Los Angeles County
Metropolitan Transportation Authority

Quantifying the Influence of Transit on Land Use Patterns in Los Angeles County

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Metro

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Executive Summary

Metro's buses and trains are an integral part of Los Angeles County's urban fabric. Angelenos take 1.3 million trips per day on Metro's vehicles to travel between home, work, school, and shopping destinations. As the County continues to grow, some new housing, employment, and retail destinations are attracted to major transit nodes. Metro's Transit Oriented Development (TOD) projects, now thriving around several rail stations, are a case in point. In catalyzing these compact developments, Metro's influence on transportation patterns extends beyond the buses and trains it operates daily. People who live and work in compact developments not only ride transit more often, but also walk and bike more and make shorter driving trips. These indirect effects of transit contribute to an overall greener transportation system.

Metro conducted this study in accordance with APTA's "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit" ('the APTA Protocol').[1] The APTA Protocol encourages transit agencies to take credit for their land use impacts in calculating their impacts on GHG emissions. It proposes that agencies use a default national 'land use multiplier' of 1.9, applied to an estimate of vehicle miles traveled (VMT) reduced directly through mode shift, to estimate the indirect impact that transit systems have on VMT via land use patterns. The APTA Protocol also recommends that transit agencies determine their own land use multipliers through studies such as this one. At present, the transit industry is actively working to refine the concepts and techniques used to estimate the impacts that transit systems have on land use patterns, including the concept of the land use multiplier.

This study tests two approaches for quantifying the relationship between Metro's transit service and land use patterns in Los Angeles County. We use a regression analysis to track changes in population and employment densities in Los Angeles County over time. This time series approach attempts to tease out any systemic relationship between Metro's major transit nodes and patterns of growth over the last 20 years. Recognizing that various factors may affect development patterns in the County, the time series analysis asks whether areas around rail stations and major bus transfer points on average experience denser development than other places.

A separate regional comparison analysis examines the transportation patterns of the average resident of Los Angeles County. Specifically, we compare the amount that Angelenos travel by car and by transit to the travel patterns of other regions' residents. Differences in travel patterns are at least partially shaped by differences in land use patterns. We also test the regional comparison analysis on sub-regions within Los Angeles County.

The two approaches produce results that are complementary, if not directly comparable. The time series analysis tracks *changes* in land use patterns around transit nodes over relatively short periods of time, from 1990-2010. The regional comparison approach compares current travel patterns at the county level, which are the result of many decades of transportation and development history. It asks how travel patterns in Los Angeles would be different if the

1 American Public Transportation Association, "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit", August 2009.

transportation network and land use patterns were like those of a neighboring region. Both approaches are informed by previous studies in the field.

For the time series analysis, we constructed models to test the hypothesis that population and employment densities have increased more rapidly near major transit nodes than elsewhere over the last 20 years. We used separate models for population and employment. The models also incorporated other possible predictors of densification: pre-existing densities, proximity to freeway ramps, proximity to a central business district (CBD), and industry mix. We found only weak evidence to support the hypothesis. Areas near major transit nodes had a very slight tendency to see higher employment growth rates than other areas. They had no consistent tendency to see higher growth in population.

The results of the time series analysis stand in contrast to the visible results of Metro's TOD projects, where some of Metro's transit stations have clearly catalyzed compact development patterns. Both the presence of a rail station and Metro's program promoting the use of Metro-owned land around stations for transit oriented developments have been essential to these projects. Still, Los Angeles remains a multi-centric region whose modern history is substantially shaped by the automobile. Even as significant developments have occurred around some rail stations, development has continued in many parts of the County far from rail stations and major bus transfer points. The model results indicate that the County has grown in areas not adjacent to transit nodes in addition to areas adjacent to transit nodes.

The regional comparison approach compared average levels of driving and transit use in Los Angeles County to levels in the rest of the Southern California Association of Governments (SCAG) region, of which Los Angeles County is a part. When compared to residents of surrounding counties, Los Angeles County's residents are significantly more likely to choose transit over travel in private vehicles. In addition, residents of Los Angeles County travel fewer miles per year in motorized vehicles than residents of neighboring counties—likely because of denser land use patterns in Los Angeles that permit shorter trips and more walking and biking. For every additional mile traveled on transit by Angelenos versus their neighbors in the SCAG region, Angelenos eliminated almost 8 miles of driving.

The regional comparison approach presented some methodological challenges at geographical scales larger or smaller than a county. The assumptions underpinning the approach appear to break down when comparison regions of different scales are used. Data quality is an issue for smaller geographical areas. We examined travel patterns as well as land use patterns in nine sub-regions in Los Angeles County. There was a high level of consistency among different measures of sustainable land use patterns (density, land use mixing, street network connectivity, and jobs accessibility) within individual sub-regions; however, the regional comparison approach did not produce reasonable results for most of the sub-regions.

This study shows that *recent* patterns of development in Los Angeles County have not been substantially altered by transit infrastructure, in spite of several success stories at Metro's TODs. Still, historical transit infrastructure very likely contributed to denser development patterns in Los Angeles than in surrounding counties. The results of this study do not preclude a greater shift in development patterns toward transit in the future. Los Angeles' modern rail system has existed for only 20 years, a relatively short period in the development history of American cities. Meanwhile Metro's Measure R projects are adding 236 miles of rail and bus rapid transit lines to the system, accompanied by targeted TODs, over a 30 year period. The next few decades of transit and land use development in Los Angeles may therefore tell a different story.

Following the APTA protocol, the results of this study suggest Metro can use a multiplier of 5.3, a conservative result drawn from the regional comparison analysis conducted in this study, to calculate its land use impacts. However, as Los Angeles' urban development pattern does not appear consistent with various assumptions underpinning the regional comparison concept, a rethinking of the multiplier concept in the APTA methodology is therefore recommended for future studies.

1. Introduction

1.1. Purpose of the Study

Transit is an essential part of the urban fabric in Los Angeles County. Metro's 2,200 buses and 142 miles of rail track provide approximately 1.3 million trips per day for the County's 9.8 million residents. Around half of those trips would be made by driving a car if Metro's buses and trains were not available. Keeping those additional cars off the road on a daily basis is the direct impact of Metro's service on transportation patterns.

Metro's service also affects land use patterns in the County in the longer term. For example, Metro has worked actively in recent years to promote compact transit oriented developments (TOD) around many of its rail stations. These TODs consist of high-density mixed residential, commercial, and entertainment uses, which depend on Metro's service for transportation of many residents, workers, and visitors. Proximity to high capacity transit means that Los Angeles' TODs can provide less parking than an average development in the region. Less parking means more space for additional apartments or retail space, which increases the potential development densities. The availability of high quality transit can also increase land values, making higher density development economically viable.[2]

By helping to shape land use patterns, Metro has an indirect impact on travel patterns in Los Angeles County. A substantial body of literature finds that people living and working in transit rich areas tend to make more trips by foot and bike—as well as shorter car trips when they do drive— than people living in areas without transit. Much of this pattern is attributed to the typical land use patterns that go along with transit. Transit rich areas tend to be more densely developed; in fact, the presence of transit enables denser development patterns that give rise to more biking and walking, and shorter car trips.[3]

The relationship between transit systems and land use patterns is an area of ongoing research. Quantifying the relationship is of particular interest to the transit industry. APTA's "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit" ('the APTA Protocol')[4]encourages transit agencies to take credit for their land use impacts in calculating their impacts on GHG emissions. Metro conducted this study in accordance with the APTA Protocol, in order to further the state of knowledge about the impacts of transit on land use. This study also supports the APTA Sustainability Commitment, to which Metro is a signatory.

This study tests two approaches for quantifying the relationship between Metro's transit service and land use patterns in Los Angeles County. Quantification of this relationship is important for two reasons. First, quantification provides an understanding of the relative importance of

[2] ICF International for American Public Transportation Association, "The Broader Connection between Public Transportation, Energy Conservation and Greenhouse Gas Reduction," February 2008.

[3] Ibid.

[4] American Public Transportation Association, "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit", August 2009.

Metro's transit service in shaping land use patterns in the region, versus other factors that drive development. Second, quantification provides an opportunity to describe the relationship at the regional scale, beyond individual developments clustered around transit nodes.

In that context, this study addresses the question: how much do the land use patterns induced by Metro's transit service allow for biking and walking trips, and shorter driving trips? These indirect impacts can be translated into savings in transportation energy and greenhouse gas emissions, thereby creating a more complete picture of the impact that Metro's buses and trains have in Los Angeles County.

1.2. Previous Studies

The multiplier recommended by APTA is drawn from the only study that has quantified the transit-land use relationship at the national scale: Bailey et al. (2008).[5] APTA's recommended multiplier of 1.9 represents the average cumulative impact of a U.S. transit system on land use patterns over many decades. The multiplier is applied to an estimate of VMT reduced directly through mode shift from private vehicles to transit.[6] The resulting number represents VMT reduced by transit indirectly, via its impact on land use.

Table 1 provides a summary of other studies that have quantified a land use multiplier. Values range from 1.3 to 9; however the results of these studies are not directly comparable to one another since they have used different methodological approaches and focused on different geographical areas.

Table 1: Summary of Land Use Multiplier Studies[7]

Study	Cities	Land-Use Multiplier
Pushkarev & Zupan (1982)	U.S. metro areas with at least 2 million population	4
Newman & Kenworthy (1999)	32 global cities	5 to 7
Holtzclaw (2000)	Matched pairs in the San Francisco Bay Area	1.4 to 9
Neff (1996)	U.S. urbanized areas	5.4 to 7.5
Bailey et. al. (2008)	Entire U.S.	1.9
New York MTA (2009)	MTA Service Territory	1.29-6.34

The primary challenge in quantifying the relationship between transit and land use patterns is determining the extent to which transit systems are responsible for densification of land use

5 ICF International for American Public Transportation Association, "The Broader Connection between Public Transportation, Energy Conservation and Greenhouse Gas Reduction," February 2008.

6 The APTA guidance calculates this mode shift as transit passenger miles divided by the average occupancy of private vehicles (default 1.39).

7 Excerpted from American Public Transportation Assocation, "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit", August 2009.

patterns. That high capacity transit systems are generally found in dense urban environments is indisputable. Specific examples of transit playing a key role in catalyzing compact development are also plentiful, such as Metro's TODs, but there are many forces that shape urban development patterns. Most analytical approaches are incapable of proving the extent to which transit is a primary or key factor in densification. Therefore most analyses must make assumptions about the degree to which transit is a generative factor, rather than a supporting or coincidental factor, in land use densification.

