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Model-based Transportation Performance: A Comparative Framework and Literature Synthesis

MTI Report 11-09

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REPORT 11-09

MODEL-BASED TRANSPORTATION PERFORMANCE: A COMPARATIVE FRAMEWORK AND LITERATURE SYNTHESIS

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March 2012

A publication of
Mineta Transportation Institute
Created by Congress in 1991

College of Business
San José State University
San José, CA 95192-0219

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. CA-MTI-12-2805	**2. Government Acession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Model-based Transportation Performance: A Comparative Framework and Literature Synthesis		**5. Report Date** March 2012 **6. Performing Organization Code**
7. Authors Caroline Rodier, PhD, Margot Spiller		**8. Performing Organization Report** MTI Report 11-09
9. Performing Organization Name and Address Mineta Transportation Institute College of Business San José State University San José, CA 95192-0219		**10. Work Unit No.** **11. Contract or Grant No.** DTRT07-G-0054
12. Sponsoring Agency Name and Address California Department of Transportation Office of Research—MS42 P.O. Box 942873 Sacramento, CA 94273-0001	U.S. Department of Transportation Research & Innovative Technology Admin. 1200 New Jersey Avenue, SE Washington, DC 20590	**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code**
15. Supplemental Notes		

16. Abstract

In an era of limited resources and a proliferation of data, there is increasing pressure to conduct careful evaluations of the economic, environmental, and equity effects of investments and policies that influence transportation and land-use systems. This report compares performance measures recommended to achieve desired goals and reviews the literature to determine the degree to which these measures have been implemented and what they indicate about the relative effectiveness of land-use, transit, and automobile pricing policies. Despite the variation in methods and performance measures implemented in the studies reviewed for this report, the synthesis of study results suggests the direction and relative magnitude of change resulting from different types of policies, as well as potential biases introduced by omitting the representation of the land-use and transportation interaction. Overall, the performance measures indicate that carefully designed transit, land-use, and automobile pricing policies may improve travel, economic, environmental, and equity conditions for communities. However, transit and peak-period automobile pricing policies can, in some situations, lead to negative performance outcomes across some or all measures, as illustrated in studies that explicitly represent the land-use and transportation interaction.

17. Key Words Urban transportation policies, Performance evaluation, Environmental impacts, Land-use models, Traffic models	**18. Distribution Statement** No restrictions. This document is available to the public through The National Technical Information Service, Springfield, VA 22161		
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 106	**22. Price** $15.00

Form DOT F 1700.7 (8-72)

Library of Congress Catalog Card Number:
2012930702

To order this publication, please contact:

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041012

ACKNOWLEDGMENTS

The authors would like to thank the California Department of Transportation, the Hewlett Foundation, the Urban Land-Use and Transportation Center at the University of California Davis, and the Transportation Sustainability Research Center at the University of California, Berkeley, for supporting this research.

The authors also thank MTI staff, including Research Director Karen Philbrick, PhD; Director of Communications and Technology Transfer Donna Maurillo; Student Publications Assistant Sahil Rahimi; Student Research Support Assistant Joey Mercado; and Webmaster Frances Cherman. Additional editorial and publication support was provided by Editorial Associate Janet DeLand.

The contents of this report reflect the views of the authors, who are responsible for the accuracy of the data presented.

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EXECUTIVE SUMMARY

In a time of serious fiscal and environmental constraints, there has been a renewed call to identify transportation investments and related policy decisions that can optimize transportation, environmental, economic, and equity outcomes. Several influential reports[1] have articulated ways in which such outcomes may be measured (commonly known as performance measures) in the context of global warming legislation in California and the Federal Transportation Reauthorization Bill. These reports recommend numerous performance measures and metrics that correspond to roughly consistent goals. However, it is often unclear how the different performance measures relate and how they can be applied with the existing modeling tools. This study links the performance measures identified in various reports to data available from simulation tools and then groups the measures by data commonly required for performance-metric calculations. The result is a framework that can be used to compare measures, as well as the results of measures that have been implemented.

Models

Most of the performance measures recommended for use in transportation investment and policy decisions require data obtained from models that can simulate the effects of those decisions. Care must be taken to ensure that the models adequately represent the effects of proposed policies on the land-use and transportation system with which they will interact. Available travel models vary in their representation of the range of available travel options, the quality of those options, and the characteristics of people choosing them.

The locations of future development and activities are usually treated as fixed inputs to travel models. These inputs are often based on expert consultation and community visioning tools (e.g., I-Places, Community Viz). It is important to note that visioning tools are not predictive models. They allow participants in community planning meetings to dictate the location and form of future development, based on citizen values. However, visioning tools do not include the effects of economic forces that are known to play a major role in the actual form and location of new development.

Land-use models are used to forecast changes in the location and form of new developments, based on the interaction of travel costs, local economic characteristics, and relevant land-use and transportation policy and investments. For example, a new freeway project from downtown to a rural area may generate a demand for suburban housing developments and a shift in population location as some users trade lower rents for longer but now tolerable commute travel times. More advanced land-use models simulate the actions of developers in providing built space and allocate households and employment into available space, based on spatial economic forces. These forces include the cost of producing goods, services, labor, and space and the demand for them, by subregional locations (i.e., land-use zones, grid cells, and parcels). If land-use changes are not allowed to vary with changes in travel time and cost arising from new transportation policies and investments, biases may arise in the evaluation of travel benefits.

Performance-Measure Framework

This report describes a framework that groups recommended measures by the type of model data required to calculate them (see Table 1).

Table 1. Performance-Measure Framework

	Performance Measure	Required Model Data
Travel	Access	Travel time/cost by origin/destination location, mode, area (corridor, subarea, region), time of day (peak and off-peak), and/or activity type (work, school, shop)
	Proximity	Quantity of land consumed; redevelopment and/or infill by type, area, and/or location; total jobs by total households by area
	Choice	Transit, pedestrian, and bicycle mode share by area
	Congestion	Vehicle speed/distance by mode (including trucks), activity type, area (key corridors or economic destinations)
Equity	Access	Access by socioeconomic group and location
	Spatial	Clustering of socioeconomic groups by location
	Housing	Home location change attributed to rent increase by socioeconomic group
Economic	Housing	Supply and cost (rent/own) by type and location
	Financial/land-use	Built-form input to service cost, tax, and/or infrastructure cost model
	Financial/transport	Use and revenue relative to capital and operation and maintenance (O&M) costs
	Surplus	Spatial economic effects (producer and consumer surplus)
Environment	Energy/climate/air	Vehicle activity in fuel use, climate change, and emissions models
	Noise	Residential location and vehicle facilities in noise models
	Habitat/ecosystem/water	Land consumed by type and location input to habitat, ecosystem, and water models

Literature Review

The performance-measure framework is used to gauge implementation of and evidence from performance measures as documented in the literature. The studies included in this review report percentage change from a base case to a policy alternative in the same horizon year or the results of both alternatives (typically a trend or business-as-usual). The percentage-change metric was necessary to compare results across studies. Most of the studies were developed by regional or state government agencies, academic researchers, or community groups.

The survey of the literature suggested that choice and congestion measures for travel performance have been implemented widely, but access and proximity measures have not been. The recommended equity measures have also rarely been implemented, but there was a proliferation of other unique measures. With respect to economic performance, financial measures related to transportation cost were most commonly implemented. A few community visioning studies examine financial costs related to land-development patterns and housing supply (largely related to the number of assumed single-family and multifamily housing units). To date, housing affordability and consumer/producer surplus have been examined in a number of studies in Europe but in only one U.S. study. Energy, climate, and air-quality measures are commonly used. Most of the visioning studies examine habitat, ecosystems, water, and noise measures.

The relative magnitude and direction of change for the performance measures recommended for different types of policies, based on the literature review, are summarized in Table 2. The green arrows in the table denote a beneficial effect, and red arrows denote a negative effect. For travel, environmental, and equity measures, the effect is the percentage change from the base to the alternative scenario by policy type. One arrow denotes a change from 0% to 10%, two arrows denote a change from 10% to 100%, and three arrows denote a change of more than 100%. For economic measures, the effect is measured in per capita 2000 U.S. dollars. One arrow denotes a change from $0 to $10; two arrows, from $10 to $100; three arrows, from $100 to $1,000; and four arrows, more than $1,000.

The travel performance measures indicate that transit, land-use, and automobile pricing policies tend to reduce automobile mode share, increase transit and non-motorized mode share, reduce travel time and vehicle hours of delay, and improve access to central business districts (CBDs) and services. The exceptions are transit and peak-period pricing policies (i.e., cordon, parking, and congestion) simulated with a land-use and transport model. In some cities, expanded transit and increased cost of travel in the CBD has resulted in population and/or employment shifts from the city to outer areas of the region. Not surprisingly, more changes were found in scenarios that include more-comprehensive automobile pricing policies (e.g., vehicle miles traveled [VMT] tax) and combine policies. The increase in transit and non-motorized mode share also appears to be relatively large across scenarios, suggesting a potential health benefit from increased physical activity.

The environmental performance measures show reductions in greenhouse gas (GHG) and criteria air pollutants (CO, NO_x, and VOC) and a general reduction in land consumption and quality of open space. Again, when a land-use and transportation model was used to simulate transit and pricing analyses in some cities, land consumption was shown to increase and the quality of open space was diminished. As travel costs to outer areas of the region are reduced by improved transit service and costs in the center city are increased by pricing policies, there is a greater demand for housing and employment development in the outer areas of a region.

Economic performance measures generally show improved consumer surplus for land-use and transit measures, but results are mixed for pricing policies. Revenue (e.g., transit fares and automobile pricing) tends to increase across all scenarios, with the exception of congestion pricing in some cities and aggressive combined pricing policies. Externalities are reduced across all scenarios.

Equity performance measures show mixed results for housing supply across all scenarios, and spatial segregation tends to increase in transit as well as cordon and parking pricing scenarios.

Table 2. Summary of Performance Measures Examined

	Performance Measure																	
	Travel							Environmental						Equity			Economic		
Policy Type	**Travel Time**	**VHD**	**Access to City Center**	**Access to Services**	**Auto Mode Share**	**Transit Mode Share**	**Non-Motorized Mode Share**	**GHG Emissions**	**NO_x Emissions**	**CO Emissions**	**VOC Emissions**	**Developed Land**	**Quality of Open Space**	**Overcrowded Housing**	**Segregation**	**Consumer Surplus**	**Operator Revenues**	**Externalities**
Land-use	↓↓-↓	↓↓-↓	-	-	↓	↑	↑↑	↓	↓	↓	↓	↓	-	-	-	↑↑-↑↑↑	-	-
Transit	↓	↓	↓-↑	↓-↑	↓	↑-↑↑↑	↓-↑	↓	↓	↓	↓↓-↓	↓-↑	↓-↑	↓-↑	↓-↑	↓-↑↑↑↑	↑-↑↑↑	↓↓↓-↑
Land-use/ transit	↓↓-↑	↓↓-↓	-	-	↓↓-↓	↓-↑↑↑	↓↓-↑↑↑	↓↓-↓	↓↓-↓	↓↓-↓	↓↓-↓	↓↓-↓	-	-	-	↑-↑↑	-	-
Cordon pricing	↓-↑	↓-↑	↓↓-↑	↓-↑	↓	↑-↑↑	↓-↑	↓↓-↓	↓	↓	↓↓-↓	↓-↑	↓↓-↑	↓-↑	↓-↑	↓↓↓↓-↑↑↑↑	↑↑-↑↑↑↑	↓↓↓↓-↑↑↑
Parking pricing	↓-↑	↓-↑	↓↓-↑↑	↓-↑	↓	↓-↑↑	↓-↑↑	↓-↑	↓	↓	↓	↓-↑	↓-↑	↓-↑	↓-↑	↓↓↓↓-↑↑↑	↑↑↑-↑↑↑↑	↓↓↓-↑
Congestion pricing	↓	-	-	-	-	-	-	↓↓-↓	↓↓-↓	↓↓-↓	↓↓-↓	-	-	-	-	↓↓↓-↑↑↑	↓↓↓↓↓-↑↑↑	↓↓↓-↓↓
VMT pricing	↓↓-↓	↓↓-↓	↑-↑↑	↑-↑↑	↓↓-↓	↑-↑↑↑	↑-↑↑	↓↓-↓	↓↓-↓	↓↓-↓	↓↓-↓	↓-↑	↓-↑	↓-↑	↓↓-↑	↓↓↓↓-↑↑↑	↓↓↓-↑↑↑	↓↓↓↓-↓↓↓
Fuel pricing	↓↓-↓	↓↓-↓	-	-	↓	-	-	↓↓-↓	↓↓-↓	↓↓-↓	↓↓-↓	-	-	-	-	↓↓	↑↑↑-↑↑↑↑	-
Emissions pricing	↓	↓	-	-	-	-	-	↓	↓↓-↓	↓↓-↓	↓↓-↓	-	-	-	-	-	↑↑-↑↑↑	-
Combination pricing	↓↓	↓↓	-	-	↓	↑↑	↑-↑↑↑	↓↓-↓	↓↓-↓	↓↓-↓	↓↓-↓	-	-	-	-	-	-	-
Pricing/transit	↓↓-↑	↓↓-↑	↑	↓-↑	↓↓-↓	↓-↑↑↑	↓-↑↑↑	↓↓-↓	↓↓	↓↓	↓↓-↓	↓-↑	↓-↑	↓-↑	↓-↑	↓↓↓↓-↑↑↑↑	↓↓↓↓-↑↑↑↑	↓↓↓↓-↓↓
Pricing/transit/ land-use	↓↓-↑↑	↓↓-↑	↑	↓-↑	↓↓-↓	↑-↑↑↑	↓-↑↑↑	↓↓-↓	↓↓ - ↓	↓↓-↓	↓↓-↓	↓↓-↑	↓-↑	↓-↑	↓-↑	↓↓↓↓-↑↑↑↑	↓↓↓↓-↑↑↑	↓↓↓↓-↓↓↓

I. INTRODUCTION

In a time of fiscal and environmental constraints, there are increasing calls for transportation investment and policy decisions to be guided by performance-measurement criteria. In California, the Department of Transportation (Caltrans) recently issued a report that articulates performance measures necessary to achieve the state's transportation-related environmental, equity, and economic goals.[2] That report follows the September 2009 recommendations for factors to be considered in the setting of greenhouse gas (GHG) targets for regional land-use and transportation plans as required by California's Senate Bill 375 (commonly known as the Anti-Sprawl Act) and Assembly Bill 32 (the Global Warming Solutions Act).[3] These recommendations were made by the Regional Technical Advisory Committee (RTAC), a group of 21 stakeholders appointed by the California Air Resources Board (ARB). These recommendations were not limited to GHG targets but also included a broader range of potential performance measures for regional land-use and transportation plans. In the context of the Federal Transportation Bill reauthorization, the bipartisan National Transportation Policy Project (NTPP) issued a report in June 2009 which called for transportation project funding linked to measures that evaluate performance with respect to economic growth, energy, environment, and safety.[4] Versions of the reauthorized federal transportation funding bills emphasize performance measures developed through the application of consistent modeling tools.

These three reports recommend numerous performance measures and metrics that correspond to roughly consistent goals. However, it is often unclear how the different performance measures relate and how they can be applied with existing modeling tools. In this study, we first describe the basic data that are available to calculate performance metrics from current travel and land-use modeling tools. Next, we develop a framework for the performance measures recommended in the reports, based on key model input data needed to calculate their metrics. This enables us to understand how recommended measures overlap and differ. The performance-measure framework is then used to gauge implementation of and evidence from performance measures as documented in the available literature, which consists primarily of reports and publications developed by regional or state government agencies, academic researchers, and community groups. The studies included in this review report percentage change from a base to a policy alternative in the same horizon year or the results of both alternatives (typically a trend or business-as-usual). The percentage-change metric is necessary to compare results across studies. The studies include simulations, alone and in combination, of land-use, transit, and automobile pricing policies.

II. MODELS AND DATA FOR PERFORMANCE MEASURES

In this chapter, we describe models used to represent land-use and transportation systems and behavior within those systems, as well as the types and relative quality of data available from these models for use in performance measures. Models are used to estimate the likely future effects of projects and plans in regional planning documents. Agencies also collect and analyze observed data to evaluate the performance of transportation services, and these data are often used in the development of models.

The components of the land-use and transportation system forecast by models are shown in Figure 1. Population forecasts are typically generated at the county level, using demographic models that represent the interaction between population components (i.e., age, sex, ethnicity, and nativity) and fertility, death, and migration rates. Common sources for population forecasts are the U.S. Census, metropolitan planning organizations (MPOs), and, in California, the Department of Finance. Employment forecasts (e.g., by occupation and industry categories) are also typically produced at the county level and are developed in relation to population forecasts, using regional economic models. Such models typically represent interindustry relationships and growth, using input-output models and multipliers in a general equilibrium framework that balances supply and demand. Common sources for employment forecasts are firms such as Moody's and Global Insight and regional economic models such as the one provided by Regional Economic Models, Inc. (REMI) and the Transportation Economic Development Impact System (TREDIS).

The location of population and employment at a given subcounty geographic unit of analysis is typically forecast using expert consultation and community visioning tools. MPOs typically allocate population and employment through consultation with local jurisdictions and other internal analyses. The location of population and employment may be developed in consultation with community members, using visioning tools (e.g., I-Places and Community Vis). These are geo-design tools, not predictive models. Visioning tools allow participants to dictate the location and form of future development, based on citizen values; they do not include the effect of economic forces that are known to play a major role in the actual form of new development.

The locations of future development and activities are fixed inputs in expert consultation and community visioning tools forecasts. Development does not change in response to changes in transportation investment or policies (i.e., travel time and monetary cost of travel by automobile, bus, bicycle, and walking). For example, a new freeway project from downtown to a rural area may generate a demand for suburban housing developments and a shift in population location as some users trade lower rents for longer but now tolerable commute travel times. If land-use changes are not allowed to vary with changes in travel time and cost arising from new transportation policies and investments, biases may arise in the evaluation of travel benefits.

Land-use models are used to forecast the effect of economic and public policy decisions on the form of new development. These models simulate how the location and form of new development change, based on the interaction of travel costs, local economic characteristics, and relevant land-use and transportation policy and investments. More advanced land-use models simulate the actions of developers in providing built space and allocate households and employment into available space based on spatial economic forces. These forces encompass the cost of producing goods, services, labor, and space and the demand for them, by subregional locations (i.e., land-use zones, grid cells, and parcels).

Travel-demand models use the location and characteristics of population and employment and the activities they generate, along with a physical representation of the transportation system (roadways, buses, rail, sidewalks, and bike lanes), to forecast the total quantity of travel and the quality of travel (time and cost) by different methods (automobile, transit, walking, and bicycle) to and from different destinations and using certain routes. These models forecast changes in the transportation system that can then be represented in the land-use models to simulate how reductions in travel costs may impact household and employment locations.

