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Teenagers' Mode Choice To And From School And Technology Use For Transportation: Analysis Of Students From Five High Schools In Vermont And California

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TEENAGERS' MODE CHOICE TO AND FROM SCHOOL AND TECHNOLOGY USE FOR TRANSPORTATION: ANALYSIS OF STUDENTS FROM FIVE HIGH SCHOOLS IN VERMONT AND CALIFORNIA

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ABSTRACT

The carhops and drive-ins of the 1950s are symbolic of the freedom that the automobile has granted Americans. What the general public has gained from the automobile, however, may come at the expense of independent mobility and choices for today's adolescents, particularly those not yet old enough to drive or those from lower income families. Sprawl land use development patterns and limited transportation choices in most American cities often hold teenagers and their chauffeuring parents captive to the automobile. At the same time, information and communication technology is fast evolving and changing the ways in which teenagers live, interact, and communicate with others; easier transportation coordination is one potential outcome. This study seeks to examine teenagers' travel behavior for their most common destination – going to and from school – and how the use of technology influences this behavior. Survey data from five high schools, three in Northern California and two in Vermont, are used to identify the mode choice to and from school, socio-demographic characteristics, and technology use of the sampled teenagers. The built environment of the teenagers' home surroundings is determined by data obtained from the 2010 Census. Logistic regression analysis is used to describe the most significant variables influencing both mode choice to and from school, and the factors associated with the use of technology. Those variables with a family income component, such as high family education, access to a car and smartphone ownership have a positive effect on teenagers driving more to and from school. Similarly, those teens who travel longer distances depend more on rides and choose active modes of transportation than teens living in more populated neighborhoods. When it comes to technology use for transportation among teenagers, those living farther away from school, in worse connected neighborhoods are more likely to depend more on technology for arranging transportation, whereas those teens who choose active transportation modes to school depend less on. High density development policies seem the right recommendation to ensure teenagers choose active transportation alternatives to school and depend less on their parents, family, and friends to move around. Due to the strong influence of attitudes in teenagers' behavior, social education and culture adaptation programs could be suggested to encourage teens to become more confident on active transportation modes, as well as promote safe routes to school for both genders.

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CHAPTER 1 – Introduction

The carhops and drive-ins of the 1950s are symbolic of the freedom that the automobile has granted America's youth. Having the choice to drive, walk, or bike to a particular destination, however, is a privilege that not every teenager can enjoy. What the general public has gained from the automobile may come at the expense of independent mobility and choices for today's adolescents, particularly those not yet old enough to drive, or those from lower income families who cannot afford or do not have access to this mode. Income and other socio-demographic characteristics of families often define the accessibility of teenaged users to certain modes and, therefore, may affect their daily transportation routine. Public transit and other alternative modes may have the potential to offer greater autonomy for teenagers. However, sprawling land use development patterns as well as the limited transportation choices in most American cities may hold teenagers and their chauffeuring parents captive to the private automobile. These built environment characteristics may be some of the factors that influence American teenagers' choice of mode to commute to school.

Also, technology is evolving faster and faster. The internet has become a widely used tool especially in developed countries. A large majority of individuals in the country have access to the web and use it not only for business (File and Ryan 2014), browsing or even playing, but also for communicating with other individuals. In addition, the improvements that have been developed around mobile devices and tablets have been shown to increase the use of these devices at an individual user scale. Phone calls, texts, emails, online chatting, and social media are part of present day teenager's everyday life

(Craig, McInroy et al. 2014). We might not realize, but we use smartphones and computers in our everyday lives, and these technologies are making a difference in the way we live, interact and communicate with others. Teenagers have grown up using these technologies, and therefore they are part of their daily routine. In fact, according to Pew Internet and American Life project (2013) 95 % of adolescents (12–17) and 94 % of young adults (18–29) in the United States were online in 2011, and are more likely than adults to communicate using information and communication technologies (ICTs). This increase in communication alternatives for young populations may affect their way of arranging transportation. Being in constant communication with family members and friends may improve their transportation options and alternatives, increasing the number of activities they can access to. The use of technology for transportation related arrangements may make a change in the travel behavior of teenagers.

With this study, I seek to examine teenagers' travel behavior for their most common trip – going to and from school – and also factors related to their use of technology for their general transportation needs. Survey data from five high schools in the U.S. has been used in the study, two from Vermont and three from Northern California. Such surveys, developed and conducted by researchers at the University of Vermont and University of California Davis, were not the same for both states but had many questions in common. The California survey included questions related to teenagers' attitude towards transportation, which allowed for examinations of those factors. In addition to the survey data, geographical data analysis has also been developed to better define the built environment characteristics.

Specifically, the paper sets out to explore the following questions:

- What factors influence teenagers’ travel mode choice to and from school?
    - What socio-demographic and built environment factors are relevant for students from both states?
    - What attitudinal factors influence the California teenagers?
- What factors influence teenagers in using technology for arranging transportation?
    - What socio-demographic and built environment factors are relevant for students from both states?
    - What attitudinal factors influence the California teenagers?

The rest of the thesis is organized as follows. A discussion of the importance of studying travel by teenagers is followed by a detailed review of the literature on teenagers and transportation, providing sufficient background and context to understand current research findings in the area. Next, the descriptions of the methodologies used to answer the research questions are described, as well as the results and discussions of the findings. As it is described later in the study, the models used and the methodology applied do not show causality in the results. The outputs of the models may have many more affecting variables that have not been considered in this study, which is why the models show association between the explanatory and dependent variables used in this study rather than causality. Additional data and deeper analysis would be needed to obtain stronger association and potential causality relationships.

MOTIVATIONS

Teenagers, sandwiched between being children and becoming adults, undergo many changes in their lives; increases in independence and accessibility are common and significant experiences for them. Teenagers' mobility options are constrained by parental consent and age restriction on driving. On the other hand, transitioning to adulthood means behaving in a more mature way and, therefore, assuming progressively more responsibilities in the household. The ability to drive, and having access to vehicles at home, makes a difference on the travel independence and mobility options of teenagers. This unique juncture in people's lives is an interesting time to study his or her travel behavior.

The private automobile is the main mode of transportation for daily commuting among Americans, and teenagers are no exception (NHTSA 2008, Analysis 2014). Children's mobility can be limited by their parents' availability to chauffer them where they want or need to go. Teenagers, however, experience both worlds of dependence and independence in their transition towards adulthood. Access to driving and cars may become present in their lives and may impact their everyday routine. Besides, as young drivers, teenagers can also contribute more to household errands, which can make parents support this increase in their children's autonomy. Therefore, they may experience an increase in accessibility to more or other activities, and it can change their travel behavior. Nevertheless, it also has a direct effect on their mode choice to and from school. For instance, those children who would take the bus to go to school, may switch to driving if they have the chance. Similarly, and related to teenagers having a more mature behavior, many parents feel more comfortable letting their kids walk or bike alone after a certain age. Whether teenagers choose to drive for the increase in travel opportunities, or walk and bike for independence, it is crucial to understand what makes teenagers choose their transportation mode.

Teenagers' accessibility and independence is not influenced by their travel behavior only. Urban land use and transport planners have shown in various studies that choosing active transportation modes is highly correlated with the built environment around the residence of the system users. Thus, it is essential to determine the characteristics of the built environment of the teenagers in order to better understand their travel behavior and come up with policies to promote healthy transportation alternatives (Rhoulac, 2005).

In addition, ICTs such as mobile phones and the Internet have become increasingly pervasive in the modern society. These technologies provide their users with more flexibility with respect to when, where, and how to travel. Mokhtarian (2002), for instance, studied how an increase in technology use for transportation arrangements may improve communication among users and, therefore, increase efficiency in transportation connectivity. However, research has also shown that the effect of mobile phone or internet usage for travel purposes may vary (Yuan et al., 2012). Understanding the influence of ICTs in teenagers' travel behavior (Raubal, 2011) will be essential in understanding their mobility needs and accessibility options.

For these reasons, teenage travel patterns warrant closer inspection. Understanding more about how American teenagers travel may provide insights into how policy can respond to their current mobility needs, preferences, and behavior. Efforts to divert Americans out of their cars, improve access, and increase the retail and other nonwork opportunities available in and around residential neighborhoods may find teenagers to be responsive targets. At the same time, these policies may address concerns about safety, and the associated costs with automobile use. A better understanding of current teenage travel and its contribution to household travel demand is warranted before policy can respond to this need.

CHAPTER 2 – LITERATURE REVIEW

The literature for influences on travel behavior is wide in scope. Factors related to transportation mode choice can be grouped into four main categories: socio-demographic, attitudes, built environment, and virtual environment (Thulin and Vilhelmson 2006, Sidharthan, Bhat et al. 2010). Socio-demographic factors include both individual and family or friends' common characteristics (e.g., gender, age, income, parent's education, ethnicity, family size, number of vehicles in household, etc.). The built environment describes the surroundings and geographical characteristics of locations such as one's home, work, or school (e.g. population density, urbanity/rurality, land use, available infrastructure, etc.). The virtual environment defines new ways of communication and social interactions we develop and experience because of advances in technology (e.g. telephone use, the internet, social media). And attitudes define less tangible attributes that users take into account when making a decision (e.g., comfort, convenience).

Children's mode choice has been widely studied, especially their travel behavior to and from school and the factors influencing in their active mobility (Fulton, Shisler et al. 2005). Walking and biking are the two most studied active modes of transportation among children to school. Due to children's lack of independence in comparison to teens and adults, several studies found that besides individual factors, such as age or gender, parental and environmental factors heavily contribute to children's mode choice to and from school (Fyhri and Hjorthol 2009, Hjorthol and Fyhri 2009). For such a young population, the behavior of their relatives in their daily activities such as transportation can have a significant impact (Emond and Handy 2012).

For adults, income, family size, age, and type of work or working hours are some of the socio-demographic characteristics that impact their travel behavior and mode choice decision making (Hanson and Huff 1986). Although some of these factors are not the results of younger adults and choices younger adults and teenagers make, they can still affect their mode choice, and therefore are as key variables to consider (Cain 2007). The following sections discuss existing literature in the three main travel behavior and mode choice influencing variable groups: Socio-demographics, built environment and social interactions, the virtual environment, and attitudes.

Socio-Demographic characteristics

Existing research on travel behavior analysis shows the importance of socio-demographic characteristics when considering mode choice. Teenagers' and children's active transportation (AT) has been widely studied, driven by health concerns and lack of physical activity among younger populations (Alexander, Inchley et al. 2005). AT is a means of getting around that is powered by human energy, primarily walking and biking, and is also often called "non-motorized transportation." These studies, together with research that examines the transportation needs and the independent mobility options of children and teens, have identified age, gender, family size, and income as the socio-demographic variables with the greatest influence in their daily transportation behavior patterns (Clifton 2003, Bungum, Lounsbery et al. 2009, Van Dyck, De Bourdeaudhuij et al. 2010).

Young boys and low socio-economic status teenagers have higher AT rates than girls and high socio-economic-status teenagers (Bungum, Lounsbery et al. 2009, Van Dyck, De Bourdeaudhuij et al. 2010) . It has also been shown that men are more likely to choose AT than women, and that income and ethnicity are directly correlated with the mode choice and activity options of adults (Gordon-Larsen, Nelson et al. 2006).

Previous work shows the effect of family members have on individual travel behavior. Adult transportation and travel models that incorporate interactions of household characteristics have shown that the presence of children affects adult activity and travel scheduling (McDonald 2008). Similarly, and more specifically looking at teenagers, the number of siblings in the family as well as the age of those siblings influence teenagers' travel mode choice to and from school (Timperio, Ball et al. 2006, McDonald 2008, Holt, Cunningham et al. 2009, Mitra, Buliung et al. 2010). The first journeys teenagers make without their parents are very often accompanied by slightly older siblings; in fact, having siblings who walk and bike is associated with higher rates of walking and biking for high school students (Pabayo, Gauvin et al. 2011). On the other hand, the most significant travel companions for teenagers are still their parents (McDonald 2008). Within the household, mothers are very likely to drive their young teenagers to school, especially if their job and children's high school are close by, which means mother's work status strongly influences whether children and teenagers walk to school. Therefore, the day-to-day mobility of teenagers is strongly determined by the dispositions that they have incorporated into their domestic, residential, and educational sphere (Devaux and Oppenchaim 2013). The permission with which parent's grant their children, together with children’s participation level in diverse activities are also factors that influence in their mobility level and that can be clearly expanded to the mobility behavior of the teenager population (O'brien, Jones et al. 2000, Prezza, Pilloni et al. 2001, Yarlagadda and Srinivasan 2007, Fyhri and Hjorthol 2009).

Models of school travel show that differences in observed walking and biking rates result from minority and low-income students living closer to school, having lower household incomes, and, therefore, less vehicle access (McDonald 2008). Family income defines teenagers’ access to certain modes such as private automobile or even transit passes (McDonald, Librera et al. 2004). School transportation costs are often a barrier that prevent poor students from participating in after-school activities, and, in severe cases, lead to missed days of school. However, although income is exclusively a family and therefore individual characteristic, it is highly correlated to the neighborhood average income and so to land use patterns, job accessibility, existing transportation infrastructure, or population density characteristics. These variables define the built environment in which a household is located, and play a key role in understanding the travel behavior and mode choice of teenagers to and from school.

Attitudes

Attitudinal factors include individuals’ and parents’ confidence, the level of parents’ protection towards their kids, children’s willingness or appeal of using a specific mode, or even the behavior of others that affects their own (Johansson 2006, Paulssen, Temme et al. 2013). Parents’ regular mode choice and, therefore, the travel behavior pattern to which their kids have been exposed in the early years of their lives, plays a very important role in predicting children's mode choice in the future (Ferdous, Pendyala et al. 2011). Therefore, teenagers are not only affected by the built environment in which they have been raised, but also the family setting and habits to which they have been exposed.

Children whose parents have a positive opinion about biking and walking on a daily basis are in fact much more likely to commute to school by active modes of transport (Emond and Handy 2012). Similarly, travel behavior of children's friends also plays a key role in their personal transportation mode choice, showing that social environment is an essential factor to take into account when studying travel behavior and mode choice. In fact, less than 4% of the daily commutes to work among U.S. workers is done by foot or bike. The lack of active transportation among adults in the country has shown to influence children's travel behavior (Gatersleben and Appleton 2007), meaning that children whose parents either use active transportation to work or for recreational activities or encourage them to bike and walk can, in fact, considerably increase their likelihood of using active transportation (Emond and Handy 2012).

These attitudinal factors have been previously associated with increased active commuting among children (Kerr, Rosenberg et al. 2006, Rodriguez and Vogt 2009). Hume, Timperio et al. (2009) stated that this association is less significant among teenagers than in children due to their gain in independence. But McDonald (2008) wisely contributes with the potential link of that gain in independence to teenagers' access to vehicles or driving license ownership, and its clear correlation to family income.

Built environment characteristics

Numerous studies suggest that neighborhood and environmental characteristics such as population density, transportation infrastructure, job accessibility, safety, lighting, or weather are related to travel behavior and individual mobility options (Ewing, Brownson et al. 2006, Heath, Brownson et al. 2006, Brownson, Hoehner et al. 2009). In the particular case of teenagers and their routine daily school travel, neighborhood physical characteristics as well as economic characteristics significantly influence student's transportation options and mode choice (Sirard, Riner et al. 2005, Kerr, Rosenberg et al. 2006, Frank, Kerr et al. 2007, Kerr, Frank et al. 2007, Trowbridge and McDonald 2008).

Some types of neighborhood layouts and street environments have shown to expose users to more dangers from traffic and crime, and highly influence teenagers' likelihood to walk to school (Zhu and Lee 2008). Common urban form descriptive variables are land use patterns and population density. These variables have shown to be related to teenagers' walking and biking choice to access high school (Frank, Kerr et al. 2007). Kerr, Frank et al. (2007) stated that living in a mixed use neighborhood and having access to both commercial and recreational activities within walking distance from homes affect adult walking behavior and that it is also related to youth walking behavior. Distance and proximity to potential destinations has been studied in depth in active transportation and health benefit research, looking at walkability rates and recreational activities. The evidence regarding adolescents' active transportation is primarily restricted to walking to school. Proximity, population density, mixture of land uses, quality of infrastructure, street network and connectivity, and safety are among the potent correlates among adults and teenagers for active transportation trips to and from school (Braza, Shoemaker et al. 2004, Grow, Saelens et al. 2008, Nelson, Foley et al. 2008, Saelens and Handy 2008, Mitra, Buliung et al. 2010).