While providing a default multiplier figure that any transit agency in the United States can use, the APTA Protocol recognizes that the history of transit systems shaping urban development varies from region to region. Accordingly, the Protocol encourages individual transit agencies to conduct their own regional studies of the transit-land use connection.

1.3. Description of this Study

This study began with an examination of methods that could be used to quantify the indirect impact that Metro's transit service has on travel in Los Angeles County via land use patterns. A Phase I memo (dated January 21, 2011) examined four possible approaches. These were compared in terms of availability of data, level of effort to implement, accuracy and credibility of results, ease of communication, ability to be applied at the sub-regional level, and ability to be replicated in other urban regions. The Phase I memo is provided as an appendix to this report.

Two approaches were selected for application in Phase II of the study. Each approach has widely different pros and cons. The two approaches selected for application were:

- *Time Series Analysis* (called Approach 2 in the Phase I memo) - This approach uses regression analysis to analyze and predict changes in density near transit over time. Specifically this analysis looks for increases in urban densities near rail and bus lines in Los Angeles over a period of 20 years (1990-2010).
- *Regional Comparison Analysis* (called Approach 3 in the Phase I memo) – This approach compares travel patterns in denser and less dense areas.

This study examined but did not apply the structural equations modeling (SEM) approach used in Bailey et al (2008). The SEM approach offers a superior ability to determine a causative relationship between transit networks and land use patterns; however, the approach is time consuming and particularly difficult to explain. The SEM approach was not selected, in part so that more than one approach could be tested.

Sections 2 and 3 of this report describe the application and results of each approach. Section 4 examines the transit-land use relationship at the sub-regional level. Section 6 concludes.

2. Tracking Changes in Density over Time

2.1. Description of Method

The time series analysis quantifies the degree to which proximity to transit in Los Angeles County is associated with increases in density between 1990 and 2010. This approach hypothesizes that areas closer to rail stations and key bus transfer points densify more rapidly than areas farther from transit. A regression model is used to test the hypothesis and quantify the relationship.

The time series analysis tracks real changes in land use densities over time. The results can be understood in terms of recent historical developments in Los Angeles County. On the other hand, the results are constrained to the time span for which data are available. The modeling exercise does not comment on how transit systems influenced land use patterns in earlier periods in Los Angeles County's history, or how the system might influence land use patterns in future years.

2.2. Previous Studies

Two previous studies have used a time series approach to analyze the effect that rail stations have on densification of land use patterns. Both found little or no systemic effect of rail stations on land use densities.

Cervero and Landis (1997) examined change in development patterns over time in their study of the BART rail system. They established a model to predict the likelihood of vacant land development near BART stations by comparing matched pairs of BART stations and nearby freeway interchanges in the Richmond and Fremont corridors. Variables that were found to predict development included proximity to the BART station, amount of developable land, and levels of land-use mixture. Cervero and Landis used existing land use densities and neighborhood locations as control variables. The study did not control for the impact of land use policies. Although proximity to BART stations did increase the likelihood of vacant land development, most BART stations did not appear to have had a significant effect on development patterns. Land use changes around BART stations were limited to downtown Oakland, downtown San Francisco, and a handful of suburban stations. The authors posited that neighborhood opposition or a lackluster real estate market have limited changes elsewhere.[8]

Kolko et al (2011) examined changes in employment density around new rail stations that opened in California between 1992 and 2006. Like Cervero and Landis, Kolko established matched pairs of station areas and non-station areas. Changes in station area employment densities were compared to changes in the control group of matched pairs. For each station area, Kolko selected comparison areas based on similarities in land use density, proximity to a

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[8] Cervero, Robert and John Landis, "Twenty Years of the Bay Area Rapid Transit System: Land Use and Development Impacts," *Transportation Research A*, vol. 31, No. 4, pp. 309-333, 1997.

central business district (CBD), proximity to older rail stations, and proximity to highways. Kolko also controlled for national level economic trends that might affect employment growth in Los Angeles. On average, the study found no increase in employment growth around stations after the station opened. There was a discernible tendency for employment to grow more rapidly before stations opened, which suggests that rail stations are located in fast growing areas.[9]

These two studies highlight the multitude of factors that affect densification in urban areas. They also show the difficulty of demonstrating that transit investments affect land development patterns. Pre-existing land use patterns, amounts of vacant land, and proximity to other types of infrastructure and services may all affect development patterns. In addition, planning factors such as neighborhood support and proactive policy makers also play a role.

2.3. Analysis

The previous studies have looked for density changes in discrete areas of ½ mile around rail stations. In contrast, our approach analyzed all areas of Los Angeles County, allowing for rail systems to affect densities countywide. We also analyzed the impact that bus systems have had on development densities. Metro has an extensive system of buses providing service to most parts of the County. At least one previous study has suggested that bus systems have no effect on land use patterns.[10] Accordingly we focused our analysis on the components of bus systems most likely to attract development: transfer points between high capacity bus routes. These are the places with the best bus access in Los Angeles County, which should act as distinct attractors for new development.

Table 2 lists the primary variables and data sources used in the regression model. Historical population and employment densities are the dependent variables of interest. The modeling exercise attempts to explain how Metro's transit system has affected these variables, while controlling for other variables that may affect land use development patterns.

Calculating each variable required several steps. For example, creating a trend line of population densities required some geospatial analysis to match census geographies across years, since the boundaries of census geographies change from decade to decade. Calculating the distance of each location to the nearest Metro rail station required recreating historical rail maps and measuring distances in a Geographical Information Systems (GIS) software package. Calculating the distance to the nearest transfer point between high capacity bus routes required a GIS analysis to determine places where bus lines overlap. An examination of historical Metro bus maps determined that Metro's current rapid bus corridors have generally been primary bus corridors historically. Therefore the current locations of rapid bus transfer points were assumed to represent high capacity bus transfer points from 1990 to 2010.

[9] Kolko et al, "Making the Most of Transit: Density, Employment Growth, and Ridership around New Stations," Public Policy Institute of California, February 2011.

[10] Baxandall, P., T. Dutzik, and Joshua Hoen Frontier Group, A Better Way to Go: Meeting America's 21st Century Transportation Challenges with Modern Public Transit, California's Public Interest Research Group (CalPIRG) Education Fund, Sacramento, 2008.

Table 2: Time Series Analysis -Variables and Data Sources

Variable	Primary Data Source
Population Density (1990, 2000, 2010)	U.S. Census
Employment Density (2002, 2009)	Longitudinal Employer Household Dynamics
Predicted Employment Growth (2002-2009)	Longitudinal Employer Household Dynamics
Distance to Nearest Rail Station (1990, 2000, 2002, 2009, 2010)	Metro System Maps
Distance to Nearest Rapid Bus Transfer (1990, 2000, 2002, 2009, 2010)	Metro System Maps
Distance to Nearest Freeway Ramp (1990, 2000, 2002, 2009, 2010)	Freeway Map
Distance to Central Business District (1990, 2000, 2002, 2009, 2010)	1982 Census of Retail Trade

Population and employment data were available for different time periods and at different geographical resolutions. Employment data from the Longitudinal Household Employer Dynamics (LEHD) dataset are reported at the level of census blocks, the smallest unit of census geography. In order to match population datasets across years, population data were aggregated at the level of census block groups, a larger geographical unit. As a result of these spatial and temporal mismatches, we used separate models for population and employment density.

The basic forms of the models tested are described in Table 3. We tested the ability of a series of independent (or explanatory) variables to predict changes in density (the dependent variable) over time. The primary independent variables of interest (denoted with a * in the table) are distances to rail stations and rapid bus transfer points. A finding that these variables are significant predictors of changes in density would corroborate the theory of a transit-land use connection in Los Angeles County. The remaining independent variables are included as control variables. These were included in the models specified in the previous studies.(See Section 2.2). Including these variables, which may also predict changes in density, helps to isolate the impact of the primary variables of interest. Control variables include existing densities, distance to freeway, and distance to CBD. CBDs were identified using the 1982 Census of Retail Trade. An additional economic variable was included to control for national trends in employment growth that could affect employment in Los Angeles County. This predicted employment variable was calculated using a method described in Kolko et al.[11] Also included are dummy variables for individual cities in Los Angeles County. These control for any other localized factors that may drive changes in land use patterns within individual cities.

[11] Kolko et al, "Making the Most of Transit: Density, Employment Growth, and Ridership around New Stations," Public Policy Institute of California, February 2011.

Table 3: Basic Models Tested

Model 1 – Change in Employment Density, 2002-2009	Model 2 – Change in Population Density, 1990 – 2000	Model 3 – Change in Population Density, 2000 – 2010
Dependent Variables		
Change in Employment Density (increase in jobs per square mile, 2002-2009)	Change in Population Density (increase in residents per square mile, 1990-2000)	Change in Population Density (increase in residents per square mile, 2000-2010)
Independent (Explanatory) Variables		
Distance to Nearest Rail Station in 2002 (miles)*	Distance to Nearest Rail Station in 1990 (miles)*	Distance to Nearest Rail Station in 2000 (miles)*
	Distance to Nearest Rail Station in 2000 (miles)*	
Distance to Nearest Rapid Bus Transfer (miles)*	Distance to Nearest Rapid Bus Transfer (miles)*	Distance to Nearest Rapid Bus Transfer (miles)*
Employment Density in 2002 (jobs per square mile)	Population Density in 1990 (residents per square mile)	Population Density in 2000 (residents per square mile)
Distance to Nearest Freeway Ramp (miles)	Distance to Nearest Freeway Ramp (miles)	Distance to Nearest Freeway Ramp (miles)
Distance to Central Business District (miles)	Distance to Central Business District (miles)	Distance to Central Business District (miles)
Predicted Employment in 2009 (jobs per census block)		
Dummy Variables by Jurisdiction	Dummy Variables by Jurisdiction	Dummy Variables by Jurisdiction

** primary explanatory variables of interest*

Several variations on each model were tested in order to find the model that best explains changes in density over time. We tested models that excluded areas of the county that declined in density, positing that areas that lose population or employment are subject to a different set of forces than areas that gain population or employment. In general, the explanatory power of the models increased when areas that declined in density were removed. This result suggests that the explanatory variables used are better able to predict increases in population and employment density than decreases in population and employment density. We also tested models using natural log transformations of the distance and density variables. Log transformations allow for a non-linear relationship between variables. For example, using a log transformation of distance to rail allows that a change in distance from 0.5 to 1 mile has a bigger effect than a change in distance from 5 to 5.5 miles. A non-linear relationship is consistent with conventional wisdom, which holds that willingness to walk to transit drops off sharply in the 0-1 mile range. (Kolko demonstrates this non-linear relationship using data from the 2000 Census Transportation Planning Package.)[12]A half mile change in distance makes less of a difference to

[12] Kolko et al, "Making the Most of Transit: Density, Employment Growth, and Ridership around New Stations," Public Policy Institute of California, February 2011.

people living and working farther from transit, who would access transit via some mode other than walking.

