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Sustainable transport choices in public transit access: Travel behavior differences between university students and other young adults

Chang Liu[a], Eleni Bardaka[b,*], Evangelos Paschalidis[c]

[a] *Ph.D. Student, Department of Civil, Construction, and Environmental Engineering, North Carolina State University, Mann Hall, 2501 Stinson Drive, Raleigh, NC 27607, USA*
[b] *Assistant Professor, Department of Civil, Construction, and Environmental Engineering, North Carolina State University, Mann Hall, 2501 Stinson Drive, Raleigh, NC 27607, USA*
[c] *Research Fellow, Institute for Transport Studies, University of Leeds, 34-40 University Road, Leeds LS2 9JT, United Kingdom*

Abstract

This research investigates the socioeconomic and travel characteristics of student transit users in comparison to other young adults and quantifies behavioral differences in public transit access between these two population groups. Using data from a 2015 system-wide on-board survey in the Denver-Aurora region, CO, we seek to understand whether college and university students make more environmentally sustainable choices when accessing bus and light rail transit as well as identify the determinants of their choices. Our results indicate that student transit riders live in larger households with more vehicles per household member and are located substantially farther from the city center and the light rail compared to other young adults. The majority of student light rail users drive alone to light rail stations and typically do not park at the station that is the closest to their home. On the other hand, most other young adults walk to light rail stations. We also find that travel time and vehicle ownership per household member have a significantly lower impact on student choices. The identified travel differences and behavioral variations between the two population groups may be associated with the lack of affordable housing for students in the central and transit-rich neighborhoods of large metropolitan areas.

Keywords: university students; sustainable modes; public transit; young adults; travel behavior

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1. Introduction

Driving alone has been the primary transportation mode for daily travel over the past decades in the US (NHTS, 2017). The high dependence on personal vehicles has contributed to several problems in metropolitan areas, including traffic congestion, waste of energy resources, air pollution, and health problems (Katzev, 2003). In search of solutions, researchers have been studying travel behavior and the factors that contribute to the use of more sustainable transport modes, including walking, biking, and public transportation (Frank et al., 2006; Chaix et al., 2014; Shannon et al., 2006; Dong et al., 2016; Xu & Yang, 2019). Extensive adoption

*Corresponding author
Email addresses: cliu28@ncsu.edu (Chang Liu), ebardak@ncsu.edu (Eleni Bardaka), E.Paschalidis@leeds.ac.uk (Evangelos Paschalidis)

of more sustainable and active travel modes is expected to reduce pollution and the use of fossil fuels, as well as improve physical health (Frank et al., 2006; Chaix et al., 2014; Shannon et al., 2006).

Universities in car-dependent countries and around the world seek to develop more sustainable campuses (Rybarczyk & Gallagher, 2014; Shannon et al., 2006). Promoting sustainable travel modes is a significant component of such efforts (Delmelle & Delmelle, 2012). University parking policies (parking costs and restrictions) have been effective in discouraging students from driving to campus (Miralles-Guasch & Domene, 2010). At the same time, public transportation agencies often prioritize connections with campuses when they plan for transit lines and stops, and in areas with well-developed transit systems, students are more likely to use sustainable travel modes for their commute (Brown et al., 2003; Hasnine et al., 2018; Rotaris et al., 2019; Khattak et al., 2011; Zhou, 2014). In addition, studies have shown that the travel choices of college and university students largely depend on their proximity to campus; students living on campus are more likely to walk, while their off-campus counterparts drive more (Zhou, 2016; Khattak et al., 2011; Eom et al., 2009; Shafi et al., 2020). Quantifying the factors that contribute to sustainable travel choices for students is important not only because it can lead to reductions in automobile trips during their college years but because it can also result in long-term adoption of sustainable transport modes and support for sustainability policies (Balsas, 2003; Shannon et al., 2006; Heinen et al., 2010; Delmelle & Delmelle, 2012).

Current studies related to college and university students mainly focus on choice of commute mode (Nguyen-Phuoc et al., 2018; Zhan et al., 2016; Etminani-Ghasrodashti et al., 2018; Hasnine et al., 2018; Moniruzzaman & Farber, 2018). Some studies also investigate how to increase the use of active transportation modes, including walking, biking and public transportation, for this population (Akar et al., 2013; Rybarczyk & Gallagher, 2014; Rybarczyk, 2018; Mitra & Nash, 2019; Nayum & Nordfjærn, 2021). However, the travel behavior of college and university students who commute by public transportation is not well-understood yet. An improved understanding of this population can lead to more informed decisions by planners and engineers and assist with the development of policies that promote sustainable practices. Moreover, as many metropolitan areas have invested or planning to invest in light rail systems, it is essential to understand how college and university students, who make up a significant proportion of the young adult population, use such systems to commute.

This study investigates the socioeconomic attributes, travel characteristics, and behavior of young transit users who study at a college or university (for brevity referred to as "students"). We particularly explore whether students make more environmentally sustainable choices compared to other young adults when accessing public transportation, such as using more sustainable modes when traveling to a transit station or parking at the closest station when they choose to drive. Apart from identifying differences in choices between students and other young adults, we also quantify the variation in the determinants of those choices through discrete choice modeling. We use a mixed logit model to explain access mode choice for young light rail users and understand whether the built environment, mode characteristics and socioeconomic attributes have differential impacts on students and other young adults. In addition, after estimating that the vast majority of young light rail users do not park at the closest station when they drive alone or carpool, we investigate what determines station choice through a constrained mixed logit model and whether students make choices differently compared to their counterparts.

The study focuses on young public transit users (up to 35 years old) living in the Denver-Aurora Combined Statistical Area (CSA) in Colorado. Our analysis includes data from a 2015 on-board survey of the urban transit system in the Denver-Aurora CSA, CO. The regional transit agency, Regional Transportation District (RTD), operates an extensive bus system as well as a light rail system with multiple lines and free park-and-ride lots at several stations. These park-and-ride facilities provide cost-friendly opportunities for the suburban and rural population to use transit. The Denver-Aurora CSA is a medium-sized US metropolitan area with many post-secondary education institutions and a relatively large transit network that could be representative of several US metropolitan areas today or in the near future. Our research contributes to the study of travel behavior of college and university students. While most prior studies that focus on trips to universities make comparisons between students, faculty, and staff (Brown et al., 2003; Rybarczyk & Gallagher, 2014; dell'Olio et al., 2019), the selection of our comparison group, which is composed of individuals in the same generation as the students, enables us to discern the travel behavior differences arising from student status from those associated with a different stage in life. The results of this study could provide valuable information to urban and transportation planners and help guide future decisions and policies for encouraging sustainable practices.

2. Literature review: Travel behavior of college and university students

The travel characteristics of college and university students have been attracting the attention of researchers in recent years. On the one hand, post-secondary education institutions are considered as distinct trip generators that attract large numbers of students, faculty, and staff, and therefore require special attention (Xueming Chen, 2012). On the other hand, students make up a great share of the young population; for example, as of 2018, 42.5% of the US population between 18 and 24 years old are college students (USCB, 2018). Encouraging students to use sustainable travel modes can have long-term effects in their future lives as adults, and can lead to reductions in automobile trips in the long run and higher support for public policies related to sustainable transportation (Balsas, 2003; Shannon et al., 2006; Heinen et al., 2010; Delmelle & Delmelle, 2012).