Research has been done looking at the relationship between active transportation and urban form for adults, but the associated factors for adults may differ from those for teenagers. Frank, Kerr et al. (2007) looked at walking rates of young teens (12-15 years) based on the urban form surrounding their place of residence. For this group, the odds of walking were 3.7 times greater for those in highest- versus lowest-density tertile. In the analysis, number of cars, recreation space, and residential density were most strongly related to walking. In addition, Trowbridge and McDonald (2008) studied urban sprawl and miles driven daily by teenagers in the United States. Teens in sprawling counties are more than twice as likely to drive than teens in compact counties. This difference is even more significant among the youngest drivers, whose probability of driving more than 20 miles per day varied from 9% to 24% in compact versus sprawling counties, respectively.

Land use patterns and population density not only have effects on teenagers' active travel behaviors, influencing their mobility options and alternatives and accessibility, but also their driving rates (Nutley 2005, Moore, Jilcott et al. 2010, Zhang, Mohammadian et al. 2010). More than 85% of workers in this country commute to work by automobile (McKenzie and Rapino 2011). Directly linked to the urban form, distance to work, transportation resources, and employment status are some of the most influencing factors in this behavior (Schwanen and Mokhtarian 2005). This highly car dependent travel behavior among adults is not only related to urban form but also has a direct effect on teenager's travel behavior. Similar to adult's mode choice, car is still the most common mode of transportation among teenagers in the country (Rhoulac 2005). Although the number of young drivers has been dramatically declining over the past 30 years (Weissmann 2012), teenagers shift to automobile transportation as soon as they are licensed to drive and have access to a vehicle, considerably decreasing the use of active modes of transportation to access school (Davis and Dutzik 2012). This behavior is even more apparent where distances are longer, as in rural areas.

The combination of car dependency and sprawling urban form, with lower income families and less accessibility to transportation alternatives can lead to an isolated environment for teenagers (Hazler and Denham 2002). The literature for understanding teenagers' risky behaviors due to geographic isolation is wide in scope. Drinking and driving, drug abuse, vandalism, or even bullying are some of the effects from which isolated teenagers are more likely to suffer (Levine and Coupey 2003, Swaim, Henry et al. 2006, Thrane, Hoyt et al. 2006, Proctor, Linley et al. 2008). Most of these studies have been conducted by sociologists, psychologists, and psychiatrists, looking at the mental health of children and the influence of their land use pattern in their behavior. For instance, Swaim, Henry et al. (2006) found higher rates of violent behavior among students in urban communities compared to those in rural and suburban communities. Levine and Coupey (2003) introduced the term "urban advantage" in their study. They stated that teenagers' engagement in substance use or sexual behavior may be reduced among urban youth due to their greater access to confidential care. Van Vliet (1983) studied and suggested an increase in young population density as a variable influencing travel behavior and improving transportation alternatives among children and their development. Luckily, technology has proven to help teenagers overcome this geographic isolation issue, increasing communication, transportation options and improving overall mobility options among younger people (Lee 2007, Thulin and Vilhelmson 2007, Hjorthol 2008, Lee 2013).

Virtual environment

Teenagers' level of mobility considerably increases for those with their own car. However, not every teenager is old enough to drive, while others may not be allowed to drive by their parents, or might not be in a financial position to afford their own car. Even if a vehicle is available for personal use, driving is not a desirable option for trips to certain destinations because of access restrictions imposed by limited or expensive parking (Cain 2007). Increasing their exposure to technologies and, therefore, improving their connectivity among friends and family may provide teenagers with a larger variety of connection alternatives. By increasing communication between friends or neighbors, car rides could be shared, bike rides could be done together with someone else, or even walking would not have to be done alone.

Information and communication technologies, such as mobile phones and the internet have become increasingly pervasive in modern society (Thulin and Vilhelmson 2006). Having access to these technologies allows users to be more flexible about when, where, and how to travel (Townsend 2000, Thulin and Vilhelmson 2007). Although one might think that an increase in connectivity due to technology may positively affect transportation and mobility options, research has shown that the effect of mobile phone or internet usage for travel purposes may vary. Regarding this issue, two main research paths can be identified. On one hand, it has been found that using the mobile phone for transportation purposes increases the activity space of users, leading to larger movement radii and more random and harder to predict movements (Yuan, Raubal et al. 2012). Some researchers believe that technology plays an anti-socializing role, allowing users to become more independent from other users, but depend more on their accessibility to technology (Oksman and Turtiainen 2004, O'Keeffe, Clarke-Pearson et al. 2011). On the other hand, some studies have analyzed the contrary effect: how an increase in technology use for transportation arrangements may improve communication among users and therefore better and more efficient transportation alternatives (Townsend 2000, Mokhtarian 2002). In fact, it is very likely that much of the impact is in the form of modifications in travel patterns, such as timing, destination change, coupling with other users or a change of mode travel. Emerging technologies such as transportation phone applications can also interact and influence urban life. For instance, forms of mass communication permeate boundaries between different spatial contexts, enabling people to extend themselves in space and time by finding information about contacting people who are spatially distant from themselves (Valentine and Holloway 2002). Walker, Whyatt et al. (2009) studied the level of teenagers' engagement with technologies and its effect on their school journey. Teenagers would often change their mode choice to and from school from day-to-day or week-to-week, based not only on their activity needs, household situation or built environment characteristics, but also based on the relationships, communications, and mutual needs they would build with their classmates using the technology (Walker, Whyatt et al. 2009). Instant messaging (IM), as a particular way of virtual communication, enables social congregation among teens such as event planning, meeting others for shopping or seeing a movie (Alison Bryant, Sanders-Jackson et al. 2006). Grinter and Palen (2002) studied the efficiency of IM at enabling multiple people to coordinate around numerous personal and physical constraints all at once. This virtual mobility provided by phones and computers can replace, complement, or even generate physical mobility and transportation in various teenager contexts (Thulin and Vilhelmson 2006, Thulin and Vilhelmson 2007, Yuan, Raubal et al. 2012). Including the effect of the use of technology related to transportation is an essential step that should be studied in travel behavior analyses, especially when analyzing such a technologically active group as teenagers (Lee 2007, Lee 2013).

CHAPTER 3 – DATA

Two different data sets were examined in this study. Survey data has been used to determine socio-demographic, virtual environment characteristics, attitudes of teenagers, and geographical data has been used to determine built environment characteristics. The following subsections describe in depth the origin of each data set, as well as the data description, processing, and analysis.

SURVEY DATA

Origin and school environment description

The survey data used for this study are secondary data that were developed and conducted by researchers at the University of Vermont (Cope and Lee, 2011) and the University of California (Handy, Lovejoy et al. 2013) ,Davis. The data provided by these researchers was in excel and word format, and was later processed and completed with additional data. Two of the surveyed high schools are located in Chittenden County, Vermont (South Burlington HS and Champlain Valley Union HS) and the other three in Northern California (Davis HS, Sequoia HS, and Tamalpais HS). The surveys for the two states were different, but similar in question type and survey design. These characteristics allowed for examination of relationships among teenagers and their travel behavior across the two states. The following sections describe the data collection procedures as well as sampling sizes and respondent rates for each high school.

Study from the University of Vermont

The study developed by researchers from the University of Vermont was conducted in the years 2011/2012. The purpose of the study was to investigate the travel behavior of teenagers and their relationships with external factors. Researchers utilized a mixed-methods approach to understand teen mobility.

Quantitative data in this study were collected through both teenagers' and parents surveys in October 2011. All parents in both high schools were contacted first, and at the end of their survey they were asked for permission to contact their teenagers by email to continue with the second survey. The surveys were completed electronically, and the total number of collected full parent and teenager surveys were 146.

In addition to these two surveys, a second phase was conducted by Cope and Lee. This phase involved five students who volunteered and were interested in follow-up activities related to the study. In a variety of exercises, students shared their personal perspectives on travel modes, activity hubs in their communities, and common transportation routes. In addition, in order to gain insights on the interaction between communication and mobility, a "text review" methodology was created. Each student shared text message content related to arranging transportation. They identified instances in the past week when they discussed about going to a place or doing an activity, and they described with whom they were sharing those texts as well as the times, dates, destinations, travel modes, and activities they were planning. This text review exercise revealed how teens use various forms of messaging to coordinate activity and transportation plans, which could complement technology related questions in the survey (Cope and Lee, forthcoming).

The two studied high schools are located in Chittenden County, the most populated county in Vermont. Both selected High Schools are located in this County, and therefore the survey results obtained are not representative of the rest of the State. Figure 1 and Figure 2 show the location of both high schools and the municipalities.

South Burlington High School (SBHS) is located in the town of South Burlington. It has a population of 18,612 and a population density of 950 person/sq. mi (3.5 times higher than the density in Chittenden County). Champlain Union Valley High School (CVUHS) is located in the town of Hinesburg but the school district includes the towns of Charlotte, Hinesburg, Shelburne, Williston, and St. George study there. The total population of the five municipalities is 24,449, and the population density is 183 person/sq.mi (less than a half lower than in the County).

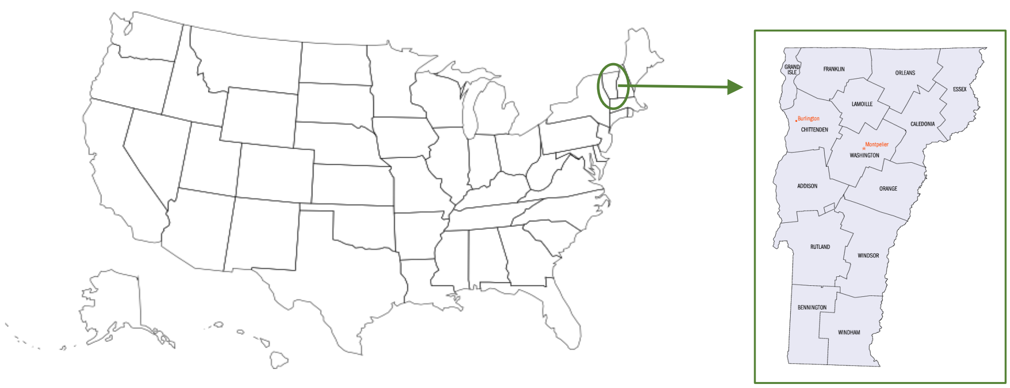


Figure 1 *Location of the State of Vermont*

Figure 2 *Location of Chittenden county and SBHS and CVUHS*

The main reasons why these two high schools were selected was the similar socio-demographic characteristics of the students but very different built environment characteristics for each school district. Although the high schools are only ten miles apart, the population densities of the districts are considerably different. The population density in Chittenden County is more than four times larger than the average State density. Within the most populated county in the State (272 person/sq. mi) there is a significant variation among the towns where the sampled students in the two chosen high schools are located.

Compared to the predominantly white population in the State, Table 1 shows that Chittenden County is more diverse and also wealthier. The income gap is much more significant in the CVUHS school district, where the median family income is considerably higher than in South Burlington and both the State and the County, but the percentage of families with an income lower than $25,000 is also higher. On the other hand, very small differences can be seen when it comes to the percentage of workers commuting by car in each town.

Table 1 *Socio-demographic attributes of the two high school locations in Vermont*

	South Burlington, VT (South Burlington High School, SBHS)	*CVUHS High School Town District*	*Chittenden County*	*Statewide in VT*
Median family income	$83,000	$100,096	$84,284	$68,227
Families <$25,000	6.7%	19.5%	9.1%	12.6%
Families >$200k	8.3%	3.0%	8.3%	4.8%
% Workers commuting by car	86.7%	84.3%	80.9%	84.5%
% White only	90.6%	100.0%	94.2%	96.7%
% Hispanic (of any race)	1.0%	0.0%	1.0%	1.0%
% Asian (alone or with any other race)	5.3%	0.0%	2.8%	1.0%

Source: U.S. Census Bureau, 2010

The survey questions included teenagers' individual characteristics (age, gender, race, bicycle ownership, driving license, mobile phone ownership), household (Lovejoy and Handy 2013)characteristics (number of siblings, parent's income, highest education degree in household, number of vehicles in household), transportation related questions (mode to/from school, use of technology for transportation) and also the address of the household.

Study of Northern California

The study developed by UC Davis was an exploratory study that was designed to identify key factors affecting whether or not high school students bicycle to school. The survey was first designed and conducted in 2008 in Davis by Dr. Handy and her research group. Davis is a prosperous university town with a population of around 65,000 located in Central Valley, California. Davis is well-known for its bicycling culture, but not representative of Northern California Counties, which is why two more High Schools were selected in which to conduct this survey, Tamalpais HS, in Marin County, and Sequoia HS, in San Mateo County (Lovejoy and Handy 2013) (Figure 3).

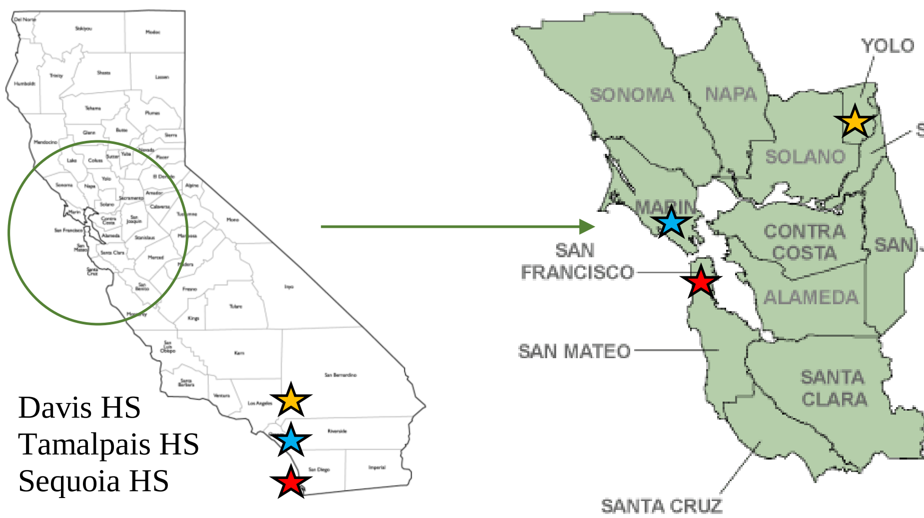


Figure 3 *Locations of Davis, Tamalpais, and Sequoia high schools in Northern California*

Surveying Davis, Sequoia, and Tamalpais, the surveyed sample targets high schools situated in more diverse built environments, enriching the mode choice proportions. The two other schools included in the study meet this criterion in that they are not nearly as bicycling-oriented as Davis, but are also in Northern California in communities with at least some bicycling activity and infrastructure.

While a broader array of schools could better capture the full range of experiences in different community types, Tamalpais and Sequoia together provide diversity well beyond the Davis context. The three schools -- and the communities in which they are situated – differ from each other in important ways, including the flavor and extent of bicycling culture in the broader community; the level of investment in bicycling infrastructure in the vicinity of the school; the topography and catchment area for the high school itself; and the socio-demographic make-up of each community.

In each case, researchers from California relied on a lead faculty member from the school to help coordinate the distribution and collection of the surveys. These faculty leads identified a date and time to conduct the survey that would work for their school's schedule, selecting a time period in which all students could be included while minimally interfering with class time. During the designated time period, the teacher in each classroom passed out the survey, read a statement assuring students that it was voluntary, and then collected the completed surveys. Although cooperation was invited via encouragement from the lead faculty person, as well as endorsed by school administration, teachers in each classroom were not required to participate in the study.

The total sample size of this data set is 2,900; 1164 students from Davis, 1011 from Sequoia, and 725 from Tamalpais High School.

