

# School Location and Student Travel

## Analysis of Factors Affecting Mode Choice

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**This study is the first to examine the relationship between mode of travel to school and the full range of factors that might affect mode choice. With data from Gainesville, Florida, a multinomial logit model was estimated to explain school mode choice for a sample of K–12 students. Students with shorter walk or bike times to school proved significantly more likely to walk or bike. If confirmed through subsequent research, this finding argues for neighborhood schools serving nearby residential areas. Students traveling through areas with sidewalks on main roads were also more likely to walk. If confirmed, this finding argues for “safe routes to school” sidewalk improvements. As noteworthy as the significant factors are those that did not prove significant. School enrollment was not significant after controlling for travel time between home and school. Larger schools may draw students from larger areas and thereby indirectly affect mode choices. But school size does not appear to have a direct effect on mode choices. Land use variables such as density and mix also were not significant. The travel behavior literature emphasizes the importance of such variables in travel decision making. Apparently, school trips are different. They tend to be unlinked to other activities, and thus reduce the need for proximity to other land uses. They are mandatory; thus the walking environment may be less important than it is with discretionary travel. And school trips involve children, who may be less sensitive to walking conditions than are their adult counterparts.**

According to the recently released 2001 National Household Travel Survey (NHTS), fewer than 15% of students between the ages of 5 and 15 walked to or from school, and a mere 1% biked (1). In 1969, at the time of the first Nationwide Personal Transportation Survey (predecessor to NHTS), 48% of students walked or biked to school (2, derived from table on p. 9 that applies to students in elementary and intermediate grades, the closest counterparts to the 5 to 15 age range reported for 2001). A survey by the Centers for Disease Control and Prevention (CDC) found that even children living close to school were not walking or biking in large numbers; only 31% of children ages 5 to 15 who lived within a mile of school walked or biked (3). In 1969, the comparable figure was close to 90% (2, derived from table on p. 9 that applies to students in elementary and intermediate grades, the closest counterparts to the 5 to 15 age range reported for 2001).

Why the decline in walking and biking to school? In the CDC survey, parents cited long distances as a primary barrier to their chil-

dren walking or biking to school. Schools have been increasing in size and drawing students from ever-larger areas. Between 1940 and 1990, the total number of elementary and secondary public schools fell by 69% despite a 70% increase in the U.S. population (4). School campuses have been increasing in size as well, partly because of minimum acreage requirements adopted by state and local school authorities. So-called mega schools are typically placed in outlying areas, where large sites are available and land prices are low (5–14). This means relatively few students live within comfortable walking or biking distance of these schools, which may account for much of the decline in walk and bike mode shares.

Yet, as already noted, even short school trips are now made primarily by automobile, indicating that other factors are at work. A poor walking environment has been linked to automobile dependence in the general population and would be expected to discourage walking and biking to school. “Poor walking environment” means a built environment of low densities, little mixing of land uses, long blocks, incomplete sidewalks, and other hallmarks of sprawl (15–17).

This study is the first to examine the relationship between mode of travel to school and the full range of factors that might affect mode choice.

### FACTORS INFLUENCING SCHOOL MODE CHOICE

A literature search uncovered four previous studies relating mode choice on the journey to school to built environmental factors. They collectively suggest that children are more likely to walk or bike to small schools in walkable neighborhoods than to large schools in remote locations. The percentage of students walking to school was found to be four times higher for schools built before 1983 than for those built later (an average of 16% walk to older schools versus 4% to newer schools) (5). School age is not a very good proxy for the whole range of factors that distinguish small schools in walkable neighborhoods from mega schools in remote areas, so results of this study must be considered suggestive instead of definitive.

A study of fifth-grade students at 34 California public elementary schools showed that walking and biking rates were associated with neighborhood population density (positively) and school size (negatively), this after controlling for the percentage of students on public welfare and the percentage of ethnic minorities (18). The number of intersections per street mile, a measure of walkability, was related to walking and biking rates in simple pairwise correlations but not in multiple regression models with other variables. The use of aggregate travel data is a serious limitation of this study.

A study of school mode choice in California found that walking and biking to school were more likely when a household lived within

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a mile of the school (19). Walking and biking were less likely when a household had more licensed drivers to provide rides. These were the primary influences on school mode choice. Certain pedestrian-friendly design features had positive influences on walking and biking, such as the presence of street trees within a quarter mile of school; other features had negative influences, such as short blocks and mixed land uses. The limitation of the study to only six school sites meant there was little variance in built environmental conditions across survey respondents, and the significance of these variables accordingly was limited.

