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The rail transit system and land use change in the Denver metro region

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ABSTRACT

One of the goals of constructing and operating an extensive rail transit system in the Denver metro region since 1994 has been growth and development of land use along the rail transit system. This paper analyzes the trend of land use growth and development around the rail transit system mostly from 2000 to 2010. Primarily land parcel data collected from the assessor's office of several counties in the metro region have been used to determine change in the amount of different types of land use namely commercial, mixed, industrial, multi-family residential and single-family residential near and far from the rail transit system. Change has been analyzed in terms of total square footage of the building areas as well as land use density. Statistical significance tests (Wilcoxon/Kruskal–Wallis test) have been conducted to understand if the amount of change taking place near the rail transit system is greater than away from the system. The growth of commercial land use was significantly higher near the rail transit system. More growth in multi-family residential land use has also occurred near the rail transit system, but was not significantly greater than areas away from the system. Single-family residential land use has noticeably increased in places away from the rail transit system. The other types of land use have not shown any consistent pattern in their growth either near or away from the system. Overall, a noticeable amount of land use change, especially commercial land use, has taken place around the rail transit system from 2000 to 2010. However, this change in land use cannot necessarily be attributed to the construction and operation of the rail transit system. Other factors may have influenced the growth of land use around the rail transit system more than the presence of the rail transit system itself.

1. Introduction

In the U.S., to date, the rail transit industry has experienced three major periods of growth and development: first in the late 1800s when commercially successful rail transit systems started operating, second starting in the 1970s when a series of rail transit systems were rejuvenated and built to counter the ill effects of automobiles especially traffic congestion and urban sprawl (Knox and McCarthy, 2005; Pucher, 2004; Vuchic, 2007) and third in recent times with a drastic rise in gasoline prices beginning in August 2005 (Lane, 2009) and increased road infrastructure maintenance and expansion costs. During each phase of growth and development of the rail transit industry there was noticeable change in the organization, pattern and size of the urban areas as indicated by several studies published since the 1970s.

Like other parts of the U.S., in Denver, the administrative capital of Colorado located at the eastern foothills of the Rocky Mountains, the rail transit system grew and developed in multiple phases. An extensive streetcar network developed in the late 1800s that was eventually shut down by 1950. Then starting in 1994 a new light rail system began to operate in the metro region. In 2004, Denver area voters approved the $4.7 billion (now estimated to cost $7.4 billion) FasTracks plan to add 122 mi of light and commuter rail service to the existing system and it is currently being implemented. During the first and second major periods of growth the "streetcars accessed virtually the entire city" (Ratner and Goetz, 2013: 33) and it was expected that the new light rail system and Fastracks will generate major changes in the urban land use of the Denver metro region especially through Transit Oriented Development (TOD) around the station areas.

This study uses parcel-level data to understand the urban land use changes that have taken place in the Denver metro region along with growth and development of its rail transit system since the 1990s. Previous studies of the impact of recent rail transit system development on urban form in the Denver metro region have focused on the land use changes within 1/2 mile of rail transit stations (Ratner and Goetz, 2013; RTD, 2013). This study uses statistical significance tests to understand whether the urban land use changes taking place near the rail transit system are significantly different from those taking place away from the system. This comparison should thus control for land use changes that are occurring throughout the Denver metro region, and pinpoint whether changes near the rail transit system are above and beyond what would be expected based on general population and economic growth trends in the metro region. In other words, are areas near the rail transit system accounting for a greater degree of land use development than the average for the entire metro region?

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This study does not determine whether the rail transit system is a causal factor affecting land use change in the Denver metro region. There are many factors that affect urban land use patterns, and the provision of rail transit may possibly be one of those factors. The purpose of this study is not to identify causal factors behind land use change but to provide a baseline of land use development in areas: 1) presently served by rail transit, 2) to be served by future FasTracks lines, and 3) not served by rail transit now or to be served by FasTracks. Land use theory would suggest that if accessibility is improved (or expected to improve) due to the initiation of rail transit, land use development should increase in areas directly served by the rail transit. In order to assess whether the initiation of rail transit is having an effect on land use, the first step is to assess whether and how land use has changed near the rail transit system. Because other studies conducted on transit-oriented development in Denver (Ratner and Goetz, 2013; RTD, 2013) have identified substantial changes in land use near rail transit stations, the purpose of the current study is to compare land use changes near the rail transit system with those away from the rail transit system to detect significant differences. If significant differences are found, then there exists a possibility that rail transit provision is a causal factor. If significant differences are not found, then there would be no possibility that rail transit is a causal factor. So, this study is an additional step in the process of determining if and how rail transit might be influencing land use change in the Denver metro region. It also provides a baseline analysis of current land use that can be updated in future years as new rail transit lines are added.

This paper has been arranged in the following manner. Section 2 reviews literature on the change of urban land use along with growth and development of rail transit systems. Section 3 provides basic information about the Denver metro region, its rail transit system and transit supportive land use policies. Section 4 describes the method of analysis, study area, time period of the study and process of data collection and preparation. Section 5 provides the results of the analysis. Finally, in Section 6 conclusions are reported along with limitations of the study.

2. Literature review

As the U.S. rail transit industry entered the second major period of growth starting in the 1970s, scholars recognized that there exists a connection between rail transit systems and urban land use change. Through detailed quantitative and qualitative analysis scholars attempted to find the extent of the change during the first two major periods of growth. These research works led to the production of urban area growth theories and models (Adams, 1970; Muller, 1981; Hartshorne and Muller, 1989) and detailed case studies regarding urban land use changes near and away from the rail transit lines and stations (Knight and Trygg, 1977; Webber, 1976; Dyett et al., 1979; Cervero and Landis, 1997; Kenworthy, 1991; Glick, 1992; Dueker and Bianco, 1999). These case studies, in turn, generated a group of journal articles and reports (Cervero and Seskin, 1995; Huang, 1996; Badoe and Miller, 2000; Newman and Kenworthy, 1996; Vessali, 1996; Parsons Brinckerhoff Quade and Douglas Inc., 1996) that summarized the important findings of the case studies and identified commonalities among them.

A scan through these theories, models, case studies and reports, published from the 1970s to 1990s, reveal several characteristics of the connection between rail transit systems and urban land use change. In the late 1800s and early 1900s, rail transit systems changed the shape of the urban areas from circular to star-shaped as settlements developed along the radiating rail transit lines. They also facilitated the expansion of the urban areas by increasing accessibility to the central city from peripheral areas, though not nearly as much as automobiles and highways would in the mid to late 20th century. The rail transit systems rejuvenated or built since the 1970s had less impact on the organization, pattern and size of urban areas. This happened because they did not significantly increase accessibility since automobiles by that time had already reached most parts of the urban areas. These rail transit systems, however, did have a profound impact on urban areas when supported by favorable governmental policies, physical and economic conditions such as existence of an active downtown area, presence of large sized non-utilized or underutilized parcels near the rail transit systems, supportive local zoning policies and public–private investment to initiate growth. They attracted urban development, especially commercial activities, around them. This trend was not only noticeable in the central business district and other major employment centers but also in the suburban areas. This consolidation of land use, especially dense, compact, mixed land use around the station areas is known as transit-oriented development (TOD). In some of the urban areas, the rail transit systems continued the process of decentralization, multi-nucleation and expansion. However, the magnitude of expansion was much less when compared to that of the late 1800s and early 1900s.