The travel behavior and transportation barriers of students highly depend on their on-campus or off-campus residence location (Zhou, 2016; Khattak et al., 2011; Allen & Farber, 2018; Eom et al., 2009; Shafi et al., 2020). As an example, it has been estimated that 42% of off-campus students in four major universities in Virginia drive alone to school (Khattak et al., 2011). In addition, a study at North Carolina State University found that on-campus students are more involved in activities than off-campus students, and about 80% of their trips starting from campus residence are made by walking (Eom et al., 2009). Similarly, Shafi et al. (2020) did a study for Monash University, Australia, and found that international students, the majority of whom live on campus, are more likely to walk or cycle for academic-related trips. Whether campuses are located at urban or suburban areas also affects off-campus students' travel behavior (Khattak et al., 2011). In Virginia, off-campus students who study at urban campuses are found to drive more and make more trips to non-academic activities compared to those studying at suburban campuses (Khattak et al., 2011). Some of the factors that may influence this behavior are the higher probability of urban-campus students to be employed and to live with family members (Khattak et al., 2011). The distance between off-campus students' residence location and campus also plays an important role in their travel choices. In Los Angeles, students who live more than five miles away from the UCLA campus primarily drive alone, while 73% of the students who live between two and five miles from campus use alternative modes (Zhou, 2014).

Public transportation agencies usually integrate post-secondary education destinations in the transit network to improve accessibility. Additionally, universities try to discourage solo driving by increasing parking costs and providing transit passes (Zhou, 2014; Miralles-Guasch & Domene, 2010). As a result, students living in areas with well-developed transit systems are found to be less likely to commute by personal vehicle (Brown et al., 2003; Hasnine et al., 2018; Rotaris et al., 2019; Zhou, 2014). For example, Hasnine et al. (2018) found that 49% of the students in the city of Toronto take transit when commuting to school. Similarly, a study in Iran found that 56% of the students choose transit for university-related trips (Etminani-Ghasrodashti et al., 2018). Rotaris et al. (2019) showed that students in Milan and Rome primarily commute to school by public transportation while the majority of students choose personal vehicles for non-commuting trips. Similarly, in Spain, Gurrutxaga et al. (2017) found that 50% of students of the University of the Basque Country take the bus for daily trips to campus. Overall, prior studies on college and university students have mainly explored mode choice for trips to post-secondary education. We contribute to this research area by focusing on a more distinct population group, students who commute by public transportation, and investigating whether their behavior and choices differ compared to other young adult transit users.

3. Study area

Our study area is the Denver-Aurora Combined Statistical Area (CSA) in Colorado (Figure 1). As of 2019, the Denver-Aurora CSA has a total population of 3,617,927 and a total area of 13,056 square miles. Many universities and colleges are located in the central part of the Denver-Aurora CSA. For example, the Auraria campus is approximately half a mile from the Denver Central Business District (CBD) and includes the University of Colorado Denver, Metropolitan State University of Denver, and Community College of Denver. Approximately 42.5% of the population between 18 and 24 years old is enrolled in college or graduate school in the City and County of Denver compared to 39% in the Denver-Aurora CSA as of 2018 (ACS, 2018).

Housing affordability is becoming an important issue, especially for students, in the downtown and other attractive locations within the study area (CHFA, 2018; NAR, 2019). The Denver-Aurora CSA belongs to one of the least affordable areas within Colorado and has been ranked as the 17th least affordable metropolitan statistical area in the US (NAR, 2019). As of 2018, 50% of Colorado renters pay 30% or more of their household income for rent, and 24% of Colorado renters pay more than 50% of their income for rent (CHFA, 2018). Many middle-income households cannot afford market-rate rent even though they do not qualify for income-restricted housing (CHFA, 2018).

[Figure 1 near here]

[Figure 2 near here]

The Denver-Aurora CSA is served by the Regional Transportation District (RTD). Nowadays, RTD operates more than 140 local and regional bus routes, nine light rail lines, and three commuter rail lines. RTD has a service area of 2,342 square miles serving approximately 3.08 million people. As of 2019, there are 95 million annual boardings (60 million bus boardings and 34 million rail boardings). The downtown area has a dense transit network, including a multi-modal hub, the Union Station, that connects light rail, commuter rail, and bus services. Between 2013 and 2015, RTD had a 4-zone fare structure (Figure 2). Since 2016, RTD has a simplified fare structure, separating local trips (trips crossing up to two zones), regional trips, and trips to and from the airport. Besides paying cash per trip, several types of passes are offered, such as day pass, 10-ride ticket pass, and monthly pass. Discount fares are available for seniors (65 and older), individuals with a disability, and youth ages six to 19. RTD also operates Park & Ride lots at 84 bus and rail stations, which are free to vehicles with license plates registered within the RTD service area. Despite the extensive RTD network and services, 74% of workers over 16 years old in the Denver-Aurora CSA drive alone to work (Census Reporter, 2018).

Representing such a large share of the population, the travel patterns of students in the Denver-Aurora CSA are of interest to public agencies in the area. RTD offers a college pass, which is mandatory and included in the student fees for the 11 participating universities and colleges. Only under certain circumstances, such as living outside of the RTD service area, currently serving military, and owning a different RTD pass, a student can waive the fee of an RTD college pass. The RTD college pass is more affordable compared to parking permits offered by the universities. As an example, the Auraria campus provides parking permits ranging from $85 to $553 per semester, while the least expensive permits only allow access on one specific day of the week. In comparison, the estimated cost of the RTD college pass, which includes unlimited rides on transit, is less than $131 per semester. A recent survey indicated that approximately 87% of the students at the Auraria campus were satisfied with the RTD college pass (CCD, 2020).

4. Survey information

A system-wide, on-board survey was conducted by RTD in 2015 to collect information on the travel patterns of passengers and support transit project proposals to the Federal Transit Administration. The survey sample covered the RTD service area (Figure 1), and the sampling target was 10% by transit route, time of day, and trip direction. Questions on many passenger and trip attributes were included, such as location of origin, boarding, alighting, and destination, access and egress mode, and passenger socioeconomic attributes. Passengers were asked questions by a surveyor who recorded their responses on a tablet device.

The surveyor also conducted some basic quality control checks while recording the passenger responses. The questionnaire took approximately 5 minutes to complete. In total, RTD recorded about 38,000 trips that took place on bus or rail within the RTD service area. Automatic passenger counts were used to develop weights for each recorded trip. These weights accounted for ridership per trip direction, time of day, and bus/rail routes and transfers. The analysis in the following sections is conducted using unweighted data because the survey weights were not developed on the basis of demographic characteristics and are therefore not relevant for comparisons between population groups. This study is based on the 2015 RTD transit network, which corresponds to the year the on-board survey was collected. The RTD light rail lines, stations, and zone-based fare structure in place in 2015 are shown in Figure 2.

