Travel Behaviour and Society 15 (2019) 74–87

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

Comparing the travel behavior of affordable and market-rate housing residents in the transit-rich neighborhoods of Denver, CO

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ARTICLE INFO

Keywords:
Affordable housing
Equitable transit-oriented development
Mode choice
Urban rail
Household survey

ABSTRACT

Equitable transit-oriented development (ETOD) extends an increasingly accepted model for station-area growth by intentionally co-locating affordable housing and transit nodes in order to reduce low-income households' aggregate housing and transportation costs. Local, regional and state government agencies have enacted ETOD policies to promote this socially vital land use/transportation nexus. This study focuses on Denver, CO, where numerous market-rate, mixed-income, and income-restricted (i.e., affordable) apartments have been built within a 10-min walk of Regional Transportation District (RTD) rail stations. The objective of this research is to compare the travel behavior of station-area residents living in market-rate and affordable apartment units by analyzing the data collected through a household survey distributed to 21 properties with over 2400 units located within a 10-min walk of a rail station. Results from 312 responses indicate substantial differences in key socioeconomic characteristics of the residents (employment status, age, and vehicle ownership), in transportation mode choice, and frequency of use of public transportation (bus and light rail) for accessing employment, healthcare, and grocery stores between residents of affordable and market-rate apartments.

1. Introduction

A vital role of transit is to expand regional economic opportunity by providing affordable access to employment, education, and healthcare services for low-income households that may not be able to afford other means of transport. In the last 30 years, transit-oriented development (TOD) has emerged as an effective means of creating communities centered on transit, increasing transit ridership, and mitigating heavy traffic, noise pollution, air pollution, urban sprawl, and other problems associated with urban areas (Cervero and Duncan, 2002). However, some recent studies have found evidence of or risks for gentrification in neighborhoods near new urban rail stations that could displace low-income households (Bardaka et al., 2018; Kahn, 2007; Pollack et al., 2010; Zuk et al., 2015). Denver, Portland, and San Francisco are few of the cities that have been experiencing gentrification close to urban rail corridors (Baker and Lee, 2017; Chapple, 2009; Denver, 2016). Equitable transit-oriented development (ETOD) attempts to mitigate the negative socioeconomic externalities of transit investment by intentionally co-locating affordable housing and transit nodes in order to reduce low-income households' aggregate housing and transportation costs and increase access for these transit-dependent populations (Center for Neighborhood Technology, 2017).

TOD has been associated with high transit ridership, although this varies by region and transit system (Cervero et al., 2004). As cities change station-area zoning to promote ETOD and transit agencies pursue development to increase transit ridership around station areas, it is important to quantify and compare the travel behavior of low-income station-area residents and their higher income peers. Despite the limited research in ETOD, it is reasonable to hypothesize that residents of affordable housing developments close to transit are likely to use transit more compared to the residents of market-rate housing developments, because they tend to be transit-dependent. However, mode choice and frequency of transit use of low-income station-area residents may not be drastically different from other station-area residents, for the following reasons. First, low-income housing residents are more likely to be older, disabled, and have poor health compared to other residents (Gibler, 2003; Digenis-Bury et al., 2008). Therefore, low-income residents may have difficulty accessing transit and, so, may travel by transit less frequently than higher income residents. Second, low-income households typically register for income-restricted housing and enter an over-subscribed queue of other prospective tenants. If selected for a unit, a low-income household will likely take the unit, regardless of its location or implications for future commute trips and mode. This could be a cause of spatial mismatch: the employment location of some low-income

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https://doi.org/10.1016/j.tbs.2019.01.001
Received 3 April 2018; Received in revised form 29 June 2018; Accepted 3 January 2019

residents may be too far from their assigned residence and not accessible by public transportation. The two aforementioned reasons challenge the hypothesis of drastically higher transit use by affordable housing residents in station areas compared to market-rate residents. They also demonstrate the need for research in this area to assist with understanding the differences in travel behavior between residents of low-income, mixed-income, and market-rate properties as well as the underlying factors (related to socioeconomic characteristics, employer incentives, lack of opportunity for residential choice) which may impact their travel choices.

The overall objective of this study is to partially fill this research gap by attempting to respond to two key research questions: (1) What are the main socioeconomic differences among residents of different transit-oriented developments that may relate to their travel behavior? (2) What are the differences in terms of mode choice and frequency of transit use among the aforementioned residents and how do they vary by socioeconomic group and trip purpose? To respond to these two questions, this study evaluates the results of a household survey that was distributed to 21 station-area properties in Denver, CO, in May 2017. In Denver, numerous low-income, mixed-income, and market-rate housing developments have been built within walking distance of light rail stations. Based on 312 survey responses, we find that the residents of low-income and market-rate station-area apartment units significantly differ in terms of employment status, age, and vehicle ownership. For example, only 39% of the respondents residing in low-income units were employed compared to 95% in market-rate units. In addition, we compare mode choice and frequency of use of light rail and bus services for all survey respondents, the employed respondents who commute to work, and the retired or unable to work respondents. We also focus on the frequency of transit use for accessing medical care and grocery stores. Among other results, we find that based on the survey responses, the frequency of transit use for non-employed affordable housing residents, who constitute the majority of affordable housing residents, significantly surpasses that of the employed market-rate residents. Our findings contribute to the limited-researched topic of ETOD resident travel behavior and can be used by transit agencies who are interested in understanding how different types of residential developments around station areas contribute to transit ridership generated from these areas. Additional studies and a different research design and methodology, which would include comparisons between residents of station-areas and other areas within a region, would be required for understanding how ETOD policies impact ridership at the regional level. Furthermore, larger-scale studies need to be conducted in Denver and other urban areas to allow for the generalization of the research findings.

2. Travel behavior and characteristics of TOD residents

ETOD is a relatively new model of housing development that has been applied extensively only to a small number of U.S. cities. Consequently, research in the area of travel behavior of ETOD residents has been very limited. On the contrary, there has been extensive research on the travel preferences of TOD residents. TOD and joint development, a subset of TOD referring to the transit agency as a fiscal partner in the development, have been implemented around the U.S. for more than 30 years. Landis et al. (1991) documented that by 1990, transit agencies in more than 20 cities had partnered on constructing more than 114 joint-development projects. More recently, Cervero et al. (2004) collected information on over 100 TOD projects through surveys sent to transit agencies, and found that the majority of these projects are located next to heavy rail stations, followed by light rail and commuter rail.

Cervero (1993) conducted one of the first studies on the travel behavior of TOD residents, surveying 27 residential projects within two thirds of a mile of five California transit systems. The study concluded that, on average, 19% of the residents commuted to work by transit, with highest rates on the Bay Area Rail Transit (BART), the rail share was significantly higher (33%). Additionally, Cervero (1994) found that BART TOD residents were five times as likely to commute by BART compared to the average worker living in the Bay Area. A similar study was repeated approximately 10 years later by Lund et al. (2004) and found no statistically significant changes in the travel behavior of TOD and non-TOD residents in the Bay Area, compared to the previous study. In a comprehensive assessment of the benefits of TOD and joint development throughout the U.S., Cervero et al. (2004) summarized the results of previous research and concluded that residents living close to rail stations are five to six times more likely to commute by transit compared to other residents in that region. Renne and Ewing (2013) studied the travel behavior differences of TOD residents over time and found that in 2000, 36.6% of TOD residents commuted by public transportation, compared to 34.4% in 2010. Zamir et al. (2014) found that people living in TOD in Washington D.C. and Baltimore, MD, made fewer trips by auto and traveled shorter distances by all modes of transportation. Cervero (2007) argued the existence of residential self-selection in the neighborhoods around transit stations: individuals with a preference of transit-oriented living choose to migrate in transit-rich neighborhoods. However, Cao and Schoner (2014), who investigated the travel patterns of station-area residents in Minneapolis, found that the people who moved close to the Hiawatha light rail (after its opening) use transit as often as new residents in comparable urban corridors not served by light rail.

Kwoka et al. (2015) studied the travel characteristics of workers in Denver using data from a 2009 travel behavior survey conducted by the Denver Regional Council of Governments (DRCOG). The study revealed that living close to a Denver light rail station does not increase the probability of using non-car modes to commute to work, unless the work location of the commuters is near a transit station area. This finding aligns with other studies that have shown that developing properties close to transit is not sufficient for high transit mode share. Elements of the built environment such as design principles that prioritize pedestrians over automobiles, high level of walkability, and street connectivity at the destination play a significant role in mode choice (Cervero, 2007; Ratner and Goetz, 2013). Additionally, parking availability at the origin and the destination is a critical parameter in mode choice decisions (Chatman, 2013).

