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Assessing the effects of new public transportation routes : an equity analysis on the changing accessibility of Albuquerque, New Mexico

Calvin Tribby

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Approved by the Thesis Committee:



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ASSESSING THE EFFECTS OF NEW PUBLIC TRANSPORTATION ROUTES: AN EQUITY ANALYSIS ON THE CHANGING ACCESSIBILITY OF ALBUQUERQUE, NEW MEXICO

BY

CALVIN P. TRIBBY

**B.S. APPLIED MATHEMATICS
UNIVERSITY OF NEW MEXICO, 2007**

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

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Geography**

The University of New Mexico
Albuquerque, New Mexico

August 2009

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ABSTRACT OF THESIS

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**ASSESSING THE EFFECTS OF NEW PUBLIC TRANS-
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B.S., Applied Mathematics, University of New Mexico, 2007

M.S., Geography, University of New Mexico, 2009

ABSTRACT

This research details the application of a public transportation accessibility model using travel time as the accessibility measure. The primary objective was to develop a multi-modal network model for detecting change in travel time at the household level as the result of the implementation of new rapid bus routes. This method is situated in the accessibility measures of transportation equity, a focus of research in the broader field of transportation geography. The level of detail that current accessibility studies use to evaluate public transit are not detailed enough to capture travel time changes at the household level and through varying time periods throughout the day. The result of this research is the successful application of this network to highlight the travel time changes at the household level of new transit investments.

The multi-model network was developed in ArcGIS and accounts for the walking time from home to the bus stop, the waiting time at a bus stop, the travel time on the bus, and any necessary transfers. Both peak and off-peak time periods were modeled. The application of this network to a case-study of the Westside of Albuquerque, NM

demonstrates how household-level effects of new transit investments can be modeled, with implications for a finer level of detail for social justice studies. Specifically, the Northwest quadrant of Albuquerque benefits through greater time savings compared to the Southwest quadrant, though both sections are in the service area of two new significant public transportation investments. This is despite the greater need in the Southwest quadrant for public transportation based on socio-economic characteristics.

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Chapter One: Introduction

1.1. Background

The focus of this paper is public transportation equity, measured through the spatial-temporal accessibility it affords, and how recent changes to the public transportation system in the City of Albuquerque have affected it. It is important to the field of transportation geography and its inherent study of equity, because as transit becomes more acceptable and experiences greater utilization by a wider socio-economic range of people in Albuquerque, due to higher personal transport costs, environmental concerns, and increasing congestion in the region, the influences on the design and planning of the transit system are changing. The traditional transit users in Albuquerque, the vehicle-less, low income, and elderly and young people, are affected by this increased attention in the public transit system in numerous ways. If they are fortunate, the routes they use will be improved with expanded service hours, frequency, and capacity. If not, they are plagued by continued neglect through poor service times and bad route choices, which can affect a population's well being and quality of life (Apparicio, Abdelmajid, Riva, and Shearmur 2008; Kwan, Murray, O'Kelly, and Tiefelsdorf 2002).

The research question that I seek to address is how the recent additions to the transit system in Albuquerque, specifically the Rapid Ride lines, increase the temporal accessibility that the transit network provides for the traditional transit users to the city. The important distinction here is the provision of travel time, and if and how it has changed for transit users. The spatial accessibility and catchment areas for the system in general are not necessarily improved when these new routes are aligned on roads with

existing bus routes, hence a measure of temporal accessibility is more appropriate to measure changes.

1.2. Goal

The goal of this paper is to map the effect that recent changes to the public transit system have had on the accessibility that the system provides in Albuquerque, NM and to quantify this change in accessibility of the city to traditional transit users, the vehicle-less, low income, and elderly and young people.

1.3. Objectives

The first objective is to model the temporal accessibility that the transit system provides to the city, to account for the A.M., P.M., and off-peak variability, in both bus frequency and travel time, and include spatial accessibility to the system through walking.

The second objective is to quantify the change in accessibility of traditional transit users caused by the additional routes, using accessibility to downtown as the representative destination to measure the change in time. My hypothesis is that the South Valley, in the southern portion of the study area, which is not directly served by the new routes, will see a negligible impact in their temporal accessibility, despite the socio-economic need of the area.

The expectation of this research is that the increase in temporal accessibility of the city afforded by the addition of the recent Rapid Ride bus routes does not improve the temporally underserved areas of the city and where traditional transit users are clustered,

but caters to “choice commuters”, those who have access to a vehicle and commute to the major employment centers in the city, but could decide to take public transit if they view it as feasible.

This prediction is based on observation of the distribution of current routes which are concentrated in certain parts of the city and the priority in new resources given to the Rapid Ride over other bus routes. While, as previously mentioned, this does not increase the spatial accessibility necessarily for those without access to an automobile; the provision of free parking lots at the ends of the Rapid Ride lines does provide increased accessibility for those with cars and therefore incentivizes the service for those with access to an automobile. While the shifting of transportation modes from private car to public transit is an admirable goal and helps reduce congestion and pollution, this has created a biased focus for the expansion of the transit system and neglects commuters who do not have this choice and are outside of these selected corridors. The City of Albuquerque Mayor Martin Chávez has acknowledged this as an influence on the system: “We are starting to see more and more people use our bus system as a choice rather than a necessity” (City of Albuquerque 2008a).

A more distributed network of transit with comparable service times for all, while maintaining a few high capacity corridors with a balance between “choice commuters” and traditional transit users is the best way to expand public transportation in Albuquerque, as argued in the Public Transportation Equity literature (e.g., Sanchez 2008; Martin, Jordan, Roderick 2008; Lucas 2006) and reviewed later.

1.4. General Area of Study

The study area is located in Albuquerque, New Mexico, which had an estimated population of 504,949 and a metropolitan statistical area population of 816,811 in 2006 (BBER June 2007; April 2007). The urban spatial structure of Albuquerque is similar to the completely motorized network that Rodrigue, et al. defines as:

[A]n automobile-dependent city with limited centrality. Characterized by low to average land use densities, this automobile oriented city assumes free movements between all locations. Public transit has a residual function while a significant share of the city is occupied by structures servicing the automobile, notably highways and large parking lots (2006).

These characteristics predominately describe Albuquerque, compared to the other urban spatial structure representations Rodrigue, et al. propose: weak centers, strong centers, or traffic limitation urban areas (2006). These urban structures are generally defined by higher land use densities, greater accessibility to urban transit, and have less land allocated to highways and parking in the central city. Albuquerque's spatial structure does not reflect these elements, which is an inhibitor of the commuting mode share of transit in the city, but does not diminish its necessity.

Through a visual survey of the transportation infrastructure and land use distribution, the conclusion that the spatial structure of Albuquerque as a completely motorized network is plausible, but there is also quantitative evidence to support this observation. The residual function of public transit in Albuquerque is revealed by the transportation mode split in the city. In the 2000 Census, 77.7% of commuting in Albuquerque was done by driving alone and only 1.7% was achieved by public transportation (MRCOG 2007). The dismal mode share of transit in Albuquerque confirms the minor, and hence residual role transit contributes to commuting, though

there has been a recent increasing trend. An all-time high in bus ridership was reached in September 2008, representing a 9% gain in riders over August 2008, and a 17% increase over September 2007 (City of Albuquerque 2008a). These statistics could signify that the current mode share of transit could be a higher percentage of commuting trips than the 2000 Census, but this cannot be confirmed.

The sections of the population dependent on public transit appear cogent to Albuquerque, as 12 percent of households earning under \$20,000 a year use transit in a typical week, significantly more than middle-income groups and more affluent residents (City of Albuquerque 2001). But the survey did not include the handicapped, young, or vehicle-less, the latter of which constituted 7.2% of Albuquerque's population in 2000 (MRCOG 2004). Support for improving the public transportation system is also favored more by the under \$20,000 income a year, with 90.9% of citizens within this category reporting this as a middle, high, or extremely high community priority (City of Albuquerque 2006). This is compared to 83.6% and 83.4% of Albuquerqueans reporting this as a similar priority in the next two higher income categories (City of Albuquerque 2006). Therefore, the socioeconomic indicators used here to judge accessibility to transit dependent populations will be income under \$20,000 a year, residents under 18 or 65 and over, and the vehicle-less.

Another indicator of the completely motorized network in Albuquerque is its high automobile dependency. Rodrigue, et al. (2006) defines high automobile dependency when more than three quarters of commuting trips are made with the automobile. By this definition, Albuquerque has a high automobile dependency, with 77% of commuting trips by automobile in 2000, which supports the classification of the structure of the city as a

completely motorized network. A final validation of motor vehicle dominance in the city is a significant share of land being occupied by parking lots. A recent article in *Salon News* confirms that “Downtown Albuquerque, N.M., now devotes more land to parking than all other land uses combined” (Mieszkowski 2007). The spatial structure of Albuquerque is congruent with the definition of a completely motorized network, as reflected in the limited viability and acceptance of public transit in the city, and highlights the necessity of the system to provide primarily for transit-dependent users, not automobile owners.

The study area is suited to this analysis because the recent addition of new transit investments allows the comparison of the system before and after to assess the effects on the transit-dependent population. Specifically, the study is constrained to a portion of Albuquerque, the Westside, defined as west of the Rio Grande and emphasized in Figure 1.1. This area contains both of the Rapid Ride Routes, and also some high proportions of transit-dependent populations. The presence of these two factors makes the Westside ideally suited to measure the change in accessibility of the public transit system. The Rapid Ride routes extend east, beyond Downtown, but are considered to end Downtown for this study. Downtown is defined for this study to be the Alvarado Transportation Center, at the corner of First Street and Central Avenue Southwest. This choice of Downtown as the origin and destination of trips represents it as an actual ending point of a trip, say for employment, or as a transfer for other city buses, intercity buses or rail, or continuing on the Rapid Rides eastward. The time savings would still be representative though, whatever the ending destination is, once Downtown.

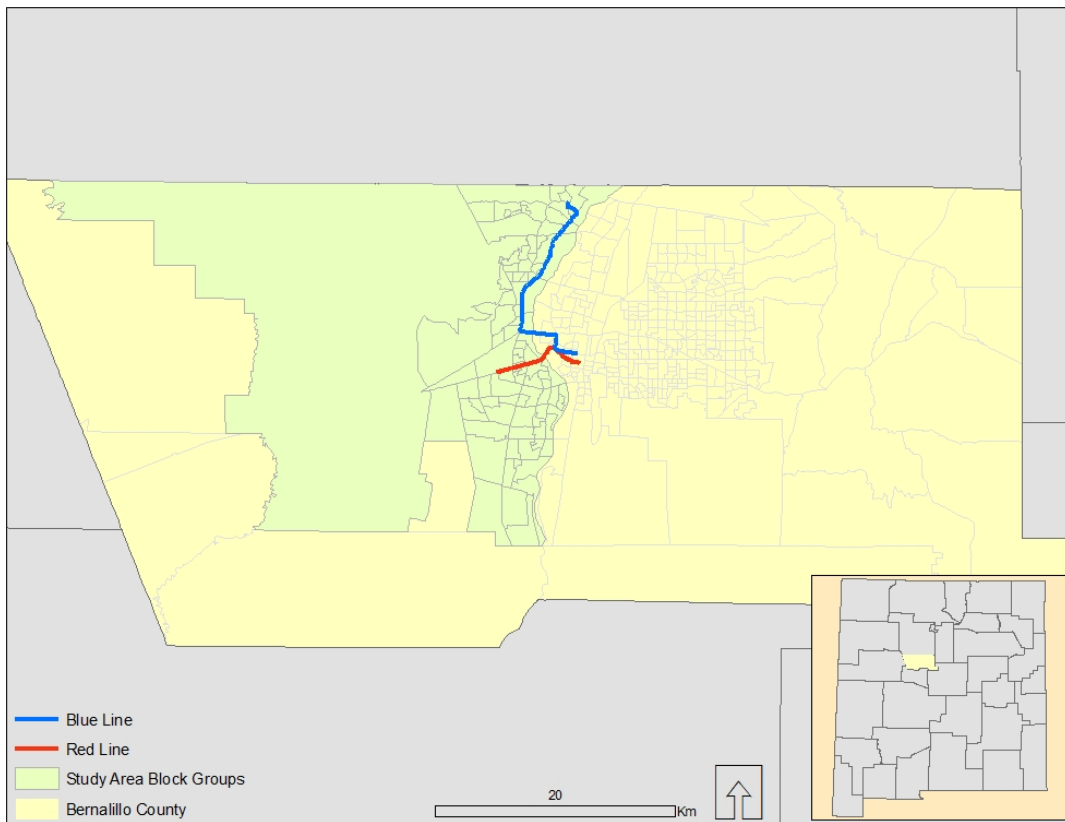


Figure 1.1. Study Area within Bernalillo County with the Westside of Albuquerque indicated and the extent of the Rapid Ride Lines considered

Albuquerque’s status as a completely motorized network is not necessarily a bad classification, as Lucas details some positive aspects, like the role it has played in the increased participation of women in the workforce, or the increased activities and distances able to be traveled due to cars (2006). This network provides the city with excellent accessibility by automobile, though during peak travel times the average annual delay travelers are facing is higher compared to other medium sized cities. The city as a whole only has average congestion among the same group (Schrank and Lomax 2007). This congestion is tolerable for new residents from larger cities with worse congestion, but the focus on this type of accessibility in the city ignores those who do not have access

to an automobile. A consequence of Albuquerque's completely motorized network is that transit is forced into a subservient mode of transportation. Therefore, the mandate of public transit in Albuquerque, to offset this spatial inequity, is to provide equitable mobility for those most dependent on it (Sánchez, Stolz and Ma 2003). This is achieved by increasing the accessibility for those without access to automobiles when planning and implementing additional improvements to the transit system (Wu and Hine 2003).

The use and distribution of Information and Communication Technologies (ICT) within the study area are numerous. First, with regards to temporal accessibility influences, the city has recently unveiled a trip planner for the bus system available on its web site (City of Albuquerque 2008b). The user inputs the starting location, ending location, day and time of arrival or departure for the trip. This query returns possible route choices and transfers, if necessary, based on the input criteria, as well as trip duration, walking distance, and total fare. Whether this has a positive influence upon traditional transit users is uncertain. This trip planner requires a computer to access the internet, which if one is not available at home, could be temporally and spatially restricted by the hours and location of the public library. Other ICTs for consideration in the transit system are the LED time boards on most of the Rapid Ride Red Line stops, which display the expected arrival of the next bus. While this does not substitute for the knowledge of the actual schedule, it does provide an added sense of convenience, if not practical utility. Also, on the Rapid Ride Red Line is the provision of wireless internet access on the bus. While this might not directly aid the accessibility of the system, it is an amenity to lure a segment of the population with access to wirelessly enabled devices to increase utilization of the buses, and possibly the system as a whole.

1.5. Bus stop and Pedestrian Environment Amenities

Another consideration of the physical environment of the transit system is the provision of bus stop and pedestrian amenities. The effects of amenities, or lack thereof, can have a potential impact on the desirability and usage of the system. For example, stops that lack sidewalks provide additional impedance to patronage, as stops without a bench would provide further disincentive to use and reflect the neglect of ABQ Ride. This effect is implicitly acknowledged by the city, as the Rapid Ride stops are uniform in their amenities, designed to elicit a positive and salient perception in users. These stops include permanent shelter and bench structures, as well as a trash can, lighting and most with an LED display with the time until the next bus comes. Such service improvements, or perceived higher quality of service, help to define the Rapid Ride routes as premium transit.

1.6. Premium Transit

Premium transit in the City of Albuquerque is the Rapid Ride bus routes (Appendix A) which includes the Red Line and the Blue Line and are modeled after Bus Rapid Transit (BRT). BRT includes many attributes of a light rail line, but in the much more economical form of a bus, such as separate rights of way, permanent stops spaced farther apart and at major destinations, frequent service, and the implementation of Information Technology Systems (Zimmerman and Levinson 2006). The City defines the Rapid Ride as a “[S]ystem, [that] when combined with fewer stops and quicker loading, will translate into faster, more efficient, comfortable service” (City of Albuquerque 2007). While the Rapid Ride contains some aspects of a BRT system and

the Red Line follows a route recommended as a high capacity transit corridor in the Rapid Transit Project, the absence of a dedicated bus way prevents its classification as a true BRT (City of Albuquerque 2003). The determination of the route locations and their relation to transit dependent users for this new transit service is crucial to the accessibility of the network and the equitable distribution of transit services in Albuquerque.

1.7. Bus Specifications

The Rapid Ride buses have a capacity of 86 passengers and three bicycles, compared to the capacity of 45 passengers and two bicycles typical to other buses in the ABQ Ride fleet (City of Albuquerque 2007). The increase in volume of passengers and bicycles that these vehicles can carry increases the accessibility on the routes they serve. Whether the accessibility of the locations of individual stops is increased by the Rapid Ride is uncertain. Since the stops are spaced farther apart, it at first appears that this would decrease accessibility, but there might be an offset to this. There could be a perception of increased quality of service and buses, which could increase the catchment area, or distance people are willing to travel to stops (Swope 2007). Since there is not a light rail system in Albuquerque to compare the Rapid Ride to, but only the normal buses in the ABQ Ride fleet, Rapid Ride is seen as a significant improvement over regular buses, not a step down from rail, and might increase the appeal of transit. Also, the further spacing of stops allows a greater distance to be traveled in less time, increasing the accessibility of the route once a rider is on board (Murray 2003). Since the Rapid Ride nearly doubles the capacity and increases the frequency of the routes they run on, the location of these routes and their stops have major implications for increasing the

accessibility to the city that the transit system as a whole provides and is a suitable measure for the change in equity of the system.

Chapter Two: Literature Review

The pertinent literature to the assessment of the changing accessibility of the city of Albuquerque, afforded by the public transportation system, resides within the field of transportation geography. Included in this field are the study of transportation equity and its associated measures of temporal accessibility, Information and Communication Technology accessibility, and spatial accessibility. These three accessibility metrics are by no means the only ones, but are most relevant to this study and are not usually considered exclusive of each other. Also reviewed are the network approach to accessibility analysis and its implementation in a Geographic Information System, designed for transportation analysis. A brief discussion is also provided for Space-Time Accessibility Measures, of which influences my method of determining accessibility. These areas are all interrelated to the field of transportation geography and its various measures of accessibility and their implementations.

2.1. Transportation Geography

Transportation geography has undergone significant transformations in methodologies and theories in the last twenty years. This has been instigated by the increasing sophistication of spatial analytical technologies, as well as the increasing importance of globalization on philosophy and process in transportation research (Keeling 2007). Also, the increasing importance of environmentally sustainable transportation alternatives is driving interest in public transportation research (Kawabata 2004; Polzin 1999; Handy and Niemeier 1997). Important philosophical and methodological shifts are also the result of the increasing adoption of information and

communication technologies and their impact on travel, plus the recognition of the limitations of aggregate data and the necessary improvements to using it for transportation research. As these shifts are occurring, the relevance of research to planning and policy are now recognized as crucial applications for transportation geography and also to elucidate the land-use/transportation relationship (Polzin 1999), as with geography in general, for “the specter of such a world simply underlines and magnifies the importance of achieving deeper understanding of accessibility and mobility processes” (Hanson 2006).

A new conceptualization of urban travel, created by the increasing adoption of information and communication technologies (ICT) within developed countries, has led to both philosophical and methodological shifts in transportation geography. Mei-Po Kwan (2007) introduces a new metaphor for urban spatial interaction, which is influenced by the “new mobilities paradigm”. This view transcends the separation of transportation research and social sciences, recognizing each as important factors in studying the other (Sheller and Urry 2006). This paradigm states that the traditional focus of transportation geography, specifically pertaining to personal transport and accessibility, on the importance of the spatial characteristics of distance and proximity has been diminished and further complicated than simple past models of transportation flows based on land use can explain (Kwan and Weber 2003). For personal travel, travel time is not regarded as dead time anymore, but can be filled with activities due to the enabling technologies of mobile and wireless devices, and therefore it is not always sought to be minimized (Kwan 2007). This technological innovation complicates

transportation research models and may explain individuals' complacency with increasing congestion and delay in travel, among many other things.

ICT has implications on both space-time coordination and activity-travel behavior, which both influence the utilization of public space and affect the mobility and amount of travel of urban residents. The increase in mobility and increase in ICT adoption are mutually reinforcing (Kwan 2007). Increased mobility leads to an increased need to stay in contact, and increased contact with social networks provides for an increase in opportunities for mobility. ICT, most importantly, may lead to significant changes in the function and role of existing nodes, places of importance, in urban and transportation systems, through the increase in personal mobility and spatial freedom they provide (Kwan 2007).

The methodological implications of the wide spread adoption of ICT are the increased automation, accuracy, and ease of tracking individual travel over traditional written travel diaries (Kwan 2007). This will lead to a greater perception of personal mobility, but is not without privacy concerns and conversely, accuracy considerations (e.g. Gruteser and Grunwald 2003; Kwan, Casas, and Schmitz 2004). But, without an understanding of the individual's social networks, explanation of personal travel will still not be known. With ICT, our social networks now move with us and affect our travel decisions in real-time, and need to be included in individual-focused analysis, rather than place-to-place analyses, to reveal the reasons why we travel (Wellman 2001).

The recognition of the limitations that spatially-aggregated data impose is also fostering new methodologies. For instance, remote sensing can be used to increase the resolution of socioeconomic indicators relevant to public transit demand. Wu (2006)

uses remotely-sensed data to measure impervious surface and vegetation cover to estimate socio-economic levels and derive demand for public transit at a finer resolution than transit analysis zones. Casas (2007) highlights the limitations of traditional transportation-equity studies that are based on local indices of deprivation, and often use data analysis zones. Local clusters are normal in these studies, for example, with low-income housing. But this is not suitable for measuring the lack of access to transport systems for the disabled, who are not easily represented by aggregated and spatially autocorrelated data. She instead uses individual travel diaries to measure transportation equity and hence social exclusion in her study area. Casas' (2007) choice of data collection provides a much more detailed level of analysis, not available from aggregated data, but which is required by her research question. These two examples show that the adaptation of methodology to a specific study area has allowed the development of methods for data collection that are conscious of the scale necessary for meaningful results.

The reevaluation of spatial urban transportation models and methods of data collection, based on the new information and communication technology paradigm, as well as advances in remotely sensed data and GIS systems, is necessary for transportation geography to continue with the relevance of its research and to have a deliberate impact on policy and planning.

2.2. Public transportation equity

Transportation equity ultimately seeks to “provide equal access to social and economic opportunities by providing equitable access to all places” (Sánchez, Stolz and

Ma 2003). For public transit, this would manifest itself as equitable access for users dependent on its service to the opportunities of the city, and is one of the fundamental goals of urban transportation planning (Lui and Zhu 2004). It has been recognized that the transportation policies adopted after World War II emphasized highway development over public transportation, and these have had an inequitable effect on minority and low-income populations, including restricted accessibility to the city (Sánchez, et al. 2003). In automobile-dependent cities in the United States, the justification for subsidizing public transit is to provide a travel option for those that would otherwise not have one: the elderly, the poor, the handicapped, and the young (Murray and Davis 2001; Black 2003; Sánchez, et al. 2003). The United States Government also recognizes this and the relevant necessity of equity as one of the nine critical issues facing transportation in the first decade of the new century: “A transportation system dominated by the automobile generates challenges for those with limited incomes, physical disabilities, or those who do not drive” (Transportation Research Board 2005). Furthermore, the most disadvantaged rely on transit, taxis, and walking and therefore have the most limited accessibility and mobility, due to lack of automobile access (Transportation Research Board 2005; Kawabata 2004). Public transit is seen as a social service and not as a means to “stimulate additional growth and development because the overall increase in accessibility is insignificant to current accessibility” (Black 2003). Therefore, the principal importance of public transportation in automobile-dependent American cities is to help improve the accessibility to jobs and services for those marginalized by society and the spatial structure of the city because they lack access to an automobile (Litman 2007).