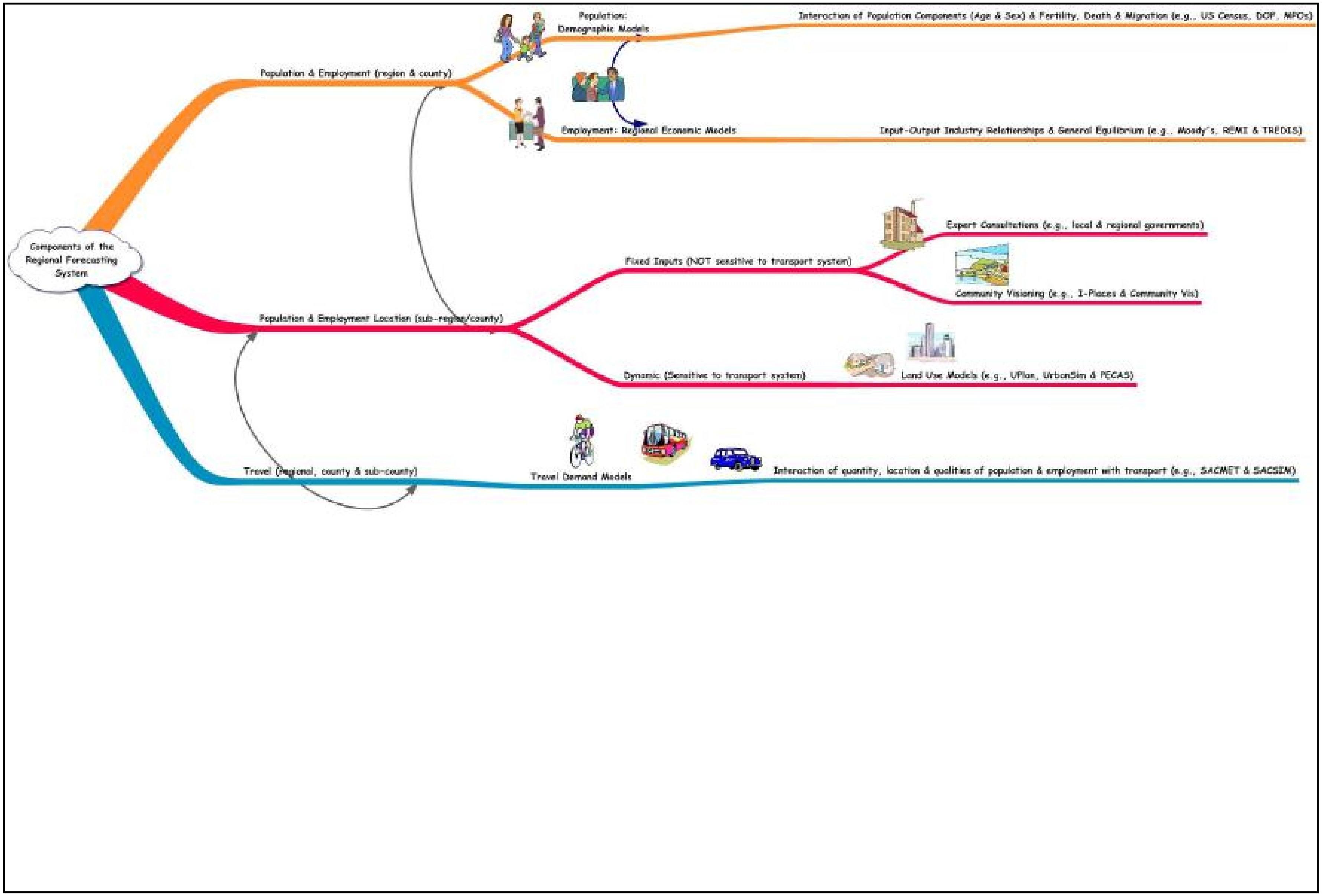

Figure 1. Components of the Regional Land-Use and Transportation System

Three types of travel-demand models (traditional four-step, advanced four-step, and activity-based microsimulation) are currently used to simulate transportation systems. The differences among these types of models and the benefits of model improvements are described below and summarized in Table 3. The range of variables that may represent the supply of transportation is shown in Table 4.

The traditional four-step travel-demand model was developed more than 50 years ago to estimate the effects of major roadway and rail projects. In the model, household and employment are categorized into geographic spatial units known as origin and destination zones. Trips that start out from these zones are categorized by purpose, according to fixed rates established from survey data. For example, if an origin zone has 100 households and each household generates 1.5 work trips per day, the origin zone generates 150 work trips per day. Next, each of these trips is "attracted" to a destination zone in direct proportion to the size of the destination zone's population and employment and in inverse proportion to its distance (including roadway/rail transit travel time) from the origin zone. Fixed adjustment factors are introduced into the model so that the estimated distribution of trips between origin and destination zones matches observed data. Then, the mode (automobile or transit) used for each trip is determined based on fixed factors or parameters that weight the relative influence of travel time and cost variables by mode, based on survey data. The supply is typically limited (as shown in Table 4). Finally, the trip will be completed on a specific road or rail line if that is the fastest route to the destination.

In the early 1990s, the four-step model framework began to be improved to address concerns about the environmental effects of new roadway projects and the potential for transit-oriented development. Improved four-step models maintain the sequential framework of the traditional four-step model; however, their theoretical and behavioral foundation is improved in one or more of the four steps. Improved four-step models maintain an aggregate framework but introduce socioeconomic attributes by employing a range of household market segments (e.g., size, income, automobile ownership, workers, children). The activities of driving behavior are also improved by expanding the categories of employment types in destination zones (e.g., office, retail, services, manufacturing, government, medical, education). The representation of transportation supply is typically enhanced by (1) adding carpooling, bus transit, walking, and bicycle mode choices and the necessary physical description (or network and land-use variable) to support their representation; (2) using smaller zones to improve estimation of the travel time and cost of travel by different modes to different destinations; and (3) expanding the time-of-day segmentation (morning peak, off-peak, and afternoon peak). In general, the travel time and cost of travel are represented consistently throughout the hierarchy of the model. The relative importance of time and cost attributes of choice alternatives is estimated from surveys and is included in the mathematical structure of the model.

Recently, the requirements of federal transit funding and global-warming legislation (e.g., California's AB 32 and SB 375) have spurred the development of activity-based models (ABMs) of travel demand that are significantly more sensitive to a broad range of policies that influence travel demand. ABMs are characterized by their use of a disaggregate framework that enables a more complete and consistent representation of microeconomic theory throughout the model system. The probability of an individual traveler selecting a given alternative is a function of his or her socioeconomic characteristics and the relative attractiveness of the alternative. All individuals and their socioeconomic characteristics for the study area are generated through a statistical process known as a synthetic population, which typically expands the U.S. Census sample of households in a manner that represents the entire population. The description of activity destinations is expanded to include more-detailed industry and occupation categories. Microsimulation is the mathematical technique used to track individuals, their characteristics, their activities, and the attributes of alternatives as experienced by unique individuals. Activities or day patterns driving individuals' need to make travel-related choices are based on surveys. Tours are the unit of analysis in a day pattern. A tour represents a closed or half-closed chain of trips starting and ending at home or at the workplace and includes at least one destination and at least two successive trips. A tour represents the traveler's choice to engage in a specific activity, when to travel, where to travel, with whom to travel, and what mode to use. The description of transportation supply is typically good, i.e., small zones and detailed networks describe the full range of available modes (see Table 4). Specific routes of travel by mode are selected by separate time periods representing a full 24-hour day, usually by using static assignment methods along with dynamic assignment processes.

Post-processors, based on elasticities taken from the literature, can be used with outputs from travel-demand models to enhance their representation of land-use policies such as transit-oriented development, mixed use, and smart-growth land-use. ABMs with high-quality presentation of transportation supply should be able to simulate the effects of these policies without the use of post-processors. This is preferred, because the use of post-processors with travel-demand models runs the risk of double counting travel benefits resulting from land-use policies.

It is important to note that the above discussion of travel models assumes the use of consistent travel times throughout the modeling process. The model starts with posted speed-limit travel times and is then run with consecutive iterations until the travel times experienced by travelers on roads and transit are consistent with those used by travelers to make decisions about whether to travel, when to travel, where to travel, and how to travel. If travel times are not consistent, analyses of transportation and land-use policies may be biased. Documentation of analyses of transportation and land-use policies must demonstrate the use of consistent travel times in the model run(s) producing travel results.

Table 3. Description of Travel-Demand Models and Benefits of Improvements

Model Type	Limited Traditional Four Step	Enhanced Four Step	Advanced Activity Based Model	Benefits from Model Improvements
Input				
Population	1–2 household types (e.g., multifamily and single-family)	3–6 household types (e.g., household size, workers, automobile ownership, income, and children)	Individual census attributes (e.g., household composition/life cycle, age, sex, employment by occupation type, school enrollment, automobile access, and race/ethnicity)	More-detailed information about household and employment allows for better understanding and predictions of the activities that drive travel behavior and perceptions of alternatives.
Employment	1–2 employment types (e.g., retail and non-retail)	3–6 employment types (e.g., retail, office, medical, education, government, and industry)	6+ (e.g., NAICS and SOC codes)	
Framework	Aggregate	Aggregate	Disaggregate	Avoids ecological fallacy (behavior observed at the population level is incorrectly assumed to apply at the individual level) and improves policy sensitivity.
Unit of analysis	Trip	Trip	Tour	Explicitly incorporates motivation for traveling (i.e., activity at the end of the trip and places for leisure, work, shopping); tours address spatial, temporal, and social interactions; better able to simulate non-home-based travel.
Microeconomic theory: travel time and cost influence	**Limited**	**Enhanced**	**Good**	Avoids underestimating VMT and congestion from roadway projects and overestimating VMT and congestion from transit, pedestrian, bicycle, and land-use intensification projects.
Travel destination	No	Yes	Yes	
Mode choice	No	Yes	Yes	
Route choice	Yes	Yes	Yes	
Trip making	No	Somewhat	Yes	
Land-use	No	If integrated with land-use model	If integrated with land-use model	

NOTE: NAICS = North American Industry Classification System; SOC = Standard Occupational Classification.

Table 4. Transportation Supply and Benefits of Improvements (x = somewhat)

	Limited	Enhanced	Advanced	Benefits of Model Improvements
Modes				
Auto	X	X	X	
Carpool	X	X	X	
Trucks		X	X	
Heavy rail	X	X	X	Tests policies that affect modes (e.g., investment and land-use patterns) and thus the effect of mode shifts on travel and congestion.
Light rail		X	X	
Bus		X	X	
Walk		X	X	
Bicycle		X	X	
Network				
Freeways and highways	X	X	X	
HOV/HOT lanes		X	X	
Major arterials	X	X	X	
Minor arterials		X	X	
Collectors		X	X	
Heavy rail	X	X	X	Improves the quality of travel time and cost that influence the choice to use of a specific mode and thus provides more-accurate estimates of policies' effects on travel and congestion.
Light rail		X	X	
Bus		X	X	
Bike lanes			X	
Sidewalks			X	
Parking supply		X	X	
Parking charges		X	X	
Roadway tolls		X	X	
Space: Size of zone				
Large	X			
Medium		X		Improves the quality of travel time and policy effects on travel.
Small			X	
Time				
24 hours	X			
Peak and off-peak	X	X		Improves the quality of travel time and policy effects on travel.
Peak, mid-day, and off-peak		X	X	
Hourly or less			X	

NOTE: HOV = high-occupancy vehicle; HOT = high-occupancy toll.

III. COMPARATIVE FRAMEWORK FOR PERFORMANCE MEASURES

In this chapter, we develop a framework that groups the performance measures recommended in the Caltrans *Smart Mobility 2010* report,[5] those recommended by the RTAC for SB 375 and AB 32,[6] and those recommended by the NTPP[7] by subject area and by model data needed to calculate the measure. These reports were among the most comprehensive and influential in the performance-based planning debate at both the state and national level at the time this study was being conducted. Table 5 groups performance measures from the three reports into types within each of four subject areas—travel, equity, economic, and environment—based on the specific model data necessary to calculate them. The performance measures and the data required for them are shown in the first column, along with the names of measures in the reports within each specific performance-measure type. The performance-metrics column describes the common model data in more detail and provides some description, when feasible, of calculations that are likely to be necessary to operationalize the measures.

Five performance measures for travel are shown in Table 5. The first, access, is defined by travel time and cost, which should be available from a travel model for all trips/tours, times of day, origin and destination locations, trip purposes, and modes. The metrics recommended by the three data sources use some combination of these variables. Caltrans proposes a performance measure that includes both travel time and cost for all trips, destinations, and modes. The RTAC proposes measures that differ from the Caltrans measure in that travel time and cost are broken out separately. The RTAC recommends an additional measure that looks at travel time and cost by transit mode only. The NTPP's performance measures differ from Caltrans' in that travel time and cost are broken out by trip purpose and time of day (i.e., access to jobs and labor and non-work activities by peak and non-peak periods).

The second performance measure is access/criteria, which adds other criteria to travel time and cost. The criteria, which represent normative goals or boundaries for acceptable travel times by different modes from residential locations to key destinations or activities, are developed by policymakers and planners and are not calculated by a model. The metrics are often expressed in terms of total households within reach of key activities or destinations. For example, a household should be able to access certain destinations (e.g., work, school, health-care facilities, grocery stores, recreation activities) by certain modes in less than some fixed time (e.g., 30 minutes by car) or cost (e.g., $2 by transit). All three reports recommend similar measures, but they differ in their consideration of destination activities, time of day, and modes. The NTPP's measure differs from the other two by going beyond households and including access of goods to destinations.

Table 5. Performance Measures and Metrics

	Performance Measure	Performance Metrics
Travel	**Access: travel time and cost**[8] • Multimodal travel mobility[9] • Reduce travel time and/or cost[10] • Access to jobs, labor, and non-work activities[11]	Travel time and/or cost for OD travel pairs summed by mode or over all modes, area (e.g., corridor, subarea, region), time of day (e.g., peak and off-peak), and/or trip purpose/activity destination (e.g., work, school, shop)
Travel	**Access/criteria: travel time < criteria** • Accessibility and connectivity[12] • Access to nutritious foods and health care[13] • Network utility[14]	Households (and/or goods) with travel time < criteria (e.g., 30 minutes) from home to activity destination summed by mode or over all modes, area type, and/or time period
Travel	**Proximity: density and diversity** • Support for sustainable growth[15] • Redevelopment, infill, and jobs-housing balance[16]	Quantity of land consumed; redevelopment and/or infill summed by type, area, and/or location; total jobs divided by total households within specific area
Travel	**Choice: mode share** • Transit, walk, and bicycle mode share[17]	Percentage of transit, pedestrian, and bicycle trips of all trips in study area
Travel	**Congestion: vehicle speed and distance** • Congestion effects on productivity[18] • Network performance optimization[19] • Congestion relief[20] • Corridor congestion[21]	VHD by designated transportation corridor, essential trip purposes or key economic destinations, person, roadway lane miles, VMT, freight miles, transit revenue miles, and/or total for region
Equity	**Access: travel time and cost by socioeconomics** • Equitable distribution of impacts, access, and mobility[22]	Households/individuals' travel time and/or cost from home to activity destination by socioeconomic attributes summed by mode or over all modes, area type, and/or time period
Equity	**Spatial: spatial distribution by socioeconomics** • Economic and racial segregation[23]	Spatial dispersion of clusters of socioeconomic groups
Equity	**Housing: distribution by socioeconomics** • Displacement and gentrification[24]	Home location by socioeconomic groups attributed to rent increase

Economic	**Housing/cost: cost to rent/own by type** • Affordable housing[25]	Rent/own cost: total, by housing type and/or by location
	Housing/supply: supply by type • Housing supply[26]	Quantity of housing units summed: total by type and/or by location
	Financial/land-use: built form • Reduced city service and infrastructure costs[27]	Input to service cost, tax, and/or infrastructure cost model
	Financial/cost-effective: capital, operation, and maintenance costs/ performance criteria • Return on investment[28]	Cost to meet performance criteria; person-miles and revenue per dollar invested in modal infrastructure (public and private)
	Consumer and producer surplus • Efficient use of system resources[29] • Increased productivity[30]	Spatial economic effects (producer and consumer surplus) of land-use policies and transportation investment
Environment	**Energy: vehicle activity** • Energy conservation[31] • Reduced fuel use[32]	Input fuel-use models
	Air/climate: vehicle activity • Climate conservation[33] • Meet GHG targets[34] • CO_2 emissions[35]	Input emissions models; VMT/capital by speed range meets GHG target
	Air/quality: vehicle activity • Emissions/air-pollution reduction[36]	Input to emissions models
	Noise: residential location and vehicle facilities • Noise, vibration, and aesthetics[37]	Input to noise models
	Land: land consumption • Conservation open space, farmland, and forest[38]	Quantity of land consumed: total by type and/or by location
	Habitat and ecosystems: land consumption • Preservation/enhancement of habitat[39]	Quantity of land consumed: total by type and/or by location; input to habitat and ecosystem model
	Water: land consumption • Water quality and supply[40] • Impervious surface area[41]	Acres of land consumed by type and location; input to water model

NOTE: OD = origin and destination; VHD = vehicle hours of delay.

The third measure, proximity, is defined by density and diversity variables. The RTAC's recommendations specify two separate measures: (1) redevelopment and infill and (2) jobs and housing balance. Both of these measures can be obtained from land-use data entered into the travel model from either fixed estimates or modeled projections, as discussed in Chapter 2. Caltrans specifies a more general measure, “support for sustainable growth,” which evaluates the quantity of undeveloped land consumed for future development purposes.

Choice, the fourth measure, refers to the traveler’s decision to travel by one of many available modes, based on the quality of those modes and the preferences of the traveler. The focus of the Caltrans and RTAC recommendations is travel by transit, walk, and bicycle modes. Larger shares among these modes may lead to less congestion, reduced environmental impacts, increased access of lower-income households to jobs and services, and improved physical health.

The fifth measure, congestion, includes vehicle speed and distance variables. All of these measures include VHD. Caltrans specifies performance measures that emphasize economically essential trip purposes and destinations and categorizes VHD by region, person, and vehicle facility types, while the NTPP focuses on VHD within a specific transportation corridor.

Performance measures are suggested for equity evaluations of transportation investment, plans, and policies. Caltrans recommends an equity measure that specifies access (travel time and costs) by different socioeconomic groups. The RTAC recommends two measures: The first is related to the spatial separation of clusters of socioeconomic groups (or segregation), and the second is related to increased rents in areas that formerly provided affordable housing for lower-income households and the resulting movement of households out of those areas. Both measures require land-use models that simulate the effects of the transportation system on household rents and include detailed socioeconomic attributes of households.

Both Caltrans and the RTAC recommend performance measures and metrics for the economic impacts of transportation plans beyond change in travel time and costs. The RTAC calls for performance measures related to the supply and cost of housing. Such measures would, ideally, use a spatial economic model to estimate change in the cost and supply of housing; however, assumptions about changes in housing unit types (e.g., single-family vs. multifamily) could also be used for such analysis. The RTAC also recommends performance measures that look at the infrastructure, service, and taxpayer costs of land-development patterns. This requires using output from land-use models or assumptions about future land-use patterns of development in service and infrastructure cost models. Caltrans calls for cost-effectiveness analyses of transportation investments in the form of return-on-investment calculations. Such metrics require capital and operation and maintenance (O&M) costs of transportation investments and traveler use and revenue outputs from the travel model. Both Caltrans and the RTAC suggest consumer and producer surplus measures that can be obtained only from advanced land-use models that represent the spatial economic system of an area.

The performance measures for the environmental impacts of transportation investments and policies include energy, air/climate, air quality, noise, land, habitat and ecosystems, and water. All of these measures use data available from travel and land-use models as input into environmental models of specific impacts or for integration into other databases. Energy, air/climate, and air quality all use vehicle-activity data (e.g., vehicle speeds, volumes, and distance by facility type and geographic location) as inputs to impact models. The measure for energy is fuel/petroleum use; the measure for air/climate is CO_2 and GHGs; the measures for VMT and air quality are criteria pollutants. The land, habitat and ecosystems, and water categories all use land consumption by type and by location, which can be forecast by a land-use model, prescribed from a visioning process, or forecast based on local knowledge and plans. Again, these data are entered into the travel model. Measurement of land preservation on sensitive lands, as well as input land-consumption data, can be used in these analyses. Land-consumption data are used in water models and habitat and ecosystem models to measure these impacts. Noise impacts also require a model that uses vehicle activity and facility-location types as well as residential-location data.

IV. IMPLEMENTATION OF PERFORMANCE MEASURES

In this chapter, we use the performance-measure framework developed in Chapter 3 to survey the types of performance measures implemented in the literature reviewed for this study.

BACKGROUND

The U.S. regional visioning studies reviewed here present the results of participatory planning processes, typically sponsored by a region's MPO and/or non-profit organizations and aimed at developing a common land-use and transport vision. As noted earlier, these studies typically include a wide range of travel, environment, and economic performance measures.

In California, the Sacramento Area Council of Governments (SACOG) pioneered "Blueprint" planning in California.[42] Following SACOG's example, with support from Caltrans, the Metropolitan Transportation Commission (MTC), the Southern California Association of Governments (SCAG), the San Diego Association of Governments (SANDAG), and the San Joaquin Valley developed regional visioning scenarios.[43] All four major MPOs included their land-use strategy in official regional transportation planning documents. SACOG was allowed by the U.S. Environmental Protection Agency (EPA) to use its land-use plan in its official alternative regional transportation plan as part of its air-quality conformity process. The other MPOs include the visioning scenarios as unofficial alternatives. SACOG, SCAG, SANDAG, and the San Joaquin Valley have visioning documents that are separate from their Metropolitan Transportation Plans (MTPs), and because they typically include a broader range of performance measures, they are included in the U.S. regional visioning studies section of the synthesis table. The SACOG visioning study uses a travel model and a land-use model.