5. Descriptive analysis

Our sample contains 17,275 survey records of college and university students and other young adults up to 35 years old who use RTD bus and light rail. This section provides an in-depth descriptive analysis with regard to the socioeconomic attribute and travel characteristic differences between students and other young adults.

5.1. Socioeconomic attributes

[Table 1 near here]

About 44% of the young transit users in our sample are college or university students. Although not directly comparable, approximately 32% of the population between 15 and 34 years old in the Denver-Aurora CSA was enrolled in school in 2015 (ACS, 2015b). This may suggest that young transit users are disproportionately students, compared to their share in the CSA population. Table 1 summarizes and compares the socioeconomic characteristics between students and other young adults in our sample. We find that more students live in households with more than four people compared to their counterparts. This result is consistent with previous research that shows students are more likely to live in shared rental housing after considering rent affordability and commute distance to campus (Zhou, 2014). In addition, a higher proportion of students in our sample has a household annual income less than $15,000 compared to other young adults. The differences in the two income distributions are related to the large share of non-employed and part-time employed students. The majority of students in our sample are part-time employed while 81% of the other young adults have full-time jobs. In 2015, in the Denver-Aurora CSA, 69% of adults aged between 16 and 34 were part-time or full-time employed (ACS, 2015a) in comparison to 86% of all young adults in our sample. (Detailed, direct comparisons between the survey sample and the CSA population cannot be made due to the lack of comprehensive Census data on the student population.) With respect to household vehicle ownership, a substantially smaller proportion of students lives in households with zero vehicles compared to other young adults. Also, 53% of students live in households with two or more vehicles in comparison to 34% of other young adults. Accounting for differences in household size, we find that on average, a student lives in a household with 0.54 vehicles/person, while a non-student young adult lives in a household with 0.42 vehicles/person. Previous studies have shown that a student's decision to own a vehicle depends on several factors, including income, commute distance, availability of other reliable modes, and cultural values (Belgiawan et al., 2016; Cullinane, 2002; Zhu et al., 2012). In the US, millenials have been found to be less likely to own a vehicle if they are in college (Dempsey, 2016), and the emergence of shared mobility, such as carsharing, has been shown to reduce vehicle ownership for students (Stasko et al., 2013). Regarding the intention to own a vehicle, in several countries, vehicle ownership still has a high cultural value, which is reflected in the students' strong intentions to own a vehicle (Zhu et al., 2012; Luke, 2018). Lastly, with regard to transit passes, 77% of students in our sample own a college pass. The majority of other young adults own a transit pass but there is still a large proportion (42%) that pays cash to board transit.

5.2. Purpose of travel

Trip purpose information by student status for young RTD transit users is presented in Table 2. As expected, most students and other young adults start from or end their trips at home. Following home-related origins and destinations, 9% of student trips originate or end at work in comparison to 38% for other young adults. Furthermore, the percentage of students whose trips start or end at a post-secondary education institution is equal to 38%. These results indicate that the majority of student trips captured in the survey are for accessing education, even though 76% of the students in the sample are part-time or full-time employed. It should be noted that in the survey, the trip purpose "College / University" is designated for students only. For example, a non-student who travels to a college or university for work, would have selected "Work" as the trip destination. It is possible that some students work within the university campus, and some of the university/college trips reflect work trips or a combination of work and education trips; however it is not possible to distinguish between the two based on the available data. The shares of social, shopping, and other trip purposes are relatively low, partially because the survey was conducted primarily on weekdays.

[Table 2 near here]

5.3. Residential location

The Denver-Aurora CSA is one of the least affordable areas in Colorado and the US in general, and many universities are located close to the Denver CBD where housing costs are typically high. In this section, we discuss the residential location of students and other young adults in relation to distance from the CBD and the RTD light rail transit (LRT) stations. We discuss separately results for bus and LRT riders, because of the differences in the network coverage between the two systems. The LRT stations (as of 2015) are concentrated in the center of Denver, while the RTD bus network covers the entire RTD service area (Figure 1). Overall, survey respondents who access LRT stations live closer to the CBD compared to those who access bus stations. Students who travel from home to a bus station are located on average 9.9 miles from the CBD, compared to 8.1 miles for other young adults. On the other hand, students who travel from home to an LRT station live on average 9 miles from the CBD, while their counterparts live on average 6.6 miles from the CBD. In both cases, students live substantially farther from the CBD. This finding could indicate that students face larger housing affordability challenges compared to other young adults; however, strong conclusions cannot be reached because the work or university/college location for each survey respondent is unknown.

Focusing on LRT users, we find that students who access the LRT live on average 2.1 miles from the closest LRT station compared to 1.3 miles for other young adults. Students and other young adults who access LRT by walking or biking reside on average within 0.75 miles of an LRT station, while longer distances (up to 49 miles) are found for those who travel to LRT by car. Students who travel to an LRT station by car live, on average, farther from LRT (0.5-1 miles farther) compared to other young adults. In the Denver-Aurora CSA, neighborhoods closer to LRT stations are more attractive to upper-class households and tend to have higher property values (Bardaka et al., 2018, 2019). Therefore, the larger distance between home and station for students who commute by LRT may be related to the lack of affordable options closer to the LRT.

5.4. Access and egress modes

The on-board survey provides detailed information on trip direction, transfers before and after the current boarding, and access and egress mode to and from transit. The main access and egress travel modes are walking, biking, kiss-and-ride (KnR), driving alone, and carpooling. Other modes that are not frequently selected (chosen by less than 0.4% of the sample) include car share, call and ride, taxi, ride share, wheelchair, and skateboard. In this section, we focus on trips that originate from home and end in any other destination to explore the transport modes that students and other young adults use.

We find that the majority (more than 89%) of individuals in our sample walk to destinations after alighting from transit. The share of other modes is much lower compared to walking, and the differences between students and other young adults are relatively small. For example, 4% of the students bike to destinations from transit stations, compared to 2% of other young adults.

The distribution of access mode choice from home to transit is shown in Figure 3. Walking is the dominant mode when accessing a bus station for both groups: approximately 89% of young transit users walk to a bus station from home. In addition, 7% of students drive alone to a bus station compared to 4% of other young adults. On the contrary, when accessing the LRT from home, we find that most students (43%) drive alone to an LRT station, while the majority of other young adults (53%) walk to an LRT station. This result may be related to differences in home location (students on average reside farther from LRT and the CBD) and vehicle ownership (students live in households with more vehicles).

[Figure 3 near here]

We also explore how choices vary between urban and suburban stations. Stations within the Denver Downtown area (located within Fare Zone A in Figure 1) are classified as urban, while the remaining stations are classified as suburban. As can be seen in Table 3, young transit users are overall more likely to walk when accessing an urban LRT station than a suburban one. Students are less likely to walk to both urban and suburban stations compared to other young adults. Approximately 22% of students drive alone to urban stations in comparison to 12% of their counterparts. The contrast is even larger for suburban stations, where about half of the students drive alone to, compared to 34% of other young adults. Similar proportions are found for biking, KnR, and carpooling.