The relevance of the maximal spatial coverage of the transit system as an expectation for the system within this particular study area, Albuquerque, NM, must be questioned as a method to examine the accessibility the system provides. Such techniques (e.g. Laporte, Mesa, Ortega, and Sevillano 2005) focus on maximizing coverage based on population density, regardless of the actual transit need of the populations. This is problematic in a city like Albuquerque, due to the low density, distributed nature, and transit needs that many neighborhoods exhibit, but not uniformly. That is, basing demand on the highest-density neighborhoods would not capture the transit need of all parts of the city. Also, the measure of spatial coverage does not account for differences in frequency of bus routes, congestion levels that vary with the time of day, and the distance that is reachable in a fixed amount of time. Such shortcomings of maximizing the spatial coverage of the transit system highlight the two prevailing views of accessibility. The first is the reliance on the traditional view of proximity for providing the potential for interaction, using aggregated geographical space, and the other view, which focuses on individuals and activities accessible to them. This latter view takes into consideration personal constraints associated with daily schedules (Horner 2004). The simplification of ignoring time is no longer necessary, and the inclusion of temporal considerations to individual accessibility is now computationally feasible and common (Weber and Kwan 2003; Kwan, et al. 2003).

2.2.1. Temporal Accessibility

With *time* being a resource that transit users also *pay*, there appears to be a gap in the literature dedicated to the equity analysis of passenger costs that includes travel time.

Time is an essential measure of individual accessibility (Kwan and Weber 2003; Kwan, et al. 2003). The significance of including locally specific travel times within a street network is that it does, in fact, allow for a significant increase in the ability to realistically assess individual accessibility within cities (Kwan and Weber 2003; O'Sullivan, Morrison, and Shearer 2000). The addition of the provision of time within the study of accessibility comes about by the increasing realization of the diminishing explanatory power of distance, due to variations in individual travel behavior, mobility offered by the street network, and location and size of activity opportunities in traditional urban accessibility models (Weber and Kwan 2003). This provision highlights the acceptance of using the street network to measure accessibility. At scales smaller than a metropolitan level, straight line and Manhattan distances may introduce substantial errors, and network based time/distance measures are more appropriate (Apparicio, et al. 2008; O'Sullivan, et al. 1999). A gap in the implementation of temporal metrics with regard to public transportation is the simplification of bus routes into lines, without regard for their actual stops (e.g. O'Sullivan, et al. 1999), or using straight-line distances to measure accessibility (e.g. Lui and Zhu 2004; Shen 2002). Time is but one consideration in accessibility analyses though, and without careful consideration of other simplifications, it may not lead to a clearer understanding of accessibility. And, with a wide variance of location-based accessibility indices available, they should be diligently implemented, though specifics are rarely justified (Horner 2004).

2.2.2. ICT Accessibility

A recent consideration of accessibility, with potential implications to affect temporal accessibility, is that of the increase in accessibility that ICTs can provide (Hanson 1998). Important is not only the possibility of the increased accessibility these technologies can provide, but also who has access to such devices. While ICTs can facilitate the relaxation of space-time constraints that limit human spatial mobility and activity space, for example by e-shopping or e-banking, such luxuries are not equally accessible to all segments of the population (Kwan and Weber 2003). So, ICTs can allow more flexible spatial and temporal arrangements of human activities to become possible, but the relation between ICTs and individual accessibility and human behavior are highly complex, with substitution for physical travel being only one of many possibilities (Kwan and Weber 2003).

Another possibility is the social and physical exclusion that can become implicitly enacted by increasing reliance on such technologies. For example, financial exclusion, defined as the physical inaccessibility of bank branches in poorer neighborhoods in the Greater London area is, in part, justified by the evolving technologies that are said to render face-to-face interactions redundant (French, et al. 2008). Such virtual mobility, enacted by ICTs, could help increase accessibility as an alternative and possible augmentation to physical mobility (Kenyon, Lyons, and Rafferty 2002). But as French, et al. (2008) emphasize, such technologies do not necessarily erase inequalities caused by low physical accessibility, highlighting the continued salience of spatial accessibility, despite the rising adoption of ICTs.

2.2.3. Spatial Accessibility

The notion of spatial accessibility is a key element to transport geography and is the conventional measurement of accessibility (Black 2003). This accessibility is the measure of the capacity of a location to be reached within a network (Black 2003; Rodrigue, et al. 2006). This definition might lead one to believe that accessibility is static and part of the built environment, influenced more by the physical structure of an urban area than by the characteristics of the citizens who are dependent upon it. But this is not the case, as it can be thought of as the situation of a location and its ease of being reached (Kwan, et al. 2003). Therefore it is not an intrinsic quality of a location, but subject to change (Harris 2001). This highlights a key difference between accessibility of, and access to, a transportation network. Access to a transit network is measured by proximity to stops, and each stop is regarded as providing uniform admission to the network (Murray and Davis 2001). This approach is less data intensive than the determination of accessibility, and provides a useful approach for analysis of transportation networks.

The methods of measuring accessibility, by contrast, are structured around the relationships between the location of places or people dependent on transit and the transport infrastructure, capacity of the network, and the network connectivity (Rodrigue, et al. 2006). Here, the location may be represented as an aggregation of people represented by a certain distance to a stop on the transit network (Harris 2001). The characteristics of connectivity, capacity, and location are important to the determination of the accessibility of the transit network, and each can be a measure of equity in public transportation.

2.3. Connectivity, Capacity, and Location

The essential elements of accessibility are location of probable transit users relative to the transit network, capacity of the transit network, and the connectivity of the network. Each one of these characteristics of a given network can be analyzed to assess its contribution to the degree of accessibility of the entire network. In a low transit environment, accessibility of a transit stop is a mere matter of convenience to a marginal segment of the population (Rodrigue, et al. 2006). Therefore, the location of stops in a transit network should be amenable to transit dependent users, and the number of such users within a given distance of a stop is one measure of the accessibility of that particular stop. This could be compared with other potential stops in the area to identify locations that are accessible to the greatest number of potential riders and can be used for planning new stops or realigning existing stops. The location of stops should be determined to be accessible to the greatest number of potential users, and this is one way to increase the demand and justify the capacity of the system.

The capacity of the system can be measured by the frequency of service and the capacity of the individual transit vehicles. Capacity of a transit route is one measure of the level of service, and the desirable level of service is dependent on the urban structure and density of the area served (Sanchez 1999). More dense areas would necessitate a higher level of service than less dense areas and this presents a problem for equity. In a low-density city like Albuquerque, this means a low level of service for the majority of the city, which affects transit-dependent users who are spatially distributed throughout the city, not just concentrated along high level of service corridors. This results in longer

wait times for service and limited service hours, both major hindrances to the accessibility of the network, and consequently the city and its services (Sanchez 1999).

The connectivity of the transit network is one measure of the accessibility of the overall transit system from a particular stop or route. There are formal mathematical measures of the degree of connectivity in a network, which analyze distances between nodes and the current connections to the total possible connections (e.g., Hanson 1986). In general though, when network connectivity increases, network accessibility increases (Black 2003). The importance of studying network connectivity, capacity, and location are essential to measuring the accessibility and, thereby, the equity of a public transportation system.

2.4. Network Approach

The network approach to transportation geography was developed during geography's quantitative revolution in the 1950's and goes beyond just the description of transportation systems, by providing a framework for systematic examination. The importance of this method to the acceptance of geographical analysis approach cannot be overstated: "The network approach was the first major paradigm to emphasize a rigorous scientific approach to research in transportation geography" (Black 2003).

The methodology for analyzing transportation using the network approach starts with the fundamental notion of defining nodes, links, and the topological relationship between the two (Longley, Goodchild, Maguire, and Rhind 2005). Nodes are defined based on the research question asked, and vary depending on the type of network studied and the geographic scale being considered (Black 2003). For example, nodes could be

considered cities, for an analysis of air traffic, or employment centers within a city for a study on commuting. Complementary to nodes are links, which can be implicitly defined, such as the flight path between cities, or physically defined infrastructure, like streets between employment centers. The spatial relationship between nodes and links needs to be defined for each specific study of transportation networks, so the necessary assumptions about contiguity can be explained (Black 2003). For a study on air traffic, a large city's airport may be assumed to be a node in the network, even though the physical location of the airport is located a significant distance out of the city. For local public transit networks, the assumption is clearer, with stops or stations acting as nodes in the network. These assumptions are fine for simple representations of transportation networks, but many researchers are interested in more complex models.

The simple definitions of links and nodes in a network of course do not model reality very accurately and are not without criticism. Some difficulties in the creation of a street network arise in the dependence on the precise definition of a nodal representation of an intersection, street center lines with technically zero width representing actual streets with a width, the possibility of extensive modification to the network model for the addition of new nodes, and the redundancy of street names for multiple segments on the same route (Goodchild 2000). These problems are less of a concern when modeling a transit network, where nodes are precisely defined as stops, but remain for the modification of the network through the addition of nodes. The simple "nodes and links" representation of a network has led to the creation of an entire subfield in Geographic Information Systems (GIS) which is focused on modeling transportation systems.

2.5. GIS-T

As equally momentous as the network approach is to transportation geography is the importance of Geographic Information Systems devoted to transportation (GIS-T) (Black 2003). Once nodes and links are identified and defined for a particular study, the best environment for analysis is in a GIS-T, using an integrated and comprehensive approach, as outlined by Lui and Zhu (2004). The three main perspectives that GIS-T offers for transportation networks are the map view, the navigation view, and the behavior view (Goodchild 2000). The map view implies an essentially static perspective, and its success lies in inverse proportion to the tendency of the network to change (Goodchild 2000). This simple linear model provides a one-dimensional referencing system for location determination, but provides no information regarding flows and hence has limited application for models that demand increased accuracy and realism. The navigation view assumes that information of a dynamic nature, including attributes such as levels of congestion and travel speeds, generally known as impedances, should be represented on the static geometry of the network (Goodchild 2000; Longley, et al. 2005). Another attribute of interest that can be represented in the navigation view is demand, for the movement of people, freight and information, and is related to nodes by locations and to links by flows (Rodrigue, et al. 2006). Demand is an estimate, usually a derived function of socio-economic factors in the region of study. The third view, in GIS-T, deals explicitly with dynamic geometry, which is the behavior of discrete objects, vehicles, people, or buses, on and off the linear network (Goodchild 2000). This perspective models complex behavior and must deal with diverse sources of data, but still needs much development (Goodchild 2000).

All of these views treat representations of features in an object-based data model. This data model regards geographic features as discrete and identifiable objects, often represented as points, lines, and/or polygons (Rodrigue, et al. 2006). While this eases network analysis, the aggregation of people into polygons to determine potential demand for transit is not without problems. Wu (2003) identifies the problems associated with the modifiable areal unit problem that results from the aggregation of data into Census Blocks, and other analysis units and the influence this has on transit planning. Wu (2003) argues for a finer resolution data set, using impervious surface and vegetation cover as measures of socioeconomic status, derived from remote sensing. The less vegetative cover and greater impervious surface fraction in the classifications developed are related to housing development, and higher population density, the indicator that holds the greatest explanatory power for transit demand (Wu 2003; Johnson 2003). This is used as a demand potential, at a much finer resolution than Census Blocks can provide. The object-based network data models and related data used for analysis in transportation research have limitations, but there are alternatives given the amount of time and data available for study.

2.6. Space-time Accessibility Measures

Space-time Accessibility Measures (STAMs) are an index that attempts to capture the access of individual people to places such as employment, shopping and recreation (Miller 1999). This broad category of analysis highlights the difference between proximity-based measures and space-time accessibility measures, namely that proximity measures capture the accessibility of individual locations, whereas individual STAMs

quantify the accessibility of individuals to those places (Miller 1999; Weber 2003).

Another benefit of the space-time accessibility approach is the readiness of the understanding of its results using isochrone maps (O'Sullivan, et al. 1999). These maps depict lines joining a set of points at equal travel time from a specific location, and can be aggregated into areas where all the points within the area can be reached in less time than the bounding isochrone (O'Sullivan, et al. 1999).

For example, the use of a STAM to compare commuting times between public transit and private automobile in urban and suburban areas in San Francisco and Boston has successfully quantified disparities between these groups and captured how they changed between 1990 and 2000 (Kawabata 2007). The main purpose of using STAMs is to include time, and these metrics are useful for assessing temporal accessibility, along with spatial accessibility, as opposed to measures that only consider the latter.

2.7. Contribution

The aim of this study is to investigate public transportation equity in Albuquerque. The study area is suited to this analysis because the recent addition of premium transit allows the comparison of the system before and after to assess the effects on the transit dependent population. Although the Environmental Justice Atlas and Data Book for the Albuquerque Metropolitan Planning Area (MRCOG 2004) admirably explores the relationships between access to a bus stop and transit dependent populations, a more detailed model of the transit system is desired. For example, it states that a greater percentage of these populations live within a 20-minute walk to a bus stop than the total population, but the frequency of the buses is not taken into consideration

(MRCOG 2004). The assumption that the provision of a bus stop within a 20-minute walk distance to transit dependent populations is sufficient needs to be challenged, as there is a significant difference between a 10-minute frequency bus and a 65-minute frequency bus, as are present on the Westside of Albuquerque. Further analysis of that started by the Mid-Region Council of Governments is needed and should include the specifics of bus frequency, as well as walking time and bus travel time, as part of the accessibility analysis for the Albuquerque public transportation system.

As noted by Murray and Davis (2001), there is a need for evaluating equity issues with current and proposed public transportation projects to see if they are meeting their objectives. In the planning profession, the concept of accessibility has rarely been translated into performance measures by which policies are evaluated and thus has had little practical impact on policy (Handy and Niemeier 1997). There is a current omission regarding the contribution and centrality of transportation systems to many geographical problems (Hanson 2006), even, “transportation is treated as so obviously fundamental to society that there is no need to explain how or why” (Keeling 2007). This study attempts to add insight to the current need of evaluating public transit equity by way of performance measures developed through accessibility research (e.g., Sanchez 2008; Martin, Jordan, and Roderick 2007) and its relation to policy and planning, as well as the significance of transportation studies to geography.

Chapter Three: Methodology

The goal of this paper is to map the effect that recent changes to the public transit system have had on the accessibility that the system provides in Albuquerque and to quantify this change in accessibility of the city to traditional transit users, the vehicle-less, low income, and elderly and young people. The change in accessibility of these groups will be used to assess the change in equity, caused by the implementation of the Rapid Rides. This will be achieved through the construction of a public transportation accessibility model, with a focus on the necessity of using travel time as the accessibility measure. This model will specifically be a multi-modal network, that is, one consisting of both a walking network and a transit network to account for the differing travel times on both. This construction will use the street network of the city, the transit system, as well as the published schedules for the selected routes, for the analysis environment. The analysis of total travel times and differences in time between before and after the Rapid Ride route additions will encompass three time periods of the day, from address points, which are points representative of houses, to model household level accessibility to the transit system. This will assume walking on the street network to access the bus stops, and will also measure the accessibility that the transit system provides to the representative destination, Downtown.

3.1. Data

The data required for construction of the network are the city street network, arroyos, and bike paths, as well as the bus routes and stops. The arroyos, seasonal water channels, have walking paths alongside, which are not represented in the city street

network. This is similar for the bike paths that do not run along city streets. Additionally, address points and land use polygons for Bernalillo County, in which Albuquerque resides, were obtained. All of these are available on the City of Albuquerque's website (<http://www.cabq.gov/gis/download.html>) and are in the form of shapefiles. These were imported into a feature dataset in a personal geodatabase in ArcGIS 9.3. The native coordinate system of the data were used, New Mexico State Plane Central, NAD 1983 HARN. The Census Block Groups and associated socio-demographic data for Bernalillo County were downloaded from the Resource Geographic Information Systems website (<http://www.rgis.unm.edu>). The time information for routes was collected from the City of Albuquerque's published bus schedules (<http://www.cabq.gov/transit/routes-and-schedules>), and only weekday, all-day routes were included in the time calculations. These schedules and route maps are located in Appendices B-H.

3.2. Methods

The overall design of the network built falls into two components and necessitates a multi-modal network to be built to integrate the walking network with the transit network. This model used the walking network to model travel time to and from the bus stops and destinations/origins. This employed an assumed walking speed on the streets, and utilized the address points and Downtown Albuquerque as origins/destinations. The transit network is used to model travel time by bus, with the two networks linked through boarding lines, which estimate the average waiting time for a bus. The network was constructed with a fine level of detail and accounts for variations in both travel time

between published wait times for the A.M. peak travel period, T_{WA} , the P.M. peak travel period, T_{WP} , and the off-peak period, T_{WO} , and the travel times on the route for the same periods, $T_{TA(X-Y)}$, $T_{TB(X-Y)}$, or $T_{TO(X-Y)}$ (Figure 3.1). Detail of the individual time accumulations on the network, the contributing elements are underlined in Figure 3.1, follows, but the total travel time is calculated by summing the walking time on the street network from the origin, the waiting time on the boarding line, the travel time on the route, and finally exiting the route and continuing on the walking network to the destination.

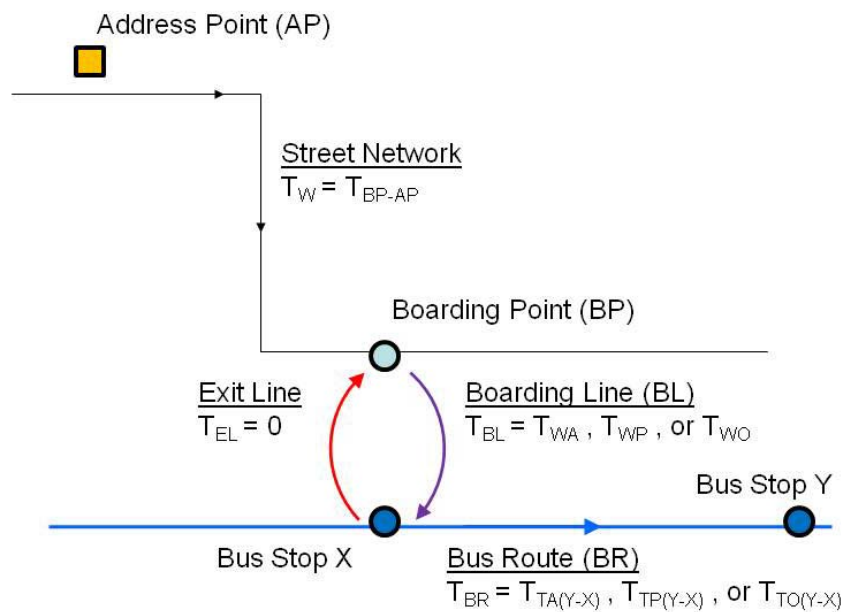


Figure 3.1. Conceptual diagram of the accumulation of travel time, starting from the Address Point and proceeding onto the Bus Route

The street network, used to represent the walking mode, was modified to include bike paths and arroyo trails, to more accurately reflect the accessibility these provide for walking in the study area. These three shapefiles were merged and inspected to remove

redundancies and the Interstate highways, which are unsuitable for walking. A field was added to this network to hold the average walking time in minutes, which is calculated by an assumed walking speed of 3 kilometers per hour, a common estimation for walking speed, multiplied by the length of the individual street segments.

The City’s bus network was the basis of the transit network built. First, the routes that served the Westside were identified from the feature class containing all of the routes. These were exported individually to feature classes and inspected visually to ensure connectivity. The routes were then copied, to create a route for each direction and isolate them topologically, and edited where they diverged (for example, on one-way streets). Five fields were added to the routes to hold the A.M. peak travel time, P.M. peak travel time, off-peak travel time, a one-way attribute, and a proportion field. The

A.M. peak travel time was calculated by averaging the duration between 7 A.M. and 9 A.M. for each segment between scheduled stops. For example, for Route 51, between scheduled stops A and B, the travel time for the A.M. peak is the average of the travel times between 7:41 A.M. and 7:48 A.M. and the next bus’ travel time between 8:46 A.M. and 8:53 A.M, which results in an average A.M. peak travel time of 7 minutes for the segment between

stops A and B (Table 3.1). The P.M. duration was calculated similarly, except it was based on the 4 to 6 P.M. time window. The off-peak time was calculated from the rest of the times not included in the previous two categories. The one-way attribute corresponds

Route 51 - Weekdays Northbound					
STOP	STOP	STOP	STOP	STOP	STOP
531a	537a	541a	545a	549a	555a
636a	642a	646a	650a	654a	700a
741a	748a	752a	756a	800a	807a
846a	853a	857a	901a	905a	912a
951a	958a	1002a	1006a	1010a	1017a
1056a	1103a	1107a	1111a	1115a	1122a
1201p	1208p	1212p	1216p	1220p	1227p
106p	113p	117p	122p	126p	133p
211p	218p	222p	227p	231p	238p
316p	323p	327p	332p	336p	343p
421p	428p	432p	437p	441p	448p
526p	532p	536p	540p	544p	550p
631p	637p	641p	645p	649p	655p

Table 3.1. Published time schedule for Route 51 by ABQ Ride

to the direction of digitization of the route segments and is necessary for the correct analysis of the bus route directions. The proportion attribute is necessary to estimate the times to stops not on the published time schedules. This first required the routes to be merged into one continuous polyline, since the segmented route geometry did not correspond to the locations of the stops originally. The routes were then split into segments by the stop points, and the length of the routes between stops was then divided by total length between the scheduled stops. For example, if between scheduled time stop A and stop B there are three bus stops, the lengths of each of the segments between each of the stops is divided by the total length between stop A and stop B. This estimates the amount of time between two scheduled time stops that it takes the bus to travel to a non-scheduled stop, when multiplied by one of the time fields. The route travel times described above were then attributed to the correct route segments, between the corresponding scheduled stops. These were calculated for both directions, for all of the routes in this study, as some variability in travel times were noticed for direction of the route and time of day.