Outside of California, visioning studies with a range of land-use, travel, and visioning tools have been conducted in Austin, Salt Lake City, Chicago, Baltimore, the Twin Cities, Atlanta, Portland, Philadelphia, and Orlando.[44]

Other studies—primarily academic and/or international studies which we term "advanced" in this report—typically develop more-specialized performance measures from travel demand models, activity-based travel models, land-use models, and/or advanced land-use models. Deakin et al. used an ABM (the STEP model) to simulate a common set of policies in the San Francisco, Los Angeles, Sacramento, and San Diego regions.[45] Rodier et al. and Johnston et al. conducted a series of simulation studies using the Sacramento region's travel-demand model with a land-use model.[46] Later, Rodier et al. used SACOG's ABM and an advanced land-use model (the Production, Exchange, and Consumption Allocation System, PECAS) to evaluate the region's "Blueprint" plan.[47] San Francisco used an ABM to simulate equity effects of transportation plans.[48] In Washington, DC, Nelson et al. and Safirova et al. used a land-use model and a travel-demand model to explore the outcomes of a range of scenarios.[49] Finally, several studies simulated consistent sets of policy scenarios across European Union (EU) regions, using land-use models and/or travel-demand models.[50]

TRAVEL PERFORMANCE MEASURES

For the access measure described in Chapter 3, the performance measure most commonly used by California MTPs is travel time by trip purpose and time of day, followed by total or average travel time, then travel cost (see Table 6). Regional visioning and advanced studies use access performance measures that are relatively consistent with those used for California MTPs, with the exception of generalized travel time and cost, which is used most frequently in the advanced studies.

The access/criteria category, defined by travel time relative to normative criteria, is rarely used. Only San Diego, San Francisco, and one United Kingdom (UK) region simulate a performance measure of travel time by mode by destination type.[51]

The proximity category, which includes density and diversity variables, is simulated most frequently by regional visioning studies and less frequently by California MTPs and advanced studies. The predominant performance measures are jobs/housing balance, distribution of housing and employment, redevelopment and infill density, and residential density.

In the choice category, most studies provide shares for all modes of transit and/or walk modes. All California MTPs include the choice/capacity performance measure of transit service, and San Diego also includes walk access to transit.[52] Visioning studies are more likely than model forecasts to include a performance measure for the quality of the pedestrian infrastructure. The SACOG visioning study includes all three.[53] The choice/capacity category is included in Table 6 based on the number of studies that use it.

Virtually all of the studies in the congestion category include an aggregate measure of VHD. The California MTPs examine congestion more carefully than visioning and advanced studies do by evaluating it by time of day, roadway, and trip purpose.

Table 6. Synthesis of Travel Performance Measures

		California MTPs						U.S. Regional Visioning Studies										Advanced Studies										
																		TDM		ABM		ALUM and TDM						ALUM and ABM
Criteria: Variables	**Performance Measure**	Los Angeles[54]	San Francisco[55]	San Diego[56]	Sacramento[57]	Los Angeles[58]	Sacramento[59]	San Joaquin[60]	Austin[61]	Salt Lake City[62]	Chicago[63]	Baltimore[64]	Twin Cities[65]	Atlanta[66]	Portland[67]	Philadelphia[68]	Orlando[69]	Sacramento[70]	Washington, DC[71]	CA Regions[72]	San Francisco[73]	Sacramento[74]	Washington, DC[75]	UK Regions[76]	UK Regions[77]	EU Regions[78]	EU Regions[79]	Sacramento[80]
Access: travel time and cost	Time			•		•	•		•	•	•						•	•	•	•	•				•	•	•	
	Time by mode								•		•			•							•					•		
	Time by trip purpose		•	•		•			•					•												•		
	Time by time of day	•		•					•													•	•					
	Time to destinations by type																									•		
	Cost			•										•											•		•	•
	Time (value) and cost															•		•	•			•	•		•	•		•
	Time/cost to destinations by type																									•	•	
Access/ criteria: travel time < criteria	Time by modes to destinations by type			•																	•			•				
Proximity: density and diversity	Jobs/housing balance				•	•	•		•		•	•					•											•
	Redevelopment and infill density						•		•	•	•	•		•			•											
	Residential density				•			•	•	•	•		•															•
	Jobs and population distribution		•		•	•			•				•			•		•				•				•	•	•
Choice: mode share	Auto		•	•	•	•	•		•		•				•			•	•			•				•	•	
	Transit service		•	•	•	•	•		•	•	•			•			•	•			•	•				•	•	
	Walk		•	•	•	•	•		•		•							•				•				•	•	
	Bicycle		•	•	•	•	•		•									•				•				•	•	
Choice capacity: network supply	Walk access to transit			•			•			•							•											
	Pedestrian infrastructure						•		•						•													
	Transit service	•	•	•	•	•	•			•					•		•	•										
	VHD	•	•	•	•	•	•		•		•				•	•	•	•	•	•						•		
Congestion: speed and distance	Daily vehicle speed	•	•													•		•										
	Vehicle speed by time of day									•						•	•		•			•	•					
	Vehicle speed by roadway															•												
	Vehicle speed/VHD by mode		•													•												
	Speed/VHD by mode by trip purpose			•																								

NOTE: LUM = land-use model, ALUM = advanced land-use model; TDM = travel demand model; ABM = activity-based model.

EQUITY PERFORMANCE MEASURES

The studies examined for this synthesis include a broader range of measures than those recommended by Caltrans, the RTAC, and the NTPP (access, spatial distribution, and housing). In Table 7 the equity performance measures include to the use of the transportation system, travel time relative to criteria, modal use and availability, emissions and noise exposure, and plan expenditure. However, very few studies use the same performance measures. Travel time and cost by income group are the most commonly used performance measures, followed by cost by income group and segregation. California MPOs and advanced studies were more likely to than other studies to develop equity performance measures. Studies that did not include equity measures are not included in Table 7.

Table 7. Synthesis of Equity Performance Measures

		California MTPs				U.S. Regional Visioning Studies					Advanced Studies			
											ABM	LUM and TDM		ALUM and ABM
Category: Variables	**Performance Measure**	Los Angeles[81]	San Francisco[82]	San Diego[83]	Sacramento[84]	Austin[85]	Portland[86]	Philadelphia[87]	CA Regions[88]	San Francisco[89]	Sacramento[90]	Washington, DC[91]	EU Regions[92]	Sacramento[93]
Access: travel time and cost by socioeconomic attributes	Travel time (value) and costs by income			•	•					•	•	•		
	Cost by income	•	•	•					•			•		
	Cost by race			•										
	Travel cost by trip purpose by income and race			•										
	All modal and transit time by vehicle access, income, gender, gender of head of and child(ren) in household, single or non-single head of household									•				
Spatial: spatial distribution by sociodemographic attributes	Segregation			•		•							•	
Housing: supply and rent by socioeconomic attributes	Housing units by type and rents paid by income													•
Use: vehicle activity by sociodemographic attributes	VMT by income, gender and/or race								•					
Criteria: travel time less than criteria by sociodemographic attributes	Employment access by mode and income	•												
	Access to parks by mode and income	•	•											
	Job and shopping access by auto and transit access, income, gender, gender of head of and child(ren) in household, single or non-single head of household							•		•				
Choice: mode share by socioeconomic attributes	Mode share by income and race													
Choice/capacity: network supply	Walk to transit by income and race			•	•		•							
Environment: exposure by socioeconomic attributes	Emissions	•											•	
	Noise	•											•	
Financial: distribution of expenditures	Distribution of plan expenditures by income and race	•	•											

ECONOMIC PERFORMANCE MEASURES

The studies shown in Table 8 include most of the economic performance measures recommended by Caltrans, the RTAC, and the NTPP. However, most of them separate capital and O&M costs and revenues from cost-effectiveness performance measures. In fact, capital and O&M costs are the most commonly used economic performance metrics across the studies. A transportation externalities performance measure is added by an EU regions study.[94] The supply of housing, including its mix, is the second most commonly used measure, and it is most likely to be used in visioning studies. Revenues are the third most common measure. Consumer surplus measures are used in four studies with land-use models.[95] Producer surplus is included in the one study that uses an advanced land-use model.[96] Housing affordability and development infrastructure costs are also included in several studies' performance measures.[97] One study includes sales and property tax as a performance measure.[98]

Table 8. Synthesis of Economic Performance Measures

		California MTPs				U.S. Regional Visioning Studies											Advanced Studies						
																	TDM	ABM	LUM and TDM				ALUM and ABM
Category: Variables	**Performance Measure**	Los Angeles[99]	San Francisco[100]	San Diego[101]	Sacramento[102]	Los Angeles[103]	Sacramento[104]	San Joaquin[105]	Austin[106]	Salt Lake City[107]	Chicago[108]	Baltimore[109]	Twin Cities[110]	Atlanta[111]	Portland[112]	Philadelphia[113]	Washington, DC[114]	CA Regions[115]	Washington, DC[116]	UK Regions[117]	EU Regions[118]	EU Regions[119]	Sacramento[120]
Housing/cost: cost to rent/own by type of unit	Affordability																						•
Housing/supply: supply by type of unit	Housing mix				•	•	•	•	•	•	•	•	•										•
Financial/transport supply: transport supply cost and O&M cost	Transport capital and O&M costs	•	•	•	•		•		•	•	•			•	•					•	•		
Financial/transport revenues: transport revenues	Revenues	•															•	•	•	•	•	•	
Financial/cost effective: capital and operations and maintenance cost against performance	Cost-effectiveness	•	•																				
Financial/land-use: built form	Development infrastructure costs								•	•			•			•							
	Regional sales and/or property tax								•														
Economic/surplus: consumer and producer surplus	Consumer surplus																		•	•		•	•
	Producer surplus																			•			•
Economic/externalities: transport externalities	Total externalities																					•	
	Accidents costs															•					•		
	Emissions costs																				•		
	GHG costs																				•		
	Noise costs																				•		

ENVIRONMENTAL PERFORMANCE MEASURES

As shown in Table 9, for the energy category, three of the four California MTPs include fuel consumption as a performance measure.[121] Fuel consumption is also included in the Sacramento, Austin, Portland, Philadelphia, and Orlando visioning studies and the California and EU regions studies.[122] VMT is the most frequently used measure for the air/climate category, followed by CO_2. Not surprisingly, in the air-quality category, emissions (criteria pollutants in the United States) are used in most of the MTPs and visioning studies and in a few of the advanced studies. The air/exposure category is added to the list of environmental performance measures in Table 9, because two studies, one in Salt Lake City and one in the EU, use measures that examine the number of people exposed to air pollutants.[123] Visioning studies take the most in-depth look at how future development affects the availability of different types of land (i.e., agriculture, farms, urban parks, ranch, sensitive land, habitat lands). Habitat, ecosystems, and water criteria are most likely to be examined by those looking at the type of land consumed by development, who do not tend to use environmental models.

Table 9. Synthesis of Environmental Performance Measures

		California MTPs					U.S. Regional Visioning Studies											Advanced Studies						
																		TDM		ABM	LUM and TDM			
Category: Variables	**Performance Measure**	Los Angeles[124]	San Francisco[125]	San Diego[126]	Sacramento[127]	Los Angeles[128]	Sacramento[129]	San Joaquin[130]	Austin[131]	Salt Lake City[132]	Chicago[133]	Baltimore[134]	Twin Cities[135]	Atlanta[136]	Portland[137]	Philadelphia[138]	Orlando[139]	Sacramento[140]	Washington, DC[141]	CA Regions[142]	Sacramento[143]	UK Regions[144]	EU Regions[145]	EU Regions[146]
Energy: vehicle activity	Transport fuel		•	•	•		•		•						•	•	•			•			•	•
Air/climate: vehicle activity	CO_2		•		•		•	•					•		•	•				•		•	•	•
	Vehicle miles traveled		•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•		•	•
Air/quality: vehicle activity	Emissions by type	•	•	•			•	•	•	•	•		•	•	•	•	•	•		•	•		•	•
Air/exposure: vehicle activity	Emissions by type								•														•	
Land: land consumption by type by location	Undeveloped land		•	•			•	•	•	•	•	•	•	•		•		•			•		•	•
	Agricultural						•	•	•	•	•		•			•								
	Urban parks						•		•				•											
	Ranchland								•															
	Sensitive land							•	•		•		•			•								
	Habitat preservation														•									
	Open space (quality, fragmentation)																						•	•
Water: land consumption by type by location	Supply						•	•		•						•								
	Quality								•				•											

V. EVIDENCE FOR PERFORMANCE MEASURES

In this chapter, the relative magnitude and direction of change of the performance measures for different types of policies are summarized. For travel, environmental, and equity measures, the effect is percentage change from the base to the alternative scenario by policy type. For economic measures, the effect is measured in per capita 2000 U.S. dollars.

POLICIES

For each policy type, we identify the studies included in the analysis, the location of the studies, and the type of model used (see Table 10). To generalize, study results are categorized by area type, defined by population size, and transit commute mode share. A region with a population of 7 million or more is categorized as large; a region with between 1 million and 7 million is medium; and a region with less than 1 million is small. Regions with transit commute mode share greater than or equal to 10% are categorized as having high-quality transit, and those with mode share less than 10% have moderate- to low-quality transit.

Box plots of the percentage change in the input policy variable (relative to the base case) by policy type are presented in Figure 2. The figure shows the frequency distribution of change for each policy type. Note that only single-policy scenarios are included, with the exception of land-use and transit policies, which show percentage change in density only.

A number of studies, including the San Francisco region's MTP and studies in Sacramento, San Francisco, the UK, and EU regions,[147] simulate *transit-only* scenarios. Transit service is significantly increased in Sacramento by expanding light rail lines and in the San Francisco region by expanding rail and ferry. In the UK regions, fares are reduced by 30% to 60%, in-vehicle transit speed is reduced by 10%, and transit frequencies are increased by 20%. In the EU regions, transit speeds and service are improved by 1% and 5%.

Table 10. Summary of Studies Reviewed by Source, Study Area, Model Type, and Policy Type

Size/Transit	Region	Model[a]	Policy Type[b]
Large/ high	Chicago, Illinois	LU(CRIEM/GIS) + TDM[148]	LUT
	Yorkshire County, UK	LU(DELTA) + TDM[149]	T, CP, GP, PT
	UK	LU(DELTA) + TDM(START)[150]	T, PT
	Washington, DC	LU(LUSTRE) + TDM(START)[151]	LU, CP, GP, VP
		TDM(START)[152]	FP
	Philadelphia, Pennsylvania	TDM(DVRPC)[153]	LU
	San Francisco, California	TDM(STEP)[154]	PP, GP, VP, FP, EP, P
		TDM(MTC)[155]	T, LU, LUTR, P, PT, PTLU
		ABM[156]	TR
Large/ moderate	San Diego, California	TDM(STEP)[157]	PP, GP, VP, FP, EP, P
		TDM(SANDAG)[158]	LUTR
	Los Angeles, California	TDM(STEP)[159]	PP, GP, VP, FP, EP, P
		TDM(SCAG)[160]	LUTR
Medium/ high	Brussels, Belgium	LU/TDM(TRANUS)[161]	T, LU, CP, PP, VP, PT, PTLU
	Naples, Italy	LU/TDM(MEPLAN)[162]	T, LU, CP, PP, VP, PT, PTLU
	Dortmund, Germany	LU/TDM(IRPUD)[163]	T, LU, CP, PP, VP, PT, PTLU
		LU/TDM(Dortmund)[164]	PT, PTLU
	Bilbao, Spain	LU/TDM(MEPLAN)[165]	T, LU, CP, PP, VP, PT, PTLU
Medium/ moderate	Austin, Texas	TDM[166]	LUT, PT
		LU + TDM[167]	LU, P
	Salt Lake City, Utah	ALU(UrbanSIM) + TDM[168]	LUT
	Sacramento, California	TDM(STEP)[169]	PP, GP, VP, FP, EP, P
		LU/TDM(MEPLAN)[170]	T, LUT, VP, PT, PTLU
		TDM(SACMET)[171]	T, LUT, P, PTLU
		LU(MEPLAN) + TDM(SACMET)[172]	T, LUT, VP, P, PT, PTLU
		ALU(PECAS) + ABM(SACSIM)[173]	LUT
		LU(MEPLAN) + TDM(SACMET)[174]	LUT
		ABM(SACSIM)[175]	LUT
	Twin Cities, Minnesota	TDM[176]	LUT
	Portland, Oregon	TDM(METRO)[177]	LUT
	Baltimore, Maryland	TDM(BMC)[178]	LU, LUT
	Orlando, Florida	TDM[179]	LU
	Atlanta, Georgia	TDM(ARC)[180]	LUT
Small/ high	Helsinki, Finland	LU/TDM(MEPLAN)[181]	T, LU, CP, PP, VP, PT, PTLU
	Edinburgh, UK	LU(LUTI) + TDM[182]	PT, PTLU
Small/ moderate	Vicenza, Italy	LU/TDM(MEPLAN)[183]	T, LU, CP, PP, VP, PT, PTLU
Small/poor	San Joaquin, California	LU(Uplan) + TDM[184]	LUT

[a] LU/TDM = Integrated land-use and travel model.
[b] T = transit only; LU = land-use only; LUT = land-use and transit; CP = cordon pricing; PP = parking pricing; GP = congestion pricing; VP = VMT pricing; FP = fuel pricing; EP = emissions pricing; P = combined pricing; PT = combined pricing and transit; PTLU = combined pricing, transit, and land-use.

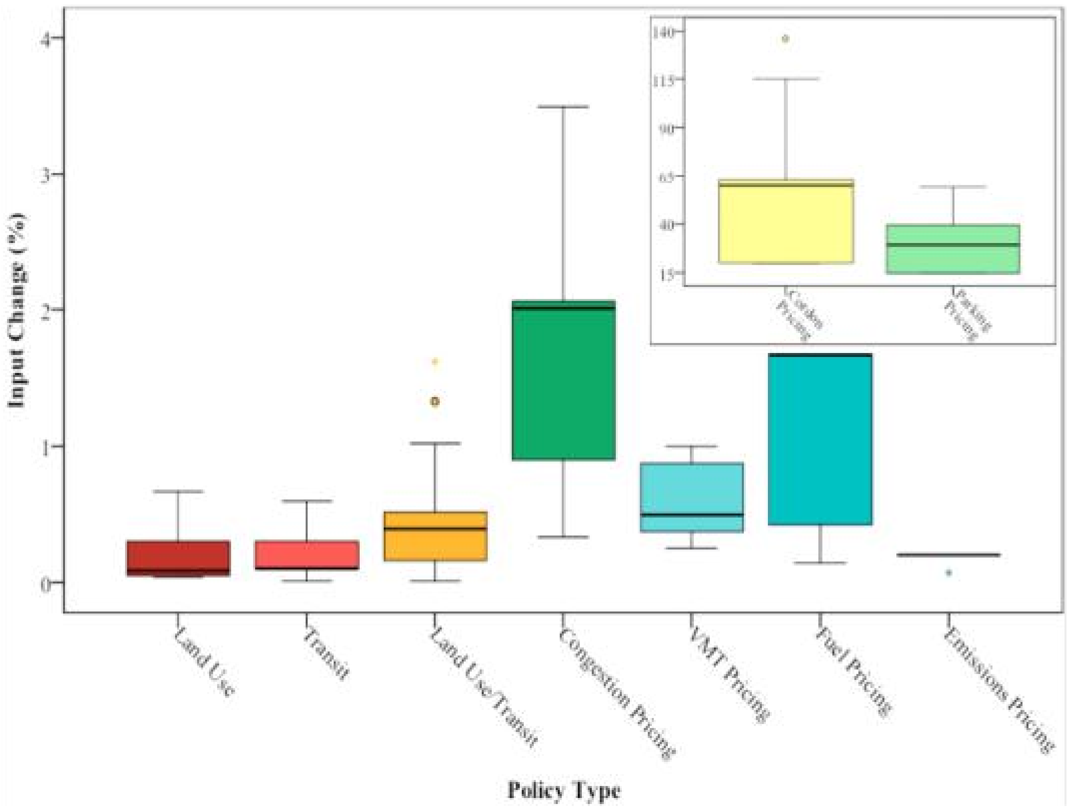

Figure 2. Box Plot of Percentage Change in Policy Variable by Policy Type[185] (N = 151)

Studies that examine the performance-intensified *land-use* patterns *only* (e.g., redevelopment, infill, and/or jobs-housing balance) include San Francisco's MTP; visioning studies in Baltimore, Orlando, and Philadelphia; and advanced studies in Washington, DC, Austin, and EU regions.[186] Most of the studies allow for a comparison of the magnitude of input land-use change, using density figures. The median percentage increase in density (N = 8) is 5%; the high is 11% in Philadelphia, and the low is 1% in San Francisco. The San Francisco scenario also includes an assumption of reduced long-distance in-commuting from the Central Valley because of a larger supply of low-income housing in the city.

