Title

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Publication Date
2007-06-01

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

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California PATH Research Report
UCB-ITS-PRR-2007-7

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

Final Report for Task Order 5110

June 2007

ISSN 1055-1425

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

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Project: PATH Task Order 5110 - A GIS-based Tool for Forecasting the Travel Demands of Demographic Groups within California – An Optimal Resource Allocation Tool

January 2007

Santa Barbara, CA

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Preface

Assessments of transportation investment from a "social efficiency" viewpoint are absent from transportation policy analysis and marketing practice. This is mainly due to the lack of tools capable to assess the role of transportation infrastructure investment on the provision of activity opportunities to residents of each locality. To fill this gap a research project was envisioned a few years ago that uses California data to examine the role of transportation infrastructure investment on the lives of individuals residing in California. This report is one of the first summaries of research conducted in the project with title **"A GIS-based Tool for Forecasting the Travel Demands of Demographic Groups within California – An Optimal Resource Allocation Tool"** administered through the PATH program at UC Berkeley for the California Department of Transportation Division of Research and Innovation. The ultimate objective of the project is to develop a methodology to optimally allocate transportation resources in California. In the past, optimal allocation of resources targeted economic growth. In this project we attempt to target social welfare by considering as output of resource allocation the provision of accessibility for the resident population. In meeting the main objective of this project we have developed the methodology in sufficient detail to enable many future projects as spin-offs of the work reported here.

From an administrative viewpoint this PATH project contains two components named task orders. Task Order 5110 ended on December 2006 and includes all the preparatory and experimental research work as well as a search for relevant data and methods to accomplish the project objective. The contents of this report reflect the work accomplished in Task Order 5110 with focus on the final method selected. This report is complementary to other research work that was discussed at a series of presentations (February 18, 2005, July 1st, 2005, and February 24, 2006) with the CALTRANS project manager (Frank Taylor) and other CALTRANS staff members.

The remaining research work continues in Task Order 6110 and a final report in that task will illustrate our findings in more detail. Both Task Orders (5110 and 6110) contain two parallel tracks of research that are mutually strengthening. These tracks are a statewide model and method development and testing of methods using Santa Barbara as a test case. In this way testing of methods is done using data from Santa Barbara and then the methods are expanded to the entire state. Also, the method development contains two analytical levels. The first level is a geographic unit (zonal level) mapping the entire state and we experiment with Census-tracts and Census-block groups to find the best unit to use. The second level we use is at the individual resident level and we develop models that explain travel behavior as a function of accessibility indicators. In this report emphasis is given to the zonal level analysis demonstrating a tool that identifies specific locations in the entire state where resource allocation has succeeded in maximizing benefits to the public. In addition, the tool and the Geographic Information System maps derived from this tool show which locations in California fail to be optimal and require their residents to travel excessively to pursue the same amount of activities when compared to other optimal locations around the state where travelling enables better time allocation. Efficiency is measured using stochastic frontier regression analysis and a wide variety of derived land use and transportation infrastructure indicators as inputs. The outputs examined are indices of location opportunities including retail, education, health, and manufacturing. The tool thus developed shows which demographic segments suffer the most from suboptimal time allocation and what type of investment is needed to alleviate this suffering. This new tool also shows the distribution of benefits of the transportation system and identifies differences in benefits across regions. In addition to the substantive findings about and mapping of the relative investment efficiency in California, this report presents the new method to assess efficiency in a multi-objective environment. It also provides a discussion about the next steps in Task Order 6110.

Abstract

Assessments of transportation investment from a "social efficiency" viewpoint are absent from transportation policy analysis and marketing practice. This is mainly due to the lack of tools capable to assess the role of transportation infrastructure investment on the provision of activity opportunities to residents of each locality. In this report, we demonstrate a tool that identifies specific locations in an entire state where resource allocation has succeeded in maximizing benefits to the public. In addition, the tool and the Geographic Information System maps derived from this tool show which locations in California fail to be optimal and require their residents to travel excessively to pursue the same amount of activities when compared to other optimal locations around the state where travelling enables better time allocation. Efficiency is measured using stochastic frontier regression analysis and a wide variety of derived land use and transportation infrastructure indicators as inputs. The outputs examined are indices of location opportunities including retail, education, health, and manufacturing. The tool thus developed shows which demographic segments suffer the most from suboptimal time allocation and what type of investment is needed to alleviate this suffering. This new tool also shows the distribution of benefits of the transportation system and identifies differences in benefits across regions. In addition to the substantive findings about and mapping of the relative investment efficiency in California, this report presents a method to assess efficiency in a multi-objective environment.

Acknowledgments

At UCSB Val Noronha and Bryan Krause converted network and US Census data into usable variables and maps that were then employed as explanatory variables in the regression models reported here. Seo Youn Yoon created the maps reported here and is currently working in Task Order 6110. Frank Taylor project manager and participants to a series of presentations in Sacramento at CALTRANS provided valuable comments. Funding was provided by CALTRANS through the California PATH program.

1. Introduction

Optimal allocation of resources for infrastructure facilities is a critical issue in planning for development but it is also a critical consideration for the every day life of travellers. In addition to optimal allocation, equally important is also the distribution of benefits in terms of infrastructure facilities (stock) and related quality of service intended here as the ability to reach desired destinations within an acceptable amount of time (service). Different regions of California have received over the years different levels of investment for private or public transportation. The residents at each of these regions are also "investing" time to travel from one location to another. These are inputs to a *production system* that has many outputs including local gross product (e.g., regional gross product) and time allocated by the residents to activities (e.g., time for paid work, time dedicated to leisure and so forth). Depending on local circumstances each region is more or less efficient in maximizing the use of these stock and service resources. Tools exist to judge how efficiently systems work but they focus on economic efficiency and they do not incorporate a comprehensive measure of transportation stock and service offered. Here, we emphasize social efficiency and bring measures of accessibility in the arsenal of resource management and resource allocation to show the degree of efficiency exhibited by different regions in enabling its residents to minimize personal costs and maximize personal benefits. The research findings presented in this report are from one aspect in a two-component research program as mentioned in the preface above.

