# Spatial Analysis of Propensity to Escort Children to School in Southern California

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**The spatial distribution of children's school commute behavior is analyzed from three perspectives: commuting to school independently of parents, commuting to school by active modes, and allocation of escorting tasks for children between mothers and fathers. Accessibility measures and population density are introduced in the propensity regression models to account for the impact of spatial characteristics around school locations and to identify the spatial distribution of behavioral patterns. The results from the models are presented as maps combining the impacts of all the significant spatial variables to display the spatial patterns of behavior and intrahousehold interaction. These patterns can identify and pinpoint the impact of barriers, with the paper offering the example of the negative impact of a park area in the middle of the city of Los Angeles, California, on children's independent and active commutes to school. Similarly, barriers create significantly different intrahousehold interaction patterns at different locations in the region. The results of this study show that an opportunity exists to expand the microanalysis to a more comprehensive treatment of travel behavior in space and to contribute to the development of models integrating land use and transportation.**

This paper analyzes the propensity to escort children to school, which can be interpreted as parents being protective about children and as children being dependent on parents for travel. Analysis of children's dependence on their parents is important in many contexts. In previous studies on the household interaction in time use, children's time use patterns had a substantial impact on their parents' activity participation and travel (*1*). Children's out-of-home activities become spatiotemporal constraints for their parents, especially when the parents must chauffeur their children. Therefore, it is important to find the interaction patterns in escorting children to school because escorting children to school is concentrated at specific times during a day and brings significant changes in the tours that parents make in the morning.

Moreover, these parental duties are, in general, inflicted differently on fathers and mothers. For example, the household travel survey conducted by the Southern California Association of Governments (SCAG) in 2001 found that mothers provided a large proportion (75.3%) of chauffeuring for children and that fathers provided a much smaller proportion (24.7%). This asymmetric allocation of parental duties results in different levels of constraints and has different impacts for certain arrangements in households on parents' time use, resource allocation, and travel patterns.

Children's travel modes to school have been viewed from many different perspectives. Generally, promotion of active modes as children's travel modes to school is expected to combat childhood obesity (*2*) and to improve children's overall well-being (*3*). The built environment has been considered one of the important factors affecting children's travel mode to school, and the relationship between children's school travel and the built environment has been addressed by the existing literature (*4–7*). Another facet of children's commuting behavior is interaction with parents. Chauffeuring children to school is viewed as a parental decision according to their socioeconomic characteristics (*8*), and allocation of chauffeuring between mother and father has also been addressed (*9–11*). Sidharthan et al. focused on the impact of spatial and social interactions in the neighborhood and found that the interaction in the neighborhood has a significant impact on the decision on children's travel mode to school (*12*). On the basis of this result, they suggested public policies targeting the local neighborhood level.

In this context, a spatial analysis that links spatial variables around school locations and different aspects of children's commuting behavior is proposed, and the geographic patterns of the impact are shown as propensity maps. Children's commuting behavior patterns that were evaluated were (*a*) commuting to school independently of parents, (*b*) commuting to school by active modes (walking and biking), and (*c*) allocation of escorting tasks for children between the mother and father. To find the characteristics of school location and their spatial patterns, accessibility indicators at school location are introduced as explanatory variables of the models. This study extends the methodology of the exploratory accessibility study conducted by the GeoTrans Laboratory for the entire state of California (*13*) and augments the study by performing more a sophisticated spatial analysis that includes intrahousehold interaction ideas.

Several different strategies have been used in travel behavior research to model intrahousehold interactions. The methodologies used include modeling with structural equation models (*1*, *14*, *15*) and structural discrete choice models (*16*) and the use of genetic algorithms (*17*), household utility maximization (*18–22*), and latent class cluster analysis (*23*). Acknowledging that modeling methodologies that include all the interacting household members and collective interaction facets provide a comprehensive framework for intrahousehold interaction, the scope of the intrahousehold interaction was kept simple to emphasize the intrahousehold interaction only in relation to spatial characteristics of the school location(s). Specific aspects of the dependence of children on their parents in commuting behavior that are listed above are evaluated, and binary logit models for the behavioral patterns of children's commute to

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school are used. Finally, the results are displayed as spatial patterns by use of geographic information system (GIS) maps.

## DATA USED

This study uses the 2001 postcensus travel survey conducted for SCAG. This region includes the six California counties of Los Angeles, Orange, Imperial, Riverside, San Bernardino, and Ventura. The purpose of the survey is to document household characteristics and travel behavior and to update the regional computerized travel forecasting model. This large-scale study of regional travel aims at providing a foundation for long-term transportation planning decisions in the region. A total of 16,939 households completed the travel diaries and socioeconomic characteristics survey, and the information was retrieved from all household members.

Of the approximately 40,000 people from the sample, 3,483 children under 16 years old went to school, preschool, or day care (hereafter collectively referred to as "school") on the survey day. The sociodemographic information for the children and families is summarized in Table 1, and the children's mode choice to school and the split of escorting children between father and mother are summarized in Tables 2 and 3, respectively. About 50% of the children (1,794) were escorted to school by their parents, and the split of escorting between fathers and mothers was 443 and 1,351, respectively. About 23.1% of the children traveled to school by active modes (walking and biking).

**TABLE 1 Summary of Sample**

| Characteristic | Frequency | Percent |
|---|---|---|
| Total number of children under age 16 who went to school | 3,483 | 100 |
| Age (years) | | |
| 0–4 | 258 | 7.4 |
| 5–10 | 1,854 | 53.2 |
| 11–15 | 1,371 | 39.4 |
| Parents' employment status | | |
| Both parents full-time workers | 875 | 25.1 |
| Father full-time, mother part-time | 299 | 8.6 |
| Father full-time, mother not employed | 917 | 26.3 |
| Employed single father | 172 | 4.9 |
| Not employed single father | 28 | 0.8 |
| Employed single mother | 457 | 13.1 |
| Not employed single mother | 242 | 6.9 |
| Other | 493 | 14.1 |
| Household income ($) | | |
| Less than 10,000 | 188 | 5.4 |
| 10,000–24,999 | 645 | 18.5 |
| 25,000–34,999 | 468 | 13.4 |
| 35,000–49,999 | 424 | 12.2 |
| 50,000–74,999 | 670 | 19.2 |
| 75,000–99,999 | 418 | 12.0 |
| 100,000–149,000 | 265 | 7.6 |
| 150,000 or more | 186 | 5.3 |
| Unknown | 219 | 6.3 |
| Child's ethnicity | | |
| White, not Hispanic | 1,285 | 36.9 |
| Hispanic | 1,377 | 39.5 |
| African American | 203 | 5.8 |
| Asian, Pacific Islander | 92 | 2.6 |
| Other | 198 | 5.7 |
| Unknown | 328 | 9.4 |

