat over-represented in the survey

Study/Project	Results	Conclusion	Major Caveats/Limitations
Before-After Project Evaluations – U.S.			
Minnesota I-394 MnPASS HOT Lanes	• Up to 5% increase in peak hour corridor throughput • 6% average increase in speeds in general purpose lanes • Speeds in the MnPASS lanes either remained the same or increased slightly • Average person travel time in the corridor decreased • Project benefits distributed relatively evenly amongst population	• The public supported the HOT lane concept • MnPASS users were satisfied with toll operations	• None reported
San Diego I-15 HOT Lanes	• 48% increase in express lane traffic volumes • 76% of FasTrak customers would leave at a different time in the morning if there were no FasTrak.	• I-15 pricing project alleviated congestion on the I-15 main lanes by redirecting an increasing share of volume onto the I-15 express lanes • Dynamic pricing structure was able to create desirable redistribution of a portion of express-lane traffic from the middle of the peak to the shoulders	• Exogenous factors played a more significant role than the project in regard total traffic increases in the I-15 corridor

Study/Project	Results	Conclusion	Major Caveats/Limitations
Before-After Project Evaluations – International			
The Stockholm Trial	• 16-24% reduction in peak hour traffic volumes • 14% reduction in VKT in charging zone • 33-50% reduction in peak hour average queue wait times • 3% reduction in average journey (travel) times	• The project was successful in managing congestion and increasing flow and accessibility	• The impact of other projects and fuel price changes were not completely controlled
	• Car trips across the pricing zone decreased by 20 percent • No project-attributable changes in walking, bicycling, telecommuting or carpooling • Trip chaining increased slightly	• The pricing project shifted trips to transit	• Exogenous factors, including fuel price changes and seasonal variation limit the strength of conclusions
	• 6% increase in total transit ridership • 4% decrease in the proportion of transit users that are satisfied with service quality	• Increases in transit use met or exceed expectations • Goals for maintaining transit rider satisfaction were not achieved due to crowding and reduced schedule adherence	• Increases in transit uses may also have been impacted significantly by fuel prices and economic development

Study/Project	Results	Conclusion	Major Caveats/Limitations
Before-After Project Evaluations – International (Continued)			
London Congestion Pricing	• 15% reduction in VKT after first year • 18% reduction in number of vehicles entering the pricing zone • 25% reduction in delays • 14% reduction in journey times • 21% increase in speeds	• The project has succeeded in its fundamental objectives in reducing congestion	• Impossible to precisely and definitively isolate project impacts from exogenous factors impacts
	• 37% increase in passengers entering central zone by bus	• Transit has accommodated significantly increased passenger levels with limited adverse impacts • Transit performance has been improved in some respects as a result of reduced roadway congestion and transit service enhancements	• Exogenous factors have influenced transit ridership and performance but some estimation of project-specific impacts are possible
	• 30% decrease in excess bus wait time in first year		
	• 20% reduction in bus kilometers not operated due to congestion		
	• (Central charging zone) 50-60% of trips formerly made by car now made by transit; 20-30 percent driving around the charging zone; 8-10% bicycling, motorcycling or walking; <1% eliminated trips; and <1 shifted car trip to non-priced times	• The charging scheme has resulted in significant travel behavior changes, with most trips shifting to transit	• Being based largely on surveys, despite best efforts, some groups are likely over or under-represented

Study/Project	Results	Conclusion	Major Caveats/Limitations
Before-After Project Evaluations – International (Continued)			
Singapore Area Pricing	• 44% reduction in traffic volumes into the priced zone • Share of HOV 4+ trips increased from 8 to 19%; bus share increased from 33 to 46% • A.m. peak speeds inside priced zone increased by 20% or more • Speeds increased 10% on inbound roadways leading to the priced zone • Motorists shifted trips to non-priced times and routes	• The pricing projects, coupled with other strategies, have been effective in providing lasting, significant reductions in traffic congestion	• None reported.

