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

Seo Youn Yoon
(Corresponding author)
GeoTrans Lab.
Department of Geography
University of California, Santa Barbara
Phone: 805-893-3867
Email: yoon@geog.ucsb.edu

Marjorie Doudnikoff
Ecole Nationale des Travaux Publics de l'Etat, France
Phone: 33-415-6326-305
Email: Marjorie.Doudnikoff@bvra.entpe.fr

and

Konstadinos G. Goulias
GeoTrans Lab.
Department of Geography
University of California, Santa Barbara
Phone: 805-308-2837, Fax: 805-893-2578
Email: goulias@geog.ucsb.edu

Abstract

Spatial distribution of children's school commute behavior was analyzed from three perspectives that are: 1) commuting to school independently of parents, 2) commuting to school by active modes and 3) allocation of escorting tasks for children between mother and father. Accessibility measures and population density were introduced in the propensity regression models to account for the impact of spatial characteristics at school locations and to identify the spatial distribution of behavioral patterns. Each of the spatial patterns created a map combining the impact of all the significant spatial variables to display patterns of behavior and intra-household interaction. These patterns are able to identify, as examples, the negative impact of a park area in the middle of the City of Los Angeles on children's independent and active commute to school and the significantly different intra-household interaction patterns at different locations in the region. 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.

Number of Words = 6,178 (body) + 1,500 (4 tables and 2 figures) = 7,618
For consideration for presentation at the 90th annual meeting of the Transportation Research Board and publication in the Transportation Research Record

Introduction

In this paper, we analyze the propensity to escort children to school, which can be interpreted as being protective about children on parents' side and as being dependent on parents for traveling on children's side. Analysis of children's dependence on their parents is important in many contexts. In our previous studies on the household interaction in time use *(1)*, children's time use patterns had a substantial impact on their parents' activity participation and travel. Children's out-of-home activities become spatio-temporal constraints for their parents especially when the parents have to chauffer their children. Therefore, it is very important to find the interaction patterns in escorting to school as escorting 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 parenthood duties are, in general, inflicted differently on fathers and mothers. For example, in the household travel survey conducted by the Southern California Association of Government (SCAG) in year 2001, a large proportion (75.3%) of the rides for children was provided by mothers, and a much smaller proportion (24.7%) of them was provided by fathers. This asymmetric allocation of parenthood 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 *(e.g., 2)* and to improve children's overall well-being *(e.g., 3)*. Built environment has been considered to be one of the important factors impacting children's travel mode to school and the relationship between children's school trip and built environment has been addressed by the existing literature *(e.g., 4, 5, 6, 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 socio-economic characteristics *(8)*, and allocation of chauffeuring between mother and father has also been addressed *(9, 10, 11)*. Sidharthan et al. *(12)* focused on the impact of spatial and social interaction in the neighborhood and found that the interaction in the neighborhood is significant on the decision on children's travel mode to school. Based on this result, they suggested public policies targeting the local neighborhood level.

In this context, we propose a spatial analysis that links spatial variables around school locations and different aspects of children's commuting behavior, and show the geographic patterns of the impact as propensity maps. Children's commuting behavior patterns that we looked at are: 1) commuting to school independently of parents, 2) commuting to school by active modes (walking and biking), and 3) allocation of escort for children between mother and father. In order to find the characteristics of school location and their spatial patterns, we introduced accessibility indicators at school location 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 it by performing more sophisticated spatial analysis that includes intra-household interaction ideas.

For modeling of intra-household interaction, several different strategies have been used in travel behavior research. Modeling methodologies include structural equations models *(SEM; e.g., 14, 15, 1)*, structural discrete choice models *(16)*, genetic algorithms *(17)*, household utility maximization *(e.g., 18, 19, 20, 21, 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 intra-household interaction, we keep the scope of intra-household interaction simple to emphasize only intra-household interaction in relation to spatial characteristics of school location(s). We look at specific aspects of dependency of children on their parents in commuting behavior that are listed above, and use binary Logit models for the behavioral patterns of children's commute to school. Finally the results are displayed as spatial patterns using Geographic Information System (GIS).

DATA USED

This study uses the 2001 post-Census travel survey conducted for the Southern California Association of Governments (SCAG). This region includes the six-counties of Los Angeles, Orange, Imperial, Irvine, 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.

Out of the approximately 40,000 people from the sample, 3,483 children under 16 years old went to school, pre-school, or daycare (referred to collectively as school hereafter) on the survey day. The children's and their family's sociodemographic information is summarized in Table 1, and the children's mode choice to school and the split of escorting children between their father and mother are summarized in Table 2. About 50% of the children (2,022) were escorted to school by their parents, and the split of escorting between father and mother was 512 and 1,510 respectively. About 22% of the children traveled to school using active modes (walking and biking).

The network data we used for this paper (Dynamap/Transportation by Tele Atlas) contains very detailed information on the road network across the entire State of California. It includes type of road network, segment length, and speed limit for each segment, turn restrictions, and one way street enabling realistic representation of transportation facilities. The types of road network provided in Dynamap/Transportation are primary roads with limited access (type 1), primary roads without limited access (type 2), secondary/connecting roads (type 3), and local/ neighborhood/rural road (type 4), vehicular trail (type 5), roads with special characteristics (type 6), and all other roadways (type 7). Not included in this network data however is the information on the public transportation network. The total length of each network type in a block group was considered as an indicator of the amount of available transportation facilities of each type in the block group.