A British study found a significant relationship between mode choice and perceived distance from home to school, with the probability of traveling by automobile instead of by foot increasing from 20% at a 0.5-mi distance to 50% at 1.25 mi and 80% at 2 mi (20). Household automobile ownership and parent employment status were also significant determinants of school mode choice, as were parental attitudes about the natural environment and automobile culture. The absence of built environmental variables, and the use of perceived instead of actual distances to school, were limitations of this study.

## MODEL SPECIFICATION AND STRUCTURE

Black et al. (20) speculated that the choice of travel mode for the school trip is an integral part of the household decision-making process. Whether an automobile is available at all depends on the household's decision about automobile ownership, which may be linked to residential location and employment decisions, which in turn may be linked to schooling decisions from the primary grades through high school. We could envision a complex joint-choice model in which school mode choice is determined simultaneously with residential location, parent employment status, and household automobile ownership levels. Estimation of such a model is beyond the scope (and data availability) of this study, as it was in Black et al.'s study (20). Instead, the simplifying assumption is made that residential location, employment, and automobile ownership decisions are exogenous to the choice of travel mode.

### Fully Specified Models

Transportation modeling usually treats mode choice as an application of consumer choice theory, grounded in the notion that people choose among alternatives—be they means of getting to work or brands of ice cream—to maximize personal utility or net benefit to themselves. After deciding to go between points A and B, people weigh the comparative travel times, costs, and other attributes of competing modes.

Traveler characteristics (e.g., income) also influence mode selection. These two attribute sets—characteristics of trip interchanges and characteristics of travelers—are used by transportation modelers to explain mode choices.

Travel behavior research by land-use analysts takes a different approach to the same subject. While the effects of income and other traveler characteristics are captured in much the same way as in travel modeling, the focus is not on trip interchanges but on trip ends—specifically, the characteristics of origins and destinations. Thus, those interested in how traditional neighborhood designs influence mode choices concentrate mainly on the densities, land-use mixes, and walking environments at the origin and destination ends of trips. Too often, how competing modes fare in terms of travel time and cost is ignored.

Model misspecification leads analysts to read too much or too little into estimated relationships (21). Statistically, the influences of omitted variables get soaked up by the modeled variables—which means transportation modelers end up overstating or understating the importance of travel time and cost, while land-use researchers end up misinterpreting the importance of the built environment.

In the case of school trips, the literature suggests that mode choice also may depend on school location (more or less accessible), school size, and grade level.

### Alternative Model Structures

McFadden developed the multinomial logit (MNL) model to explain choices made among alternatives when attributes of the alternatives themselves, and attributes of decision makers, both influence outcomes (22). In the choice of travel mode for trips to school, the attributes of alternative modes such as travel time, and attributes of students and their households such as income, would be expected to influence choices (see Figure 1).

McFadden extended his discrete choice model to include situations in which certain alternatives share important, unobservable qualities. In these cases, the application of MNL violates one of the basic assumptions, called the independence of irrelevant alternatives, upon which the MNL is built. This leads to erroneous predictions of discrete choice probabilities.

A nested logit model structure overcomes the independence of the irrelevant alternatives problem. One nested structure tested in this study has an upper level nest with car and non-car modes as available choices, and the lower level nest with school bus, walk, and bike as available choices, conditioned on a non-car choice occurring at the higher level (as in Figure 2).

The mathematical form of the nested logit model is characterized by the appearance in the model of inclusive values in the probabili-

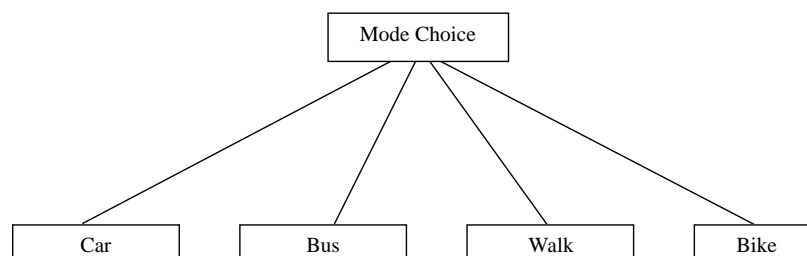


FIGURE 1 MNL structure of mode choice.