Integral for the interaction between the bus network and the walking network are the stops, boarding points, boarding lines, and exit lines. The stops were selected by route number from the bus stop shapefile from the city and whether they were outbound or inbound, and exported to separate feature classes. Visual inspection was used to include stops that were not attributed correctly and actually served multiple routes. These individual route direction stop points were copied to create boarding points, again two separate feature classes for the two directions, for each route. The stops were then snapped, or made topologically coincident, with the appropriate route line to provide for

network connectivity. The boarding points were snapped to the walking network, to act as nodes to connect the bus network to the walking network. Boarding lines were created between each boarding point and stop, to hold the average wait time, similar to the average travel time for the routes. The distance of these lines is ignored, as only the waiting time attribute of these lines is relevant. These boarding lines included the creation of the fields for the one-way attribute, A.M. peak wait time, P.M. peak wait time, and off-peak wait time. These were populated in a similar fashion as for the route lines, but the frequency of the bus at a particular scheduled stop was averaged over the aforementioned time categories. The average wait time for the specific time windows was calculated by recording the wait times between buses and then averaging them within that time window and finally, dividing by two. The boarding lines up to the next scheduled stop were given the attributes of the previous scheduled stop and since these only hold wait time information, no length calculations were necessary. To exit the bus routes back to the street network necessitates exit lines, which were copies of the boarding lines, but with the one-way attribute indicating the other direction. These hold no time information, i.e. $T_{EL}=0$, and therefore no time is accumulated for exiting the bus.

Transfers between lines necessitated establishing a connectivity policy, in which each route direction is a separate connectivity group and the only interaction between routes is through walking on the street network (Figure 3.2). This ensures that the transfer time between routes is accounted for, that is the average wait time is accumulated, before transferring to the new route.

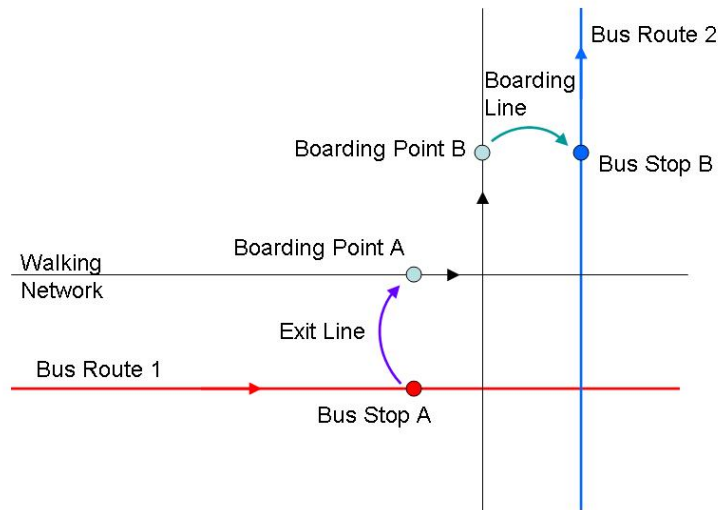


Figure 3.2. Schematic of transfers between bus routes, proceeding from Bus Route 1, through the Exit Line, Walking Network, Boarding Line, and onto Bus Route 2

With the network data attributed, a network dataset was then constructed in the feature dataset, with all of the route and walking network features. Fifteen groups were created for the connectivity policy, which determines how the networks interact topologically. One group was for the street network and the other 14 were so that each route direction had its own group (a snapshot is in Appendix I). This ensured that transfers between lines only occurred on the walking network. The boarding points were assigned to its route direction and to the walking network, to serve as the connection between the networks.

The network attributes, which are fields and expressions by which the network is analyzed, were created to assess the time to traverse the unified network during the A.M. peak, P.M. peak, and off-peak times, as well as a proportion attribute, shown in Appendix

J. The travel time attribute evaluators were the entire set of line feature classes previously attributed, but the assignment of their value depended on their role in the network (see for example Appendix K). The boarding lines, which hold the average wait time for the particular route for the three time windows, were assigned to use those fields' values directly. For example, the Time A network attribute was assigned the Time A field for all of the boarding lines, since these lines rely on the time only and not the distance of these lines. The routes, in which the travel time between the scheduled stops does depend on distance, were given the value of the time field multiplied by the proportion attribute. For example, the Time A network attribute was assigned the Time A field multiplied by the proportion field for all of the routes, resulting in the minutes it takes the bus to travel between all of the stops in both directions. The walking network evaluator was assigned the previously-calculated walking time and was constant for all the network attributes. This resulting network was copied to a new feature dataset and the network was built without the Rapid Ride routes for the baseline comparison to the current network with all of the routes included. The complete network is in Appendix L.

The address points for the City of Albuquerque were not explicitly part of the network, but were used to run the analysis. The address points in the study were visually selected to encompass the Westside, specifically west of the Rio Grande. To choose only the residential address points, a spatial join to the land-use polygon shapefile was required. But, the land-use shapefile required the selection of residential land uses, which necessitated a table join with the land use code table to identify the residential types. This appends to the land-use shapefile the land-use codes, in a many-to-one cardinality. This table was created by selecting only the residential descriptions text

(<http://www.cabq.gov/gisshapes/ABQlanduse.pdf>) and creating a table from it. This table was joined to the land use shapefile and only matching records were kept. This produced the residential land use polygon layer, which was then joined to the address points, resulting in the residential address points on the Westside of Albuquerque, approximately 65,000 points. These are in Appendix M, with relation to the network.

The other point data required is the downtown point, which was digitized on-screen, to the Alvarado Transportation Center (ATC) at Central Avenue and First Street SW, where the buses that travel downtown begin or end their routes. Two of the routes, Atrisco/Rio Bravo, and Coors Boulevard do not leave the Westside and therefore don't end Downtown. The Rapid Ride Blue Line runs through Downtown, but the closest stop to the ATC is at Fourth Street and Lomas, some blocks to the north and west. For this analysis, it was considered that Downtown as an area was the destination, so the boarding and exit lines for the Blue Line originated from the ATC.

Finally, census data, in the form of block groups was necessary to obtain the spatial distributions and measures of traditional transit dependent users. These indicators are age (under 18 or over 65), vehicle-less, and low income. The proportions of these groups were calculated, relative to the population in the block groups as a whole. Equal weighting was given to each variable proportion to produce a transit-users index, detailed more in the Results chapter. The high proportion areas of the variables are clustered on the south side of the study area, as opposed to northern portion, which has a low proportion of the variables. This identifies the areas of high transit demand from which addresses will be chosen to compare to the areas of lower transit demand.

The final analysis, the statistical comparison of travel time savings for the socio-economic indicators, necessitates splitting the census blocks into two groups: those with a significant savings and those without. First, this requires weighting the address points, to account for the number of people living at each address point. This information comes from the landuse data that was previously joined to points and adding a new field to the address points. This weight field is populated by assigning a number based on the description of the housing type. For example, a single-family house was given a weight of 1, the same as a townhouse or a mobile home. Apartments were given the middle number of the range of units. Apartments listed as 5-9 units would result in a weight of 7. Once weights were assigned, the points then needed to be related to the census block groups to make the comparison of individual travel times to socio-economic variables. This is done by spatially joining the points to the block groups resulting in a point shapefile with the census block group identifier appended to each point. The average weighted time for each block group was then determined, as it was very similar to the median time, as discussed in the Results section.

The output will allow for the comparison of times before and after the addition of the Rapid Ride Routes, and specifically, when address points are mapped onto the census block group classifications, to visually compare the change in travel time to these destinations between the most transit dependent block groups and the less transit dependent groups, while allowing for the increased influence of multiple unit address points. This will achieve the goal of mapping the change in accessibility in the City of Albuquerque, before and after the Rapid Ride Routes that the transit system provides.

Also, this allows for the quantification of the change in temporal accessibility to the transit dependent areas of the Westside, which is my second objective.

Chapter Four: Results

The results of the scenarios run show a distinct contrast between the beneficiaries of the travel time savings realized with the implementation of the Rapid Ride lines. The four scenarios run to elicit these differences were to Downtown from the address points for the A.M. peak time, from Downtown to the address points for the P.M. peak, and both directions for the off-peak time period. These scenarios were chosen to represent a morning commute into the downtown area, an afternoon commute out of the Downtown area, and traveling in either direction outside of these times. The analysis of the scenarios is broken down into visual analysis, correlations as shown with tables and figures, and then with non-parametric comparisons.

4.1. Visual Analysis

Symbolizing the individual address points by travel time savings allows individual household level differences to be visualized for each of the scenarios. This method approximates isochrones maps, which contributes to the overall goal of this paper: to map the effect of the Rapid Ride on the change in temporal accessibility that it provides. In Figure 4.1, the time savings with the implementation of the Rapid Ride routes is negligible, less than five minutes, for the majority of the address points for the A.M. commute into Downtown. Compared to Figure 4.2, the time savings, to Downtown from the address points for the off-peak period, is about the same in the southern portion, but in the northern portion more points appear to have a greater time savings (the upper limit is 4 minutes higher). This indicates that there is an additional time savings realized for some address points during the off-peak time period when compared to the A.M. peak

period. This highlights the variability of the time-savings benefits of the Rapid Ride additions, and demonstrates the non-constant time benefits of these additions. That is, there is a greater time savings for some points during the off-peak time period than the A.M. peak, which may be the result of congestion that mediates this time savings during the A.M. peak.

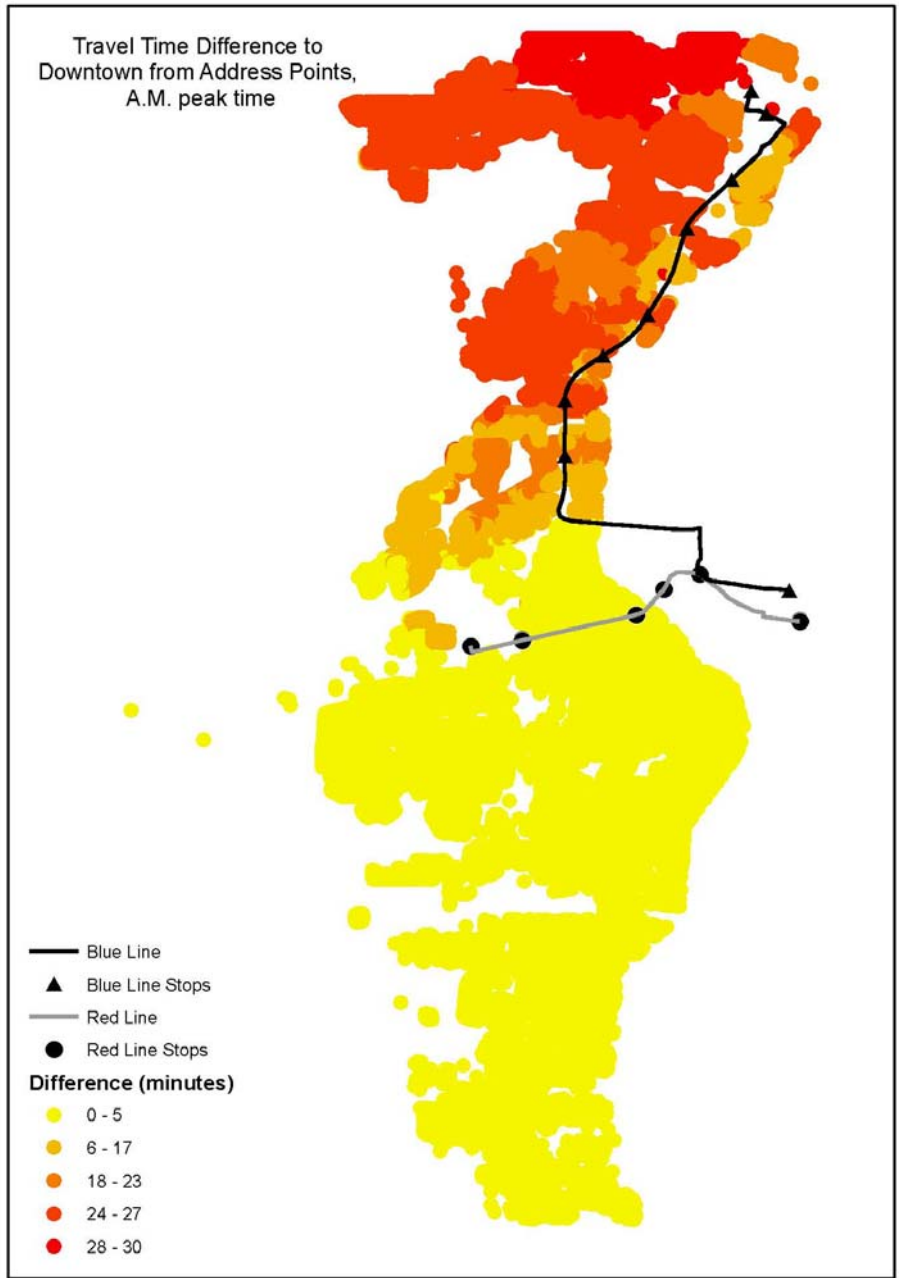


Figure 4.1. Travel time savings after the Rapid Ride additions, to Downtown from address points for the A.M. peak time period

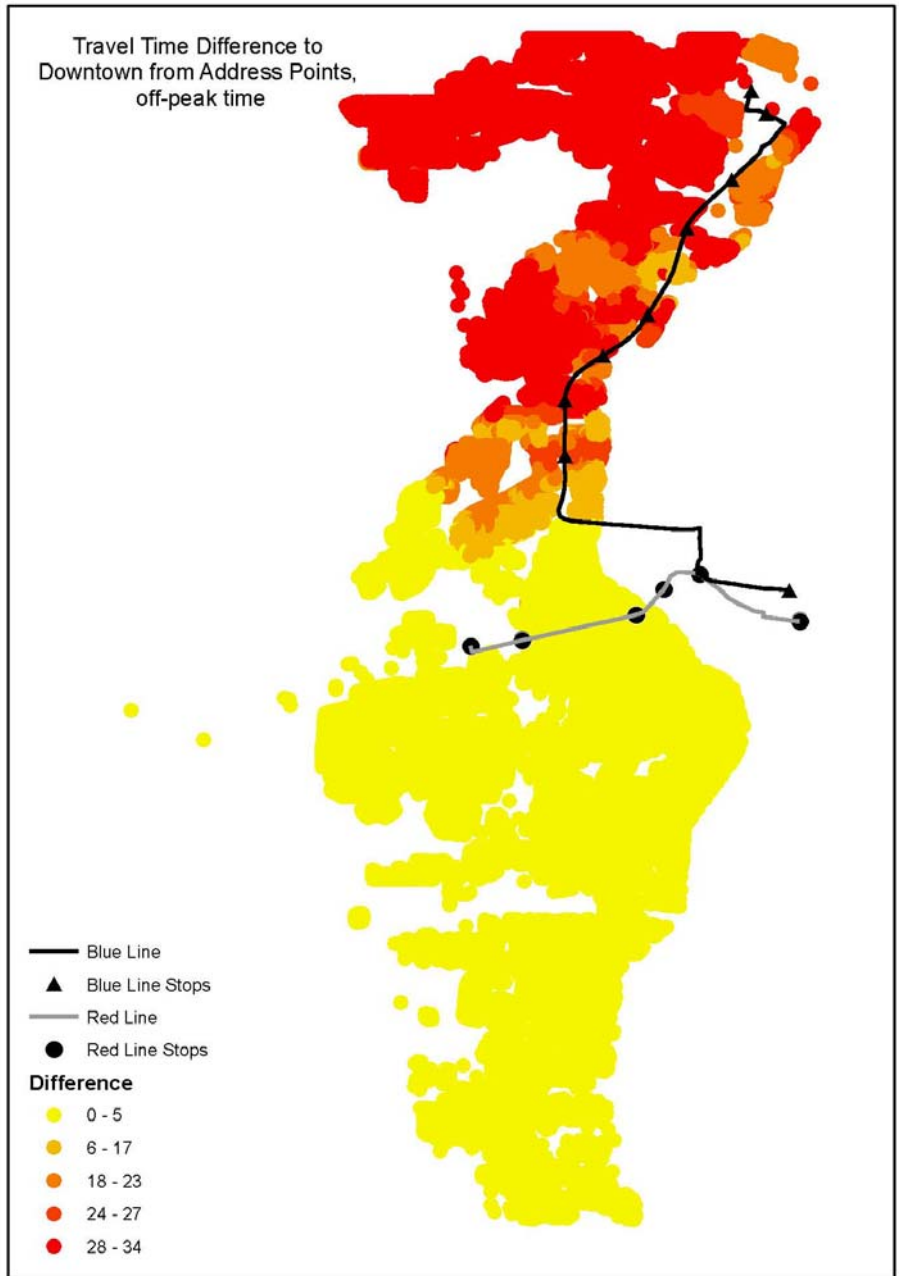


Figure 4.2. Travel time savings after the Rapid Ride additions, to Downtown from address points for the off-peak time period

The comparison between the travel-time savings from Downtown to the address points for the P.M. peak and off-peak time periods are seen in Figures 4.3 and 4.4, respectively. These appear to have a smaller variance between the distribution of time savings than the toward downtown scenarios, as they look almost the same and the range of values is the same. There does appear to be an overall greater time saving in this direction, for both time periods, than the toward Downtown scenarios, indicating a possible directional effect on the range and amount of time savings with the Rapid Rides. This may be due to the commuting patterns of increased congestion heading into the downtown area, whereas it is faster leaving the area.

The visual comparisons of individual address points between different time scenarios highlight the differing time savings actualized and allows for a fine level of analysis for differing time period and direction scenarios. For example, the effect of stop placement is apparent at this level of analysis, whereas once the points are aggregated into block groups, this detail is lost. In all of the time scenarios, hot spots of time savings are apparent around most of the Blue Line stops. This is due to the much more infrequent bus that parallels the Blue Line, as compared to the more frequent bus that parallels the Red Line and shows the smaller significance of the placement of the Red Line stops. The aggregation of these points is necessary though, to explore the relations between the time savings due to the Rapid Ride, and the socio-economic variables, which are only available at the block group level.

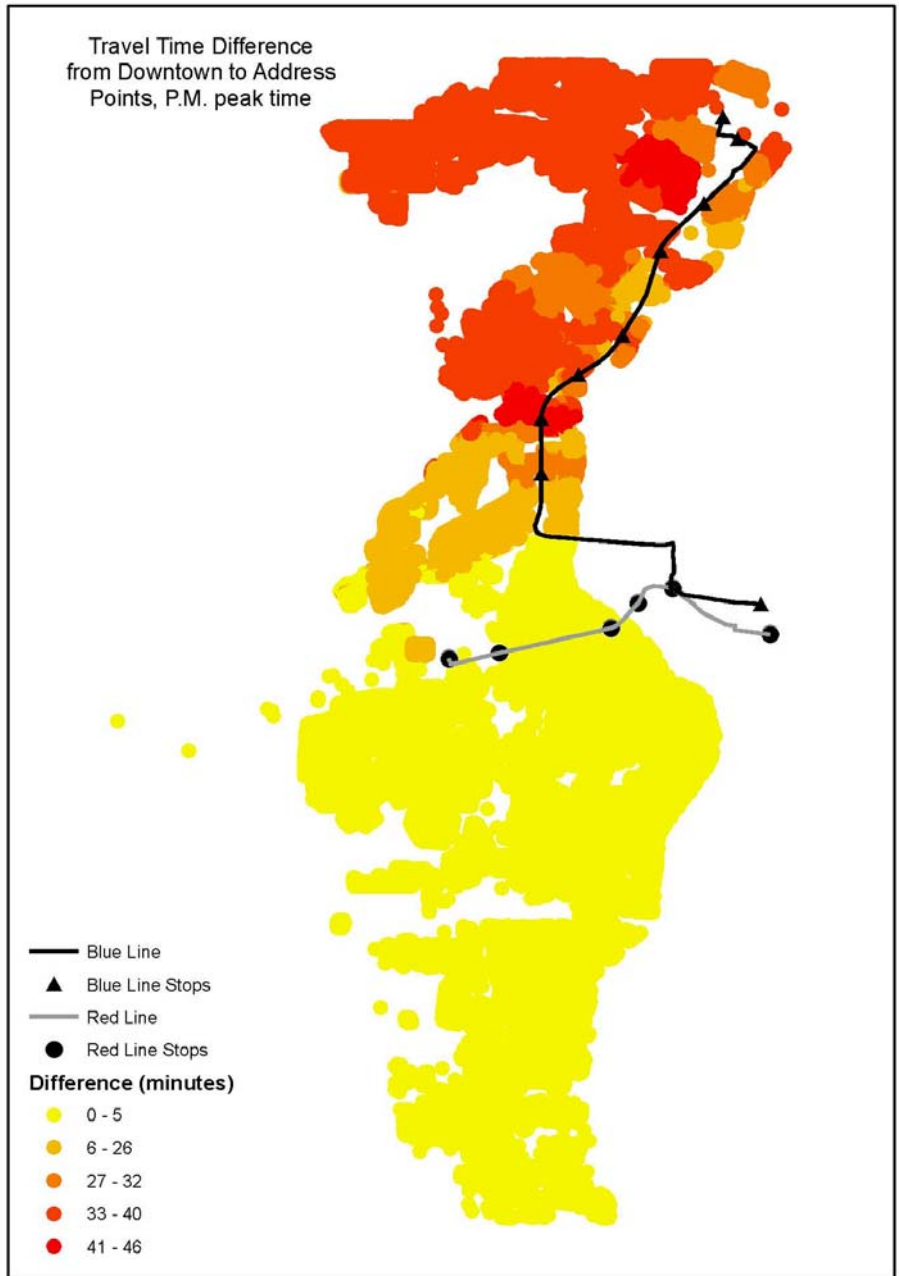


Figure 4.3. Travel time savings after the Rapid Ride additions, from Downtown to address points, for the P.M. peak time period

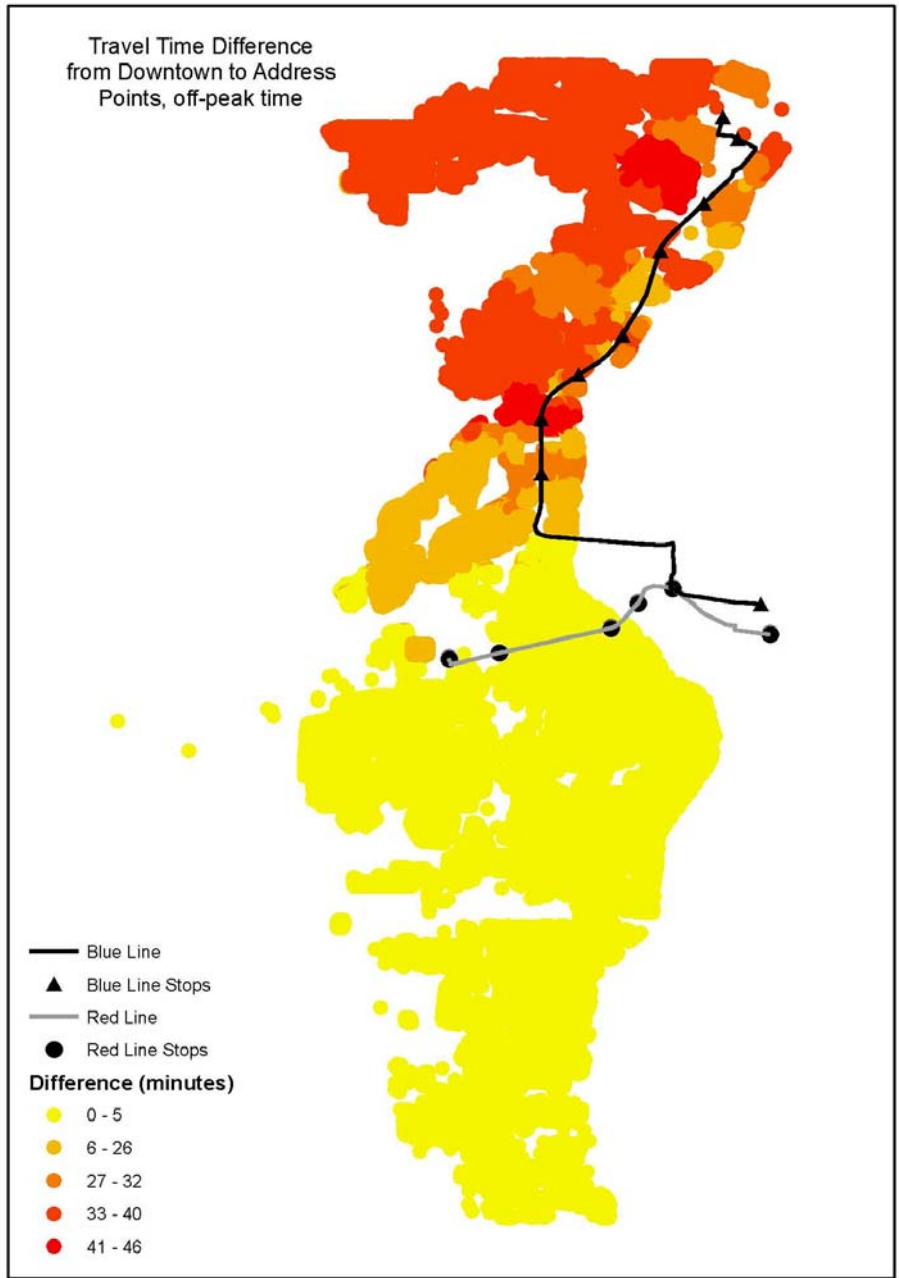


Figure 4.4. Travel time savings after the Rapid Ride additions, from Downtown to address points, for the off-peak time period

Closer analysis of the address point patterns reveals the strength of this data model. In Figure 4.5, an example of one of the address point time savings, around the Montano Plaza Blue Line stop to Downtown from the address points, shows the usefulness of using the walking network. The time saving from the addition of the Blue Line to the area, specifically its stop, is not constant for address points in an equal radius from the stop. The time savings vary, as demonstrated by the 500 meter buffer, depending on the walking network grid and the accessibility it provides. Not all points within the buffer see the same time savings, and this is particularly true for the limited access of the neighborhoods to Coors Blvd. The addresses closer to the access road see a greater savings, even though they may have a farther straight-line distance than other addresses. This example underscores the usefulness of the street network as the basis for walking accessibility to bus stops.

