

Construction of a Household-level Public Transportation Accessibility Model

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Abstract

This research details the construction of a public transportation accessibility model, with a focus on the necessity of using travel time as the accessibility measure. The primary objective of this work is to explain how this multi-modal network model was built and to highlight its usefulness through a representative example of its application. 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, with implications for a finer level of social justice studies.

INTRODUCTION

Background

As public transit becomes more acceptable and experiences greater use by a wider socio-economic range of people, due to higher personal transport costs, environmental concerns, and increasing congestion in urban areas which influence the design and planning of transit systems. The study of these design changes is important to the field of transportation geography and its inherent study of equity, because of how the distribution of new transit investments, both new routes and new vehicles, spatially affects differing populations in a city, which has a direct impact on the quality of life of its citizens (Apparicio et.al. 2008). The City of Albuquerque, NM, has recently implemented two Rapid Ride bus lines, which are rapid, limited-stop routes, and use buses with larger capacities. The potential impact of rapid bus lines, such as these, is a significant decrease in travel time for the riders who live within the service areas of these routes, or transfer to use them. But, an analysis based on only the proximity of users to these new stops and lines does not adequately capture the change in travel time that rapid bus routes enable. Though there is no consensus as to the best measure of physical accessibility, the measure closest to people's experience is that of travel time (Lovett et.al. 2002), which is the focus of this research.

This paper describes the construction of a more detailed transit analysis environment. This uses a temporal accessibility method, which allows a user to assess the household level accessibility changes that have occurred due to changes in the public transit system in Albuquerque, NM. This method is achieved by using a modified street network to

model walking, using residential address points as locations, and using time as the measure of accessibility. The contribution of this method is a network of high spatial resolution, with detailed and accurate temporal estimates of the walking, waiting, traveling, and bus transfers periods. The necessity of these provisions while using a network analysis approach is explained further in the literature.

Literature Review

The study of transportation equity, through assessing accessibility, is situated within the field of transportation geography. Also relevant are spatial accessibility and temporal accessibility, both metrics of transportation equity. These measures are best evaluated within a Geographic Information System (GIS), using a network approach.

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 (Handy and Niemeier 1997; Polzin 1999; Kawabata 2004).

The study of transportation equity, and its associated measures of temporal accessibility and spatial accessibility, ultimately seeks to “provide equal access to social and economic opportunities by providing equitable access to all places” (Sánchez et.al. 2003: 10). 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, stating that , “[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: 5). 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 degree to which the high goals of transportation equity are assessed and by which new projects are justified and implemented, depends on the both the metric and method

used to measure equity, and the accuracy of the methods of measurement. For example, the Mid Region Council of Governments (2004) measures equity of the public transportation system in the City of Albuquerque by a 20 minute walk distance to bus stops. This is problematic because it does not take into consideration the frequency of the bus at that particular stop, nor does it analyze where that bus actually goes. Conclusions drawn from this type of approach, that a greater percentage of transit dependent populations live within a twenty minute walk distance than other residents, are misleading when full consideration of travel time and destination is omitted. Furthermore, their study emphasizes two primary ways of measuring accessibility, and their effect on the conclusions drawn about equity.

The first accessibility measure is that of spatial accessibility, a key element to transport geography and it is the conventional measurement of accessibility (Black 2003). 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). 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). The difference between access and accessibility, in the context of transit, is that routes have varying frequencies between each other and throughout the day, so a measurement of access to the stop is very different than the accessibility that the stop provides. This accessibility is manifest through destinations accessible directly by the bus route, or by connections possible to other routes. The fine scale of this accessibility method necessitates the use of

the actual street network for accessibility to stops, because at scales smaller than a metropolitan level, straight line distances may introduce substantial errors, and network based time/distance measures are more appropriate (O'Sullivan et.al. 1999; Farhan and Murray 2005; Apparicio et.al. 2008).

Time is an essential measure of individual accessibility (Kwan and Weber 2003). 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). Even with the provision of time, some studies still simplify bus routes a lines, without regard for their actual stops (e.g. O'Sullivan et.al. 1999), or use straight-line distances to measure accessibility (e.g. Shen 2002; Lui and Zhu 2004), which are inadequate. With a wide variance of location-based accessibility indices available, they should be diligently implemented, though specifics are rarely justified (Horner 2004).

The network approach to transportation geography, developed during geography's quantitative revolution, and its implementation within a Geographic Information System (GIS), is the accepted method of analyzing transportation systems, specifically, using an integrated and comprehensive approach, as outlined by Lui and Zhu (2004). 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 et.al. 2005). A common representation of networks in a GIS is the

navigation view, which 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). 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.