Many of the MTPs and visioning studies explore scenarios that include both *land-use and transit policies*. The MTPs that examine these policies are conducted in Los Angeles, San Francisco, San Diego, Sacramento, Atlanta, and Portland.[187] Visioning studies are conducted in Los Angeles, Sacramento, the San Joaquin Valley, Austin, Salt Lake City, Chicago, Baltimore, and the Twin Cities.[188] Advanced studies based in Sacramento use a variety of models.[189] Again, the available studies for this policy type most commonly allow comparison of the magnitude of input land-use change, using density figures, which increase from 1% in Sacramento to 162% in the Twin Cities, with a median 30% (N = 11). Values from MTPs and other studies are lower, while values from visioning studies are all at or above the median, with a range of 30% to 64%.

Cordon pricing policies charge a toll on highways leading to central business districts (CBDs) during peak commuting hours. Studies on cordon pricing are conducted in Washington, DC, and regions in the UK and EU.[190] Cordon charges range from $2.84 to

$5.80 in Washington, DC; £0.85 to £2.34 in the UK; and values corresponding to 20 to 60 minutes of time value in the EU regions.

Parking pricing policies increase parking fees, usually in CBDs. Studies on parking pricing policies were conducted in California and EU regions.[191] The California region studies test parking-fee scenarios that include minimums of $1.00 and $3.00, while the scenarios in EU regions set parking prices corresponding to 20 to 60 minutes of time value.

Congestion pricing policies set fees high enough on highways to eliminate congestion. Results for congestion pricing are available from studies in California, Washington, DC, and the UK.[192] Scenarios in California set toll prices from 9¢/mile to 19¢/mile; prices in Washington, DC, range from 0.67¢/mile to 9.3¢/mile; and prices in the UK range up to 142 pence/km. Percentage change in inputs ranges from 33% to 349%.

VMT pricing policies increase the per-mile cost of vehicle travel on all roads throughout the day and night. Studies of VMT pricing policies include the California region scenarios (2¢/mile fee), Sacramento scenarios (1.25¢/mile to 5¢/mile fees), and Washington, DC, scenarios (9¢/mile to 14.59¢/mile fees).[193] Scenarios in EU regions increase per-mile car operating costs by 25% to 100%.[194]

Fuel pricing, like VMT pricing, increases the price of vehicle travel but allows the price to vary inversely with the vehicle's fuel efficiency. Studies of fuel pricing have been conducted in Washington, DC, and California.[195] The Washington, DC, study simulates a 25¢/gallon tax, while the California study examines the impacts of a 50¢/gallon to $2.00/gallon tax based on a $1.20/gallon base price. Percentage change in inputs ranges from 14% to 167%.

Emissions pricing increases cost of traveling based on the level of air-polluting emissions produced by a vehicle. Scenarios for emissions pricing policies are limited to the California region, which imposes an average 1¢/mile fee that varies depending on the vehicle's emissions.[196] Assuming an average automobile operating cost of 15¢/mile, the input change for these scenarios is approximately 7%.

Combined pricing policies increase automobile operating costs in multiple ways. In San Francisco, automobile operating costs are increased by 100%, parking costs increase by an average of 4.89%, and a 25¢/mile congestion charge is imposed on roadways with volume-to-capacity ratios greater than 0.90.[197] In Sacramento, automobile operating costs are increased by 30%, and parking costs of $1.00 to $4.00 are imposed.[198] California-region scenarios simulate a moderate-impact combined pricing scheme (i.e., $1.00 per day for parking and a 50¢/gallon fuel tax) and a high-impact combined pricing scheme (i.e., $3.00 per day for parking and a $2.00/gallon fuel tax).[199] In Austin, gas prices are set at $6.00/gallon (with a base price of $3.00/gallon), and a VMT fee of 10¢/mile on all roads is imposed.[200]

Combined pricing and transit policies increase automobile operating costs and improve transit service and/or reduce the cost of transit use. In the San Francisco study, a 1% increase in rail infrastructure is combined with the pricing policy described above, and in the

Sacramento study, approximately 75 new track miles of light rail are added to the region, in addition to a combined pricing policy.[201] In the UK region, one study implements a £4.00 cordon charge while also improving transit services by increasing frequencies, expanding infrastructure, and providing free fares for old-age pensioners.[202] Another study in the UK reduces bus fares by 60% and increases frequency by 20% while also implementing a distance-based fee of up to 80 pence/km.[203] A study of several EU regions evaluates a 75% increase in automobile operating costs while reducing transit fares by 50% and transit travel times by 5%.[204] Another EU study includes a simulation of the effect of technology investments, such as supporting innovative vehicles or energy efficiency, in a low- or high-fuel-price setting.[205]

Combined pricing, land-use, and transit studies are drawn from San Francisco's visioning study, which includes land-use, transit, and combined pricing strategies; advanced studies in Sacramento, which implement pricing and transit policies in conjunction with transit oriented development (TOD), infill, and an urban growth boundary; and studies in the EU, which combine TOD policies with a 75% increase in automobile operating costs, a 50% decrease in transit fares, and a 5% decrease in transit travel times.[206] Finally, another study in the EU simulates the effect of demand regulation, such as reducing the need to travel, reducing trip lengths, and shifting demand on public modes, in a low- or high-fuel-price setting.[207]

TRAVEL PERFORMANCE

In the *transit-only* scenarios, expanded transit services tend to increase transit shares (median = 6%, N = 11) and reduce automobile and non-motorized shares (median = –0.8%, N = 11; median = –0.6%, N = 9, respectively) (see Figures 3, 4, and 5). Non-motorized shares may decrease when improved service makes transit more competitive with walking and biking in terms of travel time and cost. Except in the Brussels study, congestion (VHD) and travel time are reduced in transit-only scenarios (median = –1.9%, N = 8; median = –1.8%, N = 8, respectively). In Brussels, the simulation of improved transit service with a land-use model increased land consumption and decreased density, which tends to increase trip lengths and overall travel times.[208] Not surprisingly, access to the city center and services, as measured in the EU studies, also improves (median = 1.4%; median = 0.6%, N = 6, respectively), except in Brussels.[209] Accessibility measures, as measured in the UK and San Francisco studies, most typically show increases in transit access and reductions in automobile access to destination, locations, and services (Table 11 shows accessibility performance measures implemented by destination type, policy type, and mode/time criteria).[210]

In the *land-use-only* scenarios, as densities increase, activity origins and destinations are closer together, and transportation performance measures indicate that more trips are made by non-motorized modes and transit and fewer trips are made by automobile (see Figures 3, 4, and 5). In San Francisco, the automobile mode share is reduced by 1%, transit is increased by 7%, and walking and bicycling are increased by 10% and 13%, respectively.[211] In Washington, DC, automobile trips decline by less than 1%, and transit and non-motorized trips increase by 1% to 5%.[212] As automobile travel declines, congestion may also be reduced, as reported in scenarios in San Francisco (–37%), Philadelphia

(–14%), and Orlando (–9%).[213] Total vehicle hours of travel decline in Orlando (–5%), and average daily and peak vehicle speeds increase in Washington, DC, and Austin.[214]

In the *land-use and transit* studies, increases in density and expanded transit promote transit and non-motorized travel (median = 50%, N = 19; median = 11%, N = 18, respectively) and reduce automobile travel (median = 3%, N = 23). The greatest increases in transit and non-motorized shares are reported in Sacramento, where baselines are low, as well as in visioning and advanced studies.[215] For transit, MTP values range from 4% to 111%, and the remaining visioning studies report values from 0% to 150%. For non-motorized modes, MTP values range from –20% to 15%, remaining visioning studies range from –9% to 125%, and advanced studies range from –7% to 17%. Negative values indicate a shift from non-motorized to transit modes. The greatest reductions occur in visioning studies from Chicago (–16%) and Sacramento (–11%), while MTPs report reductions of 0.3% to 7%, the remaining visioning studies report reductions of 0.3% to 8%, and the academic/international studies report reductions of 2% to 8%.[216]

As automobile use decreases in *land-use and transit* scenarios, average travel time declines (median = 14%, N = 15). MTPs report values near the median, while values from visioning studies range from 25% in Sacramento to 2% in Salt Lake City.[217] As travel times decrease, so does congestion, as measured by VHD (median = 27%, N = 24). Studies in Chicago report the greatest decrease (68%), while Sacramento's academic studies report the least change (3%).[218]

Accessibility measures relative to travel-time criteria are reported in the *land-use and transit* scenarios in the Los Angeles and San Diego MTPs.[219] Los Angeles measures accessibility through the change in "accessible jobs" (those within 45 minutes travel time) by automobile (–3%) and transit (10%). San Diego's MTP reports a 3% increase in work and higher-education trips accessible within 30 minutes.

Parking pricing scenarios in the studies reviewed tend to decrease automobile mode share (median = –2.12%, high = –4.97%, low = –0.36%, N = 14) and increase transit (N = 12) and non-motorized (N = 10) mode shares (median = 1.7%). VHD and travel time also tend to decrease in these studies (median = –2.29%, N = 20; median = –1.5%, N = 20, respectively). The exceptions are the EU cities of Bilbao, Vincenza, and Naples, in which parking pricing studies are simulated with a land-use model and show reductions in employment (10% to 0.5%) and population (8% to 0.4%) in their city centers.[220] As a result, Bilbao experiences a decline in transit mode share, Vincenza see declines in non-motorized mode share and increases in VHD, and Naples experiences increases in travel times. In California, regional scenarios show reductions in VHD ranging from 9% to 2%.[221]

Box plots of mode shares for the policy types examined are shown in Figures 3 through 9.

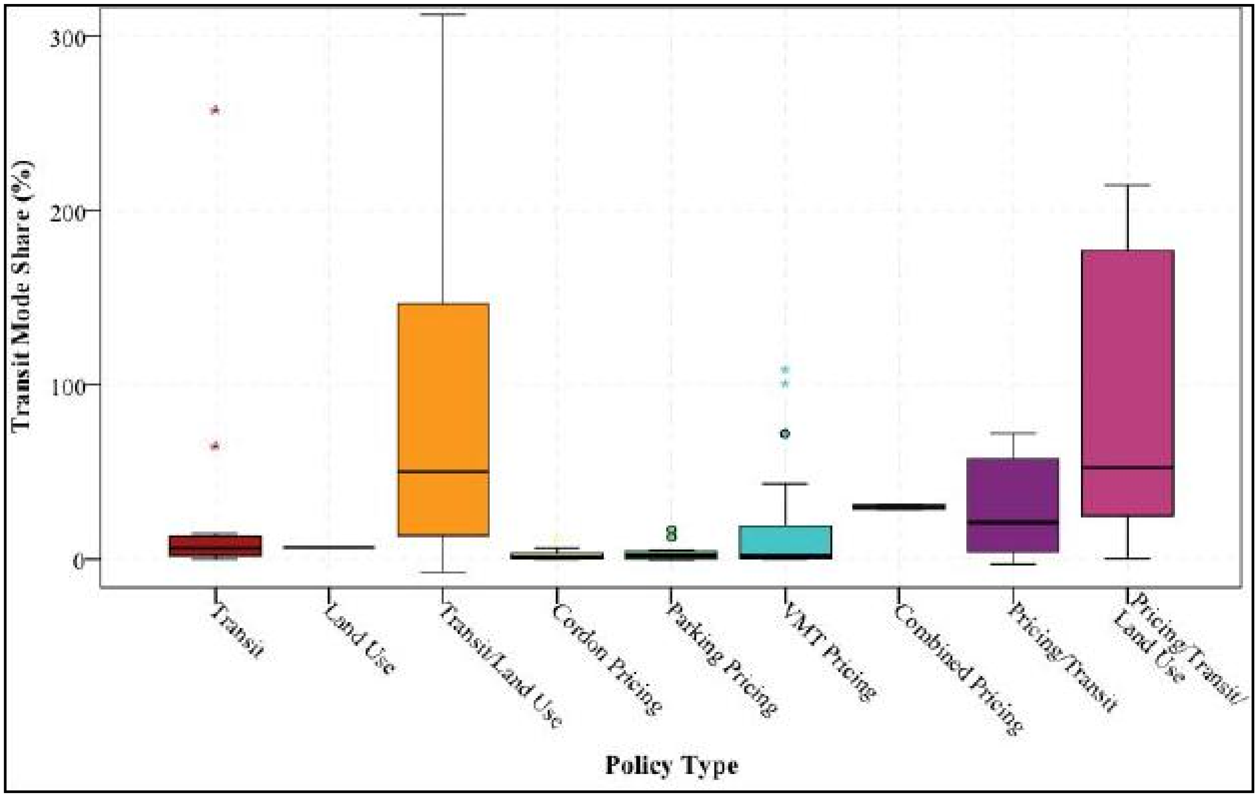

Figure 3. Transit Mode Share[222] (N = 94)

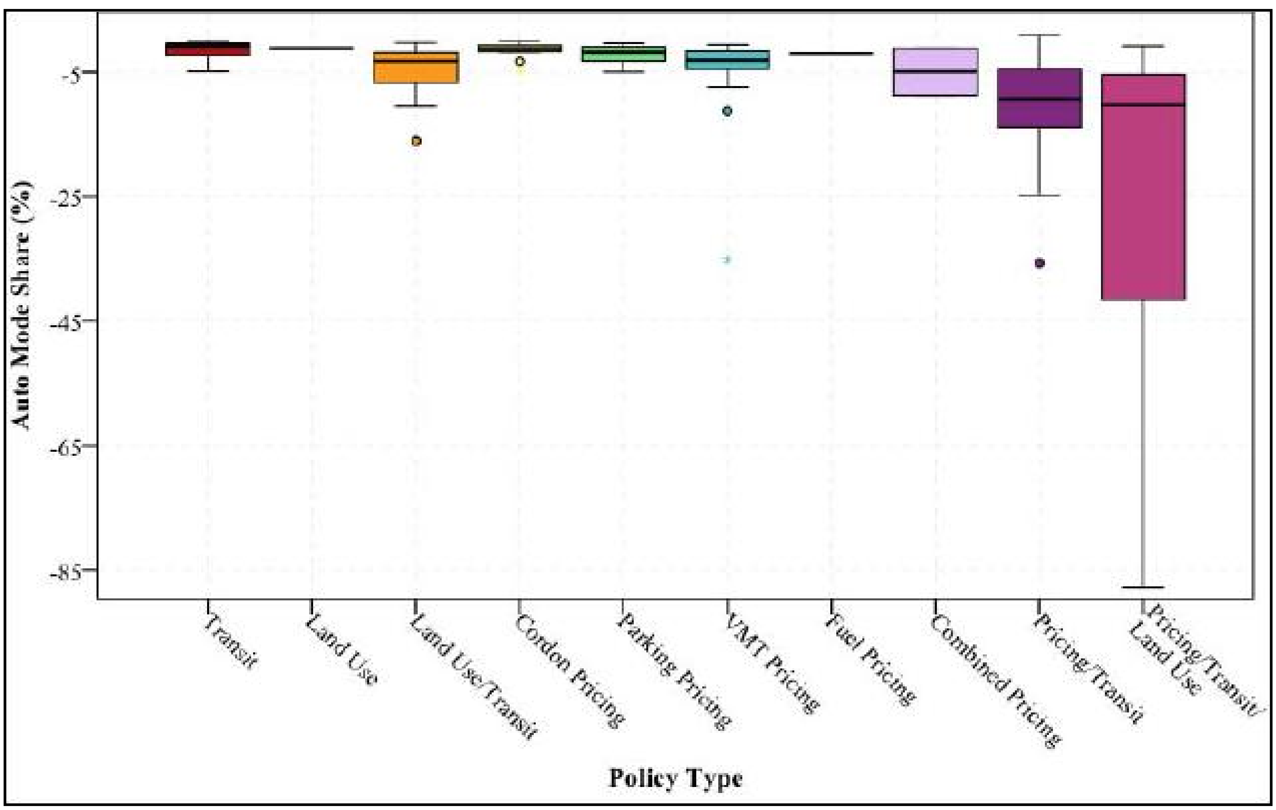

Figure 4. Automobile Mode Share[223] (N = 113)

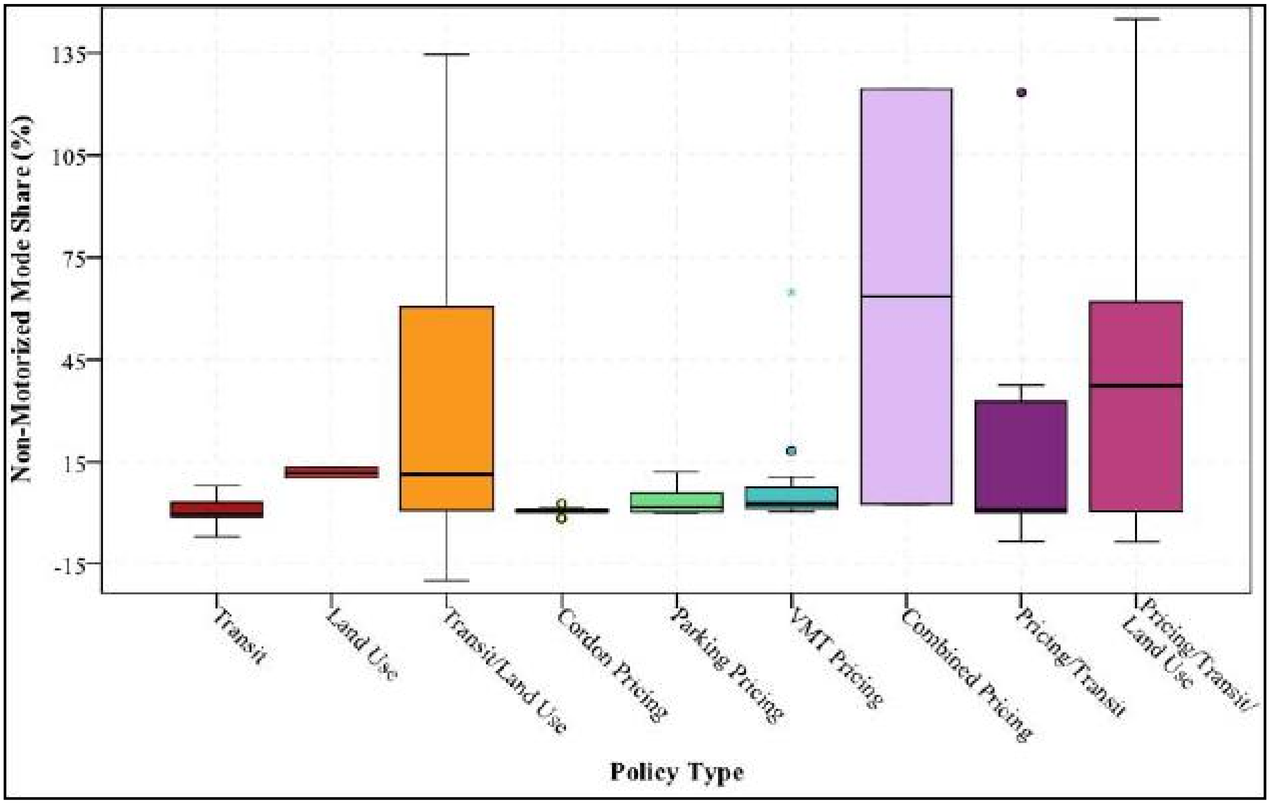

Figure 5. Non-Motorized Mode Share[224] (N = 94)