Also, in Figure 4.5, two address points near Montano Rd and Coors Blvd are labeled and are examples for the necessity of weighting the address points when looking at the average time for the block groups. Both of these points were given a weight of 50, since they represent at least 50 units, and need to reflect this when combined with points that represent single-family homes.

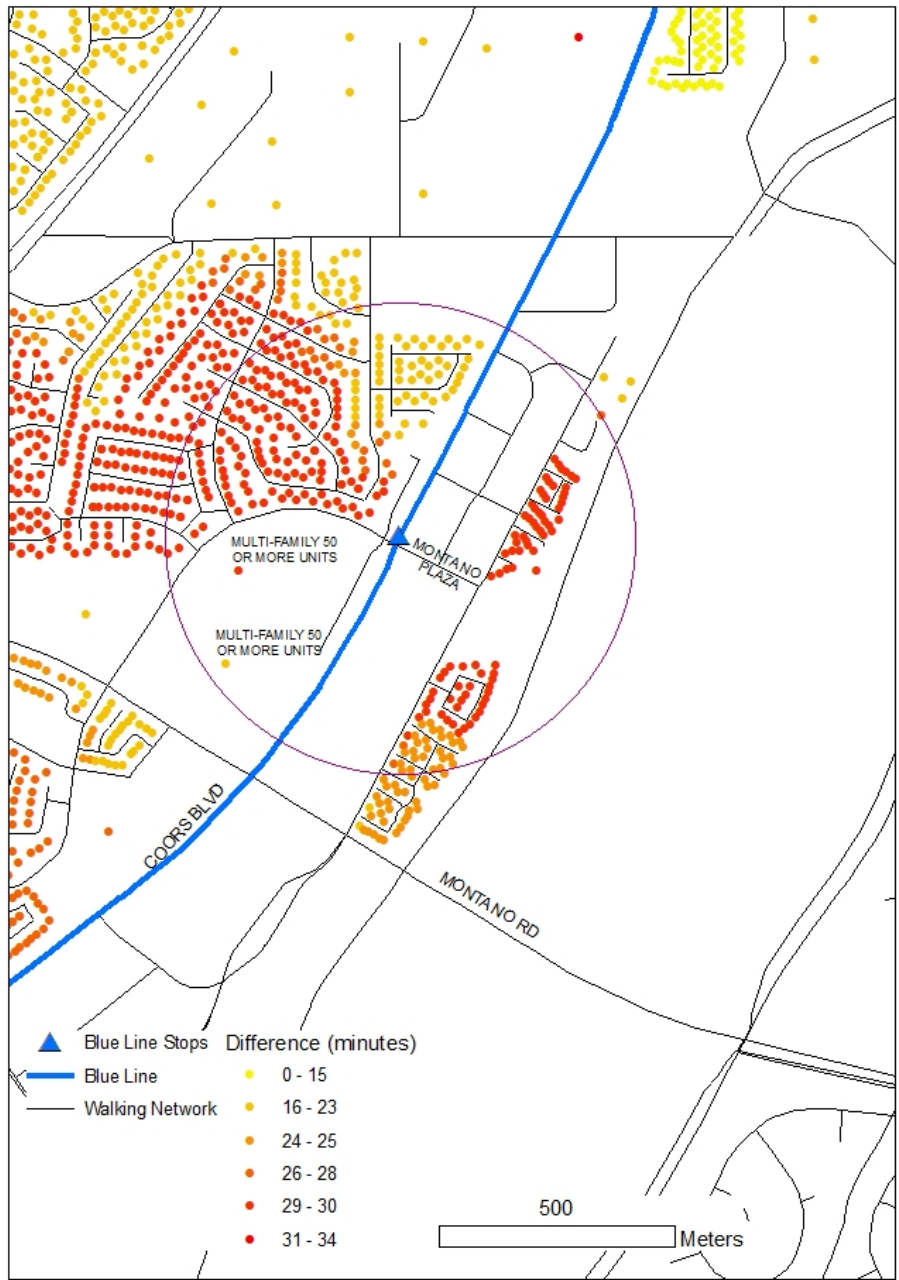


Figure 4.5. Detail of address points time savings after the Rapid Ride additions, near the Montano Plaza Blue Line stop, with 500 meter buffer for comparison of non-constant savings with distance

4.2. Correlations

After the visual analysis of the travel time savings in general, a more detailed analysis is now pursued to look for a relationship between the travel time savings highlighted in the previous section and the distribution of the transit user populations. The correlations are first demonstrated with tables to highlight the significance and strength of the relationships between travel time savings and the chosen socio-economic indicators. Next, a visual comparison between the block groups' average weighted time savings and the transit index is assessed. These correlations are between the average weighted time savings by block group with the proportion in poverty, the combined age proportion of those over 65 and under 18, the proportion without a car, and the combined index of these three, the transit index.

The results of the correlations are in Tables 4.1-4.4, from the statistical software Minitab, which detail the strength of the correlations and the associated Pearson's p-value for each. These correlations are based on the assumption of a linear relationship between these variables. The questionable normality assumption of the distribution of these variables leads to the use of a Spearman's Rank correlation (Appendix N), but the coefficients are very similar. These show negative correlations between all of the variables and the average weighted time savings, for all of the scenarios. This means that the greater the time saved, the smaller the proportion indicator is for the block group. All of these correlations are statistically significant, with p-values of 0.000. The similar strengths for each indicator across the four scenarios indicate the small variations in time savings, which is apparent when looking at the proceeding figures which visually show

these differences. The strongest negatively correlated variable is the transit index, which is to be expected, as it is merely an equally weighted average of the other three variables.

The proportion of households in poverty is the next strongest indicator. Any of these indicators could be used alone for correlations, or in combination, as the transit user index is, since they are spatially auto-correlated.

	Poverty Proportion	Combined Age Proportion	No Car Proportion	Transit Index Proportion
Average Time	-0.681	-0.550	-0.439	-0.710
P-value	0.000	0.000	0.000	0.000

Table 4.1. Correlations of average weighted travel time savings from Downtown to address points during the off-peak time period with socioeconomic variables, with Pearson's p-values

	Poverty Proportion	Combined Age Proportion	No Car Proportion	Transit Index Proportion
Average Time	-0.685	-0.547	-0.436	-0.710
P-value	0.000	0.000	0.000	0.000

Table 4.2. Correlations of average weighted travel time savings from Downtown to address points during the P.M. peak time period with socioeconomic variables, with Pearson's p-values

	Poverty Proportion	Combined Age Proportion	No Car Proportion	Transit Index Proportion
Average Time	-0.678	-0.547	-0.430	-0.704
P-value	0.000	0.000	0.000	0.000

Table 4.3. Correlations of average weighted travel time savings to Downtown from address points during the A.M. peak time period with socioeconomic variables, with Pearson's p-values

	Poverty Proportion	Combined Age Proportion	No Car Proportion	Transit Index Proportion
Average Time	-0.674	-0.551	-0.419	-0.700
P-value	0.000	0.000	0.000	0.000

Table 4.4. Correlations of average weighted travel time savings to Downtown from address points during the off-peak time period with socioeconomic variables, with Pearson's p-values

The visualization of the correlations between the average weighted travel times for the block groups and the transit index follow in Figures 4.6-4.9. In general, the higher transit index scores are in the southern half of the study area, south of Interstate 40, but within the service area of the Red Line. Also, the greatest time savings across the study area is seen in the northern portion, north of Interstate 40, in the Blue Line's service area, with some variations in the amount of time savings between different time periods.

In Figure 4.6, weighted average travel time savings from the address points to Downtown for the A.M. peak shows a few more block groups in the southern portion with travel time savings than Figure 4.7, which is for the off-peak time period. This is still insignificant, less than five minutes, and the general trend of higher time savings in the north is consistent with the visual comparison of the address points already seen.

Again, the greater travel time savings of some block groups in the off-peak time period over the A.M. peak period is evident, consistent with the address point maps previously discussed.

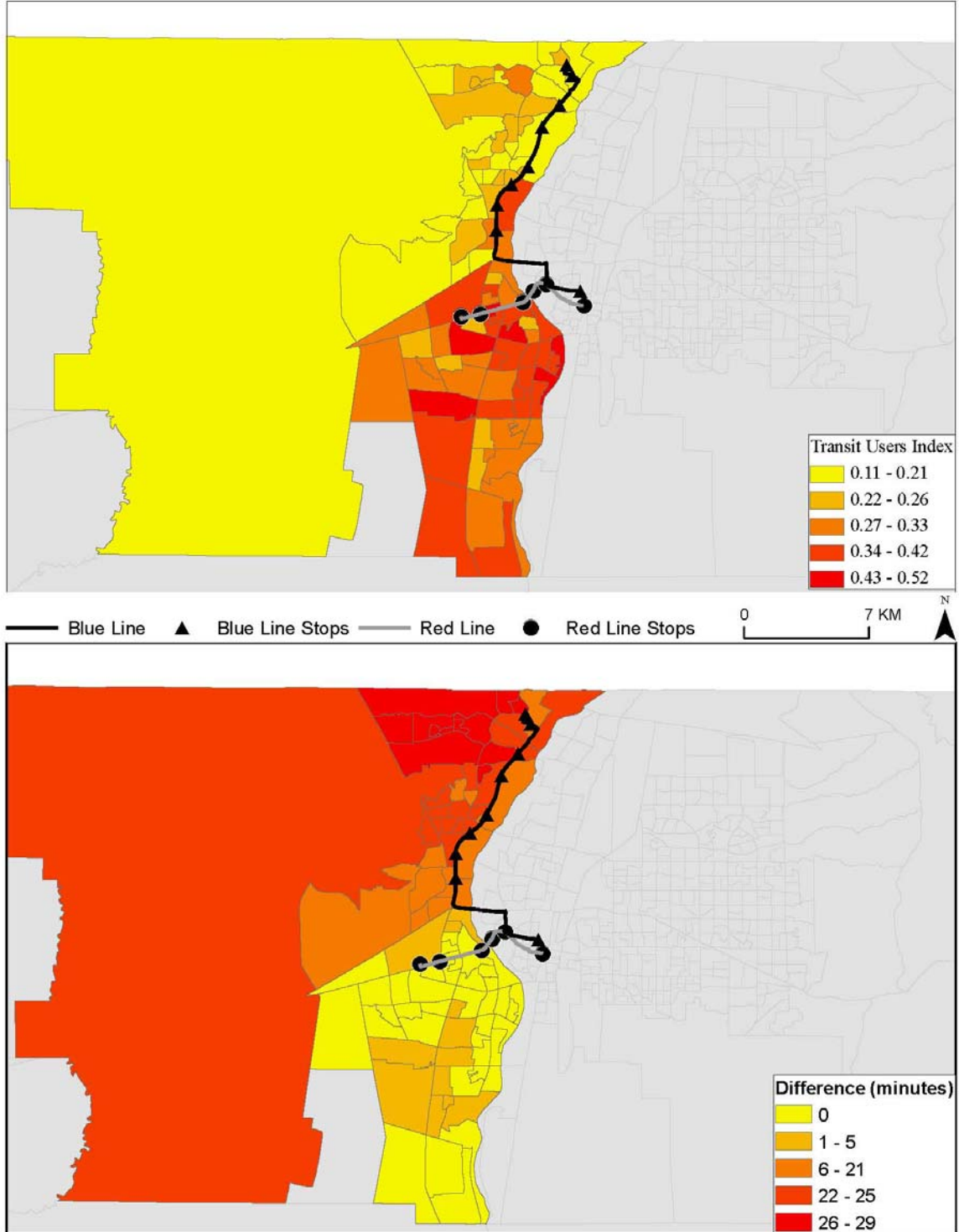


Figure 4.6. Visual comparison of Transit Index with average weighted time savings by block group for the A.M. peak time period to Downtown

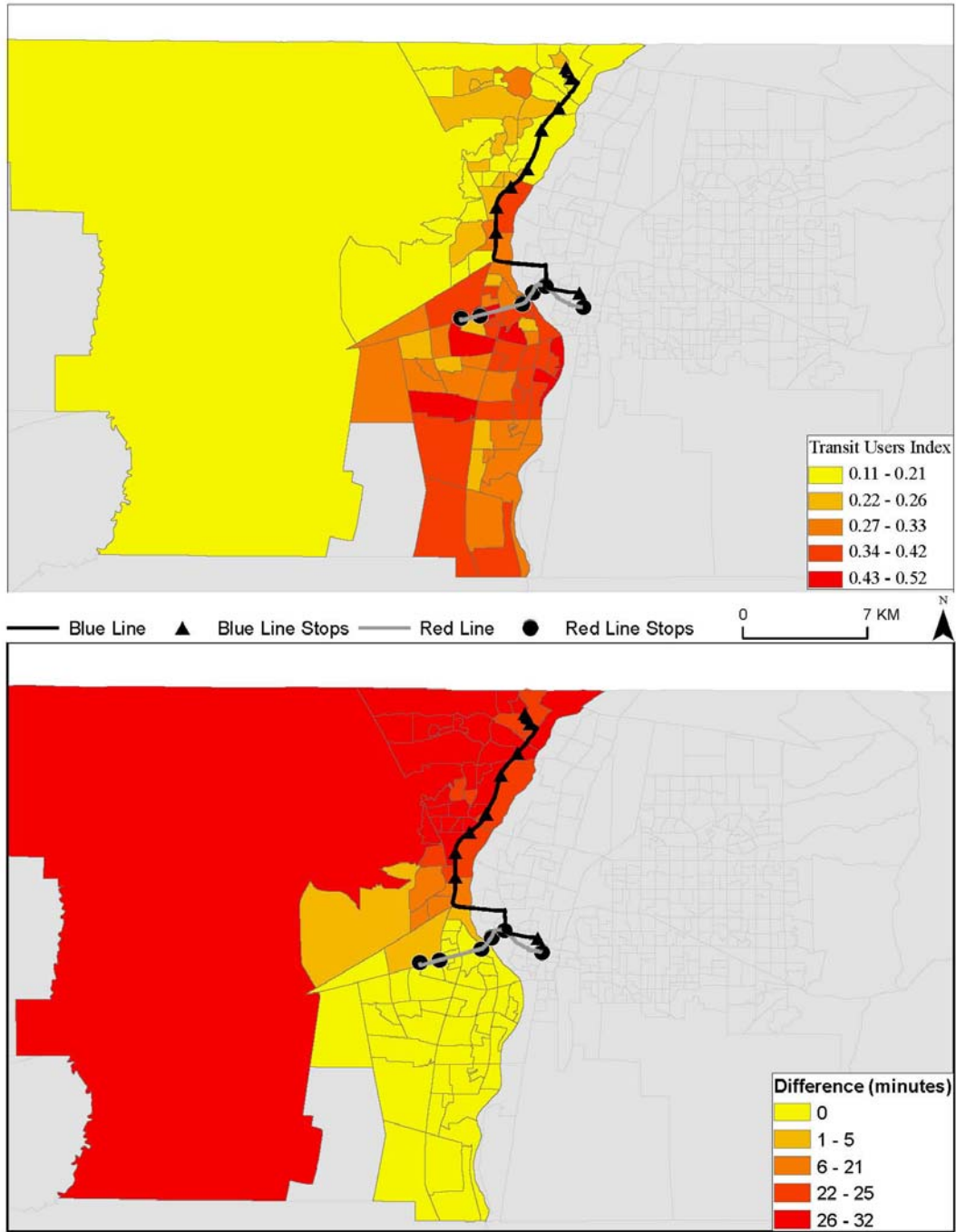


Figure 4.7. Visual comparison of Transit Index with average weighted time savings by block group for the off-peak time period to Downtown

In Figure 4.8, the weighted average travel time savings to the address points from downtown for the P.M. peak period shows some block groups with a savings differing from the off-peak period (Figure 4.9). The same dichotomy between time savings is apparent between north and south, but there is a greater number of block groups seeing a time savings between 1-5 minutes in each of these scenarios than the toward Downtown scenarios, but this still is insignificant to the overall distributions of time savings amounts.

These visual comparisons, of the aggregated time savings of the address points by census block groups and transit users index builds on the visualization of just the address points' time saving previously presented and the correlation tables. The time savings between block groups that experience a time savings and those that do not can be justified by more than just a visual comparison and is achieved through a statistical test.

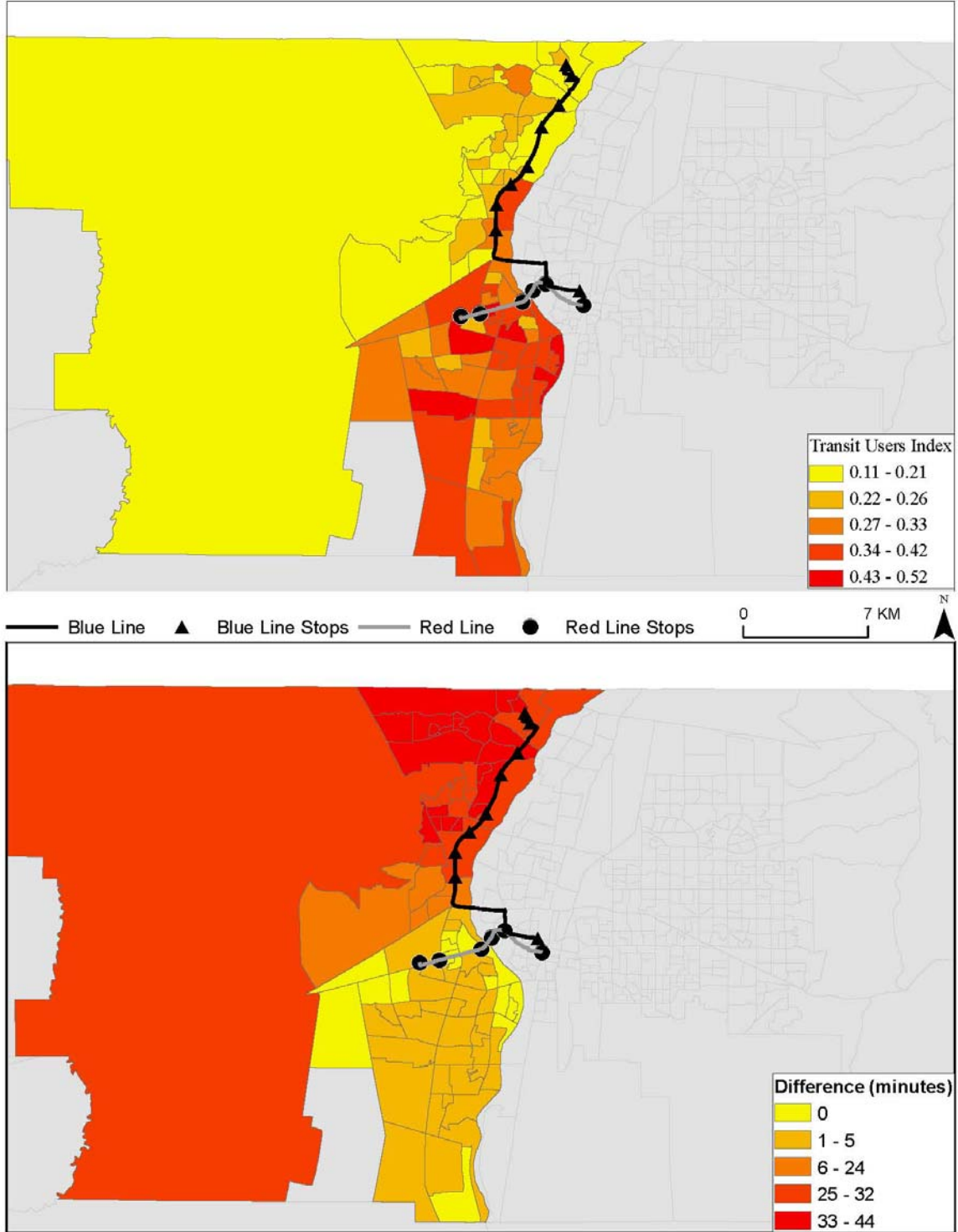


Figure 4.8. Visual comparison of Transit Index with average weighted time savings by block group for the P.M. peak time period from Downtown

