ABSTRACT

RHOULAC, TORI DANIELLE. School Transportation Mode Choice and Potential Impacts of Automated Vehicle Location Technology. (Nagui M. Rouphail, Advisor)

School-related traffic congestion is a large problem in North Carolina and throughout the nation. North Carolina Department of Transportation works with schools and municipalities to better design and retrofit campuses to accommodate the vehicular volumes that often queue onto adjacent streets and cause long delays. The large number of school trips made by automobile not only cause traffic problems, but safety problems as well, made evident by injury and fatality statistics. The goal of this research was to ultimately enhance student safety and reduce school-related traffic problems by gaining a better understanding of the household attributes and behaviors that influence school transportation mode choice in order to identify problems and prioritize solutions for school transportation, including school bus service improvements through automated vehicle location (AVL).

The primary research objective was to calibrate a school transportation mode choice model for a selected North Carolina school district. Mode choice models were developed based on factors exhibiting statistical significance in estimating the choice of automobile or school bus for the morning and afternoon school trips of children in kindergarten through eighth grade in the Wake County Public School System. The variable expressing the convenience of the school bus service for a household based on parent work schedules, perceived problems, and AVL improvements was the most influential. Model transferability tests suggest that the models can be used statewide in schools or school districts where actual automobile usage ranges from about 30 to 55% of all school trips in the morning and 15 to 40% in the afternoon.

The significant contribution of this research is the application of mode choice probability modeling to the grade school population. An assessment of the potential for AVL technologies to prompt a modal shift to the school bus was also included. Results suggest that 38% of students currently using the automobile for their morning school trips may shift to the school bus, indicating potential for a 16% overall modal shift to the school bus with the addition of AVL tracking and paging technologies.

SCHOOL TRANSPORTATION MODE CHOICE

AND POTENTIAL IMPACTS OF AUTOMATED VEHICLE LOCATION TECHNOLOGY

by

TORI D. RHOULAC

A Dissertation Submitted to the Graduate Faculty of North Carolina State University
In Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy

Department of Civil Engineering

Raleigh, NC

June 2003

Approved by:

Dr. Nagui M. Rouphail
Chair of Advisory Committee

Dr. Joseph E. Hummer

Dr. John R. Stone

Dr. John F. Monahan

BIOGRAPHY

TORI DANIELLE RHOULAC is a native of Hampton, Virginia. She was educated in the Hampton City Public Schools and graduated from Kecoughtan High School in June 1994. Her undergraduate education was completed at Howard University in Washington, District of Columbia, where she earned a Bachelor of Science degree in Civil Engineering with a concentration in Transportation. In May 1998, she began her studies at North Carolina State University in Raleigh, North Carolina, earning a Master of Science degree in Civil Engineering with a focus on Transportation Systems in August 2000. She will complete degree requirements for the Doctor of Philosophy in Civil Engineering in the summer of 2003.

Tori has a most supportive family consisting of her parents, Henry and Teresea Rhoulac, two sisters, Trina and Takashi, nephew, Jonathan Josiah Rhoulac McLean, niece, Hannah Sydney Roberts, grandparents and many aunts, uncles, and cousins. She attributes all academic and personal successes to the grace of God and the love of her family. Tori's life is best described by the words of I Corinthians 15:10a from the Holy Bible, "but by the grace of God I am what I am..."

ACKNOWLEDGEMENTS

To my Lord and Savior, Jesus Christ, thank You for guiding me, making provisions, and bringing me to this "wealthy place."

To my family and friends, thank you for your constant love and undying support.

To my advisor, Dr. Nagui Rouphail- Professor of Civil Engineering and the members of my advisory committee: Dr. Joe Hummer- Associate Professor of Civil Engineering, Dr. John Monahan- Professor of Statistics, and Dr. John Stone, Associate Professor of Civil Engineering, thank you for giving of your time and talents to make this academic achievement possible for me.

To Jeff Tsai- Director of the Pupil Transportation Group at the Institute for Transportation Research and Education (ITRE), whose vision and innovation began this school transportation research, I say a special "Thank You!"

To Mr. Vern Hatley, Mr. Phil Lambert and the Wake County Public Schools Transportation Staff and Dr. Ed Davis of the Union County Public School System, who assisted in data collection, I give special thanks also… without you this research project would not have been possible.

TABLE OF CONTENTS

TABLE OF CONTENTS continued

LIST OF TABLES

LIST OF TABLES continued

LIST OF FIGURES

LIST OF FIGURES continued

1. INTRODUCTION

1.1 Problem Definition

Each year in the United States, over five billion school trips are made using the school bus (NRC 2002). School bus trips outnumber the total transit bus trips, which also exceeded five billion passenger trips nationally in 2000 because school bus ridership is counted five days a week, approximately ten months a year, whereas transit trips are tallied seven days a week, twelve months a year (APTA 2001). There are also millions of student trips made daily by other school transportation modes – walking, biking, passenger vehicles, and daycare program vans – suggesting that school trips are significant contributors to peak hour travel patterns in this country. "Normal school transportation hours" are from 6am – 9am and 2pm – 5pm, while the generally accepted AM and PM peaks for commuter traffic are 7 – 9am and 4 – 6pm. Afternoon school trips do not fully coincide with the typical PM commuter peak, but both the morning and afternoon school travel peaks cause local traffic congestion problems in many communities. Traffic queues from school driveways and parking lots spill back onto adjacent streets because of high demand and inadequate supply of vehicle storage on school campuses. The problem is of such severity that in North Carolina, the state Department of Transportation established the Municipal and School Transportation Assistance Group in the Congestion Management Section in order to deal with school-related traffic congestion problems. From 1999 to 2001, this group completed over 90 site plan reviews and traffic operations studies at schools across the state with the goal of better accommodating and routing automobile, school bus, pedestrian, and bicycle traffic. The year 2002 began with a backlog of over 50 requests for similar services at other schools.

The Municipal and School Transportation Assistance Group also assisted with a school campus circulation study in 2002 where student loading/ unloading procedures and vehicle queuing patterns were observed at 20 schools in eight North Carolina counties. Thorough data collection efforts produced results that further substantiate the impact of school trips on traffic patterns. About 50% of the schools involved in the study experienced queues in the afternoon that exceeded their on-campus vehicle storage space causing spillback onto the adjacent street; many of these queues began prior to the time that the bell rang to release students from school (STG 2003). A subsequent impact of such recurring traffic congestion is the disruption to normal traffic patterns that becomes necessary to install turn lanes or widen roads in an attempt to enhance mobility in areas adjacent to schools.

School transportation must be seen as a multi-modal system, comprised of more than just the school bus. Only 25% of all student trips nationally are made using the school bus (NRC 2002). According to NHTSA, "school buses are the safest form of transportation for children (NHTSA 2001)." Between 1991 and 1999, school bus crashes accounted for only 4% of all student injuries and 2% of all student fatalities in the US. Passenger vehicles, including cars, light trucks, sport utility vehicles, and vans being used for school transportation, account for 84% of all injuries, 75% of all fatalities, and 59% of all trips. These statistics allude to a safety problem in school transportation due to the large number of automobile trips.

"Nationwide, there appears to be a systemic modal shift from school transportation modes that are relatively safe to modes that are causing operational and safety problems in and around school areas (UNC 2003)." The National Center for Education Statistics (NCES) reports a generally increasing trend in the number of public school students "transported at public expense" in the U.S. from 1929 to 1990. This does not include walkers, bikers, or those students whose school transportation is funded directly by a parent or guardian. Since 1990, however, a decreasing trend has been observed. Figure 1.1 displays these trends, charting the percentage of the total student population transported by school bus for each school year since 1929. Perhaps, the decreasing trend since 1990 is due to families now choosing the most convenient mode for parents and students.

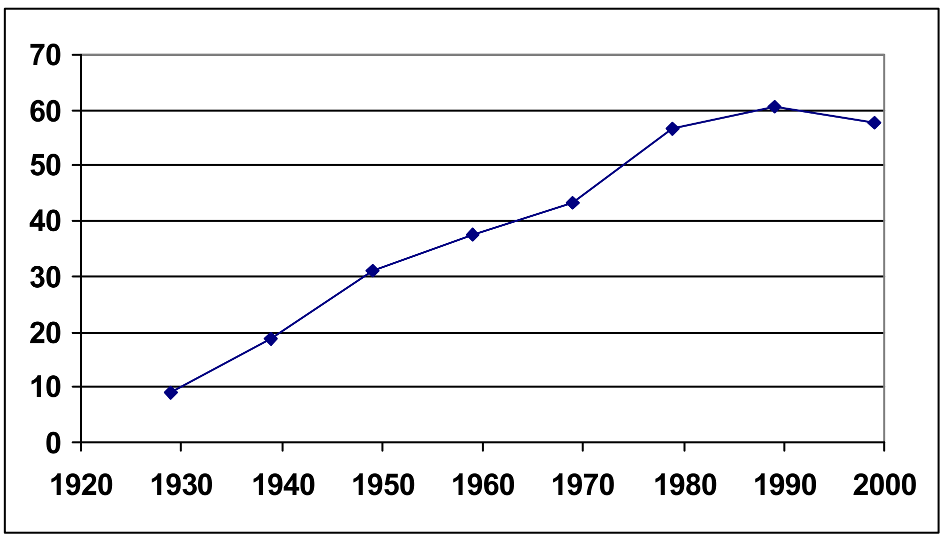

Figure 1.1 Percentage of Student Population Transported At Public Expense in the U.S. (NCES 1998)

Research is needed to gain a better understanding of why students and parents choose their respective modes of school travel. This can help identify problems and prioritize solutions for school transportation. Automated vehicle location (AVL) is a common technology used in trucking and busing systems to increase ridership and improve safety and efficiency. Similar AVL systems may prove to be beneficial for school bus systems. Through AVL, the location of each vehicle in a fleet can be tracked using Global Positioning System (GPS) receivers. Software supplements to AVL display the vehicle position on computerized maps of the area allowing for real-time information gathering, dissemination of vehicle arrival times, and quicker emergency response. Several AVL systems have been created specifically for school bus systems to provide the safety and operational benefits of tracking. Mode choice data are needed, however, to determine the potential "market," if any, for these potential improvements through AVL. "Parents and students often do not consider the associated risks [of a travel mode] and choose or encourage the use of school travel modes for reasons apart from maximizing safety or minimizing risk [like] convenience, flexibility, or cost savings (Fischbeck 2003)." AVL systems not only provide safety benefits, however, traveler convenience may also be increased.

1.2 Research Objectives and Scope

Based on the need to better understand the behaviors and decisions involved in school transportation mode choice, the following research objectives were developed:

1. To develop, calibrate, and validate a school transportation mode choice model for a selected school district.
2. To assess the potential for modal shifts based on improvements to the school bus service through AVL technologies.

The factors that contribute to school transportation mode choice were analyzed using mathematical and transportation modeling techniques. The analysis included an assessment of "customer service," which is parental perception of school bus system performance and "transportation service," which is the school bus level of service compared with other modes. Not all school transportation modes were included in the analysis. A reduced set of three modal alternatives was considered: nonmotorized, comprised of bicycle and pedestrian modes, school bus, and automobile. This decision was made primarily because of small sample sizes for the other modal alternatives.

Data collection for development of the school transportation mode choice model, consisting of a survey and geographic data for a Geographic Information Systems (GIS) analysis, took place in the state of North Carolina. North Carolina is home to the only research group in the country dedicated solely to multi-modal school transportation issues. Working closely with this group was most beneficial. The resources available through the North Carolina Department of Transportation Municipal and School Transportation Assistance group made North Carolina an optimal location as well. The organization and structure of North Carolina public schools also contributed to the site selection process. In North Carolina, public schools are managed by local education agencies (LEA) corresponding to each of the 100 counties and several other individual cities or municipalities. Each LEA uses TIMS, the Transportation Information Management System, for school bus routing and scheduling and reporting of pertinent school bus operation statistics to the state. The involvement of the state in comprehensive record-keeping is an important benefit of school transportation data collection in North Carolina.

Public school students in grades K – 12 were the focus for data collection. Private school policies differ concerning the provision of bus transportation, making the available modes vary by school. So, private schools were not included in this analysis, nor were preschool students, whose available modes also differ, based on the program in which they enrolled. No activity bus trips for student field trips or athletic events were considered in this analysis. The focus was school trips during the "normal school transportation hours" of 6 – 9am and 2 – 5pm, Monday through Friday, late August through mid June.

The survey collected data on mode choice for individual students, although the impact of other students in the household was considered. Discussion of travel time, wait time, or other similar concepts refer to that of the student. Some parents walk with their children to school or wait with their children at the bus stop; others do not. Some parents drive their children to school as part of a trip chain; others drive round-trip from the school to the home. There is large variability in parent behavior related to school travel and therefore student trips, not parent trips, were the focus of the analysis.

The survey also collected data on the reasons why students do not use the school bus service. These reasons provided the basis for the AVL analysis, so that the analysis would be problem-driven in that perceived and proven school bus system deficiencies determined the technologies that were considered. AVL technologies were the only improvements considered because of their proven benefits in public transit bus systems and because of the availability of AVL systems specifically for school buses. The purpose for the AVL component of this research was to allow for preliminary assessment of the potential for modal shift given an increase in school bus level of service.

Both linear and logistic probability models were considered for mode choice model development with utility theory as the basis. The term, "likelihood," is sometimes used interchangeably with "probability" in explaining results.

The final models are expected to be applicable in any North Carolina county. While data were collected in only one county, results from a test for transferability in another county with quite different characteristics suggest that the models are transferable to any area where the approximate automobile usage falls within a certain range in the morning and afternoon.

Ultimately, this research should increase school transportation safety and complement school planning studies throughout the state by providing a means of estimating school transportation modal shares based on certain characteristics of the student population. Further cultivation of a productive and harmonious relationship between school transportation and transportation engineering methodologies is also desired.

1.3 Dissertation Organization

This study of school transportation mode choice was undertaken using a combination of research methodologies. A description of the problem has been included in this introductory chapter, along with a definition of the research objectives and scope. The literature review of pertinent decision analysis, mode choice and probability modeling theories and methods follows in Chapter 2. Linear, logit, and probit probability models were reviewed.

Household surveys were used to collect data because surveys enable the assessment of behaviors and perceptions and surveys allow for disaggregate modeling by collecting individual student information. Transportation system performance data are often collected through demonstration projects, but this was not feasible for the AVL component due to financial constraints, so surveying was used to collect AVL data as well. Chapters 3 and 4 document the data collection methodologies and analyses for the two surveys incorporated in this research project. Chapters 4 and 5 detail the model development, calibration, and validation processes. The AVL technology assessment uses standard mathematical methods to evaluate the potential for modal shifts to the school bus due to technological improvements. These impacts are discussed in Chapter 6, along with model transferability test results and other model application issues. Finally, Chapter 7 summarizes the school transportation mode choice research with conclusions and recommendations for future research.

2. DECISION ANALYSIS AND MODE CHOICE: A LITERATURE REVIEW

2.1 Introduction

The theory of decision analysis is based on the need to consider and evaluate complex decisions amongst alternatives that differ significantly. Formal analysis of a decision, or a set of decisions, typically becomes necessary when a problem has a large number of factors or involves multiple decision makers or uncertainty. This type of analysis is not only common in business, social science, and operations research, but also in transportation. Decision analysis is used regularly in transportation planning to model a traveler's choice of destination, mode, and route.

The traditional urban transportation planning process involves four steps: trip generation, trip distribution, mode choice, and traffic assignment. Combinations of these steps are used to forecast future traffic flows and plan accordingly for new transportation facilities or improvements to existing facilities. Trip generation estimates the number of trips that will occur in a defined network based on the land use patterns in that area. Research conducted in the early 1990's studied trip generation rates for North Carolina high schools. The results showed that North Carolina high schools generate more automobile trips than the national average (Slipp 1994). The number of students enrolled, number of total parking spaces, number of bus riders, and number of employees were factors used to determine the trip rates. This study dealt solely with school trips, but the trip purposes that are included in an analysis depend on the nature and desired results of the research. Trips are usually classified by transportation planners according to their purpose, whether home-based, non-home based, work, shopping, recreational or other. In trip distribution, traveler choices of destination are analyzed and a specific point of origin and destination are assigned to each trip. Mode choice forecasts the distribution of trips among the available modes. This is the analysis of traveler choice of mode. In small cities and regions where public transportation is not provided, the mode choice step is often omitted because automobile travel is assumed for everyone. The final step, network assignment, assigns trips to specific routes in the network based on analysis of traveler choice of route. Automobile trips, for example, are assigned to the highway network of streets and freeways.

When modeling any choice, there are four fundamental issues that should be considered: the characteristics of the decision maker, the available alternatives, the attributes of the alternatives, and the decision rules that will be used in analysis (Ben-Akiva 1985). The decision maker can be an individual or a group as is the case in household decision making. The list of alternatives may comprise the universal set of alternatives for the decision being analyzed or the reduced set of alternatives available to a particular individual or group. Specified attributes are those characteristics of each alternative that differ greatly and affect choice. Finally, the decision rules are the standards used by the decision maker to select an alternative.

This chapter contains a review of literature that discusses previous mode choice research and the utility decision rule. The mode choice concepts presented are those used in urban transportation planning analyses. Similarities between home based work and home based school trips are explored, establishing a connection between the vast mode choice literature and the school transportation research problem.

2.2 Mode Choice Concepts

"Preferences among a set of options depend on the attributes of the options and of the individual involved (Horowitz 1986)." Therefore, a mode choice model of traveler preferences will include terms describing attributes of the individual making the decision, the trip purpose, and the mode, typically characterized by cost and level of service. Mode choice models do not include trip type when the research focus is a single trip purpose. School transportation research is one example, considering only home-based school trips.

School and work trips are known to behave similarly. "Work trips are undertaken with daily regularity, mostly during the morning and afternoon period of peak traffic, and overwhelmingly from the same origins to the same destinations. This is also true in the case of school trips (Papacostas 2001)." Many of the observations and theories of home-based work travel can therefore be applied to home-based school travel. Another similarity between these two trip types is the set of competing modes. In a typical transportation region, automobile and transit trips comprise the overwhelming demand placed on the transportation network. Pedestrian and bicycle modes are more popular in the urban core and areas near colleges and universities. Available school transportation modes are automobile, school bus (a form of transit), walking, biking, contracted van service, or public transit. There are sets of students whose choices are limited because they live in an area where school bus service is not provided or because their family does not own an automobile. These special groups are discussed in more detail in Section 4.3.

Individual and trip characteristics are the critical factors involved in mode choice. Relative attractiveness of the available modes is determined by many factors including cost, control of environment, and flexibility of schedules. These are barriers to widespread usage of transit that have been the focus of research efforts for decades. Individual characteristics, such as socioeconomic status, play an important role in the sensitivity of the mode choice decision to cost and preference.

2.3 Utility as a Decision Rule in Mode Choice

Utility is the decision rule used to analyze mode choice, providing "a numeric measure of attractiveness (Hunt 1990)." Disutility measures the cost, or unattractiveness, associated with a particular mode. Models of choice among modal alternatives generally attempt to maximize utility or minimize disutility by comparing (dis)utility among the available modes.

Disutility is a function of three primary considerations- out-of-pocket costs, travel time, and convenience- which are measured by a variety of factors and together make up the relative attractiveness of modal alternatives. Transit research completed at the Center for Urban Transportation Research confirms that schedule flexibility, a measure of convenience, in addition to travel time and out-of-pocket costs are the important contributors to mode choice (Ball 1990).

2.3.1 Socioeconomic Impacts: Costs and Income

Out-of-pocket costs, in transit, equal the fare. There are cases, however, where fares are subsidized, or in the case of school buses, fully funded. The out-of-pocket costs for automobile usage include only items that are "consumed," such as fuel, oil and tires. This becomes a question of average cost versus marginal cost. Average costs for an automobile include "the fixed costs of purchase, licensing, registration, and insurance payments (Wright

1992)." Marginal costs, however, involve only the consumable items used for fuel and maintenance. Drivers rarely, if ever, consider the fixed costs of owning an automobile when making the decision of whether or not to drive an automobile. Therefore, mode choice decisions are based on marginal costs instead of average costs.

Trends in the marginal costs of fuel, oil, and tires can help determine the future attractiveness of the automobile mode. Since the advent of Corporate Average Fuel Economy (CAFE) standards in 1975, fuel economy has increased for passenger cars from approximately 16 miles per gallon in 1980 to almost 22 miles per gallon in 1992 (Allen 1996). Department of Energy projections for the year 2025 exceed 30 miles per gallon (EIA 2003). Conversely, maintenance costs have increased as vehicle technology becomes more complex. Fuel prices fluctuate monthly, but follow an upward, long-term trend. Forecasted energy prices show a constant increase through the year 2025 (EIA 2003). Fuel economy trends favor the automobile, but rising gas and maintenance prices could make transit a more attractive option.

There are no out-of-pocket costs to parents whose children use the school bus service. Costs for operating an automobile are usually negligible, especially for those parents who chain their work trips with school trips. Increasing average home-to-school distances in school districts where magnet and year-round schools are options may make automobile operating costs a more important consideration in the mode choice decision. The out-of-pocket cost for students using public transit equals the fare. Consideration of these monetary factors introduces the importance of socioeconomic factors in mode choice.

Socioeconomic factors also directly impact the category of public transportation users known as "captives" or "dependents." These persons do not own or have access to an automobile and therefore are not considered transit riders by choice. A study by the Center for Urban Transportation Research (CUTR) noted several reasons that travelers with a choice select public transit for work trips into the central city, urban environment. These include cost and availability of parking, followed by traffic congestion and travel times (Ball 1990). Cities with subway systems, where travel times can be drastically reduced because of the exclusive right of way operation, were included in this study. Of the captive transit riders participating in the CUTR survey, about 37% said they would drive if an automobile were available. This means that 63% of captive transit riders would likely continue to use transit, even with an automobile available because of parking costs and availability, travel times, and traffic congestion. This may indicate that socioeconomic factors are not critical in mode choice decisions for many travelers. Further research, however, shows that choice of transit is highly correlated with income. The percentage of persons indicating a willingness to use a paratransit service for transport to work in the same survey decreased steadily from 60% in households with an annual income of less than $10,000 to 40% in households with annual incomes greater than $50,000 (Ball 1990). The potential for prompting school trip modal shifts is also expected to vary with household income.

2.3.2 Travel Time Impacts

Travel time, the second component of disutility, consists of two parts: in-vehicle and out-of-vehicle time. In-vehicle time is the time spent in route to a destination inside the vehicle of choice. Out-of-vehicle time is one measure of convenience that includes “time to walk to and from transit stops or parking places, waiting time, [and] transfer time (Beimborn 1995).” Without exclusive transit right-of-ways, both automobiles and buses are subjected to delays caused by traffic congestion, accidents, construction, and other occurrences on the highway system. Transit would have additional utility if exclusive right-of-way were provided. The stops that a bus makes to board or alight passengers cause increased in-vehicle travel times and less than ideal routing for buses.

The most important contributing factors to school bus travel time are student loading times, posted speed limits, distance traveled, traffic control devices encountered, pavement condition, lane widths, and occurrence of traffic congestion (Rhoulac 2000). These factors were determined in a research project that developed link travel time and student loading time models to provide needed updates to the TIMS, link-based routing and scheduling algorithm. Mobile Global Positioning Systems (GPS) equipment was used on-board several school bus routes as an accurate and quick means of collecting bus travel time and student loading time data for empirical model development. GPS technologies are now being used more frequently to collect school bus travel time data in individual school districts. That research helped introduce GPS technologies to the school transportation community and also led to several important findings concerning school bus travel time. First, travel time is highly dependent on the location of the school bus route, whether in a rural, suburban, or urban area. Each of the aforementioned contributing factors is dependent upon the type of area that the school bus route encompasses. "Student loading time is highly dependent on whether the stop is at an address or corner (Rhoulac 2000)." Corner stops, which take less time to complete than address stops, occur more frequently in urban areas where students meet in a common location to load the bus. In contrast, rural bus routes typically involve address stops because door-to-door service is mandated by lack of sidewalks or shoulder space and relatively high posted speed limits. Also, having to stop or slow significantly for traffic signals or traffic congestion adds to travel times in urban areas, as opposed to the nearly free-flow traffic conditions encountered in rural regions. School transportation mode choice could therefore vary by area type because of the associated travel time implications.

