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THE IMPACT OF TRANSIT ORIENTED DEVELOPMENT ON THE TRAVEL  
BEHAVIORS OF WORKERS IN DENVER, COLORADO

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A Thesis

Presented to

The Faculty of Natural Sciences and Mathematics

University of Denver

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In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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by

Gregory J. Kwoka

June 2013

Advisor: Dr. Eric Boschmann

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Title: THE IMPACT OF TRANSIT ORIENTED DEVELOPMENT ON THE TRAVEL BEHAVIORS OF WORKERS IN DENVER, COLORADO

Advisor: Dr. Eric Boschmann

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### **Abstract**

To combat unsustainable transportation systems characterized by reliance on petroleum, polluting emissions, traffic congestion and suburban sprawl, planners encourage mixed use, densely populated areas that provide individuals with opportunities to live, work, eat and shop without necessarily having to drive private automobiles to accommodate their needs. Despite these attempts, the frequency and duration of automobile trips has consistently increased in the United States throughout past decades. While many studies have focused on how residential proximity to transit influences travel behavior, the effect of workplace location has largely been ignored.

This paper asks, does *working* near a TOD influence the travel behaviors of workers differently than workers *living* near a TOD? We examine the non-work travel behaviors of workers based upon their commuting mode and proximity to TODs. The data came from a 2009 travel behavior survey by the Denver Regional Council of Governments, which contains 8,000 households, 16,000 individuals, and nearly 80,000 trips. We measure sustainable travel behaviors as reduced mileage, reduced number of trips, and increased use of non-automobile transportation. The results of this study indicate that closer proximity of both households and workplaces to TODs decrease levels of car commuting and that non-car commuting leads to more sustainable personal travel behaviors characterized by more trips made with alternative modes.

## **Acknowledgements**

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## **Chapter One: Introduction**

As the field of geography seeks to examine the relationships between humanity and its physical environment, populations are tending to cluster near one another now more than ever before. With densities in these urban areas increasing, the question of movement becomes more relevant. In the year 1900, 10 percent of the world's population lived in urban areas. In 2008, humanity crossed a milestone as it marked the first time that more people lived in urban areas than any other type of settlement. Within thirty years, nearly 60 percent of the world's population is estimated to live in urban areas. Under a medium growth scenario, world population will be almost ten billion by 2050, with approximately 3.1 billion new urban dwellers (Committee on Strategic Directions for the Geographical Sciences in the Next Decade 2010). Despite humanities' existence for millenniums, it is only in the past century that we have seen such migrations into high density areas. As a result, there has never been a more important time to begin thinking about how to best facilitate accessibility within the city structure.

The idea of transportation geography includes the location, structure, environment and development of networks as well as the analysis and explanation of the interaction or movement of goods and people (Goetz et al. 2003). As with most urban topics, there are a large variety of interested parties who should be consulted and integrated in the planning process. However, agreement between all bodies has proven to be a recurring issue that is often one of the largest obstacles to the implementation of social urban

programs such as transportation. The urban arena is a context for competing intellectual claims and traditions that at times converge on consensus but more often than not end in disagreement. Different disciplines focus on different processes and ways of knowing, and urban life is tugged and twisted in so many directions that it is difficult to know the appropriate questions to ask, let alone articulate future research directions. Mayors and other city leaders are concerned about civic boosterism and the quality of life in their cities, planners try to manage competing claims on space and movement, and environmentalists grapple with degradation and equity, while economists conjure up more appropriate models of development and growth (Aitken et al. 2003).

As an inherently multi disciplined field, transportation planning has grown into a more widely accepted branch of geography in recent years, and has infiltrated an industry that has traditionally been dominated by civil engineers on the “hard” physical science side, and by neoclassical economists on the “soft” social science side (Goetz et al. 2003). There is clearly a need for geographers to be well versed in complimentary disciplines in order to be taken seriously as contributors to the planning process of transportation systems. However, to some extent, these processes have served to fragment geography, as the linkages between interdisciplinary specialists have in many cases have become stronger than the linkages with other geographers (Johnston, 1988). Once again, it is evident that geographers are tasked with acting as the joint from which other disciplines and industries are hinged.

Government policies, particularly deregulation, liberalization and privatization have had a profound effect on transportation, fundamentally altering the structure, organization and operation of the airline, rail road, trucking, bus, maritime, and

intermodal industries (Goetz et al. 2003). Many of the present day practices of transport planning can be traced back to the 1950's and 1960's. The planning that took place, exemplified by the Federal Aid Highway Act of 1956 as well as early exercises using computer models in Chicago and Detroit, concerned the efficient movement of private cars in comfort (high levels of service) and at speed (high efficiency) (Kane, 2010). The needs of public transport and pedestrians or cyclists received little or no attention at this time. Because most of the traditional transport planning practices that are familiar today were developed in a region where the car was king (in terms of both the economy and culture), it makes sense that little thought was applied to walkable, bike friendly environments. This American style of planning was exported across the globe (Taylor, 1956). As a result, this American car culture can be seen in developing or developed nations throughout the world.

The rise in popularity of the current automobile culture can be attributed to a number of factors. Accounting for nearly 86% of all passenger-kilometers traveled in the United States, the personal vehicle is the mode of choice for most Americans because of its door to door accessibility, hauling capacity, timely flexibility and privacy (Leinbach, 2004). Until recently, the fuel that powers these vehicles, petroleum, had been so abundant and cheap that any other local mode of transportation could be considered impractical in comparison. Other advantages of petroleum include a high energy density, liquid state at ambient temperatures and pressures, and ease of transport, handling and storage (Greene, 2004). Additionally, petroleum fuels and internal combustion engines have been able to adapt through technological advances to remain the dominant energy source for transportation modes even beyond the private automobile. Such advances in

transportation are a cause of globalization in terms of shrinking the planet through space-time convergence and making possible increased global interaction (Janelle and Beuthe 1997). While globalization and technology have increased the role of transportation in connecting people and ideas, it seems the over reliance on petroleum has placed a substantial strain on society in a multitude of areas including politically, economically and environmentally. Modern transportation systems are widely regarded to be unsustainable because of 1) a heavy reliance on finite petroleum resources, 2) petroleum based emissions from vehicles, 3) motor vehicle fatalities and injuries, 4) traffic congestion, and 5) sprawl (Black, 1998).

As a finite resource in an ever developing world, petroleum has, in a relatively short period of time, become one of the most sought after commodities in the world. In conjunction with the production of countless other goods and materials, some 95 percent of the fuel used for transport is a liquid petroleum product made from crude oil (Gilbert and Pearl, 2010). As dictated by the basic law of supply and demand, rapidly decreasing supplies of this good paired with unprecedented spikes in its demand from developing countries such as India and China as they continue their ascent through an industrialized age have increased the value of this fuel. The following figure illustrates the way in which consumption rates of petroleum are far outpacing the rates at which new discoveries are made.

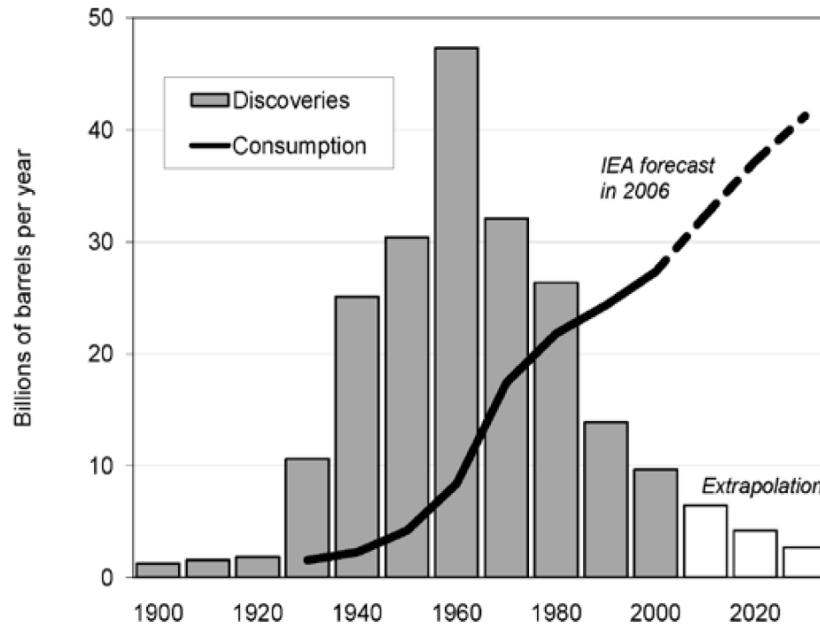


Figure 1: Actual and projected oil discovery and consumption 1900-2030 (Gilbert and Pearl, 2010)

The prolonged trend of increases in crude oil prices can be attributed to a number of factors including GDP growth (growth of oil demand), depletion of deposits, information of exhaustion of free capacities, prohibitive laws and the decline of strategic reserves, amongst other factors (Braginskii 2009). While a general consensus correlates rising oil prices with negative results on an economy, the International Monetary Fund conducted a study finding that a ten dollar rise in oil prices corresponds with a -0.75 percent impact on GGP growth. The following table illustrates the rise in crude oil prices over the past forty years roughly.

Year	Price	Year	Price	Year	Price	Year	Price
1970	3.80	1980	37.38	1990	24.51	2000	28.50
1971	4.05	1981	36.67	1991	21.47	2001	24.43
1972	4.05	1982	33.67	1992	17.97	2002	25.06
1973	4.65	1983	30.40	1993	15.78	2003	28.83
1974	8.05	1984	29.36	1994	15.31	2004	38.27
1975	9.03	1985	28.00	1995	16.81	2005	54.28
1976	9.78	1986	15.10	1996	21.03	2006	65.14
1977	10.24	1987	19.20	1997	19.00	2007	72.39
1978	10.75	1988	15.97	1998	12.40	June, 2008	140.0
1979	15.10	1989	19.58	1999	18.20		

Figure 2. Dynamics of world crude oil prices- USD per barrel (Braginskii 2009).

Despite a general increase in prices of almost all goods and services since the 1970's, a 3500 percent increase in the price of crude oil is significant enough to merit a discussion of potential alternative forms of fuels or modes of transportation. The result of a higher demand for oil by American inspired developing countries will be higher prices. As a result, the recent trend of increasing fuel prices will be even further exacerbated in the future, thus tightening the strain on the finances of American citizens.

The widespread use of fossil fuels within the current energy infrastructure has not only strained citizens financially, but is also considered the largest source of anthropogenic emissions of carbon dioxide, which is largely blamed for global warming and climate change (Balat, 2008). Of the national total, 60.3% of CO2 emissions are from motor gasoline. Amongst the greenhouse emissions created by petroleum fuels in combustion engines, 96% is CO2 (Bae, 2004). As of 2001, CO2 concentrations have increased 31% over their levels in the year 1750, and are now at levels not seen in the past 420,000 years (IPCC, 2001). On a more localized level, particulate matter is considered to be a major health concern for those living by and walking along roads with heavy traffic because of

its tendency to induce negative respiratory symptoms and aggravate asthma (Deka, 2004). Transportation alone is believed to account for 27 percent of total global energy consumption (Gan, 2003). Further, GHG emissions as a result of this are expected to grow 10 percent by 2035. However, estimates suggest that GHG emissions can be cut by as much as 65 percent by 2050 through improved vehicle efficiency, a shift to less carbon intensive fuels, changing travel behavior and operating more efficiently (Greene et al. 2011). The automobile dominated transportation culture that currently reigns supreme is illustrated in the following figure.

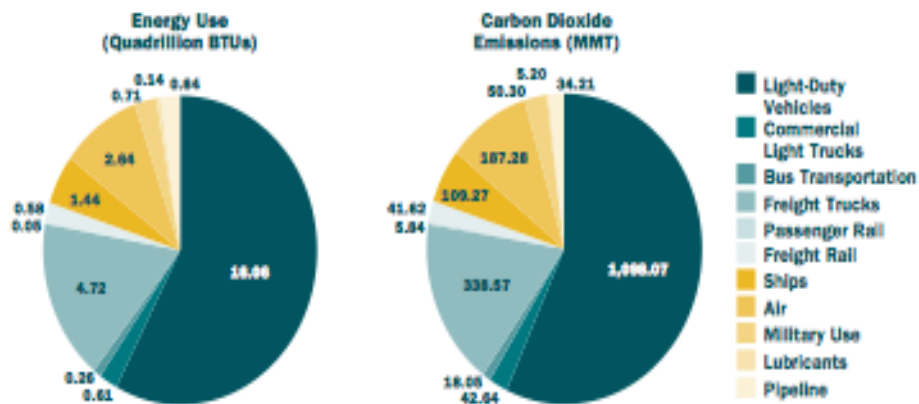


Figure 3. 2008 U.S. Transportation Energy Use (Greene et al. 2011).

Clearly, there exists an overemphasis on “Light-Duty,” or personal vehicles. Highway vehicles (light, medium and heavy duty vehicles) are the dominant form of transportation and account for 78 percent of the total U.S. transportation emissions. A more balanced approach is required in the realm of transportation to retard the negative impacts of emissions on local air quality and the global atmosphere.

Consistently high vehicle crash and fatality rates provide another compelling argument against the automotive culture. Globally, there are nearly a million fatalities and 70 million injuries (WHO, 2001). In the U.S. alone, motor vehicle accidents resulted



in almost 42,000 fatalities and 5.3 million nonfatal injuries in 2000 (Deka, 2004). While many of these accidents are between two separate drivers, in some instances, encroachment into the natural habitats of animals has resulted in wrecks. More than 200 motorists are killed each year and thousands are injured in animal-vehicle collisions, with \$200 million of insurance reimbursements (Bae, 2004). The number of animals killed along U.S. highways is estimated to number 4-6 million annually (Black, 2003). Not only has serious injury and death resulted from collisions by often reckless or aggressive drivers, but also from natural wildlife pursuing its own mobility.

Congestion is an issue of increasing magnitude that results in the decreased speed of vehicles, and ultimately culminating in both lower fuel efficiency and increased emissions detrimental to human health (Black, 2010). Although common sense would suggest that long commutes play a pivotal role in one's daily psyche, there is now scientific research that supports this hypothesis. According to researchers at Umea University in Sweden, couples in which one partner commutes for longer than forty-five minutes are 40 percent likelier to divorce (Lowrey, 2011). The researchers did not give a specific reason for why this was, but one could see instances in which long transit times exacerbate corrosive marital inequalities, with one partner overburdened by child care and the other by work. This is making people reconsider whether the benefits of having a better paying, more distant job are greater than having more time to spend with family or other more pleasurable activities.

Other research suggests that long commutes also have a significant impact on the health of commuters. People with long transit times suffer from disproportionate pain, stress, obesity and dissatisfaction (Lowrey, 2011). A survey conducted for the Gallup-

Healthways Well-Being Index found that 40 percent of employees who spend more than 90 minutes getting home from work “experienced worry for much of the previous day.” Conversely, that number fell to 28 percent for those with commutes of ten minutes or less. Along with high levels of stress, long commutes also make us feel lonely. Robert Putnam, a political scientist from Harvard, suggests that long commutes contribute to social isolation. He estimates that every 10 minutes spent commuting results in 10 percent fewer social connections that typically make us feel happy and fulfilled. As more cars continue to flood streets and highways, issues related to congestion will likely expand in their immensity.

Sprawl is another component of the currently unsustainable transportation system that results in increased infrastructure development and maintenance in far flung areas. Characterized by low density, segregated patches of land use, sprawl is not only responsible for the inefficient allocation of limited financial resources, but also has a profound impact on travel behaviors. Because such sprawling areas cannot be feasibly serviced by public transit and are also too stretched out for walking or cycling, the private automobile has emerged as the overwhelmingly most popular mode of travel for citizens in these locations. The extreme manifestation of sprawling development has without question exacerbated the car culture that currently reigns supreme.