Specific questions asked in the survey can be found in Appendix B. In the survey transportation-related, socio demographic questions, and technology use questions were asked. In addition to transportation behavior related questions, attitudinal questions were also answered by the students in a scale of 1 to 5. These questions revealed teenagers' perspective and tendency of more general matters, such as the environment. Including these attitudinal questions complemented more direct questions such as the mode choice, and better frame teenagers' behavior. Although exact household location was not asked, respondents provided the closest street intersection in order to geographically locate it for further analysis.

With respect to demographics, all three communities are somewhat wealthier than the state as a whole, according to the 2010 Census (see Table 2). Mill Valley (served by Tamalpais High) is especially wealthy and white. The community served by Sequoia is more economically and racially diverse than Davis or Tamalpais, and importantly includes students from areas beyond Redwood City where the school itself is located (and for which statistics are shown in Table 2).

Table 2 *Socio-demographic attributes of the three high school locations in California*

	Davis, CA (Davis High)	*Redwood City, CA (Sequoia High)*	*Mill Valley, CA (Tamalpais High)*	*Statewide in CA*
Median family income	$106,586	$88,525	$167,561	$70,231
Families <$25,000	11.9%	9.5%	2.9%	15.2%
Families $200k+	16.6%	17.3%	40.1%	8.4%
% workers commuting by car	68.9%	90.3%	80.1%	89.3%
% white (only)	64.9%	60.2%	88.8%	57.6%
% Hispanic (of any race)	12.5%	38.8%	4.5%	37.6%
% Asian (alone or with any other race)	25.3%	13.1%	7.7%	14.9%

Source: U.S. Census Bureau, 2010

GEOGRAPHIC DATA

Besides household location (addresses for the Vermont schools and closest intersections for the California ones), additional geographical information is considered in the analysis with various built environment variables. The distance from home to high schools can be directly calculated from the survey, but little more is known about the neighborhoods in which the households are located. In order to analyze the built environment, the following variables are considered: centrality, job access, neighborhood income, general population density and population density of teenagers.

Centrality represents the distance from each household to the closest urban area. The definition of "urban area" used in this study is the one from the Census: 50,000 or more people. Common central place models of urban form hold that properties closer to the center of a region have higher accessibility to the rich and dense work and consumption opportunities that tend to be located in the center (Cortright 2009).

For job access, data drawn from the Census Bureau's Zip Code Business Patterns database is used. Zip code information is assigned to each household and, in addition, the number of jobs within 1 mile (walking), 5 miles (biking) and 10 miles of the households are computed. This measure of job accessibility aims at capturing activity options for each household related to their locations, which are likely to increase relative to the proximity to employment opportunities.

Neighborhood income is determined as the Census 2010's reported values for median household income of the census block group in which each household is located. These income levels can be used as proxies for neighborhood quality and to reflect the external effects associated with the income level of one's neighbors. Neighborhood income levels are frequently associated with crime rates and school quality (Cortright 2009). Although these are not factors directly studied in this analysis, neighborhood income levels have shown to have impacts on the activity levels of people (Fischer, Li et al. 2004) and can, therefore, have significant effects in teenagers' mode choice and technology use for transportation.

In addition, population density in neighborhoods have shown to affect travel behavior and activity levels of teenagers (Newacheck, Hung et al. 2003, McDonald 2008, Saelens and Handy 2008, Brownson, Hoehner et al. 2009, Bungum, Lounsbery et al. 2009). Analyzing the density of teenagers living around each of the studied households will allow us to better define the characteristics of the built environment. This analysis is developed using Census 2010 population data, and looking at the number of young people living within 1 mile, 5 miles, and 10 miles from the homes. All the geographical data has been obtained through *ESRI*.

DESCRIPTIVE STATISTICS

The sample sizes for each high school are considerably different. The total number of students who answered the survey in South Burlington and Champlain Valley are 146, whereas in Davis, Sequoia and Tamalpais, this number is much larger (Table 3). While the Vermont survey has fewer respondents, it is also a richer set of data with more in-depth questions and complementary qualitative data.

Analyzing the percentage of students accessing their respective high schools in any kind of active transportation mode (walk, bike, skateboard), it can be seen that, not surprisingly, Davis has the highest proportion. Due to its geographical characteristics as well as biking habits and infrastructure, the number of students biking to high school can be up to six times higher than in Tamalpais or Sequoia (Table 3).

Table 3 Mode choice proportion per high school

	Davis	Sequoia	Tamalpais	SBHS	CVUHS
Bike/skate	33.8%	5.6%	6.6%	0.8%	0.6%
Walk	5.8%	30.6%	22.1%	8.5%	1.5%
Car/motorcycle	61.2%	70.7%	77.5%	50.2%	55.1%
Bus/train	6.7%	9.2%	9.5%	40.5%	42.8%
Total	1164	1011	725	84	61

Since the descriptive statistics show many similarities among all sampled populations, data from the five high schools has been combined for mode choice distribution analysis. The following figures show the distribution of mode choices among teenagers by high school, age and gender.

Figures 1 through 4 show the mode choice distribution by grade and Figures 5 through 8 the mode distribution by gender.