Who is the average TOD resident? Some studies have shown that TOD residents are not transit-dependent and instead own personal vehicles (Chatman, 2013; Dill, 2008). This result is not surprising considering the high property values in station areas (Baum-Snow and Kahn, 2000). In terms of household composition, Dill (2008) surveyed 300 TOD residents in Portland, OR and found that households tend to be smaller and childless, compared to households in other neighborhoods. Overall, the sociodemographic composition of the neighborhoods in station areas has been changing, which has raised gentrification concerns. A study of 42 neighborhoods in 12 metropolitan areas first served by transit between 1990 and 2000 revealed a consistent increase in income and vehicle ownership (Pollack et al., 2010). Other studies have found similar results (Kahn, 2007; Deka, 2016). The influx of upper class residents in station areas and the increase in vehicle ownership raises questions about the effectiveness of TOD as a model that increases ridership. At the same time, other studies have concluded that TOD residents own fewer cars or reduce the number of cars they own after they move into a TOD (Arrington and Cervero, 2008). Renne and Ewing (2013) studied TOD across the U.S. and found that vehicle ownership in TOD decreased from 0.72 to 0.65 vehicles per household between 2000 and 2010. Vehicle ownership is highly correlated with mode choice for station-area residents. Lund et al. (2004) found that station-area residents in the Bay area that did not own a vehicle made 79% of their trips by transit compared to station-area residents who owned at least one vehicle and made less than 27% of their trips by transit. Similar results were reported by Cervero (1994, 2007). The aforementioned studies provide important background for our work,

because one of the main differences between market-rate and low-income housing residents is the ability to own and operate a car.

3. Equitable transit-oriented development

ETOD relies on integrating affordable housing in station areas. Leading obstacles to creating ETOD include the high value of land in station areas, restrictive zoning policies, difficulty coordinating transit and housing agencies, and lack of federal support (Hersey and Spotts, 2015; Spotts, 2013). The Low Income Housing Tax Credit (LIHTC), which was created in 1986, is responsible for the majority of affordable housing units established in the U.S. Zuk and Carlton (2015) reports that, as of 2015, only 15% of LIHTC housing units are placed within 0.5 miles of a transit station. LIHTC relies on high-tax corporations opting to give a portion of their taxable income into affordable housing. However, the 2017 tax act which reduced the corporate tax rate made tax credits less competitive and the development of affordable housing even more challenging.

Municipalities, counties, transit agencies, metropolitan planning organizations, and states have enacted ETOD policies to promote this socially and fiscally vital land-use/transportation nexus. For example, in Maryland, the Departments of Housing and Community Development, Planning, and Transportation (which oversees the Maryland Transit Administration), align ETOD funding and technical assistance through the Sustainable Communities Program. Also, in 2014, the Nashville Area Metropolitan Planning Organization used the Housing and Transportation (H + T) Affordability Index to inform transportation investments in the 2040 Regional Transportation Plan, intentionally reducing H + T costs in a region where 90% of households spent more than 20% of income on transportation (Transportation for America, 2014). Some ETOD-related policies seek to incentivize developers to plan for mixed-income housing. As an example, in 2007, the Montgomery County, MD, created the Moderately Priced Dwelling Unit program to require at least 12.5% affordability in developments of 20 units or more in order to ensure inclusive development in northern Washington, DC, and suburbs. Additionally, thirty-five percent of the Los Angeles County Metropolitan Transportation Authority's portfolio is expected to include housing for households earning 60% AMI or less. LA Metro plans to meet this goal by discounting property lease or sale values up to 30%, consistent with each project's affordability target.

4. Urban rail and equitable transit-oriented development in Denver, CO

The Regional Transportation District (RTD) urban rail system (Fig. 1) began operation in 1994 with the opening of the 5.3-mile Central Corridor, including 13 stations. In 2000, RTD added 8.7 miles of rail and five stations, followed by another 1.8 miles of rail and four stations in 2002. By that time, CCD began to focus on TOD. In 2002, CCD published Blueprint Denver, a comprehensive plan that amended zoning regulations around transit stations to enable high-density and mixed-use development. In 2004, Metro Denver voters approved FasTracks, a $0.004 sales-tax increase to extend 122 miles of rail, introduce 18 miles of bus rapid transit (BRT), and construct 21,000 parking spaces in order to enhance mobility in an expanding region. Paired with a significant federal grant and a public–private partnership, FasTracks allowed RTD to open the W Line (2013), Union Station (2014), Flatiron Flyer BRT (2015), the A Line (2016) the B Line (2016), and the R Line (2017). RTD expects to open additional lines in coming years: the G Line (2018); the Southeast Rail Extension (2019); the N Line (2020). As of 2016, the RTD rail system has an average of 329,855 weekday boardings.

FasTracks set the foundation for RTD to increase transit ridership and prompt TOD across Metro Denver, ranked one of the fastest-growing areas in the U.S. However, rapid growth and transit expansion have also prompted gentrification in previously under-connected and over-looked neighborhoods attainable to low-income and workforce households. Bardaka et al. (2018) studied transit-induced gentrification in Denver using a quasi-experimental spatial econometric approach and found a significant increase in median household income and house values around the stations of the first light rail line in Denver which opened in 1994. A 2016 study by CCD's Office of Economic Development (OED) identified Denver neighborhoods at risk of gentrification and displacement and proposed a number of strategies to mitigate socioeconomic impacts of OED's revitalization programs, including protecting existing homeowners and cross-agency collaboration (Denver, 2016). Denver's development stakeholders have responded to gentrification pressure in a number of ways.

In 2010, a consortium of public and private stakeholders, including CCD, the Colorado Housing and Finance Authority (CHFA), philanthropies, and lenders, pooled $10 million to create the Denver TOD Fund available to non-profit affordable-housing developers to acquire station-area property for the creation of low- or mixed-income housing and community facilities in Denver. In 2014, the Denver TOD Fund grew to $24 million and expanded to non- and for-profit developers across Metro Denver (Hersey and Spotts, 2015). As of December 2017, the Denver Regional TOD Fund had provided $21.6 million for the creation or preservation of more than 1,212 affordable homes and 100,000 square feet of community space at 14 transit-accessible properties across the region.

CHFA administers Colorado's LIHTC program, which leverages private investment for the creation of low-income housing. In 2012, CHFA first tailored the annual LIHTC qualified allocation program to reward ETOD proposals, resulting in 14 projects with 798 low-income and 130 market-rate TOD units that year. To date, CHFA has financed 58 projects with 3,705 affordable and 800 market-rate homes within a 10-min walk of RTD rail stations in Denver. In 2013, CCD adopted an inclusionary housing ordinance (IHO) designed to encourage the creation of affordable condominiums or in-lieu payment and enacted the 3x5 Initiative to complete 3,000 low-income units in five years, which was accomplished ahead of schedule in 2017. In 2015, CCD created the $10 million Revolving Affordable Housing Loan Fund to provide gap financing for low-income housing projects. In 2017, CCD replaced the IHO with a linkage fee that requires both residential and commercial developers either to build low-income housing or to contribute in-lieu payments for future construction. In 2018, CCD doubled its prior-year commitment to pledge $30 million per year to create or preserve 6,000 low-income units over the next five years. That same year, CCD introduced incentive zoning around 38th & Blake Station, allowing building heights up to 20 stories if a project includes affordable housing.

Despite the aforementioned gains in low-income policy and finance, market-rate development far outpaces construction or preservation of low-income housing in Metro Denver. Ratner and Goetz (2013) and Bhattacharjee and Goetz (2016) used descriptive and geospatial analysis to study the land-use changes related to RTD rail stations. Both studies found significant increase in commercial development close to rail stations, and Ratner and Goetz (2013) also reported high residential development in transit-rich neighborhoods that peaked between 2006 and 2009, with the expansion of the light rail system. As of 2013, the highest transit-oriented residential and office development was observed in 2009 (66% of the total regional residential development and 60% of the total regional office development, respectively). Additionally, the highest transit-oriented retail development occurred in 2006 with 33% of the regional retail development being TOD (Ratner and Goetz, 2013). Bhattacharjee and Goetz (2016) found a statistically significant increase in the density of commercial areas around the rail stations from 1990 to 2010; an increase in multi-family residential development along the rail transit corridors was also found, although it was not statistically significant. The study also reported that multi-family residential development close to rail stations was significantly higher compared to single-family development.