**TABLE 2 Children's Travel Mode to School**

| Travel Mode to School | Frequency | Percent |
|---|---|---|
| Walk | 741 | 21.3 |
| Bicycle | 63 | 1.8 |
| Passenger in car, truck, van | 2,197 | 63.1 |
| School bus | 364 | 10.5 |
| Transit | 29 | .8 |
| Other or unknown | 89 | 2.6 |
| Total | 3,483 | 100.0 |

The network data used for this paper (from the Dynamap/Transportation database by TeleAtlas) contains detailed information on the road network across the entire state of California. It includes the type of road network, segment length, and speed limit for each segment; turn restrictions; and one-way streets, enabling the realistic representation of transportation facilities. Not included in these network data, however, is information on the public transportation network. The total length of each network type in a block group was considered an indicator of the amount of available transportation facilities of each type in each block group.

The six counties included in the SCAG region were divided into 10,631 zones by use of 2000 U.S. census block groups. The number of employees reported by the Census Transportation Planning Package was counted for each block group by using the 14 industry types classified by the North American Industry Classification System. These numbers were used as the relative amount of opportunity to participate in the related types of activities (i.e., the number of employees in the retail industry represents the opportunity to participate in shopping activities). This analysis uses the number of employees in the retail industry only as an accessibility indicator to describe different levels of mix of residence and retail businesses in each block group.

## MEASUREMENT OF ACCESSIBILITY

Although the computation of accessibility covers the entire state of California, this paper considers only the 10,631 block groups in the SCAG region. However, for the borders of the SCAG region, block

**TABLE 3 Allocation of Escort Between Father and Mother by Household Type**

| Household Type by Parents Composition | Escort by Father | Escort by Mother | Total Number of Children |
|---|---|---|---|
| Both parents full-time workers | 151 | 373 | 875 |
| Father full-time, mother part-time | 41 | 152 | 299 |
| Father full-time, mother not employed | 106 | 374 | 917 |
| Father and mother with other employment combination | 96 | 157 | 493 |
| Single father | 49 | 0 | 200 |
| Employed single mother | 0 | 204 | 457 |
| Not employed single mother | 0 | 91 | 242 |
| Total | 443 | 1,351 | 3,483 |

groups outside the region that are accessible from the origin block group are also included. Each block group was treated as a traffic analysis zone, and each block group centroid was attached to the nearest node in the Dynamap/Transportation network data set, which contains the entire spectrum of roadways in California, from local roads to Interstate freeways, which follows the classification of TIGER/Line File Census Feature Class Codes. A travel time between each pair of origins and destinations was computed on the basis of Dijkstra's algorithm (*24*) by use of the ArcGIS Network Analyst program. For this computation, the assumption was made that all the trips between the origins and the destinations are made at the speed limit of each network segment. After the travel time computation, an accessible buffer can be defined for each block group by using a threshold of travel time. The time threshold of 20 min was used to find the local accessibility of each block group. This threshold is based on the travel time to school reported in the sample. It took 14.23 min, on average, for the children in the sample to go to school by walking [standard deviation (SD) = 11.27]; 13.39 min, on average, by bike (SD = 7.37); and 11.85 min, on average, by car (as a passenger; SD = 11.76). Therefore, the buffer area of 20 min by car represents the approximate catchment area of each school.

Accessibility measures for each buffer area were then computed by summing the accessibility indicators of the block groups that belong to a buffer area. The accessibility measures considered here are

- Number of retail employees within a travel time of 20 min and
- Total number of segment kilometers by the following network types within a travel time of 20 min:
  - Primary highways with limited access (Type 1),
  - Primary roadways without limited access (Type 2),
  - Secondary and connecting roadways (Type 3),
  - Local and rural roads (Type 4),
  - Vehicular trail (Type 5),
  - Roads with special characteristics (Type 6), and
  - All other roadways (Type 7).

However, some of the accessibility measures showed high degrees of correlation with each other, which leads to redundancy in travel behavior models. Some of the accessibility measures were selectively excluded on the basis of the correlation matrix, and the number of accessibility measures included was managed to be minimal and not redundant. The accessibility measures for network Types 3, 4, and 6 were excluded because of their high correlation with other accessibility measures (the correlation between Type 3 and Type 1 is .865, the correlation between Type 4 and Type 1 is .872, and the correlation between Type 6 and Type 1 is .947). Type 7 was excluded because it was not found to be an informative functional class.

The accessibility measures that were finally included in the behavioral models are (*a*) the number of retail employees within a travel time of 20 min and (*b*) the total number of segment kilometers of a Type 1, 2, and 5 network within a travel time of 20 min.

In addition to the four accessibility measures, the population density of each block group is included as a proxy of residential density. Other methods of developing summaries of accessibility exist. In fact, the coarse spatial resolution obtained with census block groups can be rectified by use of a school-by-school analysis that also includes mode-specific accessibility measures computed with a mode-specific travel time and network with a finer spatial resolution on the basis of the alternatives available for each individual. All these are left as future tasks.

## MODELS AND RESULTS

### General Description of Models

Three behavioral models are estimated to analyze different aspects of children's commute to school. In each of the models, explanatory variables are tested in two blocks: (*a*) the set of sociodemographic variables and (*b*) the set of spatial variables used to explore the significance of spatial variables' contribution. The models are

1. Model INDEPENDENT: a binary logit model for children's independent commute to school. The variable analyzed takes the value of 1 if the child goes to school without a parent(s) escort and 0 otherwise.
2. Model ACTIVE: a binary logit model for children's active commute to school by walking or biking. The variable analyzed takes the value of 1 if the child goes to school by walking or biking and 0 otherwise.
3. Model FATHER'S ESCORT: a binary logit model for allocating escort of the children to the father. The variable analyzed takes the value of 1 if the child goes to school with the father and 0 if the child goes to school with the mother. This model is estimated only for children who are from households headed by a couple and who went to school with their parents.

The model INDEPENDENT uses two sets of explanatory variables, as explained above, to test if any sociodemographic groups are significantly more or less likely to let children travel independently and if any spatial variables have significant impacts on children's independent commute to school and alleviation of parents' obligation to take their children to school.