As the U.S. rail transit industry transitioned from the second to the third major period of growth, there was a boom in construction of light rail systems primarily due to their lower construction cost as compared to heavy rail (subway) systems (Huang, 1996). The studies and reports about the rail transit system and urban land use change connection, published since 2000, clearly reflect this boom (Center of Transit Oriented Development, 2011; Ishikawa and Tsutsumi, 2006; Handy, 2005; Foth, 2010; Hurst and West, 2014; Ratner and Goetz, 2013; Guerra, 2014; RTD, 2013). A scan through them provides a good understanding about the characteristics of the connection in the current or third major period of growth. A noticeable amount of urban development is taking place along the rail transit systems in contrast to the previous period of growth. For instance, the Hiawatha Line in the Minneapolis-St. Paul region (Minnesota, U.S.) has attracted 6.7 million sq. ft. of new development from 2003 to 2009 and the Southeast Corridor in the Denver region (Colorado, U.S.) has attracted 7.8 million sq. ft. of new development from 2004 to 2009. Most of the new urban developments along the rail transit systems are of residential type, especially multi-family residential, in contrast to most of them being commercial developments in the previous period of growth. For instance along Charlotte's Blue Line (North Carolina, U.S.) there has been a boom in residential development in the form of a wide variety of building types such as row houses, four to five storied condominiums, midrise apartments and condominium towers and in the northern part of Dallas (Texas, U.S.), multi-family residences are the dominant land use around the light rail stations since 1990. The increase in residential construction near rail transit stations is part of a more recent nationwide trend of increased residential growth in and near downtown areas as many millennials, empty nesters, and single-person households have opted for city, rather than suburban, residential locations (U.S. Census, 2012). The new urban development along the rail transit systems are primarily emerging in the downtown areas and other major employment centers. They are effectively creating a denser, more compact urban area and do not have much influence on the expansion of urban areas. In Denver, “46% of retail, 76% of hotel rooms, 49% of office, 66% of government, and 64% of cultural” TOD (Ratner and Goetz, 2013: 45) have taken place near the downtown light rail stations. This trend is however not applicable to all urban areas. In Mexico City, for example, Metro's Line B has attracted new development in the suburban areas instead of the downtown.

Supportive public sector plans, policies and initiatives, especially adopted at early stages of planning and operation, still work as an impetus towards attracting new urban development around the rail transit systems. For instance, the City of Minneapolis developed multiple station area and neighborhood plans as soon as the Federal Transit Administration (FTA) approved a federal grant for the Hiawatha Line in 2001. In Charlotte, planning along the Blue Line began more than a decade before the line started operating in 2007. Besides formulating plans of various types and scales and implementing supportive zoning policies, Charlotte city staff worked closely with the developers and helped them meet administrative requirements for construction along the line. Various supportive plans, policies and initiatives have also been adopted by the local governments of the Denver metro region which will be discussed in Section 3 of this paper.

As evident from the above discussion, numerous studies have explained the common trends of urban land use changes near and away from the rail transit systems. The primary challenge for scholars in this process was to "clearly establish a causal relationship between rail transit and changes in land use and developmental patterns" (Knight, 1980: 3). They identified several factors other than the rail transit system that were responsible for the urban land use changes around them and it has been difficult to quantify the amount of change that has taken place solely due to the growth and development of the rail transit systems. Scholars have used a variety of methods to understand the factors responsible for the land use changes and the extent to which they are responsible. Cervero and Landis (1997) used multiple regression models, while Hurst and West (2014) used difference-in-difference or matching estimators to understand the land use changes that are exclusive to the area in proximity to the rail transit systems. Green and James (1993) have statistically compared the amount of change in proximity to the rail transit systems to those away from the system to isolate the changes that have taken place solely due to the rail transit. However, there is still doubt about the causality of the changes and hence some studies have not sought to explain them (Center of Transit Oriented Development, 2011).

3. The Denver metro region, its rail transit system and transit supportive land use policies

Denver is the administrative capital of Colorado, located at the eastern foothills of the Rocky Mountains. According to the Denver Regional Council of Governments (DRCOG, the region's designated metropolitan planning organization), the Denver metro region, centering on the city of Denver, spans ten counties, namely Adams, Arapahoe, Boulder, Broomfield, Denver, Clear Creek, Douglas, Jefferson, Gilpin, and the southwestern part of Weld Counties.[1] According to U.S. Census data, the population of the metro region grew by 16% from 2000 to 2010 but the number of jobs decreased from 1.4 million in 2000 to 1.3 million in 2009 (DRCOG, 2012). For further details about population and employment refer to Section 5.1.

Rail transit has been an important mode of transportation in Denver since the 1870s, except for four decades (1950–1990) in the second half of the twentieth century (Ratner, 2001). During the time of this study (2000–2010) the Denver metro region was being served by a 34.8-mile long light rail system. The light rail system that started operation in phases (1994, 2000 and 2006), had five lines and served three travel corridors – Central, Southwest and Southeast – running through Denver County and parts of Arapahoe and Douglas counties (Fig. 1). In the metro region, planning and construction of another primarily rail-based transit system called FasTracks (Fig. 1) was also underway at this time. According to the FasTracks plan, the Regional Transportation District (RTD, the transit agency of the metro region), in collaboration with the Colorado Department of Transportation (CDOT) and DRCOG, will build 122 mi of new commuter and light rail lines, 18 mi of bus rapid transit, 21,000 new parking spaces, and improve the amenities and facilities of the previously built transit stations by 2017.[2] Six new travel corridors will be built serving the most urbanized counties of the Denver metro region namely Adams, Arapahoe, Boulder, Denver, Douglas, and Jefferson Counties and the existing light rail system will be extended. Since 2010, parts of the FasTracks project have been completed such as the 12.1-mi long West Line, from downtown Denver to the western edge of the metro region in Jefferson County, as well as the Denver Union Station — the central station connecting most of the transit lines (RTD, 2015). In 2016, four FasTracks rail lines will open including a commuter rail line to Denver International Airport.

In the Denver metro region, along with the planning, construction and operation of the rail transit system, efforts were undertaken to consolidate urban land use around the rail transit lines by creating TOD zones. This attempt began with the publication of long range plans such as *Metro Vision 2020* and *Blueprint Denver* in the 1990s. Both plans encouraged "transit-supportive development … channeling a major portion of growth into urban centers. These areas are envisioned as high-intensity, pedestrian-friendly, mixed-use locations that serve as transit origins and destinations" (TCRP, 2004: 324–325). In Blueprint Denver, a new transit mixed use zoning district (TMU-30) was created that permitted a greater amount of density along the rail transit systems. A Denver TOD Coalition was also formed, consisting of a partnership between Denver County, RTD, and the Denver Urban Renewal Agency (DURA). The primary aim of this Coalition was to associate land use and redevelopment with the new rail transit system (TCRP, 2004). The pace of urban land use development increased after 2000, with many more plans and reports supporting the attempt. Some of the notable ones are the *Transit-Oriented Development Strategic Plan* prepared by the Denver Community Planning and Development Division, as well as the *Strategic Plan for Transit Oriented Development* and the *Transit Oriented Development Annual Status Report* prepared by RTD. All the above mentioned plans and reports, and many others, proposed the creation of TOD zones around every present and proposed rail transit station in the Denver metro region. Today, each present and proposed station either already has a TOD zone around it or a plan for creating a TOD zone.

With a 35-mi light rail system already operating and expanding, another 122-mi rail-based system under construction and presence of favorable governmental policies, the Denver metro region, in the 2000s, had many factors required for a significant amount of urban land use change, in the form of consolidation, near the rail transit system.