Bicycle and pedestrian modes have longer "in-vehicle" travel times relative to automobiles because they are non-motorized, but they become more attractive when considering ease of access (out-of-vehicle travel time). The following "hierarchy" of the more prominent modes gives the threshold distances at which each is most attractive. "Walking is usually faster than the car for perhaps some 400 meters (437 yards), depending largely on the time lost getting to and parking the car. Somewhere between 20 and 400 meters the cyclist overtakes the pedestrian, having to overcome the delay of getting to the bicycle and unlocking it. The car and bicycle dominate after some 400 meters… the car overtakes the bike at around 1.5 kilometers (just under a mile), and transit overtakes the pedestrian at a similar distance (Wright 1992)." These distances apply to normal traffic conditions; congestion will make walking and biking more attractive for longer distances.

The primary factor that increases the disutility of transit, in comparison with the automobile, is out-of-vehicle travel time. "Time spent in walking, waiting, looking for a parking space, or transferring modes is more onerous than time spent moving between one's origin and destination (Poole 1994)." Mode choice models weigh access time much higher than in-vehicle time to reflect this aversion to waiting. In school bus transportation, out-of-vehicle time is the time spent walking to and waiting at the bus stop. Still, buses continue as a popular mode for home-based school trips because there is a higher tolerance for waiting associated with home-based work and the similar home-based school trip purposes. "People tend to be more willing to wait or walk longer distances for work trips than for shopping trips (Beimborn 1995)."

2.3.3 Convenience

Convenience is the third contributing factor to modal utility. This is the most difficult component to incorporate in the model because convenience is highly dependent on personal preference. What one person finds to be convenient will likely differ from what another person considers convenient. Still, an attempt should be made to represent convenience in a mode choice model. The value of privacy, peer selection, personal environment control, flexibility of scheduling, punctuality, and ease of carrying things affect overall convenience. Privacy is "the ability to keep others from invading one's personal 'airspace'" (Wright 1992). This becomes a matter of spatial tolerance. A transit bus operating at level of service "A" should have no more than one person per 12.9 square feet. An acceptable level of service, "D," is achieved when each user can occupy at least 5.4 square feet (TRB 2000). The personal automobile promotes privacy and peer selection. Peer selection is "the ability of a person to choose traveling companions that are judged compatible or at least tolerable in terms of values, standards of behavior, and other factors" (Wright 1992). Walking and bicycling allow some degree of peer selection, but transit does not. Selection of persons with whom a traveler must ride on a bus is beyond the individual traveler's control. Peer selection concerns relate directly to safety concerns. A 1988 survey of 4,000 persons in several metropolitan areas of the United States living no more than one-half mile from public transportation cited that 60% of respondents believed the private automobile to be the safest mode of transportation. Bus and automobile were described as least safe by about 15% of respondents (Ball 1990). This is another reason that the convenience term for the automobile exceeds all other modes. A mode perceived as safer than others will also be seen as more convenient.

Personal environment control is another convenience factor in favor of the personal automobile. Many travelers enjoy having full control of musical selection during a commute in their personal automobiles. Differing preferences of musical genres keep music from being played on most public transportation modes. Portable music listening devices, like a walkman or discman, however, allow the traveler to be more in control of his or her personal environment on transit trips. Conversely, there are no technologies that allow for personal control of noise level or temperature control in public transportation. There are some personal environment factors that public transportation enhances, like the ability to read during the commute (Wright 1992).

Flexibility in scheduling is another measure of convenience. Infrequent bus arrivals, characterized by systems with long headways, are not convenient for travelers. Departure times are under the full control of those choosing the automobile, bike and pedestrian modes of travel. Punctuality does play a role, but has already been accounted for in the out-of-vehicle travel times (Wright 1992). In the consideration of school transportation, the school bus comes only once per AM and PM peak period. Missing a public transit bus means that the traveler must wait until the next bus arrives, increasing out-of-vehicle travel time. Missing the school bus, however, means having to find an alternate mode of transport for that day or missing school, if no other mode is available. For elementary, middle, and some high school students, driving is not an option, so morning departure times in a passenger vehicle are not always their personal decisions. Students valuing independence often choose the bike or pedestrian modes, when home-to-school distance permits.

Walking is the least favorable mode when considering ease of carrying things. The list of commonly carried items for students includes lunches, books, book bags, musical instruments, and school projects. Bicycles are more favorable because of baskets and other devices that help to transport large items (Wright 1992). Personal automobiles are most convenient for carrying multiple items because loading and can be completed over a longer period of time, also because there are not usually space constraints. On a bus, however, all the items must be carried at the same time to the bus stop and onto the bus and the space once on board is limited.

2.3.4 The Utility Function

There is a deterministic portion and a probabilistic, or random, portion of the utility on which an individual's choice of mode is based. The deterministic function is a linear combination of variables that expresses the relative utility of a mode using the general form:

$$U_i = a_{0_i} + a_{1_i} X_{1_i} + a_{2_i} X_{2_i} + \ldots + a_{n_i} X_{n_i} \qquad \textbf{Equation 2.1}$$

where U is the utility for mode i, defined by the attributes, X_{1_i} through X_{n_i}, and weighted by the coefficients, a_{1_i} through a_{n_i} with a_{0_i} as the model constant. Utility functions can be mode specific or mode abstract. An abstract model is a single equation used to estimate the utility of several modes by changing the values of the independent variables. Mode specific models use a unique equation for each mode being analyzed so that different weights can be assigned to the same attributes (Papacostas 2001).

Field data describing trip and decision maker characteristics are necessary to calibrate utility functions. Household or individual traveler surveys are commonly used to obtain the necessary data for utility function calibration. The "weight" assigned to each variable depends heavily on the relative value that decision makers assign to that factor. For example, past research has proven that travelers value out-of-vehicle travel time, which is a common variable in traditional mode choice models, more than in-vehicle travel time; this is expressed mathematically by assigning a larger coefficient, a_n, to the out-of-vehicle travel time variable.

As with any mathematical model, there are some limitations to the deterministic utility model. Firstly, deterministic utility functions result in the same value for utility, given the same input parameters, meaning that a user will always choose to maximize utility or minimize disutility. Behavior is probabilistic, however, and sometimes choices are made that cannot be expressed numerically by a quantified utility. This introduces the probabilistic portion of utility theory, the random error term. This term, discussed in more detail in Section 2.4, is added to the deterministic portion of a utility model, acknowledging that aggregate behaviors are not full estimable.

A second limitation of the utility model is that some factors that individuals consider in choosing a mode of travel are not quantifiable and must be represented by a single constant, the mode bias term. This mode-bias term, found by "fit[ting] the model to actual travel behavior (Beimborn 1995)," accounts for the difference between what has been included in a model and what may need to be included based on observed travel behavior. Therefore, the factors that are together represented by the mode bias constant may not have the same effect on the choice model that they have on the actual choice.

Finally, the weights assigned to the utility model variables are assumed to be constant for a given trip purpose, but within a single purpose are many differences in the value assigned to the various factors. This is a source of error when utility functions are used to estimate modal split, which is described in Section 2.4.

2.4 Probability Unit Models

2.4.1 Model Specifications

When uncertainty is present in decision making, the model used to link alternatives to their consequences upon which choices are based involves an assessment of probability. Probability models attempt to estimate the probability that a given mode will be used by an individual with certain characteristics and preferences, expressed by the utility function. Individuals are studied because individual decisions determine aggregate behaviors, which are generally of interest in transportation modeling (Ben-Akiva 1985). "Measures of aggregate travel, such as bus ridership, are obtained by adding up the choices of individuals (Horowitz 1986)."

There are numerous types of probability models, including binary, multinomial, linear, probit and logit. A probability model is named by a description of the outcome variable or the random error distribution. Binary models, for example, have two possible outcomes, whereas multinomial models involve three or more choices. Linear, probit, and logit models are the most common probability models, each describing a different distribution of the random error term. "Any well-defined assumption about the distribution of [error] will lead to a choice model (Ben-Akiva 1985)." For this review of literature, only the three most common model types are considered.

The linear probability model assumes that the error term is zero and the probability that an individual will choose a specific mode is based solely on a linear combination of variables expressing utility. In the binary case, where the two available modes are identified as "0" and "1," the linear combination of variables estimates the probability that mode one will be used. A limitation of the linear probability model is that values which are negative and greater than one can be calculated. Extreme value limits can be implemented since probabilities can range only between zero and one or the negative and greater-than-one values can be used with the other individual values to estimate the aggregate statistics of interest.

The "probit," or probability unit, model assumes a normal error term distribution. The logit model is an extension of the probit model with a logistic-distributed random error. Logit and probit are "the two most commonly used alternatives to the linear specification of the probability model (Aldrich 1984)." The logistic probability unit, or "logit," model is the probability model type used most in forecasting mode choice. The logit model is characterized as "'probit-like' but also more convenient analytically" because the logit model has a "closed form" and does not involve the multiple integrals that are encountered in formulating a multinomial probit model (Ben-Akiva 1985).

The basic difference in the probit and logit models is the scale of coefficient estimates. Logit coefficients are typically 1.8 times the probit coefficients. The theoretical basis for both models is "essentially identical at all but the tails of their respective distributions (and even there the differences are but slight) (Aldrich 1984)." These models calculate the proportion of persons using each of the available modes based on the relative utility of the available modes. For the binary case, only the difference in utility is necessary for modeling, as opposed to a unique utility function for each available mode.

Interpretation of linear probability models is most simple, but can be limited when a continuous dependent variable is not involved. Non-linear probability models do not have this limitation and are therefore widely used in social science analyses, where the "attitudes, behaviors, characteristics, decisions, and events [being studied] are measured in … non-continuous ways (Liao 1994)."

The general form of the logit model is:

$$p_i = \frac{e^{U_i}}{\sum_{j=1}^{n} e^{U_j}}$$ **Equation 2.2**

where p_i is the proportion of users selecting mode i, U_i is the utility of mode i (Equation 2.1) and n is the total number of available modes. The general form of the probit model is:

$$p_i = \Phi(U_i)$$ **Equation 2.3**

where Φ denotes the standardized cumulative normal distribution.

2.4.2 Probability Model Summary

The linear probability model offers the advantage of relatively easy interpretation, but this interpretation can be limited. The logit model offers a non-linear specification of a probability model, which is proven to work well when modeling attitudes and behaviors. The logit model is also the most widely used in traditional mode choice research. Taking into account the advantages and disadvantages of the linear and logistic models, both methods were considered in model development, with selection of the final model being based on degree of fit to the actual data and simplicity.

2.5 Data Collection Methodology

"In travel demand analysis… often a single data collection effort is undertaken to serve many purposes. [Information gathered from interviewing] travelers to find out their chosen alternatives and their attributes [can be] used to estimate the parameters of travel demand models as well as to estimate characteristics of the population such as the mean income of transit users or the distribution of auto ownership across households (Ben-Akiva 1985)." Random sample surveys are commonly used to obtain data on public opinions, attitudes, or behaviors. "Surveys are… the primary way to measure attitudes and determine why people act a certain way (Hummer 1994)." Random sampling is necessary to gain responses representative of an entire population. Inferences about a population are not reliable if drawn from a nonrandom sample.

The numerous surveying methods can be classified in two broad categories- questionnaires and interviews. Each category differs in terms of cost, time and staff required, expected nonresponse bias, potential anonymity of respondents, and many other factors. "The choice of survey method depends on the type of questions and the sample anticipated (Hummer 1994)." Researchers should ensure that adequate resources are available for the method selected and minimum sample size required for their respective studies.

The mail-out-mail-back survey questionnaire format was selected for the school transportation mode choice research because of the low costs involved and the ability to obtain a widely dispersed sample, representative of an entire county or school district. This surveying method should allow for collection of quality data for use in model development, calibration, and validation.

2.6 Literature Summary

Traditional mode choice modeling methods are reviewed in this chapter because no pertinent research was found applied specifically to grade school (K-12th grade students) transportation. The multinomial logit model is the most commonly used method of estimating mode choice. The major contribution of this school transportation mode choice research is the application of probability modeling techniques to develop and calibrate a mode choice model applied specifically to grade school students. If school trips behave similarly to work trips, as expected, predictor variables related to travel time, cost, and convenience should appear in the mode choice models. Linear and logistic probability modeling methods will be used to analyze the decisions of individuals and households in school transportation mode choice. Figure 2.1 provides a flowchart illustrating the organization of this dissertation and the research methodologies used in this research.

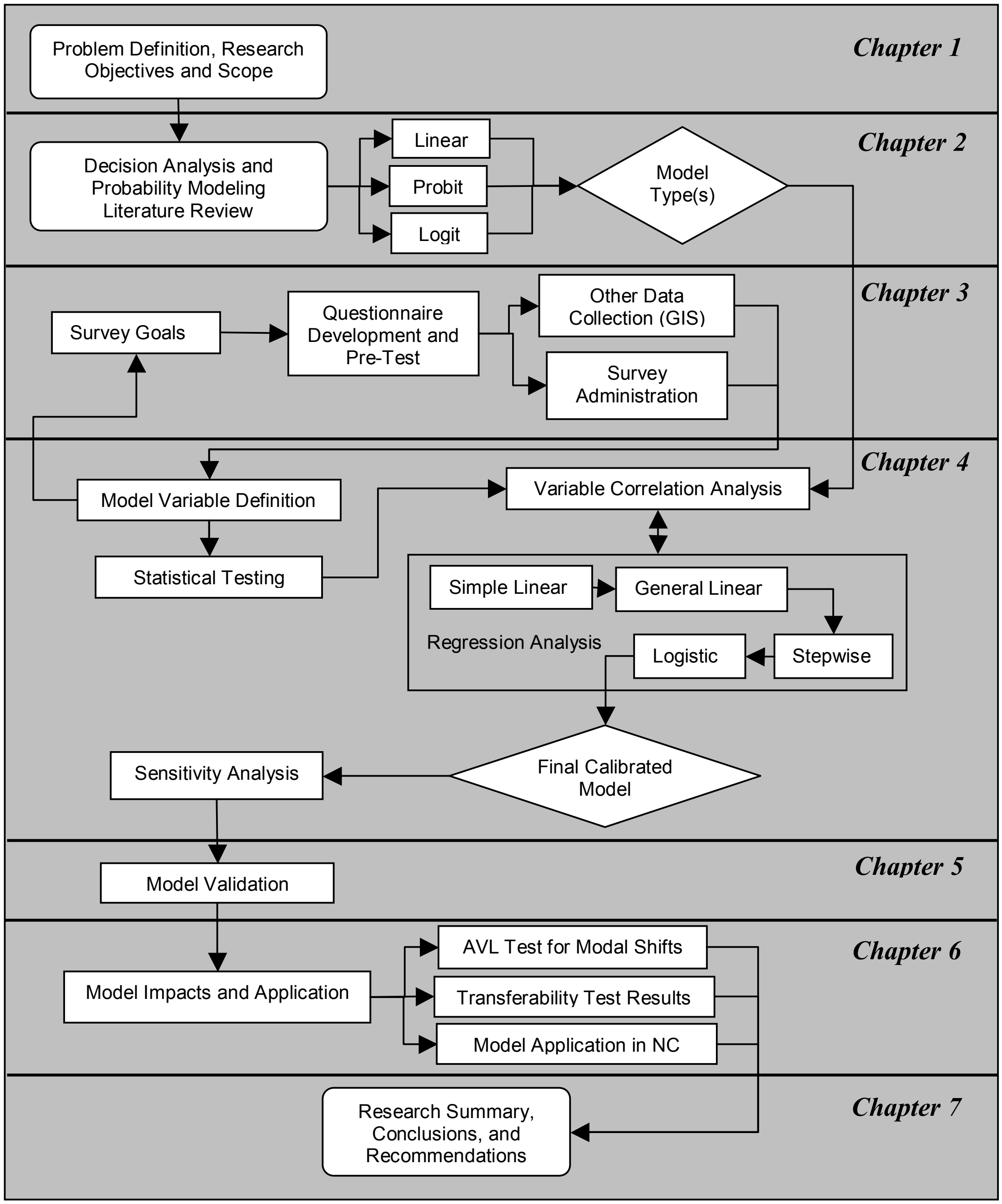

Figure 2.1 Research Methodology

3. PRELIMINARY DATA COLLECTION AND ANALYSIS

3.1 Introduction

Household surveys were used to collect data for mode choice model development. This chapter details the surveying methods and results of the preliminary survey. Households having one or more children in kindergarten through twelfth grade were asked questions in accordance with three objectives: 1) to collect data on individual student mode choice and the associated student and family characteristics, 2) to assess the parent's perception of problems associated with the school bus service, and 3) to determine parental acceptance of and willingness-to-pay for AVL technologies that could better the school bus service. The student researcher developed the survey using guidelines from the *Manual of Transportation Engineering Studies* (Hummer 1994). Budgetary constraints mandated a mail-out-mail-back survey format, instead of a telephone survey. Months of editing, review, and evaluation were completed for the survey draft questionnaire, including review by experienced surveyors and transportation staff in the selected school district and a test survey with about 20 participants. Upon receiving the necessary approvals, surveys were mailed to parents of 5000 students in the Wake County, NC public school system (WCPSS) in October 2001. Parents were given approximately one month to complete and return the surveys by mail, with an early November requested return deadline. The complete survey form is shown in Appendix A.

Wake County, where Raleigh and NC State University are located, was selected as the survey site primarily because of the professional relationships that had been established with the school transportation staff during previous research projects. Also, Wake County staff had expressed interest in exploring AVL technologies for their school bus fleet, so the information obtained in the survey would benefit their AVL research efforts, in addition to providing a supplemental means for assessing their school bus system performance.

3.2 Determining Sample Size

Surveys are intended to estimate the true value of one or more population characteristics (ASA 1997). In order to draw inference from a sample that will accurately reflect the population, careful attention must be given to determining the needed sample size.

According to the theory of probability, if the expected value for probability of success in a "yes or no" experiment is p, then the 95% confidence interval for the expected value is:

$$p \pm Z_{0.95} \times \sqrt{\frac{p(1-p)}{n}} \quad \textbf{Equation 3.1}$$

where $Z_{0.95} = 1.96$ for a two sided alternative and n = sample size. The error term is denoted by δ in Equation 3.2. The "yes/no" assessment in the school transportation survey refers to school bus ridership. A 50%-50% split was assumed for survey respondents answering the question of whether or not they ride the school bus because sampling was random and preliminary research showed about a 53% school bus ridership in Wake County. Both p and (1-p) in Equation 3.1 were set equal to 0.50, representing the maximum product. Therefore, even if actual survey responses did not yield a 50/50 split, the error in the estimate would be no greater. Solving for n yields the following equation:

$$n = \frac{0.9604}{\delta^2} \qquad \textbf{Equation 3.2}$$

Equation 3.2 calculations indicated that in order to achieve a 1% error, a sample size of approximately 9600 was required. A sample size of 385 corresponded to a 5% error. The sample size selected would depend on the maximum acceptable error rate and the expected response rate. Transportation survey response rates vary widely between 20 and 70% (Hummer 1994). Desiring a 40% response rate and an error less than 5%, a sample size of 5000 was selected. If 2000 completed surveys were returned, the associated error would be just over 2%. Having such a large sample size was beneficial because "larger samples are more likely to yield results close to the target population quantity and thus have smaller margins of error than more modest-sized samples (ASA 1998)."

3.3 Sample Selection

Stratified random sampling was used to determine which of the approximately 100,000 students enrolled in WCPSS for the 2001-2002 school year would receive surveys. The population was stratified so that there would be adequate representation in the sample responses from each part of Wake County. The computerized system used across the State of North Carolina for school bus routing and scheduling divides each county into high school attendance boundaries. There are 15 high schools in Wake County, so student names were separated into 15 categories. All elementary and middle schools are assigned to a high school attendance boundary, so with the school codes from the student information database, 15 separate databases were created corresponding to the 15 high school attendance boundaries.

Another important consideration in school bus ridership is grade level. Ridership patterns differ greatly amongst elementary, middle, and high school students. Elementary and middle grade levels are known to exhibit somewhat similar ridership patterns, but the availability of driving as a transport mode for high school students likely makes their ridership patterns different. For this reason, data were further stratified as high school (grades 9-12) and non-high school (grades K-8) in each attendance boundary.

A total of 30 strata were used corresponding to the 15 high school attendance boundaries and two grade levels, K-8 and 9-12, in each. Using a random number generator, 167 student names were selected from each of the 30 categories by the corresponding record number. Duplicate addresses were deleted if siblings with the same mailing address were randomly selected. A few of the selected students had incomplete address information; these names were also deleted from the database. After removing the duplicate and incomplete entries, approximately 4980 names remained. Twenty additional students from the alternative high school database were then randomly selected for inclusion in the survey.

In order to achieve anonymity of responses, surveys were not tracked according to the households to which they were sent. Instead, researchers planned to use average distance to school by high school attendance boundary as a surrogate measure for actual home-to-school distance in model development. Ultimately, the distance data collected in the new survey, which is discussed in Chapter 4, were used in model development.

3.4 Survey Results

Approximately 1250 surveys were returned, corresponding to a response rate of 25%. On each survey, parents or guardians were asked to provide answers for up to four children. Four was an arbitrary number selected according to the allowable space on the one page, front-and-back survey format. So, while only 25% of parents responded, data were collected for 2302 students. Using Equation 3.2, a sample size of 2300 corresponds to an expected error of about 2%. Sources of error in surveys and associated measures used to calculate this error are discussed in further detail in Section 3.7.

3.4.1 Student Age, Grade, and Gender

Analysis of survey results revealed that responses by grade level closely matched population grade level proportions. Elementary and middle school students are thought to exhibit similar bus ridership behaviors, unlike high school students. Grouping elementary and middle into a single category, WCPSS is comprised of 75% non-high school students and 25% high school students. The survey sample includes 64% non-high school students and 36% high school students. Choosing to stratify by high school and non-high school student grade levels did help to better represent high school student's school transportation characteristics in the survey. Table 3.1 shows the percentages by grade level.

Table 3.1 Survey Sample Response Rates by Student Grade Level

Grade Level	Survey Sample	WCPSS Population
% Elementary	39	49
% Middle	25	26
% High	36	25

The survey sample is almost evenly divided by student gender (48% male, 46% female); 6% did not indicate the student's gender. The distribution of ages in the survey sample is fairly equal as well. Only ages 18 and 19 have a low response rate because most students graduate from high school at age 17 or turn 18 years old during their last year of high school after early November, when this survey was completed. Figure 3.1 displays in a bar chart the percentages of survey responses by student age.