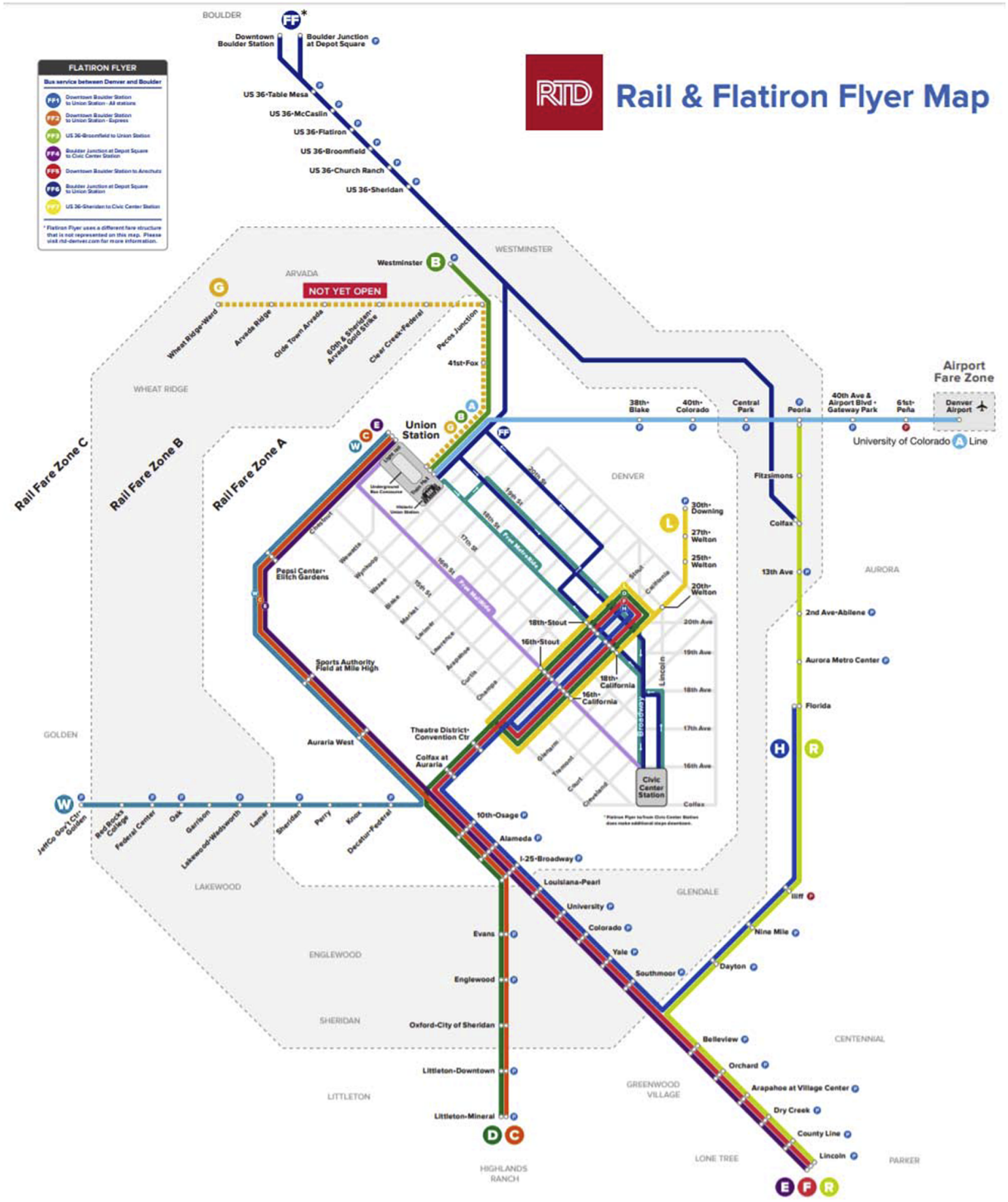


Fig. 1. The Regional Transportation District Rail System (Source:http://www.rtd-denver.com/img/map/rail-fare-map.pdf).

Overall, since 2011, 37% of units in new rental multifamily properties in Metro Denver have located within a 10-min walk of RTD rail stations (CoStar, 2017). The second quarter of 2017, CoStar Realty Information Inc. counted 40,677 units in rental multifamily properties in the aforementioned area. Although these walksheds account for only 8.2% of Metro Denver's surface, they accommodate 26.7% of its rental multifamily units (CoStar, 2017). This trend continues through 2017, as 42.3% of multifamily units permitted in Metro Denver since 2016 are located within a 10-min walk of an RTD rail station (CoStar, 2017). In addition, based on estimations for the second quarter of 2017, there are in total 47,326 units in new rental multifamily properties that are planned or under construction in the Denver Metro area; 40% of these units are within 0.5 miles of an RTD light rail line (CoStar, 2017). However, station areas include a disproportionate number of non-affordable multifamily properties. Based on data provided by CoStar, units in multifamily rental properties within a 10-min walk of an RTD station are more likely to be Class A units (the highest quality apartments in their market and area). Although Class A units in multifamily rental properties constitute 33.1% of the total units (in multifamily rental properties) in Metro Denver, they constitute 47.6% of units (in multifamily rental properties) within a 10-min walk of an RTD station (CoStar, 2017). Defining affordability as the ability of a household to

pay less than 30% of its income toward its rent, for a 2-person household earning 60% of the area median income, only 7.8% of the 1-bedroom units and 6.0% of the 2 + bedrooms units in multifamily rental properties located within a 10-min walk of an RTD rail station are considered affordable (CoStar, 2017).

Station-area affordability contrasts with transit-ridership demographics. A 2015 RTD on-board ridership survey found that 60% of rail boardings and 70% of all bus boardings included passengers whose household earns less than $50,000 annually. Comparing these numbers to the city's 2015 income distribution, in which 37% of Denver households earned less than $50,000 per year, it is understood that the RTD rail and bus services are mainly used by lower income households, even though the majority of station-area apartments are not affordable for low-income households. Despite the high proportion of low-income riders, RTD does not currently offer a discount for low-income households. RTD offers bus and rail tickets and passes with a 50% discount for seniors (65 years old and over), individuals with disabilities, and Medicare recipients. Low-income riders may access reduced fares and passes through RTD's Nonprofit Program, which offers a 50% discount to eligible non-profit or governmental community/social service organizations that provide assistance to low-income and homeless individuals; the program currently operates with a cap of $6.8 million annually. In March 2017, a 25-member working group convened to evaluate RTD's pass programs. In February 2018, the working group recommended a 40% discount for individuals earning below 185% of the federal poverty limit, among other changes. The RTD Board of Directors will consider this recommendation in September 2018.

5. Household survey design and implementation

To study the travel behavior of station-area residents in Denver, CO, a household survey was designed and distributed to 21 properties located within a 10-min walk of an RTD rail station. The focus of the survey was on collecting information on: (i) household characteristics (number of household members, number of vehicles, and parking); (ii) choice of mode, in general and for commuting to work (mode of transportation used for traveling the most distance in the last 30 days, employment status, zip code of work location, travel time, benefits offered by employer such as RTD pass and free parking); (iii) frequency of using RTD bus and rail for different purposes (general use, accessing medical care, child care, education, grocery stores, shopping malls and department stores); and (iv) demographics (age, sex, marital status, education, race/ethnicity, income, valid driver's license, disability). Similar household surveys have been conducted in the past for examining whether TOD encourages transit use. For example, Cervero (1993) and Lund et al. (2004) conducted surveys in the San Francisco Bay Area to compare the travel behavior of station-area and non-station area residents. The Association of Bay Area Governments has conducted the only survey, to our knowledge, that specifically targeted low-income housing residents and compared mode choice between station-area and non-station-area residents of five affordable housing properties (ABAG, 2014). The 2017 RTD household survey is the first survey, to our knowledge, to target both low-income housing and market-rate housing station-area residents and allow for comparisons of their travel characteristics.

As a first step, the CCD and the CHFA LIHTC property data were reviewed to identify station-area apartments, including comparable numbers of low-income, mixed-income, and market-rate properties in different station areas. Forty-four apartment properties were invited to participate in the survey, but only 21 properties accepted. Table 1 provides information on the number of properties and the number of low-income and market-rate units surveyed at each station, and the respective response rates. In addition, Fig. 2 shows the type of properties surveyed and their location with respect to the stations. Six low-income, nine mixed-income[1], and six market-rate properties within a 10-min walking distance from nine RTD rail stations were surveyed. A paper survey was distributed in the first week of May 2017 to the majority of the properties. Five market-rate apartments and one mixed-income apartment preferred an online survey, which was distributed over email to property management, who then shared it with their residents. In total, 312 responses were received with an average response rate of 13%.

Table 1
Properties surveyed and response rate.