[**Table 3 near here**]

Figure 4 suggests that vehicle ownership is associated with access mode choice. Approximately 80% of the survey respondents who do not have any vehicles in the household choose to walk to an LRT station. As the number of vehicles per household increases, the percentage of driving alone to LRT stations also increases while the shares of walking and biking decrease. Overall, students are more likely to drive alone and less likely to walk to an LRT station compared to other young adults, at any level of vehicle ownership. In addition, the share of carpooling increases with the number of vehicles per household but remains lower than 10% for both population groups. KnR does not seem to be strongly related to vehicle ownership and only small differences are observed between the two population groups.

[**Figure 4 near here**]

5.5. Light rail station choice

In this section, we discuss the type of stations college and university students access compared to other young adults. We further categorize the stations into "end-of-line" and "others" in addition to whether they are located in urban or suburban areas. We also explore whether young light rail users are likely to access the station closest to their home; that is the station with the smallest straight-line distance (lowest travel time in traffic for park-and-ride users) between the Census block centroid of a survey respondent's home and the LRT station.

Figure 5(a) presents the percentage of survey respondents who travel to urban-end-of-line, urban-other, suburban-end-of-line, and suburban-other stations, by student status. The lighter color in each category represents the share of individuals traveling to the closest station. We find that over 75% of students travel to suburban stations, compared to approximately 60% of other young adults. End-of-line suburban stations constitute the closest stations for the majority of individuals who travel there, while the same does not hold for other suburban stations. Most individuals traveling to other suburban stations do not choose the closest station. Similar results are found for the urban stations that are not located at the end of a line. Exploring station choice by access mode provides additional insights. Figure 5(b) shows that the majority of young adults walk to stations located closest to home; small differences are observed by station type and student status. On the other hand, only 20-42% of young adults access the closest station when they park-and-ride (PnR) to a non-end-of-line station either by driving alone or carpooling, and the percentages are consistently smaller for students. We note that very few survey respondents choose to PnR to end-of-line urban stations and they are therefore not shown in the figure. This descriptive analysis reveals that minimizing driving time is not the primary objective for the majority of young PnR users. In Section 7, we take an econometric approach to explain station choice and quantify its determinants as well as potential behavioral differences for college and university students.

[Figure 5 near here]

6. Determinants of light rail access mode choice by student status

In this section, we estimate a mixed multinomial logit (MMNL) model to further analyze and compare the access mode choice to LRT stations between students and other young adults. We are particularly interested in understanding whether the determinants of mode choice differ between students and other young adults. The analysis sample includes 1,668 trips made by college and university students and 1047 trips made by other young adult light rail users (up to 35 years old) who participated in the 2015 RTD survey. We focus on walking, biking, KnR, driving alone, or carpooling trips originating from home. Previous studies have shown that the choice of access mode to a rail station is significantly associated with (i) mode-specific characteristics, such as travel time, distance, and travel cost, (ii) built environment attributes, including parking capacity at the station, population and housing density, land-use mix, and interchange density, (iii) individual characteristics, such as car ownership, employment status, and income, and (iv) other related characteristics such as local weather conditions (Cervero, 1995; Debrezion et al., 2009; Kim et al., 2007; Wen et al., 2012; Chakour & Eluru, 2014; Liu et al., 2020). Our econometric analysis includes many of the aforementioned variables as well as interactions with student status that allow us to statistically test our hypothesis of behavioral dissimilarities between the two population groups.

6.1. Mixed logit model

Discrete choice models have been extensively deployed for studying travel choices (Fan et al., 1993; Etminani-Ghasrodashti et al., 2018; Moniruzzaman & Farber, 2018; Liu et al., 2020). In this study, we adopt the MMNL model to allow for random heterogeneity in individual preferences (Train, 2009). In the MMNL, the utility that an individual i derives from an alternative $j \in \{1, \ldots, J\}$ is:

$$U_{ij} = \beta' x_{ij} + \varepsilon_{ij},\ \ j = 1, \ldots, J \tag{1}$$

where x_{ij} is a vector that contains mode, built environment, individual, and other attributes; β is a vector of coefficients of these attributes; and ε_{ij} is an independently and identically distributed random error term that follows an extreme value distribution (Greene, 2018). The coefficients are assumed to vary across individuals in the population with density function $f(\beta|\phi)$, where ϕ represents the distribution parameters. The probability of individual i choosing alternative q is the integral of the multinomial logit probabilities over a density of parameters (Train, 2009):

$$P_{iq} = \int (\frac{e^{\beta' x_{iq}}}{\sum_j^J e^{\beta' x_{ij}}}) f(\beta|\phi) d\beta \tag{2}$$

The MMNL model is estimated using simulated log likelihood; Eq. 2 cannot be evaluated analytically, making exact maximum likelihood estimation not feasible (Train, 2009).

6.2. Explanatory variables

The variables considered in the analysis of access mode choice are presented in Table 4. Google Direction API is used for estimating the minimum travel time from home to LRT stations. The travel time estimates are based on the time, day, and month of each trip record for a future year. For driving alone, KnR, and carpooling, travel time estimates include time in traffic if applicable at the trip time. We hypothesize that travel time may have have a differential impact on the utility of each mode.

[Table 4 near here]

We consider several station-area attributes, such as land use, parking, housing, population, and interchange density, and whether the station is close to the downtown area. High parking capacity may be associated with higher probability of choosing to drive to a station. We also hypothesize that high-density station areas with diverse land uses encourage the use of non-motor modes. We use the land-use index developed by Cervero (1995), which provides an estimate of the mixture of land uses between 0 (one land use) and 1 (equal mix of land uses). With respect to individual characteristics, we consider vehicle ownership per household memberas well as student, employment, and driver's license status. We hypothesize that higher vehicle ownership and the possession of a driver's license increases the probability of using motorized modes. We also consider weather conditions and average temperature assuming that they may affect the probability of walking and biking.

6.3. Access mode choice analysis results and discussion

We use R's package Apollo (Hess & Palma, 2020) to estimate an MMNL model of light rail access mode choice. Descriptive statistics of the model variables are presented in Table 5. While all the variables presented in the preceding section were considered in the analysis, some are not included in the final model because they were statistically insignificant (such as interchange density, land-use index, weather and urban station indicators).

[Table 5 near here]

[Table 6 near here]

Table 6 presents the model results. Our model includes an indicator variable for college and university students as well as interaction terms with other explanatory variables to quantitatively assess the behavioral differences between students and other young adults. Unobserved heterogeneity is also accounted for through the estimation of random coefficients. The travel time parameter of each mode is assumed to follow a negative lognormal distribution, which is consistent with the hypothesis of a negative relationship between utility and travel time. We find that only the travel time parameter for KnR has a statistically significant distribution with a mean of -1.284 and a standard deviation of 0.200, while the rest of the parameters do not vary randomly. For the remaining variables, walking is used as the base alternative. Consistent with our initial expectations, individuals traveling to densely populated station areas have a lower probability of driving and carpooling and a higher probability of walking, biking, and KnR. On the other hand, higher parking capacity at the station is associated with a higher probability of solo driving and carpooling to the station. Individuals living farther from the CBD have a lower probability of biking to an LRT station compared to walking, potentially due to lack of appropriate infrastructure such as bike lanes in suburban areas. Having a driver's license, a full-time job, or higher vehicle ownership increases the probability of driving alone to a station. White riders are more likely to bike and KnR to an LRT station compared to non-White riders, and for trips taken on higher-temperature days, walking is found to be the least favorable mode.