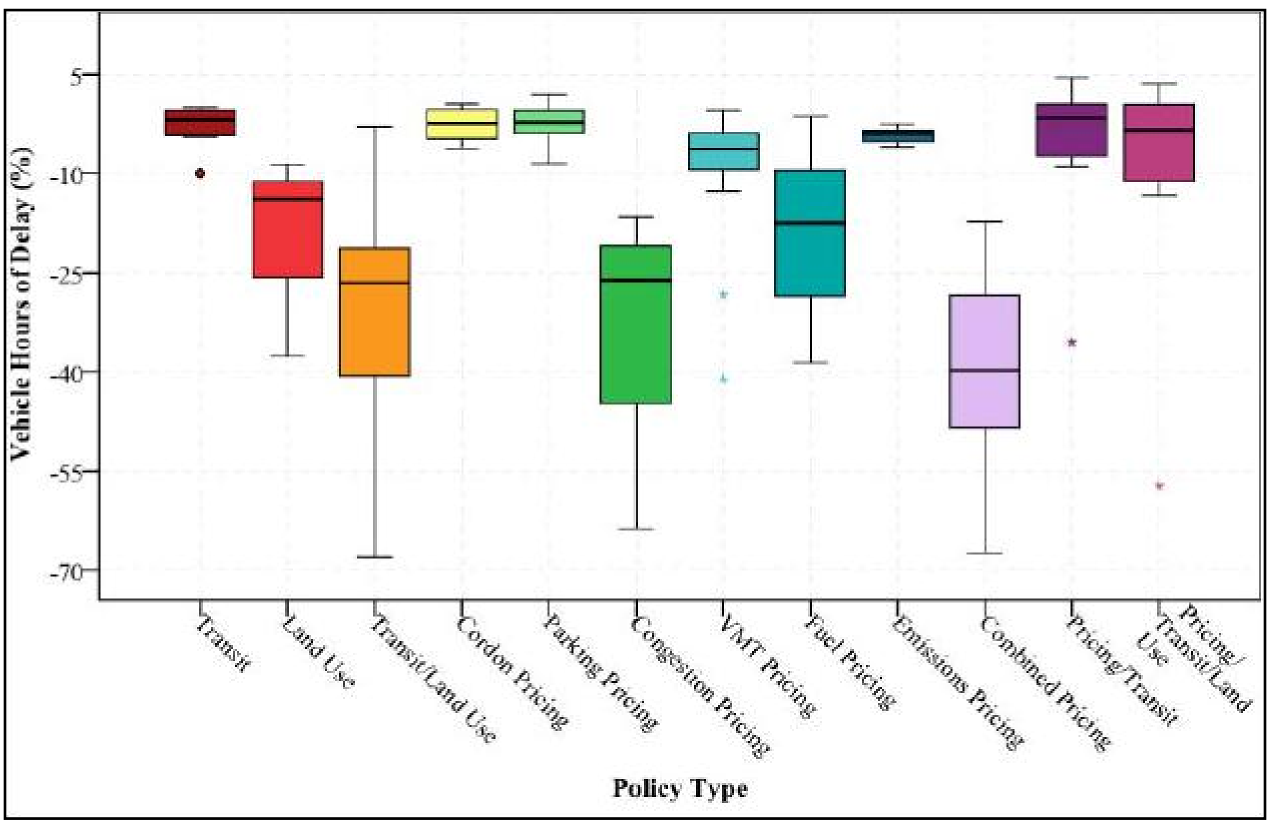

Figure 6. VHD[225] (N = 158)

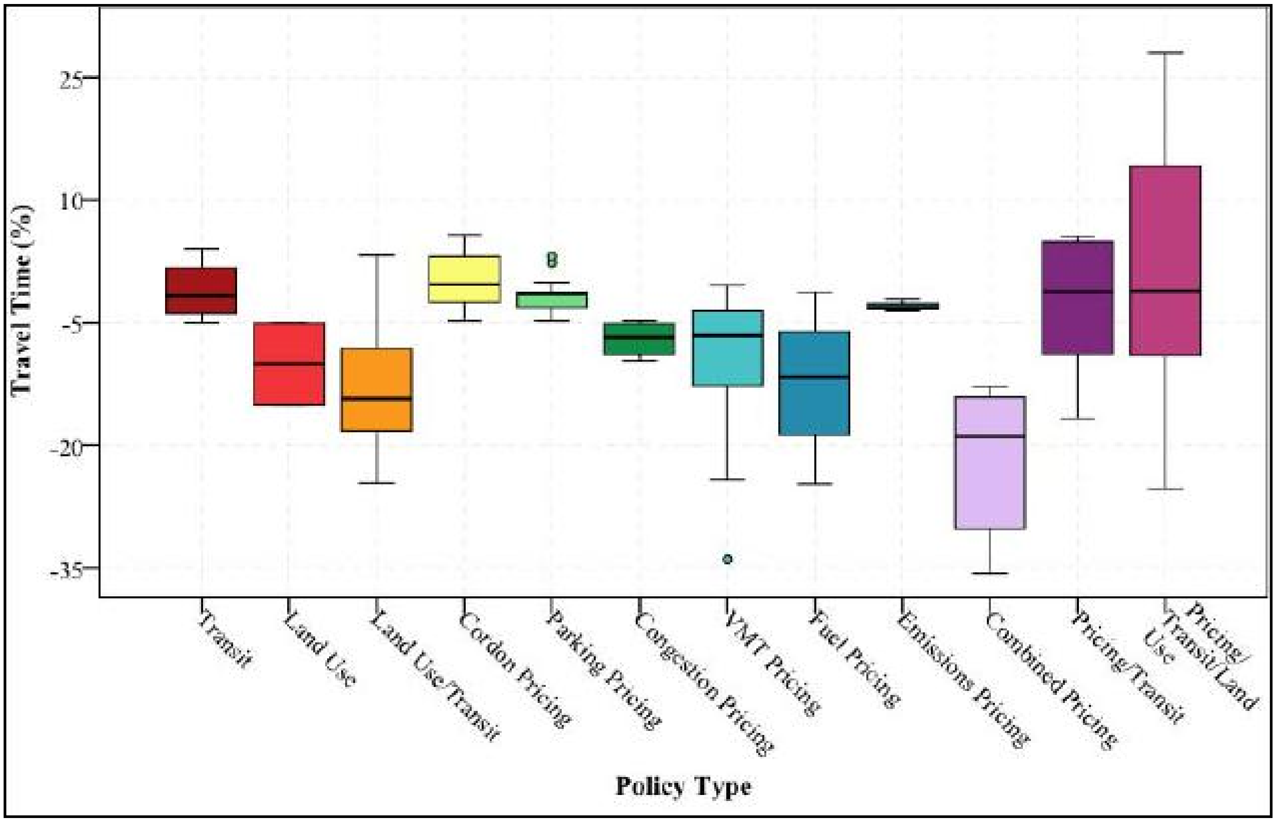

Figure 7. Travel Time[226] (N = 136)

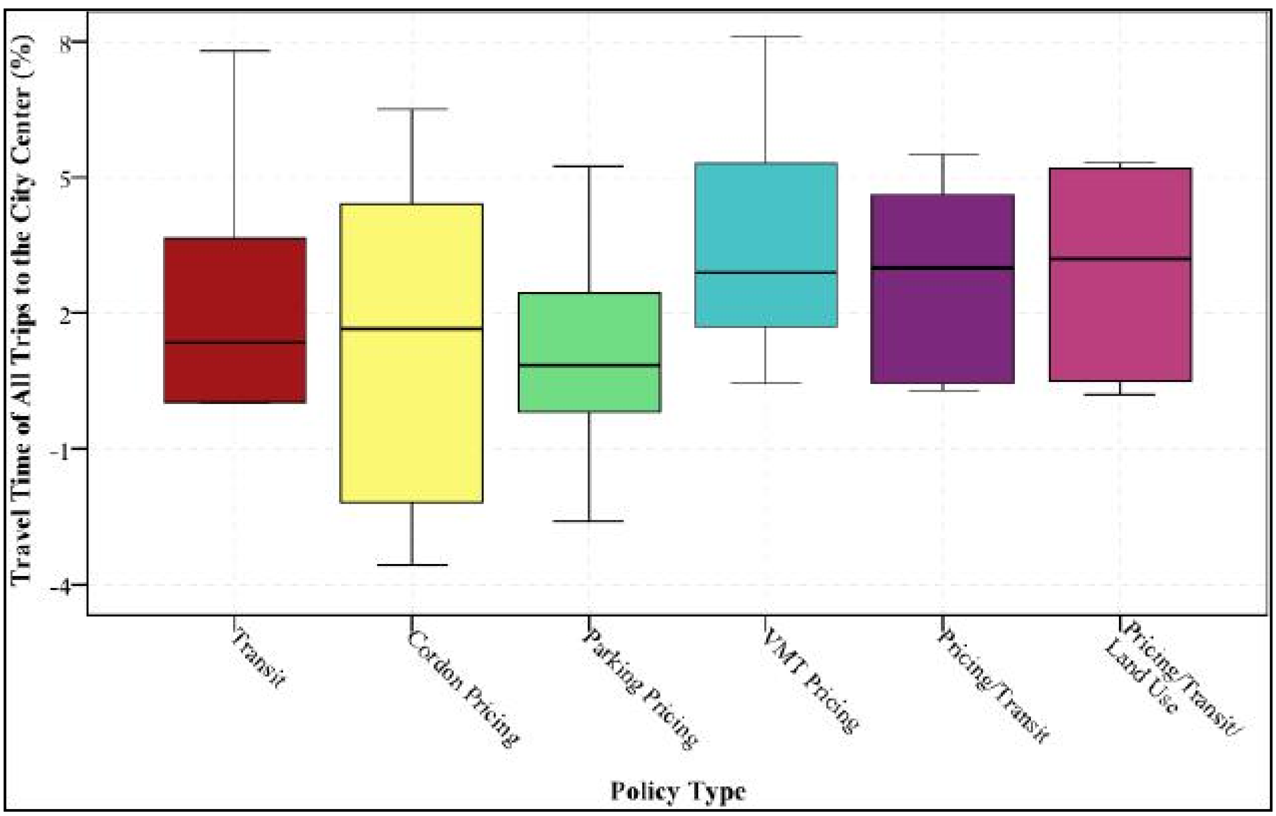

Figure 8. Access to City Center[227] (N = 63)

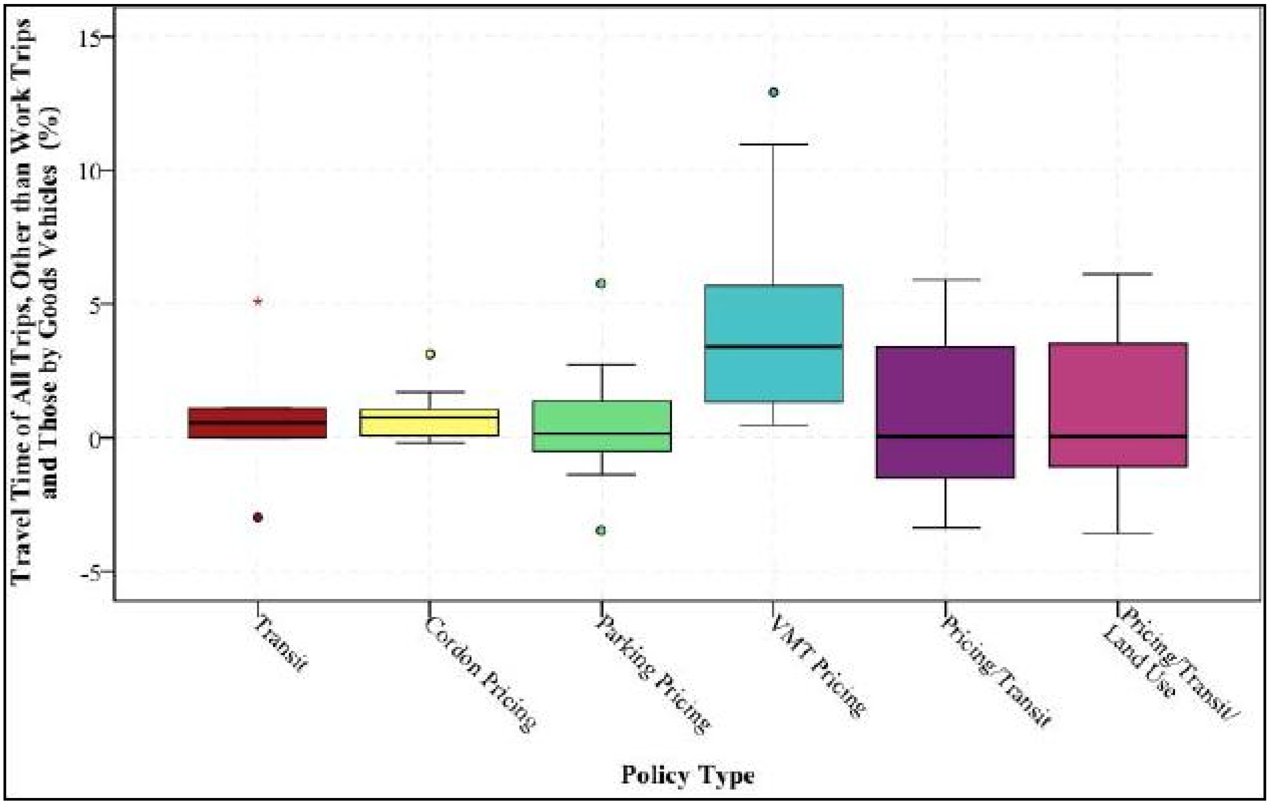

Figure 9. Access to Services[228] (N = 63)

Table 11. Accessibility Performance Measures

Destination	Mode	Time Criteria (Minutes)	Percentage Change (%)	Policy Type
All destinations	All	—	-1.0 to 0.9	Pricing and transit[229]
CBD/activity center	All	—	-22.4 to -12.1	Pricing and transit[230]
		10	6.6	Land-use[231]
Employment	All	—	-3.8 to -2.7	Pricing and transit[232]
		20	-1.2	Transit[233]
		40	0.0	Transit[234]
	Auto	15	1.3	Land-use/transit[235]
		30	-0.3 to 0.7	Pricing and transit, transit[236]
		45	0.2 to 2.7	Land-use/transit[237]
	Transit	15	22.2	Land-use/transit[238]
		30	11.0 to 13.9	Transit, land-use/transit[239]
		45	7.0 to 10.0	Land-use/transit[240]
Shopping	All	-	-2.5 to -1.8	Pricing and transit[241]
	Auto	15	-0.7	Transit[242]
	Transit	15	19.1	Transit[243]
Retail purchasing power	All	-	-2.9 to -2.0	Pricing and transit[244]
Supermarket	All	15	-1.2	Transit[245]
		30	0.0	Transit[246]
General practitioner	All	15	0.0	Transit[247]
		30	0.0	Transit[248]
Primary school	All	15	-1.0	Transit[249]
		30	0.0	Transit[250]
Secondary school	All	-	-3.9 to -2.8	Pricing and transit[251]
		20	1.0	Transit[252]
		40	1.0	Transit[253]
Further education	All	30	1.0 to 3.1	Pricing and transit, transit[254]
		60	1.0	Transit[255]
Intermodal station	All	5	8.3	Land-use[256]
International airport	All	30	12.1	Land-use[257]
Reliever airport	All	30	9.1	Land-use[258]

Cordon pricing in the EU regions tends to reduce regional automobile mode share (median = –1.2%, N = 12) and increase demand for lower-cost transit (median = 1%, N = 12) and non-motorized travel modes (median = 0.5%, N = 10).[259] VHD and travel times also tend to decline (median = –2.6%, N = 18; median = –0.4%, N = 12), while accessibility to the city center and services generally increase (center median = –1.7%; services median = –0.8%, N = 12). The exceptions to these trends are related to the land-use effects of the cordon pricing scenarios simulated with land-use models. The cordon tolls result in the decentralization of population and employment in both Naples and Dortmund. The opposite is true in Bilbao. There is a slight decrease in non-motorized modes share in Naples, and in Dortmund, VHD is increased and accessibility is decreased. Travel time for all modes increases in Bilbao, Dortmund, and Naples.

Travel performance measures for *congestion pricing* scenarios are limited to travel time and VHD. Median travel time decreases for all California scenarios (N = 4) by 7% (high = –10%, low = –5%).[260] As travel time decreases, so does congestion: the Washington, DC, and California scenarios show a median reduction in VHD of 26% (N = 8) and a median reduction in range of –64% to –17%.[261]

In the *VMT pricing* policy scenarios, as vehicle operating costs increase, automobile mode shares decrease (median = –3%, N = 22) and transit and non-motorized mode shares increase (median = 2% and 3%, respectively, N = 22) in the EU regions and Sacramento.[262] Travel time in the EU regions declines (median = –6.6%; N = 21), as does VHD in the EU regions, California, and Washington, DC (median = –6.6%, N = 27).[263] VHD reductions for California range from –11% to –8%; for Washington, DC, they range from –41% to –28%; and for EU regions, they range from –13% to –0.5%. Accessibility increases in all the EU regions (center median = –2.9%; services median = –3.4%, N = 21).

In the *fuel pricing* studies, vehicle operating costs increase and vary by the fuel efficiency of individual vehicles; thus, automobile mode shares decline. For example, in Washington, DC, automobile mode share decreases by 2%.[264] Travel time and VHD are also reduced (travel time median = 12%, VHD median = 18%, N = 17). The California-regions scenario simulates increases in fuel prices that are higher relative to the VMT pricing charges, which helps explain the larger median percentage change in travel time and VHD (see Figures 6 and 7).[265]

Emissions pricing scenarios in the California regions include travel time and VHD.[266] Travel time is reduced in all scenarios by a median of 3% (high = –4%, low = –2, N = 8). VHD is also reduced in all scenarios by a median of 4% (high = –6%, low = –3%, N = 8).

A limited number of studies include *combined pricing* scenarios. The San Francisco visioning study and the advanced Sacramento study show decreases in automobile ownership ranging from 1% to 5% and increases in transit mode share (approximately 30%) and non-motorized mode share.[267] Not surprisingly, given the magnitude of the policy change, all studies show significant reductions in travel time and VHD (median = 19%, N = 9; median = 40%, N = 10, respectively).

In the *pricing and transit* studies, automobile mode share tends to decrease in all locations (median = 9%, N = 13), while transit and non-motorized mode shares tend to increase (median = 21%, N = 14; median = 1%, N = 12, respectively). Travel time is generally reduced (median = –1%, N = 10); however, results for VHD are mixed (median = 2%, N = 7, respectively). In Edinburgh, Helsinki, Dortmund, and Naples, the pricing and transit scenarios are simulated with a land-use model.[268] Decentralized housing and/or employment resulting from the pricing and transit policies decreases transit and non-motorized mode shares in Edinburgh, decreases non-motorized modes in Helsinki and Naples, increases travel time in Naples and Dortmund, and increases VHD in Helsinki and Naples. A UK study measures accessibility through change in population within given travel times to employment, supermarket, general practitioner, primary school, and secondary school and finds percentage changes ranging from –1% to 1%.[269]

Combined pricing, land-use, and transit studies show reductions in automobile mode share (median = 10%, N = 16) and increases in transit and non-motorized mode share (median = 52% and 37%, respectively, N = 29). The exceptions to these trends are found in Helsinki, Dortmund, and Naples, where the pricing and transit scenarios are simulated with a land-use model, and land-use changes result in decreases in non-motorized mode share and increases in travel time and VHD.[270] Scenarios in Dortmund measure change in overall accessibility of population and accessibility of employment, shops, retail purchasing power, high schools, and CBD, with percentage changes ranging from –39% to –1%.

ENVIRONMENTAL PERFORMANCE

Environmental performance measures for the *transit-only* scenarios include GHG emissions, air pollutants, and land coverage (see Figures 10 to 15). All studies show reductions in GHG emissions (median = –0.4%, high = –5.9%, low = –0.01, N = 16) and air pollutants (VOC median = –2%, high = –12%, low = –0.2, N = 8; CO median = –4%, N = 2; NO_x median = –3%, N = 2) that typically parallel the automobile mode share reduction. Measures of land consumed by development are included in Sacramento studies and the EU regions study.[271] Land-use models are used in both studies. In Sacramento, land coverage declines by 0.1% to 0.5%, whereas in some EU regions, improved transit services result in an increase in the total amount of land consumed by development (4% in Brussels, 0.2% in Dortmund, and 0.1% in Helsinki). Increased accessibility to services and the city center in these scenarios may allow some residents and businesses to trade travel times for lower rents in outlying areas. There is no land-consumption change in Naples and Vicenza and a slight reduction in Bilbao (0.01%). The EU regions study also includes a measure of the quality of open space that is generally inversely related to total land consumed (median = –0.2%, high = –0.8%, and low = 0.04%, N = 6).

Environmental performance measures related to GHGs, criteria pollutants, and land consumption are available for some *land-use-only* scenarios. In San Francisco, Orlando, Philadelphia, Austin, and Washington, DC, the median GHG reduction is 2%; the high is 13% in Austin, and the low is less than 1% in Washington, DC.[272] Pollutants also decline in San Francisco, Orlando, and Philadelphia, by 1% to 4%. Land consumed by development declines by 3% in San Francisco. In Philadelphia, agricultural and wooded acres are preserved and residential water use declines by 4%.

Environmental performance measures for *land-use and transit* scenarios include GHG emissions, air pollutants, and land-coverage measures. GHG emissions are reduced by a median of 5% (N = 23), and air-polluting emissions are reduced by a median of 7% (N = 16) for NO_x, 9% (N = 17) for CO, and 12% (N = 17) for VOCs. Visioning studies report a wide range of values, while MTPs and advanced studies generally indicate relatively smaller changes.