These related areas of study form the basis of the theoretical approach to this paper, that is using a street network to model walking times to minimize error introduced by using straight-line distances, using the network approach within a GIS, and using household level point data to avoid data aggregation issues of Census data for transit analysis.

Study Area

The general area of study 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 April 2007; June 2007) (Figure 1). The area west of the Rio Grande is the specific study area, as both of the new Rapid Ride lines pass through the area. 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). A consequence of Albuquerque's completely motorized network, as defined by Rodrigue et.al. (2006), is that transit is forced into a subservient mode of transportation. Therefore, the mandate of public transit in Albuquerque, to offset this spatial inequity in accessibility by automobile compared to public transit, is to provide equitable mobility for those most dependent on it (Sánchez et.al. 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 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.

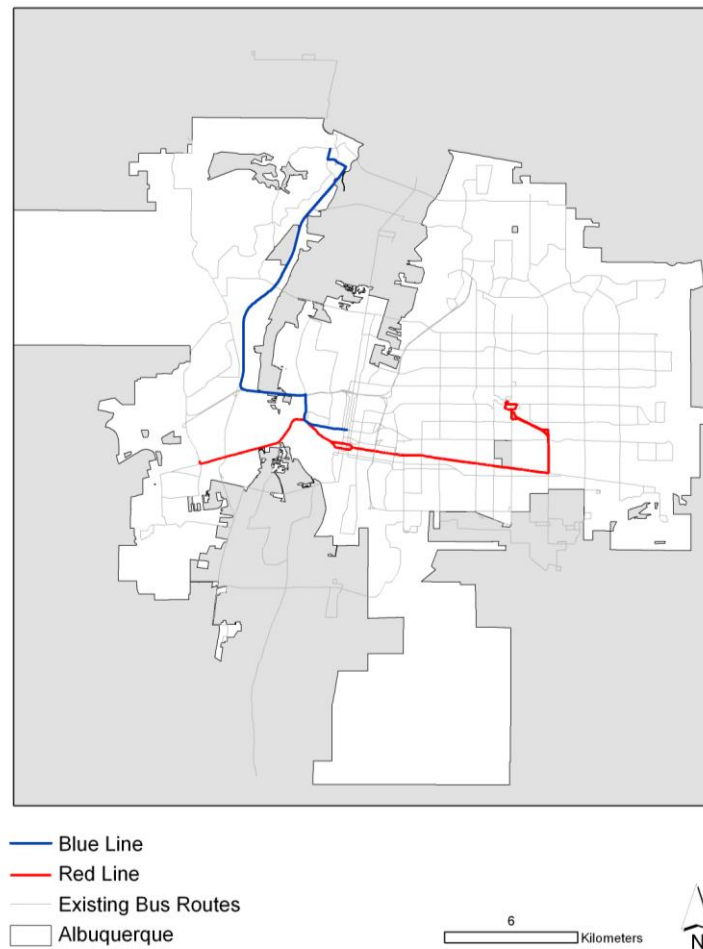


Figure 1. General Study Area, Albuquerque, NM, with the new routes emphasized over existing routes.

METHODS

Data

The data required for construction of the network are the street network, arroyos, and bike paths, as well as the bus routes and stops. 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 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.

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 2). Detail of the individual time accumulations on the network, which are underlined, 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.

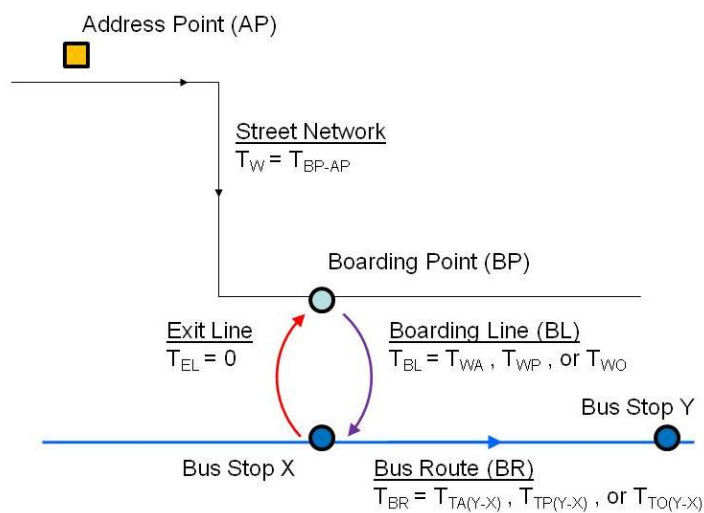


Figure 2. Conceptual diagram of the accumulation of travel time, in which the total time is calculated by taking the sum of T_W , T_{BL} , and T_{BR} , the latter two of which depend on the time period analyzed. This models the walking time to the stop, the waiting time for the particular route, and the travel time on that 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 interstates, 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, 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 insure 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 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 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 total the