The state of California is divided into geographical areas and each is treated as a production unit with its inputs represented by the different types of infrastructure (lane miles of roadways classified in a finite number of types). The outputs are indicators of the service offered to the unit's residents in terms of the amount of activities the residents of each geographical area can reach. Figure 1 provides a summary of the schema used in this project.

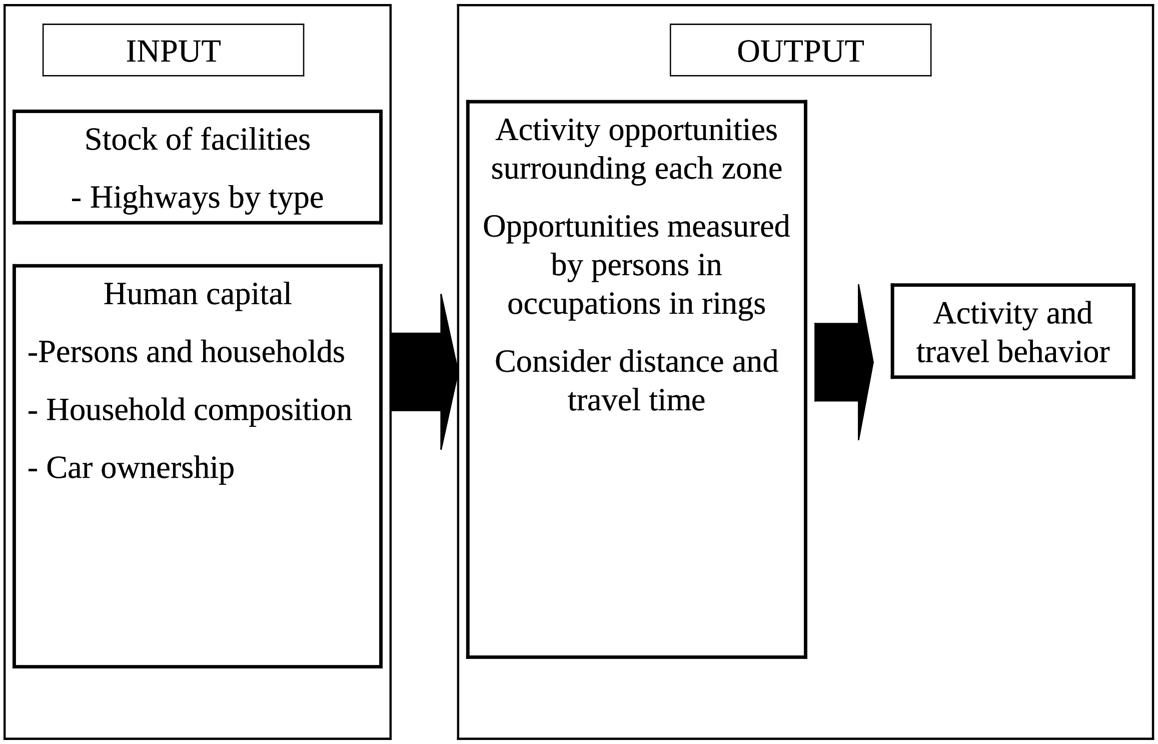

Figure 1 This project's schema

2. Background

Typical studies of transportation investment and economic development are discussed in Berechman (1994), Buffington et al. (1992), Perera (1990), Seskin (1990), and Weisbrod and Beckwith (1992). There are also regional studies addressing the impact of transportation infrastructure on local regional economic development. Assessment of these investments is based on the Gross Domestic (Regional) Product or private output as in Allen et al. (1988) and Wilson et al. (1985), benefit-cost ratios and/or differences as in Buffington et al. (1992) and Weisbrod and Beckwith (1992), property values as in Palmquist (1982) and new business creation or location as in Hummon et al. (1986). Analytical methods in these studies include: a) assessment of the effects of transportation infrastructure investments that compare and contrast the effects of investments among different regions; and b) identification of the important factors that influence and enable economic development. The study here belongs to the first group of analytical methods. Identification of the impacts from transportation infrastructure investment is particularly important when resources are scarce. From the perspective of decision makers, need assessment and accurate measurement of this need allows effective budgeting and financing of projects. It also allows for informed decisions while evaluating individual projects, balanced distribution of resources, and increased efficiency. Considerable research exists in the analysis of investment and optimal allocation of resources. Transportation improvements influence economic development, productivity, and social welfare. “Pure” economic development impacts are usually regional in nature and result from improved access to labour pools or to larger markets. While considering the economic development of different regions of a country, investment in transportation infrastructure as well as in the overall infrastructure system may play significant role in removing regional economic disparities. Within the same country and under the same development policies, significant role for transportation implies that regions with better transportation infrastructure will have better access to the locations of materials and markets making them more productive, competitive and hence more successful than regions with inferior transportation accessibility. Better accessibility and mobility also plays a significant role in human resource development of a region. For a review and an application using Data Envelopment Analysis, see Alam et al. 2004 and Alam et al. 2005 for a longitudinal analysis.

One could make similar arguments when considering the time expenditures of individuals and households to paid and unpaid work as well as free time with family and friends. However, transportation investment from a "social efficiency" viewpoint is absent from transportation practice. This is mainly due to the lack of tools capable to assess the role of transportation investment on the efficient allocation of time by the residents of each locality. The tool we aim with the analysis presented here identifies specific locations in the state where resource allocation has succeeded in maximizing benefits to the public. In addition, we aim to develop maps that show which locations in a state fail to be optimal and require their residents to travel excessively to pursue the same amount of activities as other residents of different localities.

