Transit fare structure and equity: Case of MARTA, Atlanta

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Abstract

Public transit in the US is heavily used by captive riders who depend on transit for their mobility. Studies have shown that the poor and minority groups live in the inner-city areas, travel shorter distances to downtown jobs and thus subsidize the trips by the rich suburban dwellers. These transit dependent riders also travel during non-peak hours and thus pay more for the service. However, studies have also indicated a trend of suburbanization of poverty across the cities of the United States. This is in contradiction to the earlier studies on travel patterns of transit dependent riders. This applied research paper uses the Atlanta Regional Commission's (ARC) 2009-2010 Regional On-Board Transit Survey data to examine this discrepancy and evaluate equity impacts of alternative variable fare structures.

Key words: transit, public transportation, equity

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Introduction

Atlanta has the 11th largest transit system in the United States, based on ridership, as of 2013 (USDOT 2015). Similar to several other transit systems across the country and the world, Atlanta's public transport system Metropolitan Atlanta Rapid Transit Authority (MARTA) has a flat fare structure for both its rail and bus system, i.e. it costs a fixed price, currently at $2.50 to travel from any point to another within the network, with up to four transfers allowed within a 3-hour period.

In the first section of the research paper, I look at the literature on the profile of public transit riders in the US and on the travel patterns of the different rider groups. This section also reviews the various fare structure types and the definitions of equity. Then, I elaborate on the context of the study and the research question. Further, I expand on the dataset used for the analysis and the analysis method. Finally, I discuss the results and limitations of the analysis.

Literature review

This section reviews the literature on the profile of public transit riders in the US, the travel patterns of the different rider groups, the various fare structure types, the definitions of equity and the overall context of the paper.

Public transit in the United States

The predominant mode of transportation in the United States is the automobile. As per 2009 National Household Travel Survey, 83.4% of percent trips take place in private vehicles (Santos et al. 2011). As per the American Community Survey 2013 estimates, 85.8% of the workers in the United States used private vehicle for their commute to work[1]. Only about 5% used public transit for their commute (USDOT 2013). This composition has been consistent through the

[1] 76.4% drove alone, while 9.4% carpooled

years with the public transit trips per capita increasing by a mere 2% in almost four decades: from 22 in 1973 to 24 in 2010 (Buehler and Pucher 2012).

Who uses public transit?

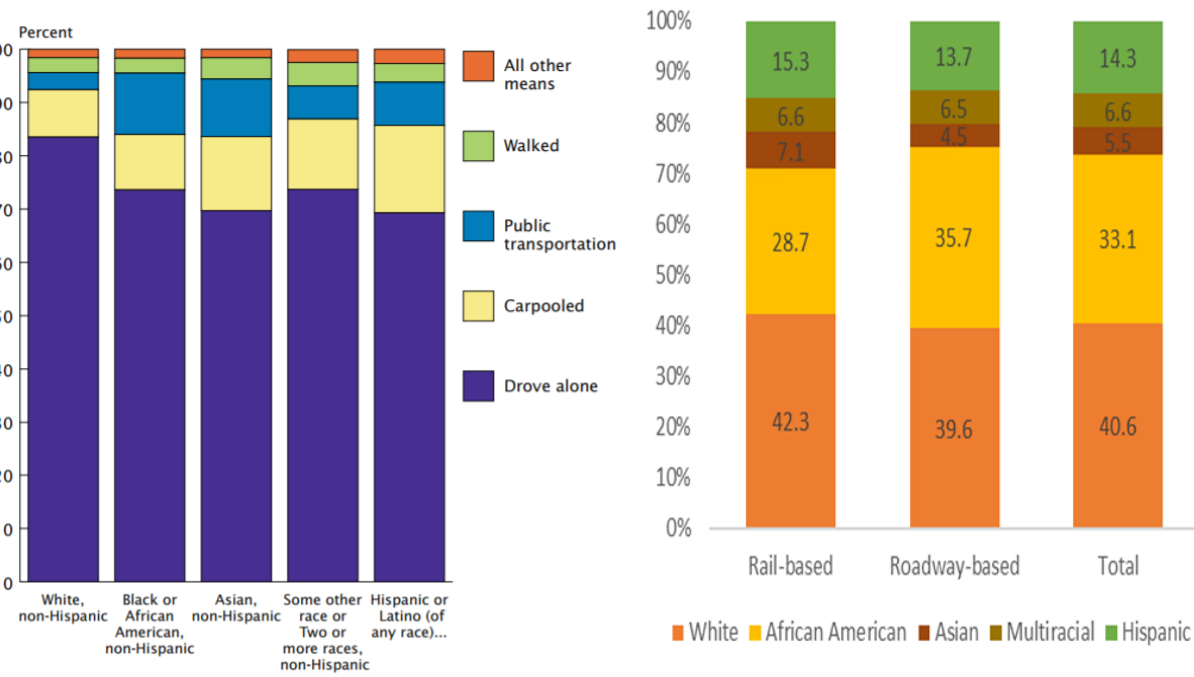
The limited use of public transit as a mode of transport makes public transit in the US first and foremost a social service even though transit agencies often envision to accomplish several other objectives through public transit (Garrett and Taylor 1999, Giuliano 2005).