The six counties included in the SCAG region are divided into 10,631 zones using the US Census 2000 block groups. The number of employees reported by the Census Transportation Planning Package (CTPP) is counted for each block group using the fourteen industry types classified by the North American Industry Classification System (NAICS). These numbers are used as the relative amount of opportunity to participate in the related type of activities (i.e., the number of employees in retail industry represents the opportunity to participate in shopping activities). In this analysis we use only the number of employees in retail industry as an accessibility indicator in order 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, in this paper we consider only the 10,631 block groups in the SCAG region. However, for the borders of the SCAG region we also include block groups outside the region that are accessible from the origin block group. Treating each block group as a traffic analysis zone, we attached each block group to the nearest node in the Dynamap/Transportation network dataset that 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 (CFCC). A travel time based on Dijkstra's algorithm *(24)* between each pair of origin and destination is computed using ArcGIS Network Analyst. 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 using a threshold of travel time. We used the time threshold of 20 minutes to find the local accessibility of each block group. We used this threshold based on the duration of trips to school reported in the sample. It took 14.23 minutes on average for the children in the sample to go to school by walking (standard deviation = 11.27), 13.39 minutes on average by bike (s.d. = 7.37), and 11.85 minutes on average by car (as a passenger, s.d. = 11.76). Therefore, the buffer area of 20 minutes by car represents the approximate catchment area of each school.

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

- number of retail employees within 20 minutes travel
- total segment kilometers by network type within 20 minutes travel
  - 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 correlation with each other, which leads to redundancy in travel behavior models. We selectively excluded some of the accessibility measures based on the correlation matrix, and managed the number of included accessibility measures to be minimal and not redundant. The accessibility measures for network type 3, 4 and 6 were excluded because of their high correlation with other accessibility measures (the correlation between type 3 and type 1 is 0.865, the correlation between type 4 and type 1 is 0.872, and the correlation between type 6 and type 1 is 0.947). Type 7 was excluded since it was not defined as uninformative functional class.

The accessibility measures that are finally included in the behavioral models are:

- number of retail employees within 20minutes travel
- total segment kilometers by network type within 20 minutes travel
  - primary highways with limited access (type 1),
  - primary roadways without limited access (type 2), and
  - vehicular trail (type 5),

In addition to the four accessibility measures, population density of each block group is included as a proxy of residential density. It should be noted there are other methods of developing summaries of accessibility. In fact, the coarse spatial resolution using census block groups can be rectified using a school-by-school analysis that also includes mode-specific accessibility measures computed with mode-specific travel time and network using a finer spatial resolution based on the alternatives available for each individual. All this is left as a future task.

MODELS AND RESULTS

General description of the models

We estimated three behavioral models to analyze different aspects of children's commute to school. In each of the models that we estimated, variables are tested in two blocks: (1) the set of sociodemographic variables, and (2) the set of accessibility measures and population density at school location 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 (independent of parents). The variable analyzed takes the value of 1 if the child goes to school without a parent; 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 walking or biking; 0 otherwise, and
3. Model **FATHER'S ESCORT:** a binary Logit model for allocating escort for children to father. The variable analyzed takes the value of 1 if the child goes to school with the father; 0 if the child goes to school with the mother. This model is estimated only for children who are from couple headed households and went to school with their parents.

The model INDEPENDENT uses two sets of explanatory variables. We test if there are any sociodemographic groups that are significantly more or less likely to let children travel independently, and if accessibility and population density at school location have significant impact on children's independent commute to school and alleviating parents' obligation to take their children to school.

With the model ACTIVE, we test a more specific type of children's independent travel. This model focuses on 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 environment around school locations, children can more easily be independent of their parents after accounting for the impact of sociodemographics. This model also addresses the possibility of relieving the parental duties of escorting their children by providing a certain type of environment that enables children's active travel.

Lastly in the model FATHER'S ESCORT we include only the children in couple-headed households who were escorted by their parents (n=1,328) and this model addresses allocation of the parental duty of escorting children to school between their father and mother to see if there is a geographic pattern in the bargaining between father and mother on escorting their children.

The purpose of including spatial variables in the models as explanatory variables is to find specific areas that have significant association with any of the three commuting patterns. Modeling 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 with a very small population in them and very few retail employees and road network accessible within 20 minutes travel. In contrast, some other block groups in the center of the City of Los Angeles are extremely dense in population, and/or have very high accessibility to retail business 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 (total segment length by network type and population density) or a count (number of employees) variable, is reclassified into a discrete variable that has 10 even classes. Each of the 10 classes represents one decile in the distribution of the variable. For example, the first class of the discrete variable for population density represents the block groups that belong to 0 to 10th percentiles in the population density distribution. This relieves the estimation bias caused by outlying observations and makes it easier to find specific areas that are significant. It also facilitates estimation in which the spatial variables can contribute nonlinear and even non-ordinal effects. This methodology is emerging from our previous statewide exploratory analysis for California correlating land use density, infrastructure supply and travel behavior *(13)*. Figure 2 shows the spatial distributions of the discretized accessibility variables over the SCAG area.

Contribution of spatial variables

The omnibus tests of each set of variables are given in Table 3. The tables provide an idea about how much the spatial variables improve each of the models over the same models with only sociodemographic variables.