More specifically in this report, we answer four key questions:

- Using largely available data, can we develop a small number of variables to describe access to activity opportunities for California residents?
- Are more roadways improving access to these activity opportunities?
- Are these roles different for different types of highways and how?
- Can we identify roadways that are prime candidates for investment?

The state of California is divided in 7049 zones using the US Census 2000 tracts. The Census tract (unit of analysis here) is selected as a first order geographical subdivision to make the analysis tractable at the state level and to provide sufficient detail to be meaningful (we will revisit this aspect in the conclusions). We assess each tract in terms of its ability to produce benefits for its residents. Figure 2 provides a schematic representation of the study and Table 1 contains a selection of unit of analysis characteristics.

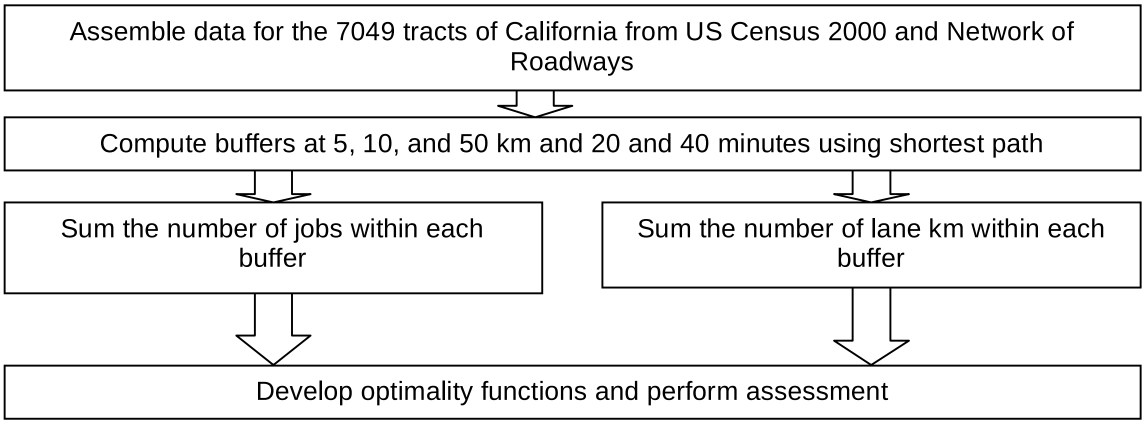

Figure 2: Computation Schema of the Study

Envisioning each tract as a production unit and developing for each tract a production function, we measure access to opportunities, treat them as outputs, and correlate them to the presence of roadways within and surrounding the tract. Access to opportunities for activity participation (e.g., leisure) and services (e.g., health) is the benefit (and output) from each tract that we will assess. Using Geographic Information Systems we compute for each tract the amount of activity opportunities reachable within 5 km, 5 to 10 km, and 10 to 50 km. We repeat the same for 20 minutes and 20 to 40 minutes travel time computed using information about speed limits on the roadway network at hand. Computation of these measures is accomplished by developing an origin-destination network with the origins and destinations as cancroids (population weighted virtual centroids in each tract). Using the same origin-destination network we also count the number of highways within 5 km, 10 km, and 50 km network distance from each centroid.

Enjoyment of access is also a function of the tract residents' ability to take advantage of opportunities offered to them. We attempt to capture this by including social and demographic characteristics of the resident population available in the Census tract databases. Transportation investment is often directed to facilities and the striking majority of this investment is allocated to roadways (this tendency is particularly pronounced in the US). An indicator of transportation supply (the input in the context of production functions) is the amount of roadways (lane kilometres). Roadways, however, serve different purposes and offer different functions to the users depending on their type (e.g., limited access freeways/motorways, secondary roads connecting limited access roadways, local roads).

Table 1: A selection of Census-tract characteristics

	Mean	Std.Dev.	Maximum*
Tract Square Km	59.0	453.7	20486.8
Tract Population	4805.2	2143.1	36146.0
Tract Households	1631.8	763.0	8528.0
Within a 5 Km Buffer from Tract Centroid			
Workers in Retail (retail)	5031.1	6937.8	54745.0
Workers in Health (health)	2644.0	3524.4	26478.0
Workers in Services but not in Health or Retail (services)	28024.4	44497.0	373127.0
Workers in Manufacturing (manufacturing)	3391.0	5547.7	59059.0
Workers in All Other Occupations (other)	5753.4	6805.7	50287.0
Primary limited access roadways (primary lim)	284.1	448.6	3244.8
Primary without limited access roadways (primary nolim)	77.9	140.6	958.5
Secondary and connecting roadways (secondary)	1867.8	2711.3	17711.4
Rural, local and neighborhood roadways (local)	8549.4	11256.1	71318.1
Special roadways (special)	342.1	591.3	4612.7
All Other types of roadways (other)	778.6	1618.7	10511.1

*The minimum is zero for all variables and tracts

Using Geographic Information Systems, we can identify and count the number of kilometres of each roadway in each tract. Roadways, however, form a complex network and the tracts are interconnected. For this reason, we perform a similar task as for activity opportunities and we count the number of roadways by type in a series of concentric rings of 5km, 5 to 10km, and 10 to 50km. We name these rings the *buffers*. We repeat the same operation for travel time using 20 minutes and 40 minutes travel time. The types of roadways we count are: primary highways with limited access (*primary lim* herein), primary roadways without limited access (*primary nolim* herein), secondary and connecting roadways (*secondary* herein), local and rural roads (*local* herein), roads with special characteristics (*special* herein), all other roadways (*other* herein). On one hand, we have as input a detailed accounting of roadways representing all past investment on highways for each origin (tract centroid). On the other hand, we consider as output the number of workers a resident departing from a centroid can reach. The types of workers that are reachable within each of the buffers are classified into: retail, health, services, manufacturing, and all other. These counts are the indicators capturing access to opportunities to participate in activities and enjoy services.