4. Research methods

To date, only one study, conducted by Ratner and Goetz (2013), has examined the connection between the rail transit system and the organization, pattern and size of the Denver metro region. The study examines the magnitude of urban land use changes that has taken place since 1997 within the present and proposed rail transit corridors with emphasis around the stations. The study explains the changes that have taken place through time within a 1/2 mile radius around rail transit stations. However, it is limited in scope and applicability when these changes are compared to the changes that have taken place in other parts of the metro region, away from the rail transit system, due to the following reasons. First, the authors provide a cursory idea about the relative magnitude of regional development taking place near the rail transit system. They have not consistently provided detailed changes by corridor, land-use category, and county. Second, the authors did not distinguish between existing and proposed stations and corridors. Third, for change in land use density, only Denver County was considered. Fourth, the results were derived using only descriptive statistics.

This paper recognizes the importance and complications of comparing urban land use changes taking place near the rail transit system with those away from the system because urban land use development occurs throughout the metro region irrespective of location in relation to the rail transit system. Hence, this study extends and improves upon the last section (*Comparing TOD to overall regional development*) of the Ratner and Goetz (2013) study. It provides detailed results of the comparison by corridor, land-use categories, and counties. The study considers urban land use changes taking place within the present and proposed rail transit corridors – half-mile corridors on either side of the rail transit lines – and non-rail transit corridors both for total land use change and land use density change. And it compares urban land use changes through

[1] The U.S. Census delimits the Denver-Aurora-Lakewood Metropolitan Statistical Area (MSA) somewhat differently including Adams, Arapahoe, Broomfield, Clear Creek, Denver, Douglas, Elbert, Jefferson, Gilpin, and Park counties. Boulder County is in the Boulder MSA, while Weld County is in the Greeley MSA. Together, these three MSAs comprise the Denver-Aurora Combined Statistical Area (CSA) which had an estimated population of 3.3 million in 2014.

[2] Despite having components such as bus rapid transit and parking, FasTracks is a primarily rail-based transit system. Hence it has been referred to and considered as a rail transit system in this study.

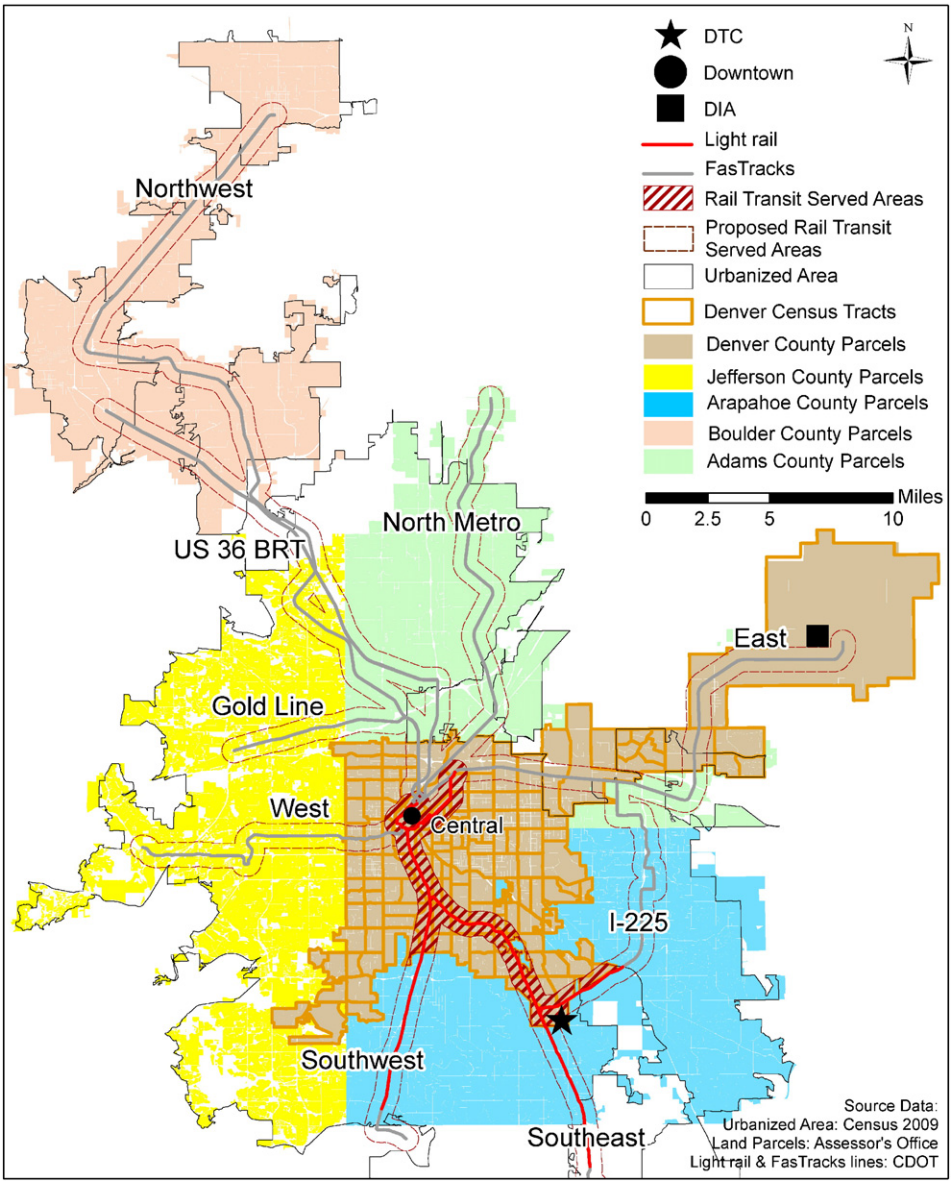

Fig. 1. Study area.

the use of inferential statistics. Based on previous studies, it is expected that increases in commercial, multi-family residential, and mixed land uses will be greater in rail transit-served areas, while increases in single-family residential and industrial land uses will be greater in non-rail transit-served areas.

4.1. Analytical methods

The methodology of this study has been mostly adopted from the study on the Bay Area Rapid Transit (BART) by Cervero and Landis (1997) and the study on the Washington Metropolitan Area Transit Authority (WMATA) system by Green and James (1993) with some modifications.

In this study, a large section of the urbanized area of the Denver metro region has been examined. It has been divided into three study groups – rail transit served areas, proposed rail transit served areas and non-rail transit served areas – and changes in them have been compared. However, it should be noted that not all the counties in the metro region were divided into three study groups. The counties outside of Denver County were divided into only two study groups – proposed rail transit served areas and non-rail transit served areas – because most of them did not have an operating rail transit system from 2000 to 2010. The spatial units (census tracts and land parcels) lying within half-mile of the present and proposed rail transit lines were considered to be rail transit served areas and proposed rail transit served areas respectively. The rest of the spatial units within the urbanized area of the counties were considered as non-rail transit served areas.

The study areas were compared in three different ways. First, the changes in total population and employment and changes in population density and employment density were compared through descriptive statistics. Second, changes in the total square footage of the building areas for different land uses were compared. Third, by calculating kernel density[3] through ArcGIS the densities of different land uses were compared. To compare changes in the total square footage of the building

[3] Kernel Density calculates the density of point features around each output raster cell. Conceptually, a smoothly curved surface is fitted over each point. The surface value is highest at the location of the point and diminishes with increasing distance from the point, reaching zero at the search radius distance from the point. Only a circular neighborhood is possible. The volume under the surface equals the Population field value for the point. The density at each output raster cell is calculated by adding the values of all the kernel surfaces where they overlay the raster cell center. The kernel function is based on the quadratic kernel function described in Silverman (1986, p. 76, equation 4.5) — ESRI, 2012.

areas and land use density, inferential statistics were used for Denver County and descriptive statistics for the other counties.