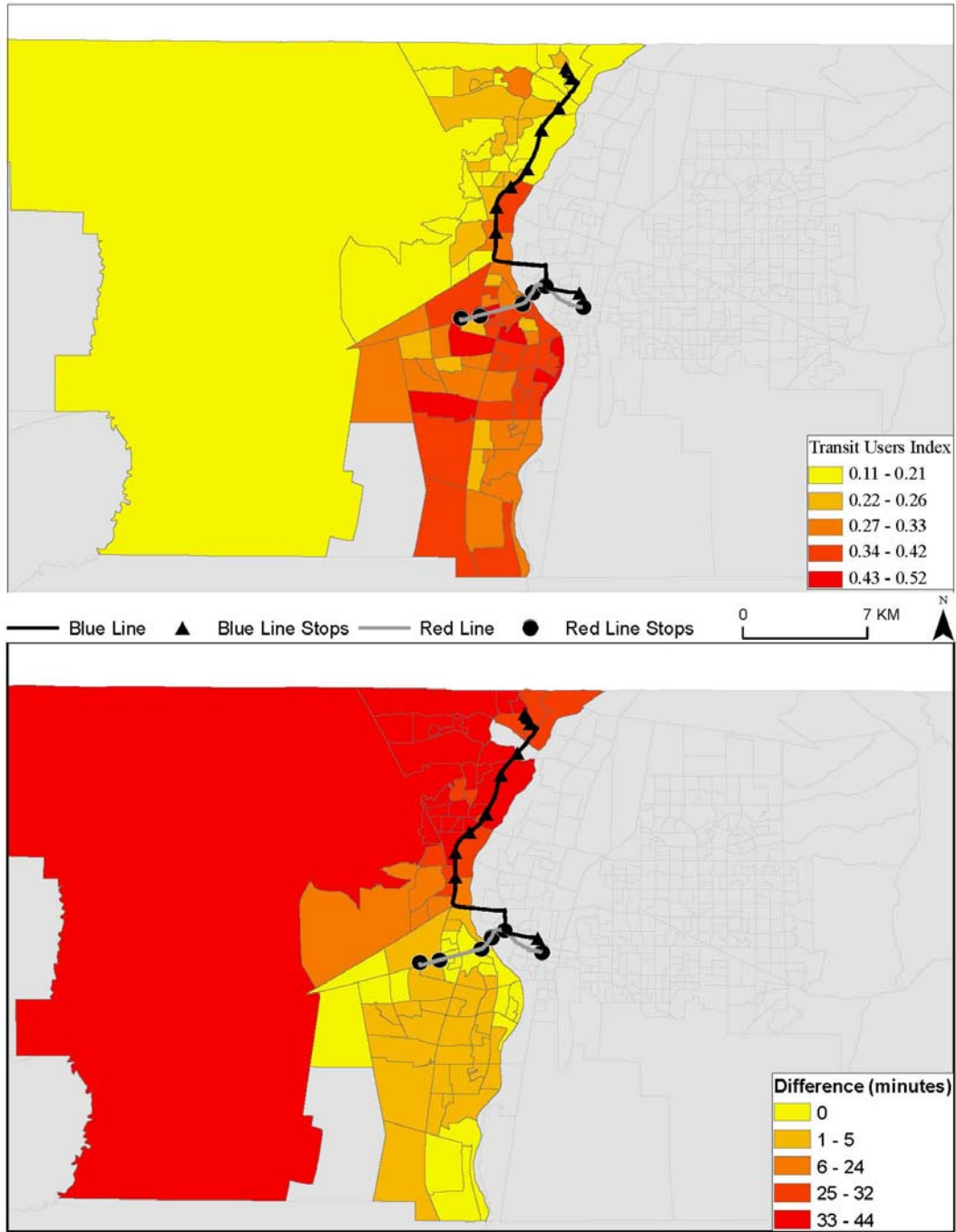


Figure 4.9. Visual comparison of Transit Index with average weighted time savings by block group for the off-peak time period from Downtown

4.2. Non-parametric Comparisons

The socioeconomic indicators were determined to be non-normal (see Appendices O-R), which were the normality results of the census data indicators for the block groups in the study area, used in all scenarios. These graphs, also produced in Minitab, show the results of Anderson-Darling normality tests, and all of the p-values are less than 0.005, leading to a rejection of the null hypothesis of normality. This test uses an empirical cumulative distribution function of the data to an expected normal distribution. These results required a non-parametric comparison to be used for evaluation of differences in socioeconomic proportions between block groups. The Kruskal-Wallis test, which compares the medians between two groups, was selected for the comparison of the indicators between groups without a significant time savings and those with one. The null hypothesis for this test is that the medians are statistically indistinguishable; whereas the alternative hypothesis is that they are statistically different.

The 5-minute time savings threshold was used to determine the two groups of block groups to compare those without a significant travel time savings and those with a savings. The average weighted time savings for the block groups was compared to the median weighted time savings, as the time savings were not normally distributed either. Figure 4.10 shows a comparison between the block groups symbolized by the 5-minute threshold for the average weighted time and the median weighted time savings from the address points to Downtown, for the off-peak time period. Apparent is the same classification for the block groups into significant time savings and insignificant savings, whether average or median time savings is used, despite the non-normality of the distribution of times. For an example of the non-normal distribution see Appendix S,

which shows the rejection of the normality assumption for the Anderson-Darling test, for the from Downtown to address points for the off-peak time period. This is a representative distribution of the other scenarios, since the time savings were not drastically different. The analysis proceeded using the average weighted travel times to classify the block groups into significant or insignificant travel time categories.

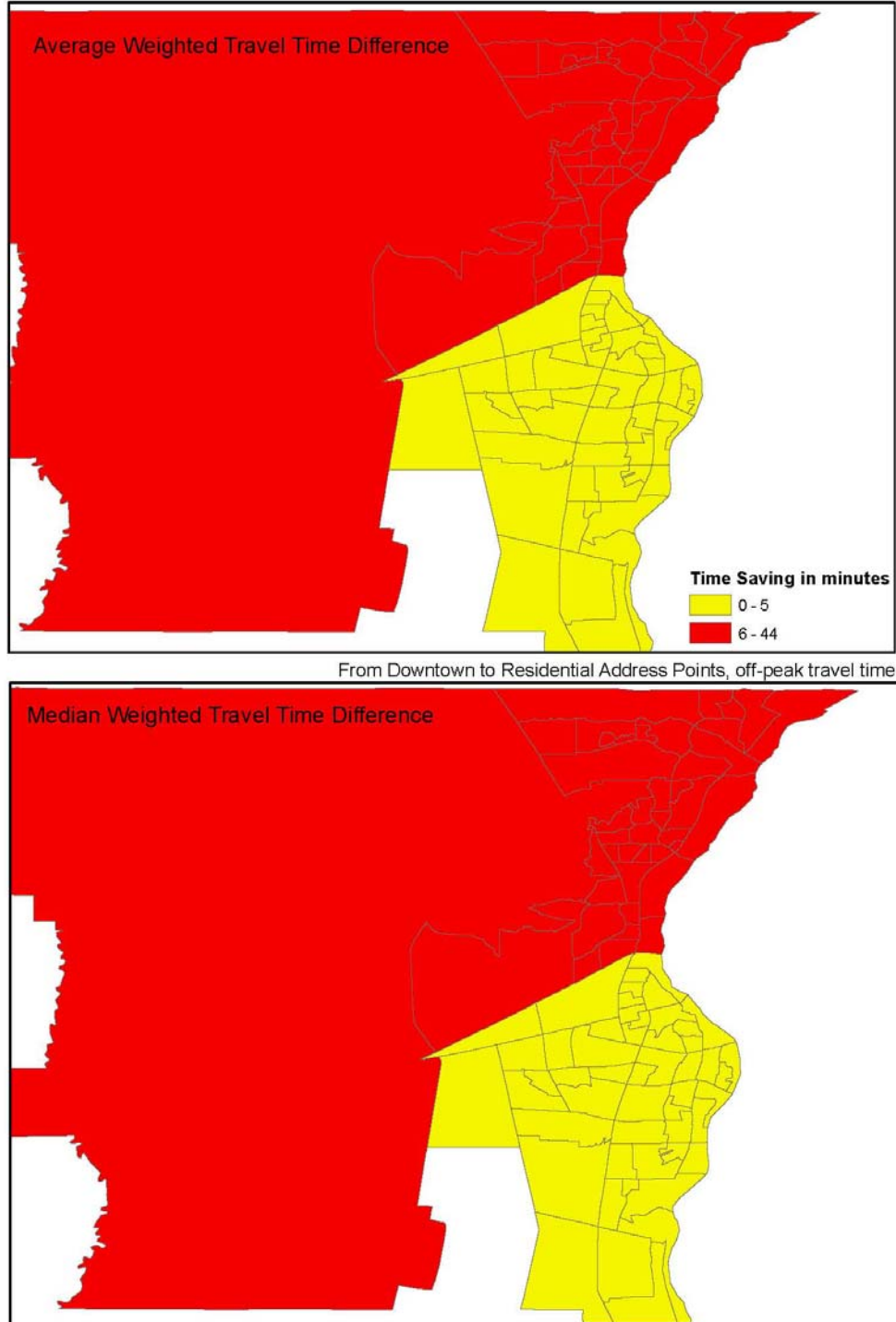


Figure 4.10. Comparison of average weighted time savings by block group to the median time, for categorization into groups with time savings and without for statistical comparison of census variables

The delineation between census block groups with a significant time savings created the same groupings for three of the scenarios. These scenarios were from downtown to address points for the P.M. peak and the off-peak time, and to Downtown for the A.M. peak period, which all resulted in the same block groups as the ones classified in Figure 4.10. This resulted in the same block groups to compare the socioeconomic variables, with 41 blocks seeing a time benefit and 51 not seeing a time benefit for these three scenarios. One scenario, to Downtown from the address points for the off-peak time, did have an additional block group classified as not seeing a time benefit (Figure 4.11).

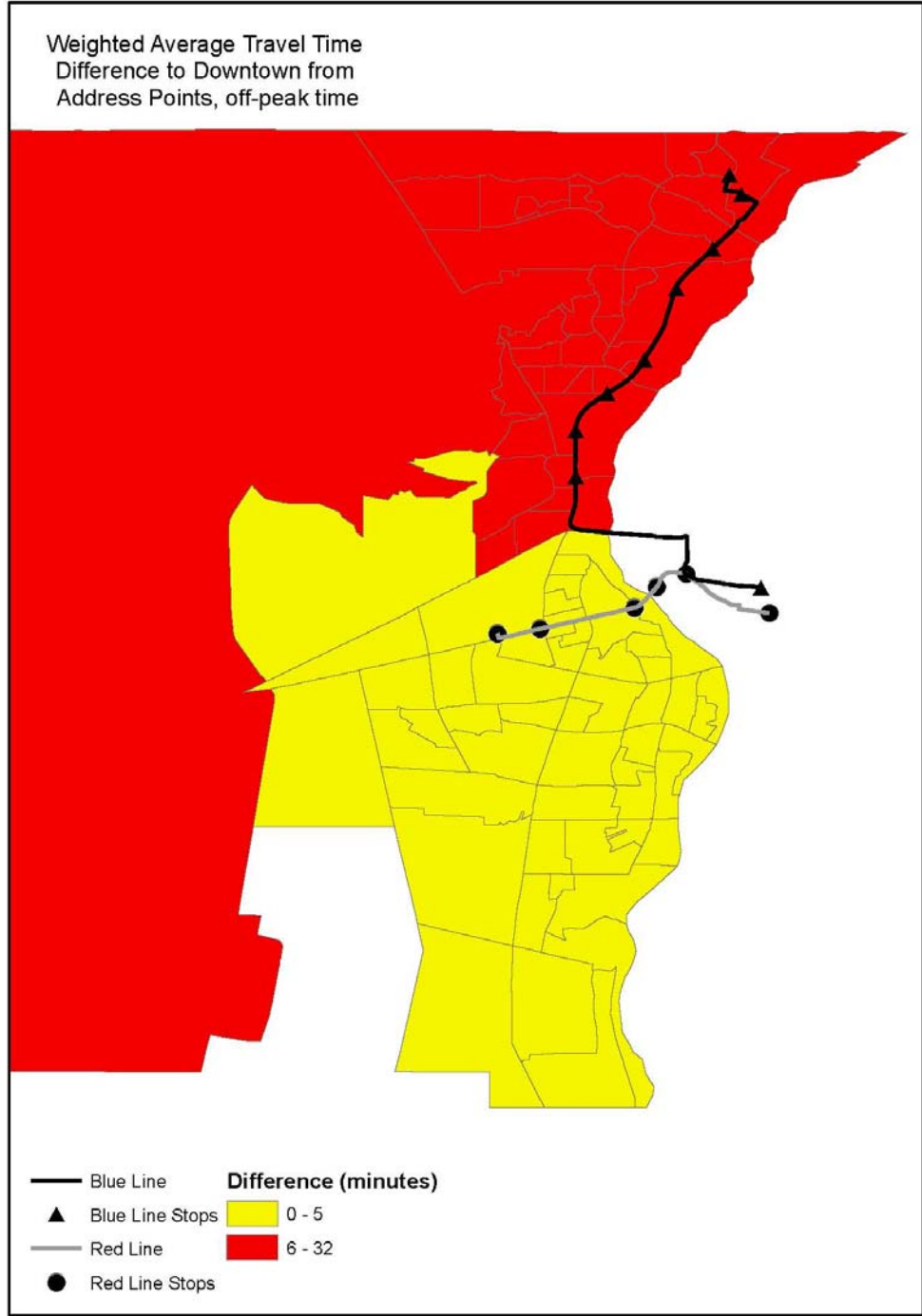


Figure 4.11. Additional block group classified in the insignificant savings category, for statistical comparison of census variables

The null hypothesis of the Kruskal-Wallis is that the medians of the indicators are equal between the block groups with time savings and those without. The p-value for all of these tests, carried out in Minitab, are in Tables 4.5-4.8, and leads to the rejection of this hypothesis at any alpha level. That is, the medians are not equal in any of the comparisons for the three time periods which had the same block groups categorized. Therefore, there is a significant difference between the median of the socio-economic indicators for the block groups that have a time savings greater than 5 minutes and those with less. Furthermore, the Z scores indicate that the medians for all of the tests for the groups experiencing a time benefit were less than the medians of the groups not experiencing a benefit. That is, the block groups experiencing the time savings benefit of greater than 5 minutes did not have as high as a socio-economic need as those that did not realize a benefit from the Rapid Ride lines. Also, similar to the correlation performed previously, the transit index has the largest Z score of the tests, indicating the strongest relationship, though the proportion in poverty is a very strong indicator as well.

Time Benefit	N	Median	Z score	P-value
Yes	41	.01216	-4.16	.000
No	51	.04396	4.16	

Table 4.5. Kruskal-Wallis test for difference of medians of the proportion of no car households

Time Benefit	N	Median	Z score	P-value
Yes	41	.3714	-6.53	.000
No	51	.4300	6.53	

Table 4.6. Kruskal-Wallis test for difference of medians of the proportion of combined age

Time Benefit	N	Median	Z score	P-value
Yes	41	.05378	-7.15	.000
No	51	.18830	7.15	

Table 4.7. Kruskal-Wallis test for difference of medians of the proportion of poverty

Time Benefit	N	Median	Z score	P-value
Yes	41	.2010	-7.45	.000
No	51	.3273	7.45	

Table 4.8. Kruskal-Wallis test for difference of medians of the transit index

For the scenario to Downtown during the off-peak period, which had an additional block group categorized as not having a time benefit, these same comparisons were run and are recorded in tables 4.9-4.12. These are very similar to the other times' comparisons, and the interpretation is the same.

Time Benefit	N	Median	Z score	P-value
Yes	40	.01248	-4.03	.000
No	52	.04874	4.03	

Table 4.9. Kruskal-Wallis test for difference of medians of the proportion of no car households

Time Benefit	N	Median	Z score	P-value
Yes	40	.3747	-6.25	.000
No	52	.4297	6.25	

Table 4.10. Kruskal-Wallis test for difference of medians of the proportion of combined age

Time Benefit	N	Median	Z score	P-value
Yes	40	.05485	-6.85	.000
No	52	.18574	6.85	

Table 4.11. Kruskal-Wallis test for difference of medians of the proportion of poverty

Time Benefit	N	Median	Z score	P-value
Yes	40	.2088	-7.12	.000
No	52	.3270	7.12	

Table 4.12. Kruskal-Wallis test for difference of medians of the transit index

4.4. Limitations

The limitations of this study are the necessary simplifications and assumptions all research must make. Only all day bus routes on the Westside of Albuquerque were considered along with the Rapid Ride routes. There are express and commuter buses within the study area, which run during the peak travel times. These would have possibly increased the accessibility during these times. Also, only weekday bus schedules were considered, but weekends would provide an additional case that could have interesting results as all of the buses are more infrequent. Validation of the assumption that the bus schedules analyzed for compilation of average waiting times and average travel times for the three time periods are reasonably accurate would require field validation- a massive undertaking. It is assumed that ABQ Ride has these schedules based on real world conditions, with them reflecting increased travel time during the peak periods, for example. Additionally, average wait times for the buses were used for the three time periods, as well as average travel times for these same periods. This simplification still required a lot of effort to calculate, but the decision to use three time period categories could be seen as arbitrary durations to average time over. The census data used is almost 10 years old, but the most current available, and did necessitate the aggregation of the time savings address points, as socioeconomic data is not available at a finer scale.

While the use of address points increases the accuracy of the measure of accessibility of individual buildings, problems arise when large complexes are represented by a point. For example, in Figure 4.5 the two large apartments, representing over 100 units are just two dots, which may have an effect on their accessibility if they have different spatial relationships with the street network. The address points are

snapped to the closest street and the analysis is run from there. The points might not represent the apartment's relationship to the closest street and could skew the results. This is also possible with any of the residential points- it is assumed the closest street to the point is the only possible route to the bus stop. This of course depends on the accuracy of the street network and obviously does not include informal passages. The street network is a more accurate representation of accessibility than radial distances from bus stops, but it still assumes that pedestrians do not cut through empty lots and otherwise not travel on the sidewalks.

The assumption of walking to the bus stop ignores bicycling, being dropped off, or using the park and ride facilities that exist for the Rapid Ride termini and used a constant walking speed of 3 kilometers per hour. The simplification of downtown as a destination was necessary and provides a representative destination as to the effects of the Rapid Ride on travel time. Whether transit users actually work downtown isn't terribly relevant, as there are transfers to other city buses, intercity buses and rail, or continuing on the Rapid Rides to destinations farther east. In any case, the time savings calculated here would still be realized with the addition of the Rapid Rides.

Chapter Five: Conclusions

The implementation of new bus routes in an automobile-oriented city should benefit those that depend on their services the most (Sánchez, et al. 2003). The construction of a detailed household-level temporal accessibility model to assess changes caused by new routes can highlight the travel time savings with consideration of bus frequencies and travel time for specific travel periods, walking time on the street network, and the use of address points as origins. The current methods and level of simplification of public transportation accessibility studies are not detailed enough to capture travel time at the household level and at varying times of day. The goal of this paper was to map the effect that recent changes to the public transit system have had on the accessibility that the system provides in Albuquerque, NM and to quantify this change in accessibility of the city to traditional transit users, the vehicle-less, low income, and elderly and young people.

The mapping of the effect of the addition of the Rapid Ride routes to travel time between address points in the study area and downtown showed a marked variation in savings for individual addresses. The address point maps symbolized by travel time savings displayed a level of detail not possible through the generalization of addresses into census block groups. The use of address points, along with detailed bus routes and stops, allows the specific effects of stops on time savings to be visualized, as noticed around Rapid Ride Blue Line Stops in the northern part of the study area. However, the intentional generalization of these points allows the approximation of travel time savings intervals to be visualized. These are useful since the travel time savings of destinations

within the given areas can be estimated, even though an analysis was not run for that particular location.

The first objective was to model the temporal accessibility that the transit system provides to the city, to account for the A.M., P.M., and off-peak variability, in frequency and travel time, and spatial accessibility to the system through walking on the street network. This model did highlight some variations between the travel times for a particular direction. For example, some residences saw a greater off-peak travel time savings with the Rapid Ride to Downtown than during the A.M. peak time period. Also, the difference between route directions was noticed as well, with time savings for the commute out of Downtown to address points was higher for some points than commuting into Downtown, regardless of time period.

The assumption that the time saving would be equal across varying time periods would miss this detail. The reason to include the variations in both the frequency of buses and the travel time of buses during the three time periods proves useful and insightful to the analysis of transit users who work or travel outside of the traditional business hours of the day, represented here as the A.M. and P.M. peak scenarios. The additional time saving may not seem like much, possibly an extra 5 minutes saved, but the simplification of temporal accessibility into one time period would miss additional benefits that might be valuable and unexpected- such as increased accessibility during off-peak hours. My hypothesis, that there is a variation, appears correct, though I did not statistically test the significance of the difference between travel time savings between the three time periods and two directions.

The use of the street network for walking to and from the destinations and origins increased the accuracy of the model and underscored the merits of this method. For example, few addresses in the southern portion of the study area were close enough to the Rapid Ride stops to walk the additional distance to utilize the service. Hence, there was no observed time savings for these address points. Instead, these address points took the local bus, Route 66, with numerous stops and a slower travel time. This goes against reason, but the time saved by not walking to the farther apart spaced Rapid Ride Red Line stops allowed them to realize the shortest time to the destination, by taking the same bus as before, despite the addition of the Rapid Ride. In reality, residents at such addresses would probably walk the additional distance to the Rapid Ride Red Line stops, as these coincide with the Route 66 bus stops. This would be more feasible, because the waiting time at these locations would be the average of both of the two bus lines, considerably shorter than either alone, which this model did not take into consideration.

The second objective was to quantify the change in accessibility of traditional transit users caused by the additional routes, using accessibility to downtown as the representative destination to measure the change in time. This time savings with the addition of the Rapid Ride routes, between the groups of transit users and the rest of the study area, was discovered to be very significant. Despite the Red Line running through the southern area, no significant travel time was observed by visual inspection of the address points, for all time and direction scenarios. First, the general correlations of block groups between the average weighted time savings and the socio-economic indicators resulted in reasonably strong, negative correlations. These were significant at any reasonable alpha-level, with p-values of 0 to three decimal places for all of the time

and direction scenarios. This means that the higher the average time savings actualized by the Rapid Ride routes, the smaller the proportion of transit users in those block groups. The implications of this result are that there was indeed a social impact to the routing of the Rapid Ride routes. Whether this resulting injustice caused by the current alignment was intentional or not is unknown, but a great disparity exists in the transit users residences and those who benefited the most.

In general, a less than 5 minute savings for most of the transit users block groups was observed, and several saw no time savings at all, depending on time period and direction. The off-peak time period to downtown from address points saw the greatest number of block groups with an average weighted time savings of 0. The visual comparison between the average weighted time savings by block group and the transit users index provided visual confirmation of the correlations provided in the tables. It also allows the magnitude of weighted time savings by block group to be visualized. The large difference between less than a 5 minute time savings and a 20 or 30 minute time savings was easily observed across all of the time and direction scenarios.

To further analyze this relationship, a formal statistical comparison was used. Since the data were not normally distributed, a non-parametric test was used, the Kruskal-Wallis test. This required the classification of block groups into those that saw a significant time savings and those that did not. The distinction of less than 5 minutes and more than 5 minutes was used for the groupings and allowed the transit users proportions between block groups to be formally tested for differences. Three of the scenarios classified the groupings of block groups as the same, with the to downtown, off-peak time classifying an additional block group in the no significant time savings category.

The Kruskal-Wallis test, which assumed the median values between the two groups were equal, resulted in the rejection of this hypothesis for all of the time and direction scenarios, even for the to downtown, off-peak scenario.