#	Light Rail Station Name	Number of Properties	Low-Income Units	Market-Rate Units	Response Rate
1	10th & Osage	5	276	113	0.10
2	20th & Welton	4	0	865	0.08
3	25th & Welton	2	112	61	0.31
4	27th & Welton	4	436	265	0.13
5	30th & Downing	1	85	0	0.05
6	38th & Blake	1	0	66	0.24
7	40th & Colorado	2	156	168	0.07
8	Decatur/Federal	1	80	0	0.19
9	Evans	1	50	0	0.10
Total		21	1113	1305	0.13

In 2016, DRCOG surveyed 2547 residents located within a 1-mile walk of an existing or under-construction rail or bus rapid transit station in Metro Denver (response rate not provided in the report) (DRCOG, 2018). The data from the 2016 DRCOG survey could not be used for the purposes of this study due to lack of information with respect to the location and the property type (affordable housing or market-rate) of the respondents' residence. Some of the summary results of the 2016 DRCOG survey are discussed for comparison purposes in the following sections. However, it should be understood that these summary results mainly represent market-rate housing, which constitutes the highest proportion of the housing population within 1 mile of the rail corridors in Denver, and can therefore only be compared with the 2017 RTD household survey responses from market-rate apartments.

6. Station-area resident characteristics and travel behavior comparisons

We use descriptive and geospatial analyses to study the socio-demographic and travel characteristics of station-area residents using the RTD household survey results. In Section 6.1, we focus on the socioeconomic characteristics of the survey respondents, including employment status, age, and vehicle ownership. Section 6.2 discusses general mode choice and frequency of transit use of the survey respondents. In addition, Section 6.3 focuses on the travel behavior of station-area residents who are retired or unable to work. Last, Section 6.4 discusses the mode choice, travel time, employment location and transit use frequency of employed station-area residents. In the following sections, the survey responses are categorized by type of property and type of unit, as follows:

- Type of Property: Three property types participated in the survey: (i) low-income properties, (ii) mixed-income properties, and (iii) market-rate properties. The term "low-income property" refers to a property that includes only income-restricted units. Mixed-income properties include income-restricted as well as non-income-restricted units. Market-rate properties have no income-restricted units.
- Type of Unit: Apartment units can be either income-restricted or market-rate. A "low-income unit" is defined here as an income-restricted unit occupied by a household earning less than 60% AMI.

[1] Mixed-income properties have low-income as well as market-rate units.

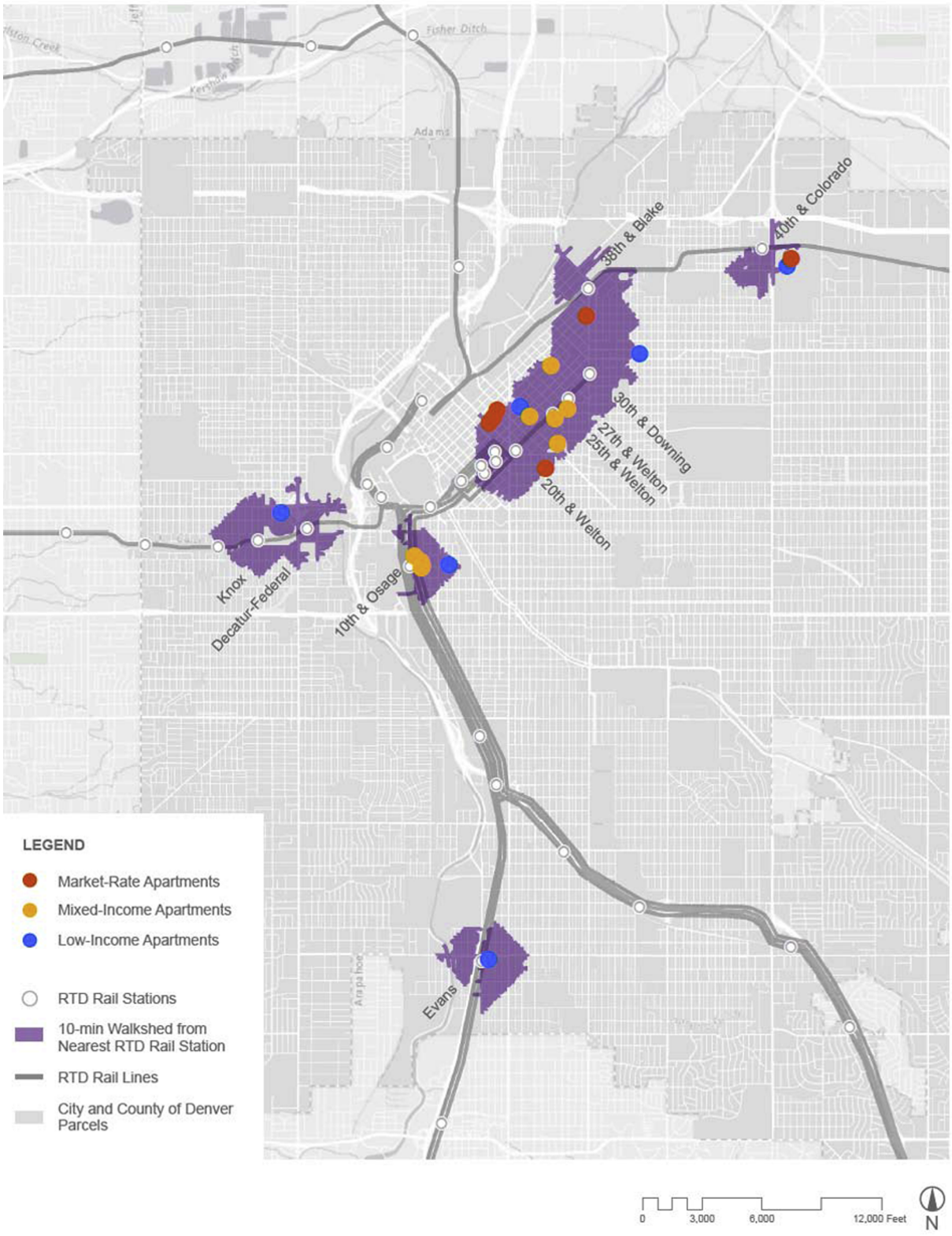


Fig. 2. Location of properties surveyed and nearest RTD rail stations.

Market-rate units are apartment units occupied by households earning over 60% AMI.

6.1. Socioeconomic indicators

This section addresses three socioeconomic characteristics of station-area residents that are of particular interest when comparing income-restricted and market-rate housing: (i) employment status, presented in Table 2, (ii) age, presented in Fig. 3, and (iii) vehicle ownership, presented in Fig. 4. Ninety-five percent of market-rate unit respondents are employed (either full or part-time). On the contrary, only 39% of low-income unit respondents are employed, while 30% are

Table 2
Employment status of the respondents by property/unit type.

Employment Status	Low-Income Property	Mixed-Income Property	Market-Rate Property	Low-Income Unit (Household ⩽ 60% AMI)	Market-Rate Unit (Household > 60% AMI)
Employed full-time	0.17	0.48	0.88	0.23	0.84
Employed part-time	0.21	0.14	0.09	0.16	0.11
Unemployed (looking for work)	0.08	0.06	0.01	0.08	0.01
Unemployed (unable to work)	0.35	0.16	0.01	0.30	0.01
Retired	0.19	0.16	0.00	0.23	0.01
Student	0.00	0.01	0.01	0.00	0.01