In addition to reliance on finite petroleum reserves, harmful emissions, motor vehicle accidents, congestion and sprawl, there are other negative consequences of the automotive culture that are sometimes overlooked. Rain or snow on impervious surface results in the runoff of highly contaminated water and has the potential to harm marine animals. Also, issues surrounding the disposal of batteries, old engines and vehicles can

create additional environmental issues (Bae, 2004). Oil spills are often highly publicized for their potential to wipe out entire ecosystems in a single incidence. Finally, impacts of noise can create psychological issues such as nervousness and behavioral disorders, or physiological effects like heart disease. (Black, 2010). In all, the current automobile dominated transportation system is one that cannot be expected to sustain travel demands far into the future. Instead, the time is now for planners and politicians to embrace alternative modes of transportation that facilitate mobility within urban areas in an economically, environmentally and socially responsible fashion.

As society continues to travel longer distances with unsustainable modes, each of the problems previously discussed will inevitably become more severe. By gaining a clearer understanding of how populations' travel behaviors are influenced by different factors, planners will be more capable of making informed decisions about how best to implement more sustainable travel strategies. This research specifically examines the role that one major element of travel, the commute, plays in the non work, personal trips of workers either living or working near transit oriented developments (TODs) in Denver, Colorado. Specifically, this study will explore whether household or workplace proximity to TODs have an impact on the commute mode choice of workers, and if commute mode has any influence on their personal travel behaviors as well. Since the majority of most populations consist of a working class, the knowledge provided in this research could be highly relevant and valuable to those with an interest in promoting more sustainable travel.

## **Chapter Two: Literature Review**

While many would agree that the current transportation system is not sustainable, there is much more controversy surrounding the criteria for determining future transit systems. The shift to a more sustainable means of movement is typically characterized by either technological or behavioral changes. Technological advancements in travel efficiency typically deal with improved reductions in greenhouse gas emissions per vehicle. Yet, technological changes do very little to discourage private automobile use. Even in an ideal technological advancement scenario where all private vehicles are powered by electricity, a new support infrastructure would be required and the current automotive culture that exists would be exacerbated with more drivers using more cars to fulfill their day to day needs. The “rebound effect” describes this phenomena where drivers will feel more tempted to use their energy efficient cars (Berkhout et al., 2000; Steg and Gifford, 2005). In short, technological innovations may limit carbon emissions on a per car basis, but will ultimately increase congestion in urban areas.

Behavioral changes in transportation are characterized by a reduction in the need to travel (particularly by car), increased use of public transport (and walking and cycling), and a reduction in travel distances (Banister, 2011). Generally, people are reluctant to embrace behavioral changes because they are perceived as a reduction in freedom of movement (Poortinga et al., 2003). Behavioral changes are also often associated with additional effort or decreased comfort. In most cases, society is resistant

to changes that require an adjustment in lifestyle, especially if there is potential for increased effort or decreased convenience (Steg and Gifford, 2005). For this reason, the collective interests of policymakers and the individual interests of citizens are often at odds. While a mixed approach would be ideal for achieving environmentally sustainable transport goals, persuading the public to make behavioral changes has been a much slower process than the adaptation of technological advancements.

Transit Oriented Development (TOD) is a concept within sustainable urban planning that has gained traction in recent years as a way to address many of the issues surrounding the traditional ways in which citizens travel. TOD is generally defined as moderate to high density residential development that also includes employment and shopping opportunities and is located within easy walking distance of a major transit stop (Lund, 2007). The main objectives of TOD are to encourage transit use, increase housing opportunities, promote walking and biking, and facilitate neighborhood revitalization. While access to transit is an undeniably crucial component of TODs, the implementation of transit must be coordinated with other land use schemes that are particularly conscious of providing quality pedestrian environments instead of those which are oriented toward the private automobile. The three Ds of TODs- density, design (provision of convenient sidewalks that encourage walking) and diversity (land use mixture) are key components of successful TODs. According to Cervero and Kockelman (1997), “higher densities, diverse land uses and pedestrian friendly designs...must coexist to a certain degree if meaningful transportation benefits are to accrue” (page 19). A fourth D, destinations,

defined as accessibility to concentrated regional destinations, also has been shown to be a key factor in transit use (Gard, 2007).

An example of just how significant the impact of TODs and their surrounding land uses can be on an urban area can be realized through a study of two cities in Brazil. The cities of Brasilia and Curitiba are both similar in size (roughly 3 million inhabitants at the metropolitan scale), are among the wealthier middle to larger size Brazilian cities, and have similar overall population densities within their built up areas. However, the organization of these densities vary. Curitiba's high densities occur in areas along radial, bus served corridors where Brasilia's densities are more uniformly spread. Additionally, land uses along Curitiba's transit networks tend to be intermixed while land uses in Brasilia were consciously segregated with offices in one part of the city, retail in another, and housing in yet another. In 2005, Curitiba averaged 355 transit trips per person per year compared to just 97 in Brasilia (Belzer and Autler, 2002). Even more, the average annual vehicle kilometers travelled per person in Brasilia in 2005 has been estimated at 16,700 compared to 7,900 in Curitiba (Santos, 2007). Thus, more sustainable transportation and land use arrangements are proven to be capable of drastically reducing the carbon footprint of residents living in urban areas.

Indeed, TOD has gained support by planners and political bodies in years past for its potential to address many issues associated with the currently unsustainable transportation system. Specifically, the rise in the level of interest in transit oriented developments in the U.S. has been spurred by a] rapidly growing motor vehicle traffic congestion nationwide and increasing desire for multimodal alternatives; b] growing

distaste for suburbia and strip development; c] growing desire for quality urban lifestyles with more walkable environments away from motor vehicle traffic; d] higher prices for gasoline and increased cost of motor vehicle ownership and use; and e] growing support for smart growth and urban sustainability changes in family structure to more single person households, young professionals, and empty nesters (Ratner and Goetz, 2013). Currently, over 100 projects exist in the United States and are found overwhelmingly in and around heavy, light and commuter rail stations (Cervero, 2009). Even more, a number of studies have reported growing market demand for pedestrian and transit oriented development (Bartholomew and Ewing, 2011). The potential for even stronger demand in the future is suggested by demographic projections (Myers and Gearin 2002). With such a frenetic rise in popularity amongst residential inhabitants in these areas, much of the recent research on TOD has followed this trend in seeking to discover whether residential proximity to transit is truly influential in terms of its ability to change travel behaviors. Yet, this extreme focus on the residential sector has left a void in TOD research, particularly in the area of workplace TOD characteristics.

To date, studies conducted on TODs' ability to influence travel behavior have shown mixed results. Researchers found that the land use effects of several US urban rail systems constructed in the 1980s and 1990s were quite weak (Webber, 1976; Knight and Trygg, 1977; Gomez-Ibanez, 1985; Dunphy, 1995; Loukaitou-Sideris & Banerjee, 2000). However in many cases, suggestions are made for a stronger emphasis on non residential components of TODs, such as retail and employment. For instance, research of a rail line in Arizona found that the value of advanced TOD is highly variable by station and

station-area type and strongly influenced by existing land use. Station areas with a critical mass of land use that is compatible with TOD, such as Employment and Amenity Centers, attract advance TOD (Atkinson-Palombo and Kuby, 2011). Additionally, a rail line study in Chicago found that when comparing subgroups (of riders), there were typically larger percentages of trips that originated from households close to transit that also terminated at work destinations close to transit (Lindsey et al. 2010). Meanwhile, a study of the development of one of the world's preeminent rail stations in Stockholm, Sweden discovered that an overriding principle in its design was to distribute industry and offices roughly in proportion to residential population, i.e. to achieve a jobs-to housing balance. Public control of land allowed this. Tax incentives were used to lure industries to new towns and to promote company-provided employee housing. New towns were also planned for a mix of housing types (single- family and multi-tenant residences) as well as land uses, with offices, civic buildings and shops intermingled (Cervero 1996).

The importance of nonresidential characteristics is further illustrated from a case study conducted by Lund, Cervero and Willson (2004) of 40 TODs situated along nine different heavy, light or commuter rail lines in California. The results of this study not only showed that TODs had higher rates of transit use than comparable non-TOD areas (Gard, 2007), but also that employment plays a large role in ridership on transit systems. A sizable 26.5% of home based *work* trips for TOD residents were made by bus or rail, whereas only 8.1% of home based *non work* trips were made by TOD residents. In addition, transit (either rail or bus) was indicated as the primary commute mode by 18.8%



of the surveyed TOD employees. Clearly, the commute represents a substantial portion of the transit ridership in this area. In reference to one of California's rail systems, the BART, Cervero and Landis (1997) found that after 20 years of operation, the BART system in San Francisco had its greatest impact on downtown access and development, especially in new downtown office space. They concluded by stating that for BART to effectively compete with the private automobile in coming years, its station areas will need to capture even larger shares of future employment growth in addition to housing (Cervero and Landis 1997).

One of the key justifications for the investments in light rail is its ability to relieve road congestion by facilitating peak hour modal shifts. However, a TODs success in achieving this goal is contingent upon the levels of employment growth in such corridors. A study using English Census data for the Greater Manchester Metrolink, South Yorkshire Supertram, Midland Metro, and Croydon Tramlink found declines in the car drive and passenger shares of work trips to city employment centers along light rail corridors. Conversely, driver car shares of those living in rail corridors actually increased for work trips to all destinations (not just those along rail corridors), indicating an increase in the decentralization of jobs beyond the reach of light rail lines. Because the rail share of trips is much lower when examining all destinations rather than just city centers, this may suggest that a stronger emphasis on employment growth should be placed in light rail corridors beyond the city center (Lee and Senior, 2013). According to this study, other factors that affect light rail ridership beyond its mere availability and access to employment areas include population density, socio demographic

characteristics of the residents in the service areas, the physical design of the scheme, and the quality of the service and complimentary public policies and schemes. Also, the ease of walking access to light rail services can increase transit ridership and reduce car ownership (Lee and Senior, 2013). The inclusion of such variables in the TOD planning process have proven to yield positive results in the case of the case of Copenhagen, Denmark. In this instance, a highly integrated approach combining land use, car parking charges and integrated accessibility planning contributed to a decline in the car's modal share in favor of public transport and cycling (Knowles, 2012). In short, the mere availability of a rail line is insufficient in spurring a modal shift. Successful TOD projects will require a more comprehensive understanding of the multitude of factors that increase levels of ridership.

On a more local level, perhaps no project better exemplifies the inclusion of the many ingredients of a successful TOD better than the Metrorail in Arlington, Virginia. With 24.4 million square feet of office space, 3.8 million square feet of retail space, 24,000 mixed income dwelling units, and over 6,300 hotel rooms, this development has been exemplary (at least in U.S. terms) in its ability to attain many of the goals of TOD (Arlington County Department of Community Planning, Housing and Development, 2002). Of the nearly 190,000 people today living in Arlington County, 26% reside in Metrorail corridors even though these corridors comprise only 8% of the county land area.

Some of the elements that made this project successful were targeted infrastructure improvements, incentive zoning, development proffers, and permissive and

as-of-right zoning- to entice private investments around stations. An important outcome of promoting mixed use development along rail corridors has been balanced jobs and housing growth, which in turn has produced balanced two way travel flows. During the morning rush hours, many of the county's Metrorail stations are both trip origins and destinations, meaning trains and buses are full in both directions. As evidence, 39.9% of Metrorail corridor residents commute to work by public transit (Arlington County Department of Community Planning, Housing and Development, 2002; United States Census, 2000). This is twice the share of County residents who live outside the Metrorail corridors. In fact, in some residential projects, 40 to 60 percent of the tenants don't even use cars on a daily basis (Belzer and Autler 2002). According to the study, ridership has been most responsive to increases in office and retail development. Every 100,000 square feet of added office and retail floorspace increased average daily boardings by nearly 50 (Cervero, 2009). The characteristics of this particular project should be studied and incorporated into the plans of other transit projects throughout the country.

A clear message from the previous case studies is that workplace proximity to light rail stops play a major role in the mode choice for commuters. Even more, a study of the rapid transit system in Taipei found that the effect of bringing workplaces nearer to transit stations is better than locating residences nearer (Tsai, 2009). Additionally, a study of a rail line in St. Louis, MO found that nearly three quarters of all light rail trip purposes were either for school or work (as opposed to personal/ recreational activities). Amongst these observations, over half of the riders cited "drive and park" as their mode to or from the transit station while only eight percent walked from their homes (Kim et al.

2007). This reinforces the necessity of gaining a clearer understanding of how workplace characteristics and proximity to light rail affects travel behaviors.

While TOD has been an attractive housing option for many, some citizens still maintain a preference for suburban living. An interview of residents in southern California revealed that changing the long standing public perceptions of “ideal” residential neighborhoods that typically consists of low density structures and single family uses has been a paramount challenge for most planners (Loukaitou-Sideris, 2010). Conversely, workers are typically less likely to choose their jobs based on workplace land use characteristics. Therefore it may be pragmatically and politically more acceptable to change policies in primarily nonresidential areas, because the users of those areas may have fewer complaints about more intense development than residential users typically do (Chatman, 2003).

Workplace locations and their associated transit services may be more effectively tailored to meet the needs of the working class through a greater understanding of the factors that influence commute mode. This “deserved emphasis on travel to work” is justified by the Federal Highway Administration for several reasons. First, employed adults travel more miles per year than those who do not work. Also, work trips place the largest strain on the transportation system because of the volumes of traffic concentrated in certain places and at specific points in the day. Finally, the commute is often the foundation around which other travel is scheduled (Redmond and Mokhtarian, 2001). A study of the Austin metropolitan area in Texas revealed several key influences of commute mode choice. The first is that stop-making at the weekly level is the

determining factor in commute mode choice. The empirical analysis also indicates that the reliability, travel time, travel costs and the presence of grocery shops near rail stations have an important impact on rail use (Bhat and Sardesai, 2005). As the most scheduled and routine of all trip purposes, the commute represents a significant segment within the study of travel behavior and deserves to be further examined. With nearly eighteen percent of all person trips and twenty three percent of all person miles in the U.S. related to commutes, an examination of workplace locations could potentially lend insight into the travel decision making processes of working populations (FHWA, 1996).

There are a number of reasons for why workplace location is often neglected as a considerable factor in home buying decision processes. First, urban residents may care about such a variety of housing and neighborhood characteristics that transportation costs are simply overshadowed in importance by other priorities (Giuliano and Small, 1993). Also, the search for lower cost housing has influenced workers to move to outlying areas far from their jobs, and has led to longer commutes. In addition, the cost of transportation has declined more rapidly than the cost of housing, thus encouraging workers to sacrifice longer commute times for higher quality housing. Finally, the locational state of the job market is characterized by decentralized employment and requires households with more than one worker to negotiate household locations in order to accommodate multiple job locations (Giuliano 2004). Through a greater understanding of both commute mode decision processes as well as the factors that repel home buyers from locating closer to their workplace, planners can acquire a better sense of the characteristics that should be emphasized in and around employment areas.

In places like the United States, United Kingdom and Netherlands, issues relating to the currently unsustainable transportation system have spurred the generation of workplace travel planning initiatives. A workplace travel plan is a package of measures that an employer puts in place to encourage and enable staff to travel to work more sustainably. An analysis of the effect of such measures was examined through a case study of twenty employers in the United Kingdom. In Britain alone, 38% of all vehicle miles traveled are for commuting or business purposes (Department for Transportation, 2009). An understanding of the factors that limit and reduce private automobile commuting could address a number of issues associated with the current car culture. Some of the key factors that increased the mode share of rail and bus for these employment areas were cheaper fares, improved off site infrastructure and service quality, better access to bus and train information, and station stops near the employment buildings. In the case of bicycling and walking, mode share was increased through high quality off site access, increased available bike parking, the existence of bike share programs, cheaply available cycle repair services, the provision of better security for bikes, cycle equipment loans, site specific maps, health benefit marketing, financial incentives like exemption from parking charges or entries into prize drawings, and the availability of shower, changing, drying, or locker facilities. Additionally, many employers had introduced some kind of travel information display (web pages, notice boards, and display stands), sent material to staff, consulted with staff representatives, made use of slogans to increase awareness of activities, and had team promotions and

competitions. Some even went so far as to provide attractive relocation packages to encourage staff to move closer to work.