Route 51 - Weekdays Northbound					
MOUNTAIN VIEW COMMUNITY CENTER	ISLETA & BARCELONA	BLAKE & TAPIA	ATRISCO & ARENAL	ATRISCO & BRIDGE	CENTRAL & ATRISCO
A	B	C	D	E	F
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 1. Published time schedule for Route 51 by ABQ. This data was the basis for determining both travel time averages and waiting time averages for the three time periods.

lengths of each of the segments between all 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 and whether they were outbound or inbound, and exported to separate feature classes. Visual inspection was used to include stops that weren't 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. The stops were then snapped, or made topologically coincident, with the route 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 routes, 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). 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.

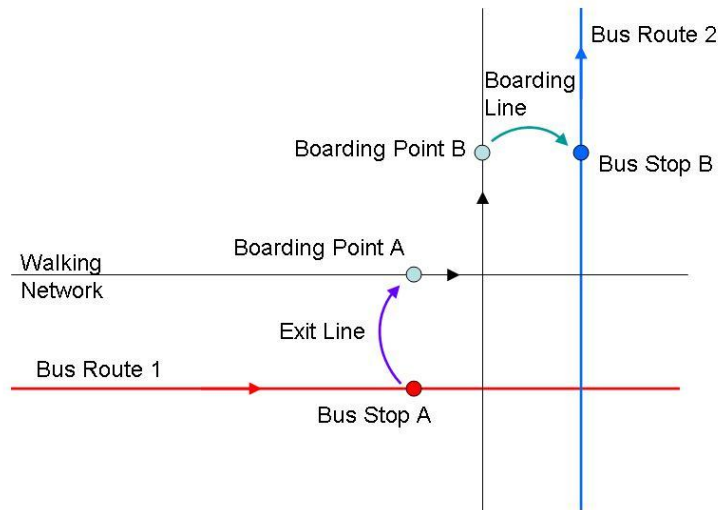


Figure 3. Schematic of transfers between bus routes, which requires exiting the current route, Bus Route 1, through an exit line, traversing the walking network, and boarding the second route, Bus Route 2. Transfers between routes are not accessible directly between bus route lines. If the boarding points for the two routes are coincident, no walking time is added, only the waiting time for the new route.

With the network data attributed, network dataset was then constructed in the feature dataset, with all of the route and walking network features. Two groups were created for the connectivity policy, which determines how the two networks interact topologically. One group was for the street network and the other was for the bus network elements. The boarding points were assigned to both groups to serve as the connection between the two 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. 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. 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 take 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 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.

Application

With the multimodal network built and attributed, the analyses that can be run are manifold. The one application focused on here is change in travel time before and after the implementation of the Rapid Ride routes (Figure 3). To assess the change in time between the network with the Rapid Ride routes and without, which augmented the bus system and didn't replace any other routes, an origin and a destination are required to measure the time difference. The downtown Albuquerque destination point was digitized on-screen, to the Alvarado Transportation Center (ATC) near the intersection of Central Avenue and First Street SW. This is where the buses that travel downtown begin or end their routes and provides connections to buses that serve the rest of the City as well as commuter rail, Amtrak, and Greyhound buses. This point was loaded as a destination in the Origin/Destination analysis in Network Analyst. Next, the origins, the residential points identified above, need to be loaded next into Network Analyst, with a snapping distance to only the street network set.