Several people without access to automobiles depend on public transit as their main mode of transportation. These riders are 'captive' riders or 'transit dependent' riders (Soberman and Hazard 1980, Garrett and Taylor 1999). In 2007, less than one-half (45.4%) of transit riders in the United States had a vehicle available as an option (APTA 2007).

The other section which public transit serves are those travelling to areas where parking is difficult and expensive. Thus, transit "provides lifeline service for the poor and commute services to wealthier workers" (Taylor and Morris 2015).

Looking at the composition of transit use, we can see that the non-white/colored population takes the transit more and within transit, takes the bus more (Figure 1). The percent of households not owning a car is also higher among non-white households, 24% for African American, 17% for Hispanic and 13% for Asian American households, as compared to the 7% of white households who do not own a car (U.S. Bureau of Census 2000). Thus, non-white population makes up a larger portion of the transit captive or transit dependent riders in the country.

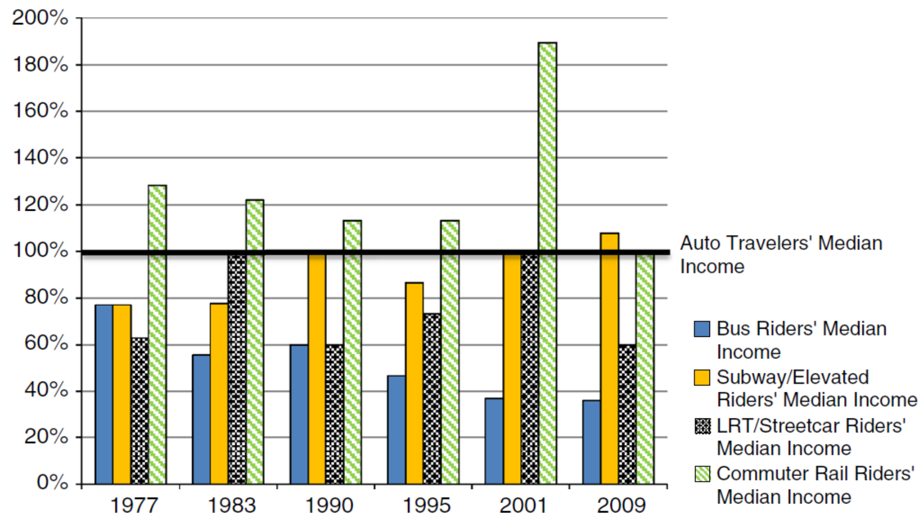
Figure 1: Composition of travel mode and type of transit used by racial groups



Source: McKenzie and Rapino 2011, APTA 2007

The results of the on-board surveys conducted by American Public Transportation Association (APTA) in 2007 shows that transit riders are from a wide range of household incomes (APTA 2007). 34.9% of the transit riders have household incomes lower than $25,000, 30.8% have between $30,000 and $50,000 and 34.3% have over $50,000. However, when you look at the split of the household incomes by type of public transit, it paints a different picture (Figure 2). The bus riders have median incomes significantly lower than those who ride the train as well as those who drive.

Figure 2: Transit riders' median income as share of auto travelers' median income, 1977-2009



Source: Taylor and Morris 2015 (based on data from National Personal Transportation Surveys and National Household Transportation Surveys)

The median household income of bus riders in 2009 was $22,500, which was $40,000 less than that of private vehicle travelers based on the National Household Travel Survey (NHTS) data. The median inflated-adjusted income of bus riders declined over 50% from $47,791 in 1977 to $22,500 in 2009 (in 2009 dollars) which shows that buses are increasingly serving the poor. The median income of the bus riders was about 80% of that of private vehicle travelers in 1977 but reduced to under 40% in 2009. This indicates that not only are the buses increasingly serving the poor, the bus riders are growing poorer (USDOT 2009, Taylor and Morris 2015). Studies have also observed that buses often serve transit dependent riders while the wealthier commute by rail (Pucher, Hendrickson, and McNeil 1981, Pucher 1982, Garrett and Taylor 1999, Giuliano 2005, Taylor and Morris 2015).