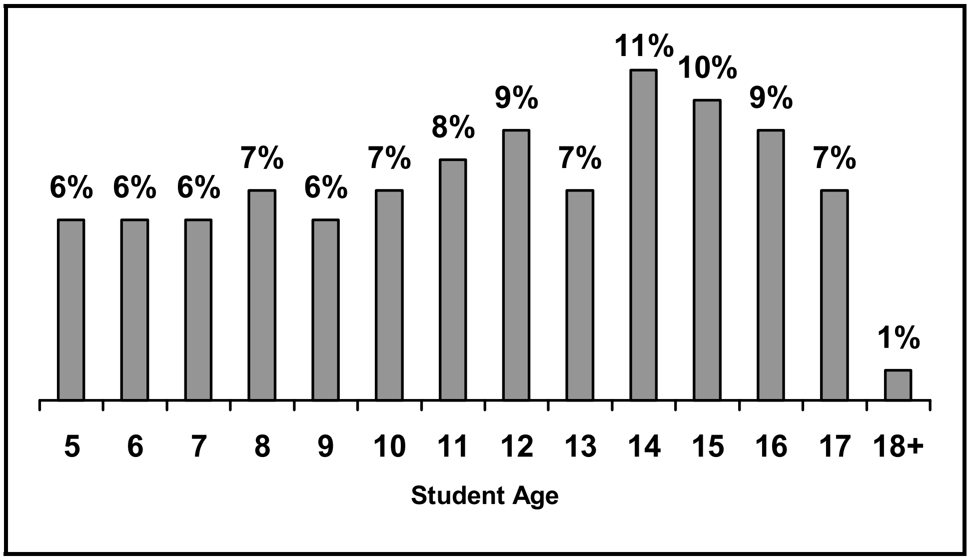

Figure 3.1 Distribution of Total Survey Responses by Student Age

3.4.2 Student Choice of Mode

Mode choice by grade level and time of day is given in Table 3.2, categorized according to the four primary school transportation modes. This chart groups the two categories of automobile travel- students driving and students being driven- whether by parent, older sibling, carpool, or other. In considering the decision factors involved in mode choice, however, the student-driving category is different from the other automobile modes. This creates two different sets from the composite survey data. High school students were noted previously as having different school bus ridership characteristics than K-8 students; this is supported by the fact that many high school students can choose to drive, while K-8 students cannot. Student drivers help to explain why the high school grade level has the largest percentage of passenger vehicle mode share for school trips. Table 3.3 further characterizes mode split for high school student trips. Nearly 25% of high school students drive to and from school. Siblings and friends driving contribute to the number of high school students riding in passenger vehicles not driven by parents. The social value placed on driving by teenagers decreases the likelihood of a modal shift from the automobile for students in grades 9-12. The only potential for modal shifts to the school bus amongst high school students may be found in the nearly 9% who ride the school bus in the afternoon, but not in the morning. This depends strongly on the reasons that student-parent teams may not choose the school bus service in the morning.

Table 3.2 Mode Choice by Student Grade Level

	Travel To School Mode			
Grade Level	**Passenger Vehicle**	**School Bus**	**Van/ Transit**	**Ped/ Bike**
Elementary- AM	42%	52%	1%	5%
Middle- AM	34%	63%	0.3%	2.7%
High- AM	63%	35%	0.5%	1.5%
AM Total	46.3%	50%	0.6%	3.1%
Elementary- PM	30%	62%	2%	6%
Middle- PM	17%	77%	1%	5%
High- PM	54%	43%	1%	2%
PM Total	33.7%	60.7%	1.3%	4.3%

Table 3.3 High School Mode Choice

	School Bus	**Automobile- Student Driver**	**Automobile- Parent/ Guardian Driver**	**Automobile- Other Driver**	**Ped/ Bike**	**Van/ Transit**
AM	35%	22.5%	23%	18%	1%	0.5%
PM	43.5%	22.5%	16%	15%	2%	1%

Parents whose children do not use the school bus service for one or both home based school trips were asked to choose up to four of ten provided reasons explaining why; space for write-ins was also provided. The complete list is given in Table 3.4 in descending rank order. Eight reasons were added to the original ten that best categorized "write-in" responses.

Table 3.4 Reasons Parents Choose Not To Use the School Bus Service

Rank	Reason	#	%
1	AM Times Do Not Fit Family Schedule	325	20
2	On-Bus Student Behavior Concerns	192	12
3	Child Does Not Go Directly To/From School	189	12
4	Bus Ride Takes Too Long	157	10
5	Bus Does Not Arrive (at Bus Stop or School) On Time	156	10
6	Bus Safety Concerns	153	9
7	Live Within Walking Distance	120	7
8	Driving More Convenient/ Preferred	98	6
9	PM Times Do Not Fit Family Schedule	77	5
10	Child Enjoys Riding With Friends	58	3
11	Bus Stop Location Concerns	37	2
12	Transportation Not Provided/ Child Does Not Attend Assigned School	28	2
13	Buses Overcrowded	13	1
14	Parent Works At School	7	
15	Buses Use Excessive Speed	3	
16	Child Has Too Much To Carry	2	1
17	Medical Reasons	2	
18	Child Disallowed On Bus by WCPSS	2	

The most frequently indicated reason for not using the school bus service is that the morning arrival times do not fit the family schedule. For most, this means that the bus arrives too early, although some parents explained that they have to leave for work before the bus arrives and do not feel comfortable leaving their children at home to ride the school bus. Early bus arrival times apply mostly to high school students. In Wake County, school bell times are staggered and bus routes "tiered" in order to use individual buses for multiple routes. High school morning bell times occur mostly at 7:30 am or 8:00 am (WCPSS 2003). Middle and elementary school bell times range from 7:45 am to 9:15 am. This bell schedule requires that the first student on many high school bus routes be picked up between 6:00 and 6:30 am. This further decreases the chance of a significant modal shift to the school bus for high school students because scheduled morning arrival times are the primary reason that students do not ride. AVL technologies can increase the school bus level of service, but do not affect the scheduled arrival time of the school bus and therefore would not likely cause a modal shift amongst high school students.

Choice of driving as a mode of school transport and bell time schedules distinguish high school students from K-8 students, who have a different set of decision factors and travel characteristics. For this reason, the research focus was narrowed to grades K-8 in the school transportation mode choice model development process detailed in Chapter 4.

Overall, school bus and passenger vehicle are clearly the two primary modes chosen for home-based school trips. Pedestrian and bicycle modes combined into a single, "non-motorized," category account for just over 4 and 5% of the morning and afternoon trips, respectively. Travel by contracted vans and transit comprises about 1% of the total morning and afternoon school trips. Considering trip characteristics and decision factors, contracted vans behave similarly to paratransit services, offering a guaranteed seat and door-to-door service. Fixed-route public transit buses operate differently and involve different decision characteristics. Therefore, these two modes should not have been grouped into one category. Considering this and the almost negligible contribution of these modes to school transportation, model development analyses in Chapter 4 focus on the passenger vehicle, school bus, and non-motorized (pedestrian/bicycle) modes of school transportation. The remainder of Chapter 3 continues to consider the K-12 results of the preliminary survey.

3.4.3 Perceived Modal Safety

Another factor thought to have a significant impact on mode choice is perception of safety. According to the preliminary survey results, many parents believe that driving their children to school is safer than having their children ride the school bus. Fatality statistics show just the opposite. "Motor vehicles are the leading cause of death for school-age children (NHTSA 2001)." Of the 800 school-age children killed in the United States during normal school transportation hours between 1991 and 1999, automobiles accounted for 75% of the fatal crashes; approximately 55% of these fatal crashes involved a teenage driver (Fischbeck 2003). Still, some parents are more comfortable driving their children to and from school. This is perhaps explained by the difference in safety and security. Safety is defined as "the condition of being safe from injury, hurt, or loss," whereas security connotes "freedom from fear or anxiety (Webster 1983)." Parents appear to consider security in their assessment of safety and choice of mode. Parents believe that a child is more secure when accompanied by his/her parent. This explains why the majority of parents surveyed indicated that driving their children to school is safer than walking, biking, or riding the school bus. Among the top ten reasons why parents do not utilize the school bus service, listed previously in Table 3.4, are student behavior and bus safety concerns. The potential for a school transportation modal shift from automobile to school bus may be dependent on addressing this perception. Figure 3.2 displays the safety rating results for the parent-driven automobile and school bus. Rating for other automobile modes, like student driving and sibling driving, are omitted because of small sample sizes; the majority of respondents did not rate these modes. Nearly 65% of parents rated driving their children to school as "very safe," while only 35% of parents rated the school bus as "very safe."

The benefits of a modal shift from the automobile to the school bus for school travel include decreasing the number of passenger cars on and around school campuses thereby decreasing conflict points and ultimately increasing safety. In order to prompt a modal shift, however, the parent-identified problems with the school bus service need to be addressed and improved.

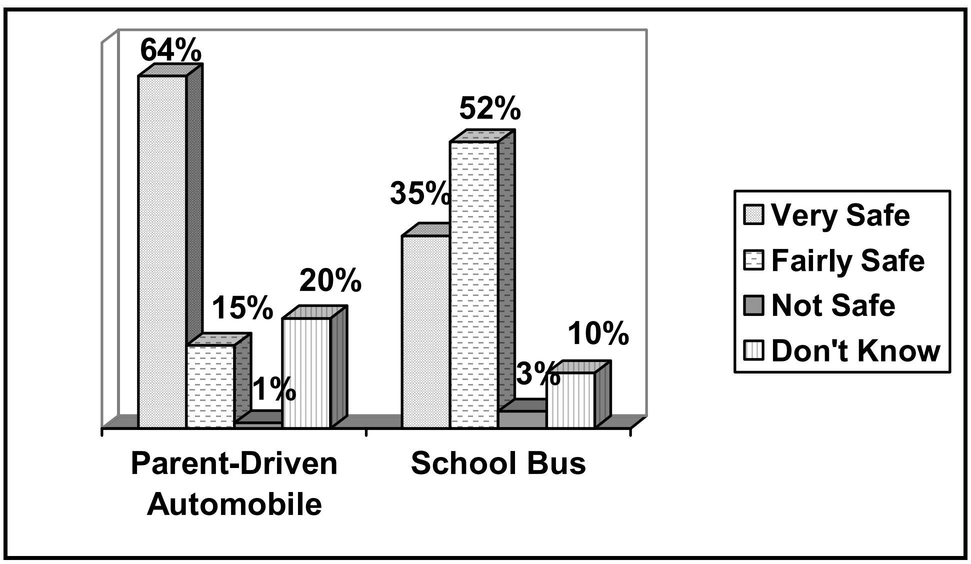

Figure 3.2 Parental Safety Rating of Two Primary School Transportation Modes

3.4.4 Identified Problems with School Bus Service

Bus stop location concern was the most frequent write-in response indicating why parents do not use the school bus service. Parents do not like to have their children waiting at a bus stop exposed to inclement weather and other dangerous conditions. The highest ranked reason overall suggests that morning pick-up times are too early. With some

WCPSS bus arrival times occurring around 6 am, students have to wait outside in the dark during winter months, adding to parental reluctance to use the school bus service. Student behavior on the bus and at bus stops is another major concern of parents, followed by concern about the bus adhering to the provided schedule. Parents do not want to leave for work and have their children at home or at a corner bus stop waiting for a school bus that may or may not arrive.

Some reasons that were given for not using the school bus service are unrelated to school bus system performance, like before and after school activities. Policy changes that require students to attend neighborhood schools may be the only viable solution to the long bus rides required to transport students across the county, but such changes are beyond the scope of this research. The primary problems with the school bus service that can be addressed by this research for school transportation operations are:

- Parental perception of passenger vehicle and school bus safety,
- Morning loading times/ patterns,
- Student bus/ bus stop behavior, and
- Bus arrival punctuality at the school, home, or bus stop.

Parents of bus riders were asked to characterize the bus arrival as “early,” “late,” “on time,” or “unpredictable,” to estimate the approximate number of times the bus arrived early or late in the morning and afternoon of a typical week, and to estimate the approximate length of time by which the bus was early or late. Figure 3.3 displays the responses. Over 70% of responding WCPSS parents characterized bus arrival as “on time.” Few buses appear to arrive early, which is advantageous because a person will often miss an early bus as opposed to having to wait for a late bus. Overall, 27% of the responding sample population had a problem with the arrival time of their child's bus. Increasing customer satisfaction for this portion of the population could help promote a modal shift to the school bus.

3.4.5 AVL Assessment

The final component of the preliminary survey was an assessment of parents' acceptance of technologies aimed at solving problems with the school bus service. Parents were asked to indicate the price they deemed "reasonable" 1) to pay for in-home bus arrival notification/ paging technology and 2) for the school system to pay for bus tracking technology, regardless of whether their child rode the school bus. Approximately 48% of parents were unwilling to pay for an arrival notification service. Another 48% indicated a "willingness-to-pay" of $1 to $20 per month for this information. Based on the overall average, parents indicated that no more than approximately $7 per month would be "reasonable" to pay in order to subscribe to an AVL bus arrival notification service. In terms of AVL for school bus tracking, 40% of parents did not support the school system spending money on bus tracking technologies, but 51% did support spending in the range of $100 to $5000 per bus. The highest, "reasonable" amount to pay for tracking was found to be just over $1300 per bus based on the average responses. Figures 3.4 and 3.5 show the relationship of bus rider responses and total responses for the willingness-to-pay questions.

The final analysis of survey data involved a general characterization of the students using each mode. Notable differences in the characteristics of students using each mode are summarized in Table 3.5. This preliminary survey data provided proof that a mode choice model could be successful. Further analysis, detailed in Chapter 4, used the information from Table 3.5 – gender, grade, and income – along with other factors, like travel distance and convenience, to develop the school transportation mode choice model.

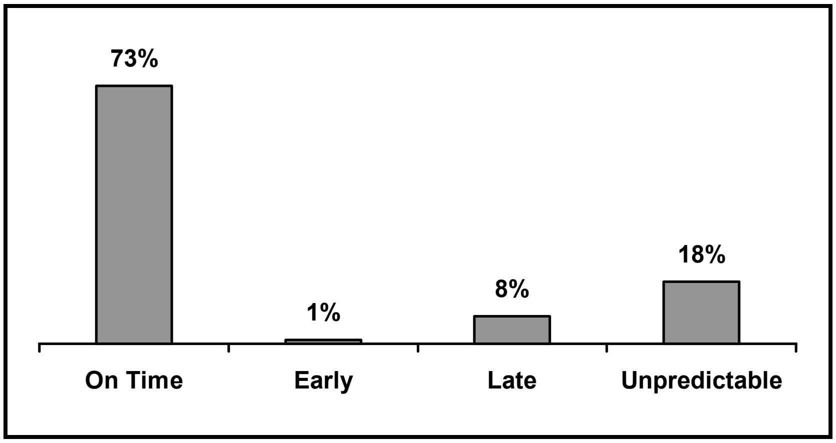

Figure 3.3 Parental Assessment of School Bus Punctuality

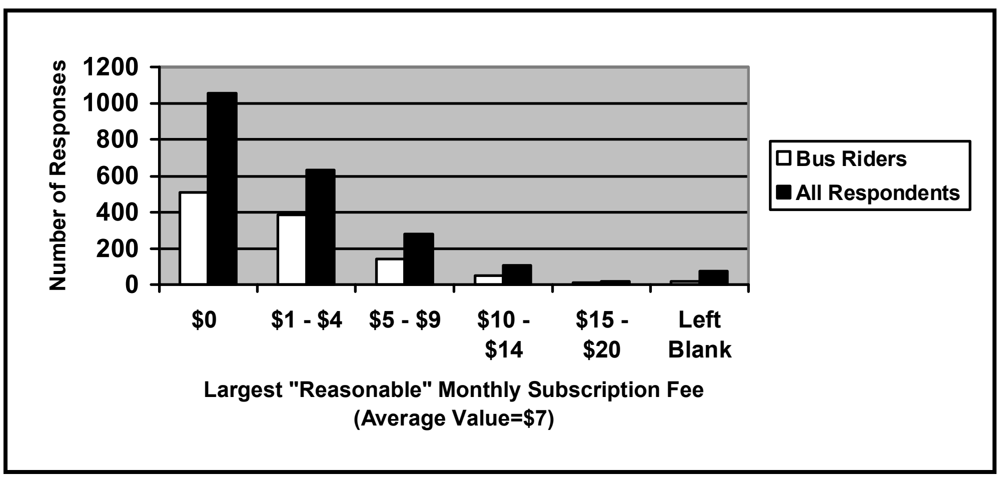

Figure 3.4 Survey Responses on Willingness-to-Pay for Monthly Subscription to AVL Rider Notification Service

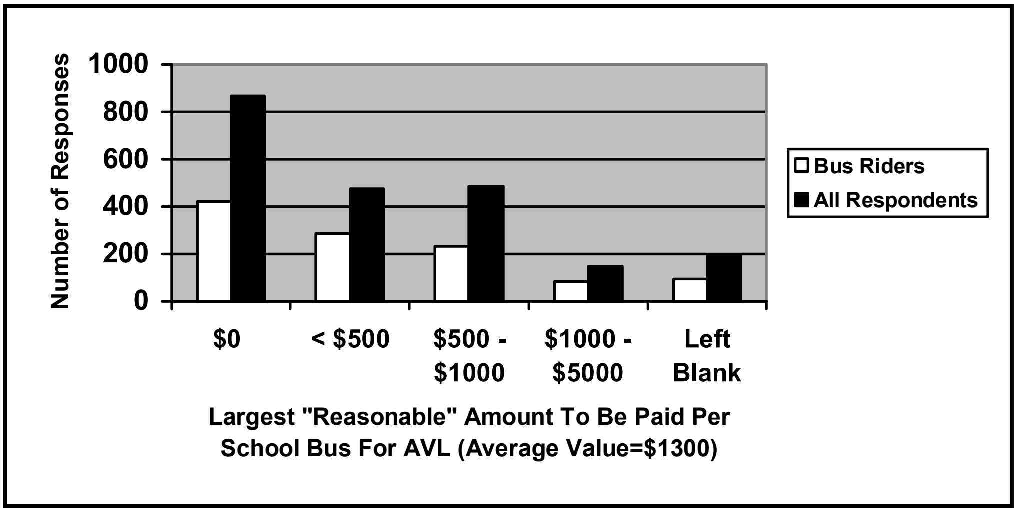

Figure 3.5 Survey Responses on Willingness-to-Pay for AVL School Bus Tracking

Table 3.5 Profile of Student Characteristics by Mode

	School Bus	**Passenger Vehicle**	**Non-Motorized**
Gender	Male	Female	Male
Grade Level	Middle	High	Elementary
District	East Wake	Sanderson	Sanderson

3.5 Spatial Analysis

In order to obtain socioeconomic and home-to-school distance data for inclusion in the school transportation mode choice model, surveyed parents were asked to identify the high school attendance boundary in which they lived. Using GIS software, the 105 Wake County census tracts from 1990 and their associated median household incomes were combined to form the 15 high school attendance boundaries that were used in Wake County at the time of the survey (growth in the Wake County student population since the survey has increased the number of high school attendance boundaries). Census tracts were merged and median income values averaged to obtain average median household incomes for each high school attendance boundary. This value was thought to be an adequate surrogate variable for actual household income of the decision-making parent-student team.

During GIS analysis, review of the survey data showed irreparable inconsistencies in parent's indicated high school attendance boundary. Some parents answered according to the high school attendance boundary in which they lived, as requested, but other parents answered according to the high school their children attended or would attend. So, if a child attended a school other than the school to which they were assigned, which is not uncommon in Wake County, the parent might not have indicated the correct attendance boundary.

In addition to household income, home-to-school distance was needed for school transportation mode choice model development. Using the Transportation Information Management System, maintained by the WCPSS transportation staff, the frequency of students living within specified ranges of school was to be identified for each high school attendance boundary. This would generate a value for the average distance to school that could be used as a surrogate measure in place of the actual student travel distance to school for each child involved in the survey. There was a concern about having such large areas over which to average, but this was thought to be the best strategy, given the inability to identify individual respondents and to obtain their address and the school to which they were assigned. Another irreparable error in the survey was noted at this time. Student data received from WCPSS included the school that each child attended, so while stratification was intended to produce responses from throughout the county according to where each student lived, surveys were mistakenly mailed according to the school to which each student was assigned.

In order to generate a quality data set for school transportation mode choice model development, resurveying was needed. The basis for the second survey was established in the conclusions and identified errors from the preliminary survey.

3.6 Survey Error

In order to confirm the validity of any survey data, an evaluation of common sources of error in surveying is necessary. Two types of error are typically found in a survey: bias, a constant error "that affects [any computed] statistic in all implementations of a survey design," and variable error, which is "measured by the variance of a statistic" caused by differences in values between the survey respondents (Biemer 1991). Sources of both variable error and bias in a survey are generally characterized as sampling or non-sampling. Sampling problems stem from the selection of the sample units or the differences in sample and population parameters. Sampling error should be minimal, barring problems with the sampling frame or random selection methodology. The sample selected should yield values statistically close to population parameters because random sampling gives each component of the population an equal probability of being selected, which should yield accurate averages. The largest component of the total error in a survey is non-sampling bias, which is further classified as observation or non-observation bias. "Biases of observation are caused by obtaining and recording observations incorrectly," while non-observation bias originates "from failure to obtain observations on some segment of the population (Andersen 1979)." Non-observation bias is also known as nonresponse bias. Other non-sampling variable errors may “stem from the respondent, the interviewing process, supervising, coding, editing, and data entry (Andersen 1979).”

Random sampling with stratification was used in the preliminary survey to minimize sampling biases. The survey was mailed to an equal number of parents in each Wake County high school attendance boundary. Non-response bias must be considered since only 25% of the surveys were returned. If sample statistics closely match population parameters, the effects of non-response bias on the data set can be deemed negligible. “Making no adjustment for nonresponse implicitly assumes that nonrespondents do not differ from respondents in any characteristic of interest. The degree to which they do differ is proportional to the amount of bias introduced by ignoring nonrespondents (Andersen 1979).”

The highest levels of nonresponse are expected from parents of high school students and parents who do not use the school bus service. Most high school students choose the automobile for home-based school trips, driving or riding with family or friends. Their parents are less likely to respond to a survey about school bus transportation, as are parents who do not use the school bus service. WCPSS population parameters giving the number of students in each grade level and the percentage of students who ride the school bus were obtained for comparison. Table 3.1 compares survey sample response rates by grade level with WCPSS population by grade level. Table 3.6 compares the survey sample response rates by school bus ridership status with the population parameters. The 95% confidence intervals for the percentage of students in the sample from each grade level (Table 3.1) indicated that the middle school sample accurately reflects the middle school population, but the high school and elementary school samples were over- and under- represented, respectively. This is to be expected, however, and is explained by the over-sampling that occurred in the high school population. In terms of school bus ridership (Table 3.6), the sample and population percentages were found to be significantly different.

Table 3.6 Survey Responses by School Bus Ridership Status

Ridership Status	Survey Sample	WCPSS Population
School Bus Rider	49%	53%
Nonrider	51%	47%

Despite these statistical differences, no adjustments were made to the preliminary survey data because concerns of bias shifted to the new survey data, which would be used in model development. New survey data were analyzed in an attempt to evaluate the effects, if any, of nonresponse bias. Those results are given in Section 4.2.

3.7 Preliminary Survey Summary

Preliminary survey results favor the development of a school transportation mode choice model because the general characteristics of students using the three prominent modes are different in terms of grade, gender, and socioeconomic status, based on the average median household income values calculated for the attendance boundaries.

The availability of driving as a choice for high school students distinguished them from elementary and middle school students. A significant number of high school students drive to school or ride with siblings and friends who drive, causing the high school modal split to heavily favor the automobile. Over 60% of high school students travel to school as drivers or passengers in automobiles during the morning peak period. Therefore, improvements to the school bus service are not likely to attract many new riders from the high school grade level because student drivers and their passengers do not choose their mode of travel based on problems with the school bus service. Instead, student drivers and their passengers are assumed to be better classified as "captive" travelers because of the social implications and freedoms associated with driving. For this reason, *only the travel patterns of non-high school students were evaluated in mode choice model development*.