Table 4 presents the results of the final regression model for employment (Model 1 in Table 3). The model excludes areas that declined in employment density and uses log transformations of variables. Starred variables are the primary explanatory variables of interest. Results for dummy variables are not shown, since there are over 100 such variables. Any variable with a p-value less than 0.05 is deemed to be a (statistically) significant predictor of change in employment density with 95% confidence.

Both distance to the nearest rail station and distance to the nearest rapid bus transfer point are significant in this model, though the magnitudes of their effects on the density change are quite low. A 10% decrease in distance to rail for a given census block is associated with a 0.95%higher rate of densification. A 10% decrease in distance to a rapid bus transfer point is associated with a 0.72% higher rate of densification. These effects are of a higher magnitude than the effects associated with distance to a freeway ramp and distance to the CBD; however, the strongest predictor of densification by far is pre-existing employment densities.

To illustrate the model results, we consider an average census block in Los Angeles County with a land area of 0.04 square miles and containing 107 jobs in 2002. The census block has an employment density of 2,675 jobs per square mile. We assume that the census block is 10 miles from the nearest Metro rail station. We first consider a scenario in which there is no change in the rail system. From 2002 to 2009, the census block would be expected to add 3.9 jobs, based on average observed growth rates over the period. We then consider a second scenario in which a new rail station opened ½ mile away from the census block in 2002. The census block would then be expected to add 4.2 jobs between 2002 and 2009. At this rate of change, it would take centuries for the impact on density associated with the new rail station to become visibly noticeable in the urban environment.

Table 4: Employment Model Results

Independent Variable	Coefficient	Standard Error	P-value
Intercept	3.239	0.057	<.0001
log of Distance to Nearest Rail Station in 2002*	-0.095	0.015	<.0001
log of Distance to Nearest Rapid Bus Transfer Point*	-0.072	0.010	<.0001
log of Employment Density in 2002	0.530	0.006	<.0001
Log of Distance to Nearest Freeway Ramp	-0.049	0.012	<.0001
log of Distance to CBD	-0.041	0.015	0.0046
Predicted Employment in 2009	<0.000	<0.000	0.0033
Sample	Excludes areas that lost employment		
Dependent Variable	Log of Change in Employment Density		
R-squared	0.456		

** primary explanatory variables of interest*

Table 5 and Table 6 present the results of the final regression models for population (Models 2 and 3 in Table 3). The models exclude areas that declined in population density and use log transformations of variables. In both population models, distance to the nearest rapid bus transfer point is a significant predictor of densification, but distance to the nearest rail station is not. Census block groups closer to bus transfer nodes tended to gain population more rapidly from 1990-2000, controlling for other factors; however, census block groups closer to bus transfer points tended to gain population *less* rapidly from 2000-2010. Consistent with the employment models, pre-existing density is the strongest predictor of an increase in population density.

Table 5: Population Model Results, 1990-2000

Independent Variable	Coefficient	Standard Error	P-value
Intercept	0.759	0.352	0.031
log of Distance to Nearest Rail Station in 1990*	0.011	0.055	0.835
log of Distance to Nearest Rail Station in 2000*	-0.004	0.051	0.941
log of Distance to Nearest Rapid Bus Transfer Point*	-0.060	0.027	0.029
log of Population Density in 1990	0.664	0.034	<.0001
log of Distance to Nearest Freeway Ramp	0.013	0.032	0.678
log of Distance to CBD	0.089	0.042	0.034

Independent Variable	Coefficient	Standard Error	P-value
Sample	Excludes areas that lost population		
Dependent Variable	Log of Change in Population Density		
R-squared	0.302		

** primary explanatory variables of interest*

Table 6: Population Model Results, 2000-2010

Independent Variable	Coefficient	Standard Error	P-value
Intercept	-0.726	0.362	.0451
log of Distance to Nearest Rail Station in 2000*	-0.037	0.037	0.320
log of Distance to Nearest Rapid Bus Transfer Point*	0.082	0.027	0.002
log of Population Density in 2000	0.767	0.036	<.0001
log of Distance to Nearest Freeway Ramp	-0.009	0.031	0.772
log of Distance to CBD	0.130	0.040	0.001
Sample	Excludes areas that lost population		
Dependent Variable	Log of Change in Population Density		
R-squared	0.276		

** primary explanatory variables of interest*

2.4. Results

On balance, the model results suggest that rail stations and major bus transfer nodes are weakly associated with densification of employment in Los Angeles County; however, these results should be interpreted with caution. The model indicates only that rail stations and transfer points for rapid bus lines are statistically associated with densification. It does not prove that rail stations cause densification. In other words, densification may occur in part because of the presence of rail stations, or Metro may simply open rail stations in areas that would see densification of employment with or without rail.

There is no consistent evidence that rail stations and major bus transfer nodes are associated with densification of population in Los Angeles County over the last 20 years.

These results are not completely unexpected, for several reasons:

- Past studies have shown that demonstrating the effects of transit on land patterns with a time series analysis is challenging, and some studies have failed to show any impact at all, as discussed in Section 2.2.
- Land development occurs slowly, particularly in built-out areas like Los Angeles County. The 20-year time frame used for this analysis may not be long enough to show land use impacts. Metro's first modern rail line opened in 1990, and a number of Metro's rail stations are less than 10 years old.
- Many different factors affect land development, and it is impossible to control for all these factors. Some of these factors may obscure the effects of transit.
- Despite an early history of development patterns based around extensive rail systems, Los Angeles County's modern development history has been substantially shaped by a preference for and dependence on the private automobile. Taking the last two decades of development history in isolation, it is certainly possible that transit systems have not played a large role in determining development patterns in Los Angeles.

Still, the model results stand in contrast to anecdotal evidence of densification around rail stations in the form of Metro-led TODs. The model results also do not capture the influence that transit has had on land use patterns in any period prior to 1990, and they do not speak to the potential for increased densification around transit infrastructure in the future.

3. Comparing Travel Patterns in Different Areas

3.1. Description of Method

The regional comparison analysis is a simple non-statistical technique to estimate the influence that transit has on all travel patterns in a region, including driving, walking, and biking trips. This approach depends on a comparison of two existing regions. For example, travel patterns in Los Angeles County can be compared to travel patterns in neighboring, more suburban counties. The comparison asks how much additional driving would occur in Los Angeles County, due to longer driving distances and fewer trips made by walking and biking, if land use patterns in the County looked like land use patterns elsewhere.

The regional comparison analysis posits a tradeoff between travel in private vehicles (vehicle miles traveled or VMT) and passenger miles traveled on transit (transit PMT). To illustrate, consider an urban community where the average resident drives 2 miles a day and takes transit 5 miles a day, and a suburban community where the average resident drives 10 miles a day and takes transit 1 mile a day. A resident moving from the suburban community to the urban community can be expected on average to decrease his driving by 8 miles a day, while increasing his transit use by 4 miles a day. On balance this resident will eliminate 4 miles of motorized travel altogether ((10+1) – (2+5) = 4). This extra four miles of travel saved is attributed to urban land use patterns that facilitate shorter driving trips and more walking and biking. More efficient urban land use patterns are at least partially dependent on the availability of transit. Each additional mile traveled on transit by the new city dweller therefore effectively eliminates 2 miles of driving ((10-2)/(5-1) = 2).

Using the regional comparison analysis, a 'leverage factor' for Los Angeles County is calculated as follows:

$$\text{Transit leverage factor} = \frac{\text{comparison region VMT per capita} - \text{Los Angeles County VMT per capita}}{\text{Los Angeles County transit PMT per capita} - \text{comparison region transit PMT per capita}}$$

This approach depends on two key assumptions:

- There is a tradeoff between VMT and transit PMT, such that in a comparison region where people drive more on average than residents of Los Angeles County, people take transit less on average than residents of Los Angeles County.
- A total decrease in motorized travel per capita in Los Angeles County versus a comparison region is directly attributable to differences in land use patterns and indirectly attributable to differences in transit availability.

The results of the analysis depend heavily upon the comparison area chosen.

3.2. Previous Studies

The regional comparison analysis was first described by Holtzclaw (2000). Holtzclaw used this approach to compare urban to suburban communities in the San Francisco Bay Area. Comparing San Francisco to suburban Danville-San Ramon, he found that every mile traveled on transit by San Franciscans was associated with a reduction of 8 VMT.[13]

Booz Allen Hamilton (BAH) applied a similar approach in their study for the New York Metropolitan Transportation Authority (NYMTA). Although the calculation method was different, the theory behind the analysis was the same; the average travel patterns in a comparison region can be compared to the average travel patterns in a control region in order to approximate the indirect effect of transit on travel patterns (via land use). BAH's approach substituted key travel variables from the comparison area for those in the control area. BAH estimated that the GHG emissions indirectly reduced through land use are 4.85 times greater than the GHG emissions emitted by NYMTA.[14]

[13] Holtzclaw, John, "Does A Mile In A Car Equal A Mile On A Train? Exploring Public Transit's Effectiveness In Reducing Driving," 2000. Available at: http://www.sierraclub.org/sprawl/articles/reducedriving.asp

[14] Booz Allen Hamilton for New York Metropolitan Transportation Authority, "Impact of Public Transportation on GHG In The MTA Area," MTA Blue Ribbon Commission on Sustainability, May 2009.

3.3. Analysis and Results

This analysis used data from the 2009 National Household Travel Survey (NHTS), which is based on a sample of U.S. households. The NHTS surveyed about 1 out of every 500 households in the Southern California Association of Governments (SCAG) region. VMT per capita and PMT per capita for California and the U.S. were sourced from the NHTS web portal. Figures for smaller geographical areas are not available online. Estimates for Los Angeles County and for other counties in the SCAG region were provided by Caltrans, sourced from the NHTS.