Our results indicate a number of differences in the determinants of access mode choice between students and other young adults. First, in comparison to other young adults, students have lower sensitivity to travel time changes for all access modes apart biking. For example, it is estimated that a one-unit increase in travel time by walking changes utility by $(-e^{(-2.288)} + 0.029 =) - 0.072$ for students and by $(-e^{(-2.288)} =) - 0.101$ for other young adults. With respect to biking, students and other young adults are found to be equally sensitive to travel time. In addition, living further away from the CBD has a lower effect on the probability of biking for students, and while full-time employment increases the probability of biking for other young adults, the opposite holds for students. Students who are full-time employed also have a lower probability of carpooling to a station, potentially due to the difficulty of coordinating a carpool with their busy schedule. The last important difference identified herein is related to vehicle ownership. We find that an increase in vehicles per household member leads to a substantially higher increase in the probability of solo driving or carpooling for other young adults compared to students. This result suggests that vehicle ownership is not as strong of a determinant of access mode choice for students.

7. Determinants of rail station choice for young park-and-ride users

Through our descriptive analysis, we demonstrate that when transit users drive alone or carpool to an LRT station, minimizing driving time is not the only factor they consider. Less than half of park-and-ride users in our sample choose to park at the station closest to their home, and therefore spend more time driving than needed to access transit. There may be a number of reasons for this behavior. Light rail users who do not own a transit pass may have an incentive to drive farther and park in stations closer to their final destination to reduce the amount of transit fare they need to pay. Others may choose to drive to stations with higher parking availability to ensure a spot in the free RTD parking lots. Last, some transit users may choose to drive farther to access stations that would minimize the amount of transfers needed to reach their final destination. Previous studies on transit users have shown that station-area built environment, travel time between home and station, service frequency and reliability, overcrowding conditions, parking availability, connectivity, and a station's location in the transit network play an important role in station choice decisions (Fan et al., 1993; Hunt & Teply, 1993; Lythgoe & Wardman, 2004; Debrezion et al., 2009; Carrion & Levinson, 2012; Chakour & Eluru, 2014; Shao et al., 2015). In this section, we conduct an econometric analysis to statistically test these hypotheses and identify potential behavioral differences between students and other young adults. We restrict our sample to young LRT users who park-and-ride (either drive alone or carpool) to an LRT station to study the determinants of station choice. We analyze 1118 trips, 816 of which are made by college or university students.

7.1. Constrained mixed logit model

Previous research in transit station choice has adopted discrete choice models with exogenously restricted choice sets based on assumed boundary values of proximity or travel time (Beimborn et al., 2003; Cervero, 2007; Debrezion et al., 2009; Chen et al., 2015; Shao et al., 2015). In this study, we adopt an improved approach that does not require hard choice set restrictions or pre-assumed boundaries. First proposed by (Martínez et al., 2009), the constrained multinomial logit (CMNL) model consists of a traditional compensatory component (as shown in Eq. 1), as well as a non-compensatory component, which represents restrictions on individuals' choices. The non-compensatory component, also called penalization or cut-off, is specified as a binomial logit function and can be based on endogenous thresholds of attributes (e.g. travel time between origin and destination estimated based on a sample) (Castro et al., 2013). In a CMNL with an upper restriction, the utility function of alternative j for individual i is:

$$U_{ij} = \beta' x_{ij} + \varepsilon_{ij} + \ln(\phi^U_{ijk}),\ j = 1, \ldots, J \tag{3}$$

where ϕ^U_{ijk} is an endogenous upper restriction of the attribute k (travel time in traffic, in our case), defined as follows:

$$\phi^U_{ijk} = \frac{1}{1 + e^{(\omega x_{ijk} + B)}} \tag{4}$$

where B is an estimated upper-bound parameter and ω is the scale parameter of the penalization term. In this analysis, the choice set consists of 46 LRT stations, and a mixed CMNL model is estimated to also account for unobserved heterogeneity in individual preferences (Train, 2009).

7.2. Explanatory variables

Most of the explanatory variables considered in this analysis have been defined in Table 4. The travel time by car from the home of each respondent to each of the 46 LRT stations is estimated using Google Maps API and accounts for local traffic conditions at the time of the trip. We also consider several station-area characteristics, including station location, parking capacity at the station, housing and population density, interchange density, and land-use index. We hypothesize that park-and-ride users are less likely to choose a station close to the CBD or a station in a diverse and densely populated area where navigating through mixed traffic may be more challenging. Three additional station characteristics (not shown in Table 4) are considered in this analysis. First, the number of light rail lines linked at the station may play an important role as transit users may be interested in driving farther to reduce light rail transfers. Second, we account for a station's location in the network through an indicator variable for end-of-line stations. Last, we consider the effect of the fare price between boarding and alighting station on station choice for those individuals who do not own a transit pass and pay in cash.

7.3. Station choice analysis results and discussion

The constrained mixed logit model is estimated in R using the Apollo package (Hess & Palma, 2020). The descriptive statistics of the model variables are presented in Table 7 and the model results in Table 8. The choice set of each traveler includes all 46 LRT stations as potential choices. After considering the effects of the explanatory variables, it is assumed that all stations do not have the same probability of being selected and that the choice set of each traveler is bounded by a travel time threshold that is endogenously estimated through the model. The two cut-off parameters, ω and B, included in the upper restriction we have assumed in the CMNL model, are statistically significant and as expected, lead to an increase in the penalization of the utility function as travel time between home and station increases.

[Table 7 near here]

Our analysis identifies four main determinants of LRT station choice for PnR users: travel time to station, parking capacity, station proximity to CBD, and number of lines connected at the station. The travel time parameter is found to vary across individuals, following a negative lognormal distribution; however, statistically significant differences specifically for students are not identified. Parking capacity and station location also affect the station choice behavior of students and other young adults in a similar manner: stations with higher parking capacity and stations located in suburban areas have a higher probability of being selected by PnR users. The importance of number of lines on station choice varies among other young adults, following a normal distribution with zero mean and 1.115 standard deviation, indicating that for approximately half of the non-student travelers, stations that connect more lines are more likely to be selected. We note that the statistical significance of the mean of a random parameter is not relevant when the standard deviation is significant and large relative to the estimated mean, as explained by Behnood & Mannering (2017). The statistically significant interaction term suggests that students are less likely to drive to stations with many connecting lines. As the number of connected lines in a station increase when moving from the suburbs to the Denver CBD (Figure 2), these results may also capture differences related to station location (urban versus suburban), a topic that has been discussed in section 5.5.

[Table 8 near here]

8. Conclusions

Our study focuses on the travel characteristics and behavior of college and university students who use public transportation. Through descriptive and econometric comparisons with other adults of similar age, we seek to discern the differences in transit access decisions and associated factors that arise from student status and the socioeconomic attributes that accompany that.