The available school transportation modes for students differ according to the distance that a given student lives from his/her school. In North Carolina, state law mandates that a school district is not required to provide school bus transportation for students living within 1.5 miles of their school, unless potentially hazardous conditions exists, such as a child having to cross railroad tracks or multi-lane roads to get to school. Students living within the "no transport zone," consisting of the 1.5-mile radius from a school, must therefore choose between the automobile and a non-motorized mode for school travel. Other students have a choice between school bus, automobile, or a non-motorized mode.

While a modal shift from passenger car to non-motorized modes for those living within walking distance of a school would be helpful in decreasing congestion around school campuses, the factors influencing decisions to walk or cycle to school, such as availability of sidewalks and trails, vary greatly by community. The task of creating a single model to estimate the mode split for more than one no-transport zone would be difficult because of the large variability in walking and biking conditions. *The focus of further research was therefore set to non-high school students living outside of the no transport zone, whose basic choices are school bus or automobile*.

4. MODEL DEVELOPMENT AND CALIBRATION

4.1 New Survey Structure

Resurveying was necessary to correct for bias of observation, caused by confusion amongst preliminary survey respondents regarding the high school attendance boundary in which they lived. The new survey also provided an opportunity to collect additional information not included in the preliminary survey, such as perceived home-to-school distance. In order to improve the survey process and the quality and usefulness of data collected, the following processes were changed in the new survey.

1. *Survey questionnaire expanded*- The original survey goals were to: a) collect data on individual student mode choice and the associated student and family characteristics, b) assess the parent's perception of problems associated with the school bus service, and c) determine parental acceptance of and willingness-to-pay for technologies that could improve the school bus service. Goal one was met in that student age, grade, and gender were collected, along with the associated parent's perception of the safest mode for school travel. Other questions that remained unanswered following the original survey included, "Can parents chain other trips with a school trip?" and "Are there sidewalks from the student home to the school?" Additional characteristics of the decision makers were collected, including information on automobile ownership and accommodation of school bus arrival times in household and parent work schedules.

2. *Wake County stratified by zip code*- Confusion about high school attendance boundaries was alleviated by having respondents indicate their zip code. Also, because zip code boundaries are smaller than the high school attendance boundaries, parameters like household income that are averaged for each boundary were more accurate because they involved a smaller number of people. Representative coverage of the county was still achieved with zip code boundaries.

3. *Focus shifted*- Having established that high school students' modal options differ significantly from elementary and middle school students, data were collected for students in grades K-8 only.

4. *Sample size reduced*- The methodology used to determine sample sizes for the original survey was discussed in detail in Section 3.2. Calculations supported sample sizes larger than 385 in order to achieve an expected error of less than 5%. Having experienced a 25% response rate and 1.8 student average per survey initially, the sample size for resurveying was set at 2000 in hopes of obtaining useful data on 500 to 1000 students.

5. *Perceived distances collected*- Instead of using the actual average distance to school for each zip code boundary as a surrogate measure for individual student home-to-school distance, the new survey included a question asking parents to estimate their home-to-school travel distance. The research team

believes that perceived distance would be more influential on mode choice than the actual distance because mode choice is based on the perception of the distance traveled. A problem may arise, however, in future school mode choice analyses that use the developed models since perceived distance data may not be readily available. Average perceived distances need to be computed by zip code for future applications of the model, if distance proves to be significant in forecasting mode choice.

The new sample for the second survey was randomly selected from 32 strata using a random number generator. The WCPSS student population database was stratified by the 32 Wake County zip codes and approximately 65 students were selected from each zip code. This yielded over 2000 students, but once records were adjusted to have no duplicates within a household and no participants from the original survey, 1994 student names remained for mailing. The new survey, shown in Appendix B, was developed, reviewed, and mailed to 1994 parents of elementary and middle school students in the WCPSS. Four surveys were rejected by the postal service as having unrecognized addresses, bringing the final sample size to 1990. A total of 478 surveys were returned with information on 796 students. This corresponds to a response rate of 24% and an average of 1.65 students per survey. The final analysis database was comprised of 679 students, whose parents provided complete survey information. This does not include the students who lived in a no transport zone or outside the area where school bus transportation was available.

4.2 New Survey Error

Nonresponse bias was again a primary concern, as with the preliminary survey, because of the 24% response rate for the new survey. In order to ensure that nonresponse did not have a measurable effect on the data, survey responses were analyzed in groups according to the average median household income for the associated zip code. A Wilcoxon two-sample test was completed for two income categories: income group one, consisting of the 16 Wake County zip code boundaries that have average median household incomes of $36,500 or less, and income group two, corresponding to the zip codes with incomes exceeding $36,500. Table 4.1 shows the data used for this analysis. For the responses in each zip code, the percent of the total sample was calculated, summing to 100% for the entire sample. The same was done for the number of students from the WCPSS population in each zip code. Ideally, the difference for each zip code between the percent of the sample and the percent of the population would be zero. The actual differences range from -3.7 percentage points to +5.4. The Wilcoxon two-sample test yielded statistics indicating a significant difference between the two income groups. The absolute value of the Z score test statistic for the percent differences would have to be less than 1.96, the Z score corresponding to a 95% confidence level, in order to accept the hypothesis that the two groups are identical. Similarly, the computed χ^2 statistic would have to be less than the critical χ^2 value of 3.84, corresponding to a 95% level of confidence. The actual values of $|Z|$ and χ^2 for the Wilcoxon two-sample test are 2.60 and 6.87, respectively. Both the Z-score and χ^2 exceed the critical values, meaning that the composite differences in the two income groups are different. The higher income group is over represented in the survey data by about 18 percentage points.

Table 4.1 New Survey Response Comparison with Overall Student Population

Zip Code	Income Group	# of Survey Responses	% of Sample	# in Student Population	% of Population	% Difference
27610 (Raleigh)	1	33	4.2	5035	7.9	-3.7
27604 (Raleigh)	1	16	2.0	3111	4.9	-2.8
27529 (Garner)	1	11	1.4	2686	4.2	-2.8
27526 (Fuquay Varina)	1	19	2.4	2654	4.2	-1.7
27603 (Raleigh)	1	20	2.6	2369	3.7	-1.1
27616 (Raleigh)	1	22	2.8	2528	4.0	-1.1
27607 (Raleigh)	1	8	1.0	1181	1.8	-0.8
27606 (Raleigh)	1	20	2.6	2155	3.4	-0.8
27591 (Wendell)	1	11	1.4	1332	2.1	-0.7
27597 (Zebulon)	1	1	0.1	491	0.8	-0.6
27601 (Raleigh)	1	8	1.0	838	1.3	-0.3
27545 (Knightdale)	1	29	3.7	2498	3.9	-0.2
27571 (Rolesville)	1	2	0.3	50	0.1	0.2
27605 (Raleigh)	1	3	0.4	87	0.1	0.2
27562 (New Hill)	1	4	0.5	128	0.2	0.3
27540 (Holly Springs)	1	33	4.2	2109	3.3	0.9
27511 (Cary)	2	31	4.0	5629	8.8	-4.8
27615 (Raleigh)	2	23	2.9	3169	5.0	-2.0
27609 (Raleigh)	2	15	1.9	2340	3.7	-1.7
27613 (Raleigh)	2	48	6.1	4181	6.5	-0.4
27592 (Willow Springs)	2	2	0.3	418	0.7	-0.4
27612 (Raleigh)	2	23	2.9	2009	3.1	-0.2
27617 (Raleigh)	2	8	1.0	644	1.0	0.0
27502 (Apex)	2	45	5.8	3222	5.0	0.7
27513 (Cary)	2	60	7.7	4061	6.4	1.3
27539 (Apex)	2	33	4.2	1376	2.2	2.1
27587 (Wake Forest)	2	33	4.2	1314	2.1	2.2
27523 (Apex)	2	32	4.1	843	1.3	2.8
27519 (Cary)	2	51	6.5	2328	3.6	2.9
27608 (Raleigh)	2	34	4.3	711	1.1	3.2
27614 (Raleigh)	2	46	5.9	1111	1.7	4.1
27560 (Morrisville)	2	58	7.4	1294	2.0	5.4

Nonresponse bias has been demonstrated, but bias does not always have a significant effect on data quality. Comparison of other sample and population parameters helped to determine the overall effect on data quality. In the preliminary survey, response by grade level and response by school bus ridership status were compared for the sample and student population. Figure 4.1 shows the percentage of responses by grade for the sample and the population. A t-test was used to verify the hypothesis that the sample and population percentages were equal against the two-sided alternative that they were different. No significant difference was found based on the computed t-statistics. The proportion of survey responses in each grade is therefore statistically equivalent to the proportion of the student population for that grade.

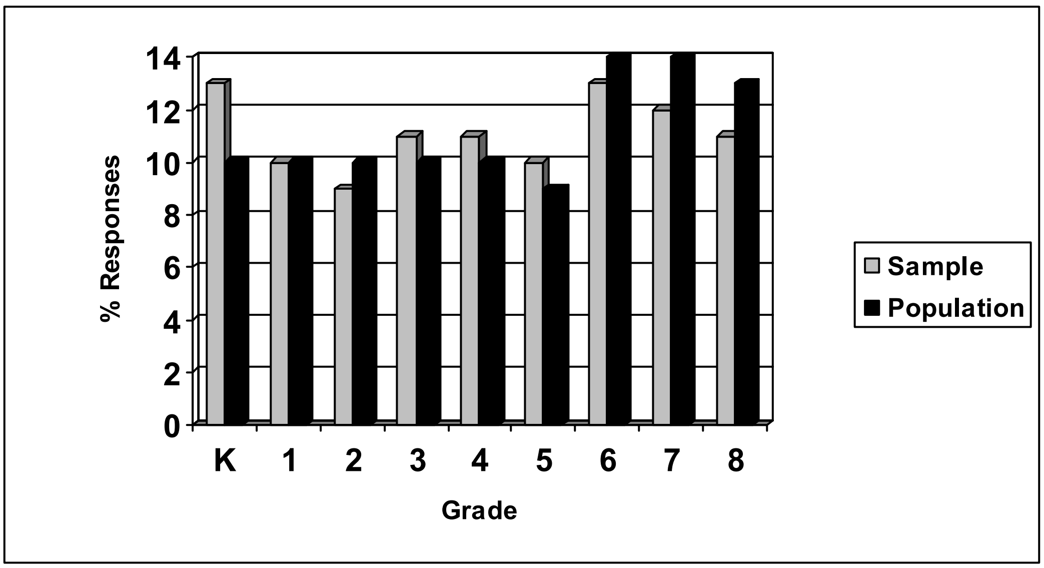

Figure 4.1 New Survey Responses by Student Grade Level

The survey sample yields AM and PM school bus mode shares of 53% and 66% respectively. WCPSS reports an average daily school bus ridership of 53% for the student population. There is a statistically significant difference between the PM reported bus ridership for the sample and the population. The computed t statistic exceeded 7.0 and the critical t value for 95% confidence is 1.96.

School bus ridership is thought to be highest among low-income groups, where access to automobiles, flexibility in work hours, and stay-at-home parents are less likely.

Yet, the data over-represent students from high-income families and school bus riders. This inconsistency suggests that the data quality may not be compromised by the difference in responses between high- and low-income groups.

The breakpoint used to differentiate high and low income groups is also a cause for the seeming nonresponse bias favoring high-income students. A value of $36,500 was selected as the breakpoint so that the high and low-income groups would have an equal number of zip codes boundaries for the Wilcoxon test. Selecting $36,500 as the breakpoint allowed the high- and low-income categories to each include 16 zip code boundaries. In Wake County, the median household income exceeds $50,000 so any breakpoint lower than this would likely prompt an overrepresentation of the higher income grouping.

In summary, the sample contains responses by grade that are similar to population percentages and does not underestimate school bus ridership as expected by a data set favoring high income families. For these reasons, no adjustments were made to the survey data prior to analysis for model development.

4.3 New Survey Analysis

There are three groups of students within the broad heading of school transportation. Figure 4.2 depicts these groups and the modal choices available to them. The definition of a "no transport zone," given in Section 3.7, varies by school district, according to the occurrence of hazardous conditions. Within any no transport zone, three modal alternatives are available – walk, bike, or automobile. The parameters specified in this research aggregate the alternatives to two – automobile or nonmotorized. Public transit and van services were not included because of small sample sizes in the survey data. The base attendance area for a school, beyond the no transport zone, is that boundary where school bus service is provided and the available modes are school bus and automobile. Nonmotorized modes are not feasible within the base attendance area, outside the no transport zone because of lengthy home-to-school distances. Finally, there are students living outside the base attendance area for the school they attend who are "automobile captive" because school bus service is not provided and distances make nonmotorized modes infeasible.

Figure 4.2 Student Transportation Zones

About 7% of students in the new survey live in a "no transport zone." The actual number of students from this sample who live in a no transport zone may be much larger. Some parents may not be knowledgeable of the law concerning school bus transportation not being provided to students living within a 1.5 mile radius of their school (barring certain hazardous conditions) and would therefore not indicate that they live "within walking distance," as defined by North Carolina state law. Another 1% of the students in the new survey sample use nonmotorized modes and were considered as living within the no transport zone, as were another 4% who use the automobile for school trips and listed perceived distances to school of 1.5 miles or less. So, the actual number of students in the no transport zone is expected to be between 7 and 12%.

School districts with "school choice" policies will likely have students outside the base attendance area. In Wake County, "students who are assigned outside their geographical area because of their request for a transfer (not magnet school) are not guaranteed transportation (WCPSS 2003)." About 1.5% of the students in the new survey are classified in this third group.

Of the students living inside the base attendance area for their respective schools, who were the focus of this research, some also live inside the no-transport zone and base their choice of school transport mode on local factors that influence walking and biking. The three fundamental factors upon which mode choice is usually based are cost, time, and convenience, where cost is negligible because of the relatively short distances. Time and convenience are the primary variables that differentiate between the available modes. Convenience in nonmotorized mode choice models should include a pedestrian environment variable, which takes into account factors like sidewalk availability, ease of street crossing, street connectivity, availability of bicycle infrastructure, building setbacks, and terrain (Rossi 2000). Components such as these are highly dependent upon the specific community or school being analyzed. The task of nonmotorized modeling for a model that will apply to an entire county or school district can be extremely difficult, so nonmotorized modes were not included in the model development analyses.

"Captive" travelers within the base attendance area were then identified. Captive is used to describe an involuntary state of being "because of a situation that makes free choice or departure difficult (Webster 1983)." The captive students within the base attendance area for the new survey are those who:

- must ride the school bus because their family does not own or have regular access to an automobile;
- must ride the school bus because parent work schedules prevent automobile pick-up;
- have before and/ or after school activities that prevent riding the school bus; or
- are involved in before and/or after school care programs which provide van transportation to and from the school.

Less than 2% of the students in the base attendance area use daycare program vans for morning or afternoon school trips. This small group of students was excluded from model development because of insufficient sample sizes and also because a modal shift is not likely since their household schedule requires alternate transportation. The other "captive" groups of students were included in model development with their limiting characteristics accounted for in model variables.

Analysis of the new survey data for the entire sample yielded the mode choice results displayed in Figures 4.3 and 4.4 for the morning and afternoon periods, respectively. Two basic conclusions can be made from these data.

1. *There is potential for modal shift from the automobile to nonmotorized modes of school transportation within the no-transport zone.* While 7 to 12% of parents perceive their distance from school to be 1.5 miles or less, only 3 to 4% of students walk or cycle on school trips. Therefore, those students who live inside the no-transport zone but currently ride in an automobile for school trips could shift to a nonmotorized mode of school transportation.
2. *The basic issue is one of school bus versus automobile.* As expected, no other school transportation mode is nearly as significant as the automobile and school bus, which together account for 96 and 94% of all AM and PM school trips, respectively.

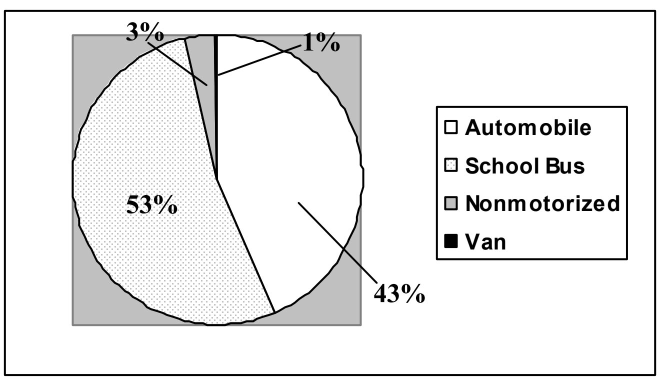

Figure 4.3 New Survey K-8 AM Modal Split

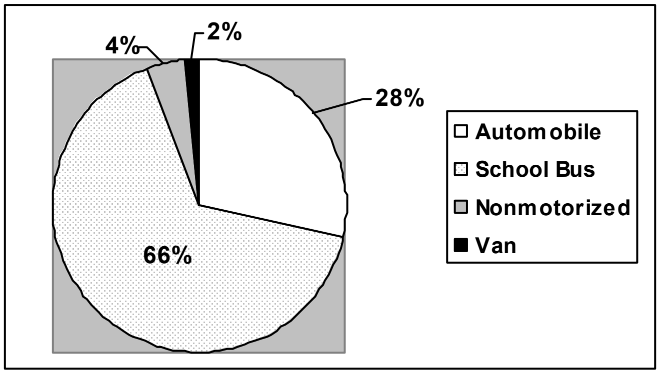

Figure 4.4 New Survey K-8 PM Modal Split

4.4 New Survey Summary and Variable Definition

The remaining analyses involve only those students having a choice between school bus and automobile for school transportation. The 679-student data set consists of the traveler and trip characteristics listed in Table 4.2. These characteristics are the variables that were used in the school transportation mode choice model development process. As aforementioned, local factors are critical in modeling nonmotorized travel, so pedestrian and bicycle modes were not considered in this county-wide modeling effort.

School travel mode is a binary variable such that 0 represents the school bus and 1 represents the automobile. The Safe Mode variable uses the following conversion from character to numeric variables: 0 = school bus, 1 = nonmotorized, 2 = motorized, and 3 = automobile. "Nonmotorized" characterizes the pedestrian and bicycle modes and "motorized" is the term assigned to those parents who believe that the school bus and automobile "tie" for most safe, outranking walking or biking.

Table 4.2 School Transportation Mode Choice Variables

Trip Characteristics:	**Household and Traveler Characteristics:**
"AM Mode"- mode used by the student for travel to school in the morning	**"K8HH"**- total number of children grades K-8 in the household
"PM Mode"- mode used by the student for travel from school in the afternoon	**"Grade"**- the student's grade for the 2002-03 school year; integer ranging from 0, for Kindergarten, to 8
"Distance"- student's home-to-school travel distance as perceived by the parent	**"Gender"**- male or female
"School"- school attended, regardless of school assigned	**"Income"**- average median household income (in $10,000) for the zip code in which the student's family lives
	"Safe Mode"- school transport mode that the parent perceives to be most safe
	"AU Convenience"- +5 to -3 value describing automobile convenience for a household based on student schedules, automobile ownership, & ability to chain trips and carpool (see Table 4.3)
	"SB Convenience"- +4 to -5 value describing parent work schedules, safety concerns, and other problems and technologies that promote or constrain school bus usage (see Table 4.4)

The school bus and automobile convenience ratings are determined by assigning point values to survey answers about automobile and school bus usage. Table 4.3 shows the conditions under which point values are assigned for the factors impacting automobile convenience. The before and after school activities considered are those that limit riding the school bus because the starting or ending times require automobile transport. The automobile convenience rating ranges from +5 to -3.

Table 4.3 Automobile Convenience Factor Definition

AU Convenience Factors	**+1**	**-1**
Automobile Ownership	✓ if yes	✓if no
Carpool Opportunity	✓ if yes	✓if no
Trip Chaining Opportunity	✓ if yes	✓if no
Before School Activities	✓ if AU transport required	
After School Activities	✓ if AU transport required	

Point values used to calculate the school bus convenience ratings are described in Table 4.4. These factors attempt to quantify household attributes and parental concerns that are compelling enough to deter utilization of the school bus service. School bus operation concerns include complaints about excessive bus operating speeds and the lack of seatbelts on school buses. The AVL paging and bus tracking factors allow for future analysis of technological improvements to the school bus service. A positive value is added to the school bus convenience of a student if that student's household subscribes to an AVL bus arrival notification service. Similarly, a positive value is added to school bus convenience if AVL bus tracking is in operation on a student's bus route. The actual magnitude of the positive values added to school bus convenience to reflect the addition of AVL technologies is assessed in Section 6.3. For variable definition purposes, the value is assumed to be one for each function – paging and tracking – making the expected range of the school bus convenience variable +4 to -5.

Table 4.4 School Bus Convenience Factor Definition

SB Convenience Factors	+1	-1
AM Scheduled Arrival Time	✓ if parent work schedules require SB	✓if time does not fit family schedule
PM Scheduled Arrival Time	✓ if parent work schedules require SB	✓if time does not fit family schedule
Punctuality Problems		✓ if yes
Bus Stop Concerns		✓ if yes
Student Behavior or Bus Operation Concerns		✓ if yes
AVL Paging/ Notification Service	✓ if a subscriber	
AVL Bus Tracking	✓ if in operation	

In a statistical analysis prior to model development, each of the convenience term components was analyzed separately to determine the individual impacts on mode choice. Linear regression results indicated that each of the school bus convenience components was statistically significant to a 95% level of confidence in estimating AM Mode and PM Mode. The significance of automobile convenience components differed according to the time period. In estimating AM Mode, the values expressing feasibility of carpooling did not display significance, while all other factors did. In estimating PM Mode, only feasibility of carpooling and before and after school activities exhibited significance. A correlation analysis of the automobile convenience factors indicated that automobile ownership, feasibility of carpooling, feasibility of trip chaining, and before and after school activities are all highly correlated with the AUConv variable. Therefore, no factors were removed from the convenience term definitions used in model development.

4.5 Model Development

A linear combination of variables, reflecting household and trip characteristics, student schedules, and parent attitudes and behaviors, is used to forecast the travel modes a student uses for morning and afternoon school trips. This function is expressed as either a utility function in a nonlinear probability model or as the direct modal share estimator in a binary linear probability model. Typical transportation mode utility models include independent variables that capture the cost, travel time, and convenience of modal alternatives. For the school transportation case, travel time, which is inversely proportional to distance, average household income, and convenience are expected to be significant.

4.5.1 Determining Predictor Variables

The initial model development task is to determine which data collected in the survey and GIS analysis are important in estimating school transportation modal share. Data were examined using simple linear regression to determine important variable relationships and the significance of each factor in forecasting mode choice. The household and traveler variables listed in Table 4.2 were analyzed to determine their ability to estimate individual student mode choice for the morning and afternoon school trips.

Regression results indicated that those variables which conventionally appear to impact commuter mode choice are not all significant contributors to school transportation mode choice. For example, perceived home-to-school distance is not a significant predictor of AM or PM mode choice. Considering only those variables that are significant to a 95% confidence level, those found to significantly impact AM mode choice are Safe Mode, SB Convenience, and AU Convenience. At an 85% confidence level, student grade is added to the list of significant AM mode choice predictors. For the PM case, six variables are significant at a 95% confidence level – K8HH, Grade, Income, Safe Mode, SB Convenience, and AU Convenience.

The importance of the school bus and automobile convenience variables was expected because parents are assumed to base mode choice decisions for their children on a maximization of utility for their respective household characteristics and preferences. Distance was expected to be significant, but was not. Data on travel times were also collected from the surveyed parents, but distance proved to be the more reliable estimate from parents. Perceived home-to-school distances from 0.2 to 30 miles were reported, not including students indicated as living outside the base attendance area for their school. Data for over 7% of students in the sample correspond to perceived distances of 15 miles or greater. This is likely due to the increasing popularity of magnet and year round school programs that require longer travel distances, but distorted perceptions could also contribute to having home-to-school distances of greater than 15 miles. Still, parents who perceive the distance between their home and their child's school to be lengthy would likely have their children use the school bus service because trip chaining and carpooling options are less convenient, especially in the afternoon. Likewise, families living closer to school might be more likely to use the automobile because of the associated convenience. Table 4.5 shows the percentage of students using each mode in three distance ranges. In the morning, there is no statistically significant difference between automobile and school bus mode shares across the three distance ranges. The differences are significant, however, in the afternoon. For this reason, distance was added to the list of variables used in regression analysis to evaluate PM mode choice.