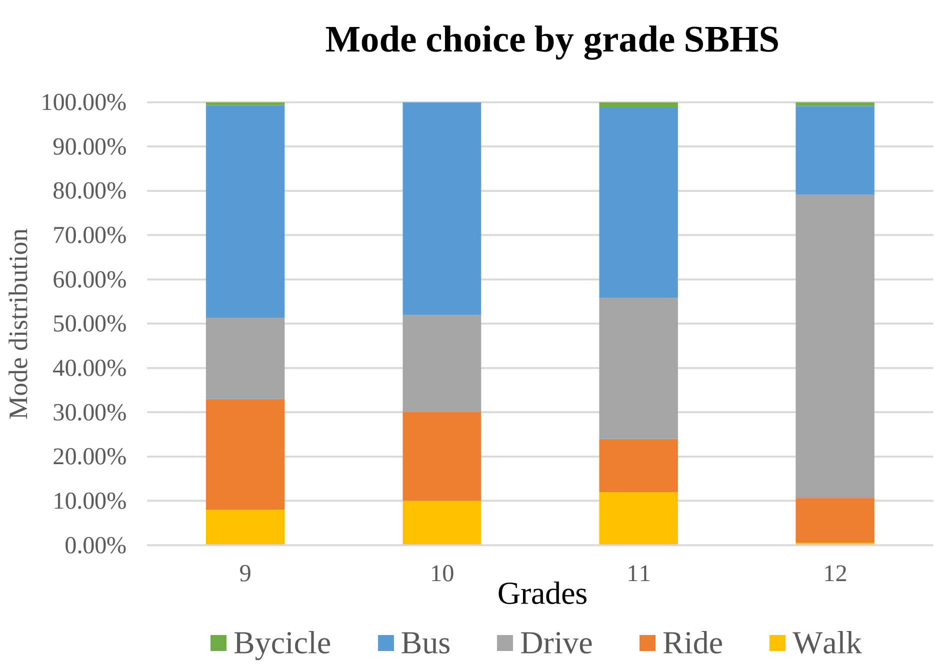


Figure 4 *Mode choice by grade in South Burlington High School*

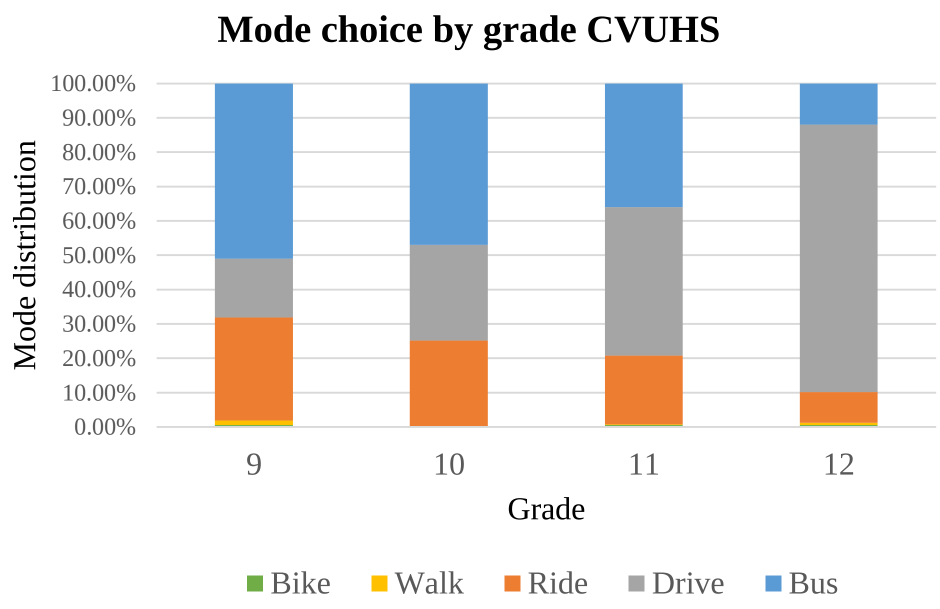


Figure 5 Mode choice by grade in Champlain Valley Union High School

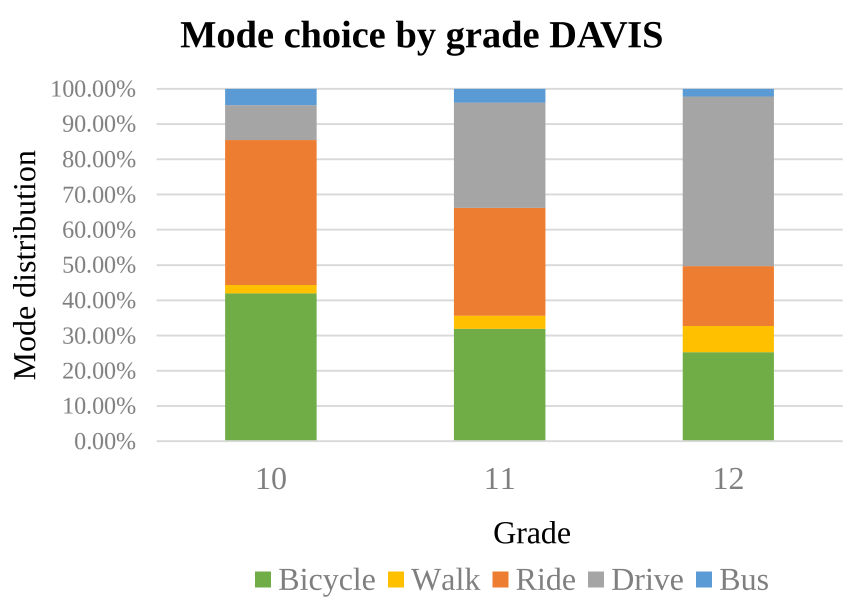


***Figure 6** Mode choice by grade in Davis High School*

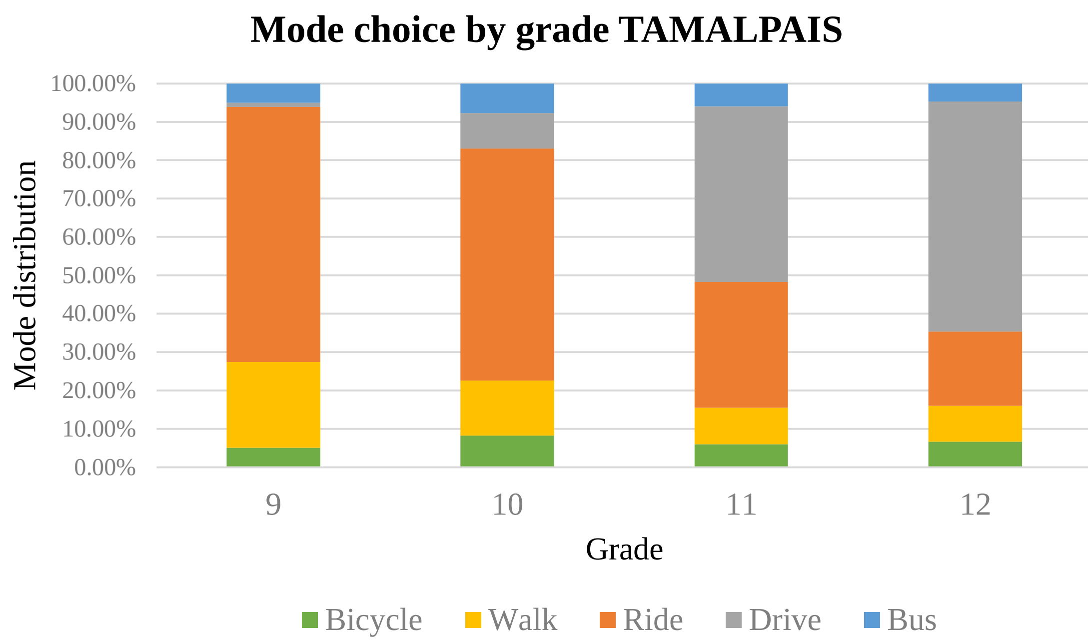


Figure 7 *Mode choice by grade in Tamalpais High School*

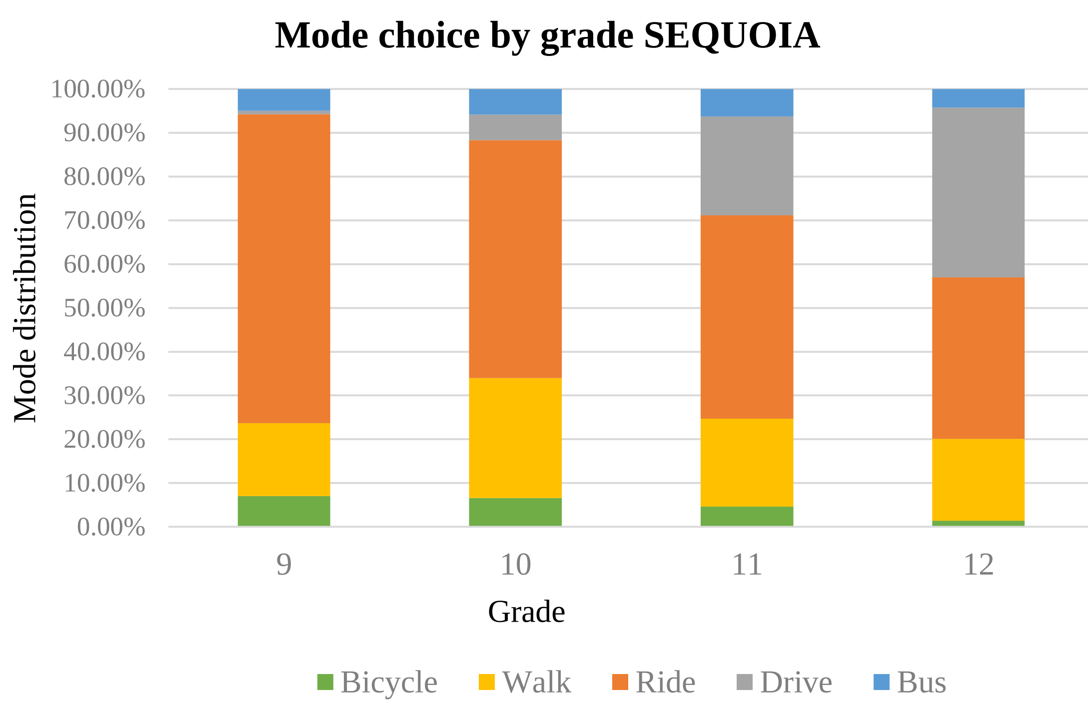


Figure 6 *Mode choice by grade in Sequoia High School*

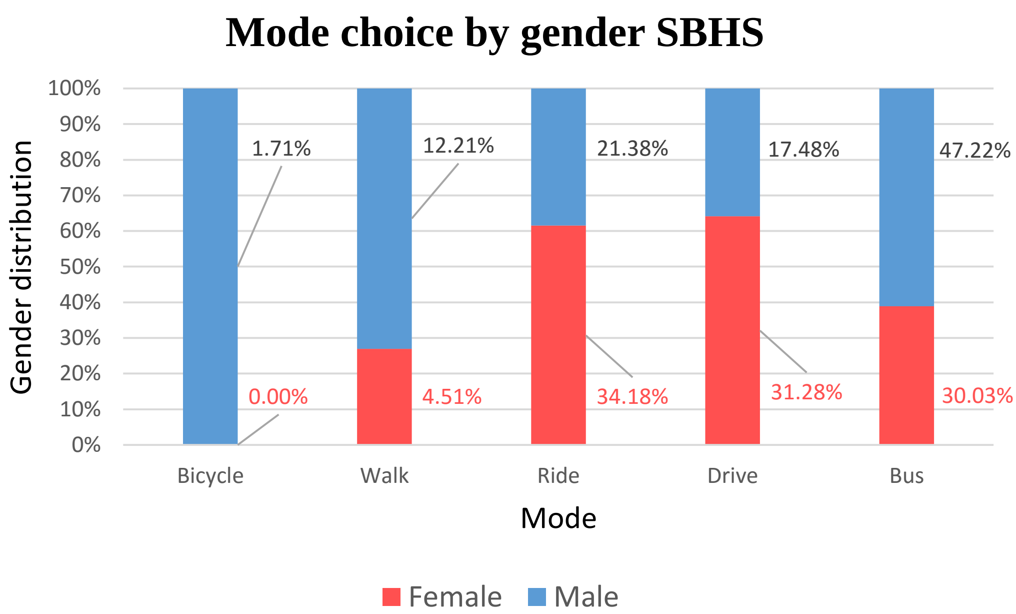


Figure 7 *Mode choice by gender South Burlington High School*

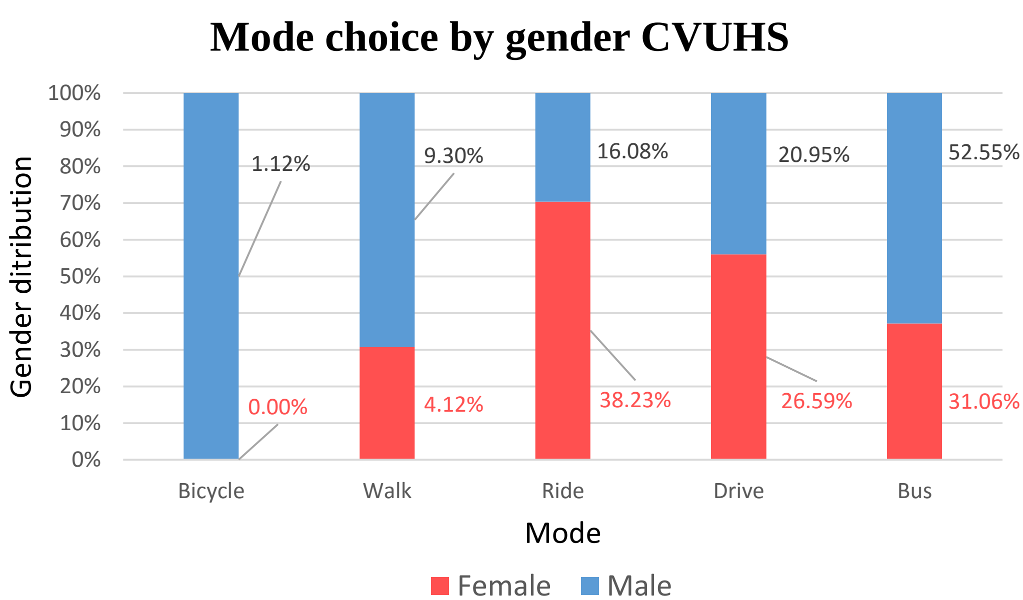


Figure 8 *Mode choice by gender Champlain Valley Union High School*

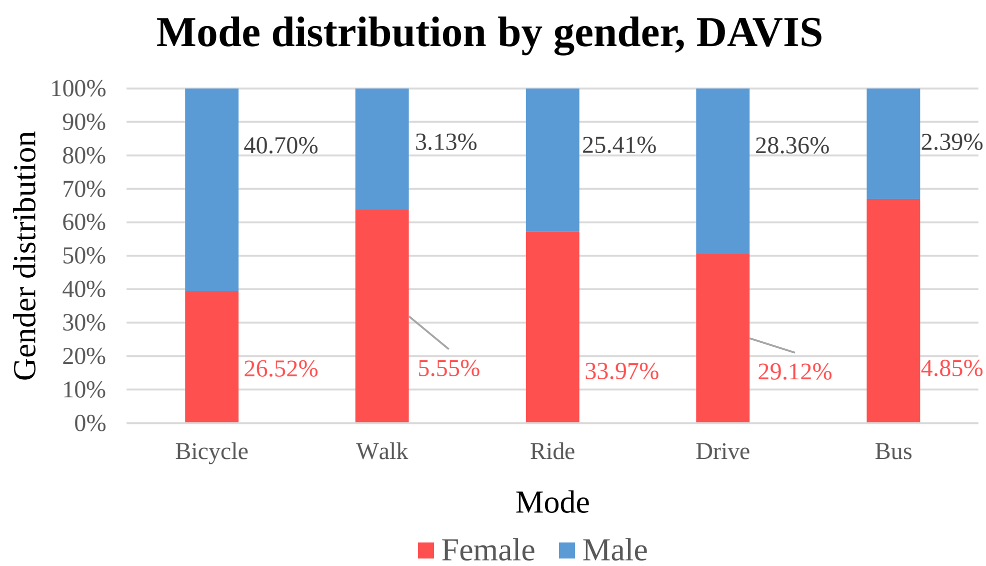


Figure 9 *Mode choice by gender DAVIS*

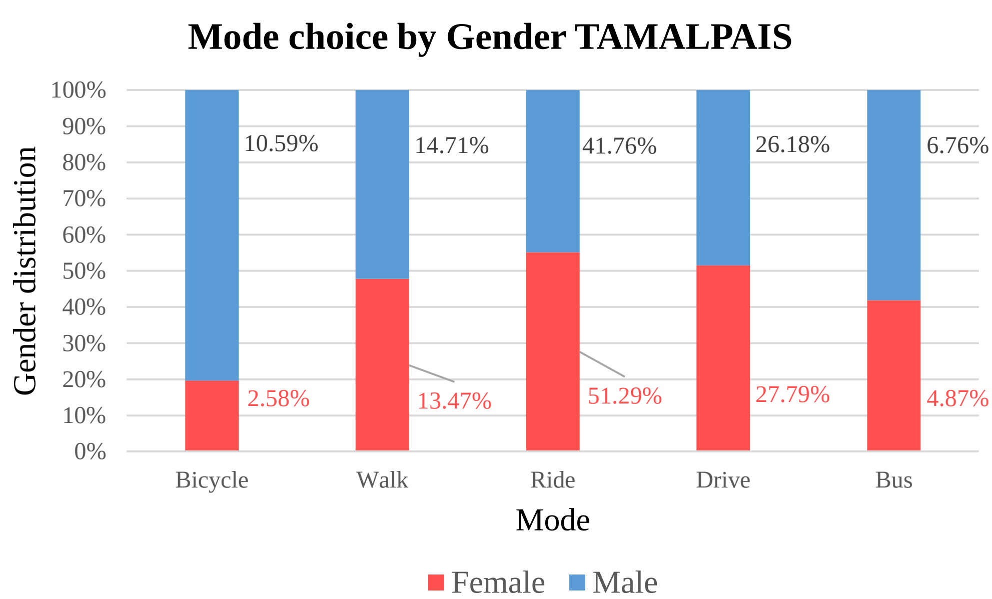


Figure 10 *Mode choice by gender TAMALPAIS*

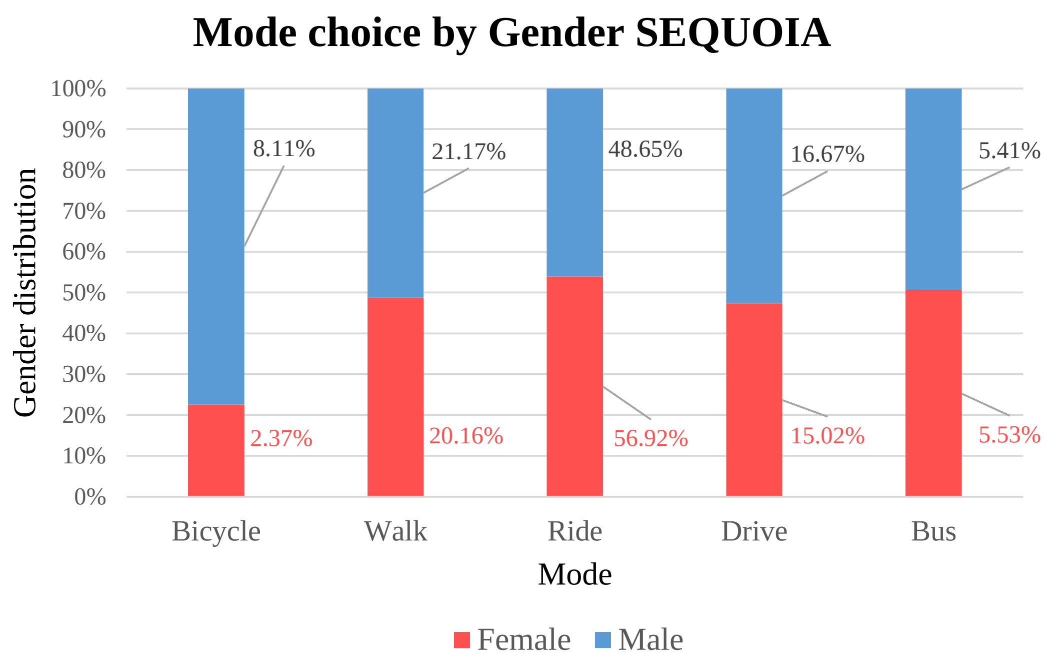


Figure 11 Mode choice by gender SEQUOIA

Although the respondents of the surveys were students from different counties and states, when looking at the effect of gender and age on their travel behavior, we can see that students of all schools follow a similar pattern. The proportion of students who drive to school increases for older teenagers. In fact, carpooling or riding with others follows the opposite trend as driving their own car, and this can be seen in all surveyed high schools. Although biking rates in Davis High School are much higher than in the other schools, the proportions of students walking, biking and riding the bus to school also decreases with age, as with all surveyed high schools. Regarding gender the distribution in teenagers' mode choice, it can also be seen that very similar patterns occur in every surveyed high school. Males walk and bike more, and ride with others less than females. They also tend to take the bus more, and overall choose to use the car less than females to access high school.

DATA PROCESSING

As previously stated, data used for this study has two main sources. One, survey data (developed and conducted by researchers in UVM and UCDavis), and the other, geographical data. In order to link both datasets together, the data were carefully processed.

For both Vermont and Californian surveys, household location information was asked of each student. This information consisted of exact home address (for Vermont) and closest street intersection (for California). These point data were geocoded in order to calculate travel distances to school as well as built environment characteristics. Some of these data, however, were either missing or were not recognized as valid locations (Table 4). Since distance to school is a key variable, only those records with valid values were selected for analysis.

Table 4 *Geocoding percentages and matches per high school*

High School	N total	N geocoded	Geocoded %	Missing cross-streets / address (%)	Not located (%)
Davis	1164	859	73.8	20	6.2
Sequoia	1011	652	64.5	19.9	15.6
Tamalpais	725	492	67.9	18.3	13.8
SBHS	62	57	91.9	4.1	4.0
CVUHS	83	75	90.4	4.5	5.1

One-mile, five-mile, and ten-mile service areas were calculated around each surveyed household, and these polygons were used to clip census tract data as well as street network data in order to calculate population parameters and network availability for each teenager. One-mile service areas represent walking distance, five-mile biking distance and ten-mile driving distance. Similarly, each household was spatially joined to geographical Federal Information Processing Standards (FIPS), and urban areas and cluster polygons.

Data analysis

Most of the variables used in the study were categorical. The surveys provided multiple options to choose from for many questions, but for the purpose of this analysis, such results have been recoded, grouped and simplified. The following table shows the answer options of the questions used in this study, and the variable recoding.

Most of the variables were recoded as binary. When developing the models, having variables with multiple categories would give unstable results due to the small number of records per category. Except for the variable "grade", which was kept as four categories, the rest of the categorical variables were reduced to only two categories. Mode to school variable, as the outcome variable in the developed model, was simplified in four categories: walk/bike, bus or other, ride, and drive. Similarly, in order to model the frequency of technology use for transportation, this variable was also simplified from five to three, but still ordinal, categories. Other variables that became significant or increased influence in the output when recoding them were: having or not having a cellphone, having or not a driving license, parent's education, and number of siblings in the family. Table 5 shows the summary of the data processing for recoding each variable.

Table 5 *Survey variables recoding*

SURVEY QUESTION	Variable	Alternatives	Recoding
What grade are you in?	Grade	9,10,11,12	
What is your gender?	Gender	Male, Female	
How do you usually get to school?	Mode to school	I bicycle I walk I skateboard A friend drives me A family member drives me Another parent drives me I drive myself I take the bus Other	Bike/Walk Bike/Walk Bus or other Ride Ride Ride Drive Bus or other Bus or other
Do you currently own or have regular access to a functioning bicycle?	Bicycle	No Yes	
Do you have a cellphone?	Cell phone	No Yes [not a smartphone (SP)] Yes, a smartphone	Not a SP Not a SP A SP
How often do you use a cell phone or technology to arrange transportation?	Frequency of technology use for transportation	Every day Most days of the week A few days a week Once a week or less Never	High Medium Medium Low Low
Most recent driver's license/permit	License	Provisional license Regular driver's license Driver learner's permit I do not have a license	Yes Yes No No
Parent's education	Education	Some High School High School Some College Associate Degree Bachelor Degree Advanced Degree Other	Low Low Low High High High Low
Do you have siblings currently living with you?	Siblings	No Yes, older Yes, younger	

The following figures show the distribution for each variable, and the recoding approach chosen to analyze and model the data. Values are shown as % of the total N value (N=1780).