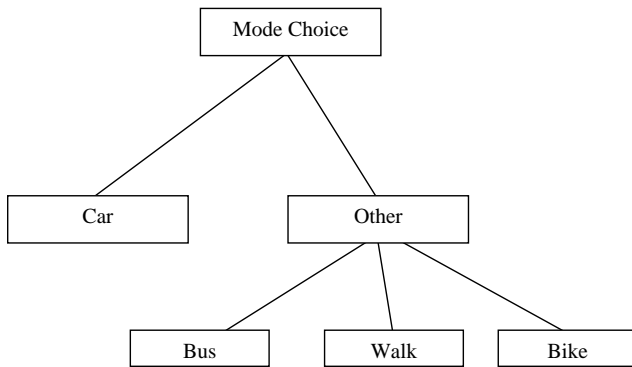


FIGURE 2 Nested logit structure of mode choice.

ties of the alternatives. For the nested logit model to be consistent with an underlying theory of utility maximization, the coefficients of the inclusive values must be between 0 and 1. The inclusive value coefficients for all nested structures tested in this study were in excess of 1.0, which argues for the MNL structure, especially in the absence of strong evidence of shared unobservables. Thus, the MNL model was chosen as the preferred specification in this study.

A well-specified multinomial model of school mode choice would take the form:

$$P_k = \exp(U_k) / \left[ \sum_{l \in K} \exp(U_l) \right]$$

where  $P_k$  is the probability of choosing mode  $k$  for a school trip and  $U_k$  is the utility function for mode  $k$  defined as follows:

$$U_k = \alpha_k + \beta T_k^{ij} + \gamma SE^m + \theta SC^n + \delta BE^i + \omega BE^j + \epsilon_k$$

where

- $\alpha_k$  = vector of constants;
- $T_k^{ij}$  and  $\beta$  = trip characteristics and corresponding parameter vectors for trips from  $i$  to  $j$  by mode  $k$ , including travel time;
- $SE^m$  and  $\gamma$  = socioeconomic characteristics and corresponding parameter vectors for a student from household  $m$ , characteristics such as income and automobile ownership;
- $SC^n$  and  $\theta$  = school characteristics such as enrollment and corresponding parameter vectors for school  $n$ ;
- $BE^i$  and  $\delta$  = built environmental characteristics and corresponding parameter vectors for origin  $i$ , with  $i$  being a neighborhood, census tract, traffic analysis zone (TAZ), or other small area (the vector may include measures of density, land use mix, walking quality, and site design);
- $BE^j$  and  $\omega$  = built environmental characteristics and corresponding parameter vectors for destination  $j$ ; and
- $\epsilon_k$  = an extreme-value error vector specific to mode  $k$ .

Given the requisite data, a logit model can be estimated that assigns a probability to a student from household  $m$ , traveling between origin  $i$  and destination  $j$ , choosing mode  $k$  for the trip to school  $n$ . The MNL model will capture most of the variables that affect the utility, or benefit, of choosing a particular mode for the school trip in question.

## DATA SOURCES AND VARIABLES

Gainesville, Florida, was chosen as the study area for two reasons: the availability of two regional travel diary surveys that, combined, offered a relatively large sample of trips to analyze; and the availability of many variables characterizing the built environment in Gainesville that could be used as independent variables in explaining mode choice.

### Travel Data

Two travel diary surveys were conducted at about the same time in Alachua County, Florida, home of Gainesville and the University of Florida. The first was a survey during the first half of 2001 under the auspices of the Gainesville Metropolitan Transportation Planning Organization (MTPO). It was a standard travel survey, beginning with telephone interviews to screen and recruit households; followed by a mail-in travel survey with demographic questions and travel diaries; and concluding with inputting, geocoding, and editing survey responses.

A second survey was conducted in the last half of 2000 by the Florida Department of Transportation (FDOT). This survey involved a much larger sample than the first. It too involved a screener survey to recruit participants and a mail-in travel diary survey with demographic questions. There was sufficient overlap in study area and survey content to permit the two surveys to be combined, thereby yielding a larger sample of usable responses.

The following table summarizes sample data for the two surveys. A total of 15,980 trips were reported, from which school trips could be extracted and mode choices analyzed. In both surveys, the intention was to identify all K–12 school trips and only K–12 school trips. This task proved far more painstaking than expected. For details on how this was accomplished, see the full report upon which this paper is based (23).