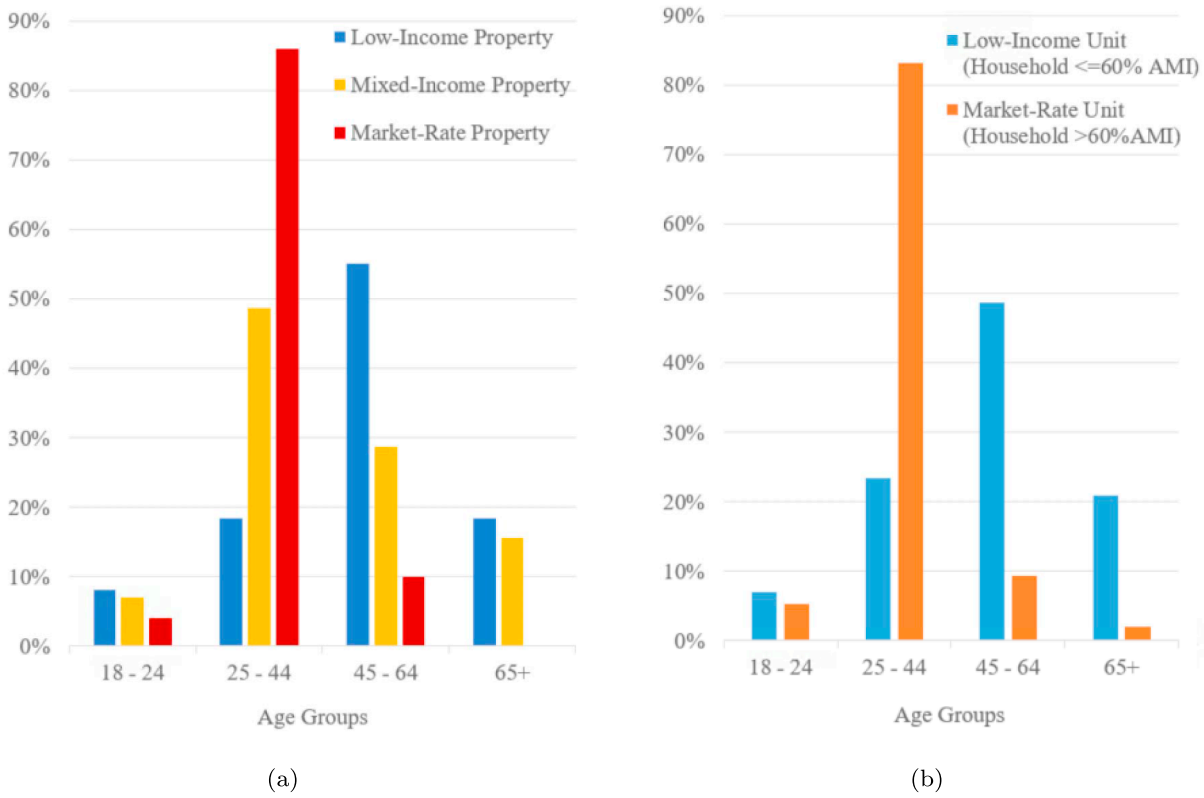


Fig. 3. Age distribution for the survey respondents by (a) property type and (b) unit type.

unable to work, and 23% are retired. In addition, 83% of market-rate unit respondents are between 25 and 44 years old, compared to 23% of low-income unit respondents in that age group. With respect to the elderly, 21% of the low-income survey respondents are over 64 years old, compared to only 2% in market-rate units.

Studies on affordable housing residents demonstrate similar results with our findings in terms of disability and age but they also find that affordable housing residents are more likely to have poor health (Digenis-Bury et al., 2008; Gibler, 2003). The differences observed in terms of employment status and age constitute an important distinction between station-area residents of different property types. Older low-income residents who are retired and/or disabled may have difficulty accessing transit and may not use transit services as frequently as market-rate residents, the vast majority of whom are found to be employed and less than 45 years old. Further investigation is necessary for understanding how these sociodemographic differences relate to variations in travel behavior of these residents.

With respect to vehicle ownership, more than half of the low-income unit respondents do not have any vehicle in the household compared to only nine percent of market-rate unit respondents. Out of the low-income respondents with zero vehicles per household, 51% has a disability that does not allow them to drive and 71% has no driver's license. In addition, 49% of market-rate unit households have one vehicle, while 40% of market-rate unit households have two vehicles.Because past studies have shown vehicle ownership to be highly correlated with mode choice (Cervero, 1994; Cervero, 2007; Lund et al., 2004), given the large disparity in vehicle ownership between low-income and market-rate residents we expect to observe significant differences in mode choice.

6.2. Mode choice and frequency of transit use

This section discusses general travel behavior by property and unit type without focusing on a specific trip purpose or age group.

Fig. 5 represents survey respondents' typical mode of travel over the most distance in the last 30 days, displayed by property type and unit type. Two-thirds of low-income unit respondents indicated that they used RTD services for traveling the most distance, compared to a roughly similar rate of market-rate unit residents who typically traveled the most distance by personal vehicle (69%). In terms of transit ridership, low-income property residents reported the highest rate (76%), while market-rate unit residents reported the lowest rate (17%), which

Fig. 4. Distribution of vehicle ownership per household for the survey respondents by (a) property type and (b) unit type.

aligns with results from previous studies (Cervero, 1993; Lund et al., 2004). As expected, the use of another motorized (taxi/rideshare, carshare, carpool) or non-motorized (walk, bicycle) mode as the main mode for traveling the most distance is relatively low for all properties and particularly low for low-income properties. For example, six percent of respondents from market-rate properties indicated that their primary mode is bicycle compared to zero percent of respondents from low-income properties. In addition, ten percent of respondents from market-rate properties used taxi/rideshare, carshare or carpool for traveling the most distance compared to zero percent of respondents from low-income properties.

Figs. 6 and 7 provide information on the frequency of use of RTD bus and rail, respectively, by property and unit type. Focusing on the market-rate units, results show that 69% and 32% of the respondents

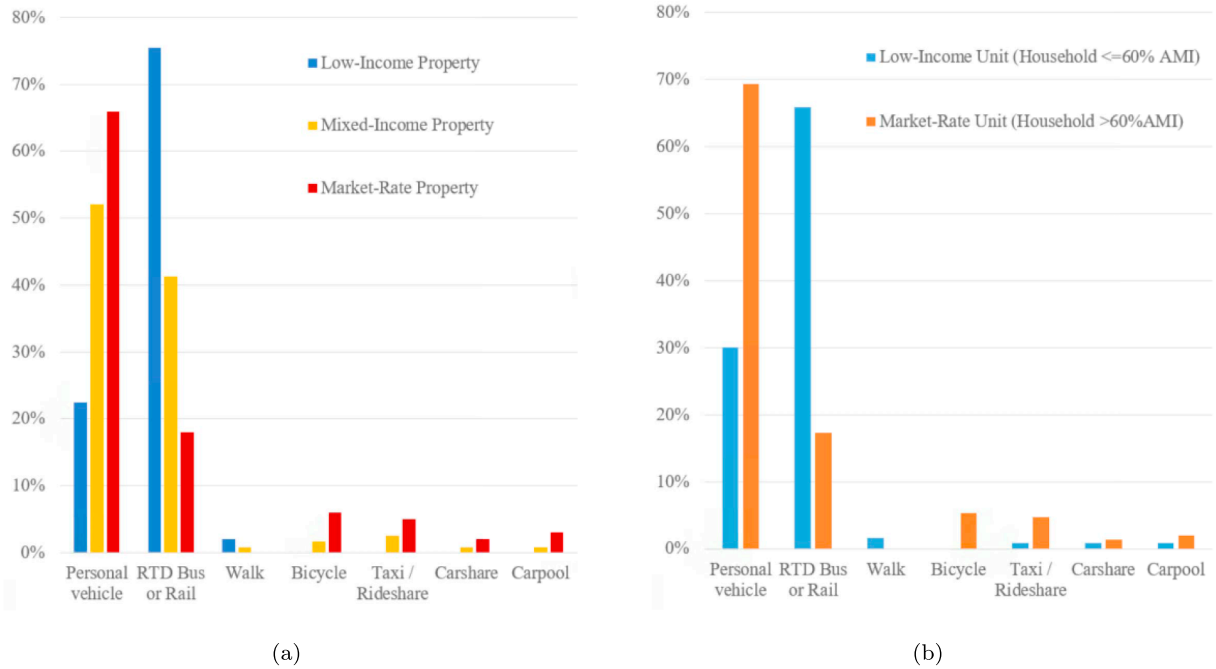


Fig. 5. Distribution of transportation mode choice for traveling the most distance in the past 30 days by (a) property type and (b) unit type, for all trip purposes.