In all, travel plans had managed to reduce the number of commuter cars by more than fourteen per one hundred staff, representing more than an eighteen percent reduction in the proportion of commuting journeys being made as a car driver (Cairns et al. 2010). Partnerships with local authorities, local public transport operators and other groups were considered a critical component to the success of travel plans. It was also noted that the extent to which local authorities can be successful in encouraging employers to implement effective travel plans in their areas will inevitably depend on the wider context in which these policy measures are encouraged. The results of this study indicate that travel planning can be inexpensive (much more so than providing company cars for instance) and can yield positive results relatively quickly. Even more, synergistic changes were reported in instances where reduced car commuting was accompanied with reduced car use for other travel (Cairns et al., 2004). In sum, strategies aimed at promoting higher shares of more sustainable commute modes can lead to changes in personal travel as well.

### **Chapter Three: Research Problem and Methods**

The above discussion of past research examining light rail ridership in different cities throughout the United States indicates that a potential exists for more in depth analyses of the relationships between TODs and transit ridership. If workplace characteristics and proximity to TODs are, indeed, effective at influencing commute mode and potentially even other trip purposes, perhaps a study that explicitly examines such behaviors is in order. To address these uncertainties, this research project seeks to measure differences in travel behaviors of workers based upon whether they work near a TOD, live near a TOD, or live *and* work near a TOD. This research argues that: a] planning policies in downtowns and job centers have stronger influences on mode choice than residentially based interventions; and b] those who do not use a private automobile as their primary commute mode will be more likely to use alternative modes (walking, biking, bus, light rail) for personal activities.

This research project is driven by the following research question: Does *working* near a TOD influence the travel behaviors of workers differently than workers *living* near a TOD? The following set of subquestions will contribute to our understanding of the factors that influence travel behaviors: 1] Is there a difference in the commute mode of workers either working near a TOD, living near a TOD, or living *and* working near a TOD? 2] Is there a significant difference in the number of non-work trips made between those who drive to work and those who do not? 3] Is there a significant difference in the



mode of non-work trips made between those who drive to work and those who do not?

4] Is there a significant difference in the average mileage of non-work trips between those who drive to work and those who do not? I plan to analyze the previous questions within each of three TOD subgroups: 1. Those who work near TOD; 2. Those who live near TOD; 3. Those who work and live near TOD. To answer these questions, I will perform statistical analyses of data provided by the Denver Regional Council of Government travel behavior survey.

First, however, it may be constructive to provide a brief discussion of the study area. Located east of the Front Range of the Rocky Mountains, metropolitan Denver, Colorado ranked 21st in the nation with a 2010 area population of 2.5 million. An enhanced emphasis on transit oriented development in this area is evident by the establishment of TOD programs with full time staff in both the City and County of Denver, the metropolitan planning organization, DRCOG, and the area's transit agency, RTD. The City and County of Denver views TOD as being more than just simply development near transit. Instead, a more comprehensive approach is used to measure its success. A TOD should create beautiful, vital, and walkable neighborhoods, provide housing shopping and transportation choices, generate lasting value for citizens and public private stockholders, and provide access to the region's jobs, government centers, healthcare facilities, and cultural and recreational destinations. The set of five goals that were developed as indicators for TOD success in Denver include location efficiency, a rich mix of choices, value capture, place making and portal or entry point (Ratner and Goetz, 2013).

In 2004, a transit and land use development program called “FasTracks” was approved by voters in the region at the expense of an increase in sales tax. In this plan, an expansion of the current light rail system along with the incorporation of bus rapid transit would be developed concurrently with the transformation of the Denver Union Station into a multimodal transit hub. As is common with the development of most transit systems, FasTracks experienced severe budget issues which have been responsible for massive delays in the production of several lines. Nonetheless, FasTracks has been able to maintain a relatively high level of commitment from its associated political bodies and funding partners within the Denver metropolitan region. The following map displaying the RTD light rail system was recently updated with the inclusion of the West line opening on April 26, 2013.

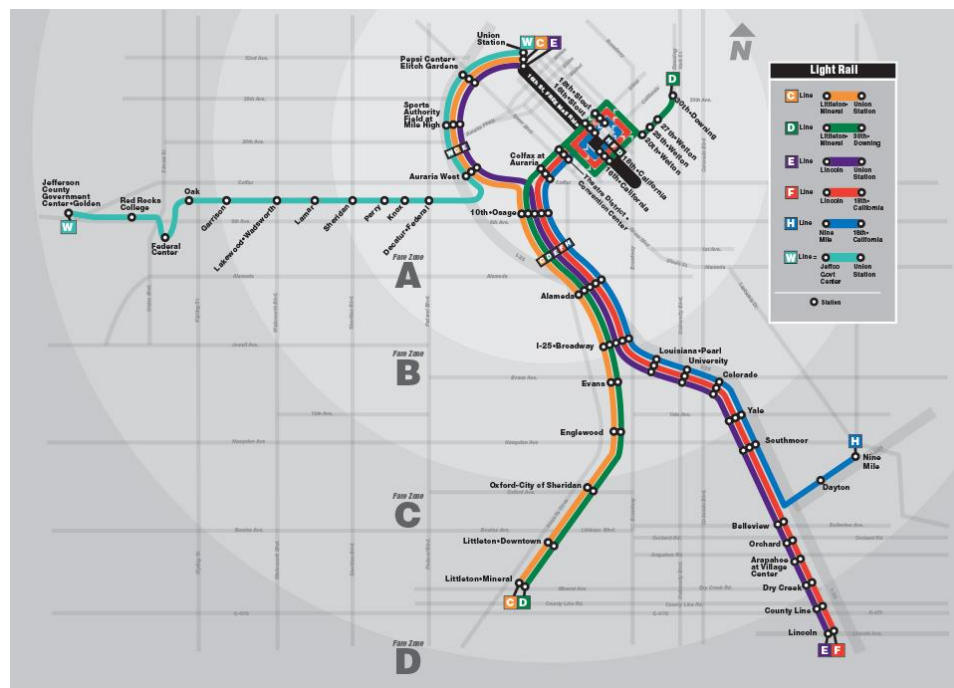


Figure 4. Light Rail System Map for Five Existing Lines Plus Future West Line (RTD-Denver, 2013)

In 2009, 65.65% of the regional residential development, 59.98% of the regional office development, and 18.66% of the regional retail development was TOD (Ratner and Goetz, 2013). Even in the face of the housing crash, residential TOD development dramatically increased while declines were experienced elsewhere within the region. In terms of workplace travel characteristics, the FasTracks program has developed over 90% of office TOD in the downtown in an attempt to increase accessibility by transit to such employment centers. Still, according to the *Commuter Survey* (2011), commuting rates for residents of the Denver metropolitan area are consistent with the national average amongst most travel modes, though bicycling rates are slightly higher.

This analysis will determine whether sustainable commute modes (rail, bus, biking, walking ect.) are more likely to be used by those who live near a TOD, work near a TOD, or live *and* work near a TOD. These evaluations will take place at three distance thresholds: a one mile Euclidian buffer distance from light rail stations, a half mile Euclidian buffer distance, and a walkshed buffer distance developed by DRCOG to more accurately simulate a “realistic” level of accessibility to the stations. From there, an exploration of personal (non commuting) travel behaviors will be conducted based on whether people drive to work or use a more sustainable mode than the automobile.

Based on previous work by Banister (2011), personal travel behavior will be measured in terms of the number, mode, and distance of trips. Again, the data were derived from the Front Range Travel Counts survey conducted by the Denver Regional Council of Governments in 2010. This survey contains data of about 80,000 trips generated by 16,200 people living in roughly 8,000 households. Therefore, this project is

divided into four steps: 1. development of a GIS database for identification, organization and selection of desired samples; 2. generation of commute mode trends based on group type and distance threshold; 3. generation of personal travel behavior characteristics (number, mode and distance) based on group type and distance threshold; and 4. a West line pretest using identical measures as in the analysis of existing lines.

As a whole, workers in the Denver metropolitan area are highly reliant upon their private automobile for both commuting as well as personal travel. Amongst the 8,011 workers who answered the survey question of typical commute mode, 83.9% cited a private automobile as their primary mode while only 16.1% made use any other mode besides a car. Similarly, 83.75% of the trips made by all respondents in this survey made use of a private automobile for personal travel as well. On average, workers throughout the entire Denver metropolitan region made 4.51 trips per day. Of these trips, the average distance traveled by car was 4.51 miles and the average mileage traveled with alternative modes was 2.39 miles. Results from this study's series of tests can be compared to see how the travel behaviors of workers living and working near TODs differentiate with those outside of such developments.

### **Step 1: GIS Database**

Using ArcGIS and DRCOG's 2010 Front Range Travel Counts survey, the workplace and household locations of workers were plotted within a half and whole mile straight line radius around each of the operational thirty six RTD light rail stops, as well as an additional half mile walk buffer that was created by DRCOG to simulate a more realistic scenario that considers barriers such as highways and railroads that may impede

users' accessibility to light rail services. These populations were then divided into TOD subgroups based on whether they work near a TOD, live near a TOD, or work and live near a TOD. It can be assumed that by using a population whose homes or workplaces are within a relatively similar proximity to transit, each worker will have equal access to the services provided by the light rail. To preserve anonymity amongst the samples, the dataset provides locational data coded to Census block centroids rather than precise coordinates. I created a shapefile containing the geocoded X,Y coordinates (Census block centroids) of the homes and workplaces around each of the thirty six operational light rail stops.

ArcGIS was also used to identify and eliminate outlier samples (discussed later) and "walking transfers." "Walking transfers" refer to instances where a trip's purpose is labeled as a "transfer" and the distance is less than 0.75 miles. These "walking transfers" were removed in an attempt to decrease the number of artificial "trip" recordings so that a more accurate depiction of actual travel behavior could be achieved. The 0.75 mile distance threshold was chosen through the use of Z score testing in Statistical Package for the Social Sciences (SPSS). A Z score test was applied to all transfer trip distances, and those assigned with a score + or - 3 (distances greater than 0.75 miles) were considered outliers. Additional outliers including personal trip numbers and distances were removed to increase the reliability of recorded travel behaviors and will be discussed in greater detail in the appropriate following sections.

## **Step 2: Commute Mode**

Once households and workplaces within transit oriented developments were identified, I divided the workers within each TOD subgroup by their “typical mode to work,” as posed in the Front Range Travel Counts survey. Those who primarily drove or rode to work in a private automobile were separated into one group, while those who used all other means (walk, bike, light rail, bus, ect.) were put into the other group. The group who uses their private automobile to commute will henceforth be labeled as “car commuters” while those who use alternative modes (including bus, rail and even walking and cycling) will be labeled “non-car commuters.” In some cases, “other” was cited as a participant’s “typical mode to work.” In most of these instances, multiple modes were listed and, as a result, those who chose “other” were grouped with the commuters who use alternative modes. As an example, a person who drives their car to a TOD and then uses the light rail to get to work downtown would be considered to use alternative modes for their commute and would be grouped as a non-car commuter.

This process provides insight into which of the three TOD subgroups engage in the most and least sustainable commute behavior. It can be assumed that those who do not use a private automobile as their primary means of commute are engaging in more sustainable travel behaviors than those who do. I hypothesize that the subgroup both living and working near TODs will use private automobiles the least for their commute since transit can theoretically fulfill this group’s mobility needs the best. The comparison between residences near TODs versus workplaces near TODs should indicate which TOD development type is more effective at influencing commute mode. Once divided

into a car commuter group and a non-car commuter group, an analysis of these groups' personal travel behaviors will indicate whether or not commute mode choice is capable of influencing more sustainable personal travel behaviors. The following figure outlining the project's process will be applied at each of the three distance thresholds:

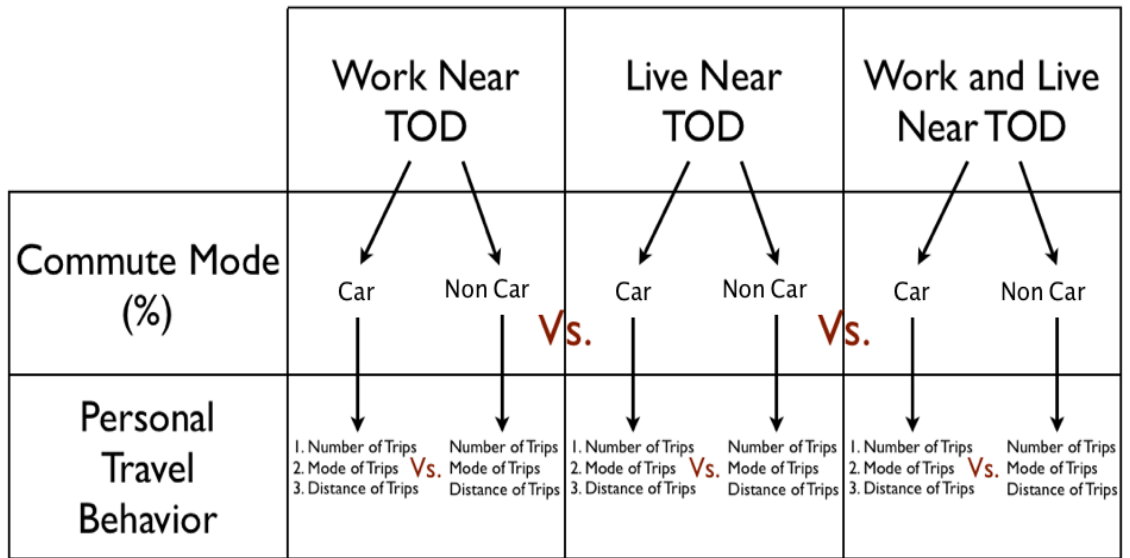


Figure 5. Workers' Personal Travel Behaviors and Commute Mode by TOD Type

### Step 3: Personal (Non-Work) Travel

Along with commute mode information, the dataset provided by DRCOG also has records of personal travel characteristics of Denver residents. With the TOD subgroups divided into car commuters and non-car commuters, the differences in personal (non work) travel behavior can be determined. Specifically, differences will be measured between car commuters and non-car commuters in terms of the number, distance and mode of personal trips made. I predict that non-car commuters will be more likely to practice sustainable travel behaviors in their personal lives with fewer trips, shorter trip distances, and more sustainable modes of transportation.

### **3A: Number of Personal Trips**

Using SPSS, I constructed an Independent Samples t- test at the 95% confidence level ( $\alpha=.05$ ) to test the following hypotheses for each TOD subgroup:

(Null Hypothesis)  $H_0: \mu_1 = \mu_2$

This says that there is no significant difference between car commuters and transit commuters in terms of the number of personal trips made.

(Alternative Hypothesis)  $H_1: \mu_1 \neq \mu_2$

This says that there *is* a significant statistical difference between car commuters and non-car commuters in terms of the number of personal trips made.

If the results of this test shows that the p (sig) value is  $< \alpha (.05)$ , we will reject the null and conclude that commute mode is a statistically significant predictor of the number of personal trips made by workers. The results of these tests will be compared amongst TOD subgroups from different distance thresholds to see whether the effect of TOD is stronger in one land use type or proximity over another.