In terms of the increment of chi-square and Nagelkerke R^2 both by ratio and difference, the model INDEPENDENT is the least affected by the spatial variables. This indicates that the sociodemographic characteristics of the children and their family have more importance in determining if the children are going to travel to school independently or not. This result also implies that although spatial variables have significant relationship with children's independent travel to school, it might be harder to change children's commute patterns by just changing 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 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. It suggests that the active modes have to 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 that sociodemographic variables contributed to the goodness of fit. It implies that it is very likely that there is a geographic pattern in allocating escort for children between fathers and mothers.

Impact of sociodemographic variables

Estimated coefficients of the three models are shown in Table 4. To aid in interpretation, only statistically significant ($p \leq 0.05$) coefficients and marginally significant ($0.05 < p \leq 0.1$) 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, children's age displays significant impacts. Younger children are less likely to travel independently to school and less likely to travel by active modes as expected. Gender of the child was significant in the model ACTIVE and marginally significant in the model INDEPENDENT, which means girls are less likely to go to school independently of their parents and to use active modes when parents do not escort them to school than boys are. Ethnicity has a significant impact both on traveling independently of parents and traveling by active modes. African American children were the most likely to go to school independently and to walk or bike to school among all the ethnicity groups, and children who did not answer their ethnicity are more likely to go to school independently than white children with a marginal significance.

Children of households with annual income more than $100,000 and less than $150,000 are less likely to travel independently than the baseline (the children of households with annual income more than $50,000 and less than $75,000), which implies that higher income encourages parents to be protective about their children's commute to school. Children of households with annual income more than $10,000 and less than $50,000 are more likely to walk or bike than the baseline (1.391-1.430 times of 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 walkability or bikability of the neighborhood around school locations. Number of siblings under eighteen 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 they might be making location choices that enable their children to walk or bike to school. Among different parenthood 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.

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

In the model FATHER'S ESCORT, both parents' employment status, work hours and work locations have significant impacts. In couple headed households, fathers are the least likely to take children to school (0.340 times of the baseline) when they are employed full-time and their wives are employed part-time, and less likely to take children to school than the baseline when they and their wives are employed full-time (0.542 times of the baseline). Fathers' long work hours (41-60 hours) have a negative impact on their propensity to take children to school, and mothers' long work hours (41-50) 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 is evidence of very different arrangements among parents based on wage-earning and spatio-temporal constraints.

Spatial patterns of the propensities

Table 4.b provides coefficients estimates for spatial variables in which we can observe several significant patterns. The results show the impact of the different levels of accessibility fairly well, including 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 are located with a certain amount of network availability around. For example, the 10^{th} (highest) decile in retail accessibility has negative impact on both children's independent and active commute to school. In order to interpret this impact within the spatial context, we need to go to the maps in Figure 1 and find out where the 10^{th} 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 Los Angeles downtown can be represented with the highest residential density and the highest retail accessibility with many other network accessibility characteristics, and a certain block group in Orange County can be represented with the 7^{th} decile in residential density and the 6^{th} decile in retail accessibility with many other network accessibility characteristics. Due to these reasons, the collective effects of all the characteristics have more behavioral implications than the impact of one significant dummy and we do not offer an explanation about each parameter in Table 4.b. Instead of looking at the coefficients separately and trying to find their implication on each behavior, maps with composite impact of all the spatial variables are generated.

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 merged together by adding up the layers. The height that each block group is extruded to show the magnitude of the coefficients, and the color shows how far they are from the baseline propensity. Significantly lower propensity than the baseline is coded in light to dark purple colors and significantly higher propensity is coded in light to dark orange colors with the baseline and block groups that are not significantly different than the baseline being white. Overall, the darker the color is, the bigger the magnitude of the coefficient is, and a detailed legend is given in the Figure as well. Since 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 are showing only those areas to make the interpretation easier.

In Figure 2.a, it is clear that an area with dark orange color extends from the center of downtown Los Angeles, where accessibility by public transit is better than anywhere else in the SCAG area. This map shows higher propensity of children's independent commute is actually distributed around the facilities that enable independent travelling. There are areas with higher propensity of children's independent commute along the coastal area, in Orange County and in southwestern corner of San Bernardino County. Except those areas, the entire SCAG area shows almost uniform propensity of children to commute to school independently. Another aspect to be noted is that there is a narrow channel with purple color in the middle of the orange-colored area (marked with a square). This spatial pattern shows that some unknown reasons may be causing spatial discontinuity in children's propensity to commute to school independently. To verify that the map is actually showing the patterns that exist in the real world, we examine a detailed map and find that this area with purple colors coincides with the Kenneth Hahn State Recreational Area, which is taking up about 2 miles X 2 miles in the middle of the urban area. The recreational area interrupts the connectivity of the network and it appears to inhibit the desirable children's behavior to travel independently. This also shows the method we are using is able to detect from the sample cases of the downtown Los Angeles and Kenneth Hahn State Recreational Area patterns of children's propensity to commute to travel independently of their parents 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 distributed in downtown Los Angeles, as is the highest propensity to commute independently. The discontinuity in the spatial distribution of the propensity to commute independently possibly due to 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 high possibility of a causal relationship between the environment where children can travel actively and their independent travel and our ability to pinpoint problematic areas for local policy action.