3. Optimality Assessment

The literature on optimal assessment of decision making units is largely populated by Data Envelopment Analysis methods (a review on a related topic can be found in Alam et al. 2004, 2005) and Stochastic Frontiers (Greene, 1980). Considering the possible measurement error in the data used, the presence of outliers, and spatial correlation we opt for stochastic frontiers that can handle some of these possibly undermining issues. However, an additional step is required in our analysis before estimating stochastic frontier production functions. The output of the number of workers that a resident departing from a centroid can reach is depicted by 25 indicators (number of workers in retail, health, services, manufacturing, and other within 5km, within the ring of 5 to 10 km, within the ring of 10 to 50 km, within 20 minutes of travel time, and within the ring of 20 to 40 minutes travel time). To reduce the data into a few variables we use factor analysis using the principal components method, extraction based on correlations, and the varimax method. This yields three components explaining 93% of the variation in the output variables used here. Each component captures a different aspect of access to opportunities surrounding each centroid and the three components are derived in such a way to be uncorrelated. Table 2 provides a summary of the component scores (high scores indicate high correlation between the output variable and the component extracted). The first component represents access of opportunities in the outermost ring between the radius of 50 km and the radius of 10 km but also within the ring defined by the radii of 20 and 40 minutes and for this named the *outer ring access* in this study. One variable, the number of workers in manufacturing within 20 minutes travel time, is more correlated with the first component than the second reflecting the predominant location of manufacturing in the outskirts of cities and closer to high speed roadways. The second component represents access to opportunities in the second ring and it is most correlated with variables defined in the ring between a radius of 5 km and a radius of 10 km (named *middle ring access* herein) and variables of within 20 minutes of travel time. Access to opportunities that are the closest to the centroid is represented by the third component (named *core access* herein), which is most correlated with the remaining variables. For each California tract we compute each of the three components (corresponding to three concentric regions around each centroid – core, middle ring, outer ring) using the scores of Table 2 and the value for each variable used to extract them. These three components replace the 25 variables and are used as the dependent variables in stochastic frontier analysis.

Stochastic frontiers were developed for models of production. A production function is the ideal amount a unit can produce for a given set of inputs. In empirical settings observed outputs are not ideal (maximum) for reasons that are due to unknown random factors and measurement error (v) that are specific to each observed unit and due to productive inefficiency that also varies with each observed unit (u). To examine the relationship between output variables (access to opportunities) and input variables (highways) a regression model is created with dependent variable (y) the indicator of output and independent variables the highway lane kilometers (x). The model we use here takes the following form:

$$y_i \quad = \quad \alpha + x'_i \beta + v_i - u_i$$

Index i represents each tract, i=1,…, 7049. We estimate three regression equations that are one for each of the three components of Table 2 (core access, middle ring access, outer ring access). In each equation y is the logarithm of the component values for each tract. The xs are number of highways of each type in each geographic subdivision. The vector **β** contains the regression coefficients we seek. Variable v is the usual random error term capturing measurement error and variable u is a positive valued offset between observed access and the ideal maximum possible given the input combination of roadways within each tract. The random error term v is assumed to be normally distributed with zero mean and constant variance across observations. The random positive valued term u is specified as a function of other explanatory variables. In the terminology of production functions the values u_i are the measures of inefficiency for each tract i in transforming lane kilometers of roadways into access to opportunities. Creating the exp($-u_i$) we obtain a measure of tract specific efficiency.

Estimation of the three models presented here is carried out using LIMDEP (Greene, 2002). Table 3 shows the regression coefficients associated with each input variable (number of lane kilometers of roadway types in the core, the middle ring, and the outer ring). The correlation between the y variable and its predicted values using the estimated model coefficients is 0.895 for the outer ring, 0.731 for the middle ring, and 0.744 for the core, representing excellent goodness of fit between data and the production function derived here.

Table 2: The three principal components extracted from 25 output variables and their scores

	Components		
	Outer Ring Access	**Middle Ring Access**	**Core Access**
Number of Workers in Retail (20 to 40 min)	0.945	0.276	0.139
Number of Workers in Services (20 to 40 min)	0.941	0.250	0.128
Number of Workers in Other (20 to 40 min)	0.941	0.275	0.150
Number of Workers in Manufacturing (20 to 40 min)	0.939	0.245	0.130
Number of Workers in Health (20 to 40 min)	0.936	0.287	0.140
Number of Workers in Retail (10 to 50 km)	0.927	0.330	0.159
Number of Workers in Manufacturing (10 to 50 km)	0.926	0.311	0.129
Number of Workers in Other (10 to 50 km)	0.925	0.329	0.157
Number of Workers in Services (10 to 50 km)	0.924	0.326	0.163
Number of Workers in Health (10 to 50 km)	0.919	0.343	0.169
Number of Workers in Manufacturing (0 to 20 min)	0.665	0.625	0.265
Number of Workers in Services (5 to 10 km)	0.234	0.878	0.296
Number of Workers in Retail (5 to 10 km)	0.322	0.868	0.275
Number of Workers in Other (5 to 10 km)	0.380	0.841	0.289
Number of Workers in Health (5 to 10 km)	0.267	0.817	0.350
Number of Manufacturing in Services (5 to 10 km)	0.438	0.766	0.220
Number of Workers in Services (0 to 20 minutes)	0.504	0.703	0.430
Number of Workers in Health (0 to 20 minutes)	0.532	0.688	0.421
Number of Workers in Retail (0 to 20 minutes)	0.585	0.680	0.389
Number of Workers in Other (0 to 20 minutes)	0.605	0.672	0.345
Number of Workers in Services (0 to 5 km)	0.071	0.198	0.955
Number of Workers in Retail (0 to 5 km)	0.139	0.226	0.942
Number of Workers in Other (0 to 5 km)	0.190	0.325	0.871
Number of Workers in Health (0 to 5 km)	0.075	0.308	0.839
Number of Workers in Manufacturing (0 to 5 km)	0.289	0.354	0.699

The signs, size, and significance of the regression coefficients show how the presence and amount of different types of roadways impact the ability of each geographical tract to provide access to opportunities. A negative sign associated with roadways in the same region (core, middle ring, outer ring) of the dependent variable is more likely to indicate competition for space with businesses and establishments providing services. A positive coefficient is more likely to indicate a clustering of establishments around those roadway types.