The strongest indicator for the relationship between travel time savings and socio-economic variables was the transit index, though all variables were significant in all comparisons. This index was an equally weighted average of the proportions in poverty, those without a car, and over 65 and under 18 in the block groups. Though, this index does not necessarily need to be created, as all of these variables are correlated and spatially auto-correlated, but the proportion in poverty provides as nearly as strong relationships as a combined index, if only one variable is sought for simplicity.

Future research could take into consideration random sampling within the study area to determine proportion of actual ridership within block groups to provide additional weighting, rather than relying on socio-economic proxies, more accurate destinations/origins, and determination of the most frequent hours that transit is used. Such additional information could further be used to increase the efficacy of new bus route additions, both for routing lines and stop placement, but also frequencies that would be the most beneficial for populations that depend most on its services. Also, a more complete model of the bus system could be constructed to assess transportation options more accurately. Not only can this model be used to analyze various scenarios in an existing public transportation network, but it can be utilized for detailed decisions about future route alignments and stop placement. Travel time to and from individual weighted residential addresses to various destinations can be analyzed and mapped, with calculated times able to be compared and maximized for the largest benefit to the greatest number of

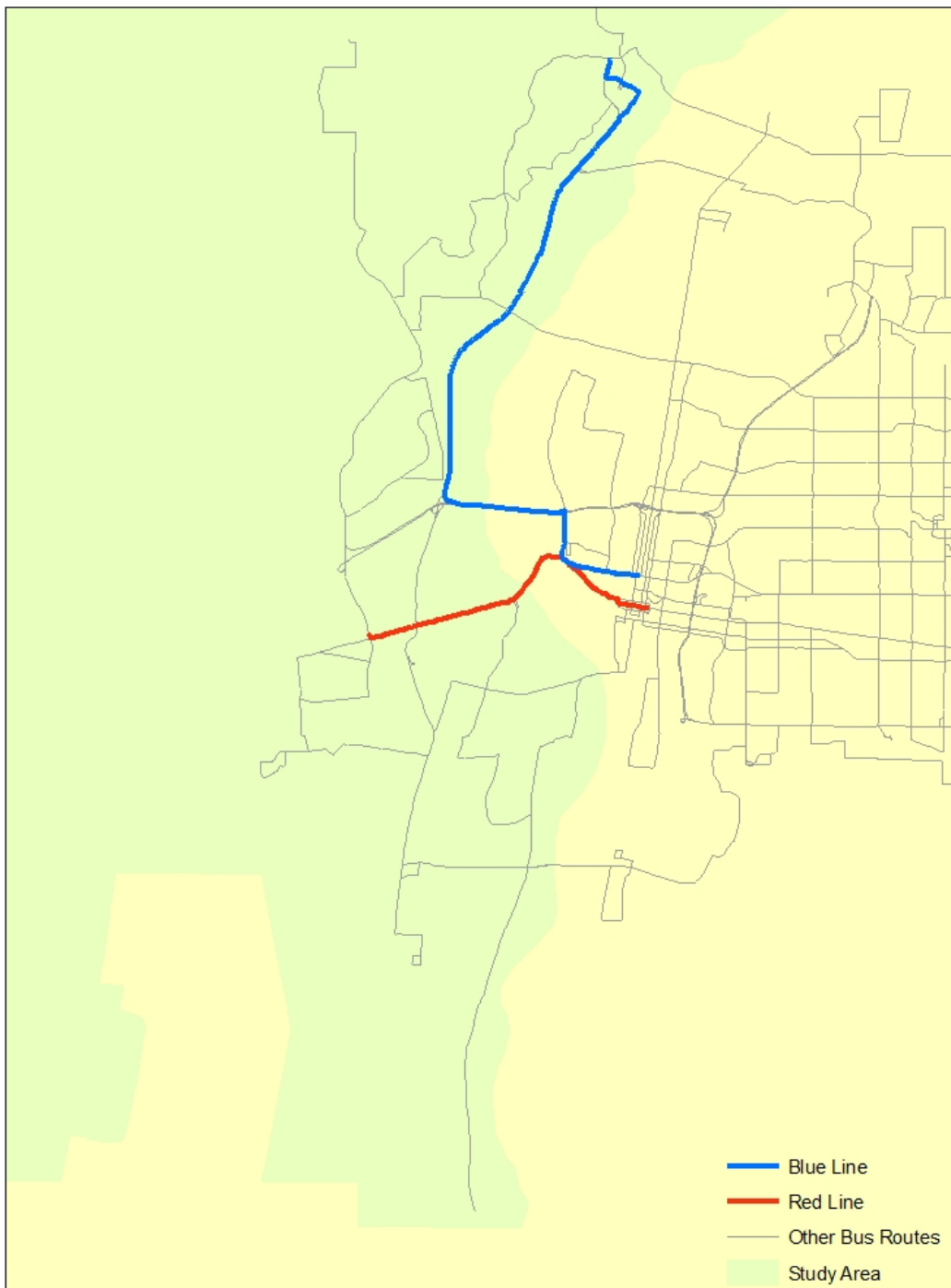
people. Whether this is based on density alone, or a weighted density, where address points within transit user's block groups are given more consideration is one possibility.

With the successful construction and implementation of this model, social justice issues can be analyzed at a finer level of detail than previously possible. The evaluation of the transportation improvements, due to the Rapid Ride implementations, are defined by this research in terms of accessibility, a correction to transportation modeling which reflects equity considerations (Litman 2007). The findings of a disparity in the spatial-temporal accessibility benefits, due to the current Rapid Ride route alignments, suggest an inequitable distribution of benefits of these routes, namely a decrease in travel time. The lack of a noticeable decrease in travel time for transit users in the southern area of the Westside is a barrier for the transition out of poverty and may significantly and adversely affect employment opportunities for people with low earnings capability (US GAO 1998). Considering that the suggested alignment of the Rapid Ride Blues Line was not followed, where it was to traverse the length of Coors Blvd, the current alignment appears to favor choice commuters into Downtown and the UNM area farther east (City of Albuquerque 2003).

The conclusion of the Mid Region Council of Government (2004) that there are no social inequalities in the distribution of the public transportation system can be challenged with these results. It is apparent that the method of assessing accessibility has a considerable influence upon the conclusions about equity that are reached. The households that benefit with the greatest time savings from the new route alignments, in the northern portion of the study area, are not where the greatest proportion of transit users are located, in the southern portion of the study area. This is visually apparent,

from the address point maps and block groups, as well as statistically confirmed through correlations and formal tests.

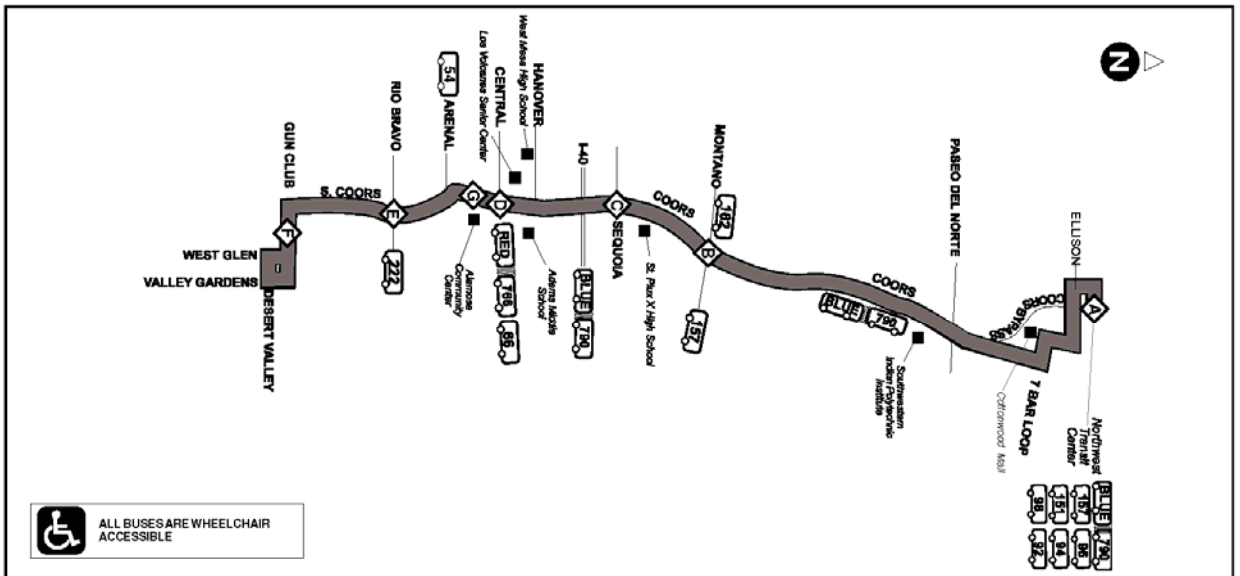
Appendix A



Study Area with Rapid Ride routes emphasized over the existing bus routes

Appendix B

Route 155 / Ruta 155 - Coors Blvd. Line Eff. 8/16/2008



Routes 155 - Weekday Southbound

A	B	C	D	E	F
558a	614a	619a	628a	639a	646a
631a	647a	652a	701a	712a	719a
703a	719a	724a	734a	745a	752a
730a	746a	751a	801a	812a	819a
800a	816a	821a	831a	842a	849a
830a	846a	851a	901a	912a	919a
900a	916a	921a	931a	942a	949a
930a	946a	951a	1001a	1012a	1019a
1000a	1016a	1021a	1031a	1042a	1049a
1030a	1046a	1051a	1101a	1112a	1119a
1100a	1116a	1121a	1131a	1142a	1149a
1130a	1146a	1151a	1201p	1212p	1219p
1200p	1216p	1221p	1232p	1243p	1250p
1230p	1246p	1251p	102p	113p	120p
100p	116p	121p	132p	143p	150p
130p	146p	151p	202p	213p	220p
200p	216p	221p	232p	243p	250p
230p	246p	251p	302p	313p	320p
300p	316p	321p	332p	345p	353p
330p	345p	353p	404p	417p	425p
400p	415p	423p	434p	447p	455p
433p	451p	456p	507p	520p	528p
506p	524p	529p	540p	553p	601p
536p	554p	559p	610p	623p	631p
606p	624p	629p	638p	649p	657p
640p	656p	701p	710p	721p	729p
719p	735p	740p	749p	800p	808p
803p	819p	824p	833p	844p	852p
841p	857p	902p	911p	922p	930p
937p	953p	958p	1007p	1018p	1026p

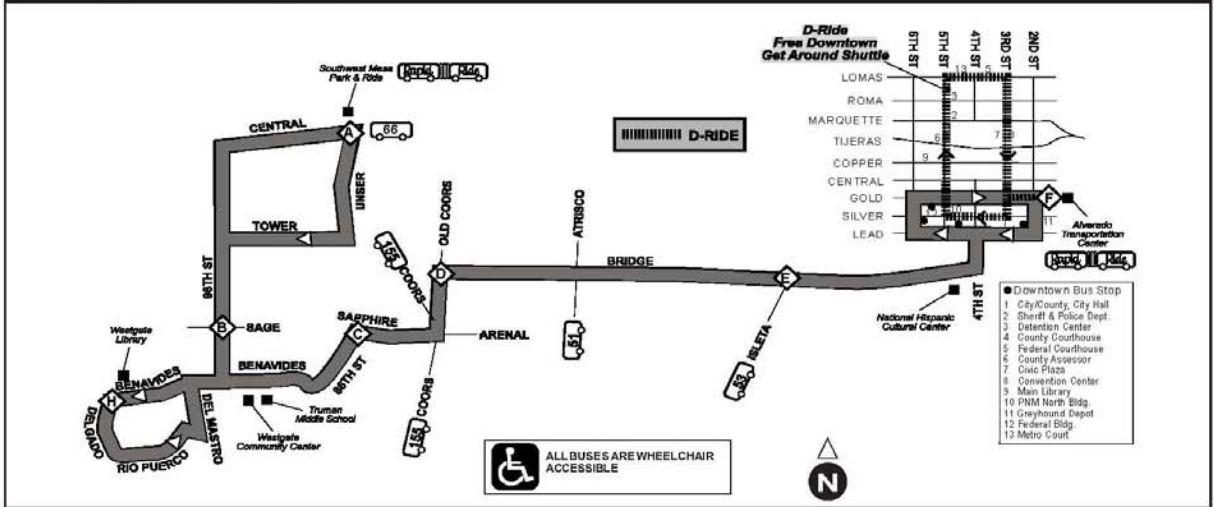
Routes 155 - Weekday Northbound

F	E	D	C	B	A
629a	635a	646a	654a	700a	715a
654a	700a	712a	721a	727a	742a
729a	735a	747a	756a	802a	817a
802a	808a	820a	829a	835a	850a
832a	838a	850a	859a	905a	920a
902a	908a	920a	929a	935a	950a
931a	937a	949a	958a	1004a	1019a
959a	1005a	1017a	1026a	1032a	1047a
1028a	1034a	1046a	1055a	1101a	1116a
1058a	1104a	1116a	1125a	1131a	1146a
1128a	1134a	1146a	1155a	1201p	1216p
1158a	1204p	1216p	1225p	1231p	1246p
1228p	1234p	1246p	1255p	101p	116p
1259p	105p	117p	126p	132p	147p
129p	135p	147p	156p	202p	217p
202p	208p	220p	229p	235p	250p
232p	238p	250p	259p	305p	320p
302p	308p	320p	329p	335p	352p
333p	339p	352p	401p	407p	424p
406p	412p	425p	434p	440p	457p
436p	442p	455p	504p	512p	529p
506p	512p	525p	534p	542p	559p
542p	548p	601p	610p	618p	634p
612p	618p	631p	639p	645p	700p
642p	648p	659p	707p	713p	728p
709p	715p	726p	734p	740p	755p
739p	745p	756p	804p	810p	825p
834p	840p	851p	859p	905p	920p
933p	939p	950p	958p	1004p	1019p

Appendix C

**Route 54/Ruta 54
Bridge/Westgate**

Eff. 1/17/2009



Route 54 - Weekday Eastbound

Route 54 - Weekday Westbound

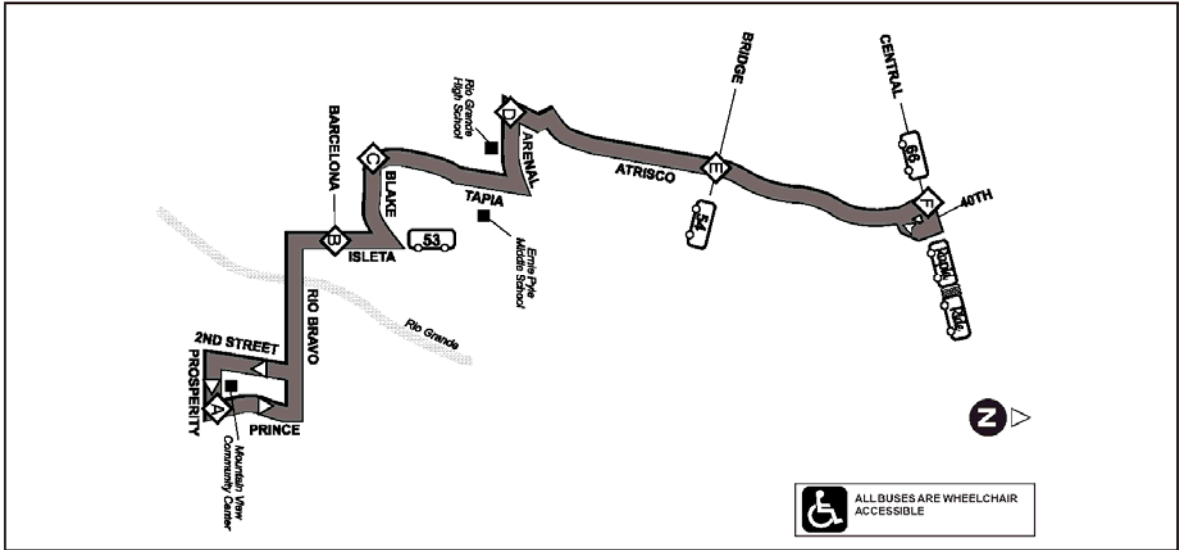
STOP	STOP	STOP	STOP	STOP	STOP
545a	551a	555a	603a	609a	618a
638a	644a	648a	656a	703a	713a
724a	732a	737a	746a	754a	804a
810a	818a	823a	832a	840a	850a
902a	908a	912a	920a	926a	935a
946a	952a	956a	1004a	1010a	1019a
1031a	1037a	1041a	1049a	1055a	1104a
1116a	1122a	1126a	1134a	1140a	1149a
1201p	1207p	1211p	1219p	1225p	1234p
1246p	1252p	1256p	104p	110p	119p
131p	137p	141p	149p	156p	205p
218p	224p	228p	236p	243p	252p
307p	313p	317p	325p	332p	343p
352p	400p	406p	414p	421p	432p
433p	441p	448p	458p	505p	516p
519p	527p	534p	544p	551p	602p
604p	612p	619p	629p	636p	646p
646p	652p	656p	704p	710p	718p
733p	739p	743p	751p	757p	805p
816p	822p	826p	834p	840p	848p
900p	906p	910p	918p	924p	932p

STOP	STOP	STOP	STOP	STOP	STOP
553a	601a	607a	614a	622a	634a
638a	646a	652a	659a	707a	719a
723a	731a	738a	746a	754a	806a
815a	823a	830a	838a	846a	858a
900a	908a	914a	922a	930a	936a
945a	953a	959a	1007a	1015a	1021a
1030a	1038a	1044a	1052a	1100a	1106a
1115a	1123a	1129a	1137a	1145a	1151a
1200p	1208p	1214p	1222p	1230p	1236p
1245p	1253p	1259p	107p	115p	121p
130p	138p	144p	152p	200p	208p
215p	223p	233p	241p	249p	257p
300p	308p	318p	326p	334p	342p
340p	348p	358p	406p	414p	423p
420p	428p	439p	447p	455p	504p
505p	513p	524p	532p	540p	549p
550p	558p	609p	617p	625p	632p
643p	651p	700p	708p	716p	723p
725p	733p	739p	747p	755p	802p
810p	818p	824p	831p	839p	845p
900p	908p	914p	921p	929p	935p

Appendix D

Route 51/Ruta 51 - Atrisco/Rio Bravo

Eff. 03/15/2008



Route 51 - Weekdays Northbound

Station	531a	537a	541a	545a	549a	555a
Mountain View Community Center	531a	537a	541a	545a	549a	555a
Isleta & Barcelona	636a	642a	646a	650a	654a	700a
Blake & Tapia	741a	748a	752a	756a	800a	807a
Atrisco & Arena	846a	853a	857a	901a	905a	912a
Central & Atrisco	951a	958a	1002a	1006a	1010a	1017a
Bridge	1056a	1103a	1107a	1111a	1115a	1122a
Atrisco & Rio Bravo	1201p	1208p	1212p	1216p	1220p	1227p
Isleta & Barcelona	106p	113p	117p	122p	126p	133p
Blake & Tapia	211p	218p	222p	227p	231p	238p
Atrisco & Arena	316p	323p	327p	332p	336p	343p
Central & Atrisco	421p	428p	432p	437p	441p	448p
Bridge	526p	532p	536p	540p	544p	550p
Atrisco & Rio Bravo	631p	637p	641p	645p	649p	655p

Route 51 - Weekdays Southbound

Station	605a	612a	616a	620a	624a	631a
Mountain View Community Center	605a	612a	616a	620a	624a	631a
Isleta & Barcelona	710a	717a	721a	725a	729a	736a
Blake & Tapia	815a	822a	826a	830a	834a	841a
Atrisco & Arena	920a	927a	931a	935a	939a	946a
Central & Atrisco	1025a	1032a	1036a	1040a	1044a	1051a
Bridge	1130a	1137a	1141a	1145a	1149a	1156a
Atrisco & Rio Bravo	1235p	1242p	1246p	1250p	1254p	101p
Isleta & Barcelona	140p	147p	151p	156p	200p	207p
Blake & Tapia	245p	252p	256p	301p	305p	312p
Atrisco & Arena	350p	357p	401p	406p	410p	417p
Central & Atrisco	455p	502p	506p	510p	514p	521p
Bridge	600p	607p	611p	615p	619p	626p

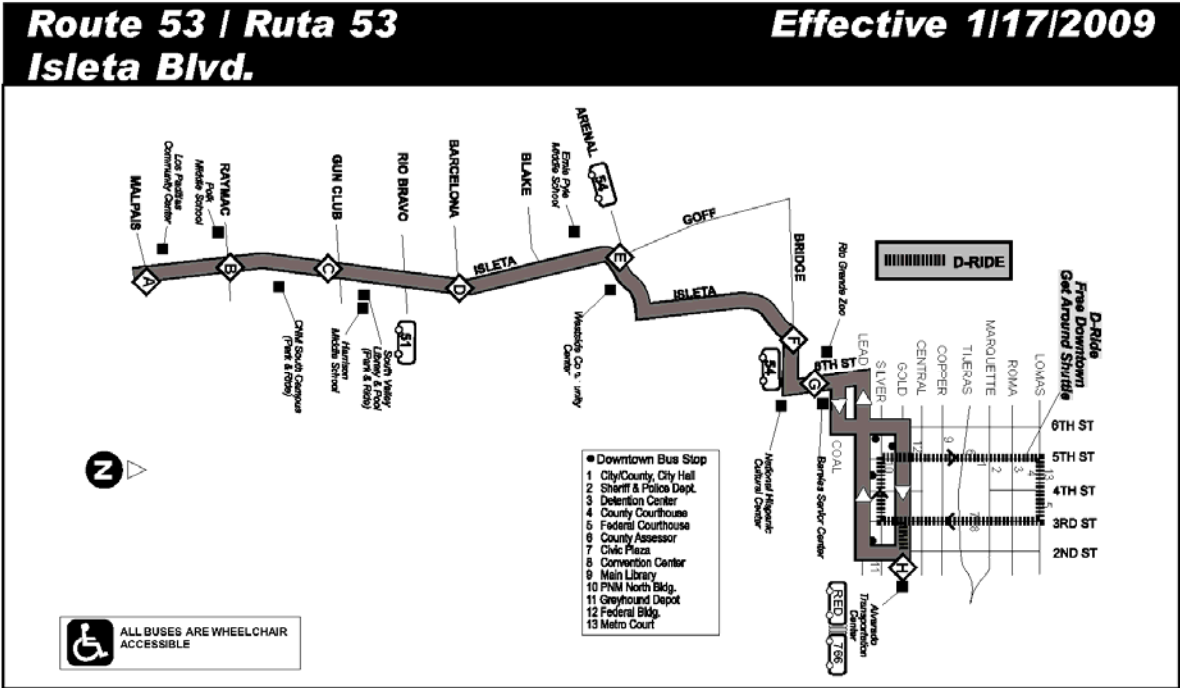
Route 51 - Saturday Northbound

Station	631a	638a	642a	646a	650a	657a
Mountain View Community Center	631a	638a	642a	646a	650a	657a
Isleta & Barcelona	736a	743a	747a	751a	755a	802a
Blake & Tapia	841a	848a	852a	856a	900a	907a
Atrisco & Arena	945a	952a	956a	1001a	1005a	1012a
Central & Atrisco	1050a	1057a	1101a	1106a	1110a	1117a
Bridge	1155a	1202p	1206p	1211p	1215p	1222p
Atrisco & Rio Bravo	100p	107p	111p	116p	120p	127p
Isleta & Barcelona	208p	214p	218p	222p	226p	232p
Blake & Tapia	313p	319p	323p	327p	331p	337p
Atrisco & Arena	418p	424p	428p	432p	436p	442p
Central & Atrisco	523p	529p	533p	537p	541p	547p
Bridge	628p	634p	638p	642p	646p	652p