	MTPO Survey	FDOT Survey
Households	374	1,766
Persons	726	3,089
Trips	3,073	12,907

### Travel Time and Distance Data

Interzonal travel times were obtained from the Gainesville regional travel model, a conventional four-step travel demand model. The model generates travel time “skims,” or minimum travel times from zone to zone, as inputs to trip distribution. Skims were available for all travel modes modeled in the four-step process, which in this case meant automobiles and transit. They were not available for walking or biking because these modes are not modeled in Gainesville.

To estimate walk and bike travel times between (and within) zones, minimum path distances were extracted from zone-to-zone highway skims and nominal speeds of travel were applied to each. Typical walking speed of children was assumed to be 3 mph, while typical biking speed was set at 12 mph.

School bus travel times could have been determined only with great effort. It would have been necessary to know the distance from home to pickup point, routing from pickup point to school, routing from school to drop-off point, and distance from drop-off point to home. It also would have been necessary to know the number of school bus stops along the way and, from that, average running speed

for each route. It is not even clear that the choice of school bus as a mode of travel is sensitive to travel time, given other considerations such as parental convenience and service availability.

This gave the following set of travel time variables:

- Estimated automobile drive time between zones by minimum path,
- Estimated walk time between zones by minimum path, and
- Estimated bike time between zones by minimum path.

One would assume that the longer the travel times by walking and biking relative to the automobile, the lower the utility of these modes. As for school bus travel, one would assume that beyond the threshold distance from home to school, where bus service becomes available to students, the utility of school bus travel is independent of travel time. This hypothesis was not testable with the current data set, and a literature search uncovered no evidence one way or another on this point. This becomes an issue for future research.

### Socioeconomic Data

As this study drew on two different surveys, only where equivalent questions were asked in both surveys could data be used. The FDOT survey, for example, asked about bicycle ownership, while the MTPO survey asked about rainfall on the date of travel. These variables could not be used to explain school mode choices for lack of complete data sets.

The following data overlapped between the two surveys:

- Number of household members,
- Number of household motor vehicles,
- Number of vehicles per household member,
- Annual household income, and
- Driver's license owned by student (1 if yes, 0 otherwise).

The number of vehicles per household member was the only measure of vehicle supply relative to demand available for both surveys. Vehicle availability would have been better represented by vehicles per driver or vehicles per driving age household member.

The utilities of walking, biking, and school bus riding were expected to decline with vehicle availability, possession of a driver's license, and perhaps with household income.

### School Data

School enrollment data for public schools were obtained from the Alachua County School District. For private schools, it was necessary to contact schools individually. Schools were located by TAZ from their addresses with the help of MapQuest and a Gainesville TAZ map.

For FDOT survey respondents, matching school trips to specific schools proved tricky. Instead of the usual travel diary method of asking respondents for the addresses of destinations or closest cross streets and geocoding the results, this survey provided respondents with a generalized TAZ map of Alachua County and asked the respondents to identify the TAZs of origin and destination. For about half of all school trips, respondents chose TAZs with schools in them, and the match was obvious. For the other half of trips, the generalized nature of the map left respondents with only a generalized idea

of where trips began and ended. They were often off by a TAZ or two from the closest school location. Matches were made in these cases based on closeness of the TAZ to the one reported by the respondent and based on the grade level of the respondent corresponding to the grade levels of the school.

For the MTPO survey, matching school trips to schools was pro forma, because respondents nearly always provided the names of places where trips started and ended. Schools were identified by name and were already located within known TAZs.

Two data elements were included in the data set: school enrollment level and high school (1 if yes, 0 otherwise).

The utility of walking and biking was expected to decline with enrollment, as schools would be drawing from larger areas. Whether this variable would be significant after controlling for travel time to and from school was anyone's guess. It is certainly possible that school size would have an additional negative effect on walking and biking due to, for example, the tendency for large schools to be placed on large sites with deep building setbacks and acres of parking hostile to pedestrians.

### Built Environmental Data

The final set of variables related to the built environment around the school and home or other trip end. Many land use travel studies have represented the built environment in sophisticated, multidimensional ways (4). However, to the authors' knowledge, the Gainesville database characterizes the built environment more completely than any to date, quantifying more qualities of the built environment.

Data on the built environment were available from multiple sources. All variables were estimated for TAZs in the Gainesville metropolitan area. A subset of available variables was tested, those that held the most promise of explaining walk and bike trips.