Table 3: Stochastic Frontier Regression Coefficients

	Outer Ring		Middle Ring		Core	
	Coeff.	**t ratio**	**Coeff.**	**t ratio**	**Coeff.**	**t ratio**
Constant	-0.413	-3.13	0.857	13.80	1.685	17.89
Log(primary lim in core)	-0.094	-1.71	0.203	11.17	0.443	13.01
Log(primary lim in core) ^{2}	-0.053	-2.29	0.070	8.48	0.135	8.95
Log(primary nolim in core)	0.016	0.23	-0.181	-8.11	0.477	10.25
Log(primary nolim in core) ^{2}	0.001	0.05	-0.039	-5.26	0.137	9.17
Log(secondary in core)	0.035	0.94	-0.195	-13.96	0.748	25.71
Log(secondary in core) ^{2}	-0.072	-5.71	-0.011	-2.07	0.172	19.97
Log(local in core)	-0.101	-3.75	0.091	8.28	-0.160	-7.86
Log(local in core) ^{2}	0.021	2.89	0.020	6.55	-0.100	-20.05
Log(special in core)	0.068	1.21	-0.190	-10.05	-0.145	-4.59
Log(special in core) ^{2}	0.045	2.02	-0.050	-5.91	-0.103	-6.92
Log(other in core)	-0.004	-0.22	-0.010	-1.53	-0.058	-5.36
Log(other in core) ^{2}	-0.003	-0.47	-0.001	-0.59	-0.024	-6.66
Log(primary lim in middle ring)	0.098	2.33	-0.020	-1.07	-0.115	-3.70
Log(primary lim in middle ring) ^{2}	0.077	5.83	-0.036	-6.60	-0.055	-6.56
Log(primary nolim in middle ring)	0.048	3.44	0.039	9.50	-0.082	-9.54
Log(primary nolim in middle ring) ^{2}	0.028	5.13	0.003	1.69	-0.047	-13.76
Log(secondary in middle ring)	-0.155	-3.18	0.146	6.08	-0.249	-6.01
Log(secondary in middle ring) ^{2}	-0.065	-6.13	0.044	9.09	-0.062	-7.06
Log(local in middle ring)	0.025	0.63	-0.014	-0.69	0.059	1.69
Log(local in middle ring) ^{2}	0.015	2.14	-0.020	-6.01	0.058	10.11
Log(special in middle ring)	-0.083	-1.78	0.085	4.37	-0.009	-0.25
Log(special in middle ring) ^{2}	-0.071	-5.22	0.061	11.10	0.012	1.28
Log(other in middle ring)	0.034	1.76	-0.005	-0.69	0.042	3.13
Log(other in middle ring) ^{2}	0.021	4.80	0.006	3.93	0.023	8.69
Log(primary lim in outer ring)	0.077	1.47	-0.012	-0.36	0.002	0.03
Log(primary lim in outer ring) ^{2}	-0.051	-2.56	0.025	2.71	-0.003	-0.20
Log(primary nolim in outer ring)	-0.071	-2.18	0.045	3.16	0.041	1.70
Log(primary nolim in outer ring) ^{2}	0.007	0.75	-0.018	-3.85	0.000	-0.06
Log(secondary in outer ring)	-0.041	-0.66	0.006	0.17	-0.008	-0.13
Log(secondary in outer ring) ^{2}	0.030	2.27	-0.019	-2.65	0.010	0.82
Log(local in outer ring)	0.066	1.40	-0.062	-1.73	0.006	0.12
Log(local in outer ring) ^{2}	0.007	0.90	0.003	0.62	-0.010	-1.33
Log(special in outer ring)	-0.090	-1.80	0.058	1.97	0.009	0.19
Log(special in outer ring) ^{2}	0.093	6.18	-0.019	-2.72	0.006	0.51
Log(other in outer ring)	0.012	0.47	0.005	0.42	0.018	0.82
Log(other in outer ring) ^{2}	-0.025	-5.63	0.002	0.74	-0.008	-2.18
Constant for u	-0.718	-8.06	-17.693	-14.36	-0.144	-3.18
Household density	-0.578	-69.66	1.059	10.34		
Tract perimeter (km)					-1.375	-22.05
σ_u / σ_v	3.797	28.05	13.069	17.89	2.612	45.34
$\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$	0.680	150.31	1.359	17.65	0.468	77.43

Positive coefficients associated with variables in different regions than the dependent variable indicate a supportive relationship with access. For example, access to the outer core may be achieved by driving over local roads in the core, secondary roads in the middle ring, and again local roads in the outer ring. Different establishments however, may be reached by different combinations of roadways. As a result we obtain a variety of significance levels, signs, and sizes of coefficients that may not correspond to intuition.