Route 51 - Saturday Southbound

Station	600a	607a	611a	615a	619a	626a
Mountain View Community Center	600a	607a	611a	615a	619a	626a
Isleta & Barcelona	705a	712a	716a	720a	724a	731a
Blake & Tapia	810a	817a	821a	825a	829a	836a
Atrisco & Arena	915a	922a	926a	930a	934a	941a
Central & Atrisco	1020a	1027a	1031a	1035a	1039a	1046a
Bridge	1125a	1132a	1136a	1140a	1144a	1151a
Atrisco & Rio Bravo	1230p	1237p	1241p	1245p	1249p	1256p
Isleta & Barcelona	135p	142p	146p	151p	155p	202p
Blake & Tapia	240p	247p	251p	256p	300p	307p
Atrisco & Arena	345p	352p	356p	401p	405p	412p
Central & Atrisco	450p	457p	501p	506p	509p	516p
Bridge	555p	602p	606p	610p	614p	621p

Appendix E



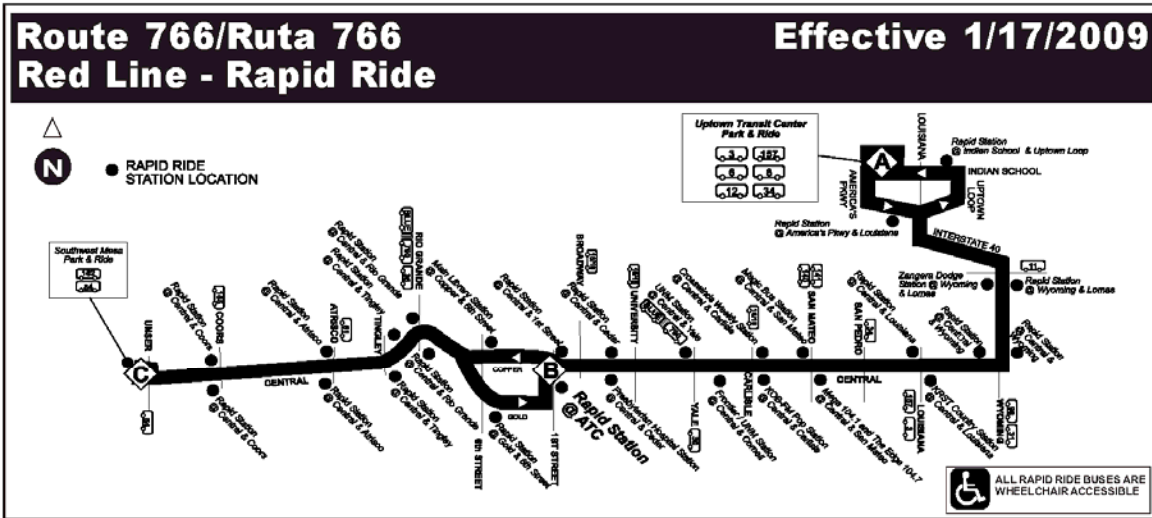
Route 53 - Weekday Northbound

Stop	532a	536a	541a	545a	553a	557a	603a	610a
MALPAIS & ISLETA	532a	536a	541a	545a	553a	557a	603a	610a
ISLETA & RAYMARC	617a	621a	626a	630a	638a	642a	648a	655a
VALLEY CAMPUS	702a	706a	711a	715a	723a	727a	733a	740a
ISLETA & BARCELONA	746a	750a	753a	759a	808a	812a	818a	825a
ISLETA & ARENAL	831a	835a	838a	844a	853a	857a	903a	910a
ISLETA & BRIDGE	916a	920a	923a	929a	938a	942a	948a	955a
8TH & ATLANTIC (ZOO)	1001a	1005a	1008a	1014a	1023a	1027a	1033a	1040a
ALVARADO TRANSPORTATION CENTER	1046a	1050a	1053a	1059a	1108a	1112a	1118a	1125a
	1129a	1133a	1136a	1142a	1151a	1155a	1201p	1210p
	1214p	1218p	1221p	1227p	1236p	1240p	1246p	1255p
	101p	105p	108p	114p	123p	127p	133p	140p
	146p	150p	153p	159p	208p	212p	218p	225p
	231p	235p	238p	244p	253p	257p	303p	310p
	316p	320p	323p	329p	338p	342p	348p	355p
	401p	405p	408p	414p	423p	427p	433p	440p
	438p	442p	445p	451p	500p	504p	510p	517p
	533p	537p	540p	546p	555p	559p	605p	612p
	620p	624p	627p	632p	640p	644p	650p	657p
	702p	706p	711p	715p	723p	727p	733p	740p

Route 53 - Weekday Southbound

Stop	620a	625a	632a	637a	643a	651a	654a	658a
MALPAIS & ISLETA	620a	625a	632a	637a	643a	651a	654a	658a
ISLETA & RAYMARC	705a	710a	717a	722a	728a	736a	739a	743a
VALLEY CAMPUS	745a	750a	757a	802a	808a	816a	819a	823a
ISLETA & BARCELONA	835a	840a	847a	852a	858a	906a	909a	913a
ISLETA & ARENAL	920a	925a	932a	937a	943a	951a	954a	958a
ISLETA & BRIDGE	1005a	1010a	1016a	1021a	1027a	1034a	1037a	1041a
8TH & ATLANTIC (ZOO)	1050a	1055a	1101a	1106a	1112a	1119a	1122a	1126a
ALVARADO TRANSPORTATION CENTER	1135a	1140a	1146	1151a	1157a	1204p	1207p	1211p
	1220p	1225p	1231p	1236p	1242p	1249p	1252p	1256p
	105p	110p	116p	121p	127p	134p	137p	141p
	150p	155p	201p	206p	213p	221p	224p	228p
	235p	240p	246p	251p	258p	306p	309p	313p
	320p	325p	331p	336p	343p	351p	354p	358p
	357p	402p	408p	413p	420p	428p	431p	435p
	450p	455p	502p	507p	515p	523p	526p	530p
	538p	543p	550p	555p	603p	611p	614p	618p
	620p	625p	632p	637p	643p	649p	652p	656p
	705p	709p	715p	720p	726p	732p	735p	739p

Appendix G



Route 766 - Weekday & Saturday

WESTBOUND

UPTOWN CENTER	ALVARADO TRANSPORTATION CENTER	CENTRAL & UNIBER	Weekday Only
A	B	C	
530a	556a	614a	
545a	611a	629a	
600a	628a	646a	
611a	639a	657a	
622a	650a	708a	
633a	701a	719a	
644a	712a	730a	
655a	723a	741a	
706a	734a	752a	
717a	745a	803a	
728a	756a	814a	
739a	807a	825a	
750a	818a	836a	
801a	829a	847a	
812a	840a	858a	
823a	851a	909a	
834a	902a	920a	
845a	913a	931a	
856a	924a	942a	
907a	935a	953a	
918a	946a	1004a	
929a	957a	1015a	
940a	1008a	1026a	
951a	1019a	1037a	
1002a	1030a	1048a	
1013a	1041a	1059a	
1024a	1052a	1110a	
1035a	1103a	1121a	
1046a	1114a	1132a	
1057a	1125a	1143a	
1108a	1136a	1154a	
1119a	1147a	1205p	
1130a	1158a	1216p	
1141a	1209p	1227p	
1152a	1220p	1238p	
1203p	1231p	1249p	
1214p	1242p	100p	
1225p	1253p	111p	
1236p	104p	122p	
1247p	115p	133p	

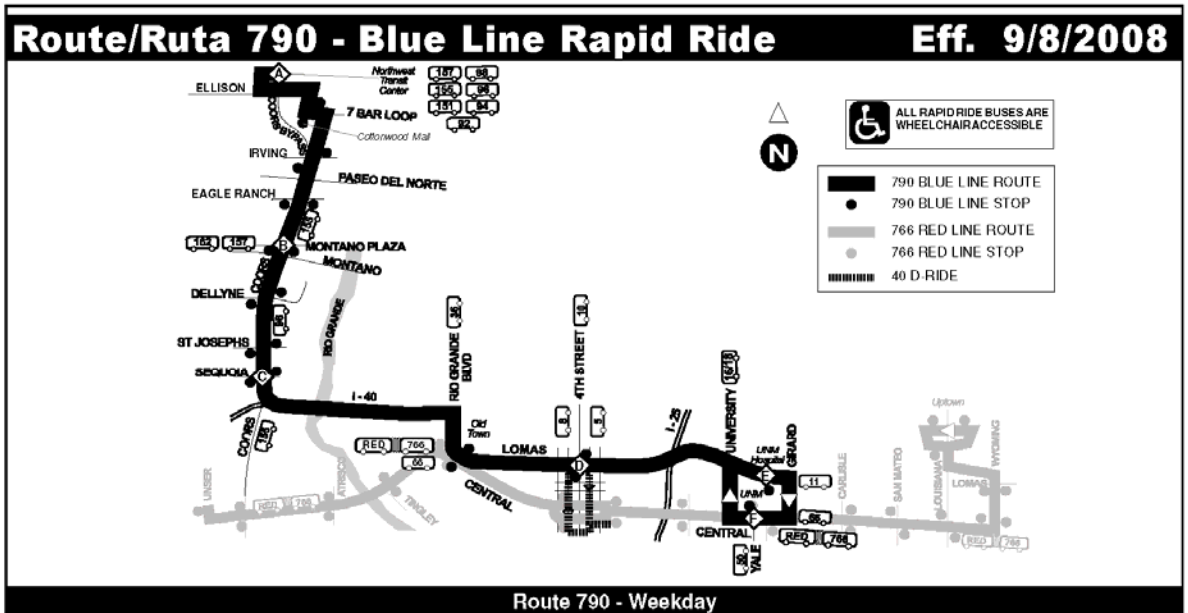
UPTOWN CENTER	ALVARADO TRANSPORTATION CENTER	CENTRAL & UNIBER
A	B	C
1258p	126p	144p
109p	137p	155p
120p	148p	206p
131p	159p	217p
142p	210p	228p
153p	221p	239p
204p	232p	250p
215p	243p	301p
226p	254p	312p
237p	305p	323p
248p	316p	334p
259p	327p	345p
310p	338p	356p
321p	349p	407p
332p	400p	418p
343p	411p	429p
354p	422p	440p
405p	433p	451p
416p	444p	502p
427p	455p	513p
438p	506p	524p
449p	517p	535p
500p	528p	546p
511p	539p	557p
522p	550p	608p
533p	601p	619p
544p	612p	630p
555p	623p	641p
606p	634p	652p
617p	645p	703p
628p	656p	714p
639p	707p	725p
650p	718p	736p
701p	729p	747p
712p	740p	758p
723p	751p	809p
734p	802p	820p
745p	813p	831p
756p	824p	842p

UPTOWN CENTER	ALVARADO TRANSPORTATION CENTER	CENTRAL & UNIBER	Weekday Only
C	B	A	
530a	545a	615a	
546a	601a	631a	
602a	618a	651a	
613a	629a	702a	
624a	640a	713a	
635a	651a	724a	
642a	658a	731a	
653a	709a	742a	
705a	721a	754a	
717a	733a	806a	
728a	744a	817a	
738a	754a	827a	
748a	804a	837a	
759a	815a	848a	
810a	826a	859a	
822a	838a	911a	
832a	848a	921a	
843a	859a	932a	
854a	910a	943a	
905a	921a	954a	
916a	932a	1005a	
927a	943a	1016a	
938a	954a	1027a	
949a	1005a	1038a	
1000a	1016a	1049a	
1011a	1027a	1100a	
1022a	1038a	1111a	
1033a	1049a	1122a	
1044a	1100a	1133a	
1055a	1111a	1144a	
1106a	1122a	1155a	
1117a	1133a	1206p	
1128a	1144a	1217p	
1139a	1155a	1228p	
1150a	1206p	1239p	
1201p	1217p	1250p	
1212p	1228p	101p	
1223p	1239p	112p	
1234p	1250p	123p	
1245p	101p	134p	

UPTOWN CENTER	ALVARADO TRANSPORTATION CENTER	CENTRAL & UNIBER
C	B	A
1256p	112p	145p
107p	123p	156p
118p	134p	207p
129p	145p	218p
140p	156p	229p
151p	207p	240p
202p	218p	251p
213p	229p	302p
224p	240p	313p
235p	251p	324p
246p	302p	335p
257p	313p	346p
308p	324p	357p
319p	335p	408p
330p	346p	419p
341p	357p	430p
352p	408p	441p
403p	419p	452p
414p	430p	503p
425p	441p	514p
436p	452p	525p
447p	503p	536p
458p	514p	547p
509p	525p	558p
520p	536p	609p
531p	547p	620p
542p	558p	631p
553p	609p	642p
604p	620p	653p
615p	631p	704p
626p	642p	715p
637p	653p	726p
648p	704p	737p
659p	715p	748p
710p	726p	759p
721p	737p	810p
734p	750p	823p
745p	759p	832p
754p	810p	843p

EASTBOUND

Appendix H



Route 790 - Weekday

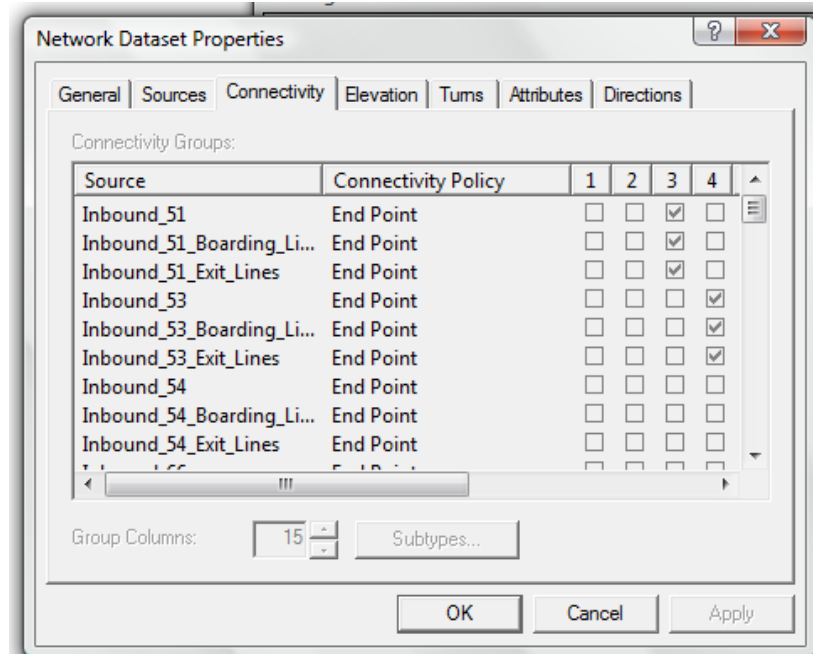
EASTBOUND

NORTHWEST TRANSIT CENTER	COORS & MONTANO	COORS & SEQUOIA	LOMAS & 4TH STREET	LOMAS at UNIV HOSPITAL	VALE & CENTRAL
A	B	C	D	E	F
530a	543a	548a	601a	609a	614a
555a	602a	613a	626a	634a	639a
618a	631a	636a	649a	657a	702a
634a	647a	652a	707a	715a	720a
649a	702a	707a	727a	735a	740a
702a	715a	720a	740a	748a	753a
720a	733a	738a	758a	806a	811a
735a	748a	753a	813a	821a	826a
759a	812a	817a	830a	838a	843a
812a	825a	830a	843a	851a	856a
831a	844a	849a	902a	910a	915a
847a	900a	905a	918a	926a	931a
902a	915a	920a	933a	941a	946a
922a	935a	940a	953a	1001a	1006a
944a	957a	1002a	1015a	1023a	1028a
1004a	1017a	1022a	1035a	1043a	1048a
1024a	1037a	1042a	1055a	1103a	1108a
1044a	1057a	1102a	1115a	1123a	1128a
1104a	1117a	1122a	1135a	1143a	1148a
1124a	1137a	1142a	1155a	1203p	1208p
1144a	1157a	1202p	1215p	1223p	1228p
1204p	1217p	1222p	1235p	1243p	1248p
1224p	1237p	1242p	1255p	103p	108p
1244p	1257p	102p	115p	123p	128p
104p	117p	122p	135p	143p	148p
124p	137p	142p	155p	203p	208p
144p	157p	202p	215p	223p	228p
205p	218p	223p	236p	244p	249p
226p	239p	244p	257p	305p	310p
247p	300p	305p	318p	326p	331p
308p	321p	326p	339p	347p	352p
327p	340p	345p	358p	407p	412p
345p	358p	403p	418p	427p	432p
403p	418p	423p	435p	447p	452p
415p	430p	435p	450p	459p	504p
431p	446p	451p	506p	515p	520p
452p	507p	512p	527p	536p	541p
514p	529p	534p	549p	558p	603p
542p	557p	602p	614p	622p	627p
615p	628p	633p	645p	653p	658p
645p	658p	703p	715p	723p	728p
715p	728p	733p	745p	753p	758p
745p	758p	803p	815p	823p	828p
815p	828p	833p	845p	853p	858p

WESTBOUND

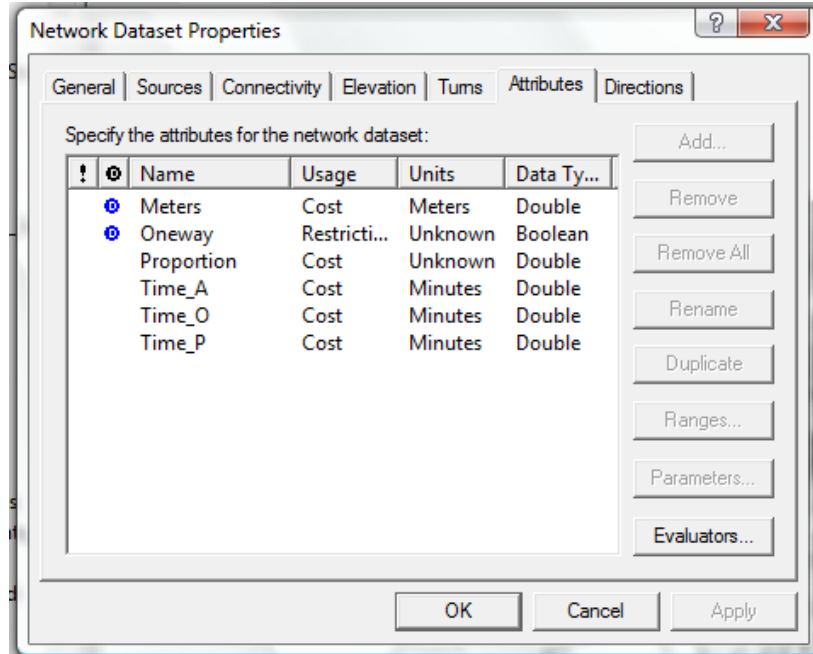
CENTRAL & VALE	LOMAS & 4TH STREET	COORS & SEQUOIA	COORS & MONTANO	NORTHWEST TRANSIT CENTER
F	D	C	B	A
616a	623a	637a	642a	655a
641a	648a	702a	707a	720a
704a	711a	725a	730a	743a
722a	729a	746a	751a	804a
742a	749a	806a	811a	824a
755a	802a	819a	824a	836a
813a	820a	836a	841a	853a
828a	835a	850a	855a	907a
845a	852a	907a	912a	924a
900a	907a	922a	927a	939a
918a	925a	940a	945a	957a
948a	955a	1010a	1015a	1027a
1008a	1015a	1030a	1035a	1047a
1030a	1037a	1052a	1057a	1109a
1050a	1057a	1112a	1117a	1129a
1110a	1117a	1132a	1137a	1149a
1130a	1137a	1152a	1157a	1209p
1150a	1157a	1212p	1217p	1229p
1210p	1217p	1232p	1237p	1249p
1230p	1237p	1252p	1257p	111p
1250p	1257p	112p	117p	131p
110p	117p	132p	137p	151p
130p	137p	152p	157p	211p
150p	157p	212p	217p	231p
210p	217p	232p	237p	251p
230p	237p	252p	257p	311p
251p	258p	313p	318p	332p
312p	319p	334p	339p	353p
333p	340p	355p	400p	415p
354p	401p	419p	424p	439p
414p	421p	439p	444p	459p
434p	441p	459p	504p	519p
454p	501p	519p	524p	539p
506p	513p	531p	536p	551p
522p	529p	547p	552p	607p
543p	550p	608p	613p	628p
605p	612p	630p	635p	649p
629p	636p	649p	654p	707p
700p	707p	720p	725p	739p
730p	737p	750p	755p	808p
800p	807p	820p	825p	839p
830p	837p	850p	855p	908p
900p	907p	920p	925p	939p

Appendix I



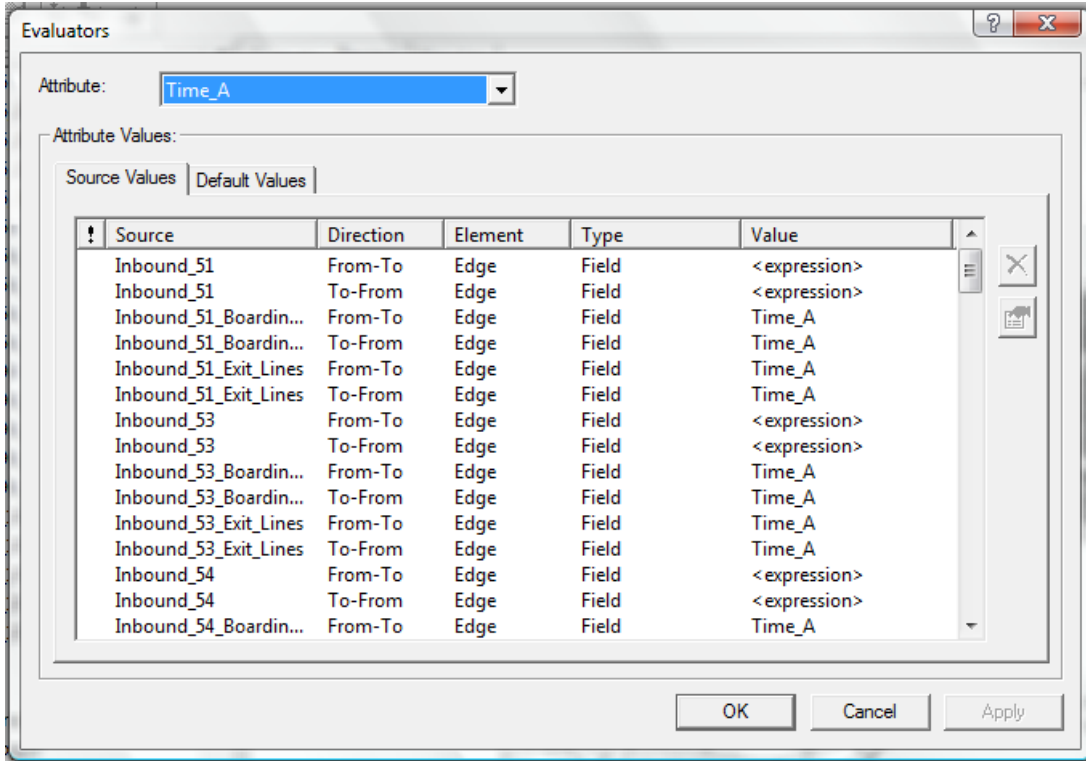
Sample of the Network Dataset Properties, Connectivity Groups