The study groups of Denver County were compared in greater detail than study groups of the other counties. For Denver County, the Wilcoxon/Kruskal–Wallis statistical significance test was conducted to examine whether the changes taking place in the rail transit served areas, proposed rail transit served areas and non-rail transit served areas in terms of total square footage of building areas and land use density are significantly different. The Wilcoxon/Kruskal–Wallis test is a nonparametric test and it was used in this study because the datasets do not have a normal distribution, which is a pre-requisite for conducting a parametric test (Lind et al., 2010). The significance test was conducted through the JMP statistical software package.

4.2. Study area (further details) and time period

As mentioned before, a large section of the urbanized area of the Denver metro region has been examined in this study. It includes Denver County and the surrounding counties — Adams, Arapahoe, Boulder and Jefferson counties.

Fig. 1 depicts all the census tracts and land parcels within the three Denver County study groups. Among all the census tracts, 45 are considered as rail transit served areas, 15 are considered as proposed rail transit served areas and 84 are considered as non-rail transit served areas. Again, it should be noted that during the time of this study, the West Line was not yet built and hence is not depicted as a present rail transit line. For the total square footage of building areas analysis, the values of all the land parcels were aggregated to the census tract level and then as required aggregated to the study group level. For the land use density analysis, the land parcel values were directly aggregated to the study group level skipping aggregation at the census tract level.

Fig. 1 also depicts all the land parcels of Adams, Arapahoe, Boulder, and Jefferson counties that have been included in this study. For these surrounding counties, since only descriptive statistics were used it was not necessary to aggregate the data to the census tract level. Instead the data were directly aggregated to the two study group level i.e. proposed rail transit served areas and non-rail transit served areas. It should be noted that Douglas County has been excluded from this study even though parts of the rail transit system lie within it because it occupies only a very small portion of the land area of the county.

In this study, the data have been analyzed for a period of 10 years from 2000 to 2010. This time period was selected considering the fact that the major portions of the light rail system –the Southwest Corridor, the Central Platte Valley line of the Central Corridor, and the Southeast corridor – started operation in or after 2000. The time frame was extended back to 1990 only for the land use density analysis of Denver County because a sufficient number of data points were not available for the significance test for the 2000 to 2010 time frame.

4.3. Data collection and preparation

For this study, both tabular and spatial datasets were collected. The following information describes each of the datasets and their sources.

4.3.1. Population and employment data

The population data were collected from the decennial census of the U.S. Census Bureau and were available at the census tract level. The employment data were collected from the County Business Patterns of the U.S. Census Bureau and DRCOG. The employment data of Denver County depict the number of jobs within each zip code of the county, whereas the employment data for the surrounding counties depict the number of people employed within each census tract of the counties. The employment density data, collected from DRCOG, is a map depicting jobs per square mile for approximately the entire metro region.

4.3.2. Land parcel data

The land parcel data for all the counties were collected from the assessor's office of the respective counties. The land parcel data consisted of a large amount of information, among which the following were used for this analysis: land use classification (commercial, mixed-use, industrial, multi-family residential and single-family residential), total square footage of the building areas and built year. The information was used to calculate the changes in the total square footage of the building areas of different land uses from 2000 to 2010. The information was also used to calculate land use density through the kernel density tool of ArcGIS. However, some of the land parcel records had to be eliminated due to reasons such as inaccuracy and insufficient information in the records.[4] After elimination, about 90% of the land parcels in Denver County and Boulder County, 94% in Adams County, 93% in Arapahoe County, and 82% in Jefferson County have been used for the purpose of analysis.

4.3.3. Spatial data

Several GIS layers were collected for this study. The county boundaries, the census tract boundaries and the urbanized area boundary were collected from the U.S. Census Bureau for the year 2009–2010. The present and proposed rail transit lines and stations were collected from CDOT and RTD.

5. Results

5.1. Changes in population and employment

According to the U.S. Census, the Denver metro region had a population of 2.8 million in 2010 — an increase of 16% since 2000. However, the region did not experience a uniform growth in population which is evident from Table 1.

According to the U.S. Census, the average population density of the region has increased from 696 persons/sq. mile in 2000 to 811 persons/sq. mile in 2010. The average population density is not uniform throughout the region. It is much higher within Denver County, 3880 persons/sq. mile (2010), than the surrounding counties because many of the surrounding counties include a large amount of

[4] The reasons for eliminating some of the land parcel records from the collected dataset are as follows:

I. Parcels did not lie within the U.S. Census Bureau defined urbanized area boundary.
II. Parcels did not have buildings on them because they were representing features such as green space, vacant land, roads, and rail. Despite having buildings some of them did not have classification data associated with them.
III. Parcels contained exempt properties. The assessor's offices do not maintain accurate information of these properties because they do not have to collect taxes from them. However, information about parcels containing Urban Housing Authority buildings was retained wherever possible. The tax exempt properties could not be eliminated from the Arapahoe County land parcel dataset.
IV. For the density analysis of the City and County of Denver, the land parcels in census tract 9800 have not been included. This census tract contains Denver International Airport and therefore the average density of this tract is very low, which could have biased the results of density analysis. For the analysis of other counties, land parcels used for industrial purposes have not been included. These counties have made no attempt to consolidate industrial land use within the rapid transit corridors. Hence it is unlikely that there will be any impact of planning and construction of FasTracks lines on industrial land use.
V. The duplicate land parcels were also eliminated by dissolving the polygons having the same parcel number and aggregating the information of these parcels.

non-urbanized area. The average density of population has also not increased uniformly throughout the region as is evident Table 2.

Table 1
Percent change in population, 2000–2010, Denver and surrounding counties.

Study groups	Counties	Percentage change in population, 2000–2010
Census tracts containing the rail transit & proposed rail transit served areas	Denver	6.63
	Adams	16.66
	Arapahoe	6.12
	Boulder	−0.94
	Jefferson	−0.30
Census tracts containing the non-rail transit served areas	Denver	5.22
	Adams	14.33
	Arapahoe	6.87
	Boulder	7.98
	Jefferson	0.84

Table 2
Percent change in average population density, 2000–2010, Denver and surrounding counties.

Study groups	Counties	Percentage change in average density, 2000–2010
Census tracts containing the rail transit & proposed rail transit served areas	Denver	9.17
	Adams	14.21
	Arapahoe	2.75
	Boulder	−2.68
	Jefferson	−0.81
Census tracts containing the non-rail transit served areas	Denver	−1.01
	Adams	10.62
	Arapahoe	6.28
	Boulder	3.18
	Jefferson	1.09

The region had 1.3 million jobs in 2009, a decrease from 1.4 million in 2000 (DRCOG, 2012). According to the U.S. Census, number of jobs or number of people employed has decreased in Arapahoe, Boulder, Denver, and Jefferson counties, from 2000 to 2010. However, Adams County has experienced an increase in number of people employed by 5.5% in proposed rail transit served areas and 8% in non-rail transit served areas. The employment density is also not the same throughout the region. According to DRCOG, in 2008, the employment density was highest in the traditional downtown area and the edge city — Denver Technological Center (DTC). The employment density was also high in some other places such as the City of Boulder (Boulder County) and the Federal Center on 6th Avenue in Lakewood (Jefferson County) (DRCOG, 2012).

5.2. Changes in land use in Denver County

This section of the paper highlights the results of total square footage of building areas data analysis and land use density data analysis in Denver County.

5.2.1. Changes in total square footage of building areas

The change in total square footage of building areas has been computed and analyzed for all the three study groups; rail transit served areas, proposed rail transit served areas and non-rail transit served areas, from 2000 to 2010, across five land use classes: commercial, mixed-use, industrial, multi-family residential and single-family residential.