As in the case of eliminating “walking transfers,” Z score testing was used in SPSS for the purpose of eliminating cases where excessively high trip number scores could be considered as outliers that could potentially skew the results of these tests. For this particular trial, some survey participants had recorded as many as thirty three trips in a single day. Obviously, such a high level of trip making is not even remotely indicative of the majority of the population. When applying the Z score test to trip numbers, the highest Z score value without exceeding + or - 3 was twelve (Z score of 2.837). As a



result, any person whose total trip number in a single day was thirteen or greater was excluded from testing.

### **3B: Personal Trip Distances**

The use of SPSS will again be used for the construction of an Independent Samples t- test at the 95% confidence level ( $\alpha=.05$ ) to investigate whether there is a statistically significant difference in the distance of personal trips made between car commuters and non-car commuters.

(Null Hypothesis)  $H_0: \mu_1 = \mu_2$

This says that there is no significant difference between car commuters and transit commuters in terms of average personal trip distances.

(Alternative Hypothesis)  $H_1: \mu_1 \neq \mu_2$

This says that there *is* a significant statistical difference between car commuters and non-car commuters in terms of average personal trip distances.

In this particular case, however, personal trip distances will again be divided based on whether the personal trip made use of a private automobile or alternative modes. In other words, this test will determine if there is a difference in personal travel distance based on mode choice. If the results of this test shows that the p (sig) value is  $< \alpha (.05)$ , we will reject the null and conclude that commute mode is a statistically significant predictor of personal trip distances. Again, the results of these test will be compared amongst TOD subgroups to see whether the effect of TOD is stronger in one land use type over another.

Z score testing was also used in this instance to eliminate trips with distance values greater than what would be reasonably expected for an average working citizen. For example, some survey participants had recorded trip distances amounting to as many as 2,107 miles for a single journey, a number whose value could easily skew results one way or another. When the Z score tests were applied to trip distance values, the highest value without exceeding + or- 3 was 110.40 miles (Z score of 2.99). As a result, 110 was designated as the cutoff point for the computation of the trip distance testing. Any trip distance whose value was 111 or greater was eliminated from the data set.

### **3C: Mode of Personal Trips**

While limiting both the number and distance of trips are characteristic of sustainable travel behavior, the mode of such trips is equally if not more important. The dataset provides the following nominal data relating to the mode of personal trips: a] walk; b] bike; c] auto/ van/ truck driver; d] bus; e] train; f] light rail; g] taxi. Chi square is a statistical method capable of investigating whether distributions of categorical variables differ from one another. Thus, chi square testing was used in SPSS to examine whether there is a statistically significant difference in the mode of personal travel behaviors between car commutes and non-car commuters. As in the case of the commute mode examination, personal trip mode groups will be divided based on whether they use a private automobile or not. The null hypothesis states that the distribution of personal travel mode for both car commuters and non-car commuters is the same. Conversely, the alternative hypothesis states that these personal travel mode distributions differ between

car commuters and non-car commuters. In this particular test, no outliers need to be removed since the data being used are categorical rather than numerically unrestricted.

I predict that those engaging in more sustainable commute modes will also be more likely to do the same for their personal errands. For example, those who take the light rail to work every day (roughly ten times per week) will be more likely to use the light rail to achieve their personal trip purposes since they would likely feel a greater sense of comfort and confidence with such a system. The results of these tests will be used to determine if there is a significant difference between the mode of personal trips for car commuters and non-car commuters at each distance threshold and TOD subgroup.

### **3D: West Pre-Test**

In addition to performing the three sets of travel behavior analyses for each of the operational thirty six RTD light rail stops, I also used the previous methods to measure the travel behaviors of residents and workers within future rail stops to the west of those that already exist. By doing so, this will establish a baseline that can be used for comparison in future studies of TOD effectiveness regarding changes in travel behavior tendencies with the implementation of enhanced transit opportunities. By developing datasets of populations' travel behaviors *before* light rail lines are opened, one can gain a clearer understanding of how the introduction of TOD impacts future travel behaviors in an area.

The West Rail Line of the RTD FasTracks corridor is a twelve mile light rail transit line that will include twelve new stations serving areas in Denver, Lakewood, the Federal Center, Golden and Jefferson County. Opening on April 26, 2013, this line will

provide rail service to the densest of all nine of the RTD FasTracks corridors (Ratner and Goetz, 2013). Because of its preexisting high density characteristics, this corridor has perhaps the best opportunity to become a classic mixed use TOD, especially when considering the state's commitment to providing even more retail and office area as well as a large medical complex. In all, the baseline data provided here could potentially be used in future studies as compelling evidence of TODs ability to promote more sustainable travel behaviors.

In all, the previous steps were made to determine whether or not: a] commute mode differs between those who live, work, or live and work near a TOD; b] distance away from TODs play a role in their services' usage; c] commute mode is capable of influencing personal travel behaviors in terms of number, distance and mode of trips. I hypothesize that groups both working and living near TODs will use alternative modes the most for their commute. What may be even more interesting, however, is to see how the groups with workplaces and the groups with households near TODs compare. Also, I predict that increased proximity to TODs will result in lower levels of car usage for both commuting and personal travel. Finally, I believe the results of these tests will show that non-car commuters travel less frequently, make shorter trips, and use more sustainable modes more for personal travel than car commuters.

## Chapter Four: Results

The first step in the process of measuring commute modes and testing their significance on influencing personal travel behaviors is to identify sample populations of workers in each TOD subgroup. Using ArcGIS, the workplace and residential coordinates (traced to the census block centroid) of workers were plotted as dots that scoured the entire Denver metropolitan region. The following figure displays this:

### Sample Screenshots

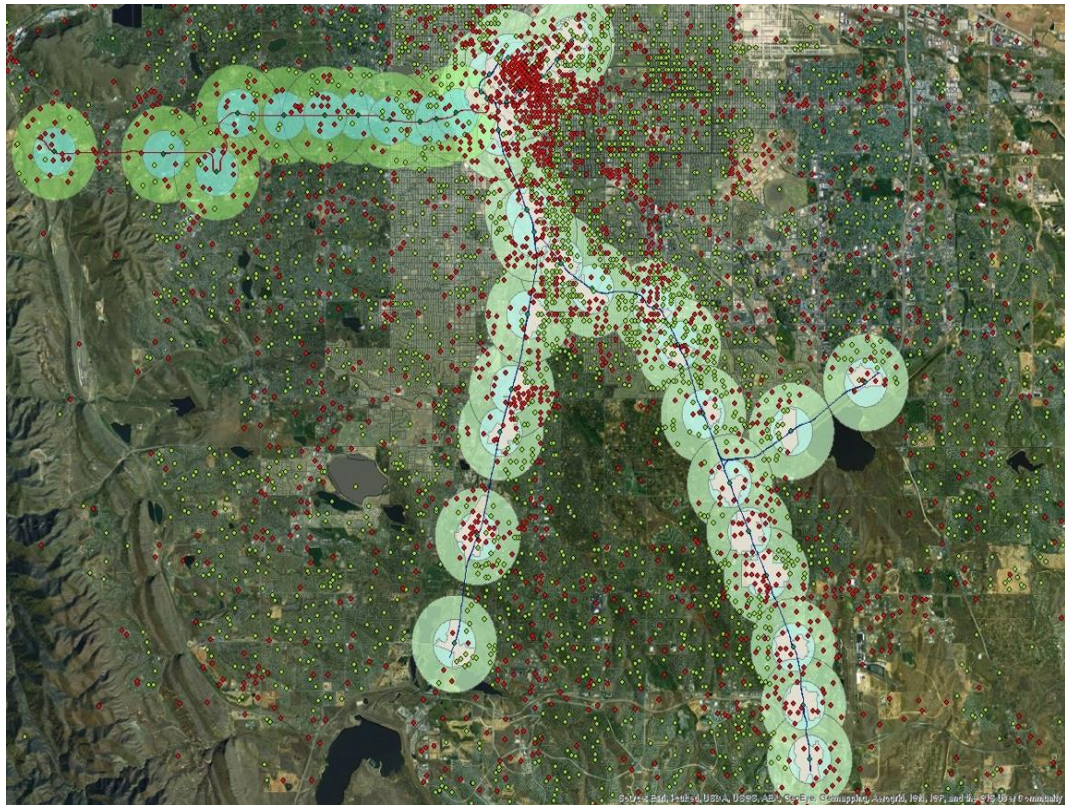


Figure 6: Workplaces Indicated as Red Dots and Residential Locations Indicated as Green Dots Throughout Entire Denver Metropolitan Area

In this, workplace locations are red dots, household locations are green dots, the one mile buffer zone around TODs are green circles, the half mile buffer zone around TODs are the blue circles, and the walksheds are the tan shapes around the TODs (existing lines only). The “Clip” function in ArcGIS removed all of the workplace and household samples that were not within the desired distance thresholds (one mile, half mile, walkshed). The “Join” tool was used to identify samples that contained both workplaces and households within each of these distance thresholds. The following figures illustrate the number and dispersion of these sample groups around Denver TODs. Orange dots are used for those both working and living near TODs, red dots are used for those with workplaces near TODs, and green dots are for those with households around TODs.

### Workplace and Household Samples

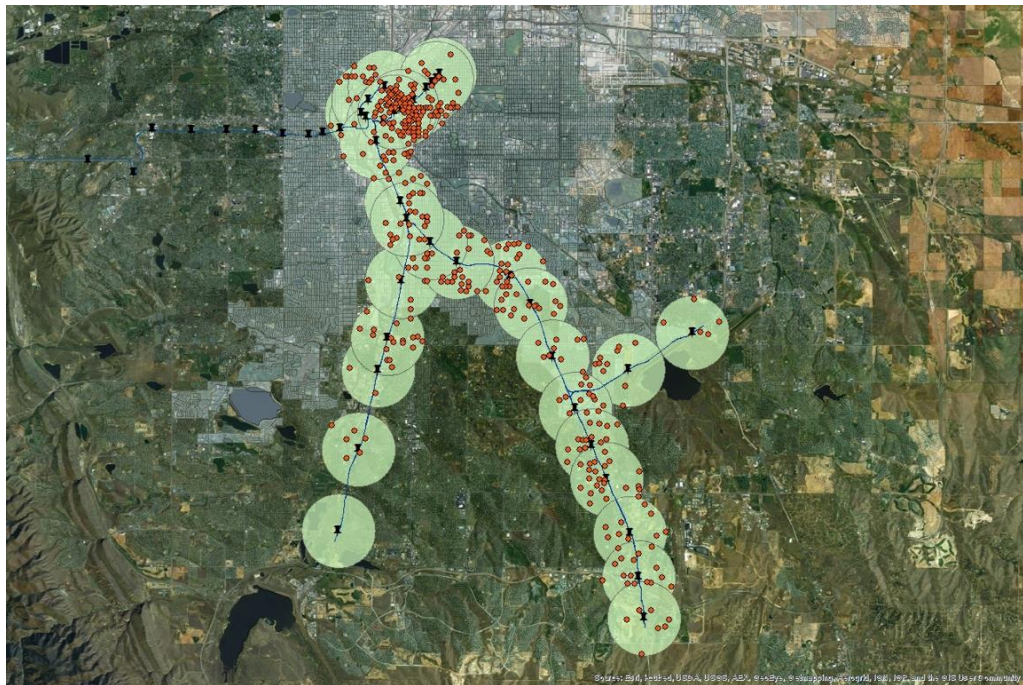


Figure 7: Orange Dots Identifying Samples with Both Workplaces and Households within One Mile of TOD (n=620)

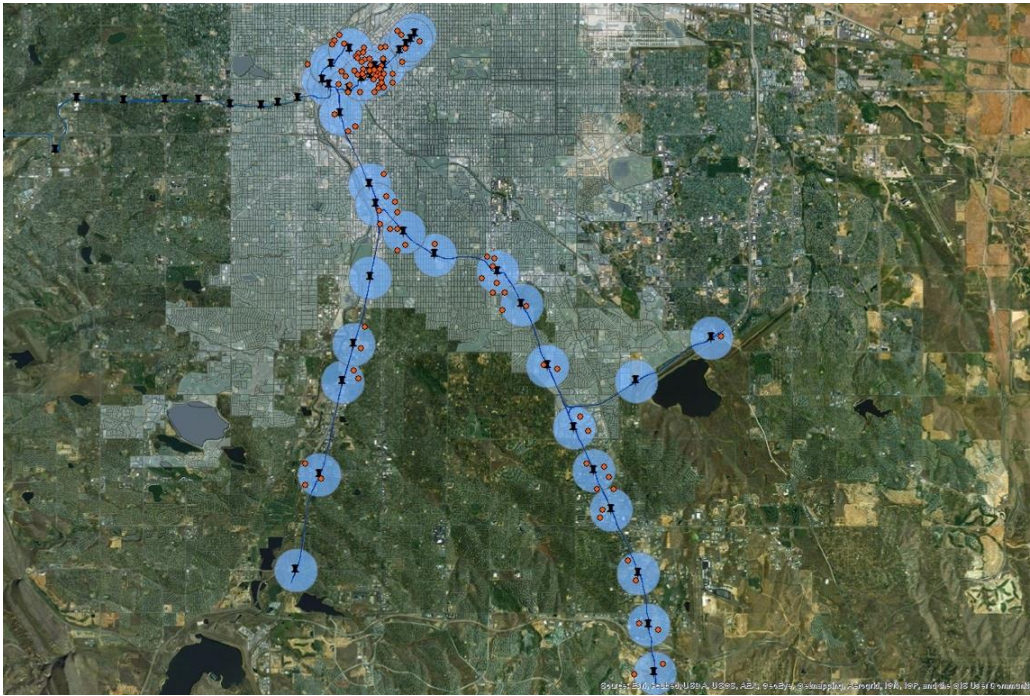


Figure 8: Orange Dots Identifying Samples with Both Workplaces and Households within a Half Mile of TOD (n=120)

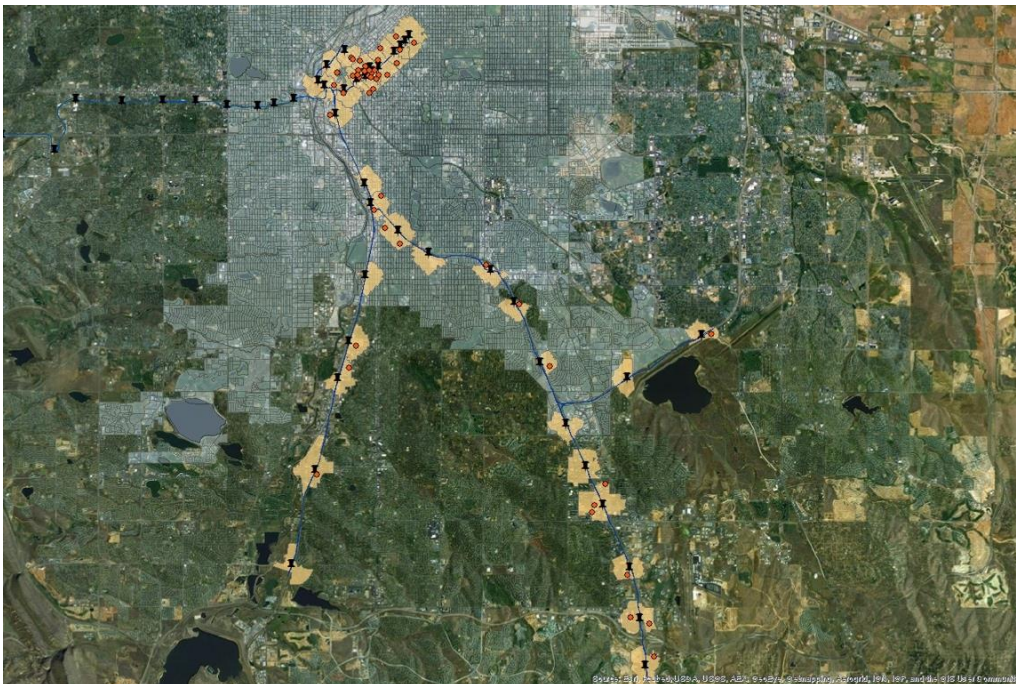


Figure 9: Orange Dots Identifying Samples with Both Workplaces and Households within the TOD Walkshed (n=47)