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APPENDIX B
Summary of Study Project Reported Environmental Findings

Study/Project	Results	Conclusion	Major Caveats/Limitations
Simulated Pricing Field Demonstrations			
Oregon Mileage Fee Concept and Road User Fee Pilot Program	No Environmental Analysis Performed		
Puget Sound Traffic Choices Study			
Commute Atlanta Mileage Based Value Pricing			
Before-After Project Evaluations – U.S.			
Minnesota I-394 MnPASS HOT Lanes	• Small increases and decreases in one-hour average CO levels, ranging from +0.29 to -.01 parts per million	• HOT lanes had no substantial impact on air quality	• None reported
	• Small project-related increases in noise levels found at three sites	• HOT lanes caused no statistically significant change in average neighborhood sound levels	• None reported
	• Beneficiaries of the HOT lane included a diverse population across all income, age, race/ethnicity, employment, and mode usage groups	• No significant correlation between socio-demographics and project benefits and attitudes	• None reported

Study/Project	Results	Conclusion	Major Caveats/Limitations
Before-After Project Evaluations – U.S. (Continued)			
San Diego I-5 HOT Lanes	• Estimated a.m. peak emissions on the control corridor increased three to five times more than emissions on the project corridor	• The HOT lanes moderated emission levels in the project corridor	• Since the impact of exogenous factors could not be precisely controlled or measured, all observed differences between the control and project corridors could not be attributed to the project.
	• On the study roadway, emissions increased significantly more on the HOT lanes than on the general purpose lanes	• Consistent with the traffic data showing increased use of the HOT lanes	
Before-After Project Evaluations – International			
The Stockholm Trial	• 8.5 -14% decrease in emissions depending on the pollutant	• The project had a positive impact on emissions	• Weather conditions thought to contribute to emissions reductions to some degree
	• Minor reduction in noise levels	• The project did not significantly impact noise levels	• None reported
	• Great variation in congestion charges paid by individual • Wealthy, inner-city men pay the most • Higher income earners pay more than lower income earners • Commercial traffic and business trips are “net winners”	• How pricing revenues are redistributed is the key to total cost-benefit effects on different people	• None reported

Study/Project	Results	Conclusion	Major Caveats/Limitations
Before-After Project Evaluations – International (Continued)			
London Congestion Pricing	• Emissions decreased by between 13 and 16% depending on the pollutant, for the original project • Emissions decreased by between 2 and 6%, depending on the pollutant, for the Western Extension	• The project had a positive impact on air quality	• Roadside monitoring results inconclusive (unable to differentiate project impacts from exogenous factors) • Calculated emissions did estimate project impacts
	• No significant, project-attributable changes in noise levels	• The project did not impact perceptible noise levels	• Roadside monitoring results inconclusive (unable to differentiate project impacts from exogenous factors) • Significant reductions in traffic volumes are necessary to reduce noise levels (to get the smallest discernable change in noise levels—3 dBA—traffic volumes must be cut in half)
	• Actual impacts were less than travelers themselves expected • Issues of greatest concern are not project related • Majority of respondents found the charge affordable	• No significant adverse and disproportionate impacts on environmental justice populations	• Despite best efforts, some groups are likely over or under-represented in data collection • Perception and attitude data are not as "scientific" as quantitative data

Study/Project	Results	Conclusion	Major Caveats/Limitations
Before-After Project Evaluations – International (Continued)			
Singapore Area Pricing	• CO reductions in a.m. peak, monthly average NO_x reductions, and reduced smoke and haze (immediately after first project)	• Project had a positive impact on air quality	• Declines in smoke and haze could not be fully attributed to the project
	• Some people did not benefit from the initial project, e.g., those for whom the cost of the charge is not off-set by reduced travel time • After some initial crowding, transit riders enjoyed better service as service was expanded over time • Middle income travelers felt adversely effected • Shifts to transit were uniform across income groups	• Although not all people benefitted equally, overall, the project did not significantly and disproportionately impact lower income people	• None reported

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