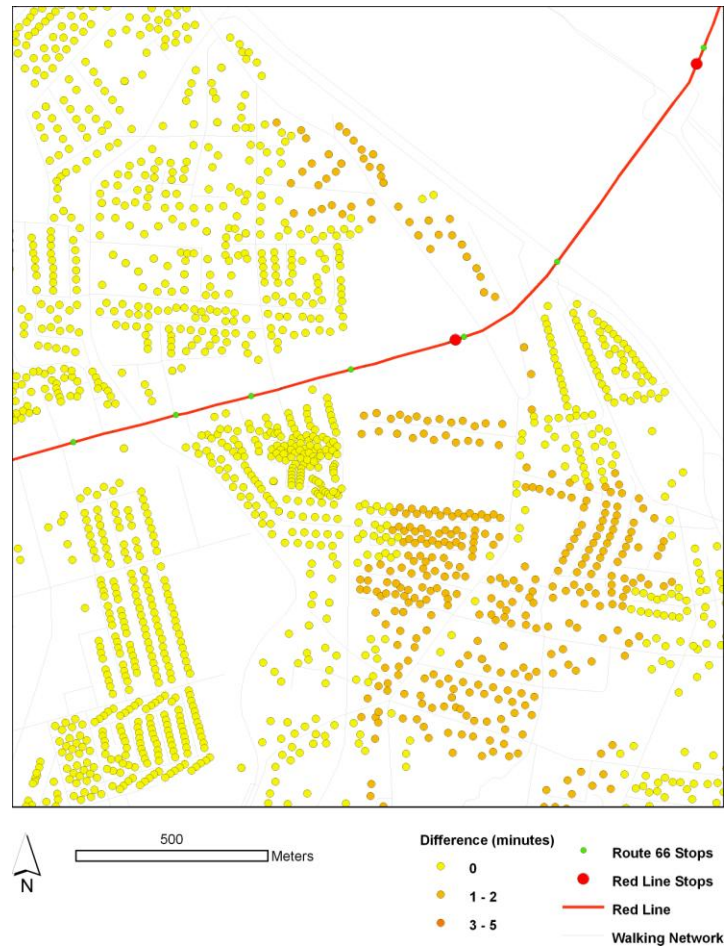


Figure 4. Time saved with the addition of the Rapid Ride Red Line of a sample of address points. This alignment was on a street that already had a bus route, so the time savings is 0 near the existing stops, but increases in proximity to the new stops.

Network Analysis provides the option to run the network with different fields to analyze to find the least cost, in this case minutes, and with different options for the origins and destinations of trips. The representative time/distance measure analyzed was the comparison of travel times to the ATC. The analysis was run with the Westside residential address points to the ATC during the A.M. peak time attributes of the network. This was analyzed with and without the Rapid Ride Routes in the network. The resulting solution tables were joined to the residential address points based on a

unique ID created previously. A new field was added and the difference between the travel times to downtown was calculated and symbolized.

Result

The spatial patterns of the change in time do not show only a dependence on the distance to downtown. For example, greater reduction in travel time is noticed at the top of the map than at the bottom of the map, despite similar distances to downtown. This is because the southern area has a greater number of existing routes, whereas the northern portion had only one. The frequency of the northern route was low; hence the large change in temporal accessibility for the area, which could only be highlighted with a model that specifically analyzes time and distance, and not only distance. Another significant result of this particular route on the time difference is due to its limited stops and decreased travel time. More time was saved close to its stops than between, which is noticeable since the spacing between stops is wide.

This has implications for equity in both the specific route that rapid buses are implemented and where the actual stops are located. If the goal of transportation equity is the provision of equal access to all places, then the beneficiaries of new transit investments should be those who rely on it the most.

CONCLUSIONS

The construction of a detailed, multi-modal network that specifically takes into consideration both bus frequency and travel time, at varying times of day, can effectively highlight changes in accessibility that additions to the network result in. Using a fine level of data, i.e. address points, allows for the time for individual addresses to be measured and compared between scenarios, which is not possible using aggregated Census data. Specifically, individual walking times can be estimated which provides for analysis of individual stops. The use of Network Analyst in GIS allows many origin and destination combinations to be run over various network attributes to draw out differences and make comparisons. This method is an improvement over currently accepted public transportation analysis techniques, which tend to simplify distance to stops and use aggregated data. Furthermore, this analysis environment was carried out in a common GIS software, ArcGIS, and not in a specialized transportation GIS and can help with detailed decisions on future stop placement and new route alignments, which would bring a finer resolution of analysis to social justice evaluations.

Limitations

This analysis took into consideration only a selection of all the bus routes in the City of Albuquerque and only the routes that provided all day service. This neglected peak-time routes, such as commuters and express routes, which would impact the temporal accessibility estimates for sections of the study area in which they operate. The assumption of walking on the street network, though modified to include locally relevant

walking paths, does not take into consideration streets not in this layer or taking short cuts, e.g. cutting through parking lots. Also, the times calculated for walking, waiting, and traveling were averages.

ABOUT THE AUTHOR

Calvin Tribby is a graduate student in the Geography Department at the University of New Mexico, and is expecting to graduate in the summer of 2009 with a M.S. in Geography. He has a B.S. in Applied Mathematics, also from UNM. His experience in GIS comes from being a teaching assistant for two semesters for the Introduction to GIS labs at UNM, and also at the Bureau of Land Management's New Mexico State Office, where he focused on geodatabase design and implementation in the personal and ArcSDE environment, and has contributed to statewide and interagency GIS initiatives. His research interests include alternative transportation policy, planning and implementation and the use of quantitative methods.

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