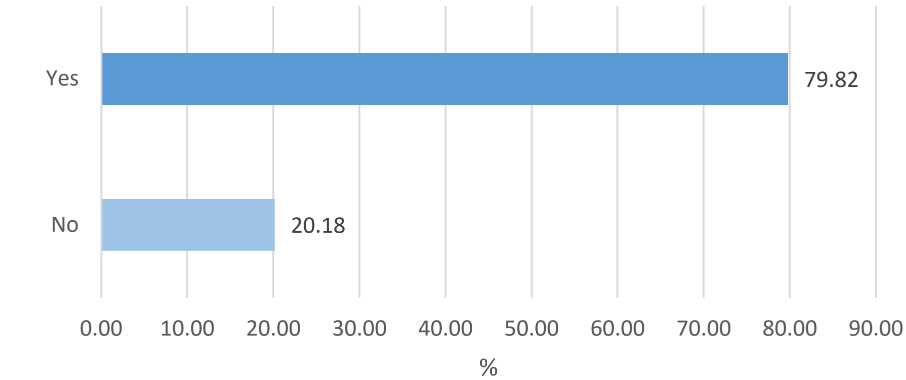


Figure 12 *Bicycle Distribution*

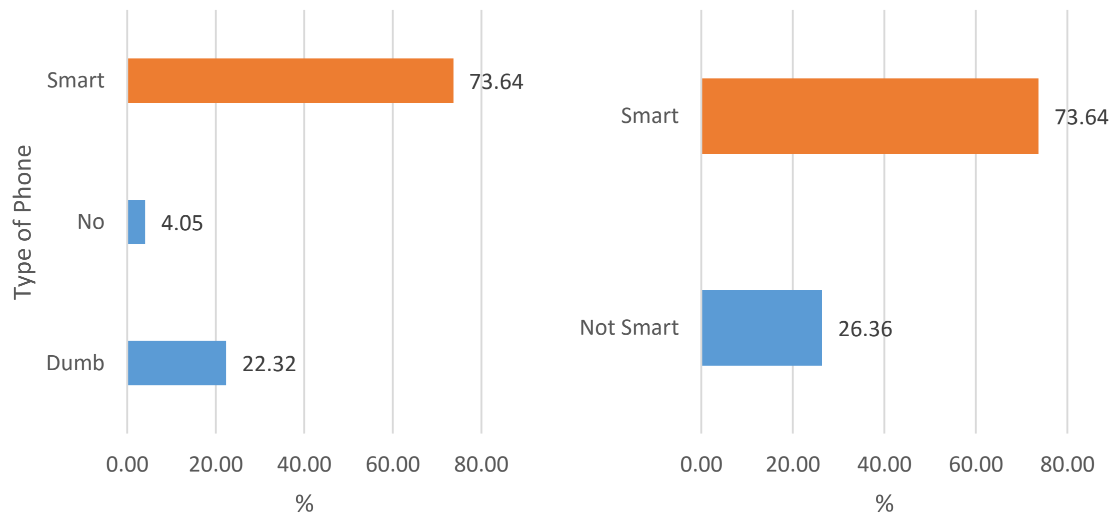


Figure 13 *Phone Distribution*

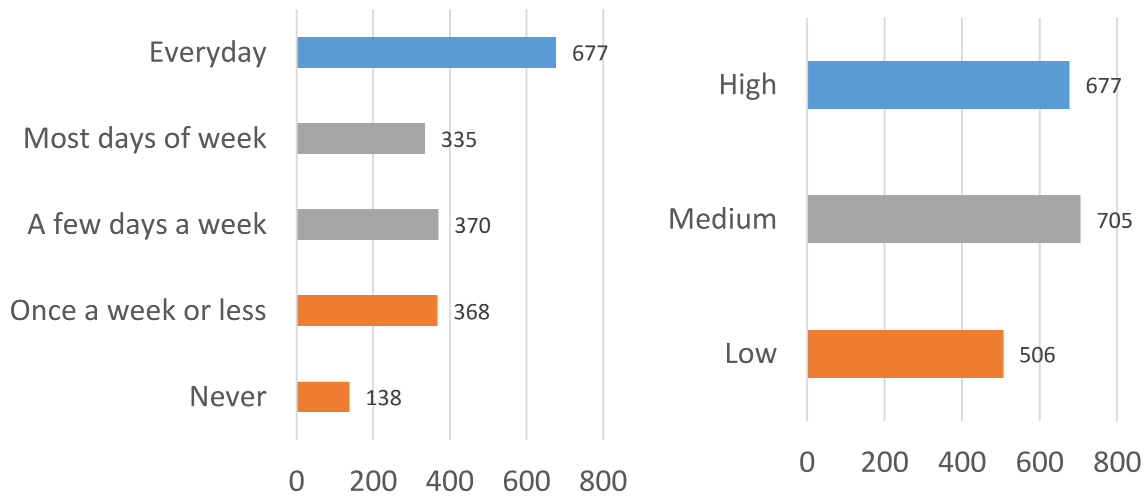


Figure 14 *Technology Use Distribution*

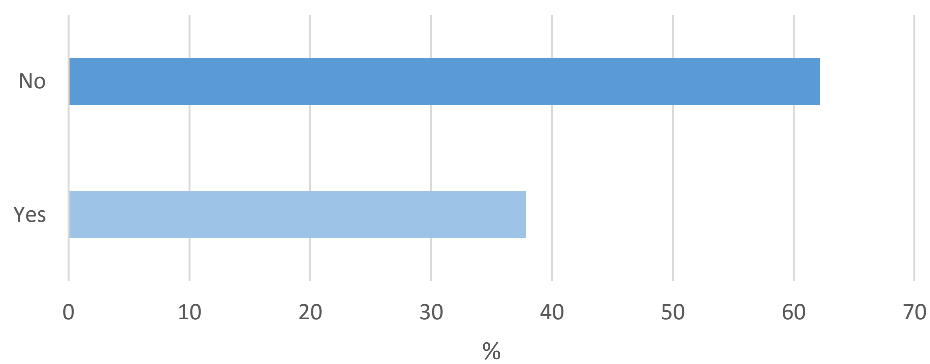


Figure 15 *Driving License Distribution*

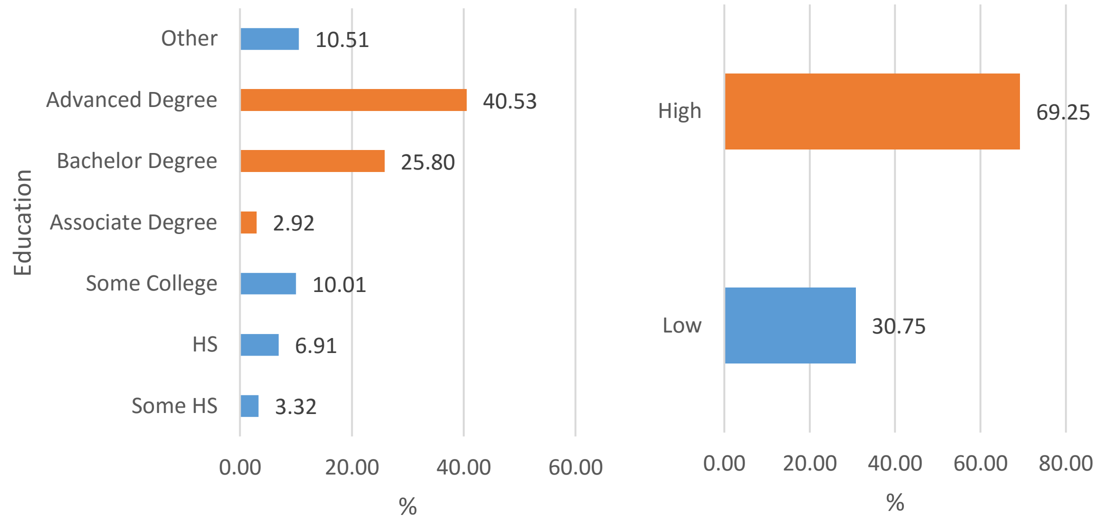


Figure 16 *Education Distribution*

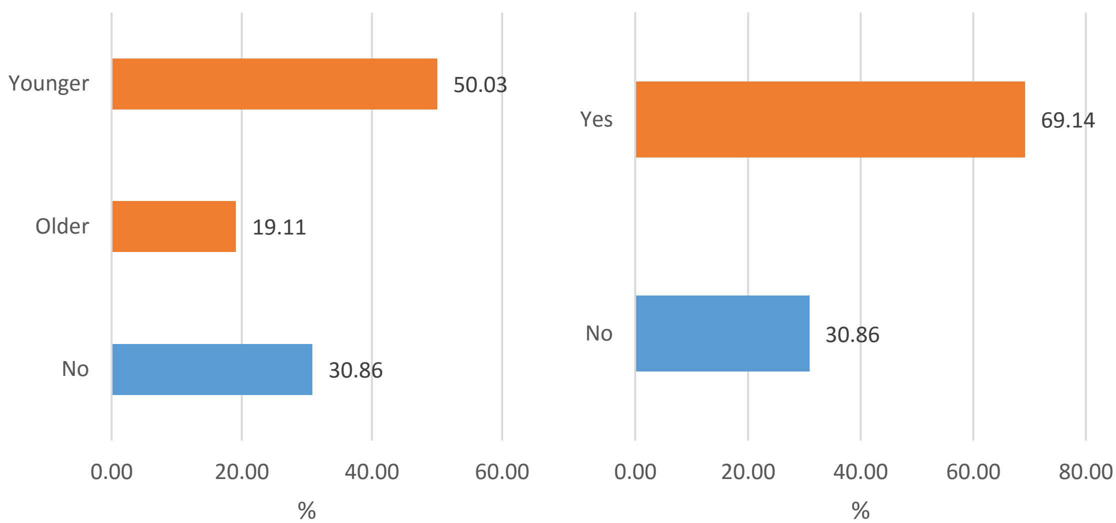


Figure 17 *Siblings Distribution*

For geographical data, most of the variables used were continuous. Therefore, no transformation or recoding was needed. However, Figures 20 and 21 as well as Tables 7 through 11 show the distribution of each geographical variable used in the models.

Table 6 shows the geographical variables used in the study:

Table 6 *Geographical data variables*

Geographical Variable	Unit	Type
Distance to School	Miles	Continuous
Urban Area	-	Binary (1 = Yes)
Total population in 1, 5, and 10 miles service areas	People	Continuous
Total street length within service areas (1, 5, and10 miles)	Miles	Continuous
Most common mode to commute to work (by census tract)	(%)	Binary (1 = >75%)
Most common job type (by census tract)	(%)	Binary (1 = >50%)

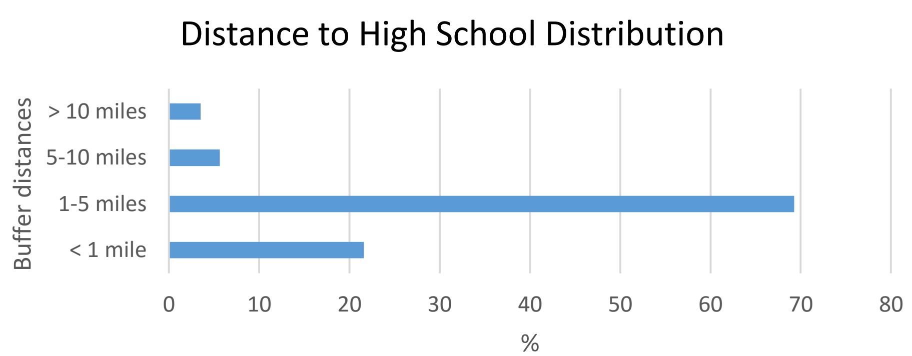


Figure 18 *Distance to School Distribution by buffers*

Table 7 *Distance Descriptive Statistics*

	Miles
Mean	1.793
Min	0.060
Max	63.363
Std	3.111

Table 8 *Population density (total and teenager) by distance buffers. Descriptive Statistics***.**

	Tot. Pop 1 mile	Tot. Pop 5 miles	Tot. Pop 10 mile	Teen Pop. 1 mile	Teen Pop. 5 miles	Teen Pop. 10 miles
Mean	6755.842	440021.484	388186.248	380.993	6363.229	6695.615
Min	265.746	0.000	35621.647	0.218	0.000	44.711
Max	15066.000	334361.113	904421.120	2167.258	25526.563	37095.482
Std	2492.076	50210.093	184376.263	519.861	3060.569	6175.335

Table 9 *Street length descriptive statistics by distance buffers*

	Street Length1 mile	Street Length 5 miles	Street Length 10 miles
Mean	0.454	5.765	9.278
Min	0.040	0.303	0.668
Max	1.037	16.066	31.299
Std	0.202	2.686	5.536

Table 10 *Distribution of transportation mode for daily commute by census tract (%)*

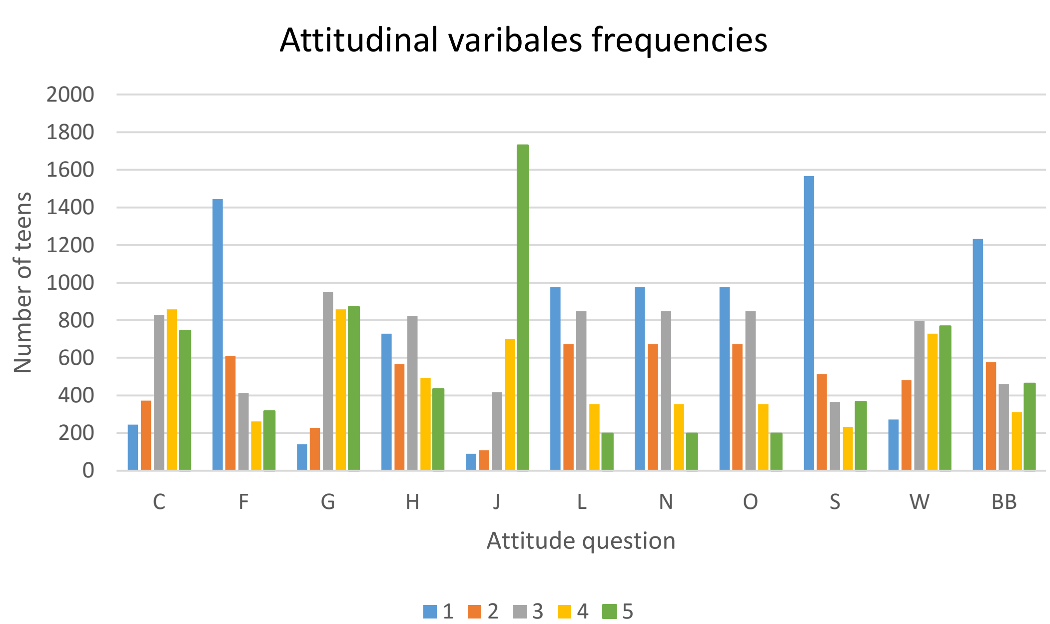
	DriveAlone	Carpool	PublicTransp	Walk	MotoBikeEtc	WorkHome
Mean	63.447	7.543	6.859	3.165	9.579	7.504
Min	20.505	1.280	0.000	0.000	0.000	0.000
Max	91.943	26.576	16.387	18.707	49.647	21.204
Std	10.788	4.082	3.973	2.697	10.295	3.954

Table 11 *Distribution of Occupations by census tract (%)*

	Management	ServiceProp	Sales	Natura	Production	Military
Mean	53.702	11.505	18.943	4.521	4.766	0.053
Min	9.329	1.749	7.899	0.000	0.436	0.000
Max	80.739	52.478	34.846	34.981	21.237	1.653
Std	16.307	8.889	5.555	4.007	3.929	0.250

***Table 12** Attitudinal questions included in the models*

Attitudinal variable	Question #	Categorical scale
I like bicycling	C	1 (Strongly disagree) – 5 (Strongly Agree)
Bicycling is my usual way of getting around town	F	1 (Strongly disagree) – 5 (Strongly Agree)
I like being driven places	G	1 (Strongly disagree) – 5 (Strongly Agree)
My parents encourage me to bicycle	H	1 (Strongly disagree) – 5 (Strongly Agree)
I feel comfortable getting places on my own	J	1 (Strongly disagree) – 5 (Strongly Agree)
I like riding the bus	L	1 (Strongly disagree) – 5 (Strongly Agree)
I can rely on my parents to drive me places	N	1 (Strongly disagree) – 5 (Strongly Agree)
I need a car to do the things I like to do	O	1 (Strongly disagree) – 5 (Strongly Agree)
One or both my parents bicycle frequently	S	1 (Strongly disagree) – 5 (Strongly Agree)
I have lots of stuff to carry to school	W	1 (Strongly disagree) – 5 (Strongly Agree)
I live too far away from school to bicycle there	BB	1 (Strongly disagree) – 5 (Strongly Agree)



CHAPTER 4 – MODE CHOICE TO AND FROM SCHOOL

STATISTICAL METHOD

All variables in the survey data set were binary or categorical variables. Since this research aimed to determine the influence of different factors on the mode choice to and from school, the outcome variables used in the models were the mode choice to and from school. Since mode choice for each surveyed teenager is a multinomial variable, multinomial logistic regression models were used.

The multinomial logistic regression function is shown in equation 3-1 (Agresti 2007). Here, the parameter α is the intercept term and β_n determines the rate of increase or decrease of the variable x_n.

Equation 4-1 *– Logistic Regression Function*

$$\ln\left(\frac{\pi(x)}{1-\pi(x)}\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$$

The odds ratio is a statistical outcome that describes the strength of association between two variables. Here, the odds ratios between the mode choice and predictor variables are calculated. Odds ratios and their confidence intervals can be obtained from the parameter β from the logistic regression, and are shown in Equation 3-2 (Agresti 2007).

Equation 4-2 – *Odds Ratio and Confidence Interval*

Odds Ratio = e^{β}

Confidence Interval = $(e^{\beta \pm \frac{z_\alpha}{2}(SE)})$

Odds ratios equal to 1.0 indicate that the event or condition is equally likely to happen for either levels of the variable. Ratios larger than 1.0 indicate an increased odds for the event in the first group. On the other hand, odds ratios less than 1.0 mean that the reverse is true but it can be difficult to interpret (for example an odds ratio of 0.75 would mean that the outcome is 25% less likely for one group). Instead, calculating the inverse of the odds ratio can lead to a more meaningful and intuitive understanding. The confidence interval describes the margin of error to be expected from the dataset. If this interval includes 1.0, there is not enough evidence to conclude an increased odds for one level of the variable or the other (Agresti 2007).