The amount of commercial area has increased within all three study groups from 2000 to 2010 (Fig. 2). The growth has been greater in rail transit served areas (45% of the total growth of the county) than in the other areas. Results of the Wilcoxon/Kruskal–Wallis significance test, at a 0.05 level of significance, also indicated that growth of the commercial area has been significantly greater in the rail transit served areas (Table 3).

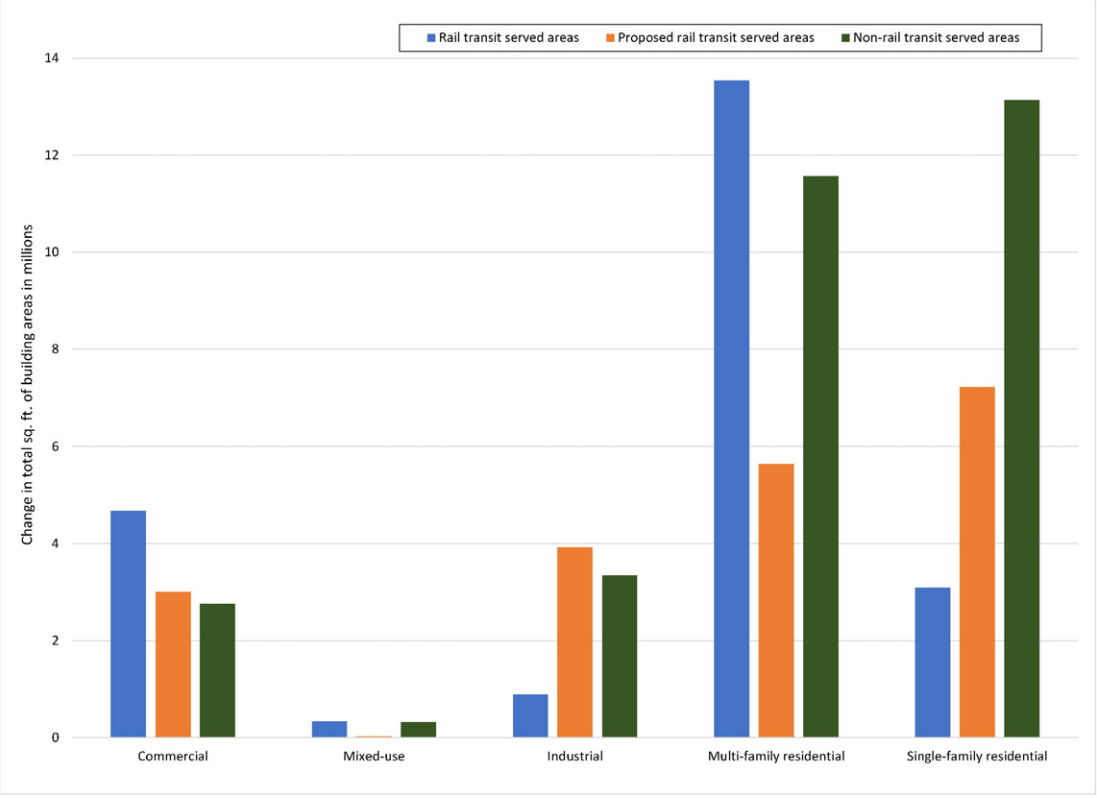

Fig. 2. Change in total sq. ft. of different land use, Denver County, 2000–2010.

Table 3
Change in total square footage of building areas of different land use, 2000–2010: Wilcoxon/Kruskal–Wallis significance test results.

Land use	p-Value	Comparison for all pairs
Commercial	0.022	Rail transit served areas are different from non-rail transit served areas.
Mixed-use	0.155	All the three study areas are similar.
Industrial	0.001	Proposed rail transit served areas are different from the other study groups.
Multi-family residential	0.069	All the three study areas are similar.
Single-family residential	0.662	All the three study areas are similar.

Level of significance: 0.05.

The amount of mixed-use area has increased primarily in rail transit served areas and non-rail transit served areas between 2000 and 2010 (Fig. 2). The growth has been greater in rail transit served areas. They have attracted 49% of the growth of the entire county. However, this greater growth was not significantly different (Table 3).

In Denver County, little effort has been given to concentrate industrial land use around the rail transit system. Yet, industrial areas have grown noticeably in the proposed rail transit served areas (Fig. 2) and results of the significance test indicate that this growth in the proposed rail transit served areas is significantly greater than in the other areas (Table 3). Industrial land use growth in rail transit served areas is much lower than either proposed rail transit served areas or non-rail transit served areas.

The amount of multi-family residential area has increased within all three study groups from 2000 to 2010 (Fig. 2). This land use has shown the most amount of growth in Denver County among all the studied land uses. A greater amount of growth has taken place in the rail transit served areas. They have attracted 44% of the growth of the entire county, but the growth has not been significantly different between the study groups (Table 3).

The growth of single-family residential area has been noticeably greater in the non-rail transit served areas from 2000 to 2010 (Fig. 2). The non-rail transit served areas have attracted 56% of the growth of the entire county, but the growth of this land use has not been significantly different between the study groups (Table 3).

5.2.2. Change in density of land use

The change in land use density has been computed and analyzed for all three study groups; rail transit served areas, proposed rail transit served areas and non-rail transit served areas, from 1990 to 2010 (the time frame has been extended for this analysis to include a sufficient number of data points for the significance test). Change in land use density has been analyzed across four land use classes: commercial, mixed-use, multi-family residential and single-family residential.

The greatest increase in commercial area density, more than 1 million sq. ft./sq. mile, took place in the downtown area and DTC (Fig. 3). Both these places are within the rail transit served areas. Hence the Wilcoxon/Kruskal–Wallis significance test, at the 0.05 significance level, indicates that commercial area density has significantly increased in the rail transit served areas from 1990 to 2010 (Table 4).