As expected, access to the outer core is influenced by roadway quantity in the core, the middle ring and the outer core. However, lower speed facilities in the core (local and secondary) seem to have a stronger influence than the higher speed (primary roadways). The middle ring primary roadways have a strong positive impact on access in the outer ring. These two indications are a reflection of the routes leading to the outer core with high presence of opportunities. However, if there are many primary roadways in the outer core they compete for space with the establishments were opportunities locate and this is reflected in a few negative coefficients associated with roadways in the outer ring (primary nolim and secondary). Access to the middle ring is even more heavily influenced by the amount and type of roads in the core (positively by high speed roadways and negatively by lower speed roadways).

The core access is not influenced by roadways in the outer ring, i.e., a driver does not need to go into the outer core when reaching places within the 5 km radius around a tract centroid and this is reflected in the lack of significance for most of the outer ring variables. To the contrary, primary roadways in the middle ring seem to decrease access to the core in a significant way. This is a reflection of the spatial organization of California's roadway network and the spatial distribution of activity opportunities adjacent to the network's roadways. Unfortunately, all this is also masked by the use of the summary indicators (components) as dependent variables that contain variables from all three regions (core, middle ring, and outer ring).

When aiming at improving access to opportunities around the core, however, provision of primary and secondary roadways appears to be a worthwhile investment. When we examine the other two components that are heavily influenced by variables that include travel time, the picture is not as clear and may be pointing out to the need for improving travel times in local and secondary roadways in regions that lead to the middle and outer rings.

The bottom portion of Table 3 contains the estimates of variables influencing inefficiency. Exp ($-u_i$) is a measure of technical efficiency and it is the ratio between achieved access over the maximum possible access achieved for the given inputs. The outer ring and middle ring efficiencies (and their opposite inefficiencies) are significantly different among tracts of different household densities (households per square kilometers). The core efficiency is a function of the perimeter of the tract indicating a possible problem with the use of tract as a unit of analysis. In a series of other specifications not shown here we also find that multi-car (>4) households live in tracts with lower efficiency presumably because they are able to combat lack of access with automobility. Other variables considered such as number of households by household size did not exhibit a clear trend. The median efficiency indicators are fairly high at 83.8%, 92.4%, and 81% for the outer ring, middle ring, and core respectively. The tenth lower percentiles are 72%, 83% and 62% for the outer ring, middle ring, and core respectively indicating a fairly good efficiency for a system that evolved without a major plan targeting high efficiency. However, considering the large size of many tracts access to opportunities may be quite different among the residents of these tracts.

The final examination we perform for these computed efficiencies here is by mapping them for the entire state. Figure 3 shows the three efficiency indicators for Los Angeles, California, using as cutoff points the 10% percentiles. The first quadrant shows the Los Angeles total lane kilometers of roadways. Each efficiency estimate captures a different aspect of access to locations and shows clearly that providing more lane kilometers does not make a geographical area more accessible for any of the three efficiency measures.

These same efficiency estimates were also computed for the entire state. Figure 4a shows the core efficiency map at 10% percentile increments. Figure 4b shows the middle ring efficiency and Figure 4c shows the outer ring efficiency.

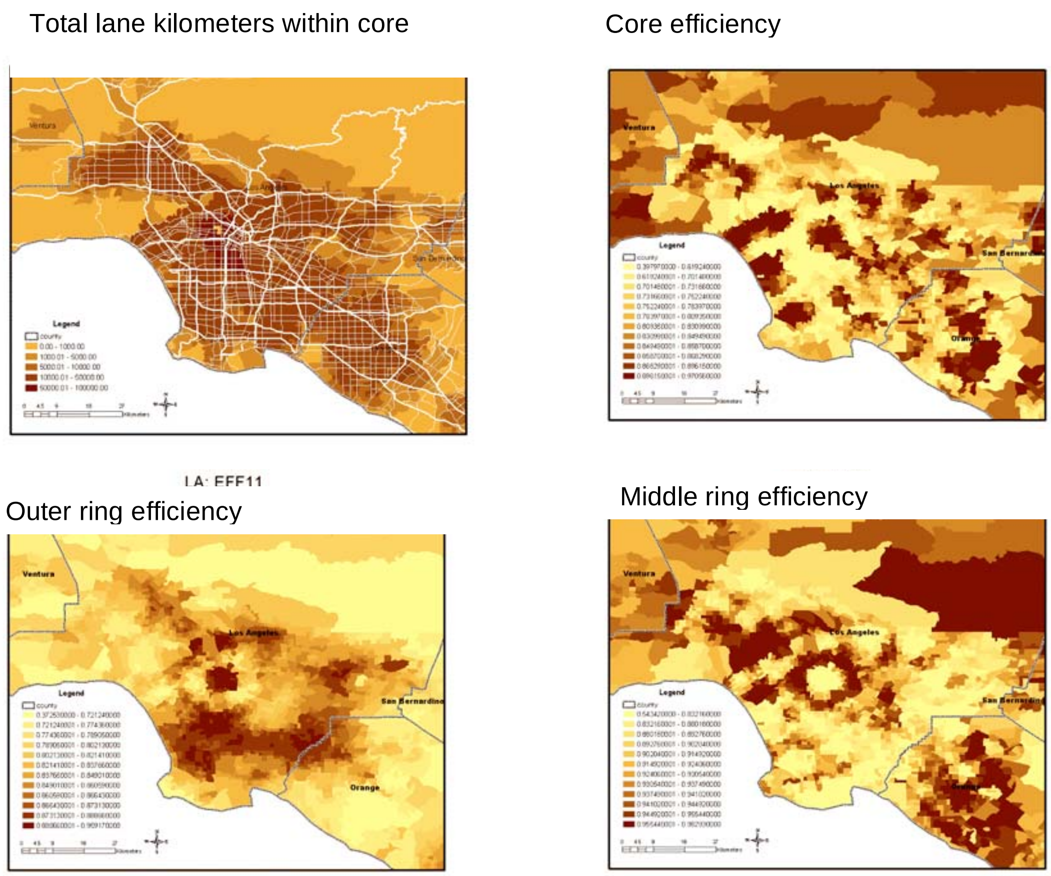

Figure 3: Maps of lane kilometers and efficiency measures in Los Angeles, California