With the model ACTIVE, a more specific type of children's independent travel is tested. This model focuses on an independent and active commute to school and the impact of spatial variables on this. The hypothesis of this model is that by having walkable or bikable environments around school locations, children can more easily be independent of their parents, after the impact of sociodemographics are accounted for. This model also addresses the possibility of relieving the parents of their duties of escorting their children by providing certain types of environments that enable children's active travel.

Last, in the model FATHER'S ESCORT, only the children in households headed by a couple who were escorted by their parents ($n$ = 1,328) are included. This model addresses allocation of the parental duty of escorting children to school between the father and mother to see if the bargaining between the father and mother on escorting their children has a geographic pattern.

The purpose of including spatial variables as explanatory variables in the models is to find specific areas that have a significant association with any of the three commuting patterns. Modeling of the contribution of spatial variables was complicated by the presence of spikes at zero and long positive tails in their distribution. For example, some rural block groups in Southern California are extremely large but have very small populations and very few retail employees and a road network accessible within a 20-min travel time. In contrast, some other block groups in the center of the city of Los Angeles are extremely dense in population or have very high levels of accessibility to retail businesses and road networks. These block groups need to be modeled together, and this makes it difficult to find specific areas that have significant meaning to each of the behavioral patterns of interest in this paper. To overcome this distributional heterogeneity, each of the accessibility measures and the population density, which are either a continuous variable (total segment length by network type and population density) or a count variable (number of employees), are reclassified into a discrete variable that has 10 even classes. Each of the 10 classes represents one decile in the distribution of the variable. This transformation relieves the estimation bias caused by outlying observations and makes it easier to find specific areas that are significant. The transformation also facilitates estimation in which the spatial variables can contribute nonlinear and even nonordinal effects. This methodology is emerging from a previous statewide exploratory analysis for California correlating land use density, infrastructure supply, and travel behavior (*13*). Figure 1 shows the spatial distributions of the discretized accessibility variables over the SCAG region.

## Contribution of Spatial Variables

The results of omnibus tests of each set of variables are given in Table 4. The data in Table 4 provide an idea of how much the spatial variables improve each of the models over the same models with only sociodemographic variables.

The increments of chi-square and Nagelkerke $R^2$ both by ratio and by difference are the least affected by the spatial variables in the model INDEPENDENT. This result indicates that the sociodemographic characteristics of the children and their families have more importance in determining whether the children are going to travel to school independently. This result also implies that although spatial variables have a significant relationship with children's independent travel to school, it might be harder to change children's commute patterns by changing just land use and accessibility in the vicinity of schools.

The story is different for the model ACTIVE, which shows much improvement in its goodness of fit when spatial variables are included in the model. This improvement indicates that children's independent travel by active modes is more related to the population density and accessibility than children's independent travel by any other mode. This finding suggests that the active modes must be addressed separately when children's independent traveling is to be addressed, and spatial variables should not be missed when children's active modes are to be analyzed.

The goodness of fit of the model FATHER'S ESCORT is improved the most by ratio when the spatial variables are added. The spatial variables contribute about 75% of the chi-square value that sociodemographic variables contributed to the goodness of fit. This finding implies that a geographic pattern in allocating an escort for children between fathers and mothers likely exists.

## Impact of Sociodemographic Variables

Estimated coefficients of the three models are shown in Table 5. To aid in interpretation, only statistically significant ($p \leq .05$) and marginally significant ($.05 < p \leq .1$) coefficients are listed. The coefficients are shown as both raw coefficients and odds ratios, and the *t*-statistic of each coefficient is listed as well.

In both the model INDEPENDENT and the model ACTIVE, the age of the child displays a significant impact. Younger children are less likely to travel independently to school and less likely to travel by active modes, as expected. The gender of the child was significant in the model ACTIVE and marginally significant in the model INDEPENDENT, which means that girls are less likely than boys to go to school independently of their parents and to use active modes when parents do not escort them to school. Ethnicity has a significant impact on both traveling independently of parents and traveling by active modes. Among all the ethnicity groups, African American children were the most likely to go to school independently and to walk or bike to school, and children who did provide their ethnicity information are more likely (with a marginal significance) than white children to go to school independently.

Children of households with annual incomes of more than \$100,000 and less than \$150,000 are less likely to travel independently than the baseline (the children of households with annual incomes of more than \$50,000 and less than \$75,000), which implies that higher income (or, presumably, wealth) encourages parents to be protective about their children's commute to school. Children of households with annual incomes of more than \$10,000 and less than \$50,000 are more likely to walk or bike than the baseline (1.391 to 1.430 times the baseline propensity), which might mean either that those households are intentionally selecting a school location in a walkable area or that the children are unavoidably walking or biking to school regardless of school locations and the walkability or bikability of the neighborhood around the school locations. The number of siblings under 18 years old has a positive impact on both independent and active commuting. This result shows that parents with four or more children are constrained in their ability to provide a ride for each of their children in the morning or that they might be making location choices that enable their children to walk or bike to school. Among different parent types, single fathers and single mothers behave in significantly different ways than other parents. Single fathers are more likely to let their children commute to school independently, but single mothers are less likely to let their children walk or bike to school. Children living with single fathers or single mothers seem to face quite different choices in their travel mode to school.

The numbers of hours that the parents work per week and work location were included in the models as proxies of spatiotemporal constraints in their activity participation and travel. The father's work hours and work location do not have significant impacts in these two models, but the mother's work hours and work location have significant impacts. When mothers work more than 40 hours and less than 50 hours per week, children are significantly more likely to go to school independently (1.550 times the baseline) and actively (1.611 times the baseline) than they are when mothers work less than 40 hours per week. When mothers work more than 50 hours and less than 60 hours per week, children are less likely (with a marginal significance) to go to school independently. However, the latter impact should be considered carefully because mothers worked more than 50 hours and less than 60 hours per week in only 30 cases. When mothers work at various locations, children are more likely to go to school independently. When mothers work at home or did not answer the work location question, children are more likely to go to school using active modes. This result shows that the impact of parents' spatiotemporal constraints on determining children's travel mode to school is asymmetric between the father and the mother.