From socioeconomic input data files for the Florida Standard Urban Transportation Model Structure (FSUTMS), Gainesville's conventional four-step model, came three data elements:

- Overall density = (residents + jobs)/area. This variable measures the overall density of a TAZ in terms of people either living or working within the TAZ. The use of a combined measure of density is desirable when the amount of land devoted to individual uses is unknown, as in Gainesville TAZs.

- Jobs-residents balance =  $1 - [\text{abs}(\text{jobs} - c \times \text{residents}) / (\text{jobs} + c \times \text{residents})]$ . This variable measures the degree of land use balance between jobs and residents at the TAZ level, where abs is the absolute value of the expression in parentheses and  $a$  is the regional ratio of jobs to residents. Values of jobs-residents balance range from 0 when a TAZ has only jobs or residents, not both, to 1 when a TAZ has the same ratio of jobs to residents as the region as a whole. Values are intermediate when TAZs have both jobs and residents, but one predominates. This variable was also measured for commercial jobs alone.

- Job mix =  $-\text{[commercial jobs} \times \ln(\text{commercial jobs}) + \text{industrial jobs} \times \ln(\text{industrial jobs}) + \text{service jobs} \times \ln(\text{service jobs})] / \ln(3)$ . This variable measures the degree of land use mixing at the TAZ level;  $\ln$  is the natural logarithm of the expression in parentheses. Values of job mix range from 0 when all jobs in a given TAZ are concentrated in one sector, to 1 when jobs are evenly divided among the three employment sectors represented in the FSUTMS database. The number 3 in the denominator is the number of different land uses. This functional form is commonly known as an entropy variable.

From the property appraiser’s database (parcel layer in the county’s geographic information system) came the following land use intensity variable for commercial properties: commercial floor area ratio (FAR) = commercial floor area/(43,560 × commercial land area). The constant 43,560 converts acres of land into square feet, which, when divided into square feet of floor area, yields a FAR. Only pedestrian-oriented commercial uses were included in the calculation—specifically, retail uses; finance, insurance, and real estate offices; general office buildings; and commercial lodging.

From the county’s bicycle and pedestrian level-of-service database came the following data elements.

- Proportion of street miles with street trees,
- Proportion of street miles with bike lanes or paved shoulders,
- Proportion of street miles with sidewalks, and
- Average sidewalk width.

These variables were available only for arterial and collector streets. From the county’s geographic information system came street density = centerline street miles per square mile. This variable measures street network density, including local streets as well as arterials and collectors.

Characterizing a TAZ’s location within the larger region are regional accessibility indices. Conventional four-step models such as Gainesville’s automatically generate regional accessibility indices as inputs to trip distribution. Regional accessibility indices, which appear as the denominator of a conventional gravity model, are computed by multiplying the number of trip attractions for each attracting zone by a friction factor inversely related to travel time from the trip-producing zone to the attracting zone, summed over all attracting zones. The more attractions nearby, the higher the accessibility index of a producing zone.

$$\text{accessibility}_{ip} = \sum_{j \in J} \text{attractions}_{jp} \times \text{friction factor}_{ijp}$$

where

accessibility<sub>ip</sub> = accessibility index of zone *i* for trip purpose *p*,

attractions<sub>jp</sub> = number of trip attractions in zone *j* for the particular trip purpose, and

friction factor<sub>ijp</sub> = interzonal friction factor for trips from zone *i* to zone *j*, again, for said trip purpose.

Accessibility indices are available for five primary trip purposes in the Gainesville model, two of which are based on broad measures of trip attraction: accessibility index for home-based other trips (which includes school trips) and accessibility index for non-home-based trips.

Both accessibility indices were normalized on a scale of 0 to 1 by dividing absolute values by the highest value for the entire urbanized area.

From the land use travel literature, one would expect the utility of walking, and perhaps biking, to increase with virtually all built environmental variables defined in this section.

### Data Summary

The original data set contained 819 K–12 school trips for which origin and destination TAZs were known. Three cases were lost for lack of travel mode data. Four cases were dropped because the mode of travel was transit bus, and another seven were dropped because

the mode was “other.” Samples were too small to model these mode choices separately. Two cases were missing school enrollment data. Eleven cases were missing household size or vehicle ownership data, resulting in undefined per capita vehicle ownership. These cases were dropped to maintain a full complement of independent variables for subsequent analysis.