Do college and university students make more environmentally sustainable choices when accessing transit compared to other young adults? Our results indicate that this is not the case for light rail riders. The majority of student LRT riders drive alone to access an LRT station and typically do not choose the station closest to their home, while most other young adults walk to stations. When traveling to suburban light rail stations, 50% of students drive alone compared to 34% of other young adults. These findings are related to the socioeconomic differences between the two population groups. On average, student transit users live substantially farther from the CBD and the light rail and own more vehicles. Their household income is lower on average compared to other young adults who are primarily full-time employed. Like many other US metropolitan areas, housing in the Denver-Aurora CSA has become unaffordable for many of its residents. It is possible that some of the observed differences in travel decisions with respect to light rail access are partially an outcome of limited availability of housing close to the LRT that is affordable to students, and not a preference towards non-sustainable travel. In the case of bus riders, no substantial differences between the two groups are found: approximately 90% of bus users in our sample walk to bus stops. The bus network covers a large service area and is more accessible by walking compared to the light rail.

We also identify the factors that are associated with light rail access mode and station choice. We find that travel time, housing location with respect to the downtown, housing density and parking availability at the station, average temperature, vehicle ownership, and employment and driver's license status are important determinants of light rail access mode choice for young light rail users. However, the magnitude of the effect of some of these determinants varies between students and other young adults. Specifically, student choices are less sensitive to a travel time increase, which is related to the higher value of time of other-young adults, who are primarily full-time employed. This result also reflects that students may be willing to accept higher travel times because they have limited options in terms of where they afford to reside, while employed young adults are able to position themselves better and lower the travel time between home and station for the mode of choice. Moreover, we find that vehicle ownership is a stronger determinant of access mode choice for non-students. Students are located further away from transit and the CBD compared to other young adults and for that reason, they may be more dependent on personal vehicles. Vehicle ownership may therefore be essential for other trips (even if the vehicle is not used for education trips). On the other hand, other young adults are more able (financially) to optimize their home location relative to their trip ends and may have simpler daily schedules. It is also important to note that these two population groups may have different motivations for using transit, which relates to vehicle ownership as well. Students are restricted by university parking policies and in most cases are obliged to own a transit pass, while other young adults are more likely to use transit by choice or because of preference for sustainable transportation and not out of necessity. This important dissimilarity may be associated with the differences found in terms of vehicle ownership, both as a socioeconomic attribute and as a determinant of access mode choice. Lastly, the probability of biking to an LRT station is less impacted by a rider's home location with respect to the CBD for the case of students, which may suggest that a student's choice to bike is less affected by the lack of bike infrastructure as the distance from the CBD increases compared to other young adults. The analysis of rail station choice reveals that young park-and-ride users do not only consider travel time to the station when deciding which station to access but also parking lot capacity, station location, and the number of lines linked. Overall, these factors are equally valued by students and other young adults. If it is assumed that minimizing driving time would result in the most sustainable station choice, then it can be concluded that both population groups demonstrate similarly unsustainable behavior given that they are equally willing to drive farther in search of higher availability of free parking and transfer convenience.

Students typically represent a disproportionate share of the transit users compared to their share in the general population, and their travel characteristics are an important topic of study. Although we focus on differences between the choices of students and other young adults, we caution against making conclusions that do not consider the restrictions that many college and university students may face when choosing where to live within a metropolitan area, a subject that has not been studied, especially for off-campus students. Planning organizations should consider policies that enable more students to live closer to transit in metropolitan areas with centrally located campuses to encourage the use of more sustainable modes when accessing transit.

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10. Declarations of interest

None

11. Author contribution statement

Chang Liu: Methodology, Formal Analysis, Writing - Original Draft; Eleni Bardaka: Supervision, Conceptualization, Methodology, Writing - Review & Editing; Evangelos Paschalidis: Methodology, Writing - Review & Editing.

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13. Tables

Table 1: Socioeconomic characteristics by student status for young transit users in the Denver-Aurora CSA

Variable	Categories	Students	Other young adults
Gender	Male	43.68%	52.50%
	Female	56.32%	47.50%
Household size	1	8.57%	15.14%
	2	25.29%	31.65%
	3	25.30%	23.99%
	4+	40.84%	29.21%
Annual household income[1]	Less than $15,000	19.62%	9.57%
	$15,000 - $29,999	22.22%	25.00%
	$30,000 - $49,999	31.58%	41.49%
	$50,000 - $99,999	20.17%	18.59%
	$100,000 and above	6.40%	5.35%
Employment status	Disabled and unable to work	0.08%	0.71%
	Employed full-time	26.50%	81.49%
	Employed part-time	49.70%	11.44%
	Homemaker	0.07%	0.42%
	Not currently employed	23.66%	5.94%
Race	Asian	10.57%	3.84%
	Black/African American	15.91%	23.33%
	Hispanic/Latino	16.83%	20.21%
	White	60.14%	56.65%
Household vehicle ownership	0	16.39%	31.35%
	1	30.48%	34.42%
	2	30.36%	24.84%
	3	14.72%	7.08%
	4+	8.05%	2.31%
Transit pass	College pass	77.46%	-
	10 rides	2.60%	9.89%
	Day pass	0.35%	1.12%
	ECO pass	2.96%	16.16%
	Monthly pass	7.33%	29.42%
	Free pass	0.54%	1.13%
	3-hour one-way transfer	2.06%	7.48%
	Cash	8.85%	41.53%
Number of survey records		7529	9746

[1] 30% of the student respondents and 33% of other young adult respondents did not wish to provide household income information. Thus, the information presented here is based on a limited sample.

Table 2: Trip origin and destination by student status for young transit users in the Denver-Aurora CSA

	Average		Origin		Destination	
Origin/Destination	Students	Other Young Adults	Students	Other Young Adults	Students	Other Young Adults
Home	45.34%	46.88%	36.49%	35.48%	54.20%	58.28%
Work	9.26%	37.80%	11.01%	44.98%	7.52%	30.62%
College / University	38.17%	-	43.47%	-	32.87%	-
Shopping	1.57%	3.03%	1.85%	3.76%	1.29%	2.30%
Social / Personal	3.29%	7.74%	4.18%	9.56%	2.40%	5.92%
Medical Service	0.28%	1.11%	0.27%	1.37%	0.29%	0.85%
Recreation / Restaurant	1.74%	2.97%	2.27%	4.29%	1.21%	1.65%
Other	0.34%	0.47%	0.46%	0.55%	0.21%	0.38%

Table 3: Access mode to urban and suburban light rail stations

	Students		Other Young Adults	
Access Mode	Urban	Suburban	Urban	Suburban
Walk	57.74%	26.29%	70.30%	39.14%
Bike	6.14%	5.09%	6.84%	6.42%
KnR	11.30%	13.78%	9.40%	15.14%
Drive alone	22.36%	49.74%	11.54%	33.94%
Carpool	2.46%	5.09%	1.92%	5.35%