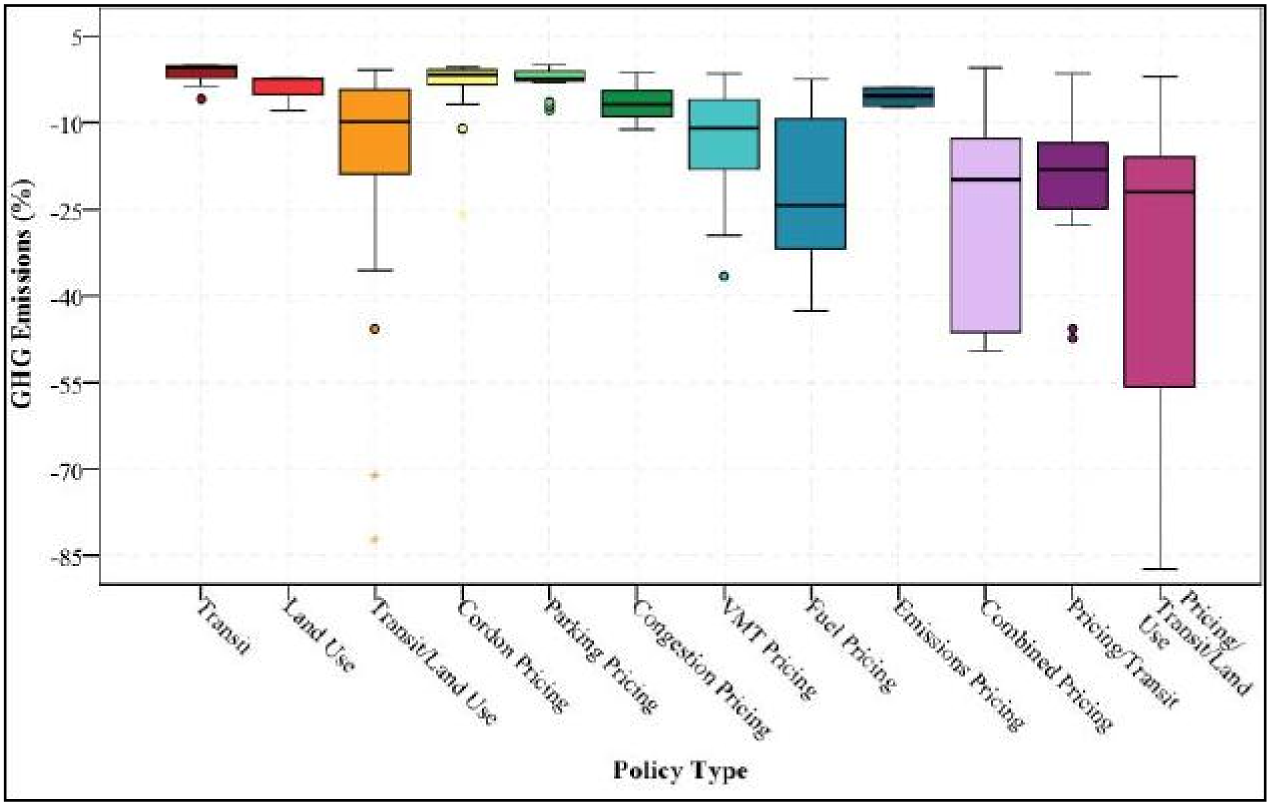

Figure 10. GHG Emissions[273] (N = 192)

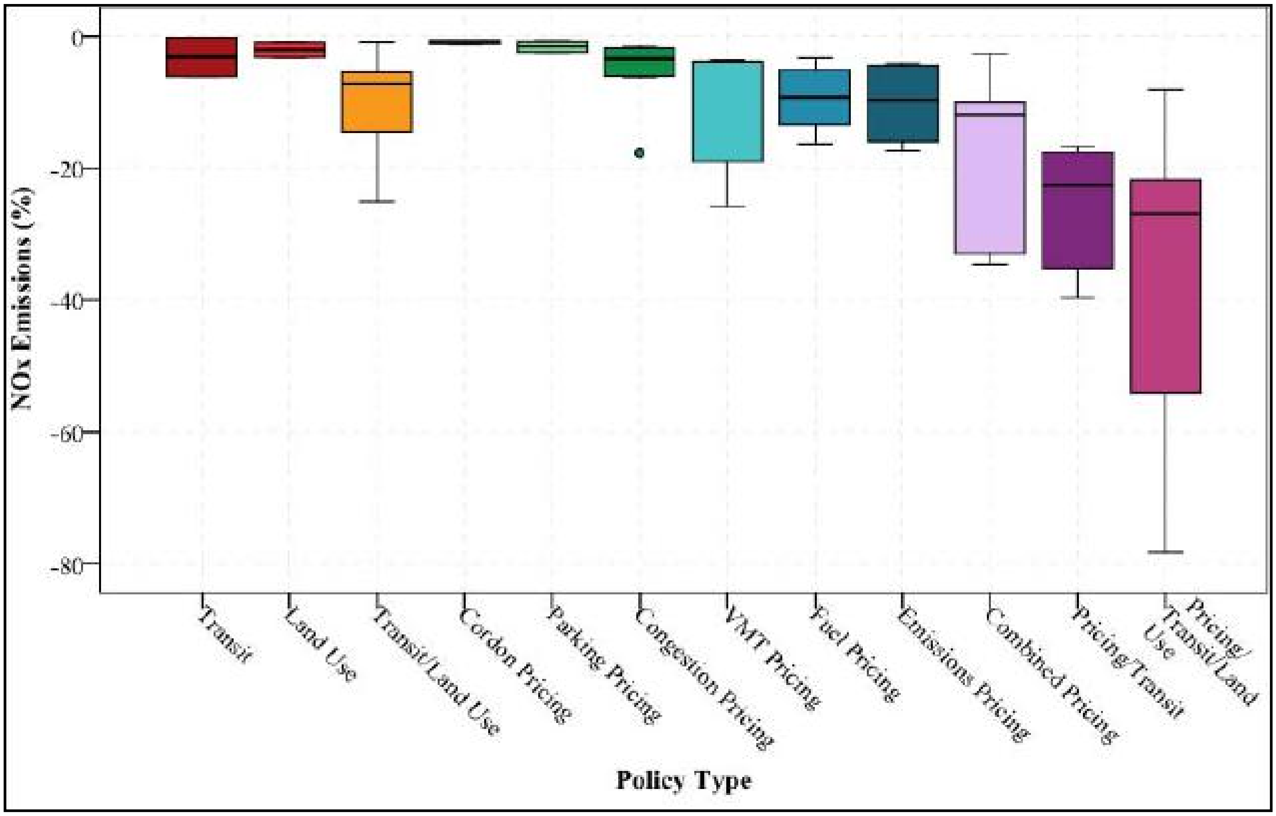

Figure 11. NOx Emissions[274] (N = 96)

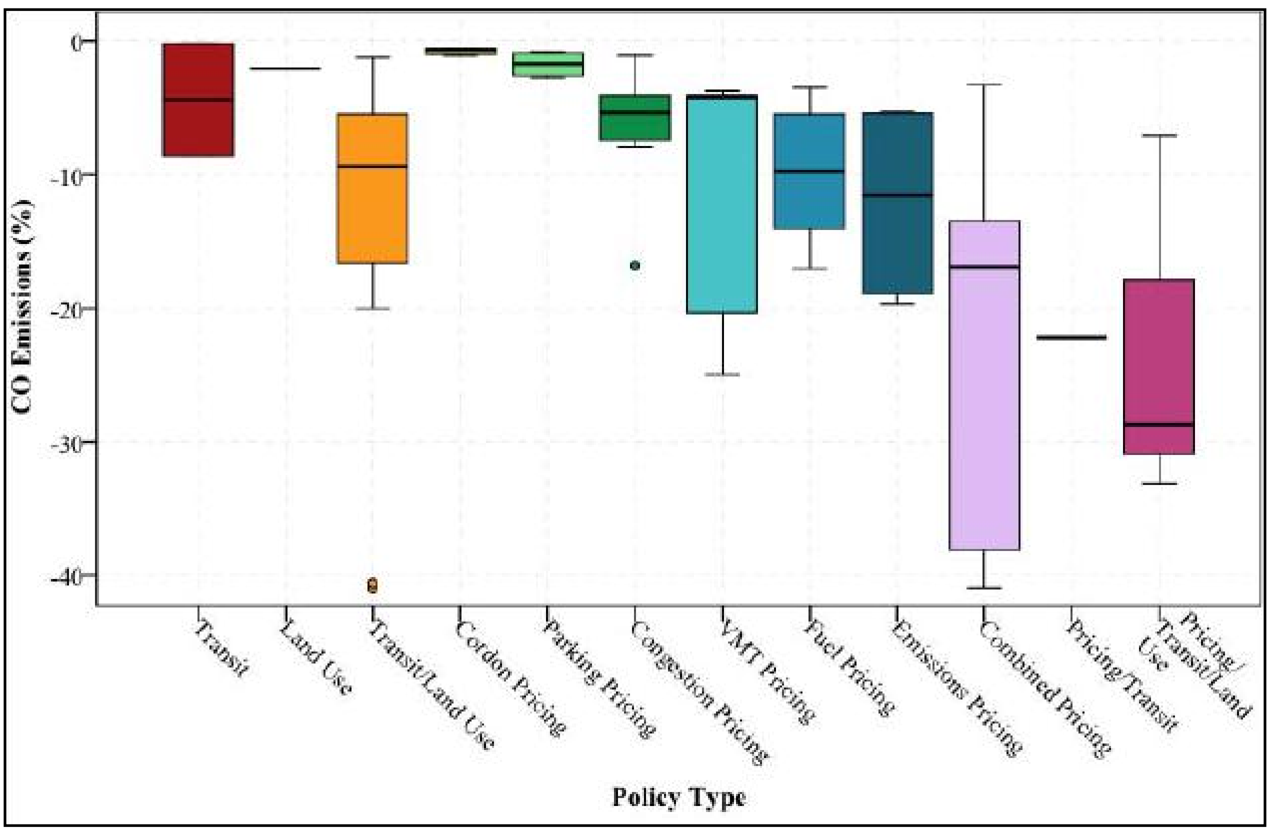

Figure 12. CO Emissions[275] (N = 86)

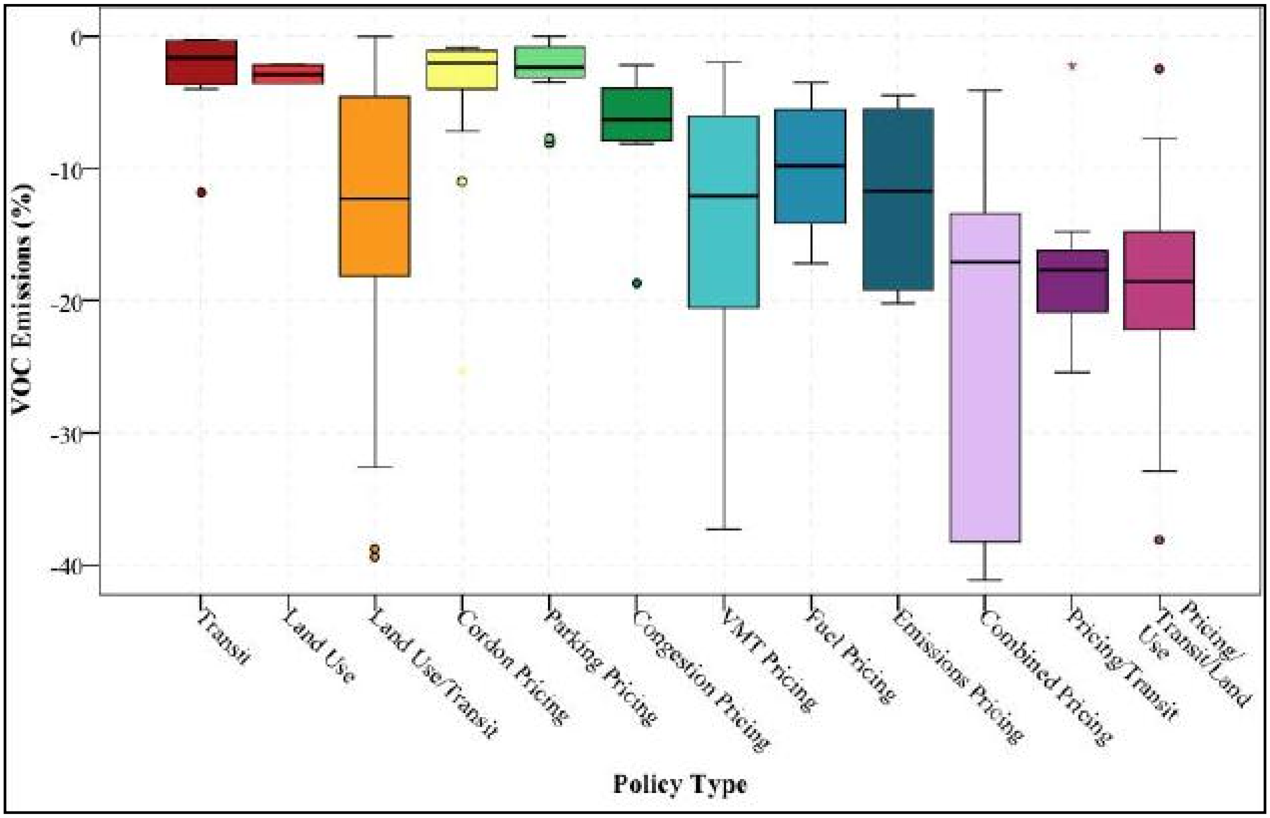

Figure 13. VOC Emissions[276] (N = 150)

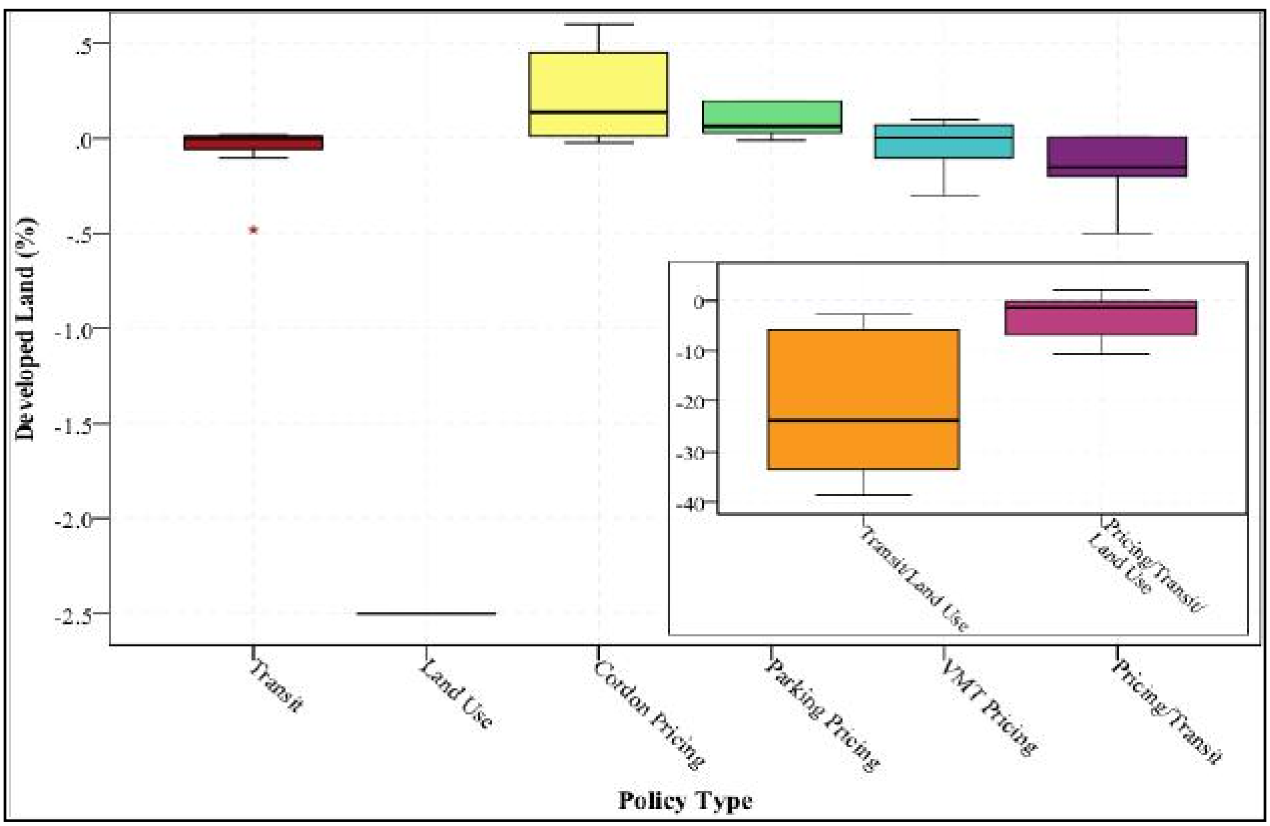

Figure 14. Developed Land[277] (N = 86)

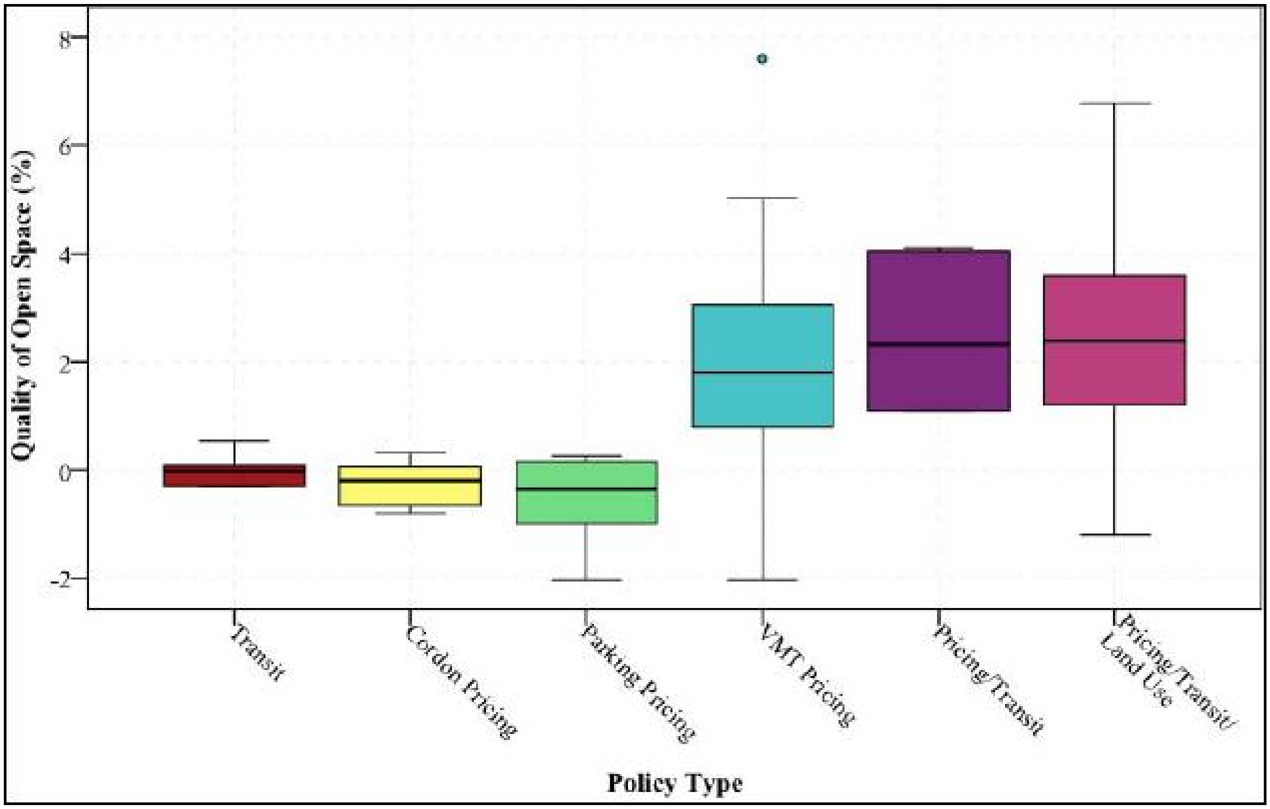

Figure 15. Quality of Open Space[278] (N = 63)

Many of the studies that include simulations of *land-use and transit* scenarios examine land-coverage measures (see Figure 14). Change in total developed land is measured in San Francisco, the San Joaquin Valley, Austin, Salt Lake City, and Sacramento; the median reduction is 24% (N = 10), ranging from 3% in San Francisco to 39% in Salt Lake City.[279] Some studies measure developed land through other metrics. San Francisco's MTP reports that 533 acres of urban open space will potentially be disrupted, and San Diego's MTP reports a 200% increase in constrained land used for transit and highway infrastructure.[280] Visioning studies in the Twin Cities and Chicago report reductions of 65% and 62% to 68%, respectively, in additional (not total) developed land.[281]

Changes in other sensitive-land types for *land-use and transit* scenarios are measured in a number of studies. The visioning studies for Sacramento, the San Joaquin Valley, Austin, Salt Lake City, and Chicago report changes in agricultural land consumed, showing a median value of 57% (N = 9).[282] The greatest reduction is reported in Austin (773%), and the smallest reduction is in Chicago (36%). The change in urban park areas is 0% in Sacramento, and reductions range from 36% to 46% (N = 3) in Austin. Austin also reports the change in ranch land consumed, with values ranging from 59% to 88% (N = 3). The San Joaquin Valley reports a 35% reduction in natural environment impacted. Austin reports reductions in land in the aquifer recharge zone and contributing zones of from 47% to 100% and 62% to 86%, respectively. In Chicago, changes in grasslands and forest consumed are –36% and –61%. The Twin Cities report a 61% reduction in sensitive land impacted by development.[283] Finally, Portland's MTP measures habitat preservation, calculating the percentage of projects intersecting high-value habitat areas (28.90% to 30.70%).[284]

Environmental performance measures for *cordon pricing* policy scenarios include vehicle-activity results for measures of GHGs and air pollutants. All scenarios reduce GHGs (median = –2%, high = –26%, low = –1%, N = 19). The Washington, DC, and EU regions scenarios show a reduction in VOC (median = –7%, N=18).[285] The Washington, DC, scenarios (N = 6) show reductions in NO_x (median = –2%) and CO (median = –3%). The EU regions study also provides environmental metrics that include percentage of land covered by development and quality of open space (N = 12) for cordon pricing policies. As described above, cordon pricing may encourage population and/or employment to relocate outside the cordoned area to avoid toll payment and/or to reduce auto travel times (for those who can afford the cordon toll). Thus, land coverage increases in all the EU regions except Helsinki, where the median increase is 0.2%, with a low of –0.02 and a high of 5%. Similarly, the quality of open space declines (median = –0.12%; high = –12%, low = 0.32%).