The greatest loss of cases was due to unknown household income. As is often the case in travel surveys, household income went unreported by a large number of respondents. The sample size could have been maintained at 792 observations by excluding household income, but instead a smaller sample and more complete set of variables were used. From a theoretical perspective, household income was too important to be omitted from the mode choice analysis. From a practical standpoint, the independence of household income from other explanatory variables including vehicle ownership per capita (*r* = 0.11) meant that household income was bringing something unique to the analysis. Eighty-one cases had to be dropped for lack of income data, but only three cases were in the underrepresented categories of walking and biking.

Two additional cases were lost when walk and bike modes were removed from all choice sets in which estimated travel times by these modes exceeded 1 hour (see the next section for a discussion of restricted choice sets). In these two anomalous cases, the bike mode was chosen even though estimated interzonal travel time by bike exceeded 1 hour. In all other cases, when either walk or bike was chosen, estimated travel times by these modes were less than 1 hour.

Complete data sets, including all variables defined previously, were available for the remaining 709 school trips. The possibility that systematic bias had been introduced was checked for by dropping cases; comparing the mean values of variables contained in the original and reduced samples indicated no such bias.

The following table presents mode of travel for the final sample of school trips. Figure 3 presents the built environments of two Gainesville high schools with contrasting mode splits.

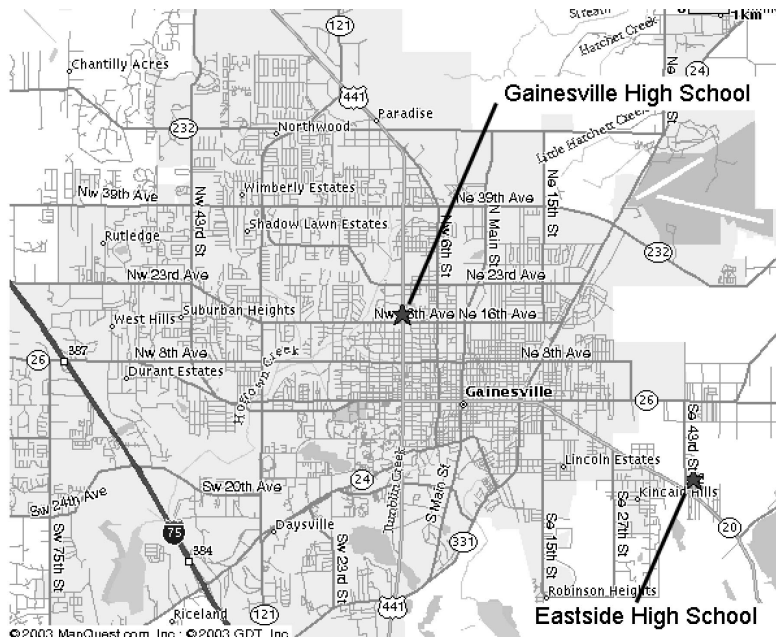
Mode	Count
Car	548
School bus	105
Walk	32
Bike	24
Total	709

### MODEL ESTIMATION

All MNL and nested logit mode choice models were estimated with full information maximum likelihood and the LIMDEP/NLOGIT software. The universal choice set for the student population studied consisted of four travel modes: automobile, school bus, walking, and biking.

### Individual Choice Sets

Practically speaking, certain modes were unavailable to certain students, and their choice sets had to be restricted. For school trips in this sample, estimated walk times ranged up to 488 minutes, while estimated bike times were as high as 122 minutes. No student could be expected to walk or bike this far. Therefore, a cutoff value of 60 minutes was established for travel times by these modes. Walk and bike modes were removed from the choice sets for trips having



(a)



Sampled Trips  
 Auto trips 38 (85%)  
 Walk trips 6 (13%)  
 Bike trips 1 ( 2%)  
 Average auto trip length: 4.24 miles

(b)



Sampled Trips  
 Auto trips 19 (100%)  
 Average auto trip length: 8.42 miles

(c)

This figure applies to students in elementary and intermediate grades, the closest counterparts to the 5–15 age range reported for 2001. Where school bus, walk, and bike modes share unobservables, the inclusive value in a nested logit model is given by

$$I_{nonauto} = \sum \log(e^{U_{bus}} + e^{U_{walk}} + e^{U_{bike}})$$

Though weather conditions generally could have been determined for the FDOT date of travel from historical weather reports, they would not necessarily apply to a particular time and place of travel within the Gainesville area. Only two bike trips exceeded the cutoff value and were lost to the sample. No walk trips exceeded the cutoff value and none were lost to the sample.