Table 4.5 Mode Choice by Perceived Home-to-School Distance

		AM Mode		**PM Mode**	
Perceived Distance	**Sample Size**	**School Bus**	**Automobile**	**School Bus**	**Automobile**
0 – 1.5 miles	88	57%	43%	65%	35%
1.5 – 5 miles	298	58%	42%	72%	28%
> 5 miles	225	56%	44%	76%	24%
Total	***611***	***57%***	***43%***	***72%***	***28%***

Gender was another variable not found to be significant in predicting mode choice for both the AM and PM cases. In Table 4.6, a detailed analysis of the data set, grouped by gender, shows that there are differences between male and female modal choices, but the magnitudes of these differences are small. Parental security concerns, for example, might be greater for girls than boys, leading to different modal decisions. Such concerns are captured in the school bus and automobile convenience variables. The data confirm that parents of males have less of a problem with the school bus service. Similarly, automobile convenience is higher for females. T-tests on these differences, however, show that only distance is statistically different between males and females at a 95% level of confidence, though the distance values differ by less than one mile. Neither AM nor PM modes differ significantly according to gender.

Table 4.6 Mode Choice Variable Means by Gender

Variable	Mean- Female	Mean- Male	Significant?
N	302	309	---
AM Mode	0.46	0.39	No
PM Mode	0.30	0.25	No
K8HH	1.91	1.94	No
Grade	3.95	4.17	No
Distance (miles)	6.21	5.33	Yes
Safe Mode	2.22	2.23	No
Income	$41,913	$41,951	No
SB Convenience	-0.37	-0.25	No
AU Convenience	1.58	1.36	No

The predictor variables included in the subsequent statistical analyses are: K8HH, Grade, Income, SafeMode, SBConv, and AUConv. Although the K8HH and Income variables did not exhibit significance in the AM case, they were included in the AM analysis since the data were needed for the PM model. Distance was also included for the PM analysis because of the distance analysis results in Table 4.5.

4.5.2 Linear Regression Analyses

The previous analysis indicated that the variables found to significantly influence mode choice were different for the morning and afternoon cases, so two separate models were developed. This section details the regression analyses of those variables found to be significant predictors of morning and afternoon school transportation mode choice.

Using "0" to represent the school bus and "1" to represent the automobile, binary linear regression was used to begin model development. The resulting models therefore forecast the probability of a student using the automobile for school trips. Each variable was analyzed using general linear model regression techniques in order to document the individual contribution of each variable to the model.

Binary linear regression results confirmed the significance of Grade, Safe Mode, SBConv, and AUConv as predictors of AM mode choice with 90% confidence. K8HH and Income were also significant at 85% and 80% confidence, respectively. K8HH, Grade, Income, Safe Mode, SBConv, and AUConv were each significant in estimating PM mode choice at 95% confidence. Distance did not display significance as an afternoon mode choice predictor. The negligible role of distance suggests that overall, students may be more actively involved in the school transportation mode decision-making process than parents. The primary six variables, excluding distance, were all significant contributors to the model sum of squares for both the AM and PM models at a 95% level of confidence, except for income in the afternoon model. In the morning, SBConv contributes most, followed by Safe Mode, AUConv, K8HH, Income, and Grade. SBConv is the primary contributor in the afternoon as well and the remaining variables in order of decreasing significance are: Student Grade, Safe Mode, K8HH, AUConv, and Income.

Forward and backward stepwise linear regression techniques were then applied to the morning and afternoon cases to further confirm which variables should be included in the models. In attempt to achieve the best possible fit, quadratic and interaction terms were included. The following variables were considered: K8HH, $K8HH^2$, Grade, $Grade^2$, Income, $Income^2$, K8HH-Grade interaction, K8HH-Distance interaction, K8HH-Income interaction, Distance-Income interaction, SafeMode, SafeMode-Grade interaction, SafeMode-Distance interaction, SafeMode-Income interaction, SBConv, and AUConv.

Backward stepwise regression results confirmed the significance of the Grade, SafeMode, SBConv, and AUConv variables for the morning mode choice model. The K8HH-Grade, K8HH-Distance, and Distance-Income interactions were also included in the model with 90% confidence. Forward stepwise regression results differed slightly. Instead of adding the SafeMode variable to the model, forward stepwise regression suggested including the SafeMode-Income interaction. Distance had previously been invalidated as a significant predictor variable for AM mode choice, but further analysis was necessary to determine which linear probability model of AM mode choice would be most optimal.

Backward stepwise linear regression results for the PM case confirmed the significance of the K8HH, Income, SBConv, and AUConv variables. The quadratic term, $K8HH^2$, and the interactions SafeMode-Grade and SafeMode-Income were also included in the model with a 90% confidence. The forward stepwise regression model did not include K8HH or Income as a predictor variable, but did include the K8HH-Income interaction. Stepwise regression results confirmed the importance of the original five explanatory variables considered for inclusion in the PM mode choice model; the form each variable was to take, however, whether an interaction or quadratic term was needed, remained to be determined.

Income appears to be a significant explanatory variable for school transportation mode choice, but further analysis challenged this result. Each student in the data set was assigned an average median household income value based on the postal zip code in which he/she lived. There were 34 unique zip codes and associated incomes represented in the data. The test for survey nonresponse bias in Section 4.2 used two groupings- high and low income- corresponding to greater than and less than $36,500. This test showed that the survey data favored "high income" students, considering that the breakpoint differentiating low and high income was lower than the average median household income in Wake County. In order to verify the significance of income as an explanatory variable in school transportation mode choice, morning and afternoon modal splits were calculated using the same high and low income categories. In the morning, approximately 37% of "low income" students and 45% of "high income" students ride to school in an automobile. In the afternoon, 27% and 28% of low- and high-income students, respectively, ride in an automobile. Neither of these differences is statistically significant at a 95% confidence. This directly contradicts the regression analysis results that income is a significant factor in forecasting school transportation mode choice.

One explanation for this inconsistency may be the correlation between income and the convenience ratings. If the convenience variables are highly correlated with income, the effects of income may be explained by the convenience terms, which are significant predictors of school transportation mode choice. Table 4.7 gives the correlation coefficients for the income, school bus convenience, and automobile convenience. The correlations are statistically significant, but are not substantial.

Figure 4.5 plots the relationship between the probability of riding in an automobile for school trips, calculated using the five-variable simple linear model, and income. The breakpoint used for high and low income, $36,500, is noted. There is no distinct pattern in AM or PM mode choice between the low- and high-income groups. No significant effects of income are indicated, so income may not be warranted for inclusion as an explanatory variable in forecasting morning or afternoon mode choice. Tables 4.8 and 4.9 were used to select an appropriate linear probability model in terms of R^2 values, C(p) values, and explanatory variables. The tables compare the AM and PM linear probability models that resulted from simple linear regression with and without income as a predictor variable, backward stepwise regression, and forward stepwise regression.

Table 4.7 Income and Convenience Correlations*

	Income	SBConv	AUConv
Income	1.00	0.13	0.18
SBConv	0.13	1.00	0.30
AUConv	0.18	0.30	1.00

*Absolute values of Pearson correlation coefficients

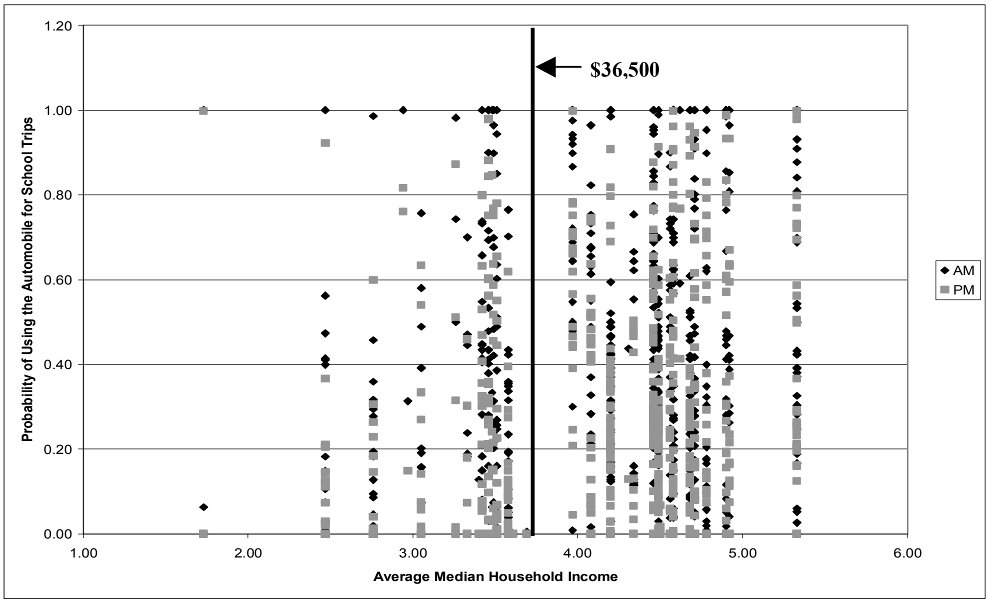

Figure 4.5 Automobile Probabilities for School Trips versus Income

Table 4.8 AM Mode Choice Model Options

Model	Explanatory Variables	p	C(p)	R^2
Simple Linear Regression	K8HH, Grade, Income, SafeMode, SBConv, AUConv	6	6.928	0.510
Simple Linear Regression (no Income)	K8HH, Grade, SafeMode, SBConv, AUConv	5	6.716	0.508
Backward Stepwise Regression	K8HH-Grade, Grade, SafeMode, AMSBConv, AMAUConv	5	3.870	0.517
Forward Stepwise Regression	$K8HH^2$, SafeMode, AMSBConv, AMAUConv	4	4.586	0.516

Table 4.9 PM Mode Choice Model Options

Model	Explanatory Variables	p	C(p)	R^2
Simple Linear Regression	K8HH, Grade, Income, SafeMode, SBConv, AUConv	6	6.177	0.443
Simple Linear Regression (no Income)	K8HH, Grade, SafeMode, SBConv, AUConv	5	12.939	0.435
Backward Stepwise Regression	K8HH, $K8HH^2$, Income, SafeMode-Income, SafeMode-Grade, SBConv, AUConv	6	2.779	0.449
Forward Stepwise Regression	K8HH-Income, $K8HH^2$, SafeMode-Income, SafeMode-Grade, SBConv, AUConv	6	3.110	0.447

One goal of model development is to calibrate the simplest model that achieves the best possible fit with the data. The multiple coefficient of determination, R^2, and error ratio estimator, C(p), are common selection techniques used to measure “goodness of fit.” The R^2 value is used to find subset models such that adding more variables to the model yields only small increases in the R^2 (Mendenhall 1996). The C(p) criterion is an estimate of the ratio of total mean square error in a reduced regression model to the full model variance. The preferred model subset is the one with the smallest C(p) value less than p+1, where p is the number of predictor variables (Mendenhall 1996).

The model options in Tables 4.8 and 4.9 that include income as a predictor variable are the “benchmarks” with which other model options are compared. Household income is often considered personal information that is not readily provided. Accurate income data would be difficult for a school or school district to collect. Therefore, the selected linear probability model should not include income, but the fit of the selected model can be compared with the best possible model, which may include income.

In the AM case, the simple linear regression model that does not include income meets the simplicity goal because no quadratic or interaction terms are included, making the model easier to interpret. The calculated C(p) value is higher for the simple linear regression model, but the associated R^2 has a negligible difference from the highest possible R^2 values in the stepwise regression models. The simple linear model without income is preferred for its simplicity and R^2.

Of the PM model options, only one does not include income as a predictor variable. The C(p) value for this model is the highest of all options, but this 5-variable model is the only model for which accurate input data can be obtained. There is also benefit in having

AM and PM models of similar form for simplicity in applying the models. Equations 4.1 and 4.2 are therefore the recommended AM and PM linear probability models. Table 4.10 gives the standard errors of the linear model parameter estimates. The linear models are compared with logistic regression results in Section 4.5.4.

$$P(AU)_{AM} = 0.226 - 0.033K8HH + 0.011Grade + 0.030SafeMode - 0.243SBConv + 0.054AUConv$$

(R^2=0.51, σ^2=0.1214, N=611)

Linear Probability Model of Using the Automobile for AM School Trips Equation 4.1

$$P(AU)_{PM} = 0.281 - 0.051K8HH - 0.019Grade + 0.027SafeMode - 0.196SBConv + 0.033AUConv$$

(R^2=0.44, σ^2=0.1138, N=611)

Linear Probability Model of Using the Automobile for PM School Trips Equation 4.2

Table 4.10 Linear School Transportation Mode Choice Models' Standard Errors

Parameter	AM Standard Error	PM Standard Error
Intercept	0.0586	0.0568
K8HH	0.0202	0.0195
Grade	0.0054	0.0052
SafeMode	0.0119	0.0115
SBConv	0.0122	0.0118
AUConv	0.0088	0.0085

4.5.3 Logistic Regression Analysis

Chapter 2 discussed in detail the traditional mode choice analysis methodology of determining a mode's utility and using the logit model (based on logistic regression) to forecast the modal share. Logistic regression for the binary dependent variable, school transportation mode choice, concerns the choice of school bus (event 0) or automobile (event 1) for school trips. Equation 4.3 expresses the general logit model form, given in Equation 2.2, applied to a binary dependent variable, where the utility of each mode, U_i, is given by the linear combination, $\beta_0 + \beta_1 x_{1_i} + \beta_2 x_{2_i} + ... + \beta_k x_{k_i}$.

$$P(i) = \frac{\exp(U_i)}{1 + \exp(U_i)} \qquad \textbf{Equation 4.3}$$

For a multinomial model, there are more than two modal options and the denominator of Equation 4.3 is changed to become $\sum_x \exp(U_i)_x$. The relationship between the multinomial logistic model and the binary logistic model can be seen in the calculations in Figure 4.6. This indicates that *the linear combinations expressing utility in the binomial case presented in Equation 4.3 represent the difference in utility between the two modal options*.

Multiplying the expressions written using the multinomial form by one yields:

$$P(event0) = \frac{\exp(U_0)}{\exp(U_0) + \exp(U_1)} \div \frac{\exp(U_0)}{\exp(U_0)} = \frac{1}{1 + \exp(U_1 - U_0)}$$

and

$$P(event1) = \frac{\exp(U_1)}{\exp(U_0) + \exp(U_1)} \div \frac{\exp(U_0)}{\exp(U_0)} = \frac{\exp(U_1 - U_0)}{1 + \exp(U_1 - U_0)}$$

Figure 4.6 Logistic Model Calculations

When applied to the school transportation models, the differences between the utility of the automobile (AU) and the utility of the school bus (SB) in the morning and afternoon can be determined using logistic regression. The survey used to collect data for model development did not assess a specific value for the "utility" that parents derive from their children's mode of school transport. "Utility" is a fairly abstract term that would likely have required more explanation than is possible in a mail-out-mail-back survey to obtain quality data. Without a numerical assessment of utility for each student in the model development data set, only the differences in utility ($U_{AU} - U_{SB}$) can be computed, using the explanatory variables from the school transportation models. The differences in utility for the morning and afternoon cases are given in Equations 4.4 and 4.5. Standard errors for these model parameters are given in Table 4.11.

$$U_{AU} - U_{SB} = -1.981 - 0.286K8HH + 0.124Grade + 0.235SafeMode - 2.106SBConv + 0.401AUConv$$

(AIC-Intercept and Covariates=342.2, N=611)

AM Difference in Utility between the Automobile and the School Bus Equation 4.4

$$U_{AU} - U_{SB} = -1.774 - 0.423K8HH - 0.158Grade + 0.277SafeMode - 1.292SBConv + 0.390AUConv$$

(AIC-Intercept and Covariates=428.0, N=611)

PM Difference in Utility between the Automobile and the School Bus Equation 4.5

Applying the above calculations to the school transportation case results in the following logistic regression equations to estimate the probability of using the automobile for morning and afternoon school trips.

$$P(AU)_{AM} = \frac{1}{1 + \exp(1.981 + 0.286K8HH - 0.124Grade - 0.235SafeMode + 2.106SBConv - 0.401AUConv)}$$

Logistic Probability Model of Using the Automobile for AM School Trips Equation 4.6

$$P(AU)_{PM} = \frac{1}{1 + \exp(1.774 + 0.423K8HH + 0.158Grade - 0.277SafeMode + 1.292SBConv - 0.390AUConv)}$$

Logistic Probability Model of Using the Automobile for PM School Trips Equation 4.7

Table 4.11 Logistic School Transportation Mode Choice Models' Standard Errors

Parameter	AM Standard Error	PM Standard Error
Intercept	0.5331	0.5611
K8HH	0.1777	0.1858
Grade	0.0483	0.0476
SafeMode	0.1057	0.1246
SBConv	0.1956	0.1190
AUConv	0.0818	0.0894

4.5.4 The School Transportation Mode Choice Models

Linear and logistic regression was used to develop probability models estimating the likelihood that a student will use the automobile for morning and afternoon school trips. The models were evaluated by considering the question, "do they work," in order to determine which form (linear or logistic) the final probability model would take. The final AM and PM models selected were then assessed on the basis of two additional criteria: 1) Are the models reasonable? and 2) Are they practical?

Do They Work?

The brier score (BS), a commonly used measure of the accuracy of probabilistic forecasts (ECMWF 2003), is calculated using Equation 4.8 where "o" is a binary observation equal to zero or one and "p" is the forecasted probability. Equation 4.9 shows the formula for computing the brier skill score (BSS), which compares a brier score to the brier score of a reference probability value (BS_{ref}). The brier scores and brier skill scores for the school transportation automobile probabilities calculated using the linear and logistic probability models are given in Table 4.12. These results indicate that both the linear and logistic models work. Although the logistic model forecasts result in slightly higher scores, the *linear models were preferred and chosen as the final school transportation mode choice models,* considering the increased simplicity of the linear models in terms of interpretation. The linear models are given in Equations 4.1 and 4.2. Validation of the linear models is detailed in Chapter 5.

$$BS = \sum (o - p)^2 \qquad \textbf{Equation 4.8}$$

$$BSS = (BS_{ref} - BS) / BS_{ref} \qquad \textbf{Equation 4.9}$$

Table 4.12 Brier Scores for School Transportation Mode Choice Model Alternatives

Student #	BS_{AM}	BS_{AM}	BSS_{AM}	BSS_{PM}
Linear	71.06	67.47	0.52	0.45
Logistic	63.50	64.13	0.57	0.47
Average	149.37*	121.82*	---	---

* denotes BS_{ref}

Are They Reasonable?

In order to facilitate a basic understanding of the linear school transportation mode choice models and determine their reasonableness, three aspects of the models were evaluated. First, model outputs were examined to ensure that the closer an automobile probability was to 0, the more likely that student was to ride the school bus, in terms of convenience factors and actual choice of mode. Using a linear probability model mandates maximum and minimum values of 1.0 and 0.0, respectively, according to the basic premise of probability. Any student whose characteristics resulted in a model-predicted probability that was negative or exceeded 1.0 was assigned the minimum or maximum value, as appropriate. Second, the model constants were evaluated. The constants appear to be reasonable, considering the average AM and PM automobile probabilities from the data, which are 0.43 and 0.28, respectively. The model constants are approximately 0.23 and 0.28, for the morning and afternoon cases, allowing for the additive and negative effects of the model variables. Base AM and PM automobile probabilities were established for those cases where student input data is not available in future applications of the models. The models cannot be assumed to indicate that a student for whom there is no model input data is 23% likely to ride in an automobile in the morning and 28% likely in the afternoon, in accordance with the model constants, because "0" values have meaning for the Safe Mode, SBConv, and AUConv variables. Instead, every student is assumed to have a 50/50 chance, or a probability of 0.5, in Equations 4.1 and 4.2, if there are no known input data to use in the model. Finally, the signs and magnitudes of the linear model coefficients were examined in order to determine if the linear school transportation mode choice models were reasonable.

The K8HH variable has a negative coefficient in both the morning and afternoon models. This is reasonable because the more children there are in a household, the more likely the children are to ride the bus, or have an automobile probability of zero. So, the negative coefficient was expected intuitively for a model forecasting the probability of riding in an automobile. The magnitudes of the K8HH coefficients are sensible in that for every additional child in the household, the student is 3% less likely to ride in an automobile in the morning and about 5% less likely to ride in an automobile in the afternoon.

Student grade has an opposite impact on the morning and afternoon models. In the AM model, grade has a positive coefficient meaning that older students are more likely to ride in an automobile. The reverse is true of the PM model, where grade has a negative coefficient. A plausible explanation for this trend is that households with more than two children are comprised primarily of elementary school children. Of the 120 students in the database from households with three or more K-8th grade children, only 24% are in the middle school grade level. So, as school bus ridership potential increases with increasing K8HH values, it may increase correspondingly with decreasing student grade. In the afternoon, parents who work outside the home are more likely to allow an older child to ride the school bus and remain at home alone than a younger child. Student grade would, therefore, have a negative coefficient in the afternoon such that the automobile probabilities of students in higher grades are pushed closer to zero.

The positive coefficient on the Safe Mode variable means that if a parent believes the automobile is the safest of all school transportation modes, his/her child will be more likely to ride in an automobile to school. The largest value for "SafeMode" is "3," representing the automobile. If a parent perceives the school bus to be safest, no amount is added to the automobile probability because the school bus is represented by a "SafeMode" value of "0."

School bus service convenience contributes more than any other variable to forecasting student mode choice; this is supported by the fact that the SBConv coefficient is the largest. School bus convenience coefficients are also negative, so a greater problem with the school bus service would increase the probability of riding in an automobile. Similarly, the automobile convenience terms have positive coefficients, meaning higher convenience ratings increase the probability of riding in an automobile.

Figure 4.7 displays the automobile probabilities estimated for each student by the AM and PM models plotted against the continuous, independent variable, perceived distance. If the forecasted probabilities clustered around the AM and PM average automobile probabilities, model development would not have been necessary because the predictions would be no better than assuming that the average automobile probability for the respective peak periods applied to all students. This plot shows that probabilities do not cluster around the averages, but display enough variability to justify modeling, though also suggesting large model variances because of the wide ranges of data.

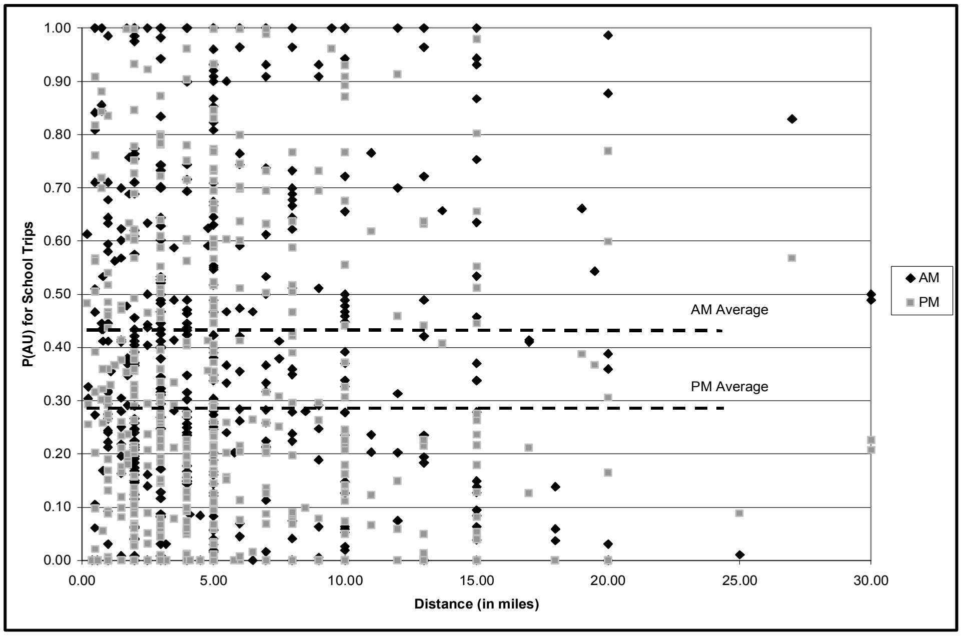

Figure 4.7 Model-Forecasted AM and PM Automobile Probabilities

Are They Practical?