Environmental performance measures for *parking pricing* scenarios include vehicle-activity results for measures of GHGs and air pollutants. All scenarios except one reduce GHGs (median = –2%, high = –8%, low = 0.02%, N = 20). The exception is Brussels, which shows a slight increase (see the transportation discussion above).[286] The California and EU regions scenarios show reductions in VOC (median = –2%, N = 20).[287] The California scenarios (N = 8) show reductions in NO_x (median = –2%) and CO (median = –2%). The EU regions study provides environmental metrics such as percentage of land covered by development and quality of open space (N = 12). As noted earlier, several of the studies suggest that parking pricing encourages population and/or employment to relocate outside of the central city to avoid high parking fees. Thus, land coverage increases in all the EU region scenarios, with the exception of Dortmund. The median increase is 0.1%, with a low of –0.01% and a high of 6%. Quality of open space also declines (median = –0.36%; high = –2%, low = 0.26%).

Environmental performance measures for *congestion pricing* include vehicle-activity results for measures of GHG and air pollutants. All scenarios reduce GHG, with a median reduction of 7% (high = –12%, low = –1%, N = 11). The California and Washington, DC, scenarios (N = 8) report reductions in VOC (median = –6%), NO_x (median = –3%), and CO (median = –5%).[288]

Environmental performance measures for *VMT pricing* policies include GHG, air pollutants, land coverage, and quality of open space. All studies include measures of GHG and VOC reductions (median = –12%, high = –37%, low = –2%, N = 28). Values in some California regions lie above the median (around –4%), while Sacramento and Washington, DC, results are below the median, at –27% and –25% to –18%, respectively.[289] CO and NO_x results in the U.S. studies indicate median reductions of approximately 4%, with values ranging from 4% to 25% (N = 7).

Land-coverage results are available from the Sacramento and EU regions studies for the *VMT pricing* scenarios.[290] Land coverage decreases (–0.01% to –0.3%) in Sacramento, Dortmund, Naples, and Vicenza but increases in Bilbao (0.02%), Brussels (2% to 3%), and Helsinki (0.1%). The quality of open space in the EU regions tends to be inversely related to land coverage. Land coverage declines when the increase in per-mile cost of vehicle travel is great enough to offset the reduced automobile travel times (or the value of time savings) from outlying areas of the regions, where rents are lower. Land coverage increases when the opposite is true.

Environmental performance measures for *fuel pricing* studies include GHG and air pollutants. All studies measure GHG, showing a median reduction of –24% (high = –43%, low = –3%, N=17). California region scenarios (N = 16) show median reductions in air pollutants of –9% (high = –16%, low = –3%) for NO_x, –10% (high = –17%, low = –4%) for CO, and –10% (high = –17%, low = –4%) for VOC.[291]

Environmental performance measures for *emissions pricing* include GHG and air pollutants. GHG is reduced in all studies (median = 5%, high = –7%, low = 4%, N = 8). NO_x emissions are reduced by a median value of 10% (high = –18%, low = –4%), CO emissions are reduced by a median value of 12% (high = –20%, low = –5%), and VOC emissions are decreased by a median value of 12% (high = –20%, low = –5%).

Environmental performance measures for *combined pricing* policies include GHG and air pollutants. GHG is reduced in all scenarios (median = 20%, high = –50%, low = 0%, N = 11), with the results from San Francisco, Sacramento, and Austin falling well below the median.[292] In Sacramento and the California regions,[293] NO_x emissions decrease by a median value of 12% (high = –35%, low = –3%, N = 9), CO emissions decrease by a median value of 17% (high = –41%, low = –3%, N = 9), and VOC emissions decrease by a median value of 17% (high = –41%, low = –4%, N = 9).

Environmental performance measures for *pricing and transit* include GHG, air pollutants, land coverage, and quality of open space. All studies include measures of GHG reductions (median = –18%, high = –47%, and low = –1%, N = 14). In Sacramento and the EU regions, median decreases in NO_x and VOC are 23% and 18%, respectively (high = –40%, low = –2%, N = 13), and CO emissions in Sacramento are reduced by 22% (N = 1).[294] Land coverage decreases somewhat (0.1 to 0.5%) in Sacramento, Helsinki, Naples, Vincenza, and Dortmund but increases in Bilbao (0.01%), Brussels (3.08%), and Dortmund (0.01%). The quality of open space in the EU regions increases in all locations except Bilbao; the median increase is 2% (high = –4%, low = 4%, N = 6).

Environmental performance measures for *combined pricing, land-use, and transit* studies include GHG, air pollutants, land coverage, and quality of open space. All studies include measures of GHG reductions (median = –22%, high = –87%, low = –2%, N = 14). Studies in Sacramento and the EU show median decreases in NO_x and VOC of 27% and 19%, respectively (high = –78%, low = –2%, N = 17), and a median 29% reduction in CO emissions is reported in Sacramento (high = –33%, low = –7%, N = 3).[295] The San Francisco, Sacramento, and EU regions studies[296] show decreases in land coverage in all locations except Brussels and Helsinki, with an overall median reduction of 1% (high = –11%, low = 2%, N = 13). The quality of open space in the EU regions increases in all locations except Helsinki; the median increase is 2% (high = –1%, low = 7%, N = 6).

EQUITY PERFORMANCE

Equity performance measures for *transit-only* policies are implemented in the San Francisco region, the city of San Francisco, Sacramento, and the EU regions.[297] In the San Francisco region, the simulated transit scenario indicates that transportation costs as share of household income increase by 5% for low-income households. In Sacramento, the simulation of traveler user benefits (i.e., value of travel time and monetary costs) by income class indicates that lower-income groups benefit least from transit improvements. The application of an ABM in the city of San Francisco enables equity analyses that examine average time savings by income classes and other socioeconomic segments. The study finds that low-income households benefit more than higher-income households, female heads of households with and without children benefit less than non-female heads of households, single-parent households also benefit less than non-single-parent households, and females benefit less than males. In the EU regions, segregation, an equity measure that quantifies an unsatisfactory spatial accumulation of low-income households, increases and is unchanged in Dortmund and slightly improved in Bilbao. Housing supply and affordability, measured in the EU studies by the percentage of overcrowded housing, remain unchanged in Bilbao and Vicenza, but there are small (less than 1%) increases in Dortmund and Helsinki and decreases in Brussels and Naples (see Figures 16 and 17).

Available equity performance measures for *land-use only* policies indicate a 12% reduction in transportation costs for low-income households in San Francisco[298] and a 359% increase in jobs in environmental-justice communities in Philadelphia.[299]

Equity effects of *land-use and transit* policies are derived through a variety of measures. The Los Angeles MTP reports transit and automobile travel-time savings by income for quintile 1 (lowest) to quintile 5 (highest), ranging from 37% to 5% for transit and 28% to 26% for automobile.[300] Los Angeles also reports changes in accessibility (automobile, transit, walking) to employment and parking by income level, with values ranging from 8% to 84% for quintile 1 (lowest) and from 8% to 65% for quintile 5 (highest). The San Diego MTP reports a 0% reduction in daily travel time for low-income groups but a 6% decline for other income groups.[301] San Diego also measures change in low-income jobs accessible within 30 minutes by automobile or transit. For automobile, results range from 0.3% for low-income residents to 0.4% for high-income residents. For transit, jobs accessible by low-income residents increase by 9%, while jobs accessible by high-income residents increase by 14%. Sacramento's and Portland's MTPs report change in environmental-justice populations within transit ranging from 2% to 164%.[302] San Francisco's visioning study reports a 9% reduction in transportation cost as a share of household income for low-income households.[303] A Sacramento study finds a per-trip benefit of $0.14 to $1.07 for low-income travelers and a $4.92 to $16.76 per-trip benefit for high-income travelers.[304] Another study in Sacramento using an ABM and an advanced land-use model shows that lower-income groups benefit more than higher-income groups from an increased supply of affordable housing and reduced transportation costs.[305]

The equity implications of population and employment relocation resulting from *cordon pricing* policies are also examined in the EU region scenarios (N = 10).[306] Spatial segregation of the lowest-income groups increases relative to that of other income groups in all EU regions except Helsinki (3% to 4% reduction in segregation) and Bilbao (less than 1% reduction). Helsinki experiences a significant influx of population to the city center, and Bilbao experiences an influx of both population and employment. The supply and affordability of housing generally improve (median = 0.13%) in all EU regions except for the highest-cordon-toll scenarios in Helsinki and Dortmund (N = 12).

The EU regions scenarios (N = 8) also measure the equity impacts of *parking pricing* policies.[307] Spatial segregation decreases in half of the scenarios, and there is a median reduction of 0.05% across all scenarios (high = –1.51%, low = 2.30%, N = 8). The two cities that show an increase in segregation (Brussels and Helsinki) experience an outflow of both population and employment from the central city after parking pricing is implemented. Housing supply and affordability improve slightly (median = 0.05%, N = 12), except in Brussels.

Equity results for *congestion pricing* scenarios are limited to the Washington, DC, area, for which the percentage of tolls paid and economic welfare effects are reported by income quartile.[308] The results suggest that higher-income travelers are more willing to pay the toll, with quartile 1 (lowest) paying 10.70% and quartile 4 (highest) paying 40.10%. All income groups lose welfare, but the lowest-income quartile loses more (0.46%) than does the highest-income quartile (0.04%).

Equity measures for *VMT pricing* policies are available in the studies of the California regions, Sacramento, and EU regions.[309] The equity effects of a VMT fee are measured in the California scenarios as change in VMT by income quintile, as well as the daily payment (given a 5¢/mile fee) by quintile. The results show that lower-income groups adjust their travel modes more often than higher-income groups, with a VMT reduction of 4% to 13% for quintile 1 (lowest) and only a 1% reduction for quintile 5 (highest). Daily payments for the fee confirm this trend—quintile 1 pays only $0.9 million and quintile 5 pays $4.5 million (in 1980 dollars). The Sacramento study applies a traveler benefit measure (value of travel-time savings and monetary cost) by income class and finds that the lowest-income class loses most from the VMT polices ($1.58 per trip), followed by the middle-income groups ($0.77 per trip), and the high-income group ($0.70 per trip) (present value in 1990 dollars, and using the MEPLAN land-use model). The EU scenarios report reduced segregation in all regions except Dortmund (median = –0.7%, high = –74%, low = 0.01%, N = 14). Housing supply and affordability decline in all EU regions (median = 0.13, N = 21), with the exception of small improvements in Brussels and Dortmund. The declines are likely due to the larger share of income that is allocated to transportation costs.

The Washington, DC study measures the equity of the *fuel tax* through the amount of tax paid by income quartile, as well as travel-related welfare losses/gains.[310] Quartile 1 (lowest) pays 19.20%, while quartile 4 (highest) pays 29.40%; however, quartile 1 loses an average of $18 million annually (in 2000 dollars), while quartile 4 gains an average of $208 million annually. This suggests that the travel-time savings for high-income groups outweigh the increased operating costs, whereas low-income groups are worse off after the fee is imposed.

No equity performance measures for *emissions pricing* are reported in the studies reviewed.

The equity effects of *combined pricing* policies are limited to San Francisco's visioning study, which reports a 22.71% increase in the share of household budget spent on housing and transportation and increases of 69.68% and 73.51% in transportation costs as shares of household income for low- and middle-income households, respectively.[311]

Equity performance measures for *pricing and transit* policies are available for all studies that examine these policies except those in the UK. San Francisco's visioning study reports a 22.87% increase in the share of household budget spent on housing and transportation and increases of 71.95% to 71.89% in transportation costs as shares of household income for low- and middle-income households, respectively.[312] In Austin, change in housing mix decreases in single-family housing by 3.96%, increases in townhouses by 172%, and decreases multifamily housing by 3.17%.[313] The Sacramento study applies a traveler benefit measure (value of travel-time savings and monetary cost) by income class and finds that the lowest-income class loses most from the VMT polices ($3.60 per trip), followed by the middle-income groups ($0.97 per trip), while high-income groups gain $1.63 per trip (present value in 1990 dollars and using the MEPLAN model).[314] The EU scenarios report increases in segregation in all regions except Bilbao and Dortmund (median = 0.0%, high = –5.40%, low = 2.98%, N = 5).[315] Housing supply and affordability decline in all EU regions (median = –0.04%, N = 6) except Brussels and Helsinki. Again, the declines are likely due to the larger share of income allocated to transportation costs.

Equity performance measures for *combined pricing, land-use, and transit* policies are reported in all studies that examined these policies. San Francisco's visioning study reports an 11.51% increase in the share of household budget spent on housing and transportation and increases of 53.85% and 58.38% in transportation costs as a share of household income for low- and middle-income households, respectively.[316] The Sacramento study applies a traveler benefit measure (value of travel-time savings and monetary cost) by income class for two scenarios and finds that all income groups lose in the urban reserve and infill scenario (from $3.78 to $0.36 per trip), while all income groups gain in the urban growth boundary scenario (from $0.01 to $8.70 per trip) (present value in 1990 dollars and using the MEPLAN model).[317] In the first scenario, high-income groups are the most negatively affected, while in the second scenario, high-income groups have the highest gain. The EU scenarios increase segregation in all regions except Bilbao and Dortmund (median = 0.0%, high = –5.40%, low = 2.98%, N = 5).[318] Housing supply and affordability decline in all EU regions (median = –0.11, N = 6) except Brussels and Helsinki as a larger share of income is allocated to transportation costs.

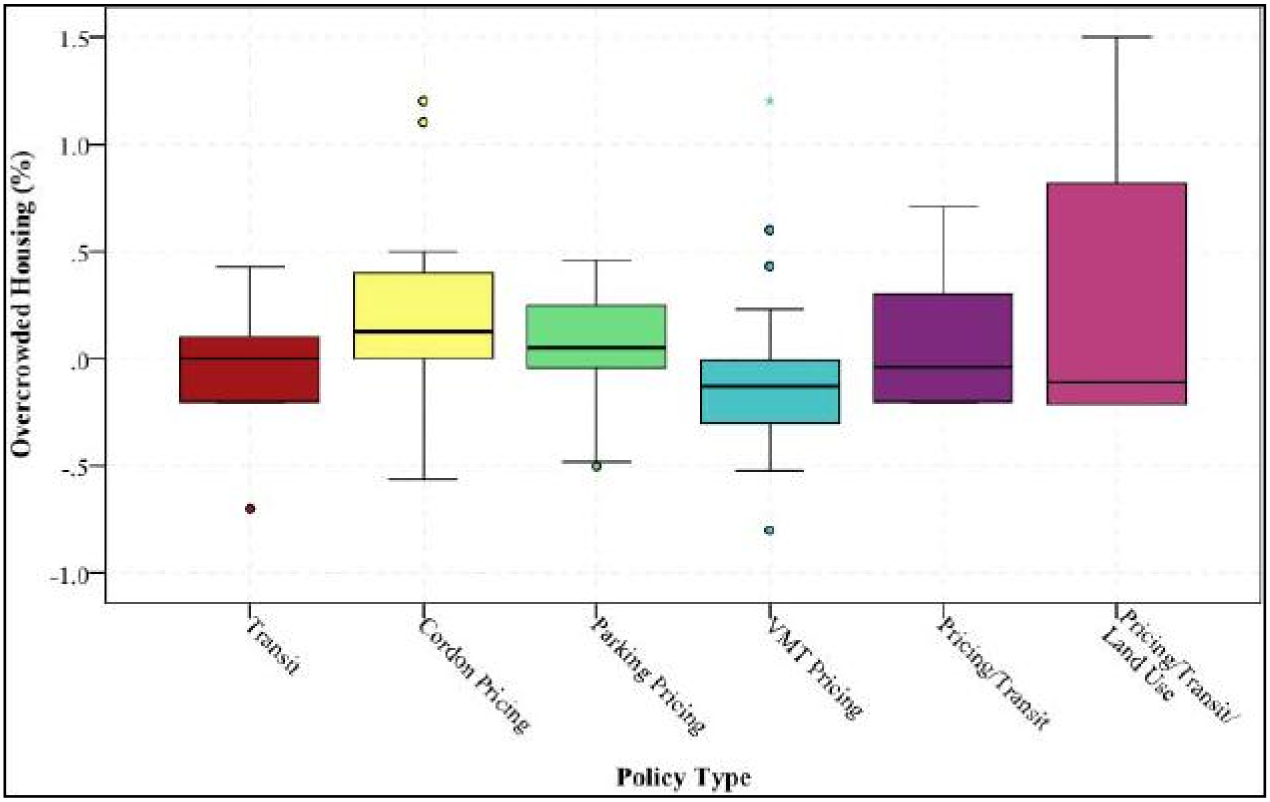

Figure 16. Overcrowded Housing[319] (N = 63)

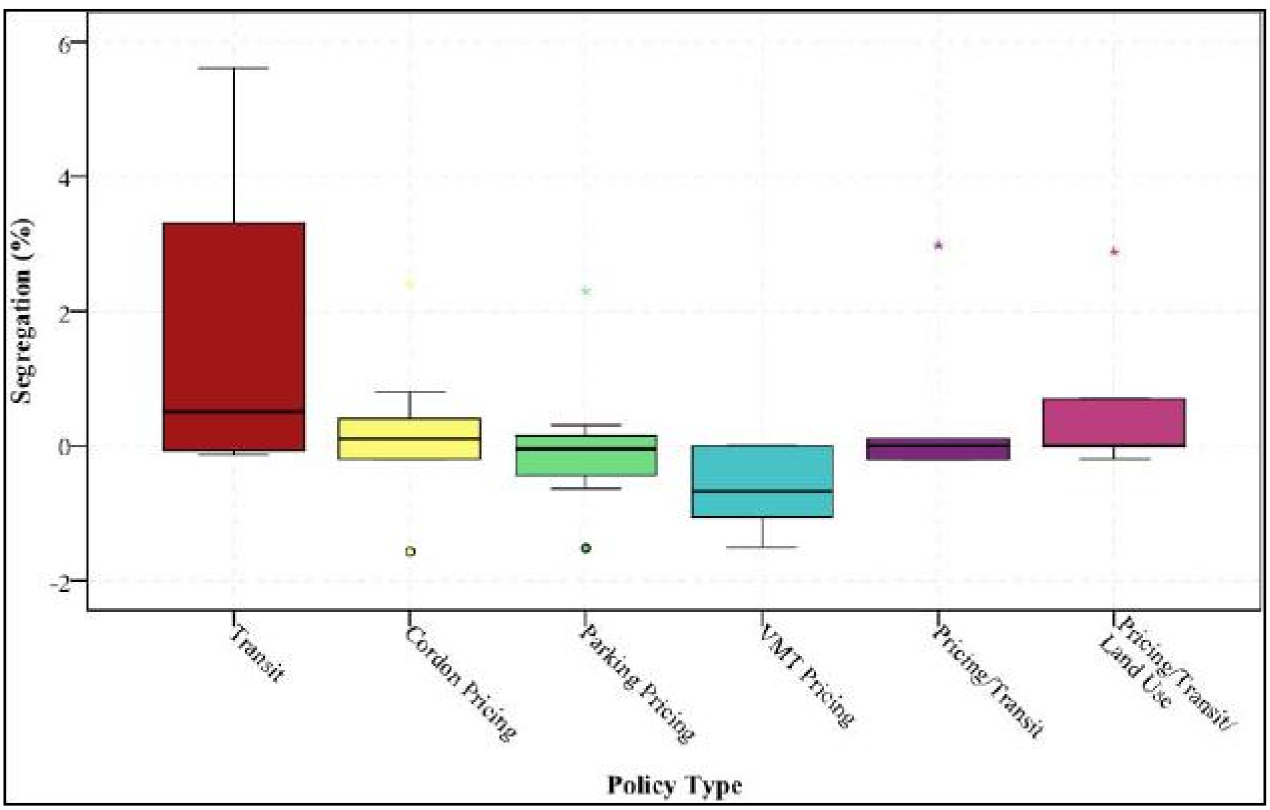

Figure 17. Segregation[320] (N = 63)

ECONOMIC PERFORMANCE

Economic performance measures are shown in Table 12. The change resulting from different policies is shown for consumer surplus, operator revenues, and externalities, with green arrows indicating a beneficial effect and red arrows indicating a negative effect. The change (in per capita 2000 dollars) provides a rough estimate of whether each policy provides an overall benefit or cost to society and allows an economic comparison to be made across policy types. One arrow denotes a change of $0 to $10; two arrows denotes a change of $10 to $100; three arrows denotes a change of $100 to $1,000; and four arrows denotes a change of more than $1,000.