Table 7 contains the data and calculated transit leverage factors for Los Angeles County and comparison regions. We compared Los Angeles County to each of the five other counties in the SCAG region, as well as to averages for California and the United States. In 2009, the average LA County resident drove about 5,800 miles and rode transit about 300 miles. In the rest of the SCAG region, the average resident drove about 7,100 miles and rode transit 130 miles. Los Angeles County's transit leverage factor, when compared to the rest of the SCAG region, is 7.8. That is, for every additional mile traveled on transit by a resident of L.A. County, 7.8 miles of driving were eliminated.

Table 7: Comparison Regions and Transit Multipliers for Los Angeles County

Geographical Area	Annual VMT per capita	Annual PMT per capita	Transit Leverage Factor for Los Angeles County*
Control Region			
Los Angeles County	5,771	305	N/A
Comparison Regions			
Orange County	6,657	139	5.3
Riverside County	7,850	69	8.8
San Bernardino County	7,332	151	10.1
Ventura County	6,830	218	12.2
Imperial County	5,766	0	N/A
SCAG Region (excluding L.A. County)	7,138	130	7.8
California	6,760	338	N/A
U.S.	7,932	425	N/A

**For some comparison regions, the transit leverage factor is not applicable (N/A), as explained below.*

When L.A. County is compared to other individual counties in the SCAG region, transit multipliers range from 5.3 (Orange County) to 12.2 (Ventura County). These results are generally consistent with the range of results reported in the literature (see Table 1).

Estimates of driving and transit ridership from the NHTS are less reliable in smaller regions and in less populated regions, because survey sample sizes are smaller in these areas. The reported VMT and PMT per capita for Imperial County are inconsistent with other evidence from the NHTS and with generally observed patterns.[15] Residents of sparsely populated areas such as Imperial County are expected to drive more than residents of Los Angeles County. We therefore discard results from Imperial County as unreasonable.

Estimates for California and the U.S. are surprising when compared to Los Angeles County. The average California resident both drives more miles per year and takes transit more miles per year than the average L.A. County resident. The same holds true for the average U.S. resident. These results indicate that California and the U.S. are not reasonable comparison regions for Los Angeles County, since there is no tradeoff between VMT and transit PMT. California and the U.S. contain many urban, suburban and rural areas, with development patterns both denser and less dense than those of Los Angeles County. Comparing average travel behavior in Los Angeles County to behavior in areas so much larger and more diverse than Los Angeles County yields little information.

Comparing Los Angeles County to the surrounding SCAG region provides more of an 'apples to apples' comparison than comparing the County to the state or the nation. Los Angeles County is part of the same urban mega-region as other counties in the SCAG region. These areas are subject to many of the same forces of infrastructure availability and housing and employment markets that affect transportation patterns. Comparing Los Angeles County to the surrounding SCAG can therefore control for some of the additional factors that affect travel patterns.

4. Los Angeles County Sub-regions

This study also explored how the influence of transit on land use patterns varies from area to area within Los Angeles County. Over periods of many years, transit service in one area may catalyze denser development patterns, and therefore more walking and biking, than in another area. Existing land use patterns in Los Angeles County reflect historically different patterns of transit infrastructure.

We considered how the transit-land use relationship varies within Los Angeles County sub-regions, in conjunction with varying land use patterns. Los Angeles County is itself a diverse area, ranging from a dense downtown of skyscrapers to sprawling suburbs to sparsely populated rural areas. Figure 1 shows the eight sub-regions within Los Angeles County as designated by SCAG:

- Arroyo Verdugo
- San Gabriel Valley Council of Governments (SCVCOG)
- Gateway Cities
- South Bay Cities
- Westside Cities

[15] VMT and PMT per capita are calculated using the NHTS Trips File. Information from the NHTS Persons file suggests that residents of Imperial County drive more on average than residents of Los Angeles County.

- City of Los Angeles
- Las Virgenes Malibu
- North Los Angeles County.

We further subdivided the North Los Angeles County sub-region into incorporated and unincorporated areas. These nine sub-regions were analyzed for land use patterns that may indicate different transit-land use relationships.

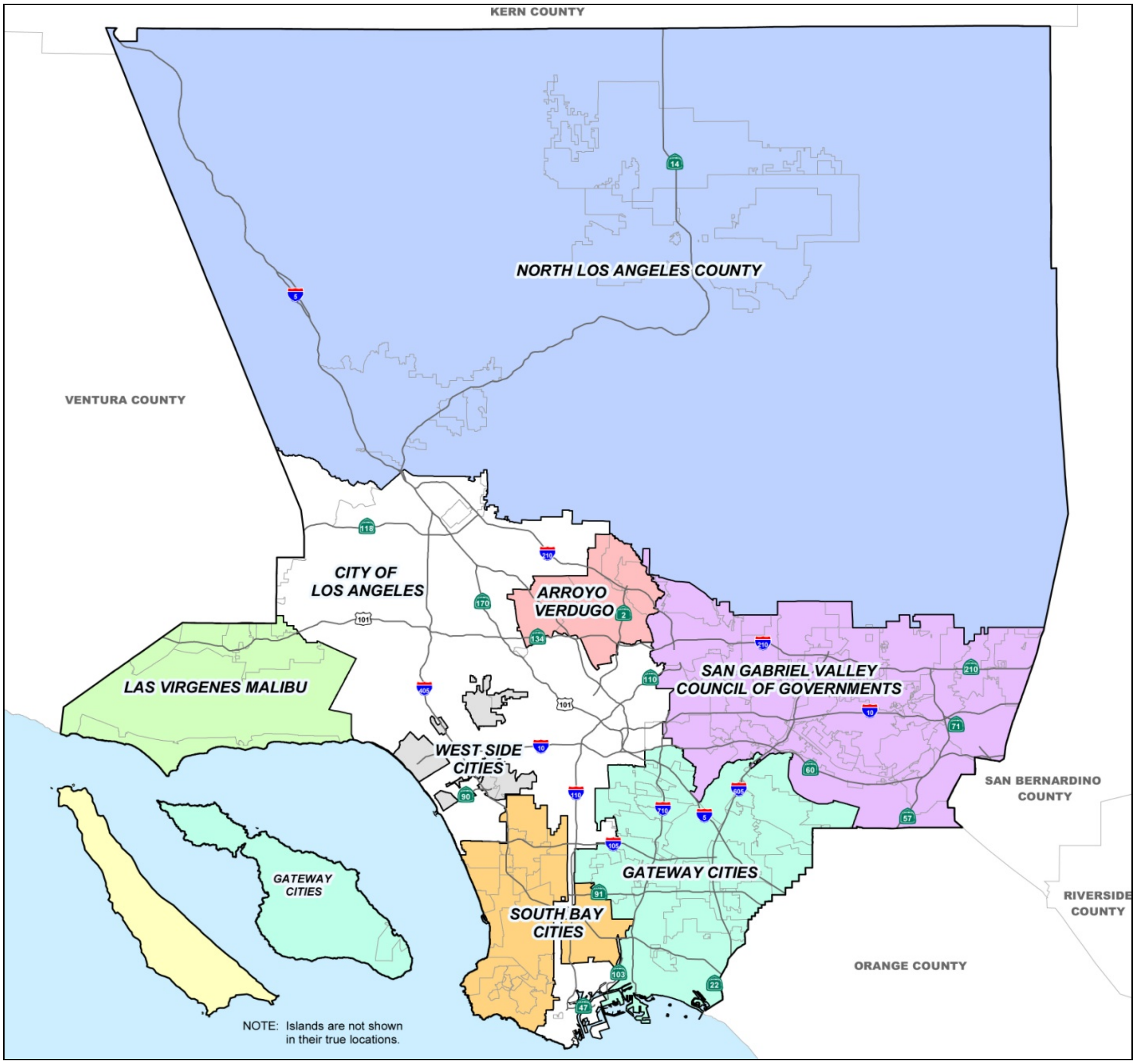
The indirect effects of transit service explored in this report include increased walking and bicycling trips and shorter driving trips. These types of travel behavior are linked to a set of land use characteristics known as the 'D' variables. As documented most recently by Ewing and Cervero, the 5 Ds are:

- Density – referring to land use density
- Diversity – referring to mixing of land use types
- Design – referring to pedestrian-friendly street design
- Destination accessibility – referring to the number of trip attractions, such as jobs, accessible within a given travel time
- Distance to transit – referring to the average distance to the nearest transit station or stop[16]

Each of these variables is negatively correlated with VMT and positively correlated with walking. In other words higher densities, more land use mixing, and better street design generally mean less driving trips and more walking trips. Since the D variables can be used to describe any community, they can potentially be used to characterize the transit-land use relationship in one area versus another.

[16] Ewing, Reid and Robert Cervero, "Travel and the Built Environment," *Journal of the American Planning Association*, 76: 3, 265 – 294, 2010

Figure 1: SCAG Sub-Regions in Los Angeles County[17]



EPA's Smart Location Index is a new GIS-based tool that calculates values for many of the D variables at the census block level nationwide. Using this dataset we calculated average values for several of the D variables for sub-regions of Los Angeles County. Rankings for each of these variables are compared qualitatively below.

[17] Excerpted from the County of Los Angeles Draft General Plan (2008), Figure 2.4

Figure 2 compares land use densities (calculated as total population and jobs per square mile) in the sub-regions. The Westside Cities have by far the highest average density, at more than 16,000 jobs and residents per square mile. Arroyo Verdugo, South Bay Cities, City of Los Angeles, and Gateway Cities have densities ranging between 10,000 and 12,000 jobs and residents per square mile. The two North County sub-regions and Las Virgenes Malibu have densities far below the other sub-regions.