In the model FATHER'S ESCORT, both parents' employment status, work hours, and work locations have significant impacts. In households headed by couples, fathers are the least likely to take children to school (0.340 time the baseline) when they are employed full-time and their wives are employed part-time and less likely than the baseline to take children to school when they and their wives are employed full-time (0.542 time the baseline). Fathers' long work

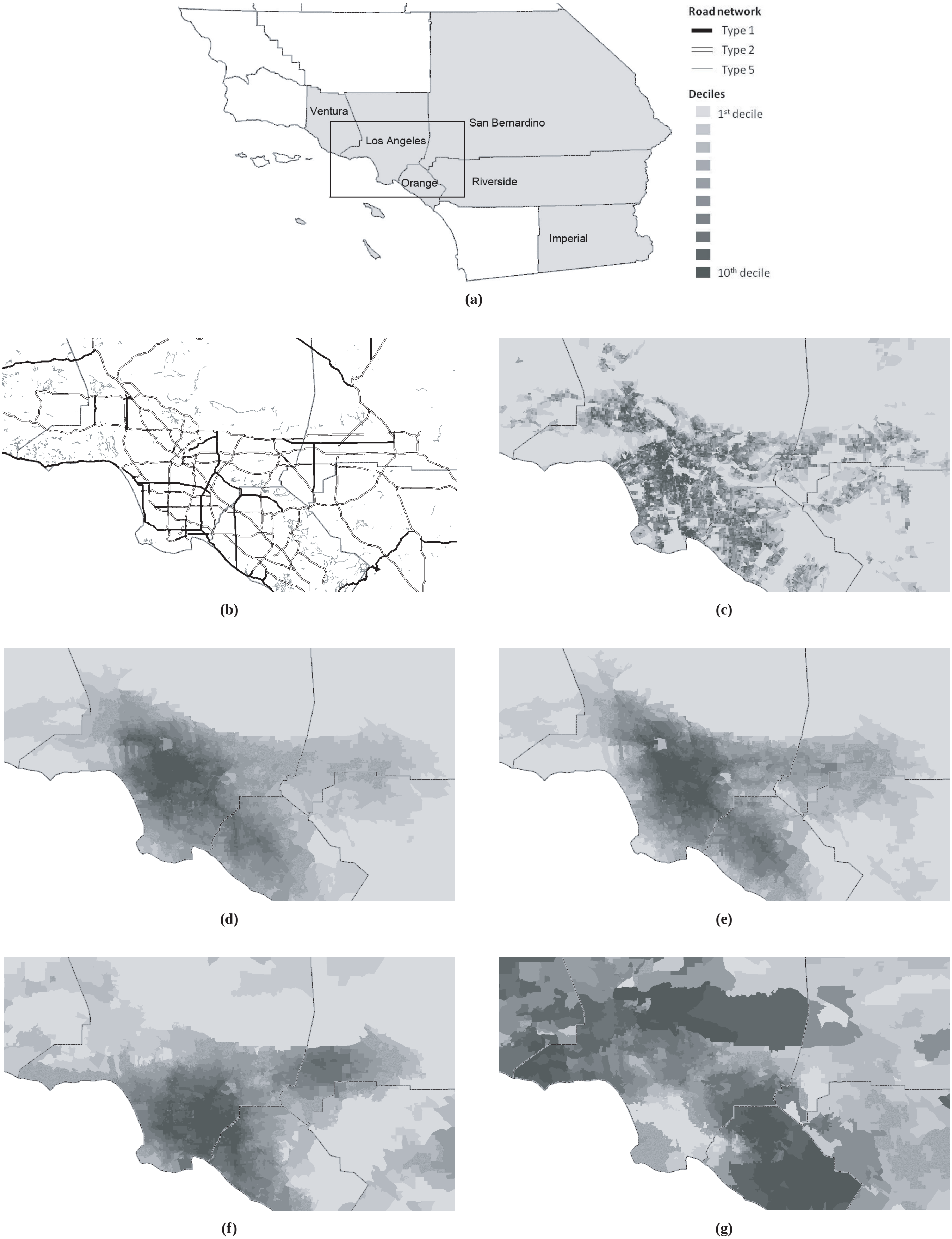


FIGURE 1 Accessibility distribution: (*a*) six counties of SCAG region; (*b*) Type 1, 2, and 5 networks; (*c*) 10 deciles of population density; (*d*) 10 deciles of retail employees within travel time of 20 min; (*e*) 10 deciles of Type 1 network within travel time of 20 min; (*f*) 10 deciles of Type 2 network within travel time of 20 min; and (*g*) 10 deciles of Type 5 network within travel time of 20 min.

**TABLE 4 Goodness of Fit**

| | Contribution of Set | | Cumulative Models | | |
|---|---|---|---|---|---|
| Variable Set | Chi-Square | Degrees of Freedom | Chi-Square | Degrees of Freedom | Nagelkerke $R^2$ |
| Model INDEPENDENT | | | | | |
| Sociodemographic | 602.824 | 50 | 602.824 | 50 | .212 |
| Spatial | 76.031 | 45 | 677.856 | 95 | .236 |
| Model ACTIVE | | | | | |
| Sociodemographic | 435.717 | 50 | 435.717 | 50 | .178 |
| Spatial | 157.632 | 45 | 593.349 | 95 | .237 |
| Model FATHER'S ESCORT | | | | | |
| Sociodemographic | 119.652 | 46 | 119.652 | 46 | .127 |
| Spatial | 90.922 | 45 | 210.574 | 91 | .217 |

hours (41 to 60 hours per week) have a negative impact on their propensity to take children to school, and mothers' long work hours (41 to 50 hours per week) have a positive impact on fathers' propensity to take children to school, which agrees with common sense. When fathers work at home, they are significantly more likely to take their children to school. This finding is evidence of the very different arrangements among parents based on wage-earning and spatiotemporal constraints.

## Spatial Patterns of Propensities

Table 5 provides coefficient estimates for spatial variables, and several significant patterns can be observed. The results show the impact of the different levels of accessibility fairly well, including an asymmetric impact of low accessibility and high accessibility. One of the cautions required in the interpretation is that each dummy variable should be interpreted as a set of block groups that is located with a certain amount of network availability around the respondent's origin. For example, the 10th (highest) decile in retail accessibility has a negative impact on both children's independent and active commutes to school. For interpretation of this impact within the spatial context, the maps in Figure 1 need to be consulted to find out where the 10th decile is located. This variable partially explains the locations of regional shopping centers or downtown areas.