Table 4: Variable definitions

Travel time	Minimum travel time between home and a light rail station (minutes)
Housing density	Dwellings/square mile within 0.5 miles from a light rail station based on 2010 Census data (10^-3)
Population density	Population/square mile within 0.5 miles from a light rail station based on 2010 Census data (10^-3)
Interchange density	Number of interchanges within 0.5 miles from a light rail station
Land-use index	0-1 index of land-use mix within 0.5 miles from a light rail station; 0 corresponds to a single land use; 1 corresponds to an even mix of land uses
Parking capacity	Capacity of RTD parking lot at a light rail station (10^-3)
Urban station	Indicator variable: 1 if a light rail station is within Zone A (Figure 1); 0 otherwise
Vehicles/person	Number of vehicles per household member
White	Indicator variable: 1 for White survey respondent; 0 otherwise
Driver's license	Indicator variable: 1 for individual with a driver's license; 0 otherwise
Student	Indicator variable: 1 for college or university student; 0 otherwise
Full-time job	Indicator variable: 1 for full-time employed survey respondent; 0 otherwise
Distance to CBD	Distance between the Denver CBD and the Census block centroid of the respondent's home (miles)
Weather	Indicator variables for weather conditions on trip day, including fair, fog, cloudy, rain, and snow
Temperature	Average temperature on trip day (C°)

Table 5: Descriptive statistics – access mode choice econometric analysis

Variable name (units)	Mean	St. Dev	Median	Min	Max
Travel time (minutes)	21.70	42.12	9.50	0.20	1129.63
Distance to CBD (miles)	8.03	5.62	7.34	0.03	63.35
Driver's license (indicator variable)	0.88	0.33	1	0	1
Housing density (units/mile^2 in thousands)	2.31	1.50	1.83	0.36	8.51
Parking capacity (parking spaces in thousands)	0.62	0.55	0.54	0.00	1.73
Student (indicator variable)	0.62	0.49	1	0	1
Full-time job (indicator variable)	0.49	0.50	0	0	1
Vehicles/person	0.62	0.39	0.60	0.00	4.00
White (indicator variable)	0.66	0.47	1	0	1
Temperature (C°)	13.06	7.36	14.21	-11.11	25.00

Table 6: Mixed multinomial logit parameter estimates for light rail access mode choice (standard errors in parentheses)

	Walk	Bike	KnR	Drive alone	Carpool
Travel time (negative lognormal distribution)	-2.288(0.117)***	-1.938(0.252)***	-1.284(0.253)***	-1.545(0.310)***	-1.682(0.381)***
Standard deviation of parameter distribution	0.001(0.154)	0.126(0.249)	0.200(0.102).	-0.008(0.211)	0.001(0.205)
Travel time × Student	0.029(0.014)*	0.012(0.040)	0.193(0.082)*	0.186(0.081)*	0.194(0.087)*
Constant		-3.801(0.632)***	-2.542(0.515)***	-6.404(0.79)***	-6.507(1.028)***
Student		0.522(0.734)	-0.271(0.624)	0.188(0.97)	-0.647(1.321)
Housing density		-0.227(0.099)*	-0.183(0.108)·	-0.418(0.130)**	-0.456(0.238)·
Housing density × Student		0.198(0.138)	0.091(0.141)	0.217(0.163)	0.339(0.298)
Parking capacity			0.420(0.273)	0.857(0.255)***	0.941(0.402)*
Parking capacity × Student			-0.104(0.351)	-0.348(0.318)	-0.087(0.509)
Distance to CBD		-0.119(0.049)*	0.021(0.041)	-0.011(0.039)	-0.036(0.057)
Distance to CBD × Student		0.106(0.063)·	-0.008(0.053)	0.071(0.049)	0.048(0.070)
Driver's license				1.942(0.535)***	0.092(0.550)
Driver's license × Student				0.659(0.696)	1.348(0.839)
Full-time job		0.827(0.457)·	-0.286(0.299)	0.902(0.414)*	0.809(0.637)
Full-time job × Student		-1.186(0.540)*	-0.438(0.385)	-0.681(0.455)	-1.188(0.720)·
Vehicles/person			-0.053(0.319)	2.000(0.342)***	2.261(0.470)***
Vehicles/person × Student			-0.145(0.419)	-1.182(0.433)**	-1.766(0.621)**
White		0.664(0.197)***	0.267(0.155)·	0.122(0.146)	0.033(0.237)
Temperature		0.049(0.013)***	0.008(0.010)	0.036(0.009)***	0.027(0.015)·
N					2699
Log-likelihood at zero					-4262.872
Log-likelihood at convergence					-2429.226
AIC					5000.450
BIC					5419.400

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\cdot}p < 0.1$

Table 7: Descriptive statistics - station choice analysis

Variable name (units)	Mean	St. Dev	Median	Min	Max
Travel time (minutes)	21.96	9.39	21.12	0.78	101.52
Land-use index (index between 0 and 1)	0.65	0.21	0.66	0.00	0.96
Housing density (units/mile^2 in thousands)	29.59	22.88	20.09	3.58	85.11
Parking capacity (parking spaces in thousands)	0.31	0.44	0.44	0	17.34
Urban station (indicator variable)	0.46	0.50	0.00	0	1
Number of lines linked	2.15	1.12	2.00	1	5
End-of-line station (indicator variable)	0.13	0.34	0.00	0	1
Fare	1.27	0.68	1.00	0	3

Table 8: Constrained mixed multinomial logit model estimation results for light rail station choice (standard errors in parentheses)

Variable name	Parameter estimate
ln(Travel time) [negative lognormal distribution]	0.655(0.306)*
Standard deviation of parameter distribution	0.897(0.218)***
ln(Travel time) × Student	0.467(0.345)
Number of lines linked [normal distribution]	-0.169(0.148)
Standard deviation of parameter distribution	1.115(0.110)***
Number of lines linked × Student	-0.343(0.169)*
Land-use index	0.533(0.330)
Land-use index × Student	-0.387(0.378)
Housing density	-0.03(0.105)
Housing density × Student	0.058(0.124)
Parking capacity	1.773(0.202)***
Parking capacity × Student	-0.23(0.237)
Urban station	-0.967(0.364)**
Urban station × Student	0.468(0.407)
End-of-line station	-0.084(0.278)
End-of-line station × Student	-0.267(0.32)
Fare	0.003(0.235)
Fare × Student	0.389(0.275)
Scale ω	5.708(0.401)***
Bound B	-11.305(0.764)***
N	1118
Log-likelihood at zero	-4280.421
Log-likelihood at convergence	-1807.409
AIC	3654.82
BIC	3755.2