Figure 2: Density of Los Angeles County Sub-regions

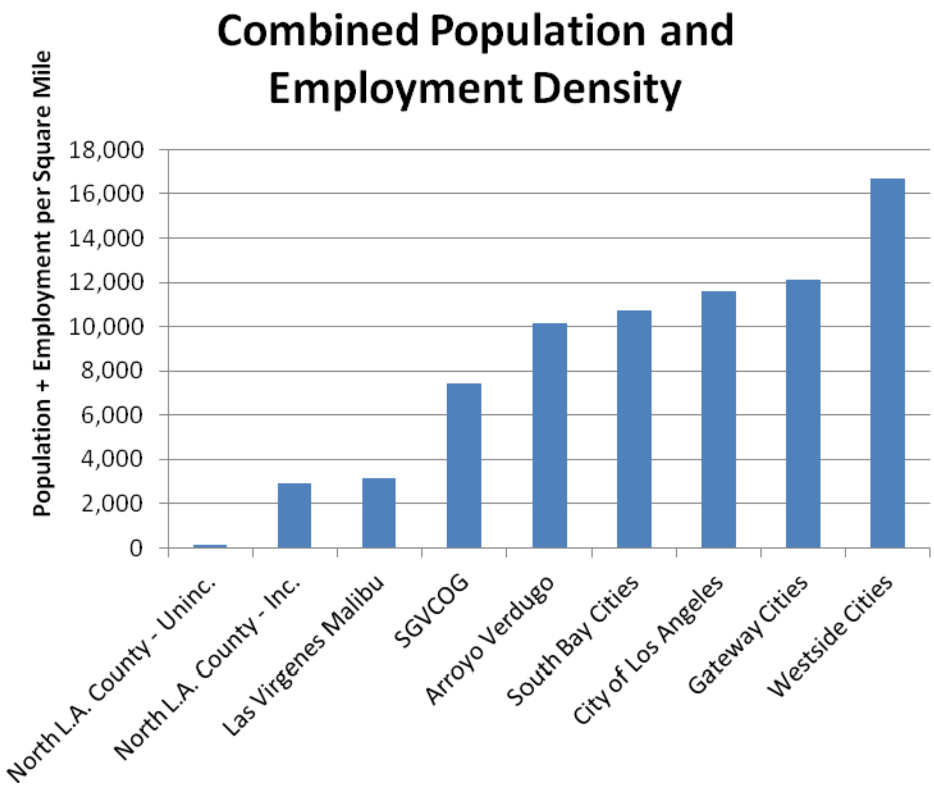


Figure 3 compares land use diversity in the sub-regions. Higher index values indicate great levels of mixing. The pattern of land use mixing among the sub-regions is very similar to the pattern for land use densities. Westside Cities stand out as having a particularly high level of land use mixing in the County. The two North County sub-regions and Las Virgenes Malibu have by far the lowest degree of mixing.

Figure 3: Land Use Diversity of Los Angeles County Sub-regions

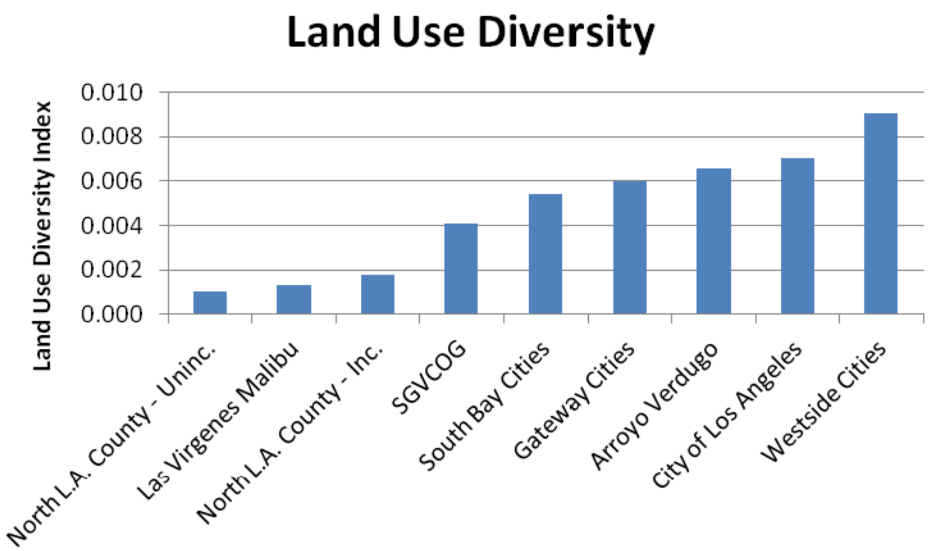


Figure 4 compares average intersection density (a measure of urban design) across Los Angeles County sub-regions. Once again, Westside Cities is at the top of the ranking, with the two North County sub-regions and Las Virgenes Malibu at the bottom. The average resident of the Westside Cities lives in an area with about 800 intersections per square mile. This suggests a highly walkable street grid. In contrast the average resident of the unincorporated areas of North Los Angeles County lives in an area with less than 300 intersections per square mile.

Figure 4: Intersection Density (Pedestrian Design) of Los Angeles County Sub-regions

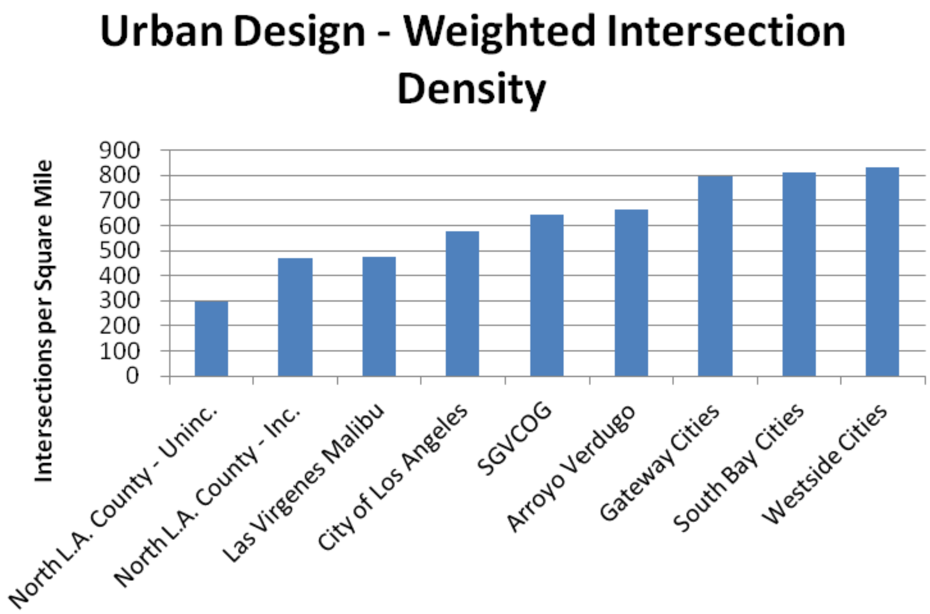
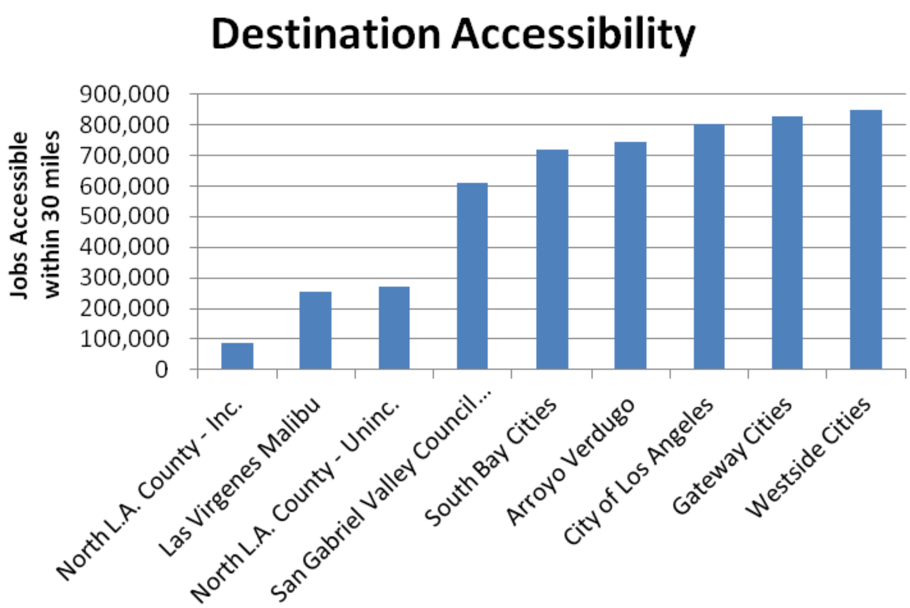


Figure 5 compares destination accessibility, in terms of the number of jobs accessible within 30 miles, across Los Angeles County sub-regions. Accessibility is weighted by travel times, such that areas with more roadway congestion are given lower accessibility ratings. Westside Cities again has the highest rating. The average resident in these areas can access more than 800,000 jobs within a 30 mile drive. Gateway Cities and the City of Los Angeles have similar accessibility ratings. Again the two North County sub-regions and Las Virgenes Malibu rank lowest.

Figure 5: Destination Accessibility of Los Angeles County Sub-regions



At a glance, the relative scores of these 4 D variables—density, diversity, design, and destinations—appear to be highly correlated among Los Angeles County sub-regions. The regions with the highest densities are also the regions with the highest rates of land use mixing, pedestrian friendly design, and destination accessibility. Higher scores on these D variables suggest lower rates of driving and higher rates of walking and bicycling. These are travel patterns associated with a more robust transit-land use connection.

Using the variables reported above, we conducted a preliminary test of the theory that areas with higher ratings of the 'D' variables should have more robust transit-land use relationships. VMT per capita and transit PMT estimates from the NHTS were gathered for the individual sub-regions, and these were compared to figures for Los Angeles County and the rest of the SCAG region to calculate transit leverage factors using the regional comparison approach. Many of the resulting leverage factors were well outside the range of results reported in the literature (see Table 1). As a result, the regional comparison analysis was not useful at the sub-regional level. This outcome is likely due in part to inaccurate estimates from the NHTS, since the survey sample sizes are very small in some sub-regions.

Still, the D variables offer a promising means of characterizing the transit-land use relationship across different urban regions or sub-regions. These variables have a quantitative relationship to rates of driving, walking, and transit use that is well documented in the literature. A more robust analysis of the transit-land use relationship, perhaps using one of the statistical analysis approaches explored in this study, could incorporate these variables to see how they influence or predict the co-evolution of transit and land use patterns over time. Ultimately this kind of information could be used to create a typology of land-use transit relationships across multiple urban regions, effectively characterizing the transit-land use relationship for all urban areas in the U.S.

5. Conclusions

This study tested two very different methods for analyzing the influence that transit systems have on land use patterns. The first method, a time series analysis that tracks changes in density over time, attempted to tease out any systemic relationship between Metro's major transit nodes and patterns of growth over the last 20 years. Recognizing that growth in employment and population has occurred throughout Los Angeles County since 1990, the first method looked for evidence that growth has been consistently concentrated near major transit nodes. Similarly to previous studies applying this method, this effort found only weak evidence that areas near rail stations and rapid bus transfer points have seen higher growth than other areas, when controlling for other factors that affect urban development patterns.