One test of the models' practicality is whether or not the models can be used to explain past trends in school transportation mode choice. For example, a practical model could account for the shifts in mode that have occurred as the number of children per household has decreased and the number of mothers working outside the home has increased over the past ten to fifteen years. As the number of children in a household (K8HH) decreases, the model begins to favor the automobile, which is being used increasingly for school trips. Fewer households have a stay-at-home parent, leading to an increase in automobile ownership and trip chaining opportunities, which increase the automobile convenience factor, thus favoring use of the automobile. Neighborhood schools are decreasing in popularity because of the rise in magnet and year-round school programs. This trend causes increased home-to-school distances, but distance was not found to significantly impact school transportation mode choice. School buses, however, have to travel farther as attendance boundaries increase to make non-traditional programs like magnet schools available to the entire student population. The early school bus arrival times at homes and bus stops in the morning decrease the convenience of the school bus, ultimately favoring the automobile for school trips. Likewise, the late drop-off times in the afternoon, or sometimes evening, decrease school bus convenience and favor usage of the automobile. The question of model practicality is considered more in Chapter 6 where model application is discussed.

4.6 Sensitivity Analysis

The test of how model outcomes change relative to changes in the explanatory variables is known as sensitivity analysis. For the school transportation mode choice models, the probability that a student will use the automobile for AM or PM school trips is determined by five explanatory variables: K8HH, Grade, Safe Mode, SBConv, and AUConv. This section focuses on the variation in automobile probability that occurs over the range of each of these variables to determine the potential impact that slight variable changes might have on school transportation mode choice when using the models.

Figure 4.8 shows the relationship between student grade and automobile probability for each K8HH value in the sample data. As grade level increases, a student is more likely to ride in an automobile for morning school trips, but the overall change in automobile probability does not suggest a modal shift based solely on increasing grade level. Between kindergarten and eighth grade, the extreme values for student grade, automobile probabilities range from just over 30% to 40% for a K8HH value of one and from just over 40% to 50% for a K8HH value of four.

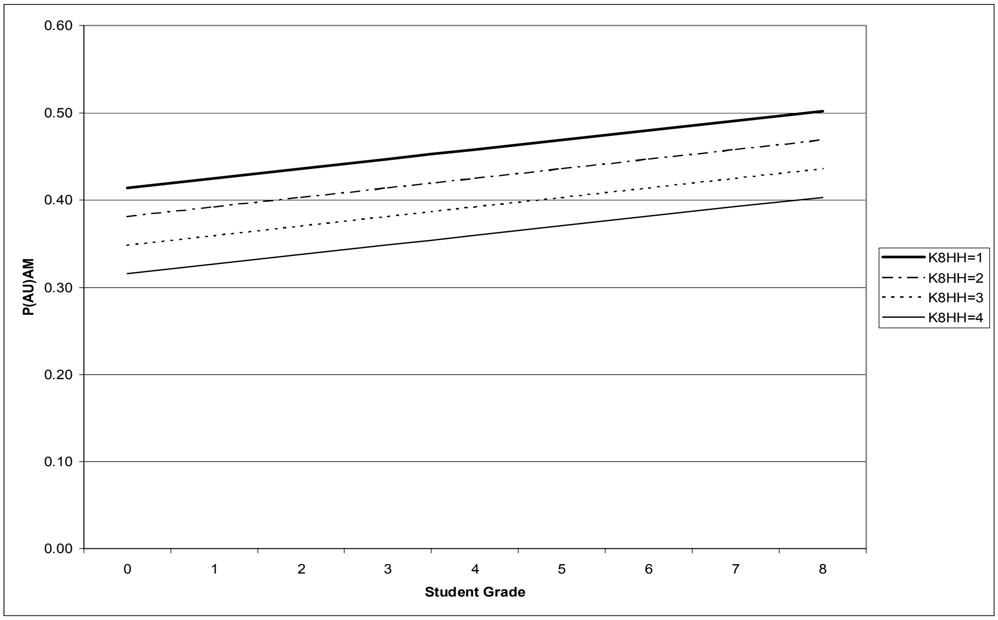

Figure 4.8 Variation in AM Automobile Probability by K8HH and Student Grade

The relationship between the probability of using the automobile for school trips and the Safe Mode variable can be seen in Figure 4.9. As the parental perception of safety varies from the school bus (value zero) to the automobile (value three), the probability that children in that household will use the automobile increases. The impact of the Safe Mode variable on the AM model is minor, however, in that the overall change in automobile probability from a Safe Mode rating of zero to three does not suggest a modal shift based on a change in perception alone.

Automobile probabilities appeared to be much more sensitive to changes in the school bus and automobile convenience terms than to changes in the student grade and Safe Mode values. Figures 4.10 and 4.11 illustrate the relationships between automobile probability and the two convenience terms. “AUConv” ranges from -3 to +5. A household who does not own an automobile and cannot therefore carpool, chain trips, or have their child(ren) participate in before or after school activities that disallow school bus usage would have an automobile probability of -3. Conversely, a household that has all of these opportunities and the children do participate in before and after school activities that require automobile transport would receive an AUConv rating of +5. A change in automobile convenience from -3 to +5 results in a change in automobile probability of over 100% and a change in mode choice.

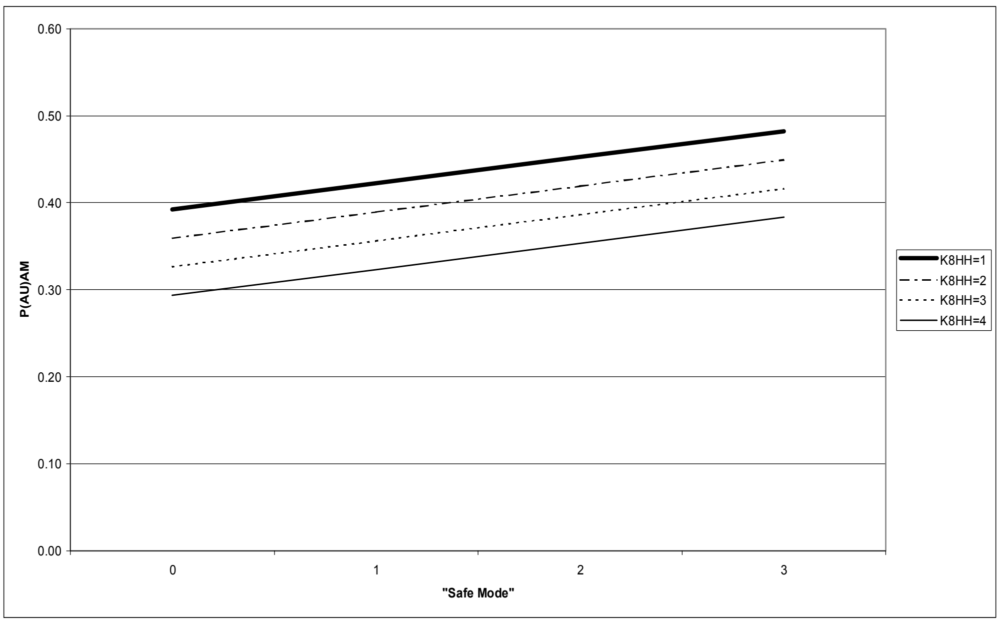

Figure 4.9 Variation in AM Automobile Probability by K8HH and Safe Mode Rating

The final variable evaluated was school bus convenience. Changes in this factor produced the largest overall changes in automobile probability. The inverse relationship is shown in Figure 4.11. For the cases where the school bus is most inconvenient, the automobile probability is one, suggesting that the child will definitely use the automobile. At the maximum value for school bus convenience, the automobile probability is zero, meaning that the child does ride the school bus. The range of possible school bus convenience terms changes the corresponding automobile probability from one extreme value (zero) to the other (one).

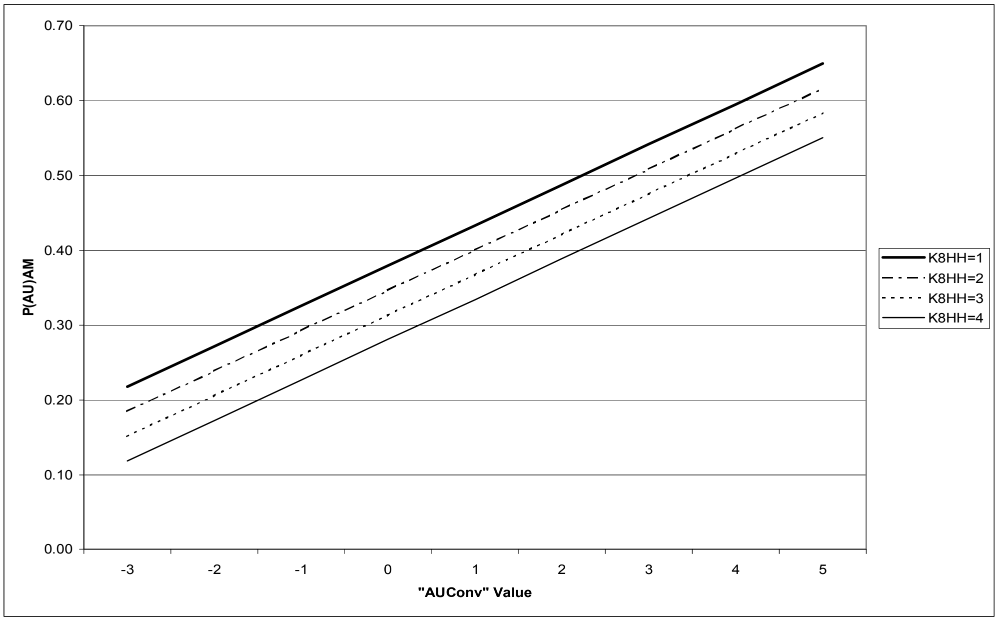

Figure 4.10 Variation in AM Automobile Probability by K8HH and Automobile Convenience

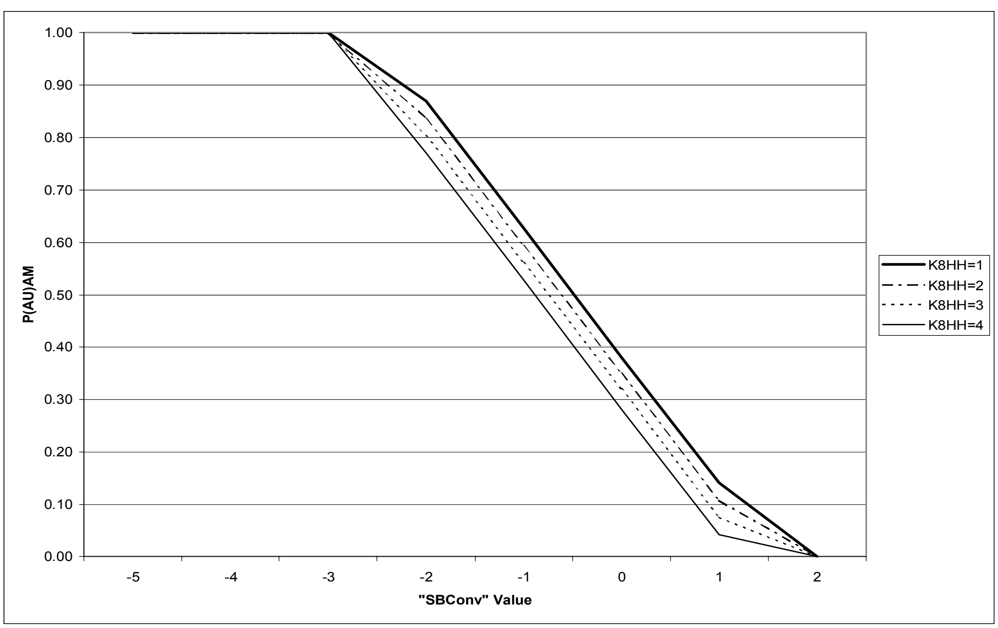

Figure 4.11 Variation in AM Automobile Probability by K8HH and School Bus Convenience

5. MODEL VALIDATION

5.1 Initial Validation Results

Confirming that the school transportation mode choice models effectively forecast modal share for a group of students other than those used to calibrate the model will help to answer the pertinent question, "do the models work?" Of the 679 students represented in the composite data set, a 10% sample was withheld from model development for validation purposes. The validation data set is comprised of 68 students. Validation was performed according to Equations 4.1 and 4.2, which give the AM and PM school transportation mode choice models. The aggregate AM and PM automobile probabilities forecasted by the models for the validation data are 0.39 and 0.27, respectively. The actual average automobile probabilities from these data are 0.40 and 0.18. This information is summarized in Table 5.1. The 95% confidence intervals for the AM and PM aggregate model estimates are 0.47 to 0.31 and 0.35 to 0.19, respectively. The AM average automobile probability from the data is within the 95% confidence interval. The PM value of 0.18, however, is slightly less than the lower confidence interval limit of 0.19. The PM average automobile probability does lie within the larger 98% confidence interval of 0.36 to 0.17. The statistical difference between the data and the model estimate is small. The relatively small sample size of the validation data set is one explanation for this difference. Both the AM and PM school transportation mode choice models were considered successful in validation because of the almost negligible difference in automobile probabilities for the PM model.

Data composition is the most plausible explanation for the nearly significant difference between the aggregate model-forecasted automobile probability and the validation data average probability in the afternoon. The data are composed of four possible mode choice combinations: (AMMode, PMMode) = {(SB, SB), (SB, AU), (AU, SB), (AU, AU)}. Table 5.2 shows the percentage composition of the calibration and validation data sets. This comparison suggests that the two data sets are similar, except in the category of students using the automobile for both morning and afternoon trips. There are significantly fewer students with a (1, 1) mode choice combination in the validation data. This explains the low automobile probability average for the validation data.

Table 5.1 Model Validation Summary

	$P(AU)_{AM}$	$P(AU)_{PM}$	Significant Difference- AM?	Significant Difference- PM?
Validation Data Average	0.40	0.18	---	---
Aggregate Model Prediction for Validation Data	0.39	0.27	no	slight-95%, no-98%
Calibration Data Average	0.43	0.27	---	---
Aggregate Model Prediction for Calibration Data	0.42	0.29	no	no

Table 5.2 Calibration and Validation Data Set Comparison

(AMMode, PMMode)	Calibration Data	Validation Data	Significant Difference?
(SB, SB) / (0, 0)	54%	57%	No
(SB, AU) / (0, 1)	3%	3%	No
(AU, SB) / (1, 0)	19%	25%	No
(AU, AU) / (1, 1)	24%	15%	Yes
Σ	100%	100%	---

5.2 Additional Validity Tests

In order to further verify the validity of the school transportation mode choice models, a second set of models were calibrated. Originally, a 10% sample was taken from the 679-student data set for validation. A similar process was completed to confirm validation. Another 10% sample was taken, using a random number generator. The remaining data were used to calibrate a second set of school transportation mode choice models, following the process detailed in Chapter 4. If the resulting models from the second analysis were similar to the original models (Equations 4.1 and 4.2), the strength of the variable relationships would be proven and the validation of the original models would be confirmed.

Predictor variable analysis of the second model calibration data used simple linear regression techniques and yielded results similar to the original analysis. Student grade, household income, Safe Mode, SB Conv, and AU Conv were the variables deemed significant to a 90% level of confidence for the AM case. The significant explanatory variables for the PM case were also consistent with those identified in the linear regression analysis of the original calibration data – K8HH, Grade, Income, Safe Mode, SBConv, and AUConv.

Backward and forward stepwise regression on the second model calibration data set included several quadratic and interaction terms in the analysis of AM mode choice. The importance of the Grade, Income, Safe Mode, SBConv, and AUConv variables was confirmed, but K8HH and home-to-school distance were also included in the models through interaction terms. Stepwise regression results for the PM case confirmed the importance of the K8HH, Grade, Income, Safe Mode, SBConv, and AUConv variables, using some quadratic and interaction terms. Table 5.3 shows the complete results of the AM and PM regression analyses for the second calibration data sets. While the linear models based on Equations 4.1 and 4.2 are the only viable options because of the unavailability of individual household income data, the differences between these models and the best possible models are small in terms of R^2 values. The linear school transportation mode choice models, given in Equations 4.1 and 4.2, were used to analyze the second calibration data set. Table 5.4 gives the results; "p" is defined as the number of explanatory variables.

Table 5.3 Mode Choice Model Options for the Second Calibration Data Set

	Model	Explanatory Variables	p	C(p)	R^2
AM	Simple Linear Regression	Grade, Income, SafeMode, SBConv, AUConv	5	6.860	0.517
	Backward Stepwise Regression	K8HH-Dist, K8HH-Grade, Dist-Income, Grade, SafeMode, SBConv, AUConv	7	4.920	0.527
	Forward Stepwise Regression	$K8HH^2$, K8HH-Dist, Dist-Income, SafeMode-Grade, SBConv, AUConv	6	10.247	0.521
	Linear Regression (w/ Equation 4.1 Variables)	K8HH, Grade, SafeMode, SBConv, AUConv	5	9.228	0.515
PM	Simple Linear Regression	K8HH, Grade, Income, SafeMode, SBConv, AUConv	6	6.325	0.446
	Backward Stepwise Regression	$K8HH^2$, K8HH-Income, SafeMode-Income, SafeMode-Grade, SBConv, AUConv	6	1.952	0.453
	Forward Stepwise Regression	K8HH, $K8HH^2$, K8HH-Income, SafeMode-Income, SafeMode-Grade, SBConv, AUConv	7	1.758	0.455
	Linear Regression (w/ Equation 4.2 Variables)	K8HH, Grade, SafeMode, SBConv, AUConv	5	7.911	0.442

Table 5.4 School Transportation Mode Choice Model Results Applied to Second Calibration Data Set

Model Predictions		Actual Data	
AM Average	**PM Average**	**AM Average**	**PM Average**
0.43	0.28	0.40	0.25

The 95% confidence intervals for the AM and PM average model estimates are 0.51 to 0.35 and 0.36 to 0.20, respectively. The actual data averages lie within the appropriate confidence interval, supporting the assumption that the original school transportation mode choice models (Equations 4.1 and 4.2) would accurately estimate mode choice for the second calibration data set. This second data analysis confirms the validation of Equations 4.1 and 4.2.

6. MODEL IMPACTS AND APPLICATION

6.1 Model Transferability

Transferability is a critical issue in model application that considers the question, "can these models transfer to other areas beyond Wake County?" Model calibration data were collected in Wake County, North Carolina and validation tests have proven that the models effectively forecast mode choice in Wake County. Additional data were collected in Union County, North Carolina to test model transferability. By comparing both the demographics and school transportation mode choice model output of Wake County and Union County, a determination was made about the areas in which the school transportation mode choice models can be applied.

6.1.1 Data Collection

Union County was selected for transferability testing because the public school system there reports the highest number of school travel-related injuries and fatalities in the state of North Carolina. From this perspective, school officials were interested in promising research that can help to improve the overall safety of their student population. The school transportation mode choice research meets this criterion because a modal shift to the school bus can improve overall student safety and the potential for such a shift due to technological improvements to the school bus can be assessed using the models. Union County staff was also the most cooperative in working with the student researcher, schools, and parents to disseminate student and parent contact information within the boundaries of school system privacy regulations.

The student information privacy policies required that the sample be selected by the Assistant Superintendent of Auxiliary Services for the Union County Public School System, who selected 13 of the county's 31 schools and gave instructions for each school to randomly select ten parents for participation in the survey. These parents were sent letters describing the survey purpose and giving the opportunity to decline participation. The final database consisted of 114 households who agreed to participate in the survey.

Data were collected using a telephone interview surveying format. Staff from the Center for Urban Affairs and Community Services at NC State University conducted the phone interviews over two weeks in May and June of 2003. Complete information was received from 75 households, representing a 66% response rate. Several phone numbers were disconnected and some calls were unanswered for every attempt in the two-week data collection period. Useful data on 124 students were received from the 75 households, corresponding to a rate of approximately 1.7 students per household.

6.1.2 County Comparison

Table 6.1 compares several demographic and school transportation characteristics for Wake and Union Counties (WCG 2003), (UCCOC 2003), (WCPSS 2003), (UCPSS 2003), (DPI 2003). Although Wake County is much larger in terms of county population, public school population, and number of school buses operated, the counties had similar school bus ridership percentages in the 2000-2001 school year. Both counties are also a part of major metropolitan areas within North Carolina – the Research Triangle (Wake County) and the city of Charlotte (Union County). Figure 6.1 shows the position of the two counties within the state of North Carolina.

Table 6.1 Wake and Union Counties' Comparison of Demographic Parameters

County Demographics	Wake County	Union County
Population	604,719	123,677
Median Household Income	$54,541	$50,638
School System Attributes	**Wake County**	**Union County**
Population	104,000	25,680
Schools (Elementary, Middle, High)	79, 25, 16	19, 6, 6
Bus Ridership	53%	50%
Buses Operated	727	200

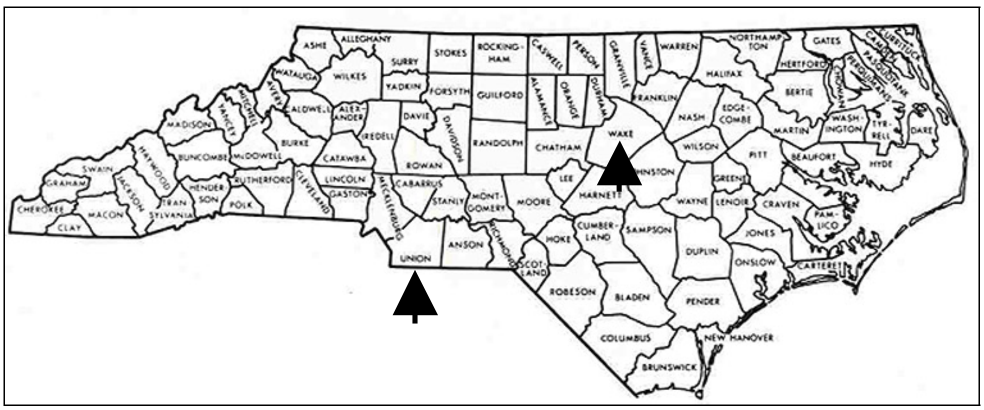

Figure 6.1 North Carolina Counties

6.1.3 Transferability Test

An analysis of the household and school trip characteristics of the 124 students in the Union County sample helped to determine whether the school transportation mode choice models effectively forecast modal share in two comparatively different areas. Application of the school transportation mode choice models to the Union County data resulted in aggregate automobile probabilities of 0.46 and 0.30 for the morning and afternoon, respectively. The corresponding 95% confidence intervals are 0.52 to 0.40 and 0.36 to 0.24. Average AM and PM automobile probabilities computed directly from the data were 0.60 and 0.32.