## Household Samples

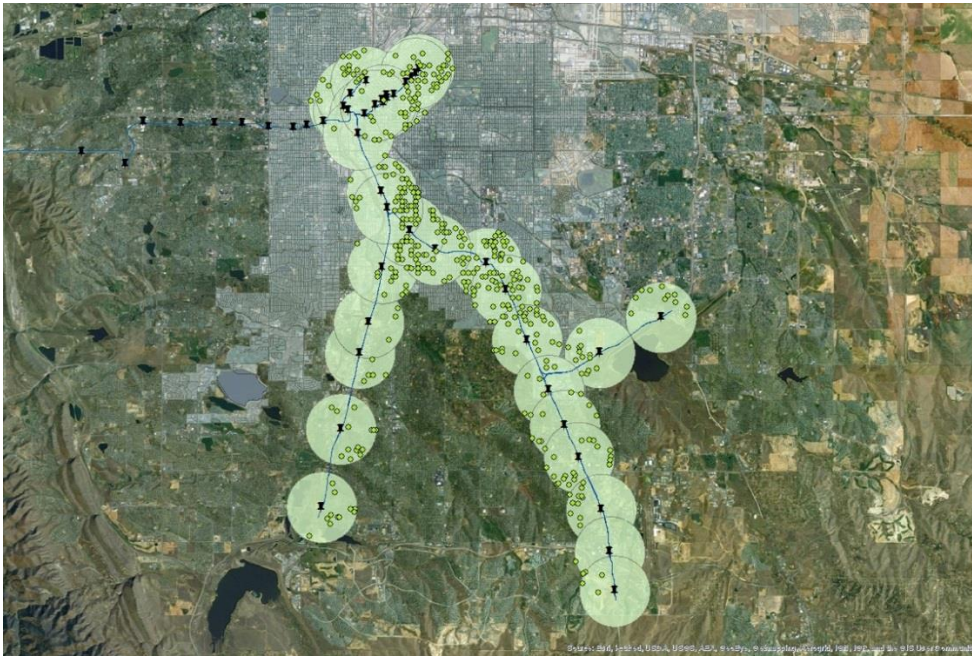


Figure 10: Green Dots Identifying Samples with Households within One Mile of TOD  
(n=557)

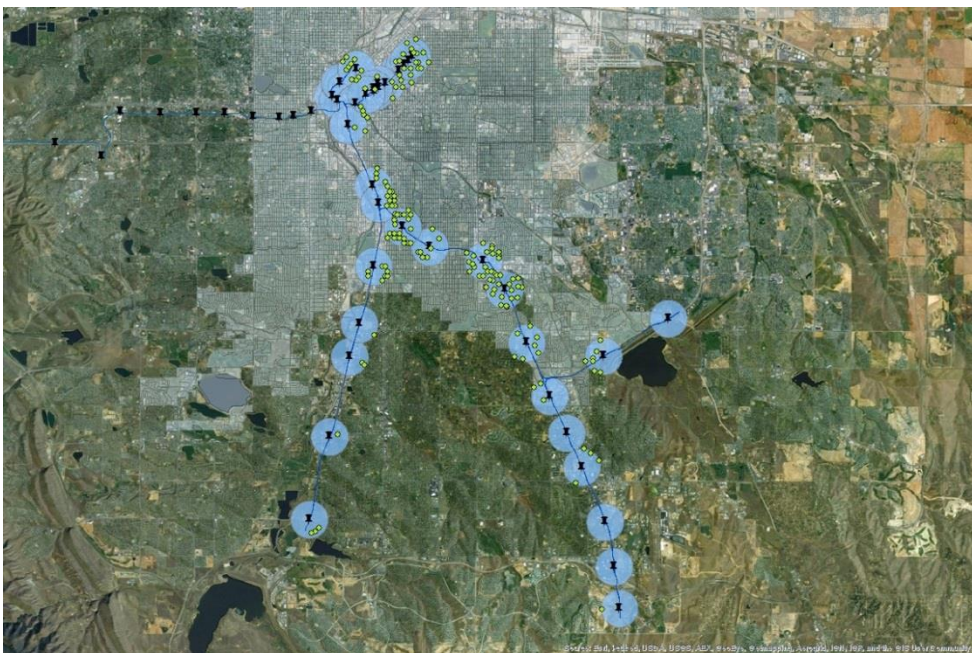


Figure 11: Green Dots Identifying Samples with Households within a Half Mile of TOD  
(n=217)



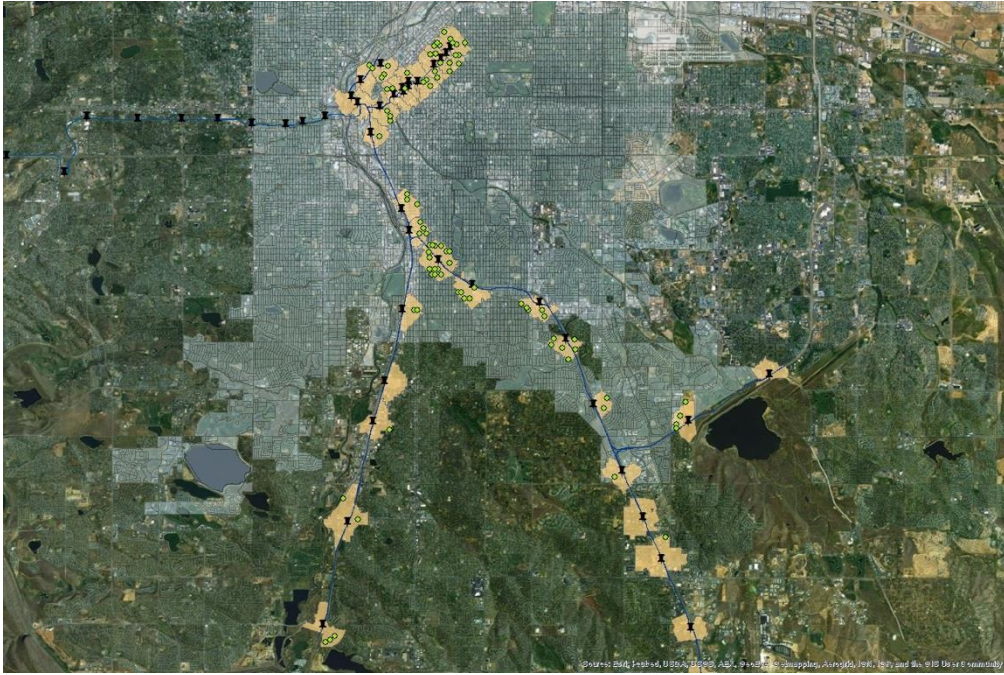


Figure 12: Green Dots Identifying Samples with Households within the TOD Walkshed (n=113)

**Workplace Samples**

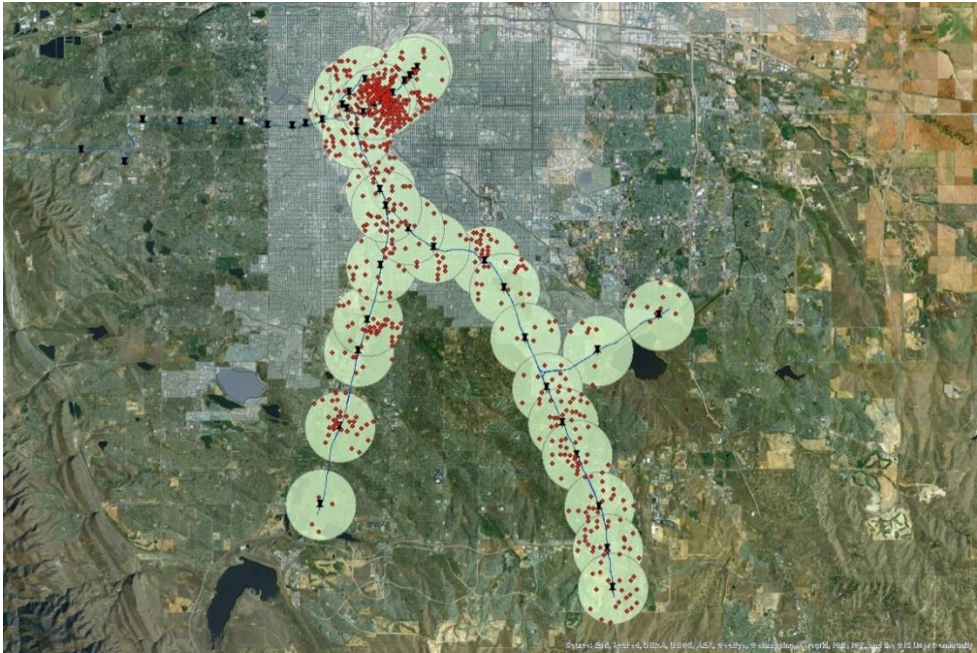


Figure 13: Red Dots Identifying Samples with Workplaces within One Mile of TOD (n= 2,262)

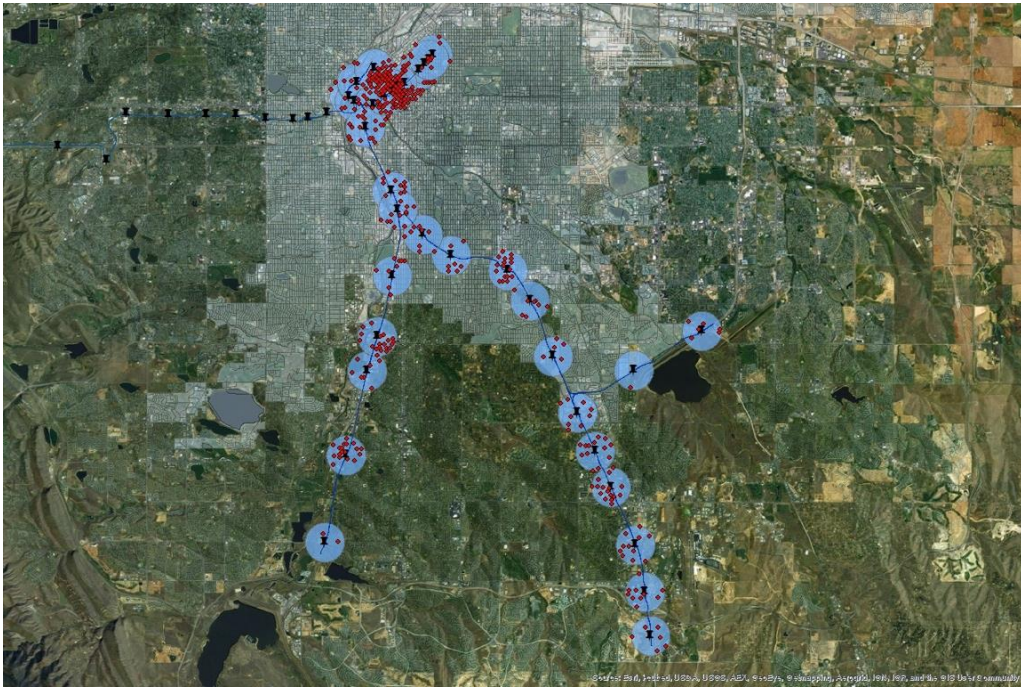


Figure 14: Red Dots Identifying Samples with Workplaces within a Half Mile of TOD  
(n=1,451)

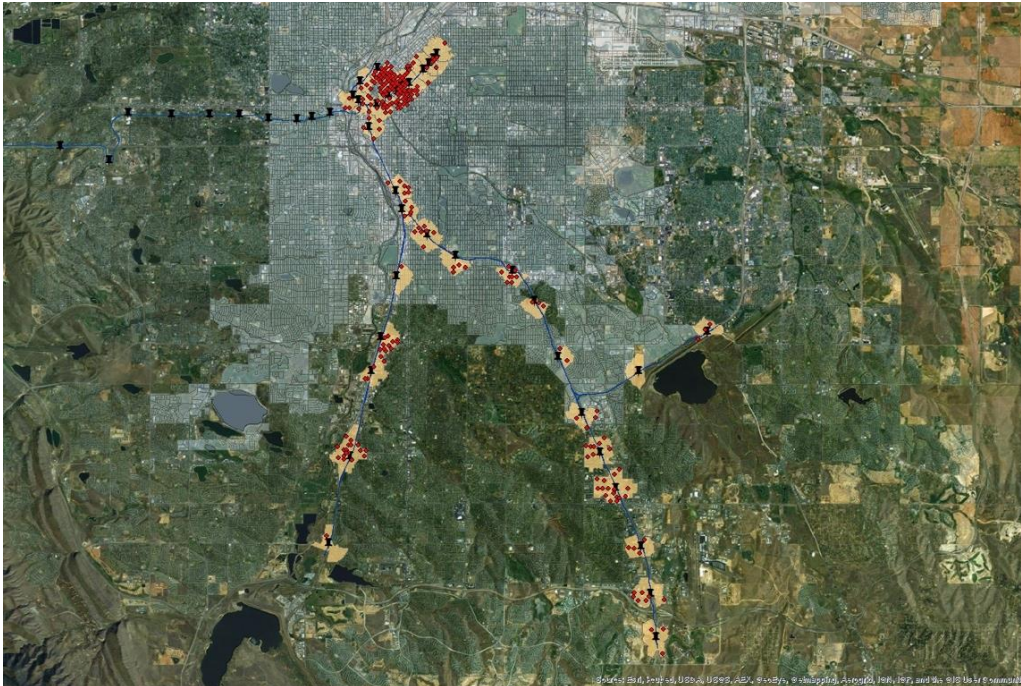


Figure 15: Red Dots Identifying Samples with Workplaces within the TOD Walkshed  
(n= 957)

## Workplace and Household Samples: West Line

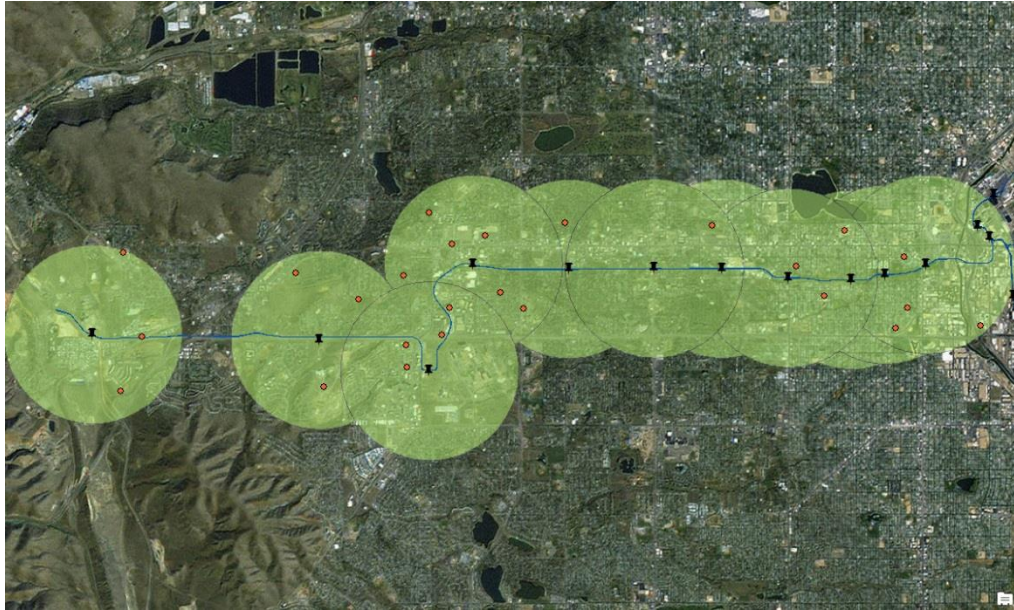


Figure 16: Orange Dots Identifying Samples with Both Workplaces and Households within One Mile of the West Line (n=25)