Another recommended caution is that each dummy variable represents one of many characteristics of the block groups that belong to the dummy. For example, a certain block group in downtown Los Angeles can have the highest residential density and the highest retail accessibility but many other network accessibility characteristics, and a certain block group in Orange County can have the 7th decile in residential density and the 6th decile in retail accessibility but many other network accessibility characteristics. For these reasons, the collective effects of all the characteristics have more behavioral implications than the impact of one significant dummy, and so the authors do not offer an explanation about each parameter in Table 5. Instead of looking at the coefficients separately and trying to find their implication on each behavioral facet, the authors generated maps with composite impacts of all the spatial variables.

The three maps in Figure 2 show the total impact of the spatial variables in each model. A GIS layer was created for each set of dummies in a model assigning the significant coefficients to corresponding block groups. The layers were then summed into one map. The gray shades show the composite impacts of the spatial variables. A propensity significantly lower than the baseline is coded in dark gray shades, and a propensity significantly higher than the baseline is coded in light gray shades, with the baseline and block groups that are not significantly different from the baseline being medium gray. A detailed legend is given at the bottom of Figure 2. Because most of the variations are concentrated in Los Angeles County, Orange County, and a small portion of both San Bernardino and Riverside Counties, the maps show only those areas to make the interpretation easier.

In Figure 2*a*, it is clear that an area with light shades extends from the center of downtown Los Angeles, where accessibility by public transit is better than anywhere else in the SCAG region. This map shows a higher propensity for children's independent commuting is actually distributed around the facilities that enable independent traveling. Areas with a higher propensity for children's independent commuting appear along the coast, in Orange County, and in the southwestern corner of San Bernardino County. Except for those areas, the propensity for children to commute to school independently is almost uniform for the entire SCAG area.

Another aspect to be noted is the group of block groups with dark shades that dissect the lightly shaded area (marked with a square in Figure 2*a*). In appearance, this spatial pattern shows that for an unknown reason, spatial discontinuity in children's propensity to commute to school independently exists. To verify that the map shows the patterns that actually exist in the real world, the authors examined a detailed map, and found that this area with darker shades coincides with the Kenneth Hahn State Recreational Area, which takes up about 2 mi$^2$ in the middle of the urban area. The recreational area interrupts the connectivity of the network, and it appears to inhibit the desirable behavior for children to travel independently. The sample cases of downtown Los Angeles and the Kenneth Hahn State Recreational Area confirm that the method used in this study is able to detect the patterns of children's propensity to commute to school independently fairly well.

Figure 2*b* shows the spatial distribution of the propensity of children to commute to school using active modes. The highest propensity to use active modes is evenly distributed in downtown Los Angeles, as is the highest propensity to commute independently. The discontinuity in the spatial distribution of the propensity to

**TABLE 5 Estimated Coefficients of Children's Commuting Behavior Models**

| | INDEPENDENT | | | ACTIVE | | | FATHER'S ESCORT | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | *B* | Sig. | Exp(*B*) | *B* | Sig. | Exp(*B*) | *B* | Sig. | Exp(*B*) |
| Coefficients Estimated for Sociodemographic Variables | | | | | | | | | |
| Child's age (years) | | | | | | | | | |
| 0–5 | –1.407 | .000 | 0.245 | –1.098 | .000 | 0.333 | | | |
| 6–10 | –0.450 | .000 | 0.638 | | | | –0.269 | .099 | 0.764 |
| Base: 11–15 | | | | | | | | | |
| Child's gender: female | –0.128 | .091 | 0.880 | –0.272 | .003 | 0.762 | | | |
| Child's ethnicity | | | | | | | | | |
| Base: white, not Hispanic | | | | | | | | | |
| Hispanic | | | | | | | 0.411 | .055 | 1.508 |
| African American | 0.314 | .085 | 1.369 | 0.443 | .032 | 1.558 | | | |
| Asian, Pacific Islander | | | | | | | | | |
| Other | | | | | | | | | |
| Unknown | 0.271 | .097 | 1.312 | | | | | | |
| Household income ($) | | | | | | | | | |
| Less than 10,000 | | | | | | | | | |
| 10,000–24,999 | | | | 0.358 | .041 | 1.430 | | | |
| 25,000–34,999 | | | | 0.332 | .057 | 1.394 | | | |
| 35,000–49,999 | | | | 0.330 | .057 | 1.391 | | | |
| Base: 50,000–74,999 | | | | | | | | | |
| 75,000–99,999 | | | | | | | | | |
| 100,000–149,000 | –0.383 | .024 | 0.682 | | | | | | |
| 150,000 or more | | | | | | | | | |
| Unknown | | | | | | | | | |
| Parents | | | | | | | | | |
| Base: couples with the other employment status combinations | | | | | | | | | |
| Both parents full-time workers | | | | | | | –0.613 | .028 | 0.542 |
| Father full-time, mother part-time | | | | | | | –1.078 | .001 | 0.340 |
| Father full-time, mother not employed | | | | | | | | | |
| Single father | 0.974 | .003 | 2.647 | | | | | | |
| Employed single mother | | | | –0.976 | .007 | 0.377 | | | |
| Not employed single mother | | | | –1.125 | .003 | 0.325 | | | |
| Number of children under age 18 years | | | | | | | | | |
| Base: One | | | | | | | | | |
| Two | | | | | | | | | |
| Three | | | | 0.257 | .068 | 1.294 | | | |
| Four or more | 0.303 | .031 | 1.354 | 0.420 | .009 | 1.522 | | | |
| Father's work hours per week | | | | | | | | | |
| Base: less than or equal to 40 h | | | | | | | | | |
| 41–50 | | | | | | | –0.433 | .023 | 0.648 |
| 51–60 | | | | | | | –0.682 | .014 | 0.505 |
| 61+ | | | | | | | | | |
| Mother's work hours per week | | | | | | | | | |
| Base: less than or equal to 40 h | | | | | | | | | |
| 41–50 | 0.438 | .008 | 1.550 | 0.477 | .020 | 1.611 | 0.511 | .086 | 1.667 |
| 51–60 | –0.726 | .072 | 0.484 | | | | | | |
| 61+ | | | | | | | | | |
| Father's work location | | | | | | | | | |
| Base: fixed location | | | | | | | | | |
| Home | | | | | | | 0.727 | .030 | 2.068 |
| Not fixed location (e.g., traveling salesperson) | | | | | | | | | |
| Not known | | | | | | | | | |
| Mother's work location | | | | | | | | | |
| Base: fixed location | | | | | | | | | |
| Home | | | | 0.553 | .032 | 1.738 | | | |
| Not fixed location (e.g., traveling salesperson) | 0.476 | .028 | 1.609 | | | | | | |
| Not known | | | | 0.517 | .024 | 1.677 | –1.095 | .003 | 0.335 |
| Father's education | | | | | | | | | |
| 11th grade or less | | | | | | | 0.843 | .003 | 2.323 |
| Base: high school graduate | | | | | | | | | |
| Two years of college–associate's degree | | | | | | | 0.438 | .062 | 1.550 |
| Four years of college–bachelor's degree | –0.271 | .049 | 0.763 | | | | 0.928 | .000 | 2.529 |