Figure 2.c shows the spatial distribution of the propensity of fathers to escort children to school. We can find noticeable spatial patterns, which are the rings formed around the downtown Los Angeles area. A ring with significantly positive propensity (orange color) of fathers to escort children to school is immediately outside of the downtown area, and further out is another ring with significantly negative propensity (purple color). The accessibility measures alone do not explain why those rings are formed with these specific patterns. One of the most promising approaches to find out the reason would be analyzing the school locations with 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 made by fathers and mothers 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 impacts school-going children's behavior but also influences their parents' behavior and the bargaining patterns between mother and father.

CONCLUSIONS

This study analyzed three different aspects of children's school commute behavior. Spatial variables including accessibility measures and population density were introduced in the regression models to account for the impact of the spatial characteristics at school location. Taking account of the impact of sociodemographics, the results of three models showed spatial distributions of the propensity of each behavior and intra-household interaction patterns. The results of each model were presented as a map combining the impact of all the significant spatial variables. This type of maps can be very useful when decision makers or planners are trying to identify specific locations where certain types of investment are needed in local policy programs that promote specific types of behavior such as children's active traveling.

As indicators of spatial characteristics influencing behavior, accessibility measures at school locations were taken 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 encompassing the origin and the destination is important. An alternative of location-based accessibility is using time-space prism accessibility *(25)*, which takes account of the origin, destination and the space between them. By using time-space prism accessibility, we 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 is one of the potential developments after this study.

In this paper we tested a methodology of analyzing geographical patterns in behavior using children's school commute behavior and parents' chauffeuring for children. This methodology was used not only to analyze individual behavior patterns but also to find the impact of spatial characteristics on interaction 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 of about ten years ago. Although we developed a rich set of accessibility measures for year 2001, many detailed databases to develop more in-depth analysis was simply not available. For example, we could not derive adequate spatial measures of walkability or bikability such as connected sidewalk and bikepath networks, or availability of school buses at different schools, which one would expect to have significant impact on children's independent or active travel. However, we found out that we were able to explain children's commute behavior even with the limited information about space 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 SCAG travel survey that is going to be conducted in 2011-2012 and related accessibility measures that will also be updated.

A final comment is about the analyses that can be done with the new data that will be available in a few years. Some of the areas in the SCAG region have gone through changes in safety, walkability, and public transportation accessibility during the ten years since the dataset used in this study were collected, which might have brought 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. By those analyses we can address the causal relationship between changes in land use and facilities and changes in behavior patterns in the region. Second, this type of analysis can be conducted at the local level with better representation of the environment with more detailed spatial information available.

ACKNOWLEDGEMENT

Funding for this research was provided by The Southern California Association of Governments, the University of California Office of the President, and The University of California Transportation Center, and Marjorie Doudnikoff's internship at University of California, Santa Barbara was supported by Ecole Nationale des Travaux Publics de l'Etat, France. This paper does not constitute a policy or regulation of any Local, State, or Federal agency.

REFERENCES

1. Yoon, S.Y., and K.G. Goulias (2010). 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* 2010(2): 245-260.

2. Koplan, J.P., C.T. Liverman, , and V.I. Kraak (eds.) (2005). *Preventing Childhood Obesity: Health in The Balance*. Institute of Medicine of the National Academies, The National Academies Press, Washington, DC.

3. Cooper, A.R., A.S. Page, L.J. Foster, and D. Qahwaji (2003). Commuting to school: are children who walk more physically active? *American Journal of Preventive Medicine,* 25, 273-276.

4. Ewing, R., W. Schroer, and W. Greene (2004). School location and student travel: analysis of factors affecting mode choice. *Transportation Research Record*, 1895, 55-63.

5. Boarnet, M.G., C.L. Anderson, C. Day, T.E. McMillan, and M. Alfonzo (2005). Evaluation of the California safe routes to school legislation: urban form changes and children's active transport to school. *American Journal of Preventive Medicine*, 28 (suppl 2), S134-S140.

6. McMillan, T.E. (2007). The relative influence of urban form on a child's travel mode to school. *Transportation Research Part A*, 41(1), 69-79.

7. Lin, J-J, and H-T Chang (2010). Built environment effects on children's school travel in Taipai: independence and travel mode. Urban Studies, 47(4), 867-889.

8. Yarlagadda, A.K., and S. Srinivasan (2008). Modeling children's school travel mode and parental escort decisions. *Transportation*, 35(2), 201-218.

9. Schwanen T. (2007). Gender differences in chauffeuring children among dual-earner families, *The Professional Geographer*, 59(4) 447-462.

10. Schwanen, T., D. Ettema, and H. Timmermans (2007). 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*, *39*(11), 2754-2773.

11. Schwanen, T., and T. de Jong (2008). Exploring the juggling of responsibilities with space-time accessibility analysis. *Urban Geography*, *29*(6), 556-580.

12. Sidharthan R., CR. Bhat, R.M. Pendyala, and K.G. Goulias (2011). A model of children's school travel travel model choice behavior accounting for spatial and social interaction effects. Paper to be presented at the 90th Annual Transportation Research Board Meeting, Washington. D.C..

13. Yoon, S.Y., T.F. Golob, and K.G. Goulias, (2009). A California statewide exploratory analysis correlating land use density, infrastructure supply and travel behavior, Proceedings of the 88th Annual Meeting of the Transportation Research Board, January 2009.

14. Golob, T.F., and M.G. McNally (1997). A model of activity participation and travel interactions between household heads. *Transportation Research B*, 31(3): 177-194.