The odds ratios were calculated to test whether various factors were more strongly associated with one mode versus another. In particular, it was used to test whether teenagers' choice of biking, walking, riding the bus, or riding with someone had increased odds compared to driving alone to school.

MODELING MODE CHOICE

Regression models can be used to serve various research needs. In this case, the multinomial logistic regressions were used in order to develop models that allowed interactions between the variables tested to see if they are significant factors in mode choice to and from school. Odds ratios were calculated from the multinomial logistic regressions. These regressions were not developed as predictive mode choice models. As seen by the R^2 in Tables 7-9, the fits for the models are not very high. The R^2 value describes how well the data fit the model by calculating the error variance. JMP calculates the R^2 by taking the ratio of the difference between the reduced (only intercept) and full (one with all variables) models' negative log-likelihoods (SAS 2012). Values close to 1.0 indicate the model fits the data well for the purposes of prediction of future outcomes. Generally, incorporating more variables into the model can produce higher R^2

values, but these additional variables might not be available, or may become very complex. Besides, nominal models rarely have high R^2 values (SAS 2012).

The logistic regression results are shown in the next section, as well as the discussion.

RESULTS AND DISCUSSION

None of the explanatory variables were alternative specific, therefore each was entered into the model as three separate interactions with the three non-reference alternatives. For this section of the study, three different models have been developed. In order to answer the research questions listed in the beginning of this document, one model (Model 4.1) considered the effects of various socio demographic, built environment and virtual environment variables in the mode choice of all surveyed teenagers in the five high schools (Table 13). Then, the effect of the attitude of teenagers is analyzed using additional attitudinal data from the California surveys. For this analysis, first, a model containing the same variables as in Model 4.1 has been run but only for the three high schools in California (Table 14). And then, attitudinal variables have been added to such model in order to determine the effects of such variables in the outcome (Table 15). Having both models allows for comparisons of the pseudo R square values and determine the effectiveness of considering attitudinal factors in these type of behavioral studies.

Model 4.1: Combined California and Vermont High Schools Model

The results for Model 4.1 – corresponding to the question of "What socio-demographic and built environment factors are relevant for students from both states?" - are shown in Table 13. It includes explanatory variables from all three categories (socio-demographic, built environment, and virtual environment) and has an entropy r-square of 0.3996. Table 13 shows that each explanatory variable in the multinomial logit model has at least one statistically significant interaction with the alternatives to at least 95% confidence, and they all have the expected signs.

Table 13 *Mode to school Nominal Logistic Regression model results (Five high schools)*

VARIABLE	**Estimate**	**Standard error**	**ChiSquare**
Bike or Walk vs. Drive to School			
Intercept	**-1.557**	0.520	8.96
Grade (9 vs. 12)	-0.065	0.365	0.03
Grade (10 vs. 12)	0.218	0.195	1.25
Grade (11 vs. 12)	-0.151	0.180	0.70
Gender (male vs. female)	0.169	0.086	3.84
Bike (yes vs. no)	**0.495**	0.123	8.592
Parents education (High vs. low)	0.087	0.113	0.59
Driving license (yes vs. no)	**-2.302**	0.149	236.27
Frequency of technology use (high vs. low)	**-0.378**	0.089	17.74
Phone (smartphone vs. not a smartphone)	**0.341**	0.103	11.04
Distance to high school (miles)	**-0.866**	0.099	93.05
Population within 1 mile service area	-1.04 e-04	5.64 e-05	3.42
Population within 5 miles service area	**5.07 e-06**	2.48 e-06	4.20
Teenager population within 1 mile service area	**4.87 e-04**	2.35 e-04	4.28
Teenager population within 5 miles service area	**1.59 e-04**	5.09 e-05	9.82
Total street length within 1 mile service area	**2.808**	0.993	7.99
Total street length within 5 mile service area	-0.025	0.068	0.13

General trend of driving to commute to work in the census tract (Over 75% vs. less than 75%)	**-0.636**	0.124	26.37
Maximum of the census tract pop. works in management positions	**0.828**	0.16	26.75
Bus vs. Drive to School			
Intercept	0.326	0.661	0.24
Grade (9 vs. 12)	0.326	0.403	0.66
Grade (10 vs. 12)	0.089	0.256	0.12
Grade (11 vs. 12)	0.138	0.252	0.30
Gender (male vs. female)	**0.275**	0.139	3.88
Bike (No vs. yes)	**0.186**	0.187	0.95
Parents education (High vs. low)	**-0.558**	0.165	11.37
Driving license (yes vs. no)	**-2.853**	0.260	120.2
Frequency of technology use (low vs. high)	0.204	0.141	2.11
Phone (smartphone vs. not a smartphone)	**0.729**	0.143	26.02
Distance to high school (miles)	0.066	0.033	3.80
Population within 1 mile service area	6.608 e-05	7.36 e-05	0.81
Population within 5 miles service area	3.467 e-06	3.29 e-06	1.11
Teenager population within 1 mile service area	-2.04 e-05	4.90 e-04	0.00
Teenager population within 5 miles service area	9.453 e-05	8.21 e-05	1.21
Total street length within 1 mile service area	**-3.702**	1.348	7.54
Total street length within 5 mile service area	**-0.206**	0.0972	4.50
General trend of driving to commute to work in the census tract (Over 75% vs. less than 75%)	0.213	0.174	1.50
Maximum of the census tract pop. works in management positions	0.017	0.193	0.01
Ride with someone vs. Drive to School			
Intercept	0.085	0.478	0.03
Grade (9 vs. 12)	0.299	0.347	0.75
Grade (10 vs. 12)	0.177	0.189	0.87
Grade (11 vs. 12)	-0.032	0.175	0.03
Gender (male vs. female)	-0.125	0.087	2.06
Bike (No vs. yes)	0.152	0.112	1.03
Parents education (High vs. low)	0.092	0.111	0.68

Driving license (yes vs. no)	**2.557**	0.145	311.04
Frequency of technology use (low vs. high)	-0.043	0.089	0.23
Phone (smartphone vs. not a smartphone)	0.041	0.105	0.15
Distance to high school (miles)	-3.52 e-04	4.89 e-05	0.45
Population within 1 mile service area	6.58 e-05	5.43 e-06	1.47
Population within 5 miles service area	-5.24 e-07	2.35 e-06	0.05
Teenager population within 1 mile service area	-3.11 e-04	2.64 e-04	1.38
Teenager population within 5 miles service area	2.55 e-06	4.71 e-05	0.00
Total street length within 1 mile service area	-1.799	0.946	3.62
Total street length within 5 mile service area	0.169	0.065	6.75
General trend of driving to commute to work in the census tract (Over 75% vs. less than 75%)	-0.122	0.114	1.13
Maximum of the census tract pop. works in management positions	**0.439**	0.148	8.76
Entropy R square	**0.3996**		

Note: Values in bold show a significance of 0.05 p-values or lower.

Regarding the comparison between choosing biking or walking, or driving to school, more variables are significant than for other mode choice comparisons. Those students who own or have access to a functioning bicycle, do not have a driving license or do not frequently use technology for arranging transportation may positively affect their likelihood to choose active transportation modes to access school. Although in this particular case, the education of the parents did not show any significance, these variables could be indirectly related to the income of the family and, therefore, with the potential available mode choice alternatives for each teenager. If the majority of the workers in the census tract where the teenagers' households were located worked in management positions (i.e., business, financial, computer, engineering, science, legal, education, and media occupations), teenagers seem to more likely bike or walk to school. Looking at built environment variables, distance to school has a very significant effect on the choice of active transportation modes among the studied teenagers. The larger the distance they have to travel, the less likely it is for them to walk or bike to school. Similarly, teenagers living in more populated areas, both within the one- or five-mile service area buffers, may be more likely to walk or bike to school. Street density also showed a potential positive correlation with the use of active transportation modes versus driving to school among teenagers.

Interpreting the results comparing bus or driving as the mode choice to access high school, fewer variables were significant in the model. The population density in the area did not impact their mode choice, but income related variables were significant. Not having a bicycle, living in a less educated household, and not having a driving license may increase the likelihood of teenagers riding the bus versus driving to school. Also, a more frequent use of technologies for arranging transportation shows an increase tendency on the use of buses for accessing school. On the other hand, better street connectivity within one mile and five mile buffers from the teenagers' households showed a negative effect on bus ridership among the studied teenagers' mode choice to school. As it has been previously mentioned, these models do not show causality, but association. In fact, we can see that having a smartphone may increase the likelihood of teenagers to take the bus vs. drive to school. However, one could argue that since a teenagers has the need or depends on public transportation to move around has a higher need of owning a smartphone. There is definitely an association between these two variables, the data used for this particular analysis is simply not detailed enough to determine the exact direction of such association.

When looking at the results for getting a ride from someone else versus driving themselves to school, only two variables were significant. Having a driving license has a very strong impact on choosing to ride or drive to school among the studied teenagers. Not having a driving license considerably increases the likelihood of teens to ride with others. Similar to the income related variables mentioned in the other model sections, those teenagers living in census tracts where workers had management occupations were also more likely to take rides to school rather than drive themselves.

Model 4.2: California High Schools Model

The results for Model 4.2 – corresponding to the question of "What socio-demographic and built environment factors are relevant for students from California?" - are shown in Table 14. It includes explanatory variables from all three categories (socio-demographic, built environment, and virtual environment) and has an entropy r-square of 0.4074. Table 14 shows that each explanatory variable in the multinomial logit model has at least one statistically significant interaction with the alternatives to at least 95% confidence, and they all have the expected signs. This model only includes records from CA high schools in order to compare the results to the following model (4-3) which includes attitudinal variables (only available in the CA survey).

The same variables as in Model 4.1 were included to build the models. Although the significance of such variables is not exactly the same, it is very similar.

Table 14 *Mode to school Nominal Logistic Regression model results (California high schools)*

VARIABLE	Estimate	Standard error	ChiSquare
Bike or Walk vs. Drive to School			
Intercept	**3.103**	0.645	23.14
Grade (9 vs. 12)	-0.301	0.370	0.66
Grade (10 vs. 12)	0.368	0.201	3.34
Grade (11 vs. 12)	-0.139	0.184	0.57
Gender (male vs. female)	**0.181**	0.090	4.02
Bike (yes vs. no)	**0.395**	0.135	8.53
Parents education (High vs. low)	0.044	0.117	0.14
Driving license (yes vs. no)	**-2.3223**	0.149	242.12
Frequency of technology use (high vs. low)	**-0.417**	0.095	19.43
Phone (smartphone vs. not a smartphone)	**-0.316**	0.109	8.34
Distance to high school (miles)	**-0.878**	0.091	92.34
Population within 1 mile service area	**0.0001**	5.94e-05	2.83
Population within 5 miles service area	4.98 e-06	2.51 e-06	1.89
Teenager population within 1 mile service area	**0.00011**	0.00025	4.88
Teenager population within 5 miles service area	**0.00016**	5.096e-05	9.82
Total street length within 1 mile service area	1.329	1.069	1.55
Total street length within 5 mile service area	**0.344**	0.086	16.00
General trend of driving to commute to work in the census tract (Over 75% vs. less than 75%)	-0.216	0.170	1.62
Maximum of the census tract pop. works in management positions	**0.756**	0.153	25.46
Bus vs. Drive to School			
Intercept	-0.545	0.799	0.46
Grade (9 vs. 12)	0.034	0.444	0.01
Grade (10 vs. 12)	0.264	0.285	0.86
Grade (11 vs. 12)	0.032	0.287	0.01
Gender (male vs. female)	-0.035	0.160	0.05
Bike (No vs. yes)	0.184	0.189	0.95
Parents education (High vs. low)	**-0.735**	0.190	15.03

Driving license (yes vs. no)	**-3.140**	0.407	59.41
Frequency of technology use (low vs. high)	**0.330**	0.164	4.04
Phone (smartphone vs. not a smartphone)	-0.106	0.184	0.33
Distance to high school (miles)	**0.067**	0.034	3.83
Population within 1 mile service area	-8.37e-05	0.00009	0.94
Population within 5 miles service area	2.75 e-06	2.68 e-06	1.11
Teenager population within 1 mile service area	3.88 e-04	5.37 e-04	0.52
Teenager population within 5 miles service area	9.71e-05	8.36e-05	1.35
Total street length within 1 mile service area	-1.895	1.503	1.59
Total street length within 5 mile service area	-0.209	0.123	2.9
General trend of driving to commute to work in the census tract (Over 75% vs. less than 75%)	-0.069	0.226	0.1
Maximum of the census tract pop. works in management positions	0.023	0.187	0.02
Ride with someone vs. Drive to School			
Intercept	0.310	0.530	0.34
Grade (9 vs. 12)	0.116	0.353	0.11
Grade (10 vs. 12)	0.314	0.194	2.61
Grade (11 vs. 12)	-0.065	0.178	0.13
Gender (male vs. female)	-0.129	0.090	2.05
Bike (No vs. yes)	-0.238	0.127	3.54
Parents education (High vs. low)	0.049	0.113	0.19
Driving license (yes vs. no)	**-2.483**	0.142	305.31
Frequency of technology use (low vs. high)	-0.055	0.094	0.35
Phone (smartphone vs. not a smartphone)	-0.055	0.113	0.24
Distance to high school (miles)	-0.0004	0.032	0.00
Population within 1 mile service area	3.42e-05	5.25e-05	0.42
Population within 5 miles service area	-5.12 e-07	2.31 e-06	0.06
Teenager population within 1 mile service area	-0.0005	0.0003	2.72
Teenager population within 5 miles service area	2.552	0.000048	0.00
Total street length within 1 mile service area	-1.144	0.916	1.56
Total street length within 5 mile service area	0.121	0.077	2.47
General trend of driving to commute to work in the census tract (Over 75% vs. less than 75%)	-0.223	0.149	2.24
Maximum of the census tract pop. works in management positions	**0.439**	0.148	8.76

Entropy R square	0.4074

Note: Values in bold show a significance of 0.05 p-values or lower.

Regarding the comparison between choosing biking or walking, or driving to school, more variables are significant than for other mode choice comparisons. Males are more likely to choose active transportation modes to access high school than females. Those students who own or have access to a functioning bicycle, do not have a driving license or do not frequently use technology for arranging transportation show a higher likelihood to choose active transportation modes to access high school. If the majority of the workers in the census tract where the teenagers' household was located worked in management positions (business, financial, computer, engineering, science, legal, education, and media occupations), the results show that teenagers may be more likely to bike or walk to school.

Comparing to Model 4.1 biking/walking vs. driving results, having higher population densities are significant in under 1 mile distances and not under 5 miles, and gender also became significant. In fact, when analyzing California teenagers exclusively, men are more likely to bike/walk to school than women. Distance to school is significant when analyzing bus vs. drive modes among teenagers in California, however, other built environment variables such as street connectivity did not show any significance in this model, unlike in Model 4.1.

Model 4.3: California High Schools Model with attitudinal variables

The results for model 4.3 – corresponding to the question of "What attitudinal factors influence the California teenagers? - are shown in Table 15. It includes explanatory variables from all three categories (socio-demographic, built environment, and virtual environment) and also attitude variables from the California survey. The entropy r-square of 0.5840 is considerably higher than the one on model 4.2, which means that including such variables increases the accuracy of the model and better explains the studied population. The significance of the variables that were also included in model 4.2 may have varied in model 4.3. All new variables included in this model (attitudinal) have at least one statistically significant interaction with the alternatives to at least 95% confidence, and they all have the expected signs.