Travel patterns of transit users and who subsidizes whom?

Public transit in the United States is heavily subsidized (Wachs 1989, Garrett and Taylor 1999, Parry and Small 2009). The average fare recovery per unlinked passenger trip in 2013 was approximately 36% of the operating cost for the trip (FTA 2014). Even though the subsidies are often justified based on their benefit to the poor, studies have indicated otherwise (Altshuler 1969, Frankena 1973).

The service coverage of public transit in United States spreads extensively due to the suburban nature of the urban areas. The ratio of fare revenue and operating cost of public transit trips reduce heavily as the trip lengths get longer as most of the transit systems in the United States, including Atlanta's MARTA (Metropolitan Atlanta Rapid Transit Authority), have flat fare structures i.e. transit serving the suburban areas cost more for the transit operators. The poor are concentrated in the inner-city areas, travel shorter distances by transit and thus benefit less from the public transit subsidies than the rich (Wachs 1989, Giuliano 2005).

The average trip length for bus riders with household incomes of $6,000 or less was only 4.4 miles, compared to an average of 8.1 miles for riders with incomes of $25,000 or more. On rail rapid transit, the under-$6,000 group averaged trips of 6.3 miles in contrast to 8.5 miles for the $25,000-and-over group relatively low-income short-distance riders appear to be less subsidized than relatively high-income long-distance riders (Pucher 1981, p.391).

Study by Tait 1979 shows that often transit routes connect to suburban residential areas and not decentralized industrial parks where the blue collar jobs are located[2]. An analysis by the Lewis Mumford Center shows that the inner-city areas have higher concentrations of colored population as compared to white population in most of the cities (Table 1). Thus, poorer low-skilled workers, who are often minority communities, tend to choose accessible lower-paying inner-city jobs over higher-paying suburban jobs. Therefore, the poor and the minority are unable to utilize the subsidized suburban transit routes and thus do not benefit from the

[2] The mismatch between residence of low-income households and their job opportunities because of segregation and decentralization is hypothesized as Spatial Mismatch (first discussed John Kain's article titled "Housing Segregation, Negro Employment and Metropolitan Decentralization". Adie Tomer in "Where the Jobs Are: Employer Access to Labor by Transit" (2012) said "the suburbanization of jobs obstructs transit's ability to connect workers to opportunity and jobs to local labor pools".

subsidy. However, there are mixed findings on the positive impact improved access to public transit has on the employment levels (Sánchez, Stolz, and Ma 2003).

Table 1 Racial composition in the inner-city of largest* cities in the United States

City	*% White, Non-Hispanic*	*% African American*	*% Hispanic*	*%Asian*
Los Angeles	31	12	44	11
New York	35	26	27	11
Chicago	35	34	26	5
Philadelphia	41	44	10	5
Washington DC	39	45	10	5
Detroit	20	71	5	1
Houston	32	25	37	5
Atlanta	31	62	4	2
Dallas	38	23	34	4
Boston	56	20	13	8

* Largest Primary Metropolitan Statistical Areas

Source: Lewis Mumford Center in Sánchez, Stolz, and Ma 2003

Studies, through the years, show that public transit subsidy skews towards rail transit. The operating subsidy per passenger were lower for bus and streetcar as compared to rapid rail and commuter rail (Pucher 1981, Pucher, Markstedt, and Hirschman 1983). In 2013, as per APTA, urbanized areas with population of over a million received lower funding for their bus transit compared to rail-based transit systems (FTA 2014). Again, the poor who use buses receive lower subsidy as compared to the richer commuters who take the train.

Studies have shown that the transit dependent riders, who are disproportionately minority and low-income, tend to travel during off-peak hours, make more trips and make more transfers between modes (Lovely and Brand 1982, Pucher 1983, Hine and Scott 2000, Wardman and Hine 2000, Beirão and Cabral 2007, Nuworsoo, Golub, and Deakin 2009, Graham 2010, Taylor and Jones 2012, White 2016).

The peak-hour commutes in a public transit system with flat-fare structure are subsidized compared to off-peak commutes because the cost for providing supplemental service to meet the peak-hour demand is significantly high (Oram 1979). The additional vehicle and labor requirement costs increases the marginal cost (per vehicle hour) of providing the service by as much as 250% (White and Neal 1960, Wabe and Coles 1975).