FIGURE 3 Sampled schools: (a) map, (b) Gainesville High School, and (c) Eastside High School (same scale).

walk and bike travel times in excess of the cutoff value. Hundreds of school trips in the sample were restricted to two or three modes. Yet, nearly all these trips were by automobile or school bus anyway, so removing walk and bike modes from the choice sets did not deplete the sample appreciably. The model was estimated with these choices eliminated from the available choice set for these individuals.

The opposite situation applied to school bus trips. To qualify for school bus service, students in the Alachua County School District generally must live 2 or more miles from school. Accordingly, the school bus mode was initially removed from the choice sets for school trips of less than 2 miles. However, this restriction was later lifted because of the large number of school bus trips lost to the sample. A review of the school district's policy indicated that exceptions to the minimum distance rule are made when a student faces hazardous walking conditions or qualifies for "courtesy" busing by virtue of living along a bus route and for various other reasons.

### Variable Selection

The automobile was treated as the base mode. The utilities of other modes were modeled relative to the automobile. The automobile having been selected as the base mode, the next decision was whether to include estimated automobile time between zones as the sole variable in the automobile utility function, as is sometimes done in mode choice modeling, or alternatively to set automobile utility equal to zero and add variables to other equations to achieve a similar fit. No model raised the significance of automobile travel time to the conventional .05 level (although some came close). For this reason, and to simplify interpretation, automobile utility was zeroed out in the final model.

Travel time estimates were included in the utility functions of walk and bike modes. As there was no reason to assume that time spent walking and biking would have the same disutility, travel time coefficients were estimated independently for the walk and bike modes. Travel time was left out of the school bus utility function for lack of any credible estimate of travel time by that mode.

All plausible combinations of socioeconomic, school, and built environmental variables were tested as explanatory variables in the utility functions of the walk, bike, and school bus modes. Variables were retained only if they proved significant at the .05 probability level.

### MODEL RESULTS

The best-fit model is presented in Tables 1 and 2. These tables present the same basic information in different forms. In Table 1, coefficient values and *t*-statistics indicate the effects of independent variables on mode choice probabilities. The convergence of the MNL model was found to be satisfactory. The log likelihood at convergence is -425, and the log likelihood with constants only in the utility function is -494. The pseudo-*R*<sup>2</sup> of the model is thus  $[1 - (-425/-494)]$  or 0.14 relative to the model with only constants.

In Table 2, the marginal effects of independent variables on mode choice probabilities are expressed as elasticities—that is, as percentage changes in probabilities associated with a 1% change in each independent variable. Elasticities are commonly used in travel research to summarize relationships between travel outcomes and explanatory variables. The values presented are point elasticities at the mean values of the independent variables.

### Travel Time Influences

As expected, students with shorter walk and bike times to and from school are significantly more likely to walk and bike, respectively. The probability of biking is particularly sensitive to travel time; an elasticity value of -2.63 means students are averse to even small increases in travel time by bike. Perhaps this is because even small differences in travel time by bike represent large differences in distance traveled (relative to distance traveled on foot). The probability of walking is less sensitive to travel time but still is significantly affected by it. The elasticity value is -0.66.

TABLE 1 MNL Model Parameters for School Bus, Walk, and Bike Modes, with Automobile as Base Mode

Variable	Bus		Walk		Bike	
	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
Constant	-1.054	-6.44	2.385	2.40	-1.301	-3.87
Annual household income (in thousand dollars)			-0.0334	-3.33		
Per capita household auto ownership			-4.570	-3.61		
License ownership indicator (1 if the individual holds a drivers license, 0 otherwise)	-2.513	-4.23				
Walk time for the trip (minutes)			-0.0527	-3.98		
Bike time for the trip (in minutes)					-0.1504	-4.07
Average sidewalk coverage for origin and destination TAZs			1.480	2.09		
Average home-based other accessibilities for origin and destination TAZs	-1.130	-2.37				
Restricted log-likelihood						-982.9
Log-likelihood with constants only						-493.9
Log-likelihood at convergence						-425.4
pseudo- <i>R</i> <sup>2</sup>						0.139
Number of observations						709