Table 15 *Mode to school Nominal Logistic Regression model results, plus attitudinal factors (California high schools)*

VARIABLE	Estimate	Standard error	ChiSquare
Bike or Walk vs. Drive to School			
Intercept	-1.467	2.007	0.53
Grade (9 vs. 12)	**-1.578**	0.495	10.17
Grade (10 vs. 12)	**0.564**	0.279	4.06
Grade (11 vs. 12)	0.248	0.261	0.91
Gender (male vs. female)	-0.281	0.150	3.50
Bike (No vs. yes)	0.055	0.201	0.08
Parents education (High vs. low)	0.114	0.178	0.41
Driving license (yes vs. no)	**2.432**	0.231	110.72
Frequency of technology use (low vs. high)	**0.365**	0.144	6.40
Phone (smartphone vs. not a smartphone)	0.024	0.167	0.02
Distance to high school (miles)	-0.986	0.088	92.33
Population within 1 mile service area	**-1.95 e-04**	8.65e-5	5.09
Population within 5 miles service area	**1.92e-5**	5.78e-6	10.99
Teenager population within 1 mile service area	**8.17 e-04**	3.59 e-04	5.18
Teenager population within 5 miles service area	7.07e-5	1.53 e-04	0.21
Total street length within 1 mile service area	2.136	1.544	1.91

Total street length within 5 mile service area	0.068	0.148	0.21
General trend of driving to commute to work in the census tract (Over 75% vs. less than 75%)	-0.330	0.227	2.13
Maximum of the census tract pop. works in management positions	0.274	0.24	1.22
I like bicycling	**0.394**	0.146	7.3
Bicycling is my usual way of getting around town	**1.463**	0.170	73.95
I like being driven places	**0.262**	0.143	3.37
My parents/guardians encourage me to bicycle	**0.548**	0.144	14.44
I feel comfortable getting places on my own	**0.459**	0.171	7.22
I like riding the bus	0.227	0.126	3.28
I can rely on my parents/guardians to drive me places	-0.120	0.125	0.92
I need a car to do the things I like to do	**-0.359**	0.127	7.91
One or both of my parents/guardians bicycle frequently	**0.459**	0.109	17.83
I have lots of stuff to carry to school	**-0.632**	0.125	25.59
I live too far away from school to bicycle there	**-0.765**	0.147	27.13
Bus vs. Drive to School			
Intercept	-15.508	121306.79	0.00
Grade (9 vs. 12)	-0.128	0.588	0.05
Grade (10 vs. 12)	0.333	0.384	0.75
Grade (11 vs. 12)	0.358	0.391	0.84
Gender (male vs. female)	**-0.529**	0.238	4.94
Bike (No vs. yes)	-0.105	0.272	0.15
Parents education (High vs. low)	-0.412	0.283	2.13
Driving license (yes vs. no)	15.510	121306.79	0.00
Frequency of technology use (low vs. high)	0.201	0.233	0.75
Phone (smartphone vs. not a smartphone)	-0.323	0.259	1.54
Distance to high school (miles)	0.067	0.034	0.05
Population within 1 mile service area	-6.32e-5	1.31 e-04	0.23
Population within 5 miles service area	6.60e-6	6.49e-6	1.04
Teenager population within 1 mile service area	3.77 e-04	7.46 e-05	0.26

Teenager population within 5 miles service area	**3.09 e-04**	1.52 e-04	4.16
Total street length within 1 mile service area	-3.632	2.107	2.97
Total street length within 5 mile service area	-0.087	0.202	0.19
General trend of driving to commute to work in the census tract (Over 75% vs. less than 75%)	-0.131	0.337	0.15
Maximum of the census tract pop. works in management positions	0.185	0.381	0.24
I like bicycling	0.081	0.209	0.15
Bicycling is my usual way of getting around town	0.438	0.244	3.22
I like being driven places	0.390	0.235	2.76
My parents/guardians encourage me to bicycle	0.218	0.230	0.90
I feel comfortable getting places on my own	**-0.642**	0.229	7.88
I like riding the bus	**0.917**	0.197	21.74
I can rely on my parents/guardians to drive me places	-0.324	0.202	2.56
I need a car to do the things I like to do	-0.048	0.199	0.06
One or both of my parents/guardians bicycle frequently	-0.195	0.187	1.09
I have lots of stuff to carry to school	**-0.678**	0.196	12.06
I live too far away from school to bicycle there	0.219	0.168	1.70
Ride with someone vs. Drive to School			
Intercept	0.249	1.611	0.02
Grade (9 vs. 12)	-0.538	0.410	1.72
Grade (10 vs. 12)	0.392	0.247	2.51
Grade (11 vs. 12)	0.102	0.231	0.20
Gender (male vs. female)	**-0.327**	0.137	5.68
Bike (No vs. yes)	**-0.413**	0.176	5.50
Parents education (High vs. low)	0.134	0.157	0.73
Driving license (yes vs. no)	**2.507**	0.201	155.19
Frequency of technology use (low vs. high)	-0.122	0.130	0.87
Phone (smartphone vs. not a smartphone)	-0.256	0.161	2.52
Distance to high school (miles)	-0.0004	0.032	0.991
Population within 1 mile service area	6.08e-5	7.38e-5	0.68

Population within 5 miles service area	4.41 e-06	4.26e-6	1.07
Teenager population within 1 mile service area	2.59 e-04	3.55 e-05	0.54
Teenager population within 5 miles service area	1.93 e-04	1.06 e-04	3.34
Total street length within 1 mile service area	-2.244	1.257	3.19
Total street length within 5 mile service area	0.119	0.115	1.06
General trend of driving to commute to work in the census tract (Over 75% vs. less than 75%)	0.087	0.195	0.20
Maximum of the census tract pop. works in management positions	**0.427**	0.204	4.38
I like bicycling	-0.109	0.130	0.70
Bicycling is my usual way of getting around town	**0.407**	0.156	6.83
I like being driven places	**0.358**	0.132	7.33
My parents/guardians encourage me to bicycle	0.203	0.129	2.45
I feel comfortable getting places on my own	**-0.689**	0.143	23.29
I like riding the bus	0.038	0.114	0.11
I can rely on my parents/guardians to drive me places	0.064	0.116	0.31
I need a car to do the things I like to do	**-0.349**	0.118	8.71
One or both of my parents/guardians bicycle frequently	**-0.258**	0.100	6.63
I have lots of stuff to carry to school	**-0.282**	0.115	6.00
I live too far away from school to bicycle there	0.124	0.100	1.53
Entropy R square	**0.5840**		

Note: Values in bold show a significance of 0.05 p-values or lower.

Attitudinal factors have shown to clearly increase the R square value of the model. When it comes to biking or walking versus driving, teenagers' personal opinion about biking has a very strong effect on their mode choice to school. Logically, strongly agreeing with the statement of "Bicycling is my usual way of getting around places" has the most positive effect on likelihood of choosing biking/walking as the transportation mode to school among California teenagers. The fact that they like bicycling as in the "I like bicycling" statement also shows a positive effect on the likelihood of the teenager biking to school. Similarly, if their parents either encourage them to bike or even they bicycle frequently themselves, also may increase their likelihood to bike to school. Note that the association between liking a specific mode, such as bicycling or riding the bus, and the use of that mode may be bidirectional. A teenager liking to ride the bus may increase his or her likelihood to choose the bus to go to school. On the other hand if a teenager's only mode of transportation to school is the bus, he or she may also be likely to enjoy more such mode. This study does not analyze each variable deep enough, and therefore the causality between the actions cannot be determined. Although the model does show association, and therefore we can state that such variables have effect on eachother.

Signs of teenagers' independence, as in "I feel comfortable getting places on my own" has also the same effect on the studied outcome. On the other hand, those teenagers who need a car to do the things they like to do, have lots of stuff to carry to school, or agree with the statement that "They live too far away from school to bicycle there" are less likely choose to bike or walk to school.

Teenagers' independence has the opposite effect on their likelihood of riding the bus versus driving to school. Those who strongly agree with the statement of "I feel comfortable getting places on my own" are more likely to drive to school than to ride the bus. Having to carry heavy stuff to school, as for the Bike/Walk versus Drive model results also has a negative effect on choosing taking the bus among the surveyed teenagers. The only attitudinal variable with a positive correlation with taking more the bus to access school is simply liking to ride the bus.

Similar to the comparison between taking the bus or driving to school, teenagers' independence as in "I feel comfortable getting places on my own" is also significant when comparing riding and driving. Those agreeing with such statement are more likely to drive than getting a ride from someone else. If the student had a lot of things to carry, then she or he would also be more likely to drive than get a ride according to these results and liking to be driven places on the other had has a positive effect on getting rides to go to school. Surprisingly, relying on parents/guardians to drive teenagers places was not a significant variable when comparing riding with someone versus driving as their mode choice to school.

CONCLUSIONS

Comparing biking/walking, taking the bus, and riding with someone to driving, more variables influence teenagers in choosing biking/walking versus driving. In other words, more factors influence teenager's behavior when they choose biking/walking over driving. These variables are related to teenagers' individual characteristics, such as gender, age, having or not a license; to their family's characteristics, such as parent's education; to their access and use of technology; and neighborhood characteristics, such as population density (general and teenager population), street connectivity, general trend of work commute, and the main occupation within the neighborhood. Those variables directly or indirectly associated with income (parent's education, driving license) showed a positive correlation with driving to school instead of choosing any other mode. Living in denser neighborhoods and closer to the high schools were, however, negatively correlated to driving, and positively to choosing active transportation options. These results coincide with the results of teen's active transportation behavior studies mentioned in the literature (Frank, Kerr et al. 2007, McDonald 2008, Saelens and Handy 2008).

The effect of technology in the mode choice among teenagers could be considered to have a similar effect as the income related variables. Based on the results of the study one might argue that having access to such technologies and, therefore, being able to use them for transportation arrangement is directly correlated to the teenager's family income. However, the base transportation mode chosen for this study is driving. Therefore, biking and walking has only been compared to driving in the model. Further analysis should be done in order to see the different model outcomes when comparing active transportation alternatives to, for instance, riding with someone else. Since when comparing riding and driving, very few variables were significant, the results of the developed models may not explain all mode choice behaviors.

Including attitudinal factors in the model has clearly shown to improve the model outcomes. Besides individual, virtual, and teenagers' environment characteristics, it can be said that their own point of view and opinions strongly influence their travel behavior. Liking one mode over another, being more independent and confident about moving around on their own, simple convenience or comfort can help explain behaviors that are not as easy to explain. Teenagers' travel behavior is influenced by what other people choose to do around them as well as their own tastes and priorities.

CHAPTER 5 – TECHNOLOGY USE FOR TRANSPORTATION

STATISTICAL METHOD

All variables in the survey data set were binary or categorical variables. Since this research aimed to determine the effect of different variables on the teenagers' use of technology for transportation purposes, the weekly frequency of technology use for transportation of the respondents was used as the dependent variable in the models. This outcome variable, frequency of technology use, was an ordinal variable, thus an ordinal logistic regression model was used. This model tested the effect of different factors on teenagers' technology use for transportation purposes.

The ordinal logistic regression function is shown in equation 5-1, Here, the parameter α is the intercept term and β_n determines the rate of increase or decrease of the variable x_n.

Equation 5-1 *– Ordinal Logistic Regression Function*

$$\ln(\theta_j) = \alpha_j - \beta x$$

where j goes from 1 to the number of categories minus 1.

The odds ratio is a statistical outcome that describes the strength of association between two variables. Here, the odds ratios between the mode choice and predictor variables are calculated. Odds ratios and their confidence intervals can be obtained from the parameter β from the logistic regression, and are shown in Equation 5-2.

Equation 5-2 – *Odds Ratio and Confidence Interval*

Odds Ratio = e^{β}

Confidence Interval = $(e^{\beta \pm \frac{z\alpha}{2}(SE)})$

Odds ratios equal to 1.0 indicate that the event or condition is equally likely to happen for either levels of the variable. Ratios larger than 1.0 indicate an increased odds for the event in the first group. On the other hand, odds ratios less than 1.0 mean that the reverse is true but it can be difficult to interpret (for example an odds ratio of 0.75 would mean that the outcome is 25% less likely for one group). Instead, calculating the inverse of the odds ratio can lead to a more meaningful and intuitive understanding. The confidence interval describes the margin of error to be expected from the dataset. If this interval includes 1.0, then there is not enough evidence to conclude an increased odds for one level of the variable or the other.

The odds ratios were calculated to test whether various factors were more strongly associated with one mode versus another. In particular, it was used to test teenagers' technology use frequency to arrange transportation.

MODELING TECHNOLOGY USE FOR TRANSPORTATION

Regression models can be used to serve various research needs. In this case, the ordinal logistic regressions were used in order to create a model that allowed interactions between the variables tested to see if they were significant factors in the frequency of technology use for transportation. Odds ratios were calculated from the ordinal logistic regressions. These regression models were not intended to be predictive models. The R^2 value describes how well the data fit the model by calculating the error variance. There are several R^2-like statistics that can be used to measure the strength of the association between the dependent variable and the predictor variables. They are not as useful as the R^2 statistic in regression, since their interpretation is not straightforward. For this case, the McFadden's R^2 was used.

Equation 5-3 **–** *McFadden's* R^2

$$R^2{}_M = 1 - \left(\frac{L(\boldsymbol{B}^{\wedge})}{L(\boldsymbol{B}^{(0)})}\right)$$

where $L(\boldsymbol{B}^{\wedge})$ is the log-likelihood function for the model with the estimated parameters and $L(\boldsymbol{B}^{(0)})$ is the log-likelihood with just the thresholds, and n is the number of cases.

R^2 values close to 1.0 indicate the model fits the data well for the purposes of prediction of future outcomes. Generally, incorporating more variables into the model can produce higher R^2 values, but these additional variables might not be available, or may become very complex. Besides, nominal models rarely have high R^2 values (SAS 2012).

The following tables show the results of the logistic regressions.

RESULTS AND DISCUSSION

For this section of the study, three different models have been developed. In order to answer the research questions listed in the beginning of this document, "What factors influence teenagers in using technology for arranging transportation?," one model (Model 5.1) will analyze the effects of various socio demographic, built environment and virtual environment variables in the frequency of technology use for transportation arrangements of all studied teenagers in the five high schools (Table 16). Then, the effect of the attitude of teenagers is analyzed using additional attitudinal data from the California surveys. For this analysis, first, a model containing the same variables as in Model 5.1 was developed but only for the three high schools in California (Table 17). And then, attitudinal variables have been added to such model in order to determine the effects of such variables in the outcome (Table 18). Having both models allows for comparisons of pseudo R square values and determine the effectiveness of considering attitudinal factors in these type of behavioral studies.

Model 5.1: Frequency of technology use for transportation arrangement, all five high schools

The results for Model 5.1 – corresponding to the question of "What factors influence teenagers in using technology for arranging transportation for students from both states?" - are shown in Table 16. It includes explanatory variables from all three categories (socio-demographic, built environment, and virtual environment) and has a McFadden R-square of 0.0516. Table 16 shows the explanatory variables in the ordinal multinomial logit that are significant to at least 95% confidence, and they all have the expected signs.

Although all socio-demographic and built environment variables were considered to develop the model, only the ones shown in Table 16 were significant.

Table 16 *Technology use for transportation arrangements, five high schools*

VARIABLE	Estimate	Standard error	ChiSquare
Intercept [Everyday vs. few/never]	**2.240**	0.181	152.57
Intercept [Most/some days vs. few/never]	**-0.333**	0.166	4.01
Bike vs. drive to school	**0.363**	0.098	13.76
Bus vs. drive to school	0.356	0.189	3.52
Ride vs. drive to school	**0.575**	0.091	40.06
Parents education (High vs. low)	**0.176**	0.054	10.51
Phone (smartphone vs. not a smartphone)	**0.439**	0.0545	65.12
Distance to high school (miles)	**0.033**	0.016	4.24
Total street length within 1 mile service area	**-0.502**	0.259	3.77
McFadden R square	**0.0516**		

Note: Values in bold show a significance of 0.05 p-values or lower.

As has been previously mentioned, the outcome variable of frequency of use of technology for arranging transportation has been coded in three categories: High, medium, and low frequency. The higher the frequency, the higher the number, and therefore, a positive effect of an estimate in the model shows a likelihood to increase the technology use among teenagers.