Some of Metro’s transit stations have clearly catalyzed compact development patterns. Transit oriented developments around rail stations at Hollywood and Highland, Hollywood and Western, Union Station, and others are excellent examples of development patterns that promote less motorized travel, above and beyond their effect on transit ridership. Both the presence of a rail station and Metro’s program promoting the use of Metro-owned land around stations for transit oriented developments have been essential to these projects.

In spite of the anecdotal evidence for compact development around transit, Los Angeles County as a whole remains an area that has developed on a different pattern. The traditional form of urban areas has a gradation of densities from a compact core to lower density suburbs. In contrast, Los Angeles is a multi-centric urban area with densities that are broadly uniform. Each of the County’s centers acts separately to attract development. This multi-centric development pattern has been undeniably shaped by automobile travel in recent decades. Automobiles became an essential means of transportation in Los Angeles during the mid-20th century, as the County steadily shut down rail lines and built freeways. Nearly universal travel by car facilitated lower density, sprawling development patterns. Not until 1990 did Los Angeles again have passenger rail, affording opportunities for new transit oriented development. Still, car travel remains a powerful influence on development patterns in Los Angeles, as suggested by our model results. Even as significant developments have occurred around some rail stations, development has continued in many parts of the County far from rail stations and major bus transfer points. The model results indicate that the County has grown in areas not adjacent to transit nodes in addition to areas adjacent to transit nodes.

On a broader scale, the second method tested suggests that Los Angeles' historical and modern transit infrastructures have contributed to more sustainable travel patterns in the County. The regional comparison method characterized travel patterns in Los Angeles County relative to travel patterns in other regions. When compared to the surrounding counties, Los Angeles County residents are significantly more likely to choose transit over travel in private vehicles. In addition, residents of Los Angeles County travel fewer miles per year in motorized vehicles than residents of neighboring counties—likely because of denser land use patterns in Los Angeles that permit shorter trips and more walking and biking. In the early 20th century, Los Angeles had one of the most extensive rail systems in the world. That infrastructure helped to shape the County as a denser region than its neighbors, whose development histories are more closely tied to the automobile.

The first analysis method applied shows that recent patterns of development in Los Angeles County have not been substantially altered by transit infrastructure. Even so, these results do not preclude a greater shift in development patterns toward transit in the future. Los Angeles' modern rail system has existed for only 20 years, a relatively short period in the development history of American cities. The rail and bus rapid transit system has expanded rapidly in that time and will continue to expand rapidly. Metro's Measure R projects are adding 236 miles of rail and bus rapid transit lines to the system over a 30 year period, providing many more opportunities for TOD. With this expansion comes an opportunity for greater recognition of the value of high capacity transit among Angelenos. When residents, employees, and employers place more value on proximity to transit, developers will place more value on proximity to transit also.

Metro conducted this study in accordance with the APTA Protocol, which encourages transit agencies to establish land multipliers for their own regions. APTA's recommended multiplier of 1.9 represents the average cumulative impact of a U.S. transit system on land use patterns over many decades. In this study, the time series analysis did not find strong evidence of transit's effects on land use on a countywide basis; however, the analysis examined a limited 20 year timeframe of Metro's history, which is not representative of the cumulative impact of transit in Los Angeles. The results of the time series analysis are therefore not recommended for application in place of the average national multiplier. Results from the time series analysis should instead be used to understand the short-term impacts of Metro's transit system on land use.

The comparison approach, on the other hand, demonstrated a substantial difference in travel patterns between Los Angeles County and surrounding counties. This difference is attributable to differences in land use patterns, which are linked to differences in transit systems. The results from this method are within the range of results for the land use multiplier reported in the literature. They are also consistent with the scope of the average national multiplier proposed by APTA, in that they capture the cumulative impacts of many decades of transportation investments and urban development. Results from the comparison approach range from a multiplier of 5.3 to 12.2, depending on the comparison area chosen. To conservatively apply these results, Metro can use a value of 5.3 as its land use multiplier. The multiplier is applied to an estimate of VMT reduced directly through mode shift from private vehicles to transit.[18] The resulting number represents VMT reduced by transit indirectly, via its impact on land use.

At present, the transit industry is actively working to refine the concepts and techniques used to estimate the impacts that transit systems have on land use patterns, including the concept of the land use multiplier. Since Los Angeles' urban development pattern does not appear consistent with various assumptions underpinning the regional comparison concept a rethinking of the multiplier concept in the APTA methodology is therefore recommended for future studies.

Future work on this topic should attempt to resolve the apparent discrepancies between the two approaches applied in this study. Transit agencies need both more evidence of the impact that their systems have on land uses and more precise information about the magnitude of those impacts. Studies of urban development patterns in the recent past may not confirm transit's role as a catalyst of compact development. In these cases, studies should examine the degree to which supportive planning and investment policies can increase the magnitude of transit's effect on land use in future years.

[18] The APTA guidance calculates this mode shift as transit passenger miles divided by the average occupancy of private vehicles (default 1.39).

Appendix: Phase I Memo

MEMORANDUM

To:	Cris Liban, Los Angeles County Metropolitan Transportation Authority
From:	Frank Gallivan, ICF
Date:	January 21, 2011
Re:	Methodologies for a Land Use Multiplier Study for Los Angeles County (Phase I Memo)

This memo summarizes work performed to date to establish a methodology to calculate a land use multiplier for Los Angeles County. In Phase I of this project, ICF has researched four potential methodologies. Our findings and recommendations and contained herein. This memo will form the basis for the selection of a methodology or methodologies to be applied in Phase II of the project.

The land use multiplier represents the indirect impact that transit systems have on non-transit travel patterns by inducing or facilitating compact development. For the purposes of this study, the land use multiplier is defined as the ratio of this indirect impact to the direct impact that transit systems have in shifting travel in private vehicles to buses and trains. Therefore, the land use multiplier can be used to scale up the passenger miles traveled on Metro services to reflect the total impact of Metro on travel patterns in Los Angeles County.

Description of Research

Four methodologies are explored in this memo:

1. Structural Equations Model (SEM) to determine the inter-relationships of transit availability, urban form, and trip making
2. Time series analysis to predict changes in density near transit over time
3. Comparison of travel patterns in denser and less dense areas
4. A sketch-modeling approach to estimate the impact of transit service and policies on non-transit trips

The methodologies vary in terms of statistical complexity and the results produced. Methodologies are explained further below.

Research in Phase I included a review of the relevant literature on calculating relationships between transit availability, land use patterns, and non-transit travel behavior. The general literature on these topics is expansive. Likewise the literature on relevant statistical techniques is substantial. Therefore only the most directly relevant sources were explored at this stage of the project. These include:

- ICF International for American Public Transportation Association, "The Broader Connection between Public Transportation, Energy Conservation and Greenhouse Gas Reduction," February 2008

- Cervero, Robert and John Landis, “Twenty Years of the Bay Area Rapid Transit System: Land Use and Development Impacts,” *Transportation Research A*, Vol. 31, No. 4, pp. 309-333, 1997
- Booz Allen Hamilton for New York Metropolitan Transportation Authority, “Impact of Public Transportation on GHG In The MTA Area,” MTA Blue Ribbon Commission on Sustainability, May 2009
- Holtzclaw, John, “Does A Mile In A Car Equal A Mile On A Train? Exploring Public Transit's Effectiveness In Reducing Driving,” 2000. Available at: http://www.sierraclub.org/sprawl/articles/reducedriving.asp

Several other studies referenced in Holtzclaw (2000) and in the American Public Transportation Association’s (APTA) “Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit (2009) were examined. These were determined to use methodologies very similar to the above referenced core studies.

For each of the core studies examined, we documented the types of data that would be needed to conduct a similar analysis for the LA Metro region, as required for approaches considered in this research. We then compared these data needs to the available data sources. We also considered the pros and cons of each of the approaches considered as highlighted by the available literature and our own professional judgment. Each of the approaches was assessed according to the following criteria:

- *Availability of data* – What data sources are available, and what knowledge gaps about data remain
- *Level of effort to implement* – Roughly how many steps and how many staff hours are needed to execute the methodology (not including reporting findings)
- *Accuracy and credibility of results* – As determined by the ability of the technique to wholly or partially calculate a land use multiplier as defined above. The likely accuracy of each method depends on both the statistical technique applied and the theoretical basis for the technique. Credibility refers to the likely acceptance of the results by the broader transportation industry.
- *Ease of communication* – How readily can both the technique used and the results be communicated to both transportation industry audiences and other audiences?
- *Ability to be applied at the sub-regional level* – This project will also estimate land use multipliers for sub-regions within Los Angeles County. As such, techniques should be applicable to individual cities or groups of cities.
- *Ability to be replicated in other urban regions* – While this study focuses on a land use multiplier or multipliers for Los Angeles County, the transit industry needs multiplier information that can be applied in urban areas across the country. To the extent possible, the technique(s) applied here should be replicable elsewhere.

Summary of Findings

The table below provides summary assessments of each of the four approaches according to the criteria above. Complete descriptions of each methodology and criteria assessment are provided in subsequent sections.

Criteria	Approach 1: SEM	Approach 2: Time Series	Approach 3: Comparison	Approach 4: Sketch Modeling
Availability of Data	Basic data are available, but additional data needs could be identified.	Basic data are available. Requires less data than Approach 1 but more than Approach 3.	Basic data are available. Requires less data than all other approaches.	Varies by policy element. Will play a determining factor in deciding which policy elements to quantify.
Level of Effort	High	Medium	Medium-Low	Medium-Low
Accuracy and Credibility	Potentially the most accurate, since quantifies causation; but results are difficult to verify. No guarantee that a credible result will be determined.	Tracks correlation rather than causation, but results are easier to verify than with SEM. Would depend on generic 5D elasticities. No guarantee that a credible result will be determined.	Tracks correlation rather than causation. Limited selection of comparison areas inhibits broader application.	Provides information on the relative impact of various initiatives rather than a complete accurate picture of transit's indirect impacts.
Ease of Communica tion	Technique is difficult to explain, but result is relatively easy to explain.	Probably the easiest to communicate.	Both technique and result are somewhat difficult to explain.	Relatively easy to communicate. Precedents exist in climate action plan and in green rating schemes.
Sub-regional Application	Could identify additional explanatory variables (typology variables) in the primary model to differentiate results by sub-region.	Could identify additional explanatory variables (typology variables) in the primary model to differentiate results by sub-region.	Can be replicated for any area, but selection of comparison sub-regions is more complicated. Has limited to no ability to control for key variables to be used in typology.	Depends upon availability of sub-regional data for each policy type.
Application in Other Urban Regions / Replicability	Any region with a robust travel survey or travel demand model could replicate.	Any region with a robust travel survey or travel demand model could replicate.	Any region with a robust travel survey or travel demand model could replicate.	Depends upon availability of data for each policy type.