*(continued)*

**TABLE 5** *(continued)* **Estimated Coefficients of Children's Commuting Behavior Models**

| | INDEPENDENT | | | ACTIVE | | | FATHER'S ESCORT | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | *B* | Sig. | Exp(*B*) | *B* | Sig. | Exp(*B*) | *B* | Sig. | Exp(*B*) |
| Postgraduate | | | | 0.401 | .058 | 1.493 | 0.539 | .067 | 1.715 |
| Unknown | | | | | | | 0.893 | .053 | 2.442 |
| Mother's education | | | | | | | | | |
| 11th grade or less | 0.383 | .004 | 1.466 | 0.260 | .063 | 1.297 | | | |
| Base: high school graduate | | | | | | | | | |
| Two years of college–associate's degree | | | | –0.328 | .017 | 0.720 | | | |
| Four years of college–bachelor's degree | | | | | | | | | |
| Postgraduate | –0.579 | .001 | 0.561 | –0.559 | .016 | 0.572 | | | |
| Unknown | | | | | | | | | |
| Number of household vehicles | | | | | | | | | |
| 0 | | | | 1.046 | .000 | 2.845 | | | |
| Base: 1 | | | | | | | | | |
| 2 | –0.298 | .004 | 0.742 | –0.761 | .000 | 0.467 | –0.504 | .039 | 0.604 |
| 3+ | –0.264 | .036 | 0.768 | –0.744 | .000 | 0.475 | | | |
| Coefficients Estimated for Spatial Variables | | | | | | | | | |
| Block group population density (percentile) | | | | | | | | | |
| <10 | 0.296 | .073 | 1.344 | | | | 0.516 | .097 | 1.676 |
| 10th | | | | | | | | | |
| 20th | 0.283 | .066 | 1.328 | | | | | | |
| 30th | | | | 0.419 | .028 | 1.521 | | | |
| Base: 40th | | | | | | | | | |
| 50th | | | | | | | | | |
| 60th | | | | | | | | | |
| 70th | | | | | | | | | |
| 80th | | | | 0.653 | .006 | 1.921 | | | |
| 90th | | | | 0.640 | .009 | 1.896 | | | |
| Number of retail employees within 20 min travel (percentile) | | | | | | | | | |
| <10 | 0.696 | .027 | 2.005 | | | | –1.038 | .061 | 0.354 |
| 10th | 0.699 | .009 | 2.012 | | | | –0.994 | .033 | 0.370 |
| 20th | | | | | | | –1.446 | .000 | 0.236 |
| 30th | | | | | | | –1.859 | .000 | 0.156 |
| Base: 40th | | | | | | | | | |
| 50th | 0.467 | .052 | 1.595 | | | | | | |
| 60th | | | | | | | | | |
| 70th | | | | | | | 1.031 | .031 | 2.804 |
| 80th | | | | | | | | | |
| 90th | –1.041 | .004 | 0.353 | –1.002 | .014 | 0.367 | | | |
| Total length of primary roads with limited access within 20 min travel (percentile) | | | | | | | | | |
| <10 | | | | –0.691 | .086 | 0.501 | | | |
| 10th | | | | | | | 0.817 | .089 | 2.264 |
| 20th | | | | | | | | | |
| 30th | | | | | | | | | |
| Base: 40th | | | | | | | | | |
| 50th | | | | | | | | | |
| 60th | | | | | | | | | |
| 70th | | | | | | | | | |
| 80th | 0.848 | .006 | 2.335 | | | | –1.864 | .002 | 0.155 |
| 90th | 1.122 | .002 | 3.073 | 1.043 | .008 | 2.839 | | | |
| Total length of primary roads without limited access within 20 min travel (percentile) | | | | | | | | | |
| <10 | | | | | | | | | |
| 10th | | | | | | | | | |
| 20th | | | | 0.633 | .002 | 1.883 | | | |
| 30th | | | | | | | | | |
| Base: 40th | | | | | | | | | |
| 50th | 0.527 | .006 | 1.693 | 0.508 | .018 | 1.662 | | | |
| 60th | 0.631 | .001 | 1.880 | | | | –0.668 | .063 | 0.513 |
| 70th | 0.381 | .056 | 1.463 | | | | | | |
| 80th | | | | | | | | | |
| 90th | | | | –0.876 | .001 | 0.417 | –0.731 | .063 | 0.481 |

*(continued on next page)*

**TABLE 5** *(continued)* **Estimated Coefficients of Children's Commuting Behavior Models**

| | INDEPENDENT | | | ACTIVE | | | FATHER'S ESCORT | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | *B* | Sig. | Exp(*B*) | *B* | Sig. | Exp(*B*) | *B* | Sig. | Exp(*B*) |
| Total length of vehicular trail within 20 min travel (percentile) | | | | | | | | | |
| <10 | | | | | | | 0.849 | .016 | 2.336 |
| 10th | | | | | | | | | |
| 20th | | | | | | | | | |
| 30th | | | | | | | | | |
| Base: 40th | | | | | | | | | |
| 50th | | | | | | | | | |
| 60th | | | | | | | | | |
| 70th | | | | –0.719 | .012 | 0.487 | | | |
| 80th | | | | | | | | | |
| 90th | –0.401 | .077 | 0.670 | | | | | | |

NOTE: Sig. = significance; *B* = β coefficient; Exp(*B*) = odds ratio.

commute independently, possibly because of the Kenneth Hahn State Recreational Area, appears in the spatial distribution of the propensity to commute by active modes as well. These agreements in the spatial distributions of the two propensities show a strong possibility for a causal relationship between the environment enabling children's active travel and their independent travel. They also provide evidence of the ability of this method to pinpoint problematic areas for local policy action.