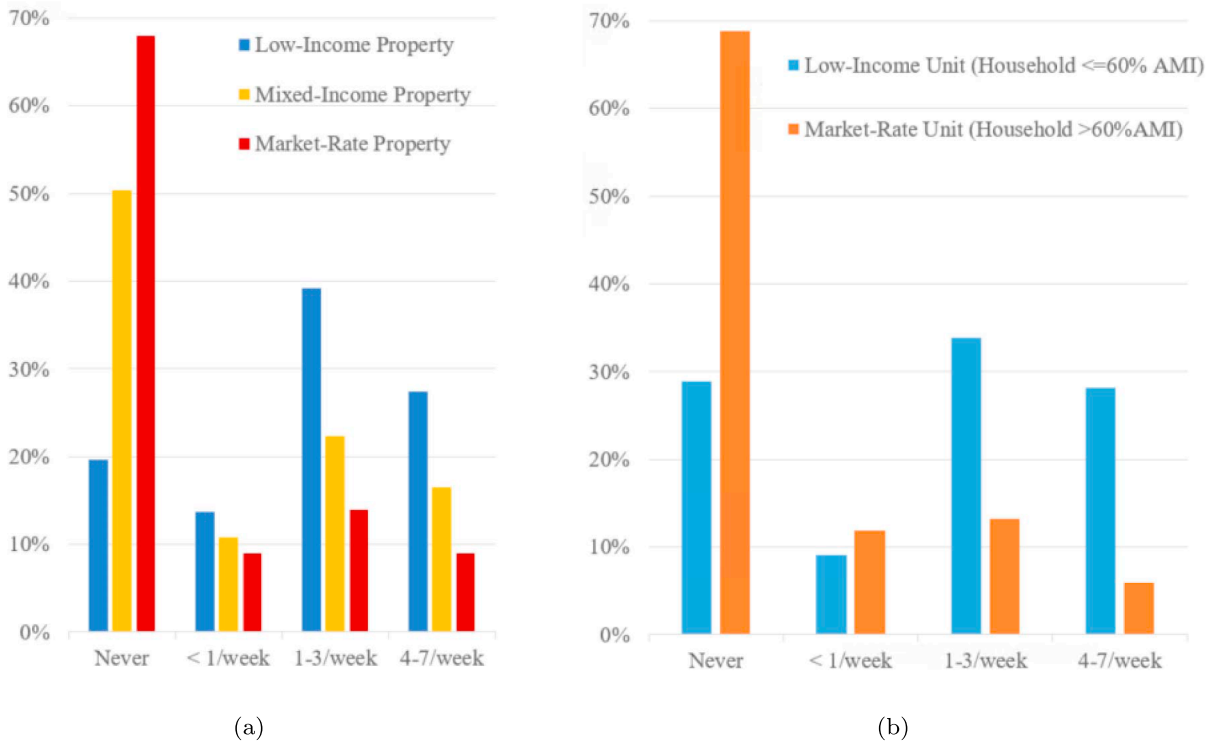


Fig. 6. Frequency of use of RTD bus in the past 30 days by (a) property type and (b) unit type, for all trip purposes.

Fig. 7. Frequency of use of RTD rail in the past 30 days by (a) property type and (b) unit type, for all trip purposes.

Table 3
Mode of transportation typically used for traveling the most distance in the past 30 days – retired and unemployed (unable to work) residents.

Transportation Mode	Low-Income Property	Mixed-Income Property	Market-Rate Property	Low-Income Unit (Household ⩽ 60% AMI)	Market-Rate Unit (Household > 60% AMI)
Personal vehicle	0.12	0.32	–	0.22	–
RTD Bus or Rail	0.84	0.68	–	0.76	–
Walk	0.04	0.00	–	0.02	–

never used RTD bus or rail, respectively, in the last 30 days; in addition, only six percent and 13% of the respondents used RTD bus or rail, respectively, more than three times per week. The frequency of use of RTD services is much higher for low-income unit residents, approximately 60% of whom use RTD services at least once per week and 28% of whom use RTD services more than three times per week. Comparing the use of RTD bus and rail, survey responses show that low-income unit residents use bus or rail with similar frequency, while market-rate unit respondents have a strong preference for rail: the frequency of use for bus is at least half that of rail. This result is justified by the preference of the higher income for faster and more direct modes of transportation.

6.3. Mode choice and frequency of transit use for residents who are retired and unable to work

As shown in Table 2, few survey respondents from market-rate units are retired or unable to work. For this reason, the analysis in this section does not present results for market-rate properties and units. Table 3 presents, in percentages, the choice of transportation mode typically used for traveling the most distance for the residents of low-income units who are unable to work or retired, and Table 4 presents the frequency of use of RTD services for the same group of respondents for three trip purposes: (i) general use, (ii) accessing medical care facilities, and (iii) accessing grocery stores. Overall, the survey found that not only do these residents primarily travel by bus and rail, but they also make frequent trips: 67% and 58% uses RTD bus and rail, respectively, at least once per week, and more than half of those use RTD services at least four times per week. In addition, transit is used frequently for accessing medical care and grocery stores. The frequency of use for bus is found to be higher than rail, perhaps due to the bus network's greater coverage than that of rail. With respect to the cost of travel by transit, 31% of the respondents indicated that they used a ticket, day pass, or monthly pass provided through RTD's Nonprofit Program; seniors and individuals with disabilities receive a 50% discount in all RTD tickets and passes.

In the recent years, significant research effort has been put into identifying the travel characteristics of the elderly and people with disabilities (Ermagun et al., 2016; Rahman et al., 2016; Szeto et al., 2017; Truong and Somenahalli, 2015). With respect to station areas, Boschmann and Brady (2013) conducted a study on the travel behavior of older adults in Denver, CO, and found that 84% of station-area residents over 60 years old primarily travel by personal vehicle. Boschmann and Brady (2013) defined station areas using a one-mile buffer (compared to a ten-minute walkshed in our study) and did not focus on affordable housing residents; therefore, results are not directly comparable.

Table 4
Frequency of use of RTD services – retired and unemployed (unable to work) residents of low-income units.

	RTD Bus			RTD Rail		
	General Use	Medical Care	Grocery Store	General Use	Medical Care	Grocery Store
Never	0.22	0.46	0.52	0.32	0.52	0.57
< 1/week	0.12	0.15	0.08	0.09	0.18	0.05
1–3/week	0.42	0.32	0.34	0.32	0.23	0.32
4–7/week	0.25	0.06	0.06	0.26	0.06	0.06

6.4. Travel characteristics of employed residents

To analyze commuting travel behavior and mode choice, we focus on the respondents that are full-time and part-time employed. Fig. 8 summarizes the transportation mode choice for traveling the most distance to work. Based on the responses received, 35% of employed residents of low-income units use RTD bus to commute; the second most popular mode is personal vehicle (29%) while the third most popular mode is RTD rail (27%). Regarding the employed residents of market-rate units, 43% of the respondents typically use their personal vehicle to commute; the second most popular mode is walking (20%) while the third most popular mode is RTD rail (14%). Overall, 20% of the employed survey respondents residing in market-rate units use RTD bus or rail for their daily commute, compared to 63% in low-income units. Further research is necessary to understand and explain the choice of commuting mode for the residents of low-income units. For example, it could be the case that the long waiting list for income-restricted units does not allow room for selecting among different properties, potentially resulting in some low-income households being placed far from work or other activities of interest, compelling them to drive more. It is also important to investigate why the RTD bus is chosen as commuting mode by most respondents compared to RTD rail. One potential reason is that the RTD bus network provides higher coverage of Metro Denver compared to RTD rail. Therefore, given the restrictions with respect to residential choice, a low-income unit resident may be more likely to access employment by bus than by train, which would justify the higher percentage of residents using the bus. It should also be noted that the majority of rail stations have connecting bus service and that, overall, the properties surveyed are located in areas with access to bus service.

To further investigate the travel characteristics of employed affordable and market-rate housing residents, we first calculate the sample mean and standard deviation for travel time for employed residents that commute to work. Table 5 presents the results by property and unit type. We observe that the highest difference between low-income and market-rate units in terms of average travel time is for the RTD bus. The travel time for the low-income unit respondents that typically commute by bus is on average 55 min compared to 26 min for market-rate units (more than 50% difference). As previously discussed, further research is necessary for understanding and quantifying the potential externalities of the residence location choice restrictions (due to the low supply of affordable housing) for affordable housing residents with respect to commute mode choice and travel time. Multiple factors may be responsible for higher commute time for affordable housing residents. However, it is important to investigate how ETOD and affordable housing regulations may contribute to this problem in order to be able to improve the quality of life of the residents.