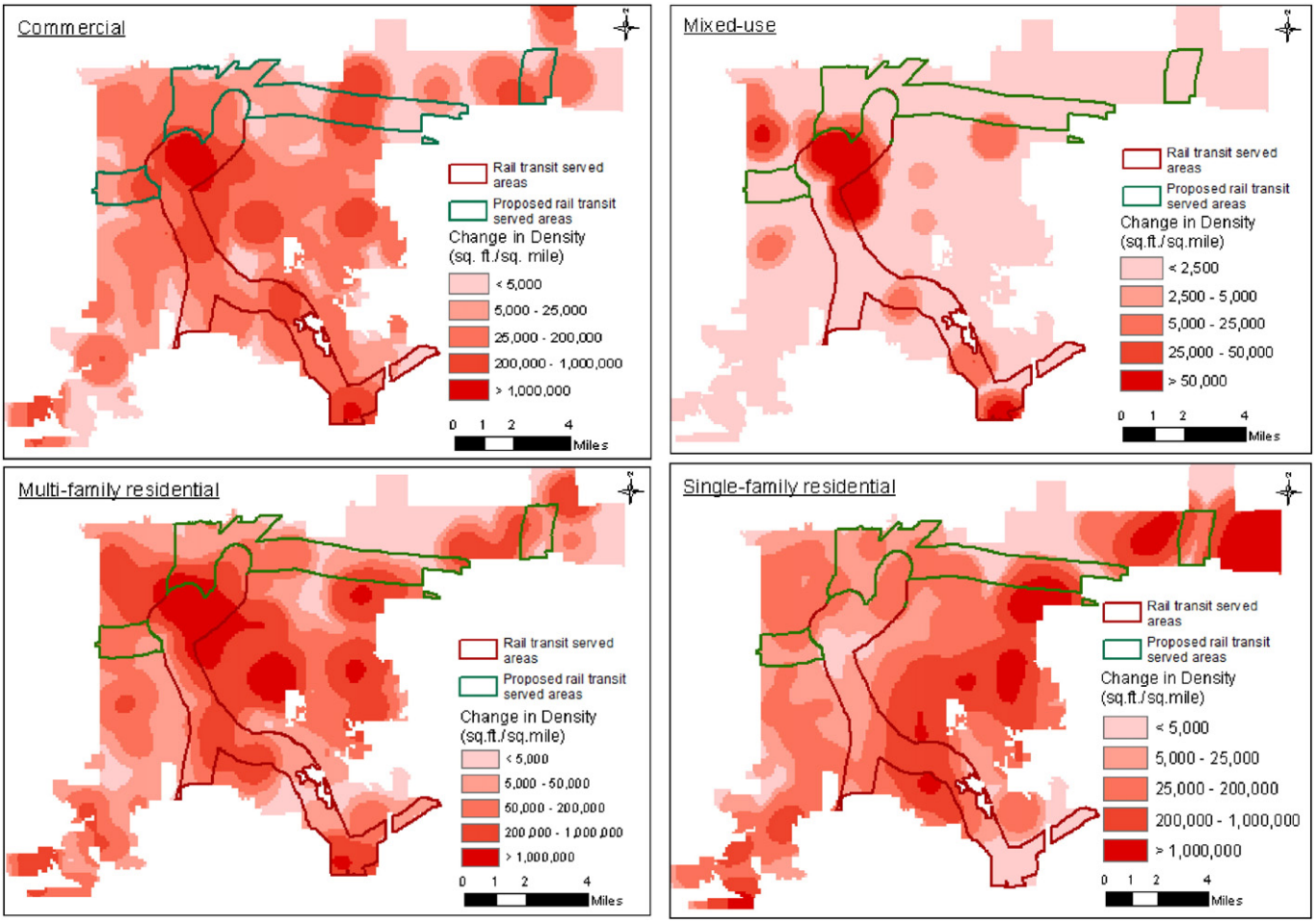

Fig. 3. Change in land use density, Denver County, 1990–2000.

Table 4
Change in land use density, 1990–2000: Wilcoxon/Kruskal–Wallis significance test results.

Land use	p-Value	Comparison for all pairs
Commercial	0.024	Rail transit served areas are different from the other study groups.
Mixed-use	0.170	All the three study areas are similar.
Industrial	0.694	All the three study areas are similar.
Multi-family residential	0.276	All the three study areas are similar.
Single-family residential	0.167	All the three study areas are similar.

Level of significance: 0.05.

Places experiencing the greatest amount of change in mixed-use area density of 50,000 and more sq. ft./sq. mile are not completely contained within the rail transit and proposed rail transit served areas (Fig. 3). Denver downtown and DTC have experienced a noticeable amount of growth and are served by rail transit. However, the West Highlands neighborhood, to the west of downtown has also experienced a large amount of change and is in non-rail transit served areas. The change in mixed use area density has not been significantly different between the study groups from 1990 to 2010 (Table 4).

Places experiencing the greatest amount of increase in the density of multi-family residential area by 1 million or more sq. ft./sq. mile, are not only located in the downtown area or DTC but also in many other areas throughout the county (Fig. 3). The change in multi-family residential area density has not been significantly different between the study groups from 1990 to 2010 (Table 4).

Unlike other types of land use, change in density of single-family residential area has been the greatest in the non-rail transit served areas (Fig. 3). The areas experiencing the largest change in density of 1 million and more sq. ft./sq. mile are found mainly in the eastern part of Denver County. Surprisingly, the change in single-family residential area density was not significantly different between the study groups from 1990 to 2010.

5.3. Changes in land use in counties surrounding Denver County

This section also highlights the results of a similar kind of data analysis as the previous section except that the focus is on the counties surrounding Denver County namely Adams, Arapahoe, Boulder and Jefferson.

5.3.1. Change in total square footage of building areas

The change in total square footage of building areas in the surrounding counties has been computed and analyzed for two study groups:

a) existing or proposed rail transit served areas and b) non-rail transit served areas, from 2000 to 2010, across three land use categories: a) commercial, b) multi-family residential/mixed and c) single-family residential. Some of the important findings of this analysis are as follows:

1) In each county, a greater amount of commercial area growth was attracted towards the existing or proposed rail transit served areas

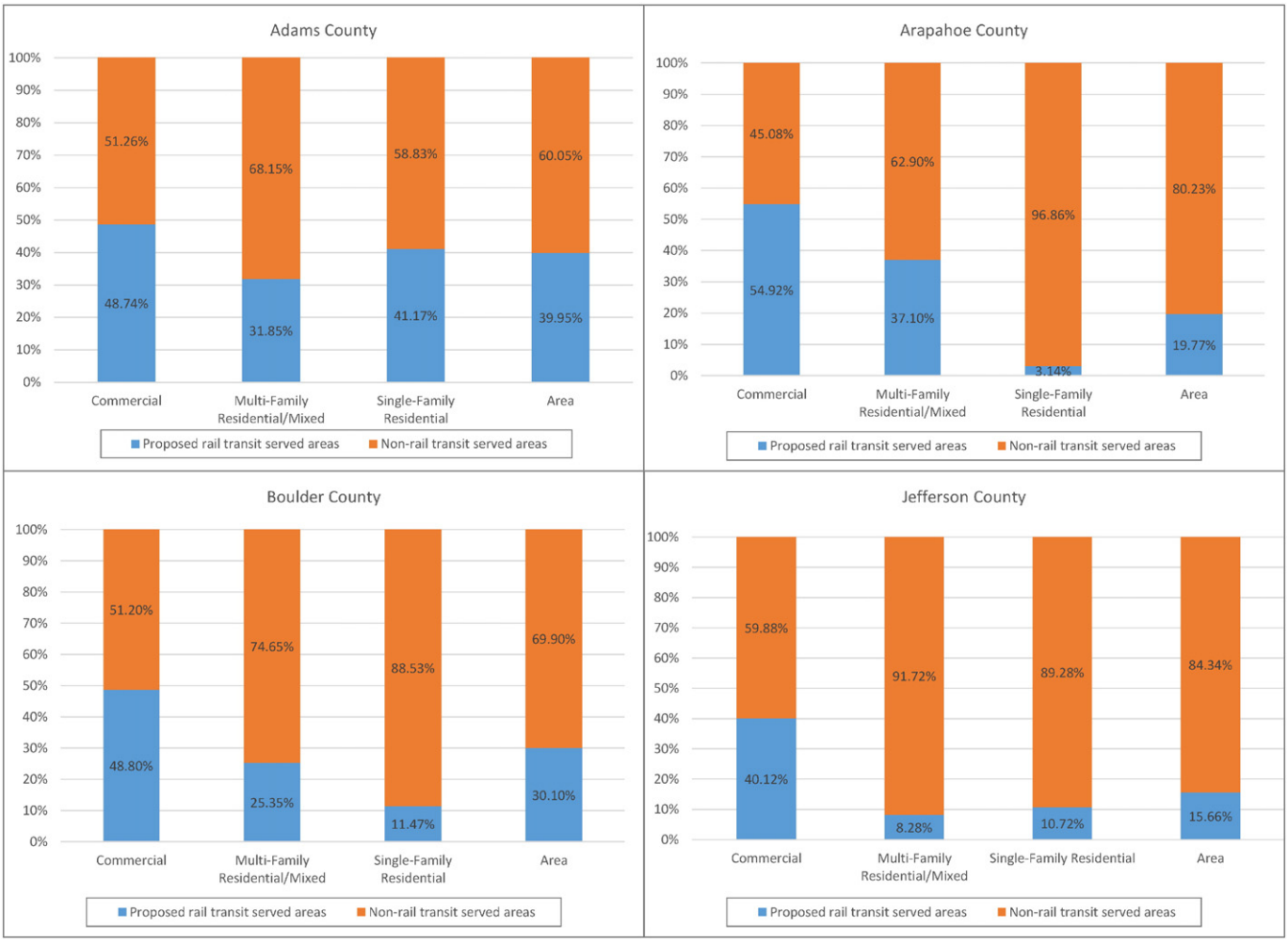

Fig. 4. Percentage change in total sq. ft. of different land use, 2000–2010.

when compared to the amount of land area available in this study group (Fig. 4). For instance, in Adams County, 49% of commercial area growth was attracted to the existing or proposed rail transit served areas which represented 40% of the total land area available in the county. In Arapahoe County, the existing or proposed rail transit served areas have attracted 55% of commercial area growth in comparison to 20% of the land area available. In fact, in Arapahoe County, a greater amount of commercial area growth (55%) was attracted towards the existing or proposed rail transit served areas than outside (45%) irrespective of the amount of land area available.