Appendix J



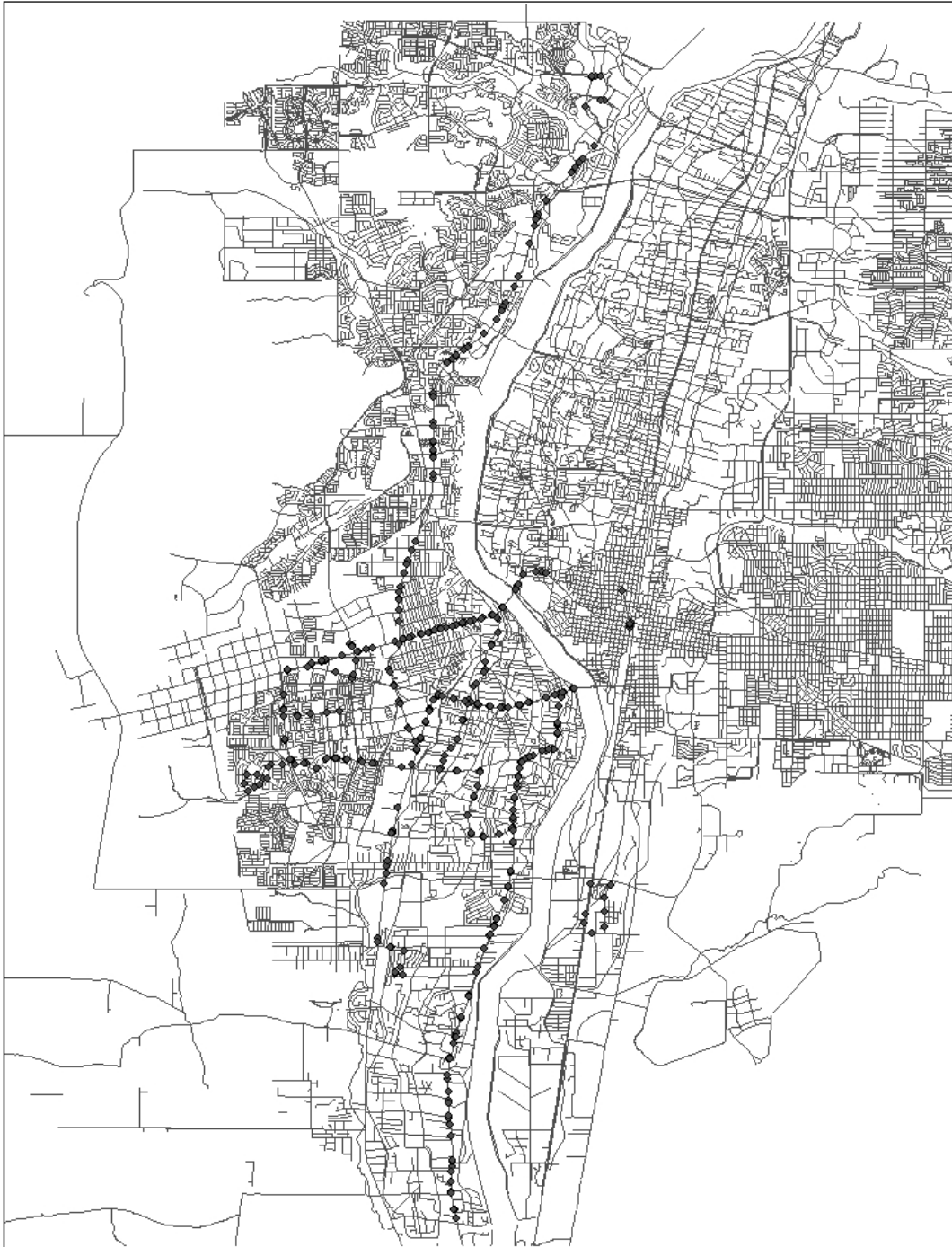
Network Dataset Properties, Attributes: Time A.M. peak, off-peak, and P.M. peak

Appendix K



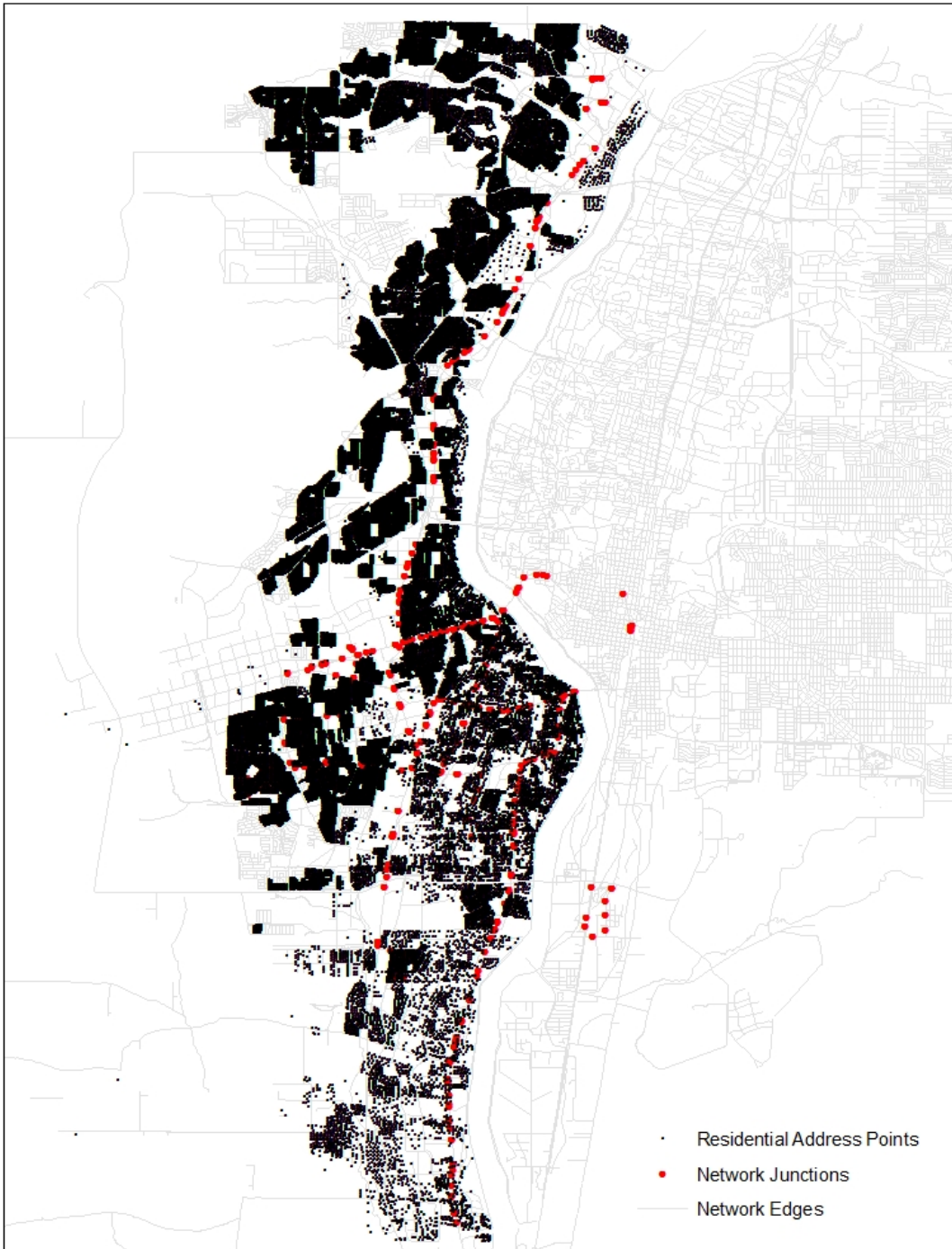
Example of the evaluators for the A.M. peak time period, including bus routes, boarding lines and exit lines

Appendix L



Completed network, which includes the walking network and the select bus routes and associated elements, with the nodes connecting the two networks also displayed

Appendix M



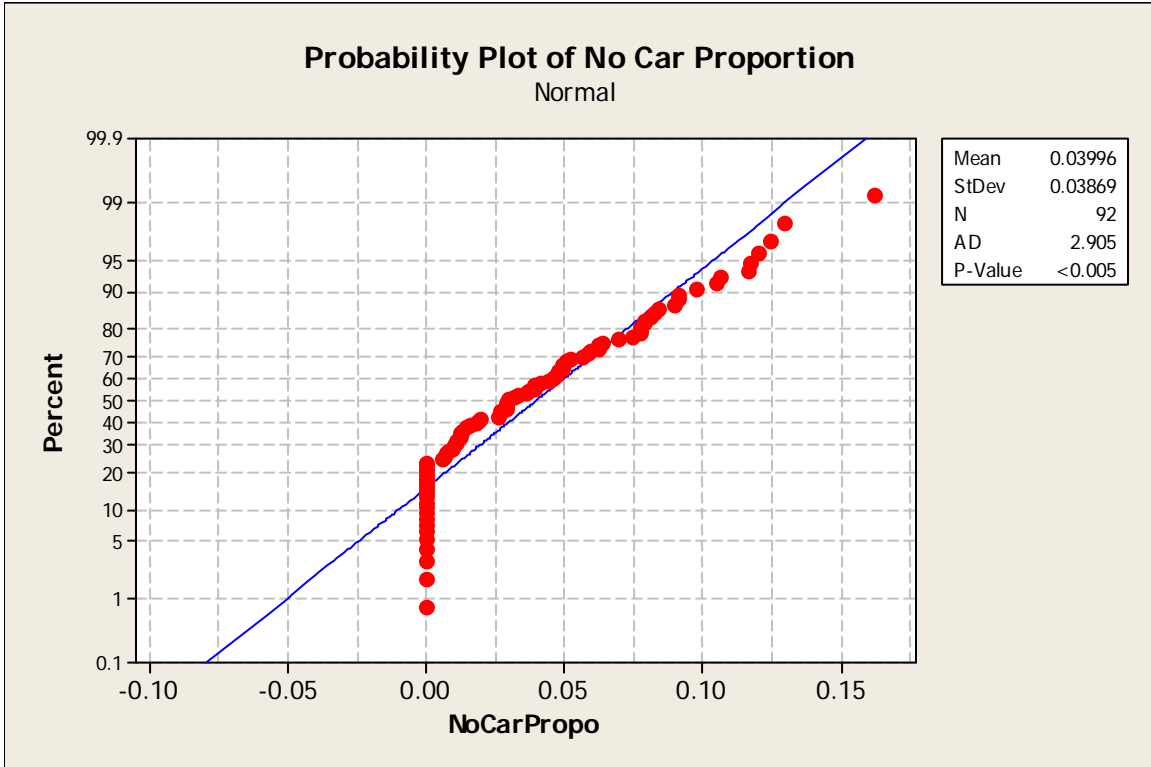
Residential address points in relation to the complete network

Appendix N

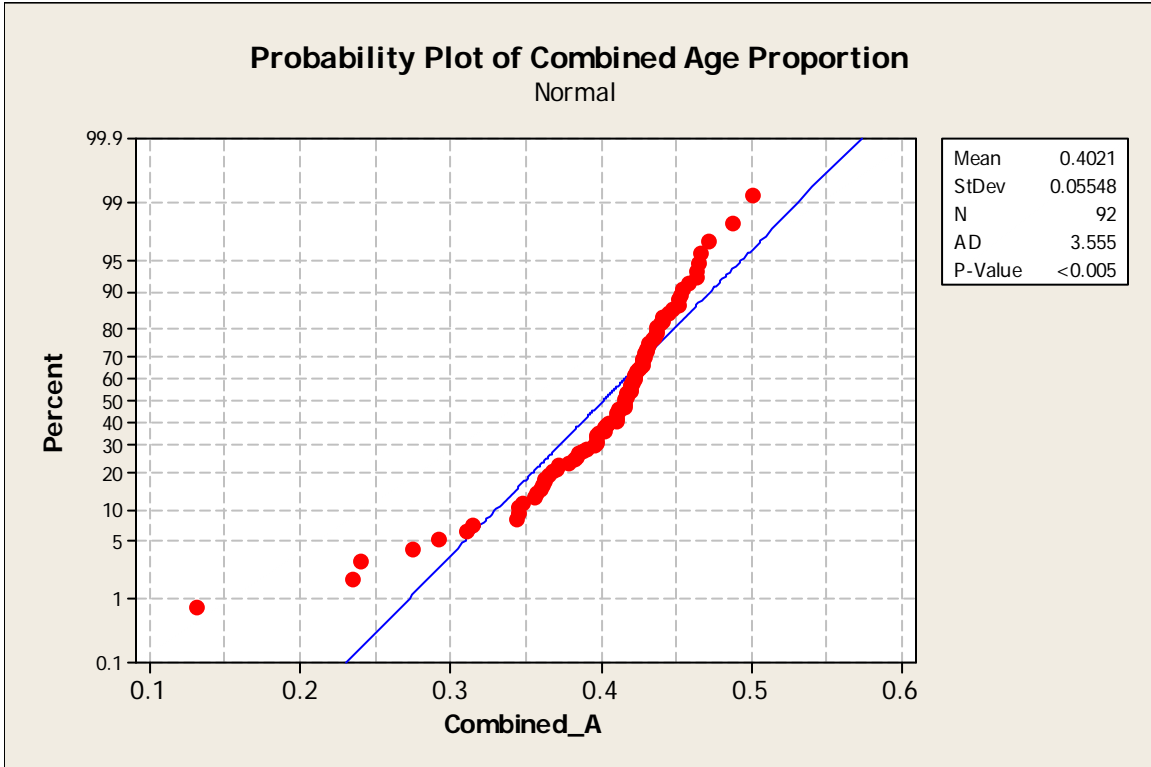
	Rank No Car	Rank Combined Age	Rank Poverty	Rank Transit Index
A.M. to Downtown	-0.449	-0.597	-0.727	-0.726
P.M. from Downtown	-0.447	-0.536	-0.711	-0.706
Off-peak to Downtown	-0.417	-0.609	-0.732	-0.729
Off-peak from Downtown	-0.429	-0.525	-0.701	-0.694

Spearman's Rank correlations ρ values

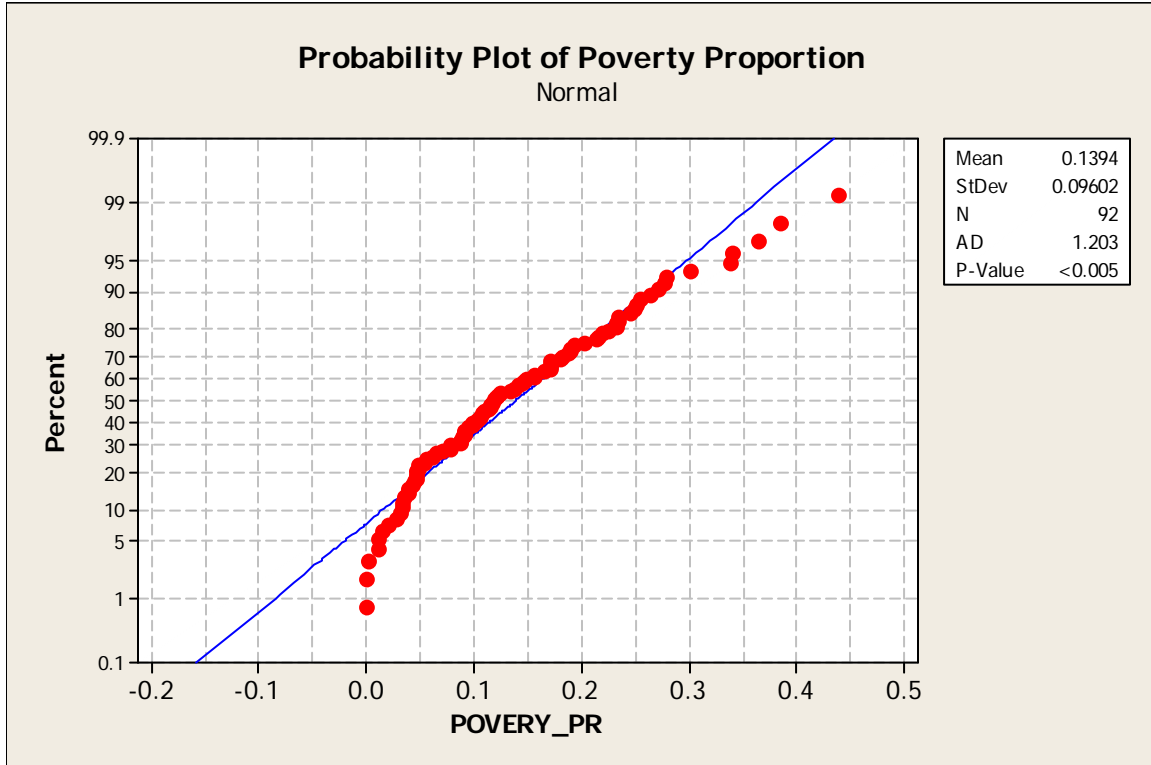
Appendix O



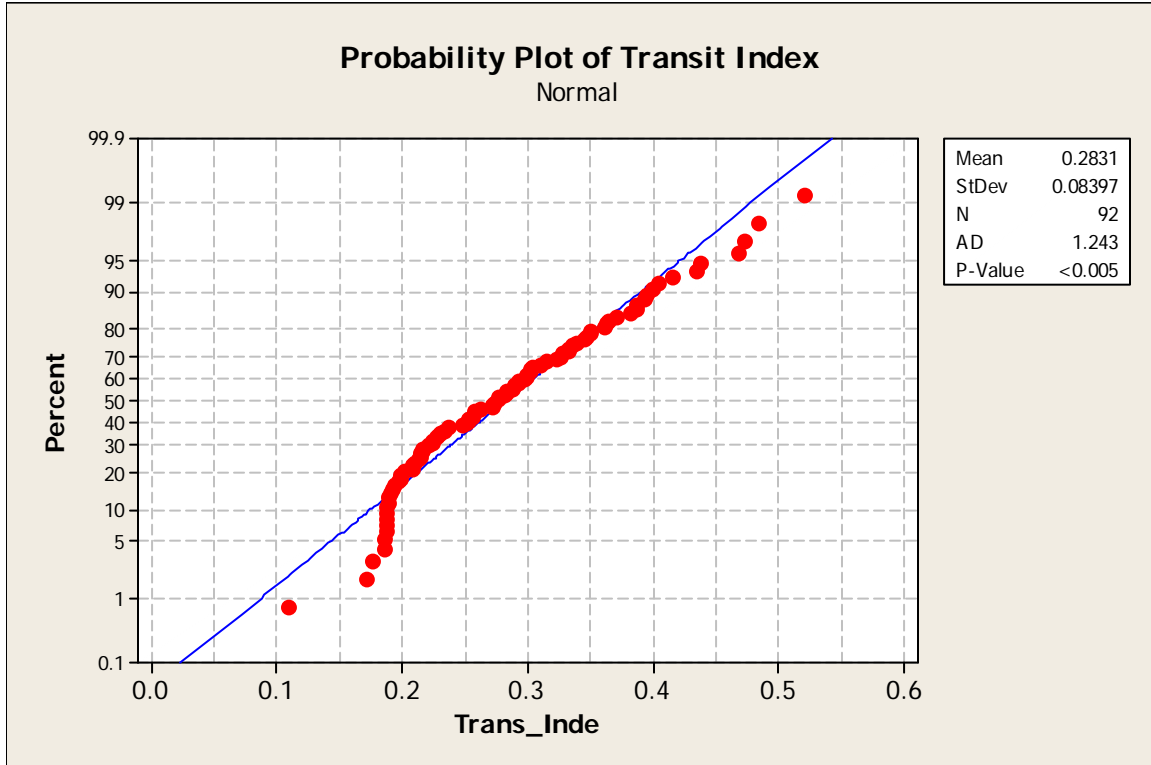
Appendix P



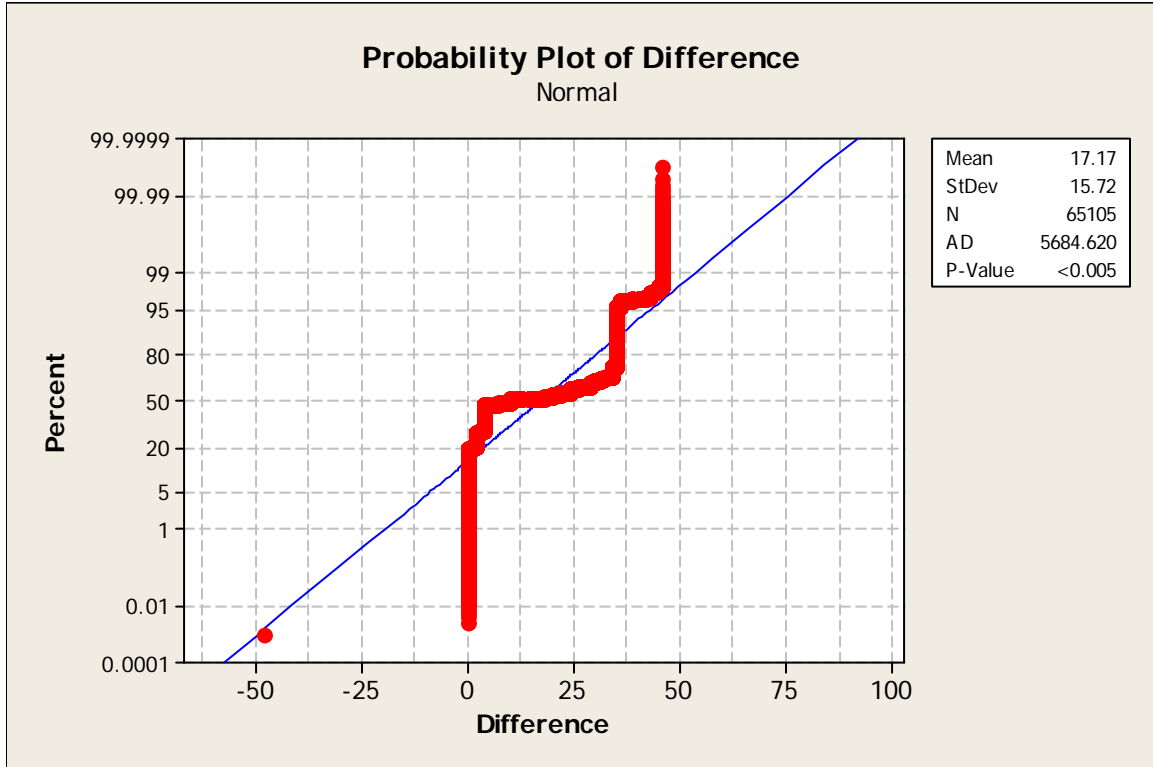
Appendix Q



Appendix R



Appendix S



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