15. Golob, T. F. (2003). Structural equation modeling for travel behavior research. *Transportation Research Part B: Methodological*, *37*(1), 1-25.

16. Gliebe, J.P., and F.S. Koppleman (2005). Modeling household activity-travel interactions as parallel constrained choices. *Transportation*, 32: 449-471. Springer.

17. Meister, K., M. Frick, and K.W. Axhausen (2005). A GA-based household scheduler. *Transportation*, 32: 473-494. Springer.

18. Zhang, J., H.J.P. Timmermans, and A.W.J. Borgers (2002). A utility-maximizing model of household time use for independent shared and allocated activities incorporating group decision mechanisms. *Transportation Research Record*, 1807: 1-8.

19. Zhang, J., and A. Fujiwara (2006). 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: Methodological*, 40(1): 54-74.

20. Srinivasan, K.K., and S.R. Athuru (2005). Analysis of within-household effects and between-household differences in maintenance activity allocation. *Transportation,* 32: 495-521. Springer.

21. Srinivasan, S., and C.R. Bhat (2005). Modeling household interactions in daily in-home and out-of-home maintenance activity participation. *Transportation,* 32: 523-544. Springer.

22. Bradley, M., and P.Vovsha (2005). A model for joint choice of daily activity pattern types of household members. *Transportation*, 32: 545-571, Springer.

23. Goulias, K. G., and K. Henson (2006). On Altruists and Egoists in Activity Participation and Travel: Who are they and do they live together? *Transportation,* 33(5): 447-462.

24. Dijkstra, E. W. (1959). A note on two problems in connection with graphs. *Numerische Mathematik*, *1*(1), 269-271.

25. Hägerstrand, T. (1970). What about people in regional science? *Papers and Proceedings of the Regional Science Association*, 24: 7-24.

Table 1. Summary of the sample

	Frequency	Percent
Total number of children under 16 who went to school	3483	100
Age		
0~4	258	7.4
5~10	1854	53.2
11~15	1371	39.4
Parents' employment status		
both parents fulltime worker	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	.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	1285	36.9
Hispanic	1377	39.5
African American	203	5.8
Asian/pacific islander	92	2.6
Other	198	5.7
Unknown	328	9.4

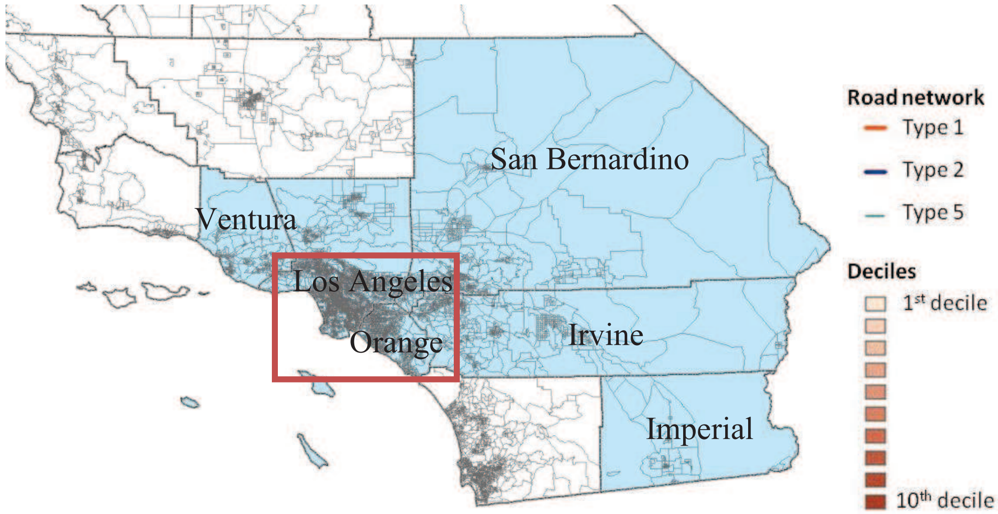
Table 2. Children's travel mode to school (a) and allocation of escort between father and mother by household type (b)

a.

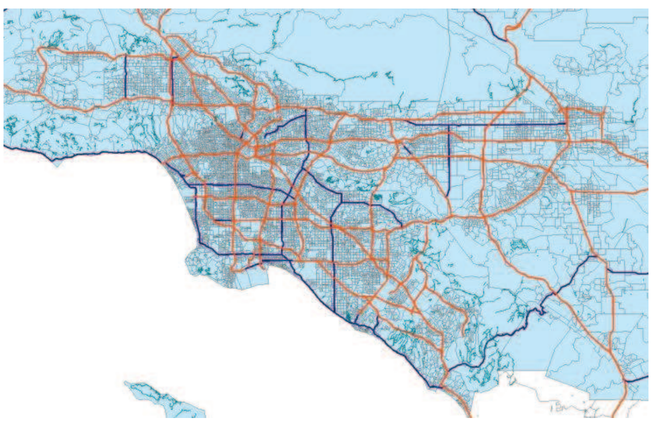
Travel mode to school	*Frequency*	*Percent*
Walk	741	21.3
Bicycle	63	1.8
Passenger in car/truck/van	2197	63.1
School Bus	364	10.5
Transit	29	.8
Other or unknown	89	2.6
Total	3483	100.0

b.