Figure 2*c* shows the spatial distribution of the propensity of fathers to escort their children to school. Noticeable spatial patterns can be found. These patterns consist of the rings formed around the downtown Los Angeles area. A ring with a relatively positive propensity (lightly shaded areas) for fathers to escort their children to school is immediately outside the downtown area, and farther out is another ring with a relatively negative propensity (dark shades). The accessibility measures alone do not explain why those rings with these specific patterns are formed. One of the most promising approaches to finding the reason would be analyzing the school locations in relation to the children's home location and the destination (work location) of their fathers, which is left as a future task. However, the spatial patterns shown on the map give an idea of the tours that fathers and mothers make in the morning. These tours are most likely to be significantly different around the two rings, assuming that children are sent to schools that are close to home. Therefore, this map may also indicate that the accessibility around school locations not only affects children's behavior when they are going to school but also influences their parents' behavior and the bargaining and task allocation patterns between mothers and fathers.

## CONCLUSIONS

This study analyzed three different aspects of children's school commute behavior. Spatial variables, including accessibility measures and population density, were introduced in regression models to account for the impact of the spatial characteristics around school locations. When the impact of sociodemographics is taken into account, the results of three models showed spatial distributions of the propensity of each behavior and intrahousehold interaction patterns. The results of each model, presented as maps combining the impact of all the significant spatial variables, are informative. These types of maps can be useful for decision makers and planners trying to identify specific locations where certain types of investments in local policy programs that promote specific types of behavior, such as children's active traveling, are needed.

As indicators of spatial characteristics influencing behavior, accessibility measures at school locations were used as explanatory variables in this study. However, when one makes decisions about a trip, not only the accessibility at the destination but also the accessibility in the space between and the spaces encompassing the origin and the destination are important. An alternative to the use of location-based accessibility is the use of time–space prism accessibility (*25*), which takes into account the origin, the destination, and the space between them. By using time–space prism accessibility, investigators can have accessibility measures that are more integrated into individual schedules of activities and consider the complete choice set of the many activity-related decisions. This procedure is one potential future direction for new model development emerging from this study.

The study described here tested a methodology of analyzing geographical patterns in behavior by using children's school commute behavior and parents' behavior in chauffeuring their children. This methodology was used not only to analyze individual behavior patterns but also to find the impact of spatial characteristics on interactions between individuals. The results of this study show an opportunity to expand the microanalysis to a more comprehensive treatment of travel behavior in space and to contribute to the development of models integrating land use and transportation.

This study, however, uses data collected in 2001 and shows behavioral patterns from about 10 years ago. Although a rich set of accessibility measures was developed for the year 2001, many detailed data for the development of a more in-depth analysis were simply not available. For example, adequate spatial measures of walkability or bikability, such as connected sidewalk and bike path networks, or the availability of school buses at different schools, which would be expected to have a significant impact on children's independent or active travel, could not be derived. However, it was found that even with the limited information about space, children's commute behavior could be explained, and it was possible to define the data needs for future development of this methodology. This is particularly important for the newly designed California statewide as well as

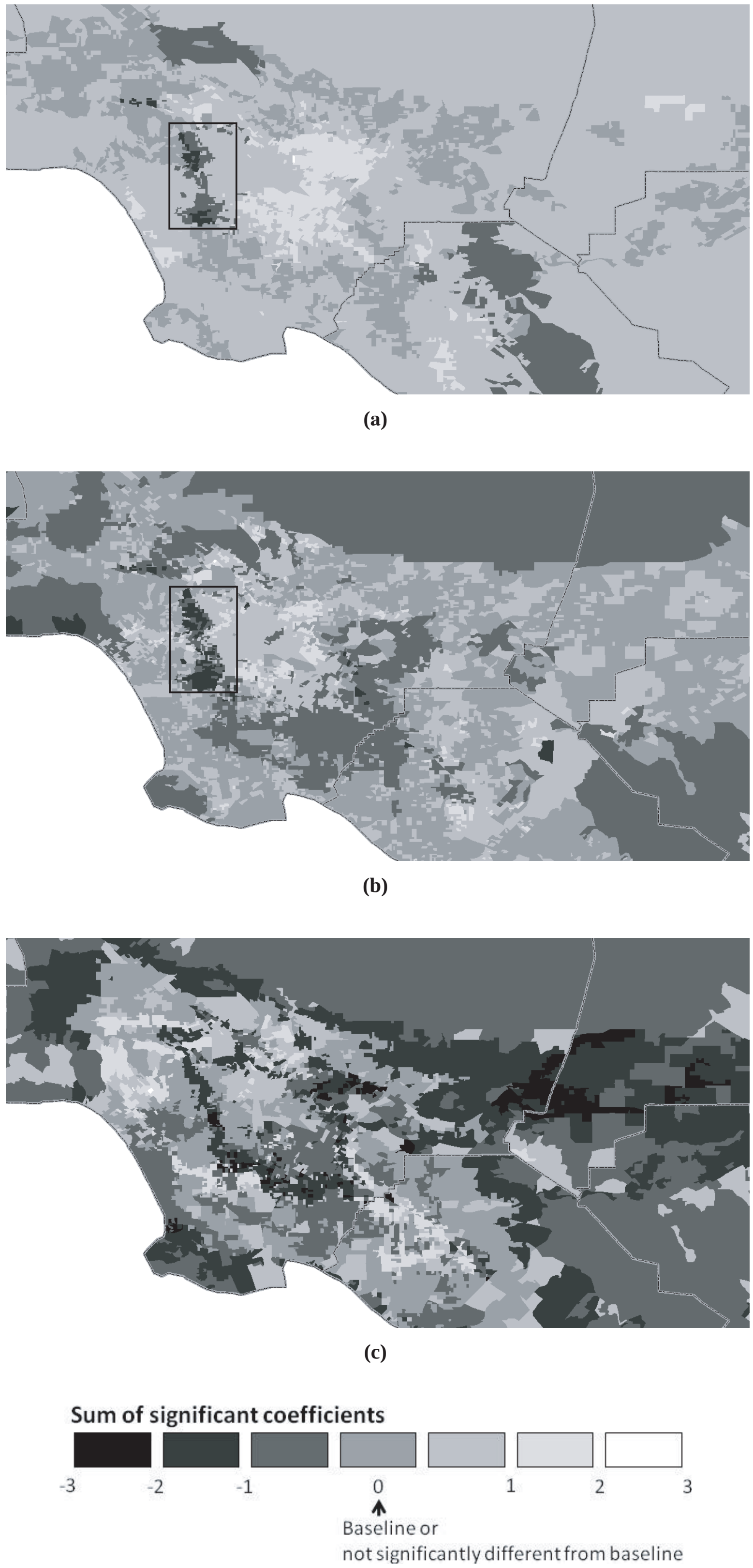


FIGURE 2 Propensity maps for the three models estimated: (*a*) children's propensity to commute to school independently of parents, (*b*) children's propensity to commute to school by active modes, and (*c*) father's propensity to take children to school.