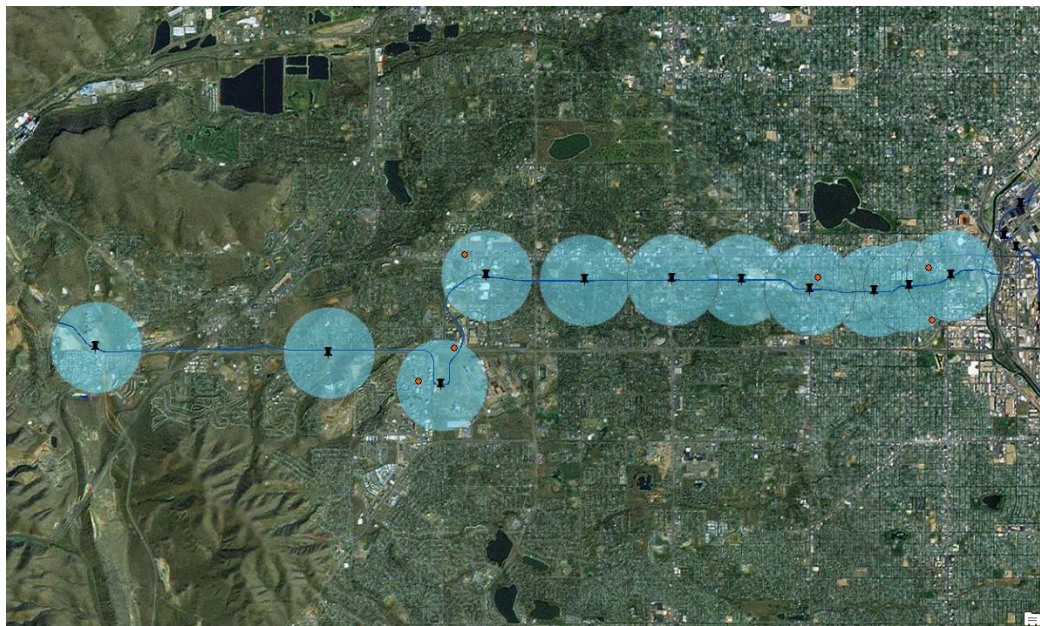


Figure 17: Orange Dots Identifying Samples with Both Workplaces and Households within a Half Mile of the West Line (n=6)

## Household Samples: West Line

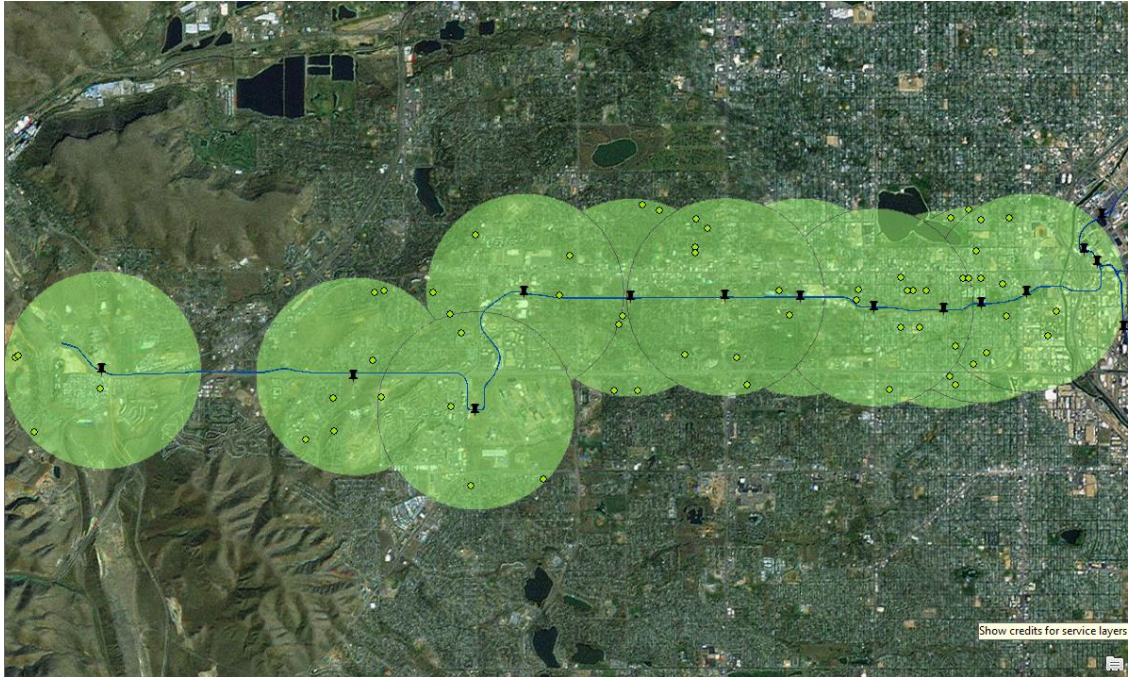


Figure 18: Green Dots Identifying Samples with Households within One Mile of the West Line (n=85)

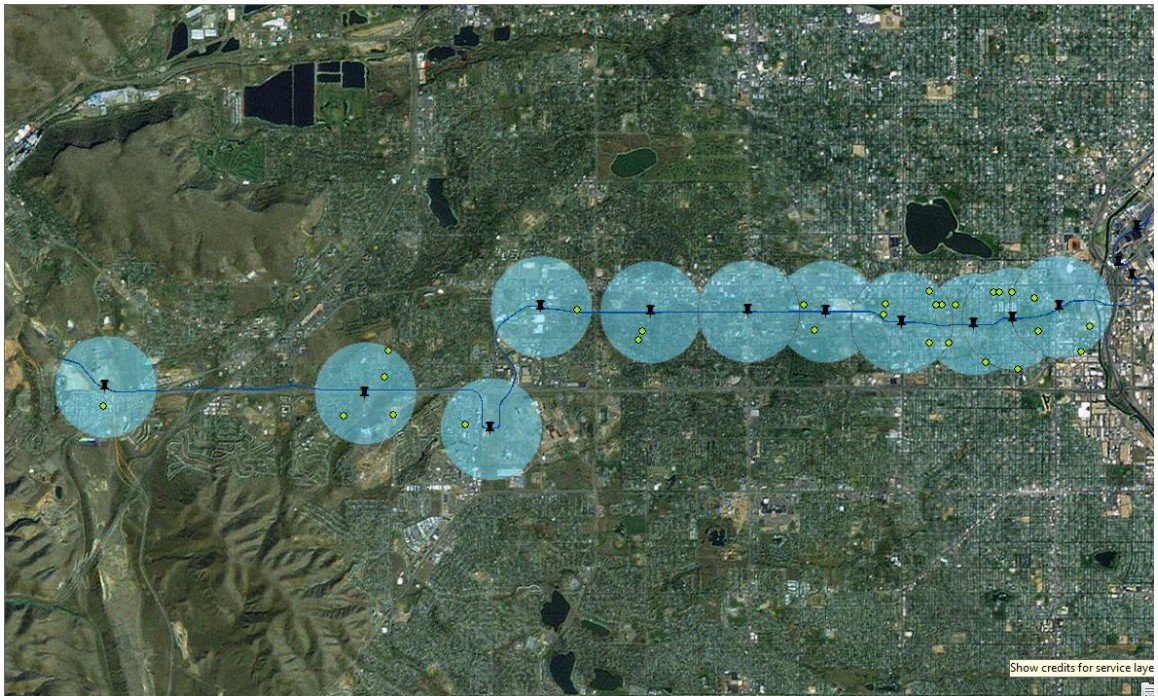


Figure 19: Green Dots Identifying Samples with Households within a Half Mile of the West Line (n=44)

## Workplace Samples: West Line

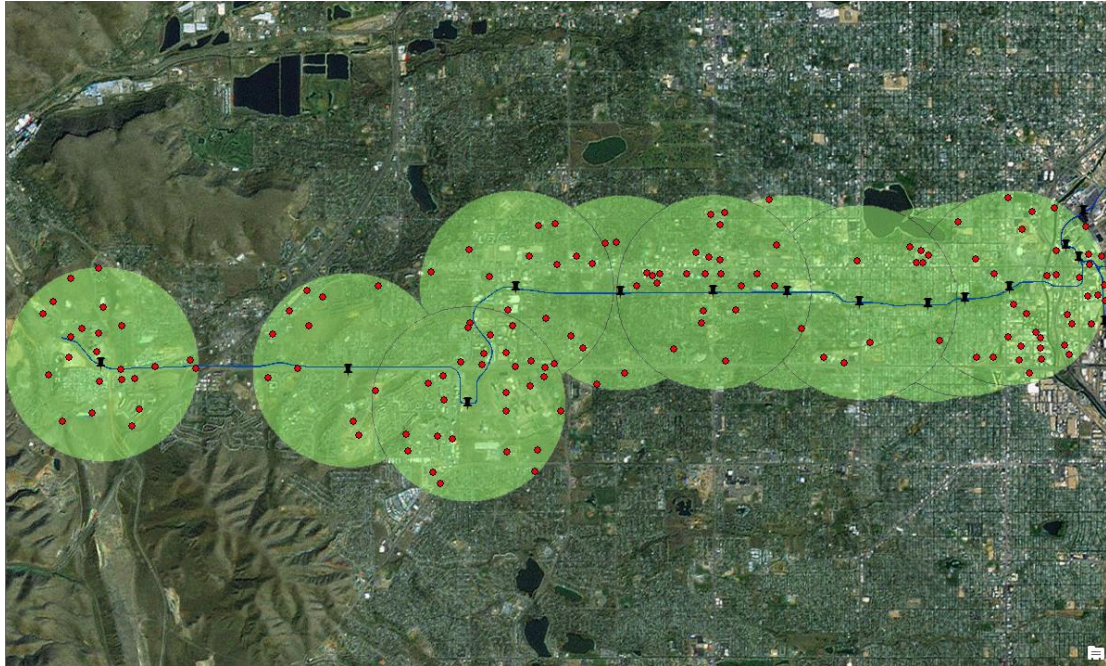


Figure 20: Red Dots Identifying Samples with Workplaces within One Mile of the West Line (n=285)

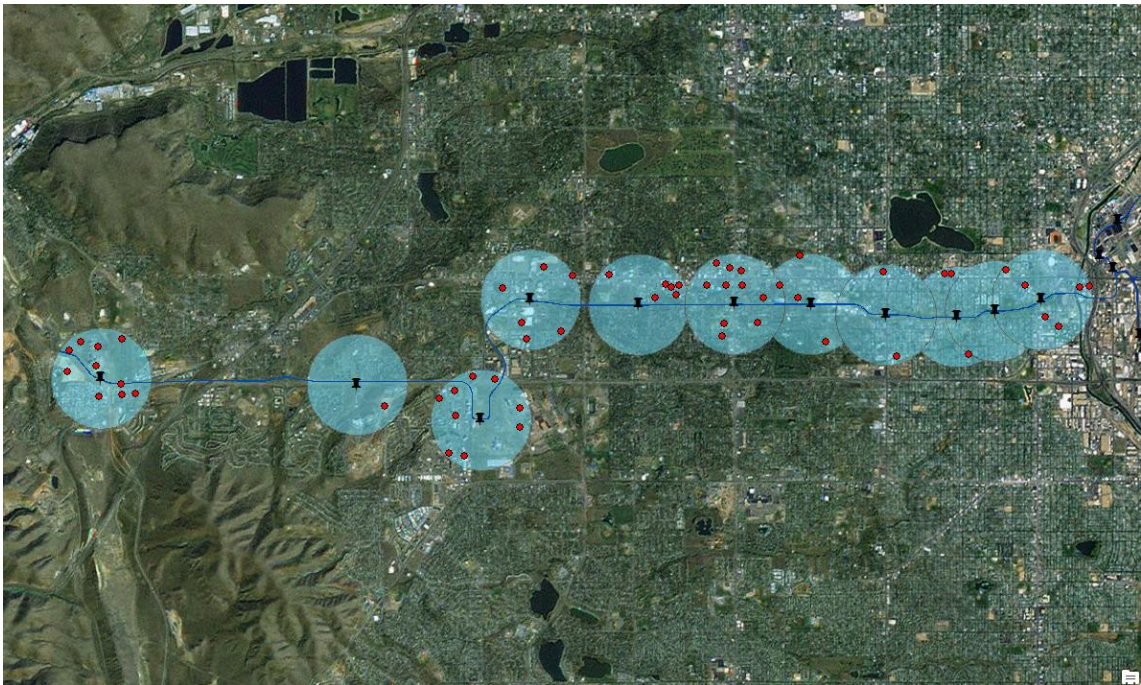


Figure 21: Red Dots Identifying Samples with Workplaces within a Half Mile of the West Line (n=123)

## **Commute Mode**

Once the TOD subgroups were identified and developed based on their proximity to rail lines, a computation of each's commute mode share provided insight into which of the groups is most likely to commute by more sustainable modes, and also whether distance from these TOD facilities play a role in car usage for commuting. After non-car commuters and car commuters were identified within each TOD subgroup, tests on each of these commuting groups' personal travel behaviors were conducted with hypothesis and chi square testing. Again, the term "non-car commuter" is used in this study to limit confusion by describing workers who travel to their workplace by any other mode besides the private automobile. But first, the following table illustrates how typical commute mode (CMT Mode) varies between TOD groups (workplaces, residences, and workplaces and residences) at different distance thresholds (one mile buffer, half mile buffer and walkshed).

Commute Mode							
		n	%	n	%	n	%
		Workplace and Household		Household		Workplace	
1 Mile	Transit	216	34.8%	61	11.0%	591	26.1%
	Car	404	65.2%	496	89.0%	1671	73.9%
	Total	620		557		2262	
		Workplace and Household		Household		Workplace	
.5 Mile	Transit	60	50.0%	39	18.0%	464	31.3%
	Car	60	50.0%	178	82.0%	987	68.9%
	Total	120		217		1451	
		Workplace and Household		Household		Workplace	
Walkshed	Transit	29	61.7%	29	25.7%	352	36.8%
	Car	18	38.3%	84	74.3%	605	63.2%
	Total	47		113		957	

Table 1: Commute Mode Share (Existing TODs)

An example of how the graph should be read goes as such (using the “1 Mile Workplace and Household” TOD subgroup): Amongst the 620 workers whose workplaces and residences are within the one mile buffer zone surrounding light rail stops, 216 cited a mode other than the private automobile as their typical commute mode while 404 cited driving or being a passenger in a car as their typical commute mode. For this subgroup of those who have both workplaces and residences within one mile of a

light rail stop, 34.8% of workers use alternative modes for their commute while 65.2% use a private automobile.

This graph should be interpreted in two ways. Reading across horizontally, we can see which TOD type (household, workplace or both) is more effective at gaining larger shares of non-car commuters within the same distance threshold. Also, when reading down vertically, one can see the way that commute mode changes within the same TOD type as the distance threshold changes.