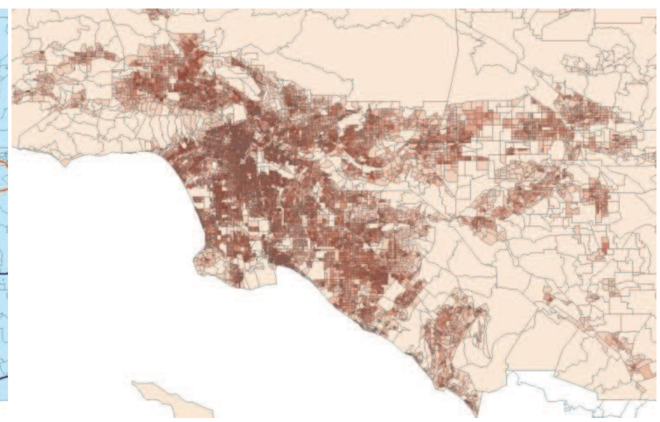
Household type by parents composition	*Escort by father*	*Escort by mother*	*Total number of children*
both parents fulltime worker	151	373	875
father full-time, mother part-time	41	152	299
father full-time, mother not employed	106	374	917
father and mother with other employment combination	96	157	493
single father	49	0	200
employed single mother	0	204	457
not employed single mother	0	91	242
Total	443	1351	3483



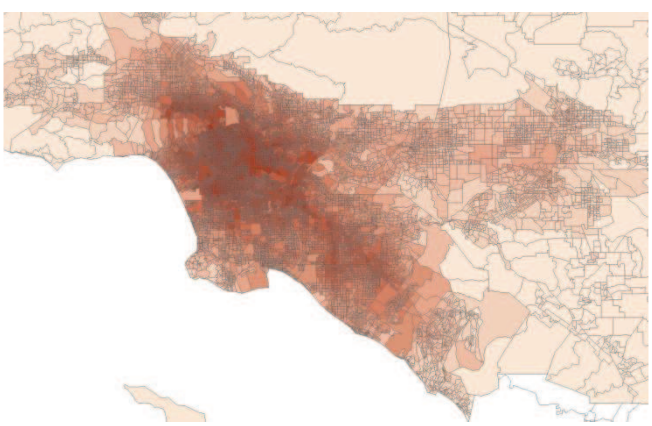
a. Six counties of the SCAG region



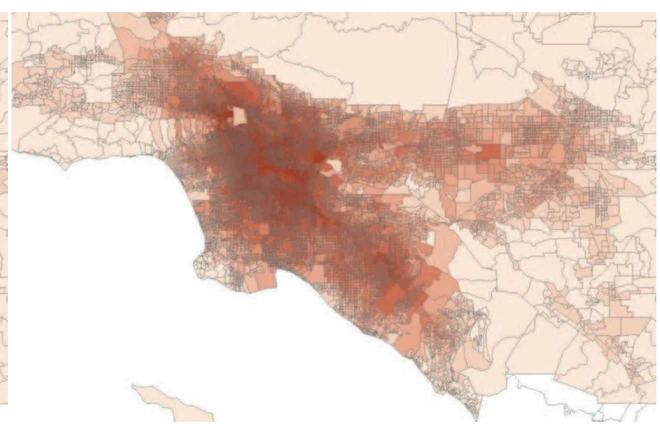
b. type 1,2 and 5 network



c. 10 deciles of population density

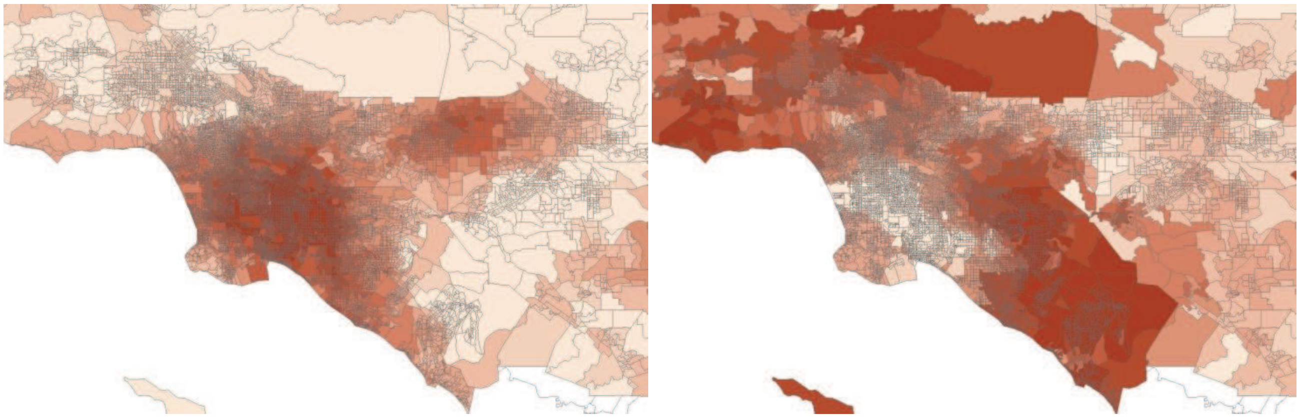


d. 10 deciles of retail employees within 20min



d. 10 deciles of type 1 network within 20min

Figure 1. Accessibility distribution (continued in the next page)



f. 10 deciles of type 2 network within 20min

g. 10 deciles of type 5 network within 20min

Figure 1. Accessibility distribution (continued)