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\cdot}p < 0.1$

14. Figures

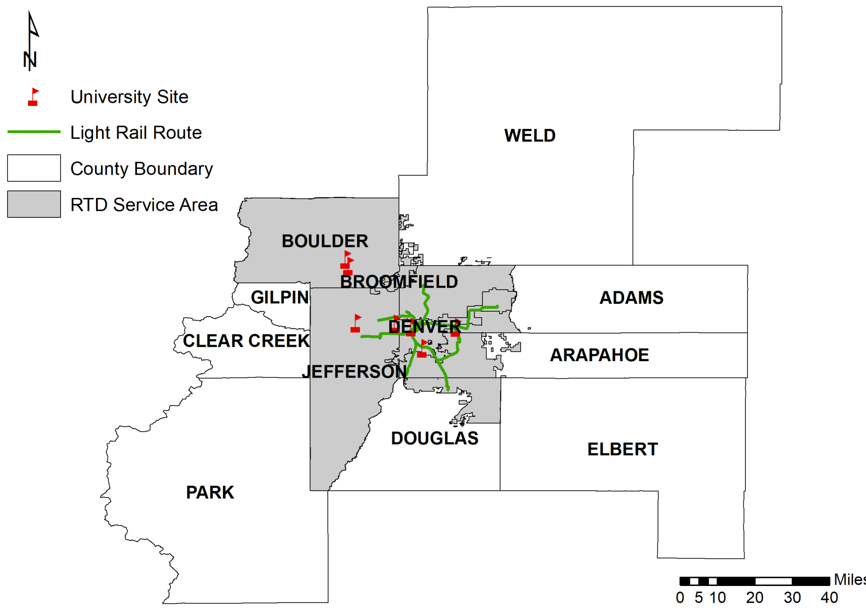


Figure 1: Denver-Aurora CSA and RTD service area

Figure 2: RTD rail and fare zones in operation in 2015 (RTD, 2013)

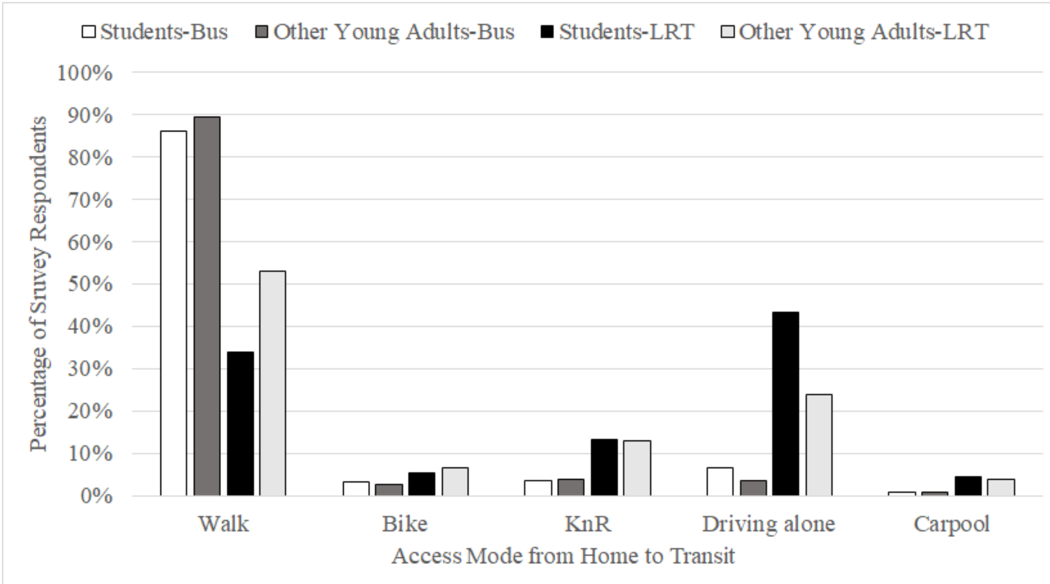


Figure 3: Transit access mode by student status

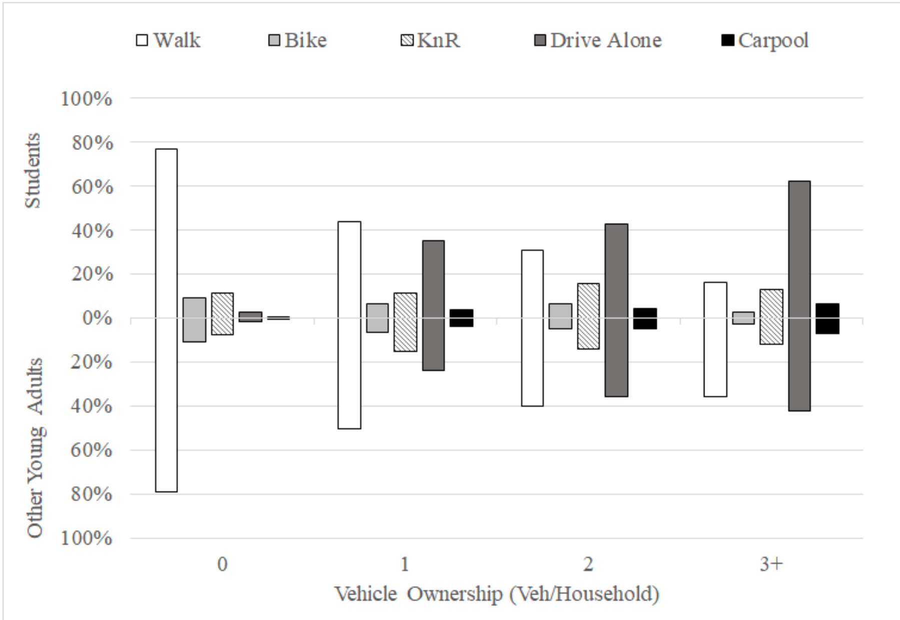
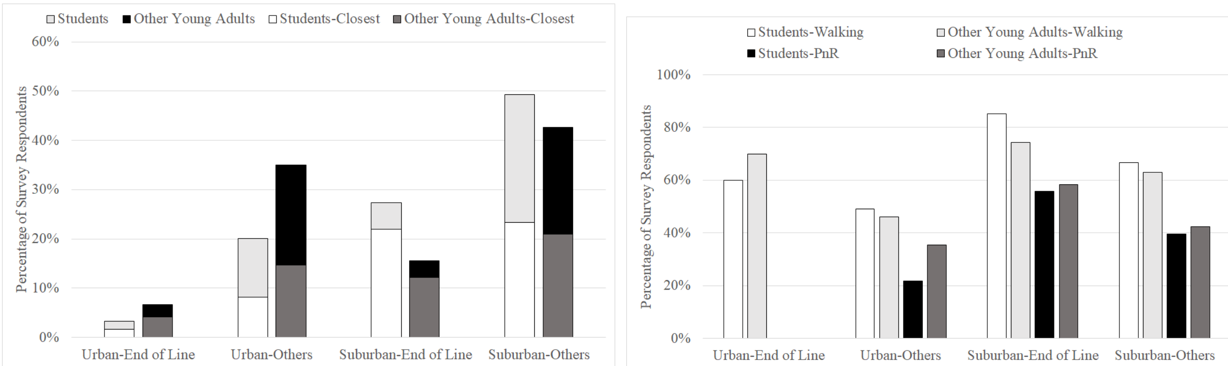


Figure 4: Light rail access mode distribution by student status and household vehicle ownership



(a) Station choice

(b) Choice of closest station by access mode

Figure 5: Light rail station choice by student status and access mode

15. List of figures