We can see through this literature that public transit based on the common flat fare structure has several equity as well as efficiency concerns. I will focus on the concept of equity and earlier research on transit and equity in the following sections.

Transit equity

Norman Krumholz, in the context of urban planning, defined equity as providing “choices to those . . . residents who have few, if any choices" (Krumholz 1982). McDaniel and Repetti defined equity in two ways: horizontal equity and vertical equity, in the context of taxes. Litman built on this framework and suggested three categories of looking at equity in the context of transportation. However, I have divided them into two main categories and subdivided the vertical equity category:

1. Horizontal equity

   According to this definition, individuals and groups with equal ability and need, receive equal shares of resources, bear equal costs and are treated in the same manner. The individuals bear the costs of their transportation facilities and services; they get what they paid for and pay for what they get. Horizontal equity can be defined as being fair. It also follows the principles of economic efficiency and cost-based pricing.

2. Vertical equity

   According to this definition, the individuals and groups who are disadvantaged are supported and given additional favor to compensate for overall inequalities through subsidies, discounts, special services, etc. (Camporeale et al. 2017).

a. Vertical equity with regard to income and social class

   It works towards ensuring that economically or socially disadvantaged groups do not bear excessive external costs.

b. Vertical equity with regard to mobility need and ability

   It works towards ensuring support to all the individuals and groups, without focusing on how much they pay for what they get. It ensures that the transport services are accessible to all users, including those with mobility impairments.

A large number of studies have looked at equity in the context of transportation; looking at employment access (Bocarejo and Oviedo 2012), transportation costs (Haas et al. 2006), transit access (Delmelle and Casas 2012), transit service frequency (Delbosc and Currie 2011), transit connectivity (Welch and Mishra 2013), transit route planning (Camporeale et al. 2017), etc.

Another major component of transit that determines equity is transit pricing and fare structure. Equity of setting of fares is assessed with three possible criteria (Nuworsoo, Golub, and Deakin 2009:

1. Benefit Criterion

   It asserts that people should pay for services in proportion to the benefits they receive from them. For example, transit passengers might pay more for express services than for slower, multi-stop local services or pay more for direct services than for services requiring a transfer, etc.

2. Cost Criterion

   It asserts that people pay for the use of the transit services in proportion to the cost of providing service to them. This is complex to determine for individual riders, but time-of-day and other structures that consider distance partially capture it.

3. Ability to pay criterion

   It asserts that people pay for the use of transit in proportion to their wealth. Charging lower fares to groups such as the youth, the elderly and the disabled partially achieves this. However, in these arrangements, there is no guarantee that the actual rider getting the benefits within the group is economically disadvantaged. Some transit agencies have fare passes specifically for low-income groups, such as City of Madison's Low Income Pass (City of Madison 2017), SFMTA's (San Francisco Metropolitan Transit Authority) Lifeline Pass (SFMTA 2017), etc.

Several studies look at the equity of transit fares; however, before we consider them, first, we will look at the various ways of structuring fares.

Fare structure types

We can broadly classify the fare structure types into two types: flat fares and differentiated fares.

Flat fares

A flat fare is charged for every trip made, regardless of the distance travelled, time of travel, route taken, type of service (express or non-express), etc.

The rest of the fare types are based on the concept that the fare will depend based on certain factors.

Distance based fares

The fare is charged based on the distance travelled in that trip, i.e. a price per trip distance is applied.

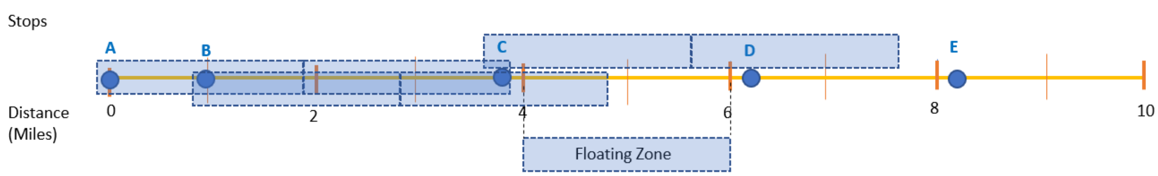
Zone based fares

The network/urban area/transit-coverage area is divided into zones. The fare is charged based on the number of zones crossed.