Causation versus correlation

A key distinguishing factor among the approaches examined is the ability to quantify the causative effect of transit on land use patterns. Ideally the land use multiplier would represent only those impacts induced by transit. Only Approach 1 (SEM) is able to track the causative effect. Other approaches more accurately quantify the correlation of transit availability with land use patterns. That is, they determine the extent to which transit and compact development patterns are found in conjunction, without addressing the question of which causes or induces the other.

Conclusions and Recommendations

In addition to using different types of analyses, the approaches considered for this study would also achieve slightly different objectives. Approaches 1 and 2 are statistical analyses that could provide new evidence that transit in Los Angeles County induces land use changes. If the evidence is apparent, these approaches will also provide a quantitative basis for Metro to take credit for these changes. Approaches 3 and 4 would not provide new evidence for a land use multiplier. Rather they assume that transit agencies can take some credit for the benefits of compact development. Based on this assumption, they establish reasonable means to quantify this credit. *Therefore, if the principal objective is to provide new evidence for a land use multiplier in Los Angeles County, Approaches 1 and 2 are superior. If the principal objective is to quantify the assumed effect of transit on land use, Approaches 3 and 4 are superior*. Both objectives have value.

Given the level of effort estimated to carry out each approach, and allowing for some contingency for complications that may arise in carrying out any approach, the following are possible scopes for Phase II of this project:

- Approach 1 only
- Approaches 2 and 3
- Approaches 3 and 4

If multiple approaches are pursued, one of the approaches should be designated as primary, in order to prioritize the use of resources.

ICF and Metro will discuss the findings of the memo and jointly select an approach or approaches. More detailed information on each approach is provided below.

Approach 1: Structural Equations Model (SEM) to determine the inter-relationships of transit availability, urban form, and trip making

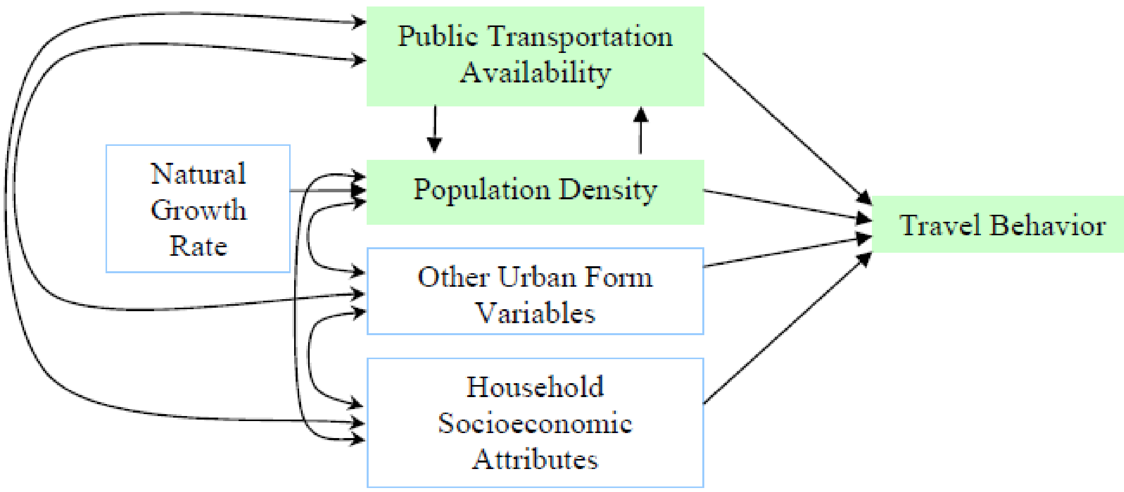
SEM is the most statistically complex approach. An SEM approach posits multiple equations and feedback loops connecting transit availability, urban form, and travel patterns. In this respect it is theoretically capable of representing all of the real-world interactions between transit systems, urban density, and trip making. SEM works by simultaneously solving multiple equations. For example, one equation would relate transit availability to urban form. A second equation would relate urban form to trip making. SEM can also estimate conditional relationships (e.g., “X caused Y, but only when Z is present”).

With multiple equations, a variable can be dependent in one equation and explanatory in another equation. As a result, SEM can account for feedback loops between explanatory variables and can predict both the direct and indirect effects of one variable on another. This capability allows for a more realistic picture of the factors that affect travel behavior than does single-equation modeling, in which only one variable is impacted by other variables.

SEM can also help disentangle feedback loops between explanatory variables. For example, if public transit availability causes an increase in urban density, which in turn causes an increase in public transit availability, a positive feedback loop exists. SEM can estimate the magnitude of the influence of each variable on the other. This step is necessary in order to determine the total effect of any one variable on another.

ICF (2008) used SEM to determine a national land use multiplier. Figure 1 below diagrams the relationships between key variables as determined in that exercise. This study found that the indirect effect of public transportation availability on travel behavior (roughly equivalent to the land use effect of transit) is about twice as large as the direct effect (roughly equivalent to the mode shift impact of transit).

Figure 1: Diagram of model used in ICF (2008)[1]



Because SEM is a complex statistical technique, the results of the model are difficult to verify. Other criticisms of SEM include: it confirms rather than tests assumptions, it is difficult to interpret, it has no single significance test for variables, and it is very sensitive to sample sizes and outliers.[2] To address some of these concerns, ICF can compare various versions of the model using different subsets of data and different data years. **SEM is the only technique that can determine the extent to which transit causes changes in land use patterns, rather than the extent to which transit is correlated with changes in land use patterns.**

Table 1 below summarizes the types of data needed to conduct an SEM analysis to determine a land use multiplier for Los Angeles County. The basic data needed to analyze a single year, as with ICF (2008), is available. It may also be possible to analyze data points from more than one year simultaneously.

Table 1: Data Needs for Approach 1

Data Category	Source	Data Points	Resolution	Years	Geocoded	Sample Size

[1] Endogenous variables are represented with shaded boxes, and exogenous variables are represented with unshaded boxes. A straight, one-headed arrow from variable category A to variable category B indicates that one or more variables in A are predictors in the equation for a variable in B. Curved, double-headed arrows indicate variables that are allowed to covary without a specified direction.
[2] Booz Allen Hamilton for New York Metropolitan Transportation Authority, "Impact of Public Transportation on GHG In The MTA Area," MTA Blue Ribbon Commission on Sustainability, May 2009

Data Category	Source	Data Points	Resolution	Years	Geocoded	Sample Size
Housing and Demographics	U.S. Census or SCAG datasets	• Housing stock • Population	Census: Census Blocks. SCAG data: TAZ	Census: 1990, 2000 SCAG: 1980-2030	SCAG may have geocoded data	Census:100 %. SCAG datasets: unknown.
Employment	CTPP[3] or SCAG datasets	• Employment	CTPP: Census Blocks Groups or TAZ. SCAG data: TAZ	Census: 1990, 2000 SCAG: 1980-2030	SCAG may have geocoded data	CTPP: 1/6 households. SCAG data: unknown
Household Travel Patterns	SCAG Travel Survey (STS) or modeled data	• Distance to work • Income • Vehicle Ownership • Miles traveled by mode	STS : household addresses[4]. Modeled data: TAZ	STS: 1980,1990, 2000 Modeled data: To 2030?	STS : Yes, at Census Tract level. Modeled data: unknown.	Travel Survey: 1/500 households. Modeled data: N/A
Transit Availability	Metro GIS files or CNT database[5]	• Geocoded bus and rail lines	N/A	Current year	Need to calculate distance for each block group	100%
Birth and Death Rates	U.S. Census	• Birth and Death rates	Census Blocks	1990,2000	No	100%

Assessments of Approach 1 according to the established criteria are as follows:

- *Availability of data* – Sufficient data are available for a basic analysis; however, a large amount of data is required. Additional data needs could be identified during testing of the model. Some data could be available from more than one source.
- *Level of effort to implement* – High. Will require identification of several data sources and geocoding of most data sources to compile a dataset. Addition of more years or cities would add to data collection and coding effort. Conducting model runs is also more labor intensive than other methods.
- *Accuracy and credibility of results:* Tracks causative effect of transit availability on VMT via density, whereas other techniques only track correlation. Captures feedback loops between transit and density, and thereby answers the question at hand more accurately. However, it is difficult to verify the accuracy of the model. There is also no guarantee that a credible model will be developed. That is, the modeling effort may not confirm the hypothesis that transit availability induces land use changes in Los Angeles.
- *Ease of communication:* The SEM technique is difficult to explain; however, the result is not so difficult to explain. Causation is generally easier to explain than correlation.

- *Ability to be replicated at the sub-regional level* – Additional explanatory variables could be added to the primary model to represent differences among sub-regions. The

[3] Census Transportation Planning Package
[4] May not be available at this level for confidentiality reasons
[5] The Center for Neighborhood Technology (CNT) has compiled a dataset of Metro transit availability that includes information on bus levels of service. This dataset could potentially be used to separate high capacity bus routes from other bus routes in Los Angeles County.

predictive power of these sub-regional variables could then be used to determine distinct sub-regional relationships between transit and land use patterns.

- *Ability to be replicated in other urban regions* – Any region with a travel survey or a robust travel demand model (with non-auto mode capabilities) could replicate. It might be preferable to include all cities in a single model run.

Approach 2: Time series analysis to predict changes in density near transit over time

This approach uses regression analysis to determine the relationship of transit lines to changes in urban development patterns over time. Specifically this analysis would look for increases in urban densities near rail and bus lines in Los Angeles over a period of 20-30 years. Los Angeles provides a good opportunity to conduct this type of analysis because modern rail transit opened just 20 years ago. Changes in other urban environmental variables, such as land use mixing, could also be tracked. Using a robust national body of research on the relationship of density and land use mixing to travel patterns (the 5Ds), resulting changes in travel behavior can be estimated.