Economic performance measures for *transit-only* policies are available from studies in Sacramento, San Francisco, UK regions, and EU regions.[321] In San Francisco, the share of household budget spent on housing and transportation increases by 0.8%. In Sacramento, traveler user benefits (value of travel time and monetary costs) per trip range from $0.01 (modest expansion simulated with a TDM and present value in 1995 dollars) to $11 (very aggressive expansion simulated with an ALUM and 1990 dollars) relative to the base-case scenario. In the UK, total consumer surplus increases by £1,765 to £15,387 (in 2002 pounds), total gross domestic product (GDP) increases from £678 to £5,327 (in 2002 pounds), and benefit-cost ratios range from 2.6 to 3.2. In the EU regions, total traveler benefits per capita (in 2002 euros) increase for all regions except Bilbao (median = €223, high = €1,554, and low = –€1, N = 6). Externality costs decrease for noise (median = €27, N = 6) except in Bilbao (–1€), as well as for GHG (median = 27€, N = 6) and emissions (median = €12, high = €164, and low = €2, N = 6). Accident costs also decrease in all EU regions except Helsinki (median = €16, N = 6). In addition, revenue for public transport operators is increased from 0.00% to 12.00%, while tax revenues from transport vary from –5.30% to 6.50% and revenues from car parking vary from –8.00% to 0.80%, depending on the mode shift in the region.

In San Francisco, economic performance measures for *land-use only* policies show an increase of 5.3% in employed residents and 1.3% in mean household income and a 10% reduction in mean household income allocated to transportation and housing costs.[322] In Philadelphia, measures indicate a 3% reduction in annual crashes and 32% decrease in supportive-infrastructure costs.[323] In Washington, DC, total annual traveler user benefits, including the value of travel time saved and reduced monetary travel costs, in simulated land-use only scenarios range from $94 million to $1,051 million (in 2000 dollars).[324]

Economic performance measures for *land-use and transit policies* in MTPs report total project expenditures ranging from $20 billion to $532 billion, depending on the size of the region. Los Angeles' MTP cites a cost-benefit ratio of 2.21 and accident reduction of –1.61%, while San Francisco's MTP reports a cost of $12 per VHD reduced per year, $2,630 to $8,365 per ton of particulate matter (PM) reduced per year, and $1,378 per 1,000 tons of CO_2 reduced per year (in 2007 dollars).[325] Visioning studies in Austin, Salt Lake City, and the Twin Cities show reductions in infrastructure cost ranging from 71% to 39%.[326] Sacramento's advanced study reports average consumer and producer surplus benefits.[327]

Economic performance measures for *cordon pricing* policies are available for Washington, DC, and the UK and EU regions.[328] In Washington, DC, changes in externality costs for accidents, air pollution, and climate are reduced by about 1%, and annual total traveler user benefits increase from $51.5 million to $86.3 million (in 2000 dollars). In the UK, the total annual change in traveler benefits is –£7,924 (in 2002 pounds), and the change in total GDP is –£1,207 (in 2002 pounds). In the EU regions, total annual traveler benefits per capita are reduced in Bilbao, Dortmund, Naples, and Vicenza, but they increase in Brussels and Helsinki (median = –€53, high = –€1,592, and low = €948, N = 6). However, as shown in Table 12, these decreases in consumer surplus are offset by increases in operator revenues and decreases in externalities. Externality costs decrease for noise (median = €35, N = 12), except in Bilbao and Helsinki, as well as for GHG (median = €63, N = 12), emissions (median = €60, N = 6), and accident costs (median = €16, N = 6), except in Bilbao. In addition, revenue for public transport operators increases from 0% to 12%, while tax revenues from transport vary from –5% to 7%, and revenues from car parking vary from –8% to 1% in the UK regions. Change in public transport operator revenues in the EU regions ranges from 0.4% to 19%, and tax revenues from transport range from –15% to 26%. Mode shifts and tax schemes in various regions influence the direction of change for revenues.

Economic performance measures are available for California and the EU regions.[329] The California scenarios measure the economic impacts of *parking pricing* through change in annual revenues, ranging from $142 million to $4,151 million (in 1980 dollars). In the EU regions, total annual traveler benefits per capita are reduced in all scenarios except those in Brussels (median = –€258, high = –€3,120, and low = €451, N = 12). As with cordon pricing policies, decreases in consumer surplus are offset by savings in revenues and externalities. Externality costs decrease for noise (median = €22, N = 12), except in Dortmund and Helsinki, as well as for GHG (median = €49, N = 12), emissions (median = €34, N = 12), and accident costs (median = €68, N = 12), except in Brussels. The change in public transport operators’ revenues ranges from –3% to 19%, tax revenues from transport decrease from –16% to 0%, and revenues from car parking increase from 20% to 360%.

Economic performance measures for *congestion pricing* scenarios are available for the California regions, Washington, DC, and the UK regions.[330] In California, annual revenues increase by $443 million to $7,343 million (in 1980 dollars) after the toll is implemented. Washington, DC, scenarios reduce externality costs by –19.37% to –2.09% and result in a consumer surplus ranging from –$226 million to $919 million (in 2000 dollars). Finally, scenarios in the UK suggest negative overall impacts on society, with decreases in consumer surplus of £39.7 million to £63.7 million (in 2002 pounds) and decreases in public transport operator revenues of £72,729 to £107,031.

Economic performance measures for *VMT pricing* policy scenarios are available for the California regions, Washington, DC, and the EU regions (see Figure 4).[331] The California scenarios measure economic impacts of a VMT fee through change in annual revenues ranging from $349 million to $3,144 million (in 1980 dollars). Scenarios in Washington, DC, decrease externality costs by 19% to 26% and increase total annual consumer surplus by $250 million to $434 million (in 2000 dollars). Total user benefits decline in all EU regions (median = €2,189, high = €5,093, low = €464, N = 21), and thus, on average, the value of time savings is not sufficient to offset the additional monetary costs. However, the overall effects on society are positive due to increased revenues and decreased externality costs. In the EU regions, revenues of public transport operators increase by 0% to 133%, revenues from car parking increase by 100% to –4%, and tax revenues from transport increase by –100% to 76%. The direction of change varies with the magnitude of mode shifts and regional tax and parking structures. Externality costs decline in all the EU scenarios (N = 21): noise (median = €615), GHG (median = €305), emissions (median = €149), and accident costs (median = €317) (in 2001 euros).

All *fuel pricing* study scenarios measure economic performance through change in annual revenues, which amounts to $734 million (in 2000 dollars) in the Washington, DC, scenario and from $414 million to $9,428 million (in 1980 dollars) in the California scenarios.[332] Average welfare loss to consumers in the Washington, DC, study is estimated to be $485 million annually (in 2000 dollars).

Economic performance for *emissions pricing* is measured through change in annual revenues, which ranges from $116 million to $1,106 million annually (in 1980 dollars).

Economic performance for *combined pricing* policies is measured in the California-regions scenarios through change in annual revenues, which ranges from $1,016 million to $20,206 million (in 1980 dollars).[333]

Economic performance measures for *pricing and transit* policies are available for San Francisco, the UK, and the EU regions.[334] San Francisco reports a total annualized capital and annual O&M cost of $4,931 million (in 2007 dollars). In the UK, total GDP is increased by £10,475 (in 2002 pounds), public transport operator revenues are increased by £1,951, parking revenues are increased by £1,214, taxes are increased by £11,176, and toll revenues are decreased by £74,573. Total user benefits decline in all EU regions except Helsinki (median = –€704, high = €6,138, low = –€3,656, N = 6), and thus, on average, the value of time savings is not great enough to offset the additional monetary costs.[335] However, in several scenarios, revenue increases and externality savings offset these consumer surplus decreases. The EU regions report changes in public transport operator revenues ranging from –25% to 104%, changes in car parking revenues from –38% to –7%, and changes in tax revenues from transport from –9% to 33%. The direction of change varies with the magnitude of mode shifts and regional tax and parking structures. Externality costs decline in all of the EU scenarios (N = 6): noise (median = €99), GHG (median = €366), emissions (median = €192), and accident costs (median = €451) (in 2001 euros). An EU study in Helsinki reports increases in total benefits ranging from €7,151 to €7,868 (in 2005 euros), savings in externalities from €1,406 to €2,328, transport user benefits from –€1,435 to €2,750, changes in government revenues from €1,147 to €3,242, and changes in operator net revenues from €2,565 to €3,016.[336]

Economic performance measures are available for *combined pricing, land-use, and transit* studies in San Francisco and the EU regions.[337] San Francisco reports a total annualized capital and annual O&M cost of $4,931 million (in 2007 dollars). The EU regions report changes in public transport operator revenues ranging from –22% to 106%, changes in car parking revenues of from –37% to –6%, and changes in tax revenues from transport of from –10% to 32%.[338] The direction of change varies with the magnitude of mode shifts and regional tax and parking prices. Total user benefits decline in all EU regions except Helsinki (median = –€704, high = €6,218, low = –€3,681, N = 6), and thus, on average, the value of time savings are not great enough to offset the additional monetary costs. Externality costs decline in all of the EU scenarios (N = 6): noise (median = €65), GHG (median = €383), emissions (median = €190), and accident costs (median = €437) (in 2001 euros). An EU study in Helsinki reports increases in total benefits ranging from €10,947 to €12,292 (in 2005 euros), savings in externalities ranging from €2,226 to €3,309, transport user benefits ranging from –€6,934 to –€3,626, changes in government revenues ranging from €15,291 to €16,003, and changes in operator net revenues ranging from –€1,600 to –€1,430.[339]

Table 12. Economic Performance Measures (in per capita 2000 dollars)

Policy Type	Location	Surplus	Revenues	Externalities
Transit	Sacramento[340]	↑		
	United Kingdom[341]	↑	↑ - ↑↑↑	
	Bilbao[342]	↓	↑	↑
	Brussels[343]	↑↑↑↑	↑↑↑	↓↓↓
	Dortmund[344]	↑↑↑	↑↑	↓↓
	Helsinki[345]	↑↑↑↑	↑↑↑	↓↓
	Naples[346]	↑↑↑	↑↑↑	↓↓↓
	Vincenza[347]	↑↑↑	↑↑	↓↓
Land-use	Washington, DC[348]	↑↑ - ↑↑↑		
Land-use/transit	Sacramento[349]	↑-↑↑		
	Washington, DC[350]	↑↑		↓↓
Cordon pricing	United Kingdom[351]	↓	↑↑↑	
	Bilbao[352]	↓↓↓↓	↑↑↑	↑↑↑
	Brussels[353]	↑↑↑ - ↑↑↑↑	↑↑↑↑	↑↑↑
	Dortmund[354]	↓↓↓	↑↑ - ↑↑↑	↓↓↓
	Helsinki[355]	↑↑↑	↑↑↑↑	↓↓↓↓ - ↓↓↓
	Naples[356]	↓↓ - ↑↑	↑↑	↓↓↓↓ - ↓↓↓
	Vincenza[357]	↓↓↓ - ↓↓	↑↑↑	↓↓↓
Parking pricing	CA regions[358]		↑↑↑	
	Bilbao[359]	↓↓↓↓	↑↑↑	↓↓↓
	Brussels[360]	↑↑↑	↑↑↑	↓↓ - ↑
	Dortmund[361]	↓↓↓	↑↑↑↑	↓↓↓ - ↓↓
	Helsinki[362]	↓↓↓↓ - ↓↓↓	↑↑↑	↓↓↓
	Naples[363]	↓↓↓	↑↑↑	↓↓↓
	Vincenza[364]	↓↓↓	↑↑↑	↓↓↓ - ↓↓
	CA regions[365]		↑↑↑	
Congestion pricing	Washington, DC[366]	↓↓ - ↑↑↑		↓↓↓ - ↓↓
	United Kingdom[367]	↓↓↓ - ↓↓	↓↓↓↓↓	

VMT pricing	CA regions[368]		↑↑↑	
	Washington, DC[369]	↑↑↑		↓↓↓
	Bilbao[370]	↓↓↓↓	↓↓↓ - ↑↑	↓↓↓
	Brussels[371]	↓↓↓↓	↑↑ - ↑↑↑	↓↓↓↓ - ↓↓↓
	Dortmund[372]	↓↓↓↓	↑↑ - ↑↑↑	↓↓↓↓ - ↓↓↓
	Helsinki[373]	↓↓↓↓ - ↓↓↓	↓↓ - ↑↑↑	↓↓↓
	Naples[374]	↓↓↓↓	↑↑ - ↑↑↑	↓↓↓↓ - ↓↓↓
	Vincenza[375]	↓↓↓↓	↓↓ - ↑↑	↓↓↓↓ - ↓↓↓
Fuel pricing	CA regions[376]		↑↑↑ - ↑↑↑↑	
	Washington, DC[377]	↓↓	↑↑↑	
Emissions pricing	CA regions[378]		↑↑ - ↑↑↑	
	CA Regions[379]		↑↑↑ - ↑↑↑↑	
	United Kingdom[380]		↓↓↓↓↓	
Pricing and transit	Bilbao[381]	↓↓↓↓	↓↓↓	↓↓
	Brussels[382]	↓↓↓↓	↓↓↓	↓↓↓
	Dortmund[383]	↓↓↓↓	↓↓↓	↓↓↓↓
	Helsinki[384]	↑↑↑↑	↓↓↓↓	↓↓↓↓
	Naples[385]	↓↓↓	↓↓↓	↓↓↓↓
	Vincenza[386]	↓↓↓	↑↑↑	↓↓↓↓
	Edinburgh[387]		↑↑ - ↑↑↑	
	Helsinki[388]	↑↑↑	↓↓↓ - ↑↑↑↑	
Pricing, transit and land-use	Bilbao[389]	↓↓↓↓	↓↓↓	↓↓↓
	Brussels[390]	↓↓↓↓	↓↓↓	↓↓↓
	Dortmund[391]	↓↓↓↓	↓↓↓	↓↓↓↓
	Helsinki[392]	↑↑↑↑	↓↓↓↓	↓↓↓↓
	Naples[393]	↓↓↓	↓↓↓	↓↓↓↓
	Vincenza[394]	↓↓↓	↑↑↑	↓↓↓↓
	Edinburgh[395]		↓↓ - ↑↑↑	
	Helsinki[396]	↑↑↑	↓↓↓	↓↓↓↓

NOTE: Externalities for Washington, DC, studies include air-pollution, accident, climate change, oil dependency, and noise costs; externalities for EU studies include accidents, emissions, GHG, and noise costs.

VI. CONCLUSIONS

In an era of limited resources and a proliferation of data, there is increasing pressure to conduct careful evaluations of the economic, environmental, and equity effects of investments and policies that influence transportation and land-use systems. This report compares performance measures recommended to achieve desired goals and reviews the literature to determine the degree to which these measures have been implemented and what they indicate about the relative effectiveness of land-use, transit, and automobile pricing policies.

Many of the studies we reviewed used traditional or updated four-step travel-demand models. Visioning tools were used in many studies to enter alternative, but fixed, land-use patterns in the travel model. Some studies used both land-use and transportation models and thus allow changes in the transportation system to influence land-development patterns, which in turn influence the transportation system.

The survey of performance measures suggests that most of the recommended measures have not been implemented in transportation and land-use planning studies in the United States. More of the measures have been implemented in European studies.

Travel performance measures, such as access, proximity, choice, and congestion, can be obtained from advanced four-step models; however, the new generation of ABMs should improve the quality of travel-time and cost estimates across a broader range of modes (including local and long-distance trucks) and more-detailed categories of activities and destination locations.

The survey showed little commonality in the equity measures implemented in studies to date. This is an area in which regional stakeholders have the opportunity to come together to clearly articulate concerns and evaluate the ability of available tools to measure the impact of policies on those concerns. Current advanced travel models can examine changes in accessibility by a limited number of income categories and relatively coarse geographic areas. Activity-based travel models can provide more-detailed representation of sociodemographic characteristics of individuals, households, and geographic areas. Spatial economic models are necessary to calculate the displacement of disadvantaged populations due to policies and plans that increase rents in certain areas.

Few economic performance measures have been implemented in the United States. Regional governments and community groups have evaluated the financial cost of transportation plans but rarely their cost-effectiveness. Regional visioning studies are more likely to evaluate financial effects of built form; however, these evaluations are typically based on information generalized from the literature. Measures of consumer and producer surplus must be evaluated with spatial economic models. Since few of these are operational in the United States, the measures are rarely implemented.

Environmental performance measures related to energy, air quality, and climate change have been frequently evaluated. In the United States, visioning studies are generally used to evaluate effects of projects on sensitive lands, habitats, ecosystems, and water. Most of these evaluations are based on external specification of land-development patterns created through consultation, using community visioning tools. However, these patterns do not explicitly consider the effect of economic factors (including changes in transportation systems) that are known to play an important role in the actual form and location of new development. Spatial economic models are needed to evaluate these factors as well.

Despite the variation in methods and performance measures implemented in the studies reviewed for this report, the synthesis of study results suggests the direction and relative magnitude of change resulting from different types of policies, as well as potential biases introduced by omitting the representation of the land-use and transportation interaction. Overall, the performance measures indicate that carefully designed transit, land-use, and automobile pricing policies may improve travel, economic, environmental, and equity conditions for communities. However, transit and peak-period automobile pricing policies can, in some situations, lead to negative performance outcomes across some or all measures, as illustrated in studies that explicitly represent the land-use and transportation interaction.

ABBREVIATIONS AND ACRONYMS

ABM	Activity-Based Model
ALUM	Advanced Land-Use Model
ARB	California Air Resources Board
CBD	Central Business District
EPA	Environmental Protection Agency
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
LUM	Land-Use Model
MPO	Metropolitan Planning Organization
MTC	Metropolitan Transportation Commission
MTP	Metropolitan Transportation Plan
NTPP	National Transportation Policy Project
O&M	Operation And Maintenance
OD	Origin And Destination
REMI	Regional Economic Models, Inc.
RTAC	Regional Technical Advisory Committee
SACOG	Sacramento Area Council Of Governments
SANDAG	San Diego Association Of Governments
SCAG	Southern California Association Of Governments
TDM	Travel-Demand Model
TREDIS	Transportation Economic Development Impact System
UK	United Kingdom
VHD	Vehicle Hours Of Delay
VMT	Vehicle Miles Traveled

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Funded by U.S. Department of Transportation and California Department of Transportation