Based on these interpretations, it becomes evident that, amongst the TOD types, those both living and working near TODs are most likely to use alternative commute modes since over one third of their typical commute modes make use of more sustainable modes than the private automobile. As proximity to TOD increases, the share of non-car commuters increases to fifty percent for those within a half mile, and to over 60 percent for those within the walkshed. This makes sense since transit is able to serve both ends of the work trip. When comparing households and workplaces, we see that workplaces within TODs are able to garner a larger share of non-car commuters than households. However, the percentage increase in non-car commuter share is larger for households than workplaces as proximity to TODs increase. Only eleven percent of workers whose households are within one mile of a TOD use alternative commute modes, but this share increase by fourteen percentage points when the distance threshold is reduced to the walkshed boundary. Conversely, twenty six percent of the workers whose workplaces are within one mile of a TOD are non-car commuters, yet this share only increase by roughly ten percentage points as the distance threshold is reduced to the walkshed



boundary. While the group both living and working near TOD are clearly the most likely to use alternative modes to commute, groups with workplaces near TOD follow in terms of their non-car commute share, with household non-car commuter shares being the least though increasing at a faster rate than workplace groups as proximity to TODs increase.

<b>Commute Mode: West Line</b>							
		n	%	n	%	n	%
		Workplace and Household		Household		Workplace	
1 Mile West	Transit	5	20.0%	11	12.9%	19	6.7%
	Car	20	80.0%	74	87.1%	266	93.3%
	Total	25		85		285	
		Workplace and Household		Household		Workplace	
.5 Mile West	Transit	2	33.3%	4	9.1%	7	5.7%
	Car	4	66.7%	40	90.9%	116	94.3%
	Total	6		44		123	

Table 2: Commute Mode Share (Future West Line TODs)

When comparing the commute mode share for groups along the currently unopened West Line, we see much larger shares of private automobile use across the board. This makes sense, however, since effective transit services are not yet available for those living and working along this line. Again, those who have both workplaces and homes along these stops are most likely to use transit for their commute mode, and this share increases as proximity increases. However, contrary to what was found in the analysis of the existing lines, workers with households within these TOD stops are more

likely to be non-car commuters than those with workplaces in these areas. Also, in these two TOD groups non-car commuter shares decrease as proximity to TODs increase. One should expect these anomalies to be reversed once the West Line opens, especially since many of the stops on this line are major employment areas in Denver. It should be noted that a watershed distance threshold was not used in the case of these western lines because such a shapefile was not available, and also because it would further reduce an already small sample size.

### Number of Personal Trips

The following graph examines whether there is a difference in the *number* of personal trips made based on the TOD subgroups' commute mode. Each TOD subgroup (ex. "Workplace and Household 1 Mile") is divided into two groups consisting of car commuters and non-car commuters. Based on typical commute mode, the results of this test indicate whether there is a difference in the average number of personal trips made by car commuters and non-car commuters on a given day.

Number of Personal Trips							
<u>TOD Subgroup</u>	<u>Commute Mode</u>	<u>n</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error Mean</u>	<u>Sig</u>	<u>Sig 2 Tailed (Equal Variances Assumed/ Not Assumed)</u>
Workplace and Household 1 Mile	Transit	216	4.05	2.538	0.173	0.500	0.106
	Car	404	3.71	2.524	0.126		
Workplace and Household .5 Mile	Transit	60	3.92	2.367	.306	0.590	0.826
	Car	60	3.82	2.594	.335		

Number of Personal Trips							
Workplace and Household Walkshed	Transit Car	29 18	4.38 3.78	2.624 2.478	0.487 .586	0.694	0.440
Household 1 Mile	Transit Car	61 496	4.36 3.29	2.563 2.180	.328 .098	0.174	0.000
Household .5 Mile	Transit Car	39 178	4.18 3.24	2.892 2.220	.463 .166	0.013	0.061
Household Walkshed	Transit Car	29 84	3.72 3.00	2.374 2.271	.441 .248	0.405	0.146
Workplace 1 Mile	Transit Car	591 1671	5.32 4.37	2.34 2.26	.096 .055	0.274	0.000
Workplace .5 Mile	Transit Car	464 987	5.21 4.03	2.451 2.391	.114 .076	0.540	0.000
Workplace Walkshed	Transit Car	352 605	4.45 3.33	2.181 2.219	.116 .090	0.341	0.000

Table 3: Number of Personal Trips Based on Commute Mode (Existing TODs)

An example of how the previous graph should be read goes as such (using the “Workplace and Household 1 Mile” TOD subgroup): Amongst the 216 non-car commuters both living and working within one mile of a TOD, the average person takes 4.05 personal trips per day. Conversely, amongst the 404 car commuters both living and working within one mile of a TOD, the average person makes 3.71 trips per day. Since the “Sig” value in this case, .500, is greater than our desired level of significance,  $\alpha=.05$ , we will take the test’s “Equal variances assumed” value, .106, for the “Sig 2 Tailed” value. In cases where the “Sig” value is less than .05, we take the test’s “Equal variances not assumed” value for “Sig 2 Tailed.” However in the case of the “Workplace and

Household 1 Mile” subgroup, the “Sig 2 Tailed” value is less than our level of significance, .05, so we can conclude that there is no statistically significant difference in the number of personal trips made between non-car commuters and car commuters. For this test, as well as all of the following graphs showing test results, I have highlighted all of the subgroups who have shown statistically significant differences at the 95% confidence level between non-car commuters and car commuters.

Based on this graph, we see that there are no instances where car commuters make more trips in a day on average than non-car commuters. However, there are instances where non-car commuters make more trips in a day on average than car commuters. This is the case for people whose household is within one mile of a TOD and all of the groups of people whose workplace is near a TOD at each distance threshold.

<b>Number of Personal Trips: West Line</b>							
<u>TOD Subgroup</u>	<u>Commute Mode</u>	<u>n</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error Mean</u>	<u>Sig</u>	<u>Sig 2 Tailed (Equal Variances Assumed/ Not Assumed)</u>
Workplace and Household 1 Mile West	Transit Car	5 20	4.60 3.40	2.510 2.415	1.122 .540	0.872	0.334
Workplace and Household .5 Mile West	Transit Car	2 4	3.50 2.75	.707 .957	.500 .479	0.460	0.391
Household 1 Mile	Transit Car	11 74	4.00 3.55	2.098 2.228	.632 .259	0.976	0.535

<b>Number of Personal Trips: West Line</b>							
Household .5 Mile	Transit	4	5.25	1.708	.854	0.375	0.157
	Car	40	3.60	2.216	.350		
Workplace 1 Mile West	Transit	19	4.74	2.997	.688	0.102	0.004
	Car	266	3.13	2.311	.142		
Workplace .5 Mile West	Transit	7	4.86	3.976	1.503	0.001	0.263
	Car	116	2.99	1.993	.185		

Table 4: Number of Personal Trips Based on Commute Mode (Future West Line TODs)

The results of the tests on personal trip generation between commuting groups for the West Line yielded similar outcomes as those in the existing lines. With less statistically significant groups, it is clear that commute mode plays less of a role in the amount of trip making for workers along the West Line. However, there was one instance where a statistically significant difference was noticed. Again, we see that non-car commuters with workplaces within one mile of a TOD make more personal trips than do car commuters. In all other instances, there is no significant difference in the number of personal trips made based on commute mode.

### **Personal Trip Distance**

After splitting each TOD subgroup based on their commute mode, the results of the following tables indicate whether there is a statistically significant difference in the distance of personal trips. In this particular test, however, the differences in personal trip distances are determined according to personal trip mode. For example, this test can answer more specific questions related to differences in personal trip distance such as, “Do car commuters make longer personal trips by car than non-car commuters make by car?” An example of how to interpret the following graph would go as such (for

“Workplace and Household 1 Mile”): Amongst those both working and living within one mile of a TOD, non-car commuters made 458 personal trips using alternative modes and traveled an average distance of 2.45 miles. Car commuters made 89 personal trips with alternative modes and the average trip distance for such trips was 2.29 miles. Also, non-car commuters made 417 personal trips using the private automobile and the average distance for these car trips were 4.10 miles. Car commuters made 1,363 personal trips by car, with an average distance of 3.79 miles. In this particular case, there is no statistically significant difference in the distance of personal trips made by alternative modes or the car because the “Sig 2 Tailed” value is less than .05.

Distance of Personal Trips (Miles)								
<u>TOD Subgroup</u>	<u>Personal Trip Mode</u>	<u>CMT Mode</u>	<u>n Trip</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error Mean</u>	<u>Sig</u>	<u>Sig 2 Tailed (Equal Variances Assumed/ Not Assumed)</u>
Workplace and Household 1 Mile:	Alternative	Transit	458	2.45	3.61	.169	0.358	0.717
		Car	89	2.29	4.39	.466		
	Private Automobile	Transit	417	4.10	7.09	.347	0.040	.421
		Car	1363	3.79	6.04	.164		
Workplace and Household .5 Mile:	Alternative	Transit	133	2.67	3.98	.345	0.258	0.992
		Car	22	2.68	6.13	1.31		
	Private Automobile	Transit	102	3.38	4.07	.402	.096	.254
		Car	207	4.75	11.8	.822		
Workplace and Household Walkshed	Alternative	Transit	69	2.64	4.53	.545	0.951	0.712
		Car	10	2.05	5.78	1.83		
	Private Automobile	Transit	58	3.50	4.89	.642	.437	.714
		Car	58	3.18	4.40	.578		

Distance of Personal Trips (Miles)								
Household 1 Mile	Alternative	Transit Car	150 98	3.61 1.50	5.94 3.54	.485 .357	0.000	0.001
	Private Automobile	Transit Car	118 1536	4.17 4.52	5.21 5.68	.480 .145	0.685	0.525
Household .5 Mile	Alternative	Transit Car	85 38	2.20 1.46	4.04 3.98	.439 .646	0.558	0.353
	Private Automobile	Transit Car	78 538	5.40 4.12	7.67 4.82	.868 .208	0.000	0.154
Household Walkshed	Alternative	Transit Car	54 12	2.80 1.89	5.23 3.50	.711 1.01	0.560	0.570
	Private Automobile	Transit Car	54 240	5.33 3.93	7.93 4.55	1.08 .294	0.002	0.215
Workplace 1 Mile	Alternative	Transit Car	1766 426	5.00 2.04	9.95 4.69	.237 .227	0.000	0.000
	Private Automobile	Transit Car	1433 7049	4.91 5.45	7.23 6.82	.191 .081	0.284	0.010
Workplace .5 Mile	Alternative	Transit Car	1349 311	5.48 2.18	10.4 5.17	.283 .293	0.000	0.000
	Private Automobile	Transit Car	1099 3780	4.83 5.45	7.30 6.72	.220 .109	0.119	0.009
Workplace Walkshed	Alternative	Transit Car	776 164	7.82 2.76	12.2 6.20	.437 .484	0.000	0.000
	Private Automobile	Transit Car	789 1853	4.48 4.92	6.26 6.26	.223 .146	0.009	0.099

Table 5: Distance of Personal Trips Based on Commute Mode (Existing TODs)

Based on the previous graph, we can see that most TOD subgroups show no significant difference in the distance of personal trips, thus implying that there is no difference in the distances traveled between non-car commuters and car commuters in

their personal lives. However, there are a few cases where there is, in fact, a difference in personal travel distances. In some of these instances, non-car commuters travel farther distances than car commuters. But in other cases, car commuters travel farther than non-car commuters. Gray shading is used to highlight these apparent contradictions. Upon further inspection, it becomes clear that non-car commuters travel farther distances for personal trips with alternative modes. Conversely, car commuters actually travel farther distances by car for their personal travel than do non-car commuters by car. Most of these statistically significant differences occur in the TOD subgroups of workers with workplaces near TODs, although one of such instances applies to workers with households within one mile of TOD.

<b>Distance of Personal Trips (Miles): West Line</b>								
<u>TOD Subgroup</u>	<u>Personal Trip Mode</u>	<u>CMT Mode</u>	<u>n Trip</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error Mean</u>	<u>Sig</u>	<u>Sig 2 Tailed (Equal Variances Assumed/ Not Assumed)</u>
Workplace and Household 1 Mile	Alternative	Transit	15	1.68	2.29	.591	0.00	0.674
		Car	1	.661	-	-		
	Private Automobile	Transit	8	3.20	2.03	.717	0.863	0.790
Car		67	2.87	3.44	.421			
Workplace and Household .5 Mile	Alternative	Transit	1	1	-	-	N/A	N/A
		Car	0	0				
	Private Automobile	Transit	6	2.75	2.19	.893	.003	0.124
Car		11	6.54	7.10	2.13			



Distance of Personal Trips (Miles): West Line								
Household 1 Mile	Alternative	Transit	31	3.81	4.72	.848	0.899	0.369
		Car	11	2.30	4.79	1.44		
	Private	Transit	13	5.27	6.66	1.85	0.986	0.826
	Automobile	Car	252	5.86	9.50	.598		
Household .5 Mile	Alternative	Transit	15	4.37	2.39	.616	0.035	0.000
		Car	9	.931	1.13	.376		
	Private	Transit	6	7.41	8.75	3.57	0.000	0.405
	Automobile	Car	135	4.15	4.24	.365		
Workplace 1 Mile	Alternative	Transit	47	3.59	4.60	.617	0.000	0.005
		Car	35	1.40	2.07	.350		
	Private	Transit	43	4.35	4.54	.692	0.299	0.286
	Automobile	Car	797	5.37	6.13	.217		
Workplace .5 Mile	Alternative	Transit	17	1.72	1.97	.478	0.013	0.006
		Car	8	.182	.195	.069		
	Private	Transit	17	3.78	3.76	.912	0.174	0.241
	Automobile	Car	339	5.80	7.04	.383		

Table 6: Distance of Personal Trips Based on Commute Mode (Future West Line TODs)

When analyzing personal travel distances for workers along the West Line, the results indicate similar trends as the findings from the existing lines. While there are no instances where car commuters travel farther distances by car for their personal travel than non-car commuters, there are again instances where non-car commuters travel farther distances with alternative modes than do car commuters. Again, this is most commonly found to be the case for workers with workplaces near TODs.

### Personal Trip Mode

While the previous two tests examined differences between non-car commuters and car commuters in terms of personal trip generation and distances traveled, this final

test aims to determine whether or not there is a difference in the mode of personal trips made based on commute mode. These results can illustrate whether or not non-car commuters engage in more sustainable transportation modes for their personal trips as well. An example of how the following table should be interpreted is as follows (for “Workplace and Household 1 Mile”): Non-car commuters both working and living within one mile of a TOD made 458 personal trips with alternative modes and 417 personal trips by car. As a percentage, 52.3% of non-car commuters’ trips in this TOD subgroup were made with alternative modes while 47.7% were made by car. Car commuters made 89 personal trips with alternative modes and 1,364 personal trips by car. As a percentage, 6.1% of the personal trips made by car commuters made use of alternative modes while 93.9% of the personal trips made by car commuters used a private automobile.

<b>Personal Trip Mode</b>							
<u>TOD Subgroup</u>	<u>n Total Per Subgroup</u>	<u>CMT Mode</u>	<u>Personal Trips n: Alt. Mode</u>	<u>Personal Trips n: Private Auto</u>	<u>Personal Trips %: Alt. Mode</u>	<u>Personal Trips %: Private Auto</u>	<u>Pearson Chi-Square: Sig 2 Sided</u>
Workplace and Household 1 Mile	2328	Transit Car	458 89	417 1364	52.3% 6.1%	47.7% 93.9%	0.000
Workplace and Household .5 Mile	464	Transit Car	133 22	102 207	56.6% 9.6%	43.4% 90.4%	0.000
Workplace and Household Walkshed	195	Transit Car	69 10	58 58	54.3% 14.7%	45.7% 85.3%	0.000

Personal Trip Mode							
Household 1 Mile	1902	Transit Car	150 98	118 1536	56.0% 6.0%	44.0% 94.0%	0.000
Household .5 Mile	739	Transit Car	85 38	78 538	52.1% 6.6%	47.9% 93.4%	0.000
Household Walkshed	360	Transit Car	54 12	54 240	50.0% 4.8%	50% 95.2%	0.000
Workplace 1 Mile	10674	Transit Car	1766 426	1433 7049	55.2% 5.7%	44.8% 94.3%	0.000
Workplace .5 Mile	6539	Transit Car	1349 311	1099 3780	55.1% 7.6%	44.9% 92.4%	0.000
Workplace Walkshed	3582	Transit Car	776 164	789 1853	49.6% 8.1%	50.4% 91.9%	0.000

Table 7: Mode of Personal Trips Based on Commute Mode (Existing TODs)

In the case of every TOD subgroup, there is a statistically significant difference in the mode of personal trips between non-car commuters and car commuters since the “Sig” value is less than .05 for each of them. Generally, car commuters use a private automobile for around 90% of their personal trips while non-car commuters make use of the car only about half of the time for personal travel.