Core efficiency

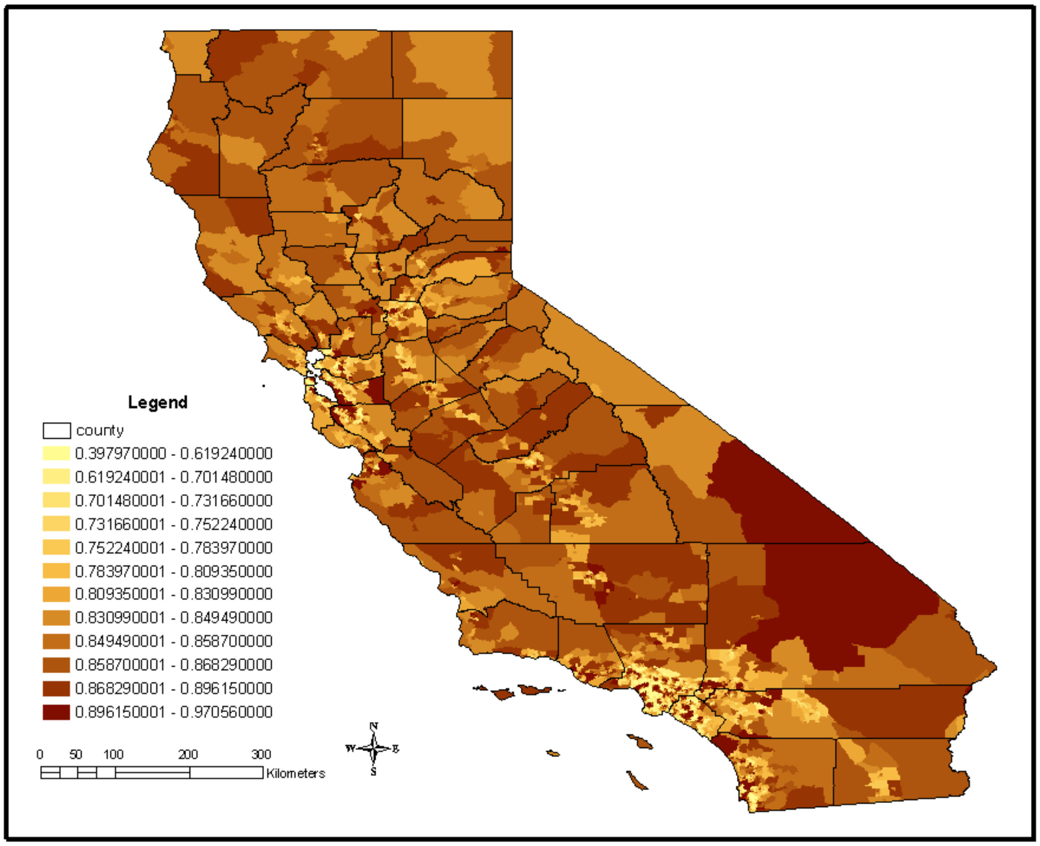

Figure 4a Core Efficiency Estimates

Middle ring efficiency

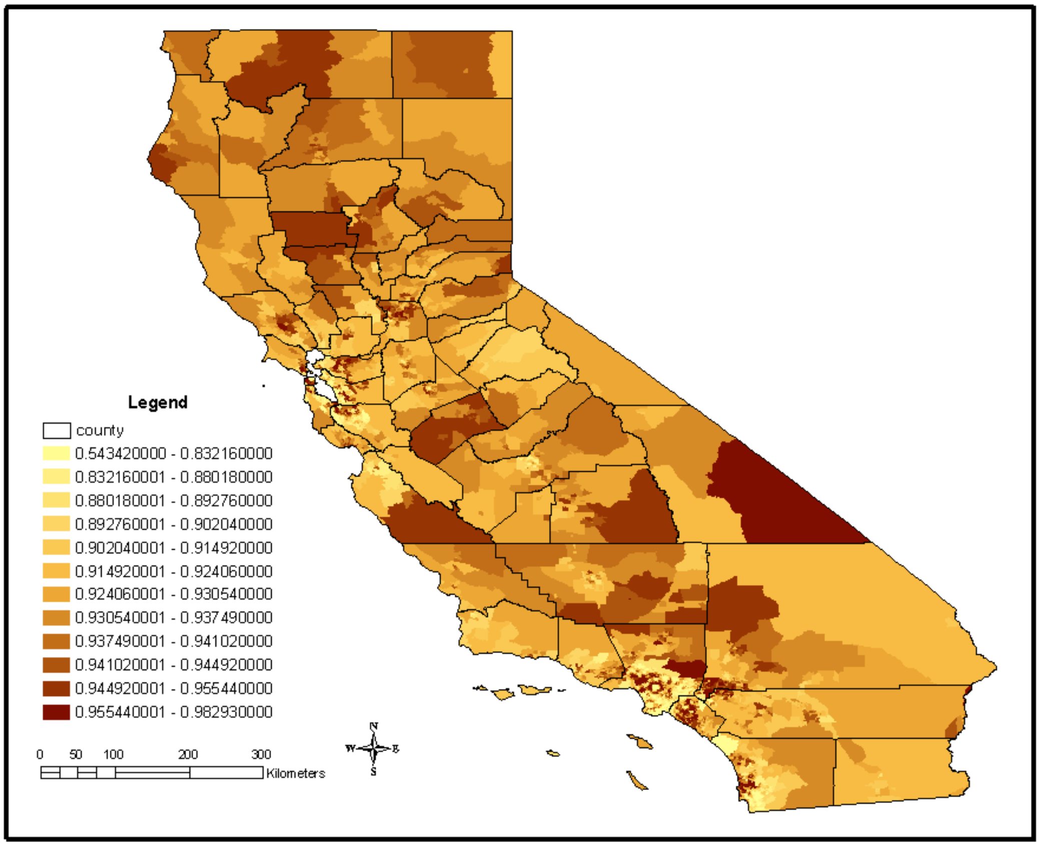

Figure 4b Middle Ring Efficiency Estimates

Outer ring efficiency

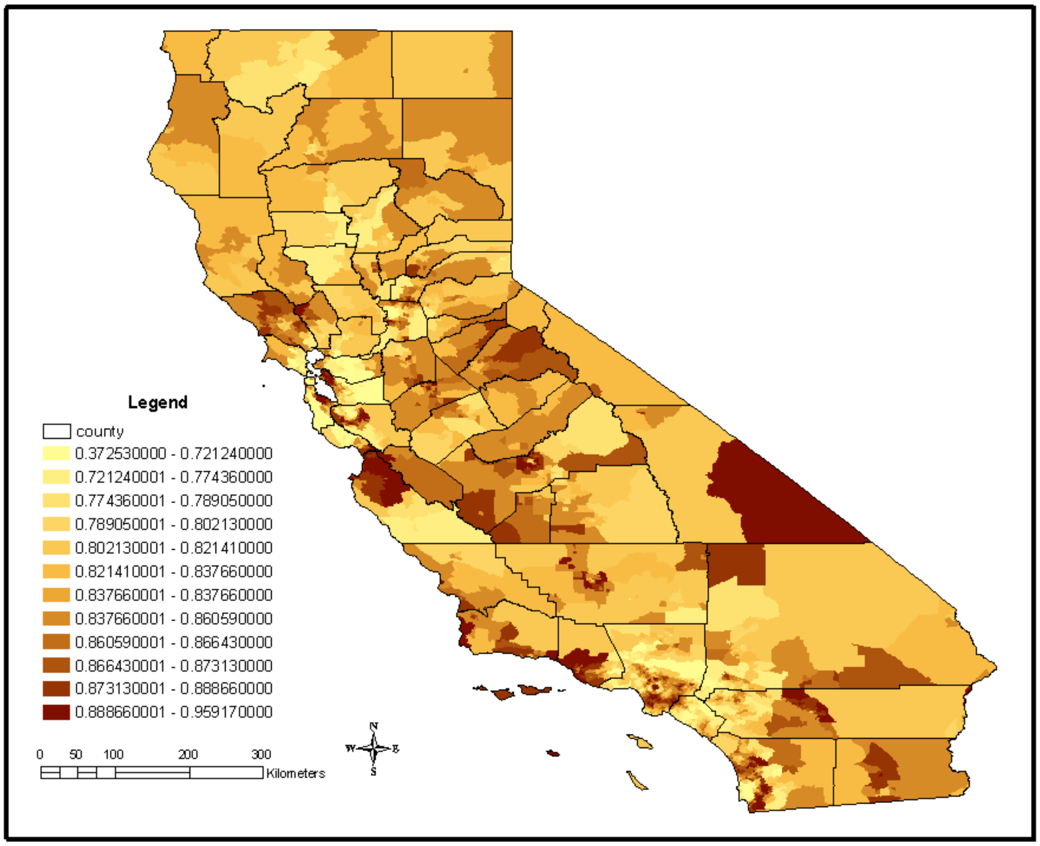

Figure 4C Outer Ring Efficiency Estimates

4. Summary and Conclusions

In this report access to activity opportunities in a variety of environments for the entire state of California is analyzed. First, three principal components are used to derive summaries of 25 variables describing the diverse access patterns. These three components represent access to opportunities in a sequence of concentric regions around a virtual origin, i.e. centroid, in each of 7049 tracts used to subdivide California geographically. The first region is a circle of 5 km network distance radius around each centroid. The second region is a ring between 5 km and 10 km around the centroid, and the third is an outer ring between 10 km and 50 km network distance from each centroid. Using the derived principal components as the dependent variables and lane kilometers of roadways as the independent variables we employ stochastic frontier analysis to identify a complex set of relationships showing that more roadways is not always better for access to opportunities, either because of competition for space or because of the spatial distribution of activity opportunities that does not follow these roadways but obeys other spatial distribution rules. The regression results also show that the role of roadways depends on the indicator considered but also the presence of other surrounding roadways. Overall, however, the presence of primary roadways has a strong positive impact on access. For core access the secondary roadways seem to have a much higher impact and merit attention for investment. Efficiency in the transformation of roadways to access depends on the residents of each tract and depends on the measurement of access (outer ring vs. middle ring). This begs for a more detailed analysis possibly using much smaller geographical areas. Preliminary tests usinf Santa Barbara County as the pilot case indicate substantial differences in the findings when the Census-tracts are large (e.g., in rural environments). In Task Order 6110 we are computing access to opportunities using the finer geographical subdivision of the block groups and the analysis reported here is repeated.

Although the data analysis offers unique and unprecedented insights at a statewide level, our study here unavoidably suffers form a variety of limitations. Employment of the principal components as a dependent variable does not allow a clear linkage between access to specific opportunities (retail, health, and so forth) and their relationship to highway types. In addition the interconnectedness of the highways makes identification of specific optimal investment segments very hard when aggregation at the level of a tract is used. The effect of data transformations to express variables in logarithms may also add approximations. In a continuation of the research here, as mentioned above, we first examine smaller geographical regions used to repeat the stochastic frontier analysis for a smaller geographical area. In addition, efforts are also directed towards a better description of the highway quality and performance and the incorporation of access provided by other modes. A parallel study also examines the time allocation and trip consolidation of individual traveler data to continue the assessment and correlation between facilities and optimal level of service provision.

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