Cervero and Landis (1997) used a similar approach in their study of the BART rail system. They established a model to predict the likelihood of vacant land development near BART stations by comparing matched pairs of BART stations and nearby freeway interchanges in the Richmond and Fremont corridors. Significant explanatory variables included proximity to the BART station, amount of developable land, and levels of land-use mixture. The study did not control for the impact of land use policies. Land use changes around BART stations were limited to downtown Oakland, downtown San Francisco, and a handful of suburban stations. The authors posited that neighborhood opposition or lackluster real estate market have limited changes elsewhere.

The statistical method used in Cervero and Landis is easier to understand than the SEM technique. On the other hand, the technique captures only changes in land use immediately adjacent to transit—not any indirect land use effects that transit might have over a broader area.

Table 2 below summarizes the types of data needed for Approach 2. Fewer variables are required than with Approach 1; however, Approach 2 calls for more years of data. Data from 1980, before Metro's modern rail lines opened, should be included.

Table 2: Data Needs for Approach 2

Data Category	Source	Data Points	Resolution	Years	Geocoded	Sample Size
Housing and Demographics	U.S. Census or SCAG datasets	• Housing stock • Population	Census: Census Blocks. SCAG data: TAZ	Census: 1980, 1990, 2000. SCAG data:2008	SCAG may have geocoded data	Census: 100%. SCAG datasets: unknown.
Employment	CTPP[6] or SCAG datasets	• Employment	CTPP: Census Blocks Groups or TAZ. SCAG data: TAZ	CTPP: 1980, 1990, 2000. SCAG data:2008	SCAG may have geocoded data	CTPP: 1/6 households. SCAG data: unknown
Transit Availability	Metro GIS files or CNT database[7]	• Geocoded bus and rail lines	N/A	Current year[8]	Need to calculate distance for each block group	100%

Assessments of Approach 2 according to the established criteria are as follows:

- *Availability of data* – Sufficient data are available for a basic analysis; less data are required than for Approach 1, but more than for Approach 3. Additional data needs could be identified during testing of the model. Some data could be available from more than one source.
- *Level of effort to implement* – High. Will require identification of several data sources and geocoding of most data sources to compile a dataset. Addition of more years or cities would add to data collection and coding effort. Conducting model runs is also labor intensive. Requires an extra step of estimating travel patterns based on land use patterns.
- *Accuracy and credibility of results:* Tracks correlation of land use patterns with transit availability over time; does not pick up causative impact of transit on land use. Results are easier to verify than with Approach 1. Also, results would be defined temporally. Would be more challenging to translate findings related to a specific time period to the total potential impact of transit. There is also no guarantee that a credible model will be developed. That is, the modeling effort may not confirm the hypothesis that transit availability induces land use changes in Los Angeles.
- *Ease of communication*: Perhaps the easiest to explain. People understand development being attracted to transit lines over time better than they understand feedback loops that are not circumscribed by a distinct time period (Approach 1) or counterfactual hypotheses (Approach 3).

[6] Census Transportation Planning Package
[7] The Center for Neighborhood Technology (CNT) has compiled a dataset of Metro transit availability that includes information on bus levels of service. This dataset could potentially be used to separate high capacity bus routes from other bus routes in Los Angeles County.
[8] Current year GIS files are available for download from Metro. Future years and previous year data layers would likely need to be created by ICF.

- *Ability to be replicated at the sub-regional level* – Additional explanatory variables could be added to the primary model to represent differences among sub-regions. The predictive power of these sub-regional variables could then be used to determine distinct sub-regional relationships between transit and land use patterns. However, with study areas potentially limited to rail and high capacity bus corridors, the potential to conduct sub-regional analyses is questionable.
- *Ability to be replicated in other urban regions* – Any region with a travel survey or a robust travel demand model (with non-auto mode capabilities) could replicate. It might be preferable to include all cities in a single model run.

Approach 3: Comparison of travel patterns in denser and less dense areas

This approach uses a simple non-statistical comparison technique to estimate the influence that transit has on non-transit travel patterns in a given region, by comparing it with one or more other regions. Transit ridership is posited as a single explanatory variable for VMT. Using this approach, the secondary effects of transit are calculated as follows:

$$\text{Secondary effects} = (\text{community}_1\ \text{VMT per capita} - \text{community}_2\ \text{VMT per capita}) / (\text{community}_2\ \text{transit miles per capita} - \text{community}_1\ \text{transit miles per capita})$$

With this approach, the result depends heavily upon the comparison area chosen. There is also no statistical basis to suggest that the secondary effects calculated can be attributed to land use, versus other variables. Rather, this approach depends on the theoretical assumption that land use is a dominant factor in the secondary effects; secondary effects are then used as a proxy for the land use multiplier. A regression analysis of the key data points across multiple communities could be performed to refine the result

Holtzclaw (2000) used this approach to compare urban to suburban communities in the San Francisco Bay Area. Comparing San Francisco to suburban Danville-San Ramon, he found that every mile traveled on transit by San Franciscans was associated with a reduction of 8 VMT.

Booz Allen Hamilton (BAH) applied a similar approach in their study for NYMTA; however, BAH's approach substituted key travel variables from the comparison area for those in the control area. The study did not explicitly allow for a correlation of transit ridership (a proxy for transit availability) with VMT. BAH estimated that the GHG emissions indirectly reduced through land use are 4.85 greater than the GHG emissions emitted by NYMTA. The results are not directly comparable to results from other studies cited here, since the land use multiplier is defined differently by BAH than it is here.

Table 3 below summarizes the types of data needed for Approach 3. The basic data needed could be obtained from SCAG's travel survey, but would be better sourced from the outputs of a travel demand model. Approach 3 requires the least data of any approach examined.

Table 3: Data Needs for Approach 3

Data Category	Source	Data Points	Resolution	Years	Geocoded	Sample Size
Household Travel Patterns	SCAG Travel Survey (STS) or modeled data	• Miles traveled by mode	STS : household addresses[9]. Modeled data: TAZ	STS: 1980,1990, 2000 Modeled data: To 2030?	STS : Yes, at Census Tract level. Modeled data: unknown.	Travel Survey: 1/500 households. Modeled data: N/A

Assessments of Approach 3 according to the established criteria are as follows:

- *Availability of data* – Data are readily available. The only outstanding question is whether SCAG and/or LA Metro would provide modeled travel data to use in place of the survey data. That would likely increase the accuracy of the results but is not necessary.
- *Level of effort to implement* – Relatively low. Most data intensive part will be summarizing the necessary travel characteristics from the survey data in the geographic units that we need, which may require some GIS analysis.
- *Accuracy and credibility of results*: Tracks only correlation of PMT (a proxy for transit availability) with VMT. Limited sample size (matched pairs) limits accuracy. The number calculated will be applicable only for the comparison pair established; however, a regression analysis could produce more broadly applicable results.
- *Ease of communication*: While the analytical approach is easy to understand, the results can be difficult to explain since they require assuming a counterfactual (e.g. if downtown LA had the same land use and travel patterns of X region…). It is potentially simpler to explain the results of Approach 2, which involves a natural evolution of land use patterns over time.
- *Ability to be replicated at the sub-regional level* – Can be replicated at any geographical level within the SCAG region, with current availability of survey or modeled data; however, the theoretical basis for choosing comparison areas is a barrier. This method is not capable of informing a regional or sub-regional typology, since there is no ability to control for the typology differentiators such as urban size, age, type of transit, etc.
- *Ability to be replicated in other urban regions* – Any region with a travel survey or a robust travel demand model (with non-auto mode capabilities) could replicate.

Approach 4: A sketch-modeling approach to estimate the impact of transit service and policies on non-transit trips

This approach differs from the others in that there is no statistical analysis applied and potentially no need to collect comprehensive data on transit systems, land use patterns, and travel behavior. Rather than attempting to establish a statistical correlation (or causation) pattern between transit and land use, this approach would use non-statistical means to quantify the potential impact that transit can have on non-transit travel patterns through, for example, transit oriented development and station area improvements. By taking a modular approach to quantification of indirect benefits related to land use patterns, this approach would provide an analytical framework that can be added to over time by additional research. As such, this

[9] May not be available at this level for confidentiality reasons

approach would not develop a land use multiplier as defined in this memo, but rather an alternative system of crediting transit agencies with *some* of the land use effects of transit.

This approach is still in conceptual development; however, we expect that it would be similar to the sketch analysis techniques applied to individual policies in climate action planning processes. Policies or planning initiatives quantified would be defined as specific land use or transportation policies that can be implemented by LA Metro and/or partner agencies. The data sources used in the analysis would be less constrained that those used in a rigorous statistical analysis. This approach also has the advantage of estimating the potential future impacts of policies in the Metro region, instead of examining just historical impacts. While this approach would not capture every change in urban form that could be associated with transit (e.g. densification that takes place with no intervention from the transit agency), it would provide a defensible quantification approach for a portion of those changes.

Approach 4 could form the basis for a point-based land use multiplier system, similar to popular rating schemes for greenbuilding. For example, transit agencies get X points for every Y square feet of TOD they help to develop. Transit agencies get X points for Y miles of pedestrian improvements around stations and stops.

No previous studies have taken this approach to developing a land use multiplier, but there are numerous studies that have examined the impacts of specific policies and programs such as TOD and pedestrian improvements around transit stations and stops. These studies would be used to inform Approach 4. For example, ICF quantified the impact of TOD developments in 7 urban case studies for EPA. Average results from this study can be used to assign significance to TOD initiatives for LA Metro.

Assessments of Approach 4 according to the established criteria are as follows:

- *Availability of data* – Varies by policy element. Will play a determining factor in deciding which policy elements to quantify.
- *Level of effort to implement* – Relatively low. Scalable, since the number of policies included is flexible.
- *Accuracy and credibility*: Typically considered to be accurate "within the ballpark". Results would be expected to provide information on the relative impact of various initiatives rather than a complete accurate picture of transit's indirect impacts. Potentially more credible than some of the other approaches since the goal of this approach is more modest.
- *Ease of communication*: Individual analyses should be easy to communicate. A comprehensive point-based system would be more challenging to communicate, but could build on the success of other systems like LEED and the emerging GreenRoads.
- *Ability to be replicated at the sub-regional level* – Would be difficult to isolate the different potential effects of such measures in different subregions, but not impossible. May be feasible for some of the policies and not for others.
- *Ability to be replicated in other urban regions* – Unclear but should be similar to LA Metro.

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