Personal Trip Mode: West Line							
<u>TOD Subgroup</u>	<u>n Total Per Subgroup</u>	<u>CMT Mode</u>	<u>Personal Trips n: Alt. Mode</u>	<u>Personal Trips n: Private Auto</u>	<u>Personal Trips %: Alt. Mode</u>	<u>Personal Trips %: Private Auto</u>	<u>Pearson Chi-Square: Sig 2 Sided</u>
Workplace and Household 1 Mile	91	Transit Car	15 1	8 67	65.2% 1.5%	34.8% 98.5%	0.000

Personal Trip Mode: West Line							
Workplace and Household .5 Mile	18	Transit Car	1 0	6 11	14.3% 0.0%	85.7% 100.0%	0.197
Household 1 Mile	307	Transit Car	31 11	13 252	70.5% 4.2%	29.5% 95.8%	0.000
Household .5 Mile	165	Transit Car	15 9	6 135	71.4% 6.2%	28.6% 95.7%	0.000
Workplace 1 Mile	922	Transit Car	47 35	43 797	52.2% 4.2%	47.8% 95.8%	0.000
Workplace .5 Mile	381	Transit Car	17 8	17 339	50.0% 2.3%	50.0% 97.7%	0.000

Table 8: Mode of Personal Trips Based on Commute Mode (Future West Line TODs)

For those along the West Line, similar results to the existing lines can again be derived from the previous chart. In all but one case, there is a statistically significant difference in the mode of personal trips made by each commute group. Non-car commuters are much less likely to use a car for their personal travel than car commuters. In the single instance where this is not the case, a low “n” value should be noted and could be one potential reason for this discrepancy with the other results.

In all, a number of interpretations can be made from the preceding sets of graphs. First, those both living and working near TODs are most likely to be non-car commuters, followed by workers with workplaces near TODs, and finally by groups with households near TODs. Also, the level of car commuting decreases as proximity to TODs increase for each subgroup. In addition, non-car commuters can travel farther distances with alternative modes while car commuters can travel farther distances by car in some

instances. Finally, the results indicate that non-car commuting can lead to more trip generation, but the mode of such trips is much more likely to make use of more sustainable modes.

## **Chapter Five: Discussion and Conclusion**

When analyzing commute mode alone, it should come as no surprise that groups with both households and workplaces near TODs are most likely to use alternative modes since both ends of their trips are theoretically being serviced by transit. The less predictable comparison found that groups with workplaces near TODs are next most likely to use alternative modes to commute instead of groups with households near TODs. However, it should be noted that the marginal increase in non-car commuters was quite high for workers with households near TODs amongst all of the TOD subgroups. The implication that an increase in household proximity to TODs can increase levels of travel with alternative modes is mirrored in Cervero's (2001) work on factors influencing pedestrian access to transit and Lee and Senior's (2013) study of how light rail services reduce car use.

Those living in households that are farther from TODs are more likely to drive to work whereas groups with workplaces farther from TODs may be more receptive to walking longer distances since they no longer have the option of using a car once the transit service drops them off near their place of employment. In all, these commuting results show that an increase in proximity to TODs can lead to a decrease in the levels of car commuting and an increase in transit use, a finding consistent with Jennifer Dill's (2008) study of transit use at TODs in Portland, Oregon.

In addition, groups with workplaces near TODs are more likely to use alternative modes for their commute. While it may seem intuitive for workplaces located near TODs and serviced by transit to yield higher shares of non-car commuters, it is important nonetheless because commute mode choice plays an important role in the travel decisions of workers' personal trips. Cairns et al. (2004) also found these synergistic changes in non commuting travel when workplace trips by car were reduced in their study of workplace travel planning in the United Kingdom. In previous works performed by Lund et al. (2004) and Dill (2008), conclusions were made that non work (personal) trips were less frequent for TOD users than commute trips. While this may be true on an aggregate scale, these studies did not analyze personal travel based on commute mode. When this is done, it becomes apparent that non-car commuters are much more likely to make use of the transit services around light rail stations than are car commuters. When adding this component to our understanding of travel behavior, the importance of developing planning strategies aimed at acquiring larger shares of non-car commuters is amplified.

Originally, I had hypothesized that non-car commuters would make fewer trips, travel shorter distances, and use more sustainable modes for personal travel. In reality, the results showed the opposite in some instances. For workers with households within one mile of a TOD, all of the subgroups of workers with workplaces near TODs in existing lines, and workers with workplaces within one mile of the West Line, higher levels of trip generation were recorded by non-car commuters for personal travel on average per day. Potentially, this could indicate that many workers rely upon transit to get to their workplace locations. This reliance on transit for commute mode could

translate to personal travel with more trips requiring multiple modes and walking trips to accomplish similar errands that could be executed with one trip by the car.

When analyzing the results of the trip distance tests, there were some cases where non-car commuters made longer personal trips than car commuters, and others where car commuters made longer personal trips than non-car commuters. In the cases of workers with households within one mile of TODs and workers with workplaces within one mile, a half mile and the walkshed of TODs, non-car commuters made longer personal trips on average than car commuters with alternative modes. However, there are no instances where non-car commuters travel farther distances by the private automobile than car commuters for personal trips. Again, these may be situations where non-car commuters are more reliant upon alternative modes for their commute, and thus are using them more extensively for personal travel as well. Another possibility is that voluntary non-car commuters develop a greater sense of comfort and confidence with transit systems that they theoretically use upwards of ten times a week (roughly five work days in a week multiplied by two trips per day). This could result in a higher level of assurance that these transit services can be used successfully to accomplish other tasks beyond commuting.

In the cases of workers with workplaces located within a whole and half mile of TODs, car commuters make longer personal trips with the private automobile than do non-car commuters. In these instances, transit is theoretically capable of serving these workers' commuting needs, though they choose to use the private automobile to accomplish their work trips instead. This may suggest that workers in these groups have



no interest at all in transit, and this mindset could also be applied to travel in their personal lives as well. Thus, if workers in these groups do, in fact, need to use transit for their personal travel, they may likely only use it as minimally as possible. This theory could also be used to explain why non-car commuters take significantly longer trips with alternative modes than do car commuters. Another thought about why there are cases of longer personal trips made with private automobiles by car commuters deals with the idea of personal perception. To many car commuters who travel long distances multiple times each week to work, the relative distances required to complete personal errands may seem short in comparison. Conversely, non-car commuters may feel that exactly the same distances required to complete personal errands are too long, since when comparing with their own personal commute may be perceived as requiring too much excessive driving. As an example, a person who drives forty minutes to work each day may perceive a twenty minute drive to a store as being short whereas a person who rides their bike to work each day may perceive that same twenty minute drive to the store as being too long. This may influence the non-car commuter to seek alternative options to accomplish similar personal tasks.

The final test of personal trip modes found that non-car commuters in every subgroup but one were much less likely to use the private automobile for personal travel. It should be noted that the one statistically insignificant case still had a fifteen percent difference between the mode of personal trips, though the number of samples was quite low (only eighteen). For all other cases, non-car commuters made roughly half of their trips by car and the other half with alternative modes. Conversely, car commuters made

upwards of ninety percent of their trips by car. An explanation for this may be as simple as non-car commuters being more mindful of their carbon footprint and choosing to use more sustainable modes for both their commute as well as personal trips. Since the commute is often the foundation around which other travel is scheduled (Redmond and Mokhtarian, 2001), non-car commuters may arrange their personal travel throughout the week with similar modes as those used for their commute, which in such cases would be anything besides a car.

While many workers may choose to live or work near a TOD based on their consideration of the environment, for others it may be out of the necessity to access services provided by such developments. Workers who do not own a car, and are thus reliant upon transit to fulfill their commuting needs, will undoubtedly use the same services for personal travel as well. In such instances, one's carbon footprint is less of an influential force in the decision making process than the mere necessity of reliance upon the transit services provided at TODs. It is possible that many of these transit dependent workers contributed to the drastic difference between car and non-car commuters in terms of personal travel mode, especially if such workers have no access to a car whatsoever.

Another potential explanation for the discrepancies between personal travel mode between car and non-car commuters may again deal with personal perception. Car commuters may over time become so accustomed to using their car each day for their commute that they gradually become reliant upon this mode for all trips over time. Non-car commuters, on the other hand, may be more receptive to accomplishing daily personal tasks without instantly gravitating towards the private automobile. Perhaps they

more easily accept the idea that the private automobile is not necessarily essential for navigation through everyday life.

Although it is difficult, if not impossible, to fully explain the reasons for why there are such discrepancies between the personal travel behaviors of car and non-car commuters, a closer examination of the data may provide more insight as to why such differences exist. The following screenshot is an example of a person’s daily travel log for a non-car commuter that is not uncommon amongst other non-car commuters in the dataset.

BothWalkAltW								
	OID	SAMPN	PERNO	PLANO	TPURP	MODE	TRIPDIST	SAMPERNO
▶	37	604624	2	3	20	1	0.26262	60462482
	38	604624	2	5	4	1	0.31027	60462482
	39	604624	2	7	9	6	1.67416	60462482
	40	604624	2	8	20	1	0.15418	60462482
	41	604624	2	9	24	1	0.13874	60462482
	42	604624	2	11	9	6	1.70848	60462482
	43	604624	2	12	4	1	0.09386	60462482

Figure 22: Typical Personal Travel Log for Non-Car Commuter

Based on this screenshot depicting a non-car commuter’s (SAMPERNO #60462482) typical personal travel on a given day, the results of the previous tests can be confirmed and more well understood. Here, this particular person made a total of seven trips with all of them making use of alternative modes and being relatively short in terms of distance. Using the coding for trip purpose (TPURP), trip mode (MODE), and trip distance (TRIPDIST), we see that this person first walked less than a mile to “eat a meal outside of the home,” walked less than a mile back home, took an express bus for 1.7 miles and then walked to eat another meal outside of the home. From there, this person

walked less than a mile to “indoor recreation/entertainment,” and then took the bus again for 1.7 miles and walked home from there. This non-car commuter was able to fulfill his or her needs for day by making multiple short trips that made use of sustainable modes.

Using an example of a typical car commuter’s personal travel behaviors in a single day, it also becomes more apparent why the previous series of tests indicated that car commuters travel more frequently and longer distances with their private automobiles.

HH1MBCarW								
	OID	SAMPN	PERNO	PLANO	TPURP	MODE	TRIPDIST	SAMPERNO
▶	31	600968	1	3	16	3	11.48129	60096801
	32	600968	1	4	25	3	27.6515	60096801
	33	600968	1	5	20	3	1.2846	60096801
	34	600968	1	6	4	3	7.25843	60096801

Figure 23: Typical Personal Travel Log for Car Commuter

Using this screenshot of a relatively typical travel log for a car commuter, it becomes evident that this particular car commuter (SAMPERNO #60096801) makes fewer trips, but travels longer distances and makes use of a private automobile. Again using the coding for both trip purpose (TPURP), trip mode (MODE), and trip distance (TRIPDIST), we see that this person drove eleven miles for “routine shopping,” drove twenty seven miles to “visit friends/relatives,” drove one mile to “eat a meal outside of the home,” and then drove seven miles back home. Again, these two examples of personal travel logs for both car and non-car commuters are representative of relatively typical patterns for each commute group and are able to help explain some of this study’s test results.

In most cases, statistically significant differences in personal travel behaviors between non-car commuters and car commuters occur in groups where workers' workplaces are near TODs. An implication of this might be that locating workplaces nearer to transit or providing transit services to employment centers could be an effective way of encouraging more use of alternative modes for not just the commute, but for other personal trips as well. Since significant differences hadn't been identified between most of the commute groups with households near TODs, an interpretation can be made that locating workplaces nearer to transit may be more effective at promoting the use of more sustainable modes than locating households nearer. This idea is shared by Tsai (2009), Dill (2008), Cervero (2009), and Lee and Senior (2013) in their studies of TODs' impacts on travel behaviors.

That is not to say that the clustering of households near transit is not important, however. After all, it was the TOD subgroups of workers both working and living near TODs who, in fact, used alternative modes the most for both their commute mode and personal travel. As a result, it should be emphasized that clustering both residential areas *and* employment centers around transit is the best strategy for achieving higher rates of more sustainable travel, a point also made by Cervero (1996) in his study of rail stations in Sweden. The idea here is that workplace characteristics should be emphasized to a higher extent when considered by transportation planners.

While this study was able to shed light on the commute patterns of workers and their results on personal travel, it is not without its limitations. First, since such a large dataset was used for the quantitative analysis of Denver workers' travel behaviors, there

is no way to wholly explain the reasons for why certain samples made their travel decisions. Instead, the test results can be used as a springboard for speculation about decision making patterns based on identifiable trends in the data. A qualitative component to this study could be useful, though its breadth would undoubtedly be scant in comparison to the sample size used in this particular investigation. Particularly, it may be helpful to explore the factors that are critical in explaining *why* workers make the travel decisions they do, as well as the potential circumstances that would influence them to travel more sustainably in the future.

In addition, the response in the dataset itself could be subject to variation based on peoples' perceptions. For example, one persons' idea of a "trip" could potentially be very different than someone else's. Since very little is known about each individual in the survey, it is difficult to control for these discrepancies. Another related limitation in this study refers to the lack of disaggregated statistics based on socio-economic status. Workers' incomes and inabilities to afford or operate private automobiles were not directly examined in the results of this study. Instead, all workers were divided and grouped regardless of their social and economic status. According to an employee and residential survey called "Who is TOD in Metro Denver?," residents living around TODs and the downtown of Denver tend to be younger, have fewer people per household, have lower incomes, and be less likely to own a house than those living outside such areas (DRCOG, 2010). Potentially, the tests could have yielded very different outcomes had each of these factors been accounted for and explicitly tested. Despite these constraints, the results of this study maintain their utility in helping to better understand the grand

picture related to the travel behaviors of workers in Denver, Colorado. Future studies could more explicitly look at how other factors such as weather, income, ethnicity, or parking pricing and availability impact levels of transit ridership.

Although my hypothesis of non-car commuters making fewer and shorter personal trips by alternative modes did not turn out to be completely accurate based on the results of the tests performed, some encouraging signs can be detected. In some cases, non-car commuters travel shorter distances by private automobile and travel longer distances with alternative modes for personal trips than car commuters. Also, while non-car commuters are more likely to make more personal trips than car commuters, the modes of such trips are less likely to use a private automobile. Though less trip generation and fewer miles traveled are typically considered to be indicative of more sustainable travel, perhaps the most important way of lessening travelers' carbon footprint and its associated consequences is through changes in mode share. It may be unreasonable to expect people to travel shorter distances and make fewer trips since human nature has constantly and consistently spurred increased levels of movement and exploration throughout history. However, if the *way* in which people proceed through life can make use of more sustainable modes, then perhaps the trajectory of the currently unsustainable transportation system can at least be slowed or even possibly reversed. By gaining a clearer understanding of the factors that influence travel behaviors, a step in the right direction can be made towards a more sustainable future.

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