SCAG household travel and add-on surveys that are going to be conducted in 2011 to 2012 and for related accessibility measures that will also be updated immediately after the survey is completed.

A final comment about the analyses that can be done with the new data that will be available in a few years is called for. Some of the areas in the SCAG region have gone through changes in safety, walkability, and public transportation accessibility during the 10 years since the data used in this study were collected, and these might have brought about changes in behavior patterns in the urban area. In that context, a longitudinal study of the region can be done to examine changes in the propensities that are explored in this study with updated accessibility measures. Those analyses can address the causal relationship between changes in land use and facilities and changes in behavior patterns in the region. Additionally, this type of analysis can be conducted at the local level with better representation of the environment when more detailed spatial information is available.

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## REFERENCES

1. Yoon, S. Y., and K. G. Goulias. Impact of Time–Space Prism Accessibility on Time Use Behavior and Its Propagation Through Intra-Household Interaction. *Transportation Letters: The International Journal of Transportation Research*, Vol. 2, No. 4, 2010, pp. 245–260.
2. Koplan, J. P., C. T. Liverman, and V. I. Kraak (eds.). *Preventing Childhood Obesity: Health in the Balance.* Institute of Medicine of the National Academies. National Academies Press, Washington, D.C., 2005.
3. Cooper, A. R., A. S. Page, L. J. Foster, and D. Qahwaji. Commuting to School: Are Children Who Walk More Physically Active? *American Journal of Preventive Medicine*, Vol. 25, 2003, pp. 273–276.
4. Ewing, R., W. Schroeer, and W. Greene. School Location and Student Travel: Analysis of Factors Affecting Mode Choice. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1895,* Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 55–63.
5. Boarnet, M. G., C. L. Anderson, C. Day, T. E. McMillan, and M. Alfonzo. Evaluation of the California Safe Routes to School Legislation: Urban Form Changes and Children's Active Transport to School. *American Journal of Preventive Medicine,* Vol. 28, No. 2, 2005, pp. 134–140.
6. McMillan, T. E. The Relative Influence of Urban Form on a Child's Travel Mode to School. *Transportation Research, Part A,* Vol. 41, No. 1, 2007, pp. 69–79.
7. Lin, J.-J., and H.-T. Chang. Built Environment Effects on Children's School Travel in Taipai: Independence and Travel Mode. *Urban Studies,* Vol. 47, No. 4, 2010, pp. 867–889.
8. Yarlagadda, A. K., and S. Srinivasan. Modeling Children's School Travel Mode and Parental Escort Decisions. *Transportation,* Vol. 35, No. 2, 2008, pp. 201–218.
9. Schwanen, T. Gender Differences in Chauffeuring Children Among Dual-Earner Families. *The Professional Geographer,* Vol. 59, No. 4, 2007, pp. 447–462.
10. Schwanen, T., D. Ettema, and H. Timmermans. If You Pick up the Children, I'll Do the Groceries: Spatial Differences in Between-Partner Interactions in Out-of-Home Household Activities. *Environment and Planning A,* Vol. 39, No. 11, 2007, pp. 2754–2773.
11. Schwanen, T., and T. de Jong. Exploring the Juggling of Responsibilities with Space–Time Accessibility Analysis. *Urban Geography,* Vol. 29, No. 6, 2008, pp. 556–580.
12. Sidharthan, R., C. R. Bhat, R. M. Pendyala, and K. G. Goulias. Model for Children's School Travel Model Choice: Behavior Accounting for Effects of Spatial and Social Interaction. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2213,* Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 78–86.
13. Yoon, S. Y., T. F. Golob, and K. G. Goulias. A California Statewide Exploratory Analysis Correlating Land Use Density, Infrastructure Supply, and Travel Behavior. Presented at 88th Annual Transportation Research Board Meeting, Washington, D.C., 2009.
14. Golob, T. F., and M. G. McNally. A Model of Activity Participation and Travel Interactions Between Household Heads. *Transportation Research, Part B,* Vol. 31, No. 3, 1997, pp. 177–194.
15. Golob, T. F. Structural Equation Modeling for Travel Behavior Research. *Transportation Research, Part B,* Vol. 37, No. 1, 2003, pp. 1–25.
16. Gliebe, J. P., and F. S. Koppelman. Modeling Household Activity–Travel Interactions as Parallel Constrained Choices. *Transportation,* Vol. 32, 2005, pp. 449–471.
17. Meister, K., M. Frick, and K. W. Axhausen. A GA-Based Household Scheduler. *Transportation,* Vol. 32, 2005, pp. 473–494.
18. Zhang, J., H. Timmermans, and A. Borgers. A Utility-Maximizing Model of Household Time Use for Independent, Shared, and Allocated Activities Incorporating Group Decision Mechanisms. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1807,* Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 1–8.
19. Zhang, J., and A. Fujiwara. Representing Household Time Allocation Behavior by Endogenously Incorporating Diverse Intra-Household Interactions: A Case Study in the Context of Elderly Couples. *Transportation Research, Part B,* Vol. 40, No. 1, 2006, pp. 54–74.
20. Srinivasan, K. K., and S. R. Athuru. Analysis of Within-Household Effects and Between-Household Differences in Maintenance Activity Allocation. *Transportation,* Vol. 32, 2005, pp. 495–521.
21. Srinivasan, S., and C. R. Bhat. Modeling Household Interactions in Daily In-Home and Out-of-Home Maintenance Activity Participation. *Transportation,* Vol. 32, 2005, pp. 523–544.
22. Bradley, M., and P. Vovsha. A Model for Joint Choice of Daily Activity Pattern Types of Household Members. *Transportation,* Vol. 32, 2005, pp. 545–571.
23. Goulias, K. G., and K. Henson. On Altruists and Egoists in Activity Participation and Travel: Who Are They and Do They Live Together? *Transportation,* Vol. 33, No. 5, 2006, pp. 447–462.
24. Dijkstra, E. W. A Note on Two Problems in Connection with Graphs. *Numerische Mathematik,* Vol. 1, No. 1, 1959, pp. 269–271.
25. Hägerstrand, T. What About People in Regional Science? *Papers and Proceedings of the Regional Science Association,* Vol. 24, 1970, pp. 7–24.

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