In addition to travel time, we investigate the spatial aspects of commuting trips. Fig. 9 shows work location (at the ZIP-code level) by mode used for the commuting trip for low-income and market-rate units. The modes displayed are (i) RTD rail or bus, (ii) personal vehicle, and (iii) both. A light green (grey) colored spatial unit implies that the majority of respondents used RTD rail or bus (personal vehicle) to

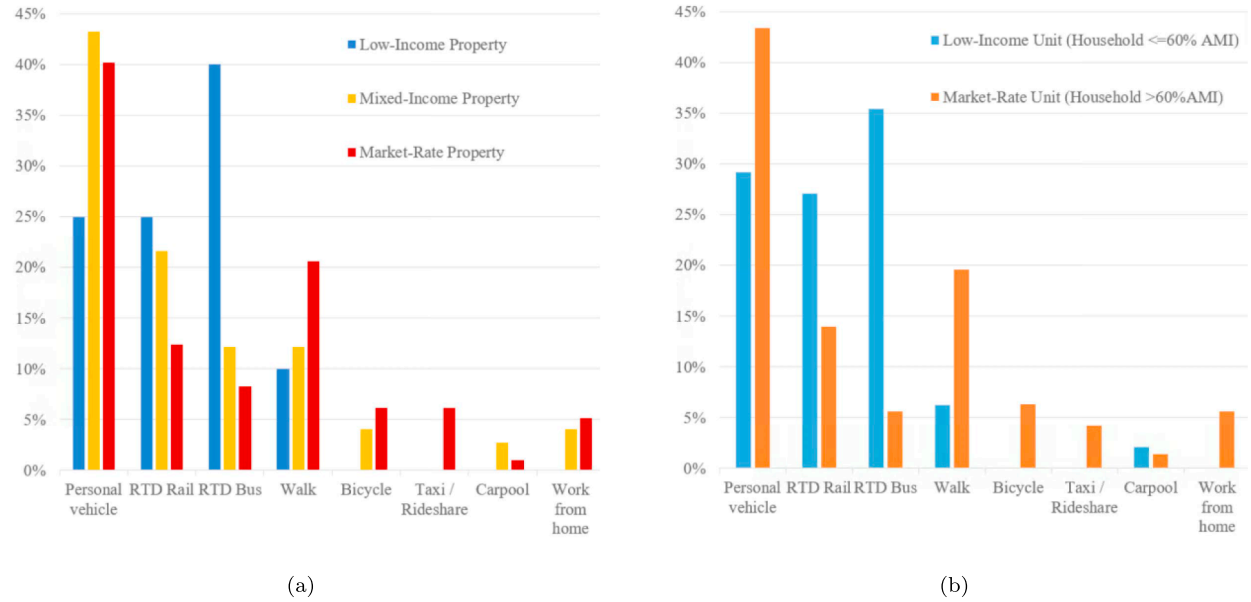


Fig. 8. Distribution of transportation mode choice for traveling the most distance in the past 30 days by (a) property type and (b) unit type, for the employed residents.

commute to that ZIP code. A dark green colored spatial unit implies that half of the residents commuting to that ZIP code used RTD services and the other half used their personal vehicle. The spatial pattern appearing in Fig. 9 (b), which presents the commuting trips taken by residents of market-rate units, suggests that, even for areas close to Downtown Denver and areas served by RTD rail, the majority of residents choose to commute by personal vehicle. The opposite holds for the employed residents of low-income units who seem to mostly utilize RTD services unless they work in the suburbs.

The importance of employer incentives on mode choice have been demonstrated by previous studies. For example, Cervero (1993) had found that when free parking is offered by the employer, the probability of a TOD resident commuting by personal vehicle increases significantly. Here, the focus is on any differences observed between station-area low-income and market-rate unit residents. Table 6 presents the percentage of respondents who commute to work by either personal vehicle or RTD services and are offered (i) an RTD EcoPass, FlexPass, Monthly Pass or CollegePass, (ii) free parking at work, and (iii) flexible work hours by their employer. We find that 44% of the employed residents of market-rate units who commute by personal vehicle are offered free parking, compared to 36% of those living in low-income units. We also find that 46% of the employed residents of market-rate units who commute by RTD rail or bus are offered an RTD pass through their employer, compared to 40% of those living in low-income units. However, only 28% of the respondents in market-rate units who are offered an RTD pass actually commute by RTD. On the contrary, 92% of the respondents in low-income units who are offered an RTD pass commute to work by RTD.

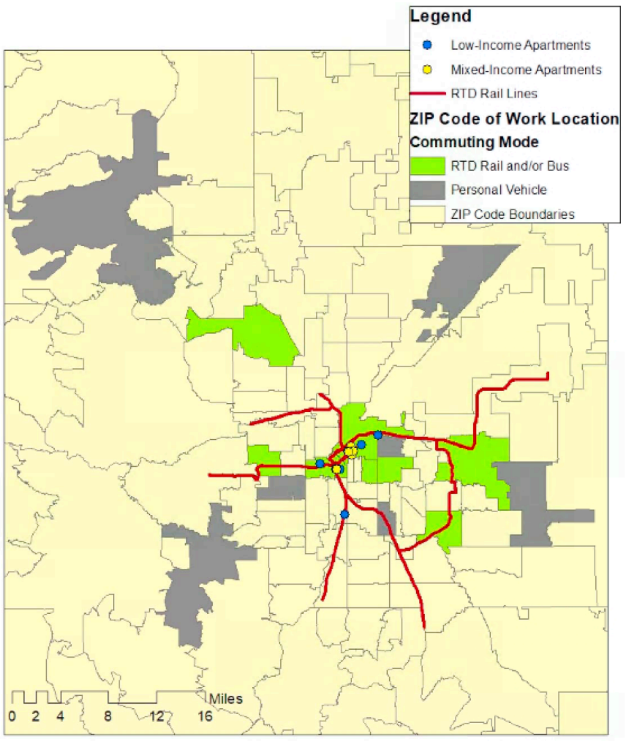
Last, we investigate the frequency of transit use by employed residents (Table 7) and we compare it to non-employed residents (Table 4). As previously discussed, the majority of low-income residents are not employed while the opposite holds for market-rate residents. It is therefore important to understand the differences in terms of frequency of transit use and the implications this has for transit ridership among employed market-rate residents and non-employed low-income residents. Focusing first on the comparisons between the employed residents of different units, we can see that 55% of employed low-income unit respondents use RTD bus at least once per week, compared to 20% for employed market-rate unit residents. The frequency of use is higher for RTD rail among the employed: 66% of employed low-income unit respondents use RTD rail at least once per week, compared to 34% among employed market-rate unit respondents.

Comparing these findings to Table 4, we can see that the majority of retired and unable to work residents of low-income units use RTD services one to three times per week, while the majority of the employed residents of low-income units use RTD services four to seven times a week. It also becomes clear that the frequency of transit use for the non-employed residents of low-income units significantly surpasses the frequency of the employed residents of market-rate units. Last, 29 to 40% of the non-employed low-income unit residents use RTD bus or rail at least once per week for accessing medical facilities and grocery stores, compared to one to seven percent of the employed market-rate residents and 16 to 31% of the employed low-income residents.

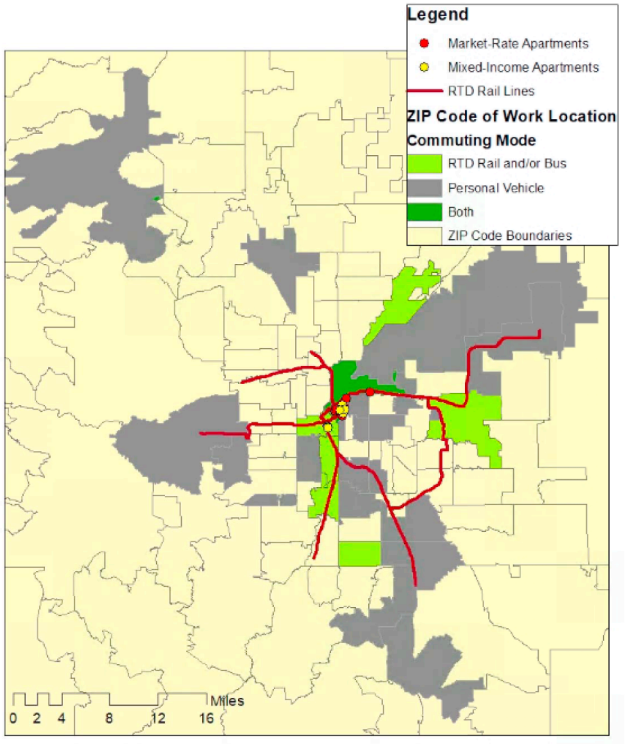
Some of the results of the survey conducted by DRCOG in 2016 are

Table 5
Descriptive analysis of travel time (in minutes) from household to work – full and part-time employed residents that commute to work.