TABLE 2 Point Elasticity Estimates from MNL Model

Variable	Bus	Walk	Bike
Annual household income (in thousand dollars)		-0.84	
Per capita auto ownership for the household		-1.16	
License ownership indicator (1 if the individual holds a drivers license, 0 otherwise)	-0.91		
Walk time for the trip (in minutes)		-0.66	
Bike time for the trip (in minutes)			-2.63
Average sidewalk coverage for origin and destination TAZs		0.42	
Average home-based other accessibilities for origin and destination TAZs	-0.31		

### Built Environmental Influences

Of the many built environmental variables, the proportion of arterials and collectors with sidewalks along them proved to have the most significant influence on walking. Values of sidewalk coverage for origin and destination zones are highly correlated for walk trips, precluding the use of both variables in the same utility function. Instead, values of sidewalk coverage for the origin and destination zones were averaged, and the average was then used as an explanatory variable. The probability of walking to school has an elasticity of 0.42 with respect to average sidewalk coverage.

Interestingly, the built environment did not have a significant effect on biking. Even the proportion of arterials and collectors with bike lanes or paved shoulders along them proved insignificant. The arterials and collectors with paved shoulders tend to be in less-developed areas, so this particular variable may not reflect the general bicycle-friendliness of the area.

One built environmental variable, regional accessibility for home-based other trips, proved related to school bus use. The more accessible the location, the less attractive the school bus relative to other modes, including the automobile. School buses may be serving as a mode of last resort for parents, chosen when parents cannot provide rides themselves because of excessive distances between home and school. As with sidewalk coverage, home-based other accessibilities are correlated for origin and destination zones and therefore were averaged to create a single variable that reflects conditions at both origin and destination. The probability of taking a school bus has an elasticity of  $-0.31$  with respect to average regional accessibility.

### Socioeconomic Influences

Students from households with higher incomes and more vehicles per capita are less likely to walk to school than to take a car, school bus, or bicycle. The probability of walking is most strongly related to vehicles per capita; its elasticity is  $-1.16$ . Less strongly related is household income, with an elasticity of  $-0.84$ . It is obvious why greater vehicle availability would make walking less attractive relative to car travel. It is less obvious why greater vehicle availability would make walking less attractive relative to other modes, or why higher income would have this effect independent of vehicle

availability. These two variables individually and together may have a strong enough influence on mode choice to overwhelm other factors favoring walk trips, such as a short distance to and from school.

Students holding drivers' licenses are less likely to take a school bus than those without drivers' licenses. This makes perfect sense. Students living too far from school to walk or bike are prime candidates for school bus service until they reach driving age, at which time they become prime candidates for driving themselves if their families' financial situation permits it.

### Omitted Variables

Notably absent from the utility functions of different modes are school variables. Enrollment did not prove significant after controlling for travel time between home and school. Larger schools may draw students from larger areas and thereby indirectly affect mode choices. But school size does not appear to have a direct effect on mode choices.

Also absent from the utility functions were land use variables such as density and mix. The travel behavior literature emphasizes the importance of such variables in travel decision making. Apparently school trips are different. They tend to be unlinked to other activities, thus reducing the need for proximity to other land uses. They are mandatory, which may render the walking environment less important than with discretionary travel. And they involve children, who may be less sensitive to walking conditions than are their adult counterparts.

### DISCUSSION OF RESULTS

In this study, students with shorter walk and bike times to school proved significantly more likely to walk and bike. If confirmed through subsequent research, this finding argues for neighborhood schools serving nearby residential areas. Students traveling through areas with sidewalks on main roads were also more likely to walk. If confirmed, this finding argues for "safe routes to school" sidewalk improvements.

The findings are only partly consistent with earlier studies of school mode choice. Distance from home to school was found to be

significant in two previous studies, a result confirmed by this study. Elements of the built environment around a school were found to be significant in two previous studies, as in this study.

But which built environmental factors influence school mode choice remains an issue. Specifically, neighborhood population density proved important in one earlier study, street tree coverage in the vicinity of school was important in another study, and age of schools (presumably a proxy for traditional neighborhood design, which in turn is a proxy for higher density and finer land-use mix) was important in a third study. None of these variables proved significant in the present study. On the other hand, sidewalk coverage was significant in this study, a result that has not been confirmed.

The role of school size in mode choice also requires further study. Student enrollment proved significant in one earlier mode choice study, but not in this study. It is tempting to say this is because this study controlled for travel time to school, while the earlier study did not, but the school size variable proved insignificant in all model specifications. So whether school size has a direct effect on school mode choice, beyond its effect on travel time to school, remains an issue.

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