Table 3. Goodness of fit

Model INDEPENDENT

Variable set	Contribution of set		Cumulative models		
	Chi-square	Degrees of freedom	Chi-square	Degrees of freedom	Nagelkerke R^2
Sociodemographic	602.824	50	602.824	50	0.212
Spatial	76.031	45	677.856	95	0.236

Model ACTIVE

Variable set	Contribution of set		Cumulative models		
	Chi-square	Degrees of freedom	Chi-square	Degrees of freedom	Nagelkerke R^2
Sociodemographic	435.717	50	435.717	50	0.178
Spatial	157.632	45	593.349	95	0.237

Model FATHER'S ESCORT

Variable set	Contribution of set		Cumulative models		
	Chi-square	Degrees of freedom	Chi-square	Degrees of freedom	Nagelkerke R^2
Sociodemographic	119.652	46	119.652	46	0.127
Spatial	90.922	45	210.574	91	0.217

Table 4. Estimated coefficients of children's commuting behavior models

a. Coefficients estimated for sociodemographic variables

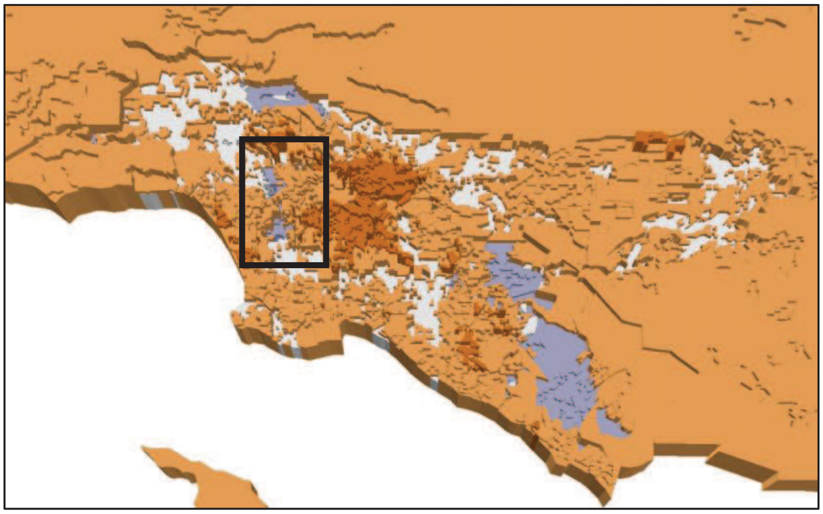
Variables	Model Independent			Model Active			Model Father's Escort		
	B	Sig.	Exp(B)	B	Sig.	Exp(B)	B	Sig.	Exp(B)
Child's age									
0~5	-1.407	.000	.245	-1.098	.000	.333			
6~10	-.450	.000	.638				-.269	.099	.764
base:11~15									
Child's gender									
female	-.128	.091	.880	-.272	.003	.762			
Child's ethnicity									
base:White/not hispanic									
Hispanic							.411	.055	1.508
African american	.314	.085	1.369	.443	.032	1.558			
Asian/pacific islander									
Other									
unknown	.271	.097	1.312						
Household income									
less than $10,000									
$10,000~$24,999				.358	.041	1.430			
$25,000~$34,999				.332	.057	1.394			
$35,000~$49,999				.330	.057	1.391			
base:$50,000~$74,999									
$75,000~$99,999									
$100,000~$149,000	-.383	.024	.682						
$150,000 or more									
unknown									
Parents									
base: couples with the other employment status combinations									
Both parents full time worker							-.613	.028	.542
Father full-time, mother part-time							-1.078	.001	.340
Father full-time, mother not employed									
Single father	.974	.003	2.647						
Employed single mother				-.976	.007	.377			
Not employed single mother				-1.125	.003	.325			
Number of children under 18									
base: 1									
2									
3				.257	.068	1.294			
4 or more	.303	.031	1.354	.420	.009	1.522			

Father's work hours per week									
base: less than or equal to 40 hours									
41~50 hours							-.433	.023	.648
51~60 hours							-.682	.014	.505
61+ hours									
Mother's work hours per week									
base: less than or equal to 40 hours									
41~50 hours	.438	.008	1.550	.477	.020	1.611	.511	.086	1.667
51~60 hours	-.726	.072	.484						
61+ hours									
Father's work location									
base: fixed location									
home							.727	.030	2.068
not fixed location (eg. Traveling salesperson)									
not known									
Mother's work location									
base: fixed location									
home				.553	.032	1.738			
not fixed location (eg. Traveling salesperson)	.476	.028	1.609						
not known				.517	.024	1.677	-1.095	.003	.335
Father's education									
11th grade or less							.843	.003	2.323
base: High school graduate									
2 years of college/Associates Degree							.438	.062	1.550
4 years of college/Bachelors degree	-.271	.049	.763				.928	.000	2.529
Post-Graduate				.401	.058	1.493	.539	.067	1.715
unknown							.893	.053	2.442
Mother's education									
11th grade or less	.383	.004	1.466	.260	.063	1.297			
base: High school graduate									
2 years of college/Associates Degree				-.328	.017	.720			
4 years of college/Bachelors degree									
Post-Graduate	-.579	.001	.561	-.559	.016	.572			
unknown									
Number of household vehicles									
0				1.046	.000	2.845			
base: 1									
2	-.298	.004	.742	-.761	.000	.467	-.504	.039	.604
3+	-.264	.036	.768	-.744	.000	.475			