Transportation Mode	Low-Income Property		Mixed-Income Property		Market-Rate Property		Low-Income Unit (Household ⩽ 60% AMI)		Market-Rate Unit (Household > 60% AMI)	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Personal vehicle	28.75	6.29	22.72	16.78	22.43	14.35	23.23	11.10	22.85	15.96
RTD Bus	53.33	25.03	60.55	30.36	26.25	17.27	55.20	30.36	26.25	17.27
RTD Rail	17.40	7.16	19.77	11.60	27.65	16.94	16.27	8.52	25.64	14.49
Walk	–	–	12.33	9.47	18.70	16.77	11.00	6.90	17.21	15.06
Bicycle	–	–	19.00	6.56	26.08	15.13	–	–	23.72	12.90
Taxi/Rideshare	–	–	–	–	25.75	21.88	–	–	25.75	21.88



(a) Employed residents living in a low-income unit



(b) Employed residents living in a market-rate unit

Fig. 9. Zip Code of Work Location and Commuting Mode.

discussed herein for comparison purposes. DRCOG (2018) found that 17% of the survey respondents used RTD bus or rail at least once a week to commute to work. Additionally, 6% of the respondents used RTD bus or rail daily for their work commute and 49% commuted to work daily by personal vehicle.[2] The top two reasons indicated by the respondents for not using public transportation were that the trip takes too long or includes too many transfers, and that they need their personal vehicle before or after work. Our results for the market-rate residents are significantly different, potentially for the following reasons: (i) our sample includes properties within a 10-min walk of a rail station while the 2016 DRCOG survey targeted properties within 1 mile of RTD rail stations; (ii) only 32% of the 2016 DRCOG survey respondents live in an apartment, compared to 100% of our respondents.

7. Conclusions, policy recommendations, and directions for future research

This paper investigates and compares the travel behavior of individuals residing in low-income, mixed-income, and market-rate apartment properties within a 10-min walk of an RTD rail station in Denver, CO. The objective of the study is to identify key socioeconomic variations among residents of different developments that may be correlated with travel behavior and quantify differences in mode choice and frequency of transit use by property type, socioeconomic group, trip purpose. The presented results are based on 312 individual responses to a household survey distributed by RTD in May 2017 to 21 apartment properties with a total of 2400 apartment units.

Based on the survey results, we find that the residents of market-rate and low-income units significantly differ in terms of age, employment status, and vehicle ownership. Specifically, 95% of market-rate unit respondents are employed compared to only 39% of low-income unit respondents; 53% of the low-income unit respondents are either unable to work or retired. In addition, 53% of the respondents who reside in low-income units live in a household with no personal vehicle, compared to nine percent for market-rate units. Given the aforementioned comparisons, it is expected to observe significant variations in terms of mode choice between residents of different station-area developments. Indeed, we find that 69% of the respondents who live in market-rate units typically travel the most distance by personal vehicle compared to 30% of those in low-income units. When it comes to commuting to work, the differences in terms of the use of personal vehicle are smaller: 43% of market-rate unit respondents typically commute by personal vehicle compared to 29% of low-income unit respondents. However, large differences are observed for transit: only 20% of the employed survey respondents residing in market-rate units use RTD bus or rail primarily for their daily commute to work, compared to 63% in low-income units.

Focusing on how frequently residents of different station-area development use public transportation, 69% and 32% of the respondents who reside in market-rate units indicated that they never used RTD bus and rail, respectively, in the last 30 days; less than 21% used transit more than once a week and less than 13% used transit more than three times a week. On the contrary, approximately 60% of low-income unit respondents indicated that they used RTD services at least once per week and 28% used RTD services more than three times per week. Although the majority of low-income housing residents are either unable to work or retired, survey results indicate that they use RTD rail and bus much more frequently in general but also for accessing healthcare and grocery stores, compared to residents of market-rate units, the majority of which are employed.

Previous research on the travel behavior of station-area residents has used a control group (non-station-area residents) to make useful

[2] People who telecommute were also considered and accounted for 7% of the total.

Table 6
Percentage of respondents commuting by personal vehicle or RTD service that receive free parking, RTD pass, and flexible work hours – full and part-time employed residents that commute to work.

Employer Incentive	Low-Income Property		Mixed-Income Property		Market-Rate Property		Low-Income Unit (Household ⩽ 60% AMI)		Market-Rate Unit (Household > 60% AMI)	
	Personal vehicle	RTD Bus or Rail	Personal vehicle	RTD Bus or Rail	Personal vehicle	RTD Bus or Rail	Personal vehicle	RTD Bus or Rail	Personal vehicle	RTD Bus or Rail
RTD Pass	0.00	0.46	0.28	0.44	0.31	0.40	0.07	0.40	0.31	0.46
Free parking	0.00	0.00	0.53	0.12	0.36	0.10	0.36	0.07	0.44	0.11
Flexible hours	0.20	0.08	0.34	0.24	0.38	0.45	0.14	0.10	0.39	0.46

Table 7
Frequency of use of RTD services – full and part-time employed residents that commute to work.

	Low-Income Unit (Household ⩽ 60% AMI)						Market-Rate Unit (Household > 60% AMI)					
	RTD Bus			RTD Rail			RTD Bus			RTD Rail		
	General Use	Medical Care	Grocery Store	General Use	Medical Care	Grocery Store	General Use	Medical Care	Grocery Store	General Use	Medical Care	Grocery Store
Never	0.44	0.71	0.62	0.27	0.78	0.62	0.68	0.90	0.85	0.31	0.87	0.83
<1/week	0.00	0.13	0.07	0.07	0.07	0.07	0.12	0.10	0.10	0.35	0.11	0.11
1–3/week	0.24	0.16	0.31	0.33	0.16	0.27	0.14	0.01	0.04	0.22	0.02	0.06
4–7/week	0.31	0.00	0.00	0.33	0.00	0.04	0.06	0.00	0.00	0.12	0.00	0.01

comparisons (Cervero, 1994; Lund et al., 2004). In summary, these studies have found that station-area residents are five to six times more likely to commute by transit compared to other residents in the same region (Cervero et al., 2004). Even though our study finds that the rate of transit use of station-area residents in market-rate units is significantly lower compared to the residents of low-income units, it is important to note that based on the results of previous research, this rate is potentially much higher compared to non-station-area residents of market-rate units. Future research should allow for more valuable comparisons by sampling across four categories of residential developments: station-area market-rate and affordable housing as well as other market-rate and affordable housing in the same urban area. Such a research design would give the opportunity to study potential accessibility and welfare benefits to low-income households due to location advantage as well as provide a better understanding of ridership gains to the transit agency. Additional research is also necessary for assessing how restrictions in terms of residential location choice (due to the currently low supply of affordable housing in urban areas) for affordable housing residents impact mode choice, travel time, and their overall accessibility to employment and other destinations.

Our results can be used by transit agencies who are interested in understanding how ETOD contributes to transit ridership generated by station areas. This is a limiting contribution because transit agencies are mostly interested in maximizing their total ridership in the region they serve. Further research, which would include a household survey representative of the entire region of interest, is necessary for assessing the impact of ETOD policies on ridership at the regional level.

An important outcome of this study is that, overall, the majority of station-area affordable housing residents primarily use the RTD bus to access employment and other destinations and tend to have longer commuting time. This finding suggests that transit agencies pursuing joint development as a means to increase transit ridership should prioritize redevelopment of park-and-ride properties for affordable housing at rail stations well served by high-frequency bus service. Moreover, as transit agencies typically do not control sizeable properties like park-and-rides on high-frequency bus corridors separate from rail stations, transit agencies should coordinate closely with municipalities with the authority to promote bus-oriented affordable housing through regulation and financial programs.

Our findings also suggest that the vast majority of the respondents who live in low-income units and are offered an RTD pass by their employer use RTD to commute to work. Seniors and individuals with disabilities are entitled to a 50% discount for passes and fares. However, there is no discount for low-income individuals, unless they receive tickets or passes through RTD's Nonprofit Program, which is currently capped at $6.8 million per year. Transit agencies should collaborate with affordable-housing developers and other stakeholders with a stake in expanding regional economic opportunity to consider fiscally prudent methods for delivering discounted passes to transit-dependent low-income households.

This paper constitutes one of the first research studies on the travel behavior of ETOD residents. However, our study is limited to a single urban area. It is, therefore, important that similar studies are conducted by other transit agencies, to allow for more generalized results. Future work should also include an analysis of the significance of parking availability and price at work and at home for different types of development. As transit agencies' joint development policies should intentionally seek to increase ridership, those policies should account for the impact of parking availability on travel behavior and potentially require development partners to significantly reduce, cap, or unbundle parking from the project, thereby promoting use of public transportation.

Acknowledgments

We would like to thank the reviewers of *Travel Behavior and Society* for their valuable comments and suggestions. We would like to acknowledge the contributions of the following colleagues to the survey preparation and data collection efforts necessary to complete this study: Jonathan Cappelli, Cappelli Consulting; Brad Calvert, Denver Regional Council of Governments; Xavier Gitiaux, Denver Regional Council of Governments; Jungwha Yuh, RTD; Dennis Yaklich, RTD; Lee Cryer, RTD; Jeff Tranguch, RTD; Lex Nast, RTD; Edin Memic, RTD; Mindy McNair, RTD; Chris Nevitt, City and County of Denver; Corey Staver, City and County of Denver; John Plakorus, Colorado Housing Finance Authority.

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