Overall, not driving to school has a positive impact in more frequently using technology for arranging transportation. Except driving on your own, the other modes to go to school may have a social component, such as sharing the ride with someone, riding the bus with friends, or even biking with friends to school. The higher the parent's education, the higher the frequency of technology use for arranging transportation. This might be directly related to the correlation of parent's education, income, and therefore higher accessibility of teenagers to different technologies. In fact, having a smartphone also increases the use of technology among the studied teenagers. Having to travel longer distances to access school also showed a positive relationship with more frequent uses of technologies for transportation. On the other hand, better street connections surrounding teenagers' homes showed a lower use of technology use for transportation arrangements among teenagers.

This is not a predictive model, but an explanatory model. As the entropy R square value shows, the accuracy of such model is not suitable for prediction. However, the significance of the variables included as well as the non-significant variables that have been excluded give enough information to understand some of the teenagers' behavior related to the use of technologies for transportation. From all the available variables, very few were significant, which could mean that not enough data was available in order to better explain such behaviors or that they may not exist significant relationships between variables . However, parent's education, and similarly having access to technologies (such as smartphones) showed that income related variables play an important role in teenagers' technology use for transportation. Regarding built environment characteristics, only two variables were significant, but helped understand that only distance or street connectivity variables impact teenagers' technology use.

Model 5.2: Frequency of technology use for transportation arrangement, California

The results for Model 5.2 – corresponding to the question of "What socio-demographic and built environment factors are relevant for students from California?" - are shown in Table 17. Although explanatory variables from all three categories (socio-demographic, built environment, and virtual environment) were originally included, only the significant ones are shown in Table 17. Each explanatory variable in the ordinal logit model has at least one statistically significant interaction with the alternatives to at least 95% confidence, and they all have the expected signs. The model and has an entropy r-square of 0.0559.

The same variables as in Model 5.1 where considered to build the model, in fact, the same variables showed to be significant in both 5.1 and 5.2 models.

Table 17 *Technology use for transportation, California*

VARIABLE	Estimate	Standard error	ChiSquare
Intercept [Everyday vs. few/never]	**1.181**	0.159	54.57
Intercept [Most/some days vs. few/never]	**-0.550**	0.158	12.16
Bike vs. drive to school	**0.444**	0.094	22.20
Bus vs. drive to school	0.257	0.182	2.00
Ride vs. drive to school	**0.195**	0.092	4.53
Parents education (High vs. low)	**0.189**	0.050	14.11
Phone (smartphone vs. not a smartphone)	**0.508**	0.053	93.40
Distance to high school (miles)	**0.017**	0.015	1.30
Total street length within 1 mile service area	**-0.556**	0.241	5.32
McFadden R square	**0.0559**		

Note: Values in bold show a significance of 0.05 p-values or lower.

Comparing Model 5.1 and 5.2, the same variables were significant. Although the R square value slightly increased for the California data, all variables had almost the same influence in the output of frequency use of technology for transportation.

Model 5.3: Frequency of technology use for transportation arrangements plus attitudinal factors, California

The results for Model 5.3 – corresponding to the question of "What attitudinal factors influence the California teenagers? - are shown in Table 18. It includes explanatory variables from all three categories (socio-demographic, built environment, and virtual environment) and also attitude variables from the California survey. The entropy r-square of 0.1093 is considerably higher than the one on model 5.2, which means that including such variables increases the accuracy of the model and better explains the studied population, but it is still very low to predict any behavior and implies more variables and data are likely needed to explain the technology use for transportation among teenagers. The significance of the variables that were also included in model 5.2 may have varied in model 5.3. However all new variables included in this model (attitudinal) are statistically significant to at least 95% confidence, and they all have the expected signs.

Table 18 *Technology use for transportation plus attitudinal factors, California*

VARIABLE	Estimate	Standard error	ChiSquare
Intercept [Everyday vs. few/never]	**5.378**	0.469	131.48
Intercept [Most/some days vs. few/never]	**3.479**	0.458	57.82
Bike vs. drive to school	**0.373**	0.100	13.87
Bus vs. drive to school	**0.388**	0.198	3.85
Ride vs. drive to school	**0.164**	0.102	2.60
Parents education (High vs. low)	**0.199**	0.054	13.47
Phone (smartphone vs. not a smartphone)	**0.438**	0.055	62.73
Distance to high school (miles)	**0.016**	0.016	0.98
Total street length within 1 mile service area	**-0.879**	0.269	10.66
I like being physically active	**-0.305**	0.056	29.45
Lots of people bicycle in my community	**0.174**	0.050	11.96
I like being driven places	**0.203**	0.045	20.19
I like riding the bus	**-0.102**	0.041	6.34
My parents/guardians allow me to go places on my own	**-0.123**	0.055	4.89
Going to/from school with friends rather than alone is a priority	**0.283**	0.041	47.53
I often go off-campus for lunch	**0.211**	0.033	41.59
McFadden R square	**0.1093**		

Note: Values in bold show a significance of 0.05 p-values or lower.

Attitudinal factors have been shown to clearly improve the outcome of the model and the accuracy of the results. Choosing any transportation mode to school except driving has a positive effect on increasing the frequency of the use of technology for transportation purposes. The fact that driving (as it has been described in this study) is done alone, means that the dependency of teenagers - who choose this mode to access school on other people - may be almost nonexistent. Those who choose biking, walking, or taking the bus might do it accompanied by friends or family members who might need to be contacted and, therefore, may use technology to do so. When it comes to riding with someone else, communication becomes an essential part of the riding act, which supports a positive correlation with technology use for transportation. However, as can be seen by the low R square values, the socio-demographic or built environment characteristics available in this study by themselves are not enough to explain the behavior of using technology for transportation among teenagers. Attitudinal factors play a key role in improving the accuracy of the model, especially statements that have social influence, such as “Lots of people bicycle in my community”, “My parents/guardians allow me to go places on my own”, or “Going to/from school with friends rather than alone is a priority”, which have been shown to be significant in the model.

Having a larger number of people bicycling in the teenager’s community makes it more likely for him/her to use technology to arrange transportation. Similarly, if they like being driven places or prefer going to/from school with friends rather than alone, they are more likely to technology for transportation arrangements. The attitude of liking a specific mode or the company of people when commuting has a strong positive effect on the use of technology among teenagers when it comes to their transportation needs. On the contrary, being more independent and being allowed to go places on their own decreases the likelihood of teenagers to use technology for arranging transportation. These teenagers may depend less on technology to arrange transportation due to their higher independence to go places on their own. On the other hand, one may argue that since their access to technology is lower, they have to build a more confident attitude towards going places on their own, and therefore become more independent. Again, relationships like this show an association between the variables, but such association may be bidirectional. Additional data and more extended analyses would be needed in order to identify the causality in these type of cases. This study identifies the relationship of association exclusively.

Although very little information about teenagers' extra-curricular activities and their needs in terms of transportation in order to do so were significant in the model outcomes, "I often go off campus for lunch" showed a positive impact on increasing the use of technology for transportation among teenagers. The fact that this statement could be related to a social event, such as sharing lunch with someone and deciding where and when to meet explains the effect on the increase of the use of technology.

CONCLUSIONS

Overall, not driving to school has a positive impact in more frequently using technology for arranging transportation. Except driving on your own, the other modes to go to school may have a social component or require coordination, such as sharing the ride with someone, riding the bus with friends, or even biking with friends to school. The higher the parent's education, the higher the frequency of technology use for arranging transportation. This might be directly related to the correlation of parent's education, income, and, therefore, higher accessibility of teenagers to different technologies. Not Surprisingly, having a smartphone also increases the use of technology among the studied teenagers. Having to travel longer distances to access school also showed a positive relationship with using technologies for transportation more often. On the other hand, better street connections surrounding teenagers' homes showed a lower need of technology use for transportation arrangements among teenagers.

Attitudinal factors have shown to clearly improve the outcome of the model and the accuracy of the results. Choosing any transportation mode to school except driving has a positive effect on increasing the frequency of the use of technology for transportation purposes. Having a larger number of people bicycling in the teenager's community makes it more likely for him/her to use technology to arrange transportation. Similarly, if they like being driven places or prefer going to/from school with friends rather than alone also makes them use technology for transportation arrangements more. The attitude of liking a specific mode or the company of people when commuting has a strong positive effect on the use of technology among teenagers when it comes to their transportation needs. On the contrary, being more independent and being allowed to go places on their own decreases the likelihood of teenagers to use technology for arranging transportation.

CHAPTER 6

SUMMARY

For the mode to school models, comparing biking/walking, bus, and riding with someone to driving, more variables influence teenagers in choosing biking/walking versus driving. In other words, more factors influence teenagers' behavior when they choose biking/walking over driving. These variables are related to teenagers' individual characteristics, such as gender, age, having or not having a license; to their family's characteristics, such as parent's education; to their access and use of technology; and neighborhood characteristics, such as population density (general and teenager population), street connectivity, general trend of work commute, and the main occupation category within the neighborhood. Those variables directly or indirectly associated with income (parent's education, driving license) showed a positive correlation with driving to school instead of choosing any other mode. Living in denser neighborhoods and closer to the high schools were, however, negatively associated with driving, and positively to choosing active transportation options. These results coincide with the results of teen's active transportation behavior studies mentioned in the literature (Frank, Kerr et al. 2007, McDonald 2008, Saelens and Handy 2008).

The effect of technology in the mode choice among teenagers could be considered to have a similar effect as the income related variables. Based on the results of the study one might argue that having access to such technologies and, therefore, being able to use them for transportation arrangement is directly correlated to the teenager's family income. However, the base transportation mode chosen for this study is driving. Therefore, biking and walking has only been compared to driving in the model. Further analysis should be done in order to see the different model outcomes when comparing active transportation alternatives to, for instance, riding with someone else. Since when comparing riding and driving very few variables were significant, the results of the developed models may not explain all mode choice behaviors. In addition, associations between technology use and, for instance, frequency of bus use cannot be identified as single direction associations. Choosing mode choice as the outcome variable may imply that the use of technology in this case may have an effect on choosing bus over driving the car to access school. However, such association is not exclusively one directional. The fact that someone takes the bus to access school may in fact affect their use of technology to arrange their transportation needs. These associations confirm the developed models are not causal, but associative, and that such associations may in fact happen in both directions.

Including attitudinal factors in the model has clearly shown to improve the model outcomes. Besides individual, virtual, and teenagers' environment characteristics, after this study it can be said that their own point of view and opinions strongly influence their travel behavior. Liking one mode over another, being more independent and confident about moving around on their own, simple convenience or comfort can help explain behaviors that are not as easy to explain. Teenagers' travel behavior is influenced by what other people choose to do around them as well as their own tastes and priorities.

For the models of technology use for transportation, income related variables show a clear influence in teens' technology use frequency. Except driving on your own, the other modes to go to school may have a social component, such as sharing the ride with someone, riding the bus with friends, or even biking with friends to school. The higher the parent's education, the higher the frequency of technology use for arranging transportation. This might be directly related to the correlation of parent's education, income, and therefore higher accessibility of teenagers to different technologies. In fact, having a smartphone also increases the use of technology among the studied teenagers. Having to travel longer distances to access school also showed a positive relationship with using more technologies for transportation. On the other hand, better street connections surrounding teenagers' homes showed a lower need of technology use for transportation arrangements among teenagers.

Attitudinal factors have also shown to clearly improve the outcome of the model and the accuracy of the results. Choosing any transportation mode to school but driving has a positive effect on increasing the frequency of the use of technology for transportation purposes. Having a larger number of people bicycling in the teenager's community makes it more likely for him/her to use technology to arrange transportation. Similarly, if they like being driving places or prefer going to/from school with friends rather than alone also makes them use technology for transportation arrangements more. The attitude of liking a specific mode or the company of people when commuting has a strong positive effect on the use of technology among teenagers when it comes to their transportation needs. On the contrary, being more independent and being allowed to go places on their own decreases the likelihood of teenagers to use technology for arranging transportation.

LIMITATIONS

The largest limitations in this study were a result of the data used. Survey design and development are expensive, and often times the surveyed samples are not large enough for some analyses. The sample size was not too small in this case, but did limit some further analyses and comparisons. In addition, although the surveys used in each state had many questions in common, they were not exactly the same. Additional data processing and therefore data records loss is associated with combining both data sets. However, the model results of combining both survey results were more meaningful in terms of identifying significant mode choice and technology use behavior variables.

The developed models are not forecasting models. R square values clearly show that such models' representation of reality is far from accurate, especially in the technology use models. When studying such complex behaviors it is known that many variables influence the outcomes, and that measuring such variables and identifying the relationships between them can be very challenging. In fact, when attitudes come in to play and variables are no longer exclusively quantitative, identifying interactions and variables' significance may hinder obtaining accurate results.

The complex relationships an associations between the analyzed variables, and the analysis and methodologies used in this study do not show causality model results. It is very important to emphasize the strong level of association between several variables that this study is not necessarily addressing. However, by developing this study we were able to identify such complex associations that lead to further research.

RECOMMENDATIONS

This study has shown that population density influences in teenagers' decision of mode choice to school. Since denser neighborhoods have a positive effect on active transportation among teenagers, fewer urban sprawl developments should be built. Bringing households closer not only could encourage teenagers to walk or bike to school, but also adults. Mixed use developments have shown to have health benefits for people living in them (Braza, Shoemaker et al. 2004, Frank, Kerr et al. 2007, Nelson, Foley et al. 2008, Saelens and Handy 2008). This would improve street connectivity and therefore teenagers' accessibility to different activities. They would also depend less on their parents, friends, or family members for rides, and would allow them to become more independent. Many parents spend long hours on taking their kids to different activities. A denser land use pattern would be a win-win situation. However, this measure would take time, and would be very costly. Also, the applied land use policies may discourage certain developments to happen in unwanted places, but they would be unpopular and hard bills to pass. In order for retail in commercial development to develop in more urban cores and this way pursue more mixed-use development cities, incentives such as lower taxation could be applied.

Since youth population density has also shown a relationship to the mode choice to school among teenagers, mixed age neighborhoods should be encouraged. Clustering same age populations can have negative effects for those who do not fit in that age range. Having populations of all ages coexisting in the same neighborhood can avoid isolation and therefore reduce crime and improve the overall safety of the neighborhood (Plybon 2002).

Technology use for transportation can be a solution for those teens living farther away from school and other activities to improve their quality of mobility and increase their accessibility. This study shows that those teens who do not drive to school make higher use of technology for transportation. Although income related parameters were also related with the same outcome (higher parent's education, having a smartphone) and that could be correlated with teenagers' access to vehicles, those teens who need to travel longer distances to access school and who lives in less-connected neighborhoods more heavily depend on technology for transportation. Ensuring good technology accessibility in these areas, such as high speed internet, or offering financial help to those in need to obtain technological devices such as smartphones, could be some policies that could help improve the transportation accessibility of these teenagers.

Riding the bus versus driving to school has not been shown to have as many influencing variables. However, gender, unlike in other cases, was significant. Historically males have been socially seen as more independent, and this culture/behavior can also be seen reflected on teenagers' travel behavior. Attitudinal variables analyzed in this study have shown that those who like to use a mode are more likely to choose it to travel to school, but also that parent's opinion on teens' ability to independently move around has a negative effect on their active and bus transportation. In order to encourage females to ride their bikes, walk or ride the bus, not only is a good infrastructure needed, but also the social trust and acceptance, and that can only be achieved by education. As it can be more of a cultural barrier, it would be harder to have an impact in older populations but addressing teenagers directly could have a positive effect on increasing females' inclination to walk, bike, or ride the bus more.

Regarding future research opportunities, many recommendations can be made in this matter. First of all, due to the high influence of attitudinal factors in the outcomes, in order to better understand travel behavior more attitudinal questions should be included in future surveys. Such questions should not only address the main individuals in the study (in this case teenagers) but also those people around them. For the future potential analysis of the data used in this study, additional questions could be asked. Although the data used for this analysis is not extensive enough, it could be interesting to use larger data sets to analyze those teenagers who do and do not have access to cars. Similarly, the same analysis could be done for those with or without access to a functioning bike. Subsectioning the data this way and adding the education variable (or income, to be more accurate) could allow extract populations with same accessibility levels and focus more in their attitudinal factors.

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