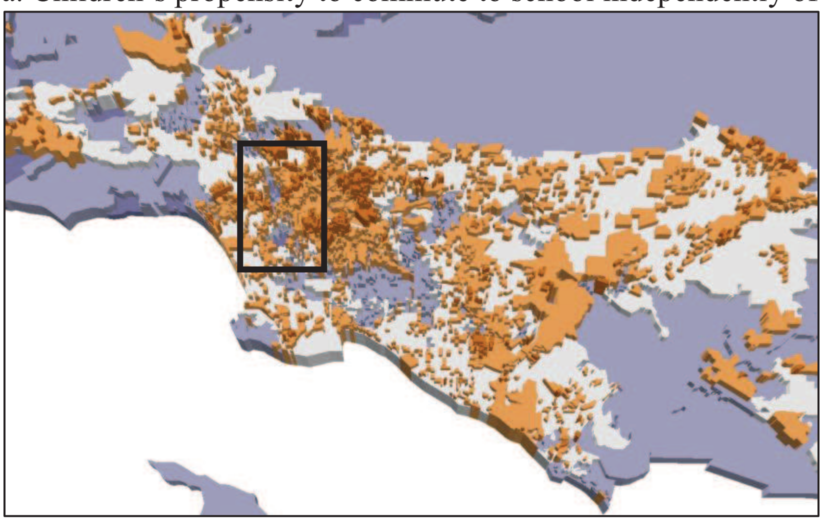
b. Coefficients estimated for spatial variables

Variables	Model Independent			Model Active			Model Father's Escort		
	B	Sig.	Exp(B)	B	Sig.	Exp(B)	B	Sig.	Exp(B)
Block group population density									
<10%tile	.296	.073	1.344				.516	.097	1.676
10th %tile									
20th %tile	.283	.066	1.328						
30th %tile				.419	.028	1.521			
base: 40th %tile									
50th %tile									
60th %tile									
70th %tile									
80th %tile				.653	.006	1.921			
90th %tile				.640	.009	1.896			
Number of retail employees within 20min's travel									
<10%tile	.696	.027	2.005				-1.038	.061	.354
10th %tile	.699	.009	2.012				-.994	.033	.370
20th %tile							-1.446	.000	.236
30th %tile							-1.859	.000	.156
base: 40th %tile									
50th %tile	.467	.052	1.595						
60th %tile									
70th %tile							1.031	.031	2.804
80th %tile									
90th %tile	-1.041	.004	.353	-1.002	.014	.367			
Total length of primary roads with limited access within 20min's travel									
<10%tile				-.691	.086	.501			
10th %tile							.817	.089	2.264
20th %tile									
30th %tile									
base: 40th %tile									
50th %tile									
60th %tile									
70th %tile									
80th %tile	.848	.006	2.335				-1.864	.002	.155
90th %tile	1.122	.002	3.073	1.043	.008	2.839			
Total length of primary roads without limited access within 20min's travel									
<10%tile									
10th %tile									
20th %tile				.633	.002	1.883			

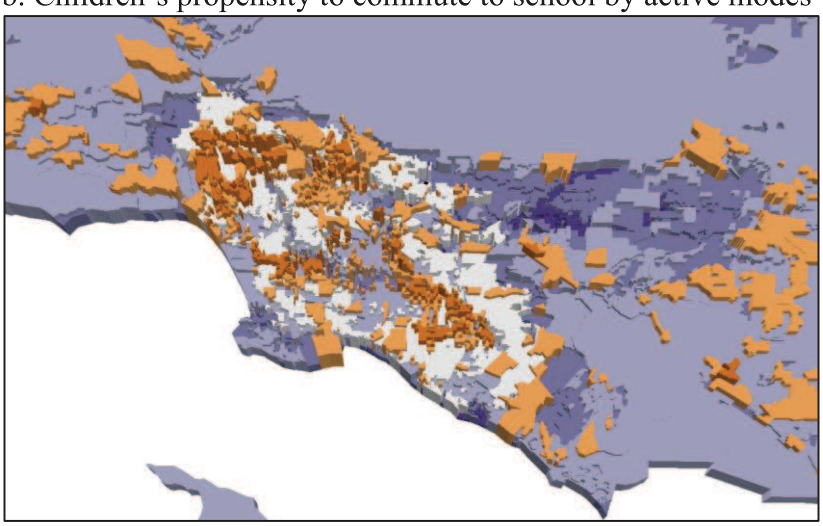
30th %tile									
base: 40th %tile									
50th %tile	.527	.006	1.693	.508	.018	1.662			
60th %tile	.631	.001	1.880				-.668	.063	.513
70th %tile	.381	.056	1.463						
80th %tile									
90th %tile				-.876	.001	.417	-.731	.063	.481
Total length of vehicular trail within 20min's travel									
<10%tile							.849	.016	2.336
10th %tile									
20th %tile									
30th %tile									
base: 40th %tile									
50th %tile									
60th %tile									
70th %tile				-.719	.012	.487			
80th %tile									
90th %tile	-.401	.077	.670						
Constant									



a. Children's propensity to commute to school independently of parents



b. Children's propensity to commute to school by active modes



c. Father's propensity to take children to school

Figure 2. Propensity maps for the three models estimated