2) Except in Arapahoe County, a greater amount of multi-family residential/mixed area growth was attracted towards the non-rail transit served areas when compared to the amount of land area available (Fig. 4). For instance in Boulder County, 75% of the growth was attracted towards the non-rail transit served areas compared to 70% of the land area available. On the other hand, in Arapahoe County more multi-family residential/mixed area growth was attracted towards the existing or proposed rail transit served areas (37%) than land area available (20%).
3) Except Adams County, greater single-family residential area growth was attracted towards the non-rail transit served areas than land area available (Fig. 4). For instance, in Jefferson County, 89% of single-family residential area growth was attracted towards the non-rail transit served areas compared to 84% of land area available. While in Adams County, 59% of single-family residential area growth was attracted towards the non-rail transit served areas compared to 60% of land area available.

Arapahoe County had a greater amount of commercial and multi-family residential/mixed area in rail transit corridors than the other counties. It is possible that the difference could be because only Arapahoe County at the time of the study had some rail transit lines in operation. All the other counties had only proposed rail transit lines.

5.3.2. Change in density of land use

Change in density of land use in the surrounding counties has been computed and analyzed for two study regions: a) existing or proposed rail transit served areas and b) non-rail transit served areas, from 2000 to 2010, across three land use categories: a) commercial, b) multi-family residential/mixed, and c) single-family residential. The important findings of this analysis are as follows:

1) High increase in density of commercial areas has primarily taken place within the existing or proposed rail transit served areas in Arapahoe and Jefferson Counties as shown in Fig. 5 focusing on Arapahoe County. Such a trend has not been noticed in the other counties such as in Adams County (Fig. 6) where commercial area growth has taken place parallel to the proposed rail transit served areas.
2) Multi-family residential/mixed land use density has increased in both the study groups. No specific trend in the location of the high increase in density areas has been noticed for this type of land use.

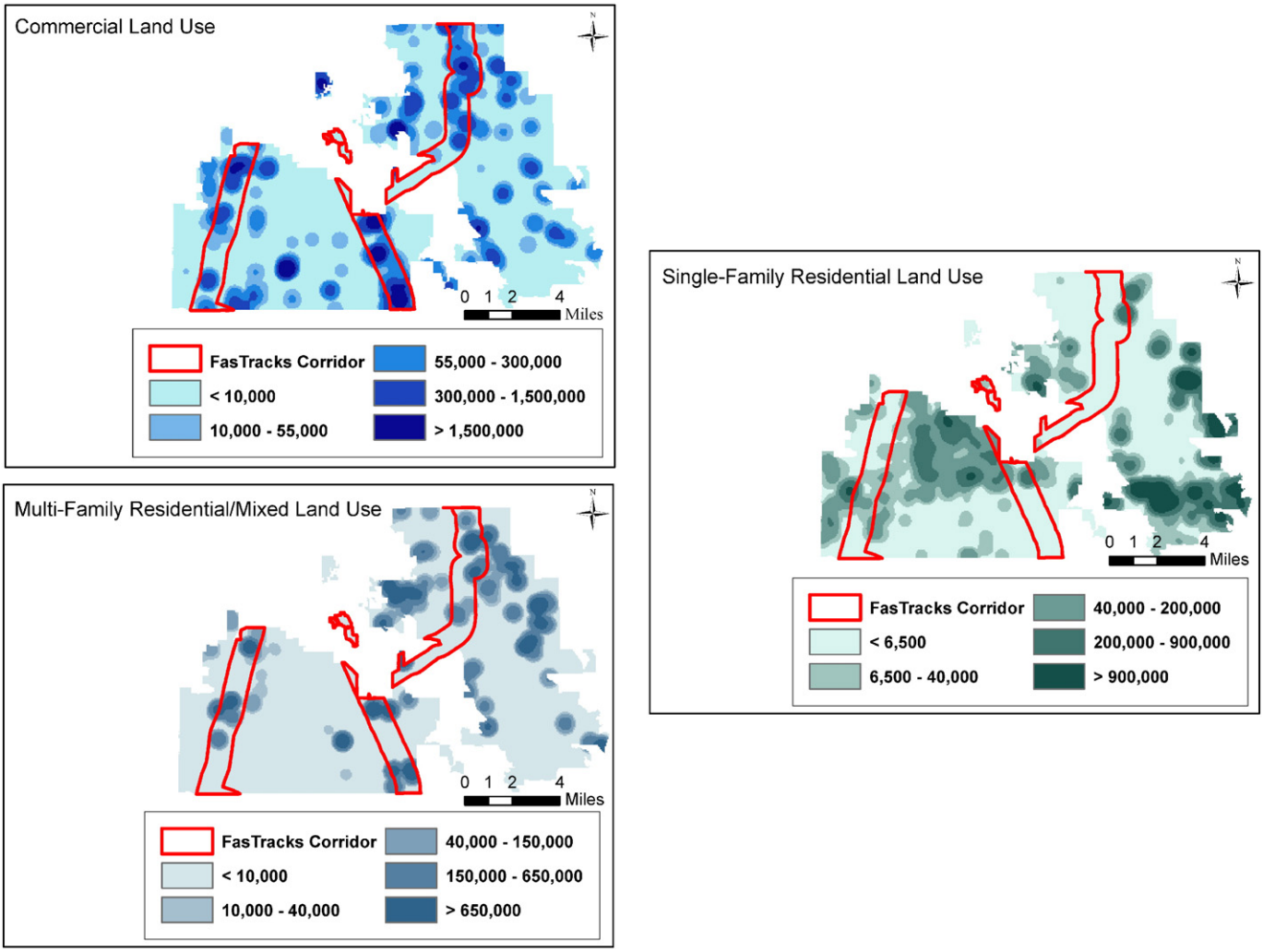

Fig. 5. Change in land use density, Arapahoe County.