The AM model did not appear to effectively forecast school transportation mode choice in Union County. The automobile probability of 0.60 was located outside the 95% and 98% confidence intervals for the AM model and even outside the 0.56 to 0.36 range corresponding to a 99.9% confidence interval. Bias is therefore suspected in the Union County sample data. The average automobile probability of 0.60 is higher than the population parameter, which suggests that no more than 50% of students are transported by automobile on average in Union County. School bus ridership counts from the state Department of Public Instruction indicate that 50 – 52% of Union County students ride the school bus, leaving only 48 – 50% to comprise the automobile, bicycle, daycare program van, and automobile modes. Therefore, in reality, 60% of all Union County students cannot be assumed to use an automobile for their morning school trips.

The PM model did effectively forecast school transportation mode choice in Union County, as the average automobile probability of 0.32 was located inside the 95% confidence interval of the model-predicted average. The success of the PM model cannot be explained by county characteristics or model variable dissimilarities because these are the same for both the AM and PM model. Union County data composition and the original calibration data composition were compared in attempt to provide an explanation for the success of the PM model. Table 6.2 gives the results.

Table 6.2 Union County Data and Validation Data Comparison

(AMMode, PMMode)	Calibration Data	Union County Data	Significant Difference?
(SB, SB) / (0, 0)	54%	36%	Yes
(SB, AU) / (0, 1)	3%	4%	No
(AU, SB) / (1, 0)	19%	32%	Yes
(AU, AU) / (1, 1)	24%	28%	No
Σ	100%	100%	---

According to inference drawn from Table 6.2, 60% of Union County students use the automobile for their morning school trip, while 43% of the students in the calibration data use the automobile in the morning. Statistically, the two data sets are different. In the afternoon, however, 27% of the students in the calibration data use the automobile, along with 32% of the students in the Union County sample. These percentages are not statistically different, given the sample sizes. Therefore, the PM school transportation mode choice model effectively estimated afternoon mode choice in Union County because the Union County modal share is similar to that of Wake County where the models were calibrated. Data dissimilarity between Union and Wake Counties in the morning provides reason for the lack of success in estimating AM mode choice in Union County.

Given the composition of the calibration data, the school transportation mode choice models can be expected to transfer to any area where AM and PM automobile ridership percentages lie within a 95% confidence interval of the calibration data percentages. Using 30 as the statistically recommended minimum sample size for "large samples" (Mendenhall 1996), the approximate confidence intervals for AM and PM automobile usage from the model calibration data are 30 to 55% in the morning and 15 to 40% in the afternoon. This suggests that the school transportation mode choice models can transfer to any school district where the actual aggregate automobile usage for all students is between 30% and 55% of all school trips in the morning and between 15% and 40% of all school trips in the afternoon.

6.1.4 Transferability Test Summary

The school transportation mode choice models indicate effective transferability only within certain ranges of actual automobile usage. The AM model appears to only forecast accurate estimates of modal share when actual automobile usage is in the range of 30 to 55% of all morning school trips. Similarly, the PM model provides accurate estimates of modal share when actual automobile usage in the afternoon is between and 15 to 40% of all school trips. Estimates of actual automobile usage can be obtained from the school bus ridership records, which are reported to the state by local school district transportation staff. The proportion of actual automobile usage should be near one minus the sum of the school bus ridership proportion and an estimated 0.05 for school trips made by walking, bicycling, or riding daycare program vans. The 5% estimated modal share for the nonmotorized and "other bus/ van" school transportation modes is an assumption based on preliminary survey results in Chapter 3.

6.2 Model Application to Individual Schools

Another important consideration was whether or not the models could be applied to individual schools. Model calibration data contain information on 67 of the 104 elementary and middle schools in Wake County. The model-estimated automobile probabilities and the average automobile probabilities from the data were aggregated by school for four of the 67 schools in the data, which had sample sizes larger than 20 observations. Although 30 is the statistically recommended minimum sample size for "large samples" (Mendenhall 1996), 20 was used for the individual school analysis so that the school transportation mode choice models could be evaluated for more than one school (only one school in the sample had more than 30 observations).

Parts a) and b) of Table 6.3 summarize the data used for evaluation of the school transportation mode choice models by individual school. These results confirm that the models provide accurate estimates of aggregate automobile probabilities only within certain ranges of actual automobile usage. The AM limits of 30% to 55% are supported by the individual school analysis results. The PM limits of 15% and 40%, however, are challenged because the average automobile probability of school 504 is 0.46 and the model does provide a statistically accurate estimate.

Table 6.3a School Transportation Mode Choice Analysis by School: Automobile Probabilities

		Data Averages		Aggregate Model Estimates	
School	Sample Size	$P(AU)_{AM}$	$P(AU)_{PM}$	$P(AU)_{AM}$	$P(AU)_{PM}$
390	31	0.21	0.21	0.37	0.26
439	27	0.27	0.32	0.43	0.34
472	24	0.75	0.25	0.54	0.30
504	29	0.50	0.46	0.55	0.43

Table 6.3b School Transportation Mode Choice Analysis by School: Confidence Intervals

	Confidence Intervals				Model Fit?	
School	AM Upper Limit	AM Lower Limit	PM Upper Limit	PM Lower Limit	AM	PM
390	0.49	0.26	0.38	0.14	no	yes
439	0.56	0.30	0.47	0.21	no	yes
472	0.68	0.40	0.44	0.17	no	yes
504	0.68	0.42	0.55	0.31	yes	yes

These results suggest that a more detailed analysis is needed on the ranges of automobile usage within which the PM school transportation mode choice models will effectively estimate modal share. Data from the Union County and individual schools' transferability tests confirm that the acceptable range of AM automobile usage for obtaining effective modal share estimates from the school transportation mode choice models is 30% to 55% of all school trips. The acceptable range for PM automobile usage, however, may extend from 15%, the confirmed lower limit, to as much as 50% of all afternoon school trips.

6. 3 Potential Impacts of Automated Vehicle Location

Determining the magnitude of modal shift to school bus that is likely to be prompted by AVL implementation on school buses was a component of this school transportation mode choice research. The survey used in Chapter 4 to obtain model development data included questions that assessed the potential for change in household modal choices because of AVL technologies. The survey asked parents to respond "yes," "no," or "maybe" to the following two questions:

- If your child does not ride the school bus, would you allow him/her to ride if for a charge of $5-$10 per month you would be provided with a pager that would sound in your home a few minutes before the bus actually arrived (shortening the time that you and/or your child must wait at the bus stop)?
- If your child does not ride the school bus, would you allow him/her to ride if the school bus positions were monitored regularly at the school transportation office (increasing student safety and improving the on time arrival of buses)?

These questions were based on specific AVL systems currently available for school buses that use GPS and two-way radio or cellular communications for tracking, providing periodic real-time vehicle position updates to a central computer with software that displays the bus locations and other information, like speed, on area maps that can zoom to the street level. AVL has been used for years to "measure system performance, ridership, and schedule adherence, provide estimated time of arrival… and display vehicles on an electronic map (Okunieff 1997)." GPS transmitters on board school buses receive positional coordinates and transmit them to receivers in homes and schools. Pager-like devices that house the receiver provide bus arrival notification to households (ITSA 2000). Some units dynamically display the distance, in miles, and time, in minutes, as a countdown to the arrival of the bus at the bus stop assigned to that home. Other units transmit an audible sequence of beeps about five minutes prior to bus arrival so that children know the time at which they should walk to the bus stop. This notification capability benefits the rider in terms of safety and the school bus system in terms of increasing operational efficiency. Bus annunciation systems have been noted to work well in areas where "school children and their parents may frequently walk long distances to their bus stop and then wait with great uncertainty for their school bus to arrive. This waiting exposes these children to all kinds of inclement weather conditions, roadside safety hazards, and other personal safety and security threats (Messer 1998)."

6.3.1 Technology Probability

Of the 611 students represented in the model calibration data, approximately 54% ride the school bus in the morning and afternoon. Less than 4% of the students use the school bus in the morning and an automobile in the afternoon. These students may participate in after school activities that require automobile transportation, although just under half of the students indicated having after school activities that prevented school bus usage. Non-sampling variable error in the survey could explain why some respondents may have participated in, but not indicated, after school activities. There is also a chance that some of these students come from households that have problems with the afternoon school bus service and therefore opt to use the automobile. Overcrowding and long bus rides that lead to late evening arrival times are reasons that parents might not use the school bus service in the afternoon. These are not the types of problems that an AVL system can address directly, so these students were removed from the analysis of possible modal shifts, along with those students who used the school bus service for morning and afternoon trips.

The data for analyzing the potential magnitude of modal shifts consisted of 211 students who used the automobile for either their morning or both school trips. Data for 49 of the 260 students that met this criterion were omitted because one or both of the technology assessment questions were unanswered. For each of the 211 students included in the technology analysis, a *technology probability* was computed. This probability was based on the parents' answers to the paging and tracking questions from the survey. "Yes," "no," and "maybe" answers were assigned probabilities of 1.0, 0.0, and 0.5, respectively. The total technology probability for an individual student was calculated by adding half of the paging probability to half of the tracking probability. For example, a person answering "no" to the paging question and "yes" to the tracking question would have a technology probability of 0.5 using the following computation: $\frac{1}{2}(0.0)+\frac{1}{2}(1.0)=0.5$.

The average technology probability for the 211-student data set was 0.38, indicating that *38% of all students using the automobile for at least their morning school trip may shift from the automobile to the school bus for at least one trip if vehicle tracking and paging technologies are deployed on school buses*. More specifically, 51% of those students who were transported to school by automobile in the morning and school bus in the afternoon may shift to the school bus. Of the students riding in an automobile for morning and afternoon school trips, 31% indicated a chance of shifting to the school bus. The difference between the 51% and 31% is intuitively reasonable because students already using the school bus service for at least one trip are expected to be more likely to shift modes and use the school bus for both trips than students who do not use the school bus service at all.

If 38% of all students using the automobile for their morning or both school trips shift from the automobile to the school bus for at least their morning school trip, an overall modal shift of 16% would result. There are 114 students in the complete, 611-student sample who ride in an automobile for their morning school trip and use the school bus for their afternoon school trip. The number of students who use the automobile for both school trips is 146. A 38% shift to the school bus amongst these 260 students corresponds to an increase in morning school bus ridership of approximately 100 trips (16% of the total 611 morning school trips represented in the complete sample).

A 16% overall shift from the automobile to the school bus in a school district the size of Wake County, where the student population numbers about 104,000, would increase school bus ridership by over 16,000 trips. This magnitude of shift would prompt a notable decrease in school campus traffic congestion and an increase in student safety because of the number of students transferring to the statistically safer school bus mode. Computed technical probabilities are regarded as probable, however, because personal opinions change with time and survey answers may exhibit similar fluctuation. If the same respondents were to participate in this survey a second time, there would likely be a change in the answers to the technology assessment questions.

Considering the paging and tracking technologies separately is useful because a complete AVL system may not be financially feasible for a school district. There are household notification systems marketed to school systems that operate independently of AVL. These systems transmit a signal from a unit on-board a school bus to the in-home pagers associated with that route. When the bus comes within one mile of the pagers programmed with the code corresponding to that bus, the pager sounds, notifying the household that the bus is one mile away and children should begin moving to the bus stop. Would notification alone prompt a large enough shift to justify the necessary expenditures? According to survey results, more parents indicate a willingness to shift modes with the bus tracking function than with the household paging function. The average likelihood of a modal shift due to paging and tracking technologies separately are approximately 29% and 47%, respectively. These results suggest that parents would appreciate school transportation staff knowing the exact location of the buses more than they would appreciate being notified in advance of the actual bus arrival time. The parental preference of tracking technologies over paging technologies is explained by the preliminary survey results in Chapter 3, which show that overall, Wake County received a 70% “on-time” school bus arrival rating from parents. Parents would value notification less if the buses in their area repeatedly arrive at the regularly scheduled time. A tabular summary of the technology probability data is given in Table 6.4.

Table 6.4 Technology Probabilities for Students "Eligible" for a Modal Shift to the School Bus

(AMMode, PMMode)	Technology Probability	Paging Probability	Tracking Probability
(AU, SB)	0.51	0.39	0.63
(AU, AU)	0.31	0.24	0.38
Total	0.38	0.29	0.47

6.3.2 AVL and the School Transportation Mode Choice Models

An important issue to consider is the impact of AVL technologies on the school transportation mode choice models. Model variables were defined such that the school bus convenience term would be modified for those households affected by an addition of any improvements to the school bus service. The school bus convenience term quantifies individual household problems with or benefits of the school bus service due to scheduling, punctuality, bus operation, student behavior, or bus stop location. Deployment of AVL technologies would increase the convenience of the school bus, but the magnitude of increase had to be determined.

The average technology probability computed in Section 6.3.1 estimates that 38% of the students currently using the automobile for their morning or both school trips will shift to the school bus with the addition of AVL tracking and household notification technologies. This 38% modal shift amongst those students using the automobile for at least their morning school trip prompts a 16% modal shift overall. The aggregate automobile probability forecasted by the AM mode choice model for the composite, 611-student data set is 0.42. In order to measure the effects of AVL technologies on the school transportation mode choice models, the school bus convenience factors for 38% of those students using the automobile for morning school trips were increased until the aggregate automobile probability decreased by 16%. The 38% sample was selected using a random number generator.

First, the SBConv value for each student in the 38% sample was increased by one and re-entered into the AM school transportation mode choice model until the automobile probability for that student decreased to less than 0.42, which is the average probability that students will use an automobile for their morning school trips. Based on deterministic, linear probability theory, the school transportation mode choice models do not always estimate an individual automobile probability that represents the actual mode used by a student. The models effectively estimate aggregate probabilities, but individual probabilities may not be accurate. The limiting automobile probability of 0.42 was therefore chosen, assuming that a probability below this average value would be low enough to emulate actual school bus usage. The school bus convenience factors of existing school bus riders were then increased using the same process in order to reflect the added convenience of AVL technologies for all school bus riders. The overall average automobile probability was monitored continuously to evaluate the aggregate impact of individual student changes.

The AM model was used to evaluate AVL impacts so that all students who traveled to school in an automobile for at least one trip could be eligible for a modal shift to the school bus, instead of only those who used the automobile for the afternoon trip if the PM model had been used. For simplicity, a modal shift was assumed to occur for only one trip. When the school bus convenience factors for all existing morning school bus riders and the new riders resulting from the 38% shift were increased such that the individual automobile probabilities were 0.42 or less, the aggregate automobile probability reflected a modal shift of just over 16%.

The final component was a computation of the average increase in school bus convenience necessary to reflect the 16% overall modal shift. When the individual increases in the school bus convenience terms of existing and new school bus riders were averaged, *school bus convenience increased by an average of 0.5 points per student*.

6.3.3 AVL Impact Summary

Technology probabilities allow for a numeric estimation of the magnitude of possible modal shifts due to the addition of tracking and/ or paging technologies on school buses. Future applications of the school transportation mode choice models can evaluate the potential impact of AVL on modal split by increasing the school bus convenience of the affected students by 0.5 points.

All effects of such a shift, however, may not be positive. The negative effects of a sizeable increase in school bus ridership must also be considered. The additional number of buses and drivers needed to accommodate an increase in school bus ridership would have to be estimated by school transportation staff and put into operation in a relatively quick time frame in order to at least maintain the existing level of service. In North Carolina, school transportation is funded by the state government based on an efficiency rating calculated primarily by a ratio of the number of students transported and the number of buses used. A source for the initial funding of the additional buses and bus driver salaries would have to be identified until the district could prove the need for the increase with the change in ridership counts. The school district must be prepared to adequately handle the increase in ridership if the addition of technology is to be effective.

School bus-related crashes may also increase as the number of students using the school bus service increases. According to the National Highway Traffic Safety Administration (NHTSA), a "school bus related crash" is defined as any injury or fatality that occurs in the vicinity of a school bus, even if the school bus was not directly involved. While an increase in school bus-related crashes may not be of notable magnitude and may be offset by other factors, school transportation staff should note that an increase may occur.

6.4 Model Application Using NCWISE

WCPSS parents are required to complete a "Personal Data Sheet" to enroll each of their K-12th grade children in school. Required information includes home address, parent names and daytime contact numbers. Data are entered into the NCWISE (North Carolina Windows of Information for Students Education) system by the NCWISE coordinator for each school across the state. Student data are maintained regularly in the NCWISE database so that school officials are able to maintain, access, and analyze data on any students in North Carolina using a single, comprehensive information system.

Figure 6.2 displays a questionnaire that can be integrated into the current NCWISE data collection process for implementation of the school transportation mode choice models. Data collected using this questionnaire would allow each school and school district to have access to the data needed to apply the school transportation mode choice models and make informed school transportation decisions. Table 6.5 gives the relationship between information collected from the questionnaire in Figure 6.2 and the school transportation mode choice model variables. Student grade is not included in Table 6.5 because this information is already a part of the NCWISE system.

Table 6.5 Integrating School Transportation Mode Choice Models and NCWISE

Question # (from Figure 6.2)	School Transportation Mode Choice Model Variable
1	Safe Mode
2	K8HH
3a – 3e	AUConv
3f – 3l	SBConv

Wake County Public School System (WCPSS)
Transportation Questionnaire

1. Which of the following ways of getting to and from school do you feel is most safe?
_____ School Bus _____ Automobile _____ Walk/Bike

2. How many children in your household are in grades K-8? _____

3. Please check the appropriate column to answer yes or no to the following questions.

	Y	N
a. Does your family own or have regular access to an automobile?		
b. Is it feasible for you to drop off/ pick up your child at school on the way to/ from work or some other activity?		
c. Is it feasible for you to carpool with other families?		
d. Does your child have **before school** care/ activities that prevent riding the school bus? e. Does your child have **after school** care/ activities that prevent riding the school bus?		
f. Do parent work schedules require that your child ride the school bus in the morning? g. Do parent work schedules require that your child ride the school bus in the afternoon?		
h. Do problems with the **scheduled** school bus arrival time keep your child from riding the school bus in the morning? i. Do problems with the **scheduled** school bus arrival time keep your child from riding the school bus in the afternoon?		
j. Do you not allow your child to ride the school bus because you know the bus **does not arrive regularly at the scheduled time**?		
k. Do your concerns about the safety or location of the **bus stop** keep your child from riding the school bus?		
l. Do your concerns about the operation, safety, or behavior on the school bus keep your child from riding?		

Figure 6.2 Model Application Questionnaire

7. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Research Summary

School-related traffic congestion during the morning and afternoon school transportation peak hours has become a large problem in North Carolina and throughout the nation. North Carolina Department of Transportation works with schools and municipalities to better design and retrofit campuses to accommodate the high vehicular volumes that many times queue onto adjacent streets, causing long delays and increasing transportation safety problems for students and commuters. The goal of this research was to gain an understanding of the household attributes and behaviors that impact school transportation mode choice, in order to identify problems and prioritize solutions for school transportation, including school bus service improvements through automated vehicle location (AVL) technologies that may ultimately enhance overall student safety and reduce school traffic congestion. School buses are described by NHTSA as the safest form of travel for children, yet school bus ridership has declined nationally over the past few years. AVL technologies have proven to attract riders to public transit because of the benefits offered by vehicle tracking, pre-trip and en-route information. Some measure was needed to assess the potential for the application of similar technologies on school buses to prompt a modal shift.

The specific research objectives were: 1) to calibrate and validate a school transportation mode choice model for a selected school district and 2) to assess the potential for modal shifts based on improvements to the school bus service through AVL technologies. Public school students in kindergarten through eighth grade were the focus because initial analysis showed that high school students demonstrate different mode choice patterns due to the student driving option that becomes available for high school-aged students and because private school policies concerning school bus transportation differ by school. Focusing on public school students ensured that each student in the sample was governed by the same school transportation policies applied to the entire school district.

Simple linear, general linear, stepwise, and logistic regression models were developed to estimate school transportation mode choice using data collected from mail-out-mail-back survey questionnaires and GIS analysis in Wake County, North Carolina. All school transportation modes were not included in the analysis. Instead, a reduced set of two modal alternatives – school bus or automobile – was considered for those students living within the base attendance boundary for their school, but outside the no transport zone where the school bus service is not available.

Two school transportation mode choice models were developed based on those factors exhibiting statistical significance in estimating the mode a student will take when presented with the choice of automobile or school bus for school trips. Two models were necessary because the effects of the explanatory variables differed for morning and afternoon trips. The AM and PM school transportation mode choice models are shown in the following equations, where P(AU) represents the probability that a student will use the automobile for school trips.

$$P(AU)_{AM} = 0.226 - 0.033K8HH + 0.011Grade + 0.030SafeMode - 0.243SBConv + 0.054AUConv$$

$$(R^2=0.51,\ \sigma^2=0.1214,\ N=611)$$

$$P(AU)_{PM} = 0.281 - 0.051K8HH - 0.019Grade + 0.027SafeMode - 0.196SBConv + 0.033AUConv$$

$$(R^2=0.44,\ \sigma^2=0.1138,\ N=611)$$

Of the five explanatory variables included in the models, school bus convenience is most influential in estimating school transportation mode choice. This variable attempts to quantify the convenience of the school bus service for a household based on parent work schedules, perceived problems with the service, and technological improvements. Other terms in the models account for household characteristics, like the total number of children in grades K-8, student grade, the school travel mode that the parent perceives to be most safe, and the convenience of the automobile. Model validation verified the effectiveness of the AM and PM models by showing that the average AM and PM automobile probabilities calculated for a validation data set were within the confidence intervals for the aggregate model estimates. Results from a model transferability test, using data from a different school district (Union County, North Carolina), suggested that the models can be used statewide in schools or school districts where automobile usage is in the range of 30 to 55% in the morning and 15 to 40% in the afternoon.

An assessment of the potential for AVL technologies to prompt a modal shift to the school bus amongst those students currently using the automobile for their morning or both school trips was the final component of the school transportation mode choice research. This technology assessment was based on a computed "technology probability," determined by the willingness of parents whose children currently use the automobile for their morning or both school trips to shift to the school bus for at least one trip with the addition of AVL tracking and notification technologies on school buses. Results suggest that 38% of students currently using the automobile for their morning or both school trips may shift to the school bus for at least one trip with the addition of AVL technologies, prompting a 16% modal shift overall.

Any improvements to the school bus service are reflected in the school transportation mode choice models by changes to the school bus convenience terms. Analysis of the average change in school bus convenience necessary to prompt an overall modal shift of 16% showed that new and existing school bus riders increase their school bus convenience by approximately 0.5 points with the addition of AVL technologies.

7.2 Conclusions

1. ***A modal shift from the automobile for high school students will not likely be prompted by improvements to the school bus service.***

Preliminary survey data showed that over 60% of Wake County high school students use the automobile for morning school trips. Over 50% choose the automobile for afternoon school trips as well. Most high school students drive or ride in an automobile with someone other than a parent. Section 2.1 indicated that trip generation rates for North Carolina high schools are higher than the nationally-accepted rates in ITE's *Trip Generation* (Slipp 1994). Evaluation of the survey results in Chapter 3 led to the conclusion that the social implications and freedoms associated with driving privileges must be overcome with increased campus parking fees or other policies aimed at discouraging student's from driving to school in order to decrease the number of teen-driven automobiles for school trips. The different factors involved with driving as an option led to the exclusion of high school students from this school transportation mode choice research. High school mode choice patterns support this decision, suggesting that technological improvements to the school bus service will not attract a large number of high school riders.

2. ***The primary factors that determine mode choice for school trips are not the same factors that have been documented in traditional mode choice models***.