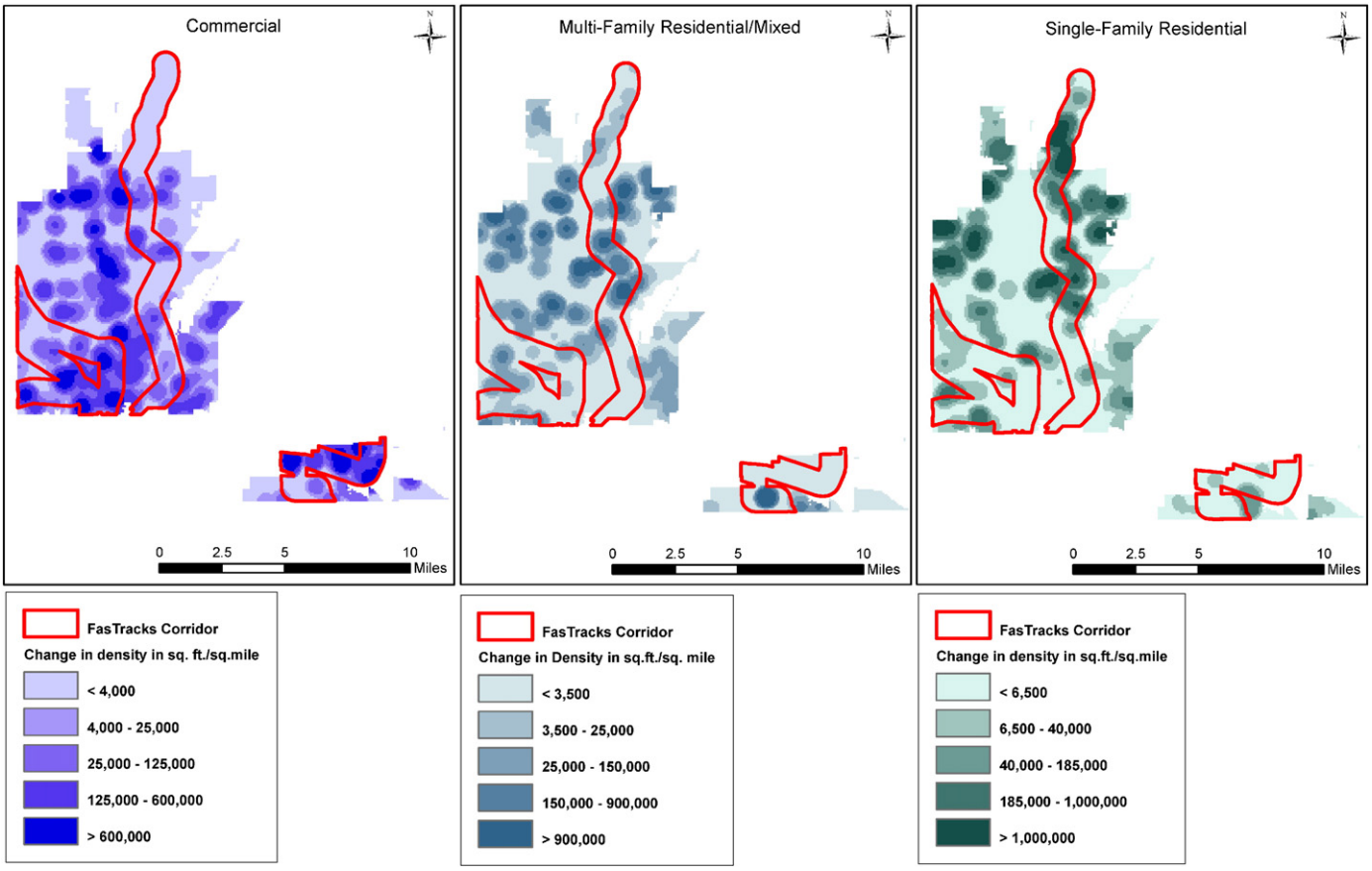

Fig. 6. Change in land use density, Adams County.

3) Single-family residential land use density has primarily increased in the non-rail transit served areas as shown in Fig. 5 focusing on Arapahoe County.
4) In Adams County (Fig. 6), a large section of the development was attracted parallel to the proposed rail transit served areas along Interstate Highway 25. The proposed rail transit line is located in an existing freight railroad right-of-way and it is difficult to attract residential and commercial development within freight railroad corridors due to nearby industrial land use.

6. Conclusion

The primary objective of this study has been to compare the land use changes around the present light rail system and emerging FasTracks system with those in other parts of the Denver metro region mostly from 2000 to 2010. Land use growth was one of the main objectives behind the construction and operation of the rail transit system in the metro region and therefore it was expected that this study would reveal increases in land use development in rail transit-served areas, specifically in commercial, multi-family residential, and mixed land use categories.

From results of this study, it can be concluded that during the current major period of growth of the rail transit system in the Denver metro region, there is a mixed pattern of land use development around the present and proposed rail transit corridors. Overall, the rate of growth in land use development between rail transit corridors and areas outside of the corridors is not significantly different. There are, however, important differences by land use category and by county.

Commercial and multi-family residential land uses are growing at a faster rate than the other types of land use. These conclusions are similar to those of several other authors (Center of Transit Oriented Development, 2011; Ishikawa and Tsutsumi, 2006; Handy, 2005; Foth, 2010; Hurst and West, 2014; Ratner and Goetz, 2013) who examined the rail transit system – urban land use relationship since 2000. The growth in commercial land use is significantly greater around the rail transit system than away from the rail transit system throughout the metro region. More growth in multi-family residential land use has also been noticed around the rail transit system than away from the system but the growth is not as significantly greater as for commercial land use. Single-family residential has primarily grown in areas away from the rail transit system which is desirable considering the fact that dense and compact developments are more welcomed around the rail transit lines and most single-family residential land use does not facilitate that.

The trend in land use growth is noticeable throughout the rail transit served areas but the rate of growth differs from county to county. Greater land use growth has taken place in Denver County than in the surrounding counties, perhaps because the rail transit system first started operating in Denver County, and most of the existing line mileage is located there. Plus, Denver County has been the most proactive in changing its zoning and developing land use plans around rail transit stations. Among the surrounding counties, Arapahoe County experienced the most land use growth around the rail transit system, likely for the same reasons mentioned above.

The growth of land use around the present and proposed rail transit lines has been influenced by many factors other than the presence and would-be presence of the rail transit system. Even though this study did not explore the causal factors behind the land use changes, a general idea about the causal factors was gathered on the basis of published literature and results of this study. The local governments of the Denver metro region have enacted multiple transit supportive policies since the 1990s such as creation of the TOD areas and rezoning of these areas to

support dense compact developments (details about these policies are provided in Section 3 of this paper). Since these policies were first implemented in the downtown area of Denver County, more development was attracted towards the downtown than other places. Many other factors such as distance to CBD, proximity to employment centers, and proximity to highways, could also explain patterns of land use change.

Modest, but not inconsequential, growth of different types of land use is still continuing around the present and proposed rail transit lines which is evident from the *2013 Transit-Oriented Development Status Report*. This is especially true for commercial and multi-family residential land use, as mentioned before. Land use growth is taking place around the proposed rail transit lines despite the fact that many of them are within freight railroad corridors and already have a huge amount of industrial land use. Surprisingly, growth of mixed land use is still not noticeable around the rail transit lines. A future study, conducted after the proposed rail transit lines start operating, may reflect increased mixed-use development around the rail transit lines.

The results of this study are consistent with results from post-2000 studies about rail transit systems and land use change in U.S. cities. Increased population and employment growth in urban activity centers, many of which are served by rail transit, has resulted in intensification of land use activity. While neither a necessary nor sufficient condition for the land use change to occur, the nearby presence of rail transit is correlated with increasing land use change, specifically for commercial uses. The results of this study also suggest that proximity to rail transit may be a causal factor in explaining the growth of commercial land use in Denver and Arapahoe Counties, but further research would need to be conducted to account for other factors that may be resulting in this pattern.

In addition, the results should be interpreted carefully because of the various limitations of the study such as unavailability of some data, absence of an analysis method to understand the increase in land use development due to proximity to the CBD rather than the rail transit system, and absence of an analysis method to consider or measure spatial autocorrelation existing within the values of the spatial units before conducting the statistical significance test. Nevertheless certain patterns of land use growth, especially commercial, in the rail transit and proposed rail transit served areas are evident, and it is possible that these patterns will intensify as the rail transit system in Denver is fully built.

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