Traditionally, mode choice is influenced by cost, travel time, and convenience, expressed through a mode bias constant. The costs associated with school transportation are negligible and perceived home-to-school distance, which is inversely proportional to travel time, did not exhibit a significant relationship with school travel mode choice. Convenience does play a critical role in school transportation mode choice, but assumes a more prominent role than in traditional mode choice modeling. School transportation mode choice for students in kindergarten through eighth grades is most influenced by the total number of K-8^{th} grade students in a household (K8HH), student grade (Grade), the mode parent's perceive to be most safe (SafeMode), the quantified convenience of the automobile (AUConv), and the quantified convenience of the school bus (SBConv). The AUConv variable expresses the combined effects of automobile ownership, ability to chain trips and carpool, and before and after school activities. "SBConv" takes into account problems with or added convenience of the school bus service due to scheduling, punctuality, behavior, operation, location of stops, and technological improvements.

3. ***School bus convenience is the primary factor in estimating school transportation mode choice***.

The school bus convenience term was found to have a considerably larger weight in the models than any other factor. Analysis of the individual components of the school bus and automobile convenience variables showed that each component of SBConv is significant in estimating AM and PM mode choice, whereas the AUConv components are not all significant as stand-alone predictor variables. Students and parents appear to base their choice of school bus or automobile for school trips on whether or not the school bus is a convenient option. Therefore, children from a household with a low school bus convenience value will likely use the automobile for school trips, regardless of the automobile convenience value. This implies that addressing parent perceptions of problems with the school bus schedule, punctuality, bus stop location, and safety is the key to prompting a significant modal shift to the school bus.

The importance of the school bus convenience terms also addresses an issue in future applications of the model. Easily accessible data sources like census data could be used to collect data for applying the mode choice models without requiring a questionnaire from parents. Estimates of the K8HH and student grade variables could be obtained without surveying parents. SafeMode, AUConv, and SBConv, however, which are critical to obtaining accurate estimates of modal share, cannot be assessed without obtaining information directly from the parents. Therefore, use of the models without these key variables is not advised.

4. ***School bus and automobile convenience terms are more important in the morning than in the afternoon***.

Equations 4.1 and 4.2 illustrate that both school bus and automobile convenience are more important in the morning peak period than in the afternoon, as is evident in the magnitude of these variable coefficients. On a typical morning in a household, student travel to school, parent travel to work, breakfast, and other activities must all be accommodated in the same one or two hours. This is not true of the afternoon, when school and work travel and other activities are distributed over a longer time period. Intuitively then, convenience of a school travel mode is most critical in the morning, whereas other variables, such as number of children in the household and student grade, increase in importance in the afternoon.

5. ***Linear school transportation mode choice models can be used to estimate aggregate modal shares and to evaluate the impacts of technological improvements or policy changes to available school transportation modes.***

The output from the models is a valuable tool for school transportation officials, providing them with the ability to estimate modal share by school or for the entire school district and to plan accordingly for the expected automobile and school bus trips. The models can help justify expenditures for AVL technologies in areas where student safety or school bus operational problems necessitate such a solution, providing an estimate of the expected decrease in automobile trips. Linear probability models can provide accurate estimates of aggregate mode choice. Aggregate automobile probabilities for a school or school district should be the focus of the model application because individual student probabilities do not necessarily reflect the actual mode used by an individual because the models are deterministic. Without additional research into the range of model transferability, the models are assumed to apply only in areas where the approximate automobile usage ranges from 30% to 55% in the morning and 15% to 40% in the afternoon.

6. ***There is potential for a substantial modal shift from the automobile to the school bus with the addition of AVL technologies on school buses***.

Results from the surveys of WCPSS parents indicate that as many as 38% of students currently using the automobile for their morning or both school trips may shift to the school bus for at least one trip if AVL tracking and paging technologies are deployed. This corresponds to a 16% modal shift amongst all students. Many parents whose children use the school bus service are displeased with the punctuality or out-of-vehicle travel time required to ensure that the child does not miss the bus. These parents indicate a willingness to pay for in-home bus arrival notification, which would increase school bus "customer service." Communication amongst parents about the increase in the school bus level of service could prompt other parents to use the school bus service. Many vehicular congestion problems on individual school campuses could be solved with a 16% or greater modal shift from the automobile to the school bus. The district-wide impacts would also be significant.

7. ***Parents appear more accepting of AVL school bus tracking technology than for in-home bus arrival notification.***

The preliminary survey included an assessment of parents' "willingness to pay" for AVL tracking and paging technologies. Approximately 48% of parents in the sample were unwilling to pay for an arrival notification service, while another 48% indicated that on average, a maximum of $7 per month would be reasonable to pay for this service. In order to evaluate the tracking technology, parents were asked to identify the amount they deemed reasonable for the school system to pay for deployment of AVL tracking on a school bus.

Of the responding parents, 40% did not support the purchase of school bus tracking technologies, but 51% indicated an acceptance of spending an average of $1300 per bus.

Paging and tracking technologies can be implemented independent of each other. Notification capability is an option when AVL is being used to track buses, but there are in-home bus arrival notification systems that operate independently of AVL. Results from the technology assessment of Chapter 6 indicated that approximately 29% of students currently using the automobile for their morning or both school trips may shift to the school bus for at least one trip with the availability of a paging/ household notification service. Over 45% of these students may shift to the school bus if tracking technologies are implemented, indicating that parents value school personnel knowing the location of the buses more than they value the ability to be notified in advance of the actual school bus arrival time. This is supported by the preliminary survey results in Chapter 3, which show that Wake County has a 70% "on-time" school bus arrival rating from parents. Parents are expected to value notification less if the buses in their area arrive regularly within the scheduled arrival time window.

7.3 Recommendations for Future Research

The potential uses for school transportation mode choice research are innumerable. This research project used customary statistical and transportation engineering methodologies to begin evaluating the important decisions and behaviors that impact school transportation mode choice. There are several issues that were beyond the scope of this study that should be considered for future research.

First, high school student mode choice is of particular importance because of the large percentage of students who drive or ride with a teenage driver for school trips and the magnitude of associated injuries and fatalities reported from automobile collisions involving teenage drivers during normal school transportation hours. Additional research might focus on the decisions and behaviors that govern mode choice and automobile safety amongst the high school student population.

Second, the school bus and automobile convenience terms proved to be critical factors in estimating school or school district modal share. These convenience terms were calculated by assigning single point values to components like automobile ownership, feasibility of chaining trips, school bus service scheduling problems, and bus stop location concerns. Further research might focus on the formulation of the convenience terms, selecting only the components that directly indicate a significant relationship with school trip mode choice and assigning different weights, as appropriate, to the components.

Third, a more precise range of school transportation mode choice model application should be determined in a more detailed transferability test. This research project tested the transferability of the models for only one county and four individual schools. The models have the potential for statewide application, but a more extensive test of model transferability would determine the exact constraints on model usage.

Fourth, the process of generating solutions to school transportation safety, school-related traffic congestion, and school bus service problems could be completed using the systems analysis approach in future research. The only solution evaluated in this research was AVL and the potential impacts of AVL on mode choice. AVL was considered because of its proven effectiveness in resolving similar problems in public transit and because of the number of AVL technologies now being marketed specifically for school buses. Heightened concern for student safety because of recent incidents involving safety breaches for students on-board school buses prompted the quick development and marketing of several school bus-specific AVL systems. This mode choice research complements these AVL systems with more information as to the actual behaviors and perceptions that can be addressed by AVL technologies for school buses. Still, using the systems analysis approach to generate potential solutions for school transportation problems could lead to the generation of other viable, valuable solutions.

Finally, this research project considered the student population inside the base attendance area for their school, but outside the no-transport zone where school bus transportation is not provided. The no-transport zone was omitted from the analysis because nonmotorized modes are feasible options within this zone and models that estimate modal share for nonmotorized modes should consider local conditions like availability and condition of sidewalks and walking/ biking paths. No local conditions were included in the school transportation mode choice models developed in Chapter 4 because of the sizeable, countywide area where the models were designed to apply. Future research might calibrate a single multinomial model that includes all students inside the base attendance areas for their respective schools, analyzing the choice between automobile, school bus and nonmotorized modes.

REFERENCES

Aldrich, John H. and Forrest D. Nelson. Linear Probability, Logit, and Probit Models. Beverly Hills, California: Sage Publications, Inc., 1984.

Allen, William G., Jr. "Forecasting the Cost of Driving," ITE Journal. Institute of Transportation Engineers, February 1996.

American Public Transportation Association (APTA). "Public Transportation Ridership Statistics," Public Transportation Fact Book, 2001.

American Statistical Association. "How to Plan a Survey," What Is A Survey Series, 1997.

American Statistical Association. "Judging the Quality of a Survey," What Is A Survey Series, 1998.

Andersen, Ronald, Judith, Kasper, Martin Frankel, and Associates. Total Survey Error. San Francisco, California: Jossey Bass, Inc. 1979.

Ball, William L. and Edward Mierzejewski. "New Findings on Factors Related to Transit Use," ITE Journal. Institute of Transportation Engineers, February 1990.

Beimborn, Edward A. A Transportation Modeling Primer. Milwaukee, Wisconsin: Center for Transportation Studies, May 1995.

Ben-Akiva, Moshe E. and Steven R. Lerman. Discrete Choice Analysis: Theory and Application to Travel Demand. Cambridge, Massachusetts: MIT Press, 1985.

Biemer, Paul P. Measurement Errors in Surveys. New York: John Wiley & Sons, Inc. 1991.

Bureau of Transportation Statistics (BTS). "Transportation Indicators Report." December, 2002.

Department of Public Instruction (DPI) Transportation Division. “North Carolina State Statistics.” <http://www.ncbussafety.org/statmap.html> Accessed May 2003.

Energy Information Administration (EIA). “Annual Energy Outlook 2003 with Projections to 2025.” Department of Energy, Report #:DOE/EIA-0383, January 9, 2003.

European Centre for Medium-Range Weather Forecasts (ECMWF). “The Brier Score” <http://www.ecmwf.int/products/forecasts/guide/The_Brier_score.html> Accessed July 2003.

Fischbeck, Paul S. and Beverly M. Huey. “The Relative Risks of School Travel.” TR News. January-February, 2003.

Horowitz, Joel L., Frank Koppelman, and Steven Lerman. “A Self Instructing Course in Disaggregate Mode Choice Modeling.” Federal Transit Administration, Report No. DOT-T-93-18, December, 1986.

Hummer, Joseph E. “Survey Design,” Manual of Transportation Engineering Studies. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1994.

Hunt, John D. “A Logit Model of Public Transport Route Choice,” ITE Journal. Institute of Transportation Engineers, December 1990.

ITS America (ITSA). “School Day Could Start With Beep, Beep, Beep,” ITS America News, Vol.10, No.7. Washington, DC, July 2000.

Liao, Tim F. Interpreting Probability Models. Thousand Oaks, California: Sage Publications, Inc., 1994.

Mendenhall, William and Terry Sincich. A Second Course in Statistics. Upper Saddle River, New Jersey: Prentice-Hall, Inc., 1996.

Merriam-Webster Incorporated. Ninth New Collegiate Dictionary. 1983.

Messer, C.J. and M.J. Pacelli. "Development of an Annunciation System for Rural School Bus Operations." Texas Transportation Institute, October 1998.

National Center for Education Statistics (NCES). "Statistics of State School Systems; Revenues and Expenditures for Public Elementary and Secondary Education." US Department of Education, September 1998.

National Highway Traffic Safety Administration. "Getting To School Safely." Brochure, 2001.

National Research Council (NRC). The Relative Risks of School Travel. Washington, DC: Transportation Research Board, National Academy Press, 2002.

Okunieff, Paula E. AVL Systems for Bus Transit. Transit Cooperative Research Program. Washington, DC: National Academy Press, 1997.

Papacostas, C.S. and P.D. Prevedouros. Transportation Engineering and Planning, 3rd Edition. Upper Saddle River, New Jersey: Prentice Hall, Inc. 2001.

Poole, Robert W., Jr. and Michael Griffin. "Shuttle Vans: The Overlooked Transit Alternative." Los Angeles, California: The Reason Foundation, April 1994.

Rhoulac, Tori D. The Application of Global Positioning Systems to Pupil Transportation. Master's Thesis, North Carolina State University, 2000.

Rossi, Thomas F. Modeling Non-motorized Travel. Washington, DC: Transportation Research Board, 79th Annual Meeting Preprint CD-ROM.

School Transportation Group (STG). "Best Practices Managing School Campus Carpool Traffic." <http://www.itre.ncsu.edu/stg> Accessed January 2003.

Slipp, Peter R. M. Trip Generation Rates for High Schools in Urbanized Counties of North Carolina. Master's Thesis, North Carolina State University, 1994.

Transportation Research Board. Highway Capacity Manual. Washington, DC: National Research Council, 2000.

Union County Chamber of Commerce (UCCOC). "County Information: Demographics." <www.unioncountycoc.com> Accessed June 2003.

Union County Public School System (UCPSS). "School Statistics."
< http://www.ucps.k12.nc.us/schools/schools.htm> Accessed June 2003.

University of North Carolina (UNC): An Inter-institutional Partnership. "School Transportation Research Initiative." January, 2003.

Wake County Government (WCG). "Demographic and Income Forecast." <http://www.wakegov.com/general/census/default.htm> Accessed June 2003.

Wake County Public School System (WCPSS). "School Bus Transportation- General Policies." < http://www.wcpss.net/transportation/policies.html> Accessed February 2003.

Wake County Public School System (WCPSS). "Bell Schedule 2002-2003" and "WCPSS Overview." <http://www.wcpss.net > Accessed February 2003.

Wright, Charles L. Fast Wheels, Slow Traffic. Philadelphia, PA: Temple University Press, 1992.

APPENDIX A:

Preliminary Survey Form

Public Opinion Survey for Wake County Public Schools Transportation
[For Parents and Guardians]

The School Transportation Group (STG) is a part of the Institute for Transportation Research and Education (ITRE) at NC State University. We research the application of technologies, policies, and planning techniques in an effort to make school transportation more safe and efficient. Having permission from Wake County Public Schools, STG would like your input in order to prioritize areas of need for school transportation. The survey should take less than 15 minutes of your time. Your answers will remain confidential--we have no way of identifying individual respondents.

Please insert and mail the completed survey in the postage-paid envelope provided to: ***School Transportation Group, ITRE-NCSU, Box 8601, Raleigh, NC, 27695 by Friday, November 2, 2001.***

Thank you in advance for your contribution!

Please complete this survey for up to four (4) of your children currently enrolled in Wake County Public Schools.

1. List the age, gender, and grade for each of your children enrolled in Wake County Public Schools in the 2001-2001 school year.
   Child 1: _____ Age _____ M (male) or F (female) _____ Grade
   Child 2: _____ Age _____ M (male) or F (female) _____ Grade
   Child 3: _____ Age _____ M (male) or F (female) _____ Grade
   Child 4: _____ Age _____ M (male) or F (female) _____ Grade

Please identify each child according to his/ her number in Question 1 for the rest of this survey. So, the child listed as Child 1 in Question 1 should also be Child 1 in Questions 2 through 7.

2. Does your child live in an area where school bus service is provided for the school that he/she attends?
   Child 1: _____ Yes _____ No _____ Don't Know
   Child 2: _____ Yes _____ No _____ Don't Know
   Child 3: _____ Yes _____ No _____ Don't Know
   Child 4: _____ Yes _____ No _____ Don't Know

In Questions 3 and 4, check the appropriate box, for each child, to answer the question. You may check more than one box if your child uses different methods on a regular basis.

3. How do your children get to school **in the morning**?

Child:	1	2	3	4
Walks				
Bikes				
Rides School Bus				
Rides Contracted Van/ Bus Or Uses Public Transit				
Drives				
Driven By Parent				
Driven By Older Sibling				
Driven By Other				
Other__________________				

4. How do your children get home from school **in the afternoon**?

Child:	1	2	3	4
Walks				
Bikes				
Rides School Bus				
Rides Contracted Van/ Bus Or Uses Public Transit				
Drives				
Driven By Parent				
Driven By Older Sibling				
Driven By Other				
Other________________				

5. **If your child __does__ ride the bus, skip to Question 6.** If your child usually **__does not__** ride the school bus, check the appropriate box or boxes to explain why.

- ☐ Bus pick up times in the morning do not fit our schedule.
- ☐ Bus drop off times in the afternoon do not fit our schedule.
- ☐ Bus does not arrive on time.
- ☐ Bus ride takes too long.
- ☐ We live within walking distance of the school.
- ☐ I have bus safety concerns.
- ☐ I have bus behavior concerns.
- ☐ My child has been (temporarily or permanently) "kicked off" the bus.
- ☐ My child does not go directly to school or come directly home after school (due to job, sports, etc.).
- ☐ My child enjoys riding with friends.
- ☐ Other- please explain. ____

____

6. **If your child __does not__ ride the bus, skip to question 8.** If your child usually rides the bus, check the appropriate box below to describe the bus arrival time.

☐ Mostly on time ☐ Mostly late ☐ Mostly early ☐ Unpredictable

7. a. If the bus is usually **__not__** on time, estimate the number of times that the bus **__does not__** arrive in the expected time frame **__for a typical week__**. (If your children ride the same bus, answer only for Child 1 and check the box to the right.)

	Estimated Number of Times Bus Has Been Early or Late		
Child	0 – 1	2 – 3	4 – 5
1			
2			
3			
4			

☐ My children ride the same bus.

b. If the bus is usually not on time, estimate the amount of time by which the bus is early or late on a typical day. (Answer for morning pick-up and afternoon drop-off.)

	By How Many Minutes Is Bus Usually Early/Late? In The Morning:					**By How Many Minutes Is Bus Usually Early/Late? In The Afternoon:**				
Child	**Not Late**	**1 to 5**	**6 to 10**	**11 to 15**	**More than 15**	**Not Late**	**1 to 5**	**6 to 10**	**11 to 15**	**More than 15**
1										
2										
3										
4										

8. In your opinion, is it safe for your child to travel to/from school by:

	Very Safe	Fairly Safe	Not Safe	Don't Know
Walking				
Biking				
Riding School Bus				
Riding Van/ Transit				
Driving				
Driven By Parent				
Driven By Older Sibling				
Being Driven By Other				

9. Traveler information technologies are available that can alert you a few minutes before the actual bus arrival (using a pager-like unit). This will minimize the amount of time your child waits outside for the bus. The parent of multiple children riding the same bus from the same household would need just one pager. What cost would you consider "reasonable" for each parent to pay to subscribe to this service?

☐ $1 - $5 per month ☐ $10 - $14 per month
☐ $5 - $9 per month ☐ $15 - $20 per month
☐ I would choose not to pay for the pager at all.

10. Vehicle-tracking technologies could improve the on-time arrival of the school bus and allow for regular monitoring of bus position, using a system that would centrally monitor the location of all buses. Which of the following costs would you consider "reasonable" for the Wake County School System to pay to add this vehicle-tracking equipment to a bus? (Consider: the average cost of a new school bus is $60,000; a new bus is not necessary to implement this technology; about 700 buses are operated each day in Wake County)

☐ Less than $500 ☐ $500 - $1000 ☐ $1000 - $5000
☐ I don't think this equipment should be bought at all.

11. In which high school district do you live?

☐ Apex ☐ Broughton ☐ Cary
☐ East Wake ☐ Enloe ☐ Fuquay
☐ Garner ☐ Leesville ☐ Millbrook
☐ Sanderson ☐ Southeast Raleigh ☐ Wake Forest
☐ Wakefield ☐ Don't Know

12. Provide any additional comments below.

____
____
____
____

Thanks again for your participation!

APPENDIX B:

New Survey Form

WAKE COUNTY PUBLIC SCHOOLS TRANSPORTATION SURVEY
[For Parents and Guardians]

The School Transportation Group at NC State University is conducting research in attempt to enhance student travel safety by understanding better how children get to and from school and the factors that influence this decision. Please provide your input by completing the following survey, which should take less than 15 minutes of your time.

Please answer the following questions for up to three (3) of your children ***enrolled in grades K-8*** *of a Wake County Public School this 2002-2003 school year. Return the completed survey in the postage-paid envelope provided to:*

School Transportation Group, Centennial Campus Box 8601, Raleigh, NC, 27695
***by Tuesday, November 26, 2002**.*

Thank you in advance for your contribution!

---

1. List the age, grade (K-8), gender (M or F), and school attended for your child(ren).

Child	*Age*	*Grade*	*Gender*	*School Attended*
1	___	___	___	______________________
2	___	___	___	______________________
3	___	___	___	______________________

2. Estimate how far (in miles) each of your children lives from his/her school.

Child 1: ____________ ***Child 2:*** ____________ ***Child 3:*** ____________

3. Estimate how many minutes it would take if your child traveled to his/her school using the following ways. (Provide answers for the ways that are feasible.)

Child	*School Bus*	*Automobile*	*Bike*	*Walk*
1	_____	_____	_____	_____
2	_____	_____	_____	_____
3	_____	_____	_____	_____

4. Circle "Y" for yes or "N" for no to answer each question about traveling to your child's school- even if he/she does not use that way to get to/from school. If the answer does not apply to all your children, write in the number (1-3) of the child to whom the answer applies.

If walking or biking:

Y N Sidewalks or walking/biking paths available?
Y N Must cross one or more major intersections?
Y N Other things exist that make walking unsafe?

If riding the school bus:

Y N Child has to wait a long time for bus to come?
Y N Child has to transfer buses to get to/from school?
Y N School bus service is reliable?
Y N Child rides bus home because parent work schedules prevent picking up?

If riding in an automobile:

Y N Your family owns or has regular access to a car?
Y N Your family could carpool with other families?
Y N You could drive your child to/from school on the way to/from work or another activity?

5. Place an "X" in the appropriate blank to indicate how your children get **to school** most often.

	School Bus	Auto	Walk	Bike	Other	
Child 1	___	___	___	___	___	Explain "Other"-
Child 2	___	___	___	___	___	________________________
Child 3	___	___	___	___	___	________________________

6. Place an "X" in the appropriate blank to indicate how your children get home **from school** most often.

	School Bus	Auto	Walk	Bike	Other	
Child 1	___	___	___	___	___	Explain "Other"-
Child 2	___	___	___	___	___	________________________
Child 3	___	___	___	___	___	________________________

7. How do you rank the following four ways children get to school in terms of safety?
(1-most safe, 4-least safe) / Example: 1 Walk 2 Bike 3 School Bus 4 Auto
Your answer: __ Walk __ Bike __ School Bus __ Auto

8. If your child(ren) ride(s) the bus, place an "X" in the appropriate blank to judge the typical bus arrival time in the morning and afternoon.

	AM			*PM*		
Child	On Time	Early	Late	On Time	Early	Late
1	___	___	___	___	___	___
2	___	___	___	___	___	___
3	___	___	___	___	___	___

9. If your child(ren) do(es) not ride the bus, place an "X" next to all reasons that explain why. If the reason does not apply to all of your children, write the number (1-3) of the child to whom the reason applies.

___ Morning pick-up times too early
___ Morning pick-up times too late
___ Afternoon drop-off times too early
___ Afternoon drop-off times too late
___ Bus does not arrive on time
___ Bus stop too far from our home
___ Child involved in before-school activities
___ Child involved in after-school activities
___ Safety concerns about student behavior
___ Safety concerns about school bus operation
___ School bus service is not provided because we live within 1.5 miles of the school.
___ School bus service is not provided because child attends school outside base attendance area.
___ Other ______________________________________

10. If your child(ren) do(es) not ride the school bus, would you allow him/her to ride if for a charge of $5 - $10 per month you would be provided with a pager that would sound in your home a few minutes before the bus actually arrived (shortening the time that you and/or your child must wait at the bus stop)? ___ Yes ___ Maybe ___ No

11. If your child(ren) do(es) not ride the school bus, would you allow him/her to ride if the school bus positions were monitored regularly at the school transportation office (increasing student safety and improving the on time arrival of buses)? ___ Yes ___ Maybe ___ No

12. Please provide your zip code: __________
(Optional) Parent's Name: ________________________

Thanks again for participating!