Floating zone fares

A floating zone is set based on distance or the number of stations (in rail). The fare is charged based on the distance or number of stations. For example, if the floating zone is set at 2miles and fare per zone is 1unit, in Figure 3, fare from A to B is 1unit, A to C is 2units, B to C is 2units, C to D is 2units, etc.

Figure 3: Floating zone fares

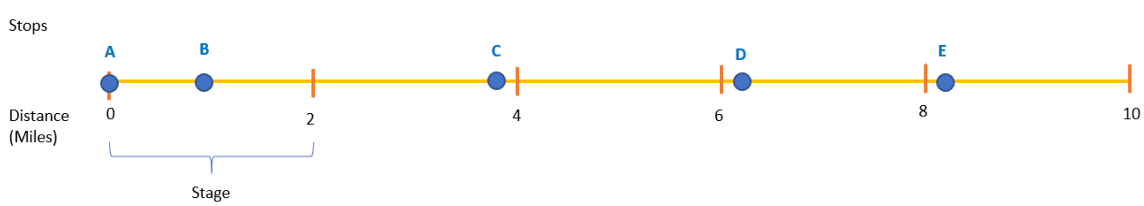


Source: Author

Stage based/ sectional fares

A stage/section is set and the fare is charged based on how many stages/sections are crossed. For example, in Figure 4, the stage is set at 2miles. If the fare per stage is 1unit, fare from A to B is 1unit, A to C is 2units, A to D is 4 units, etc. Fare from B to C is 2units, C to D is 3units and D to E is 2 units.

Figure 4: Stage based fare structure



Source: Author

Time based fares

Fare is based on the time of travel, weekday versus weekend or/and peak-hours versus off-peak hours.

Service based fare

Fare is based on the type of transit service, express versus limited-stop service or regular versus special event service.

Trip generator based fares

Fare can differ based on the origin stop/station and destination stop/station. Usually a surcharge is attached to some origins/destinations, for example, airport surcharges, amusement park surcharges, etc.

Service-quality based fares

Fare is based on the quality of the service. E.g. business class or standard/economy class.

Operator-cost based fares

Fare is based on the different costs the operator bears for different services, for example, air-conditioned or non-air-conditioned service.

Passenger based fares

Fare is based on the passenger characteristics, for example, discounted fares for students, citizens, low-income individuals, disabled, etc.

Fare structures of transit systems generally have some form of differentiation of fares. Even flat fares systems generally have passenger-based fare differentiation. Some transit systems have a combination of many of these fare types, for example, Washington's transit system (WMATA - Washington Metropolitan Area Transit Authority) has a combination of distance-based fares, time-based fares and passenger-based fares.

Vuchic in his book "Urban Transit Operation, Planning, and Economics" compares flat, distance-based and zone-based fare structures based on a number of characteristics (Table 2).

Table 2: Characteristics of various fare structures

Characteristics	Fare Structures		
	Flat	Zone-based	Distance-based/Stage-based
Equity	Poor	Good	Very Good
Passenger Attraction	Good	Very Good	Very Good
Revenue Collected	Variable	Good	Very Good
Simplicity of Collection	Excellent	Fair-Good	Poor
Simplicity of Control	Excellent	Fair	Poor
Simplicity of Passengers	Excellent	Fair-Good	Poor
Line Length	Short	Medium	Long
Network Type	Ubiquitous	Divisible in Zones	Long Lines
Travel Distance	Short	Variable	Variable

Source: Vuchic 2004 in Tsai 2009

Daskin, Schofer, and Haghani 1988 and Ling 1998 study the revenue implications of fare structure types. Andrle, Kraus, and Spielberg 1991 evaluated the effect of changing fare structure on revenue, ridership and public opinion. Ballou and Mohan 1981 developed a model to evaluate the impact of fare policies and further in Ballou et al. 1978 analyzed and found that distance-based fare policies can be developed while maintain revenue and ridership levels and improving overall equity. Chen, Lin, and Yu 2005, Nuworsoo, Golub, and Deakin 2009 and Nuworsoo, Deakin, and Golub 2012 have studied the effects of changes in fare and in elements of fare system such as the pass prices, transfer fees, etc.

Leutze and Ugolik 1979 analyzed the flat fare policy of Albany's Capital District Transit Authority (CDTA) and found that riders travelling ten minutes or less were paying an average of 32¢ per mile compared to the system-wide average of 17.9¢ per mile while riders travelling over an hour were paying only 3.9¢ per mile (1979 prices). In their analysis, Leutze and Ugolik assumed that the trip costs on the entire system was constant, irrespective of how far the users travelled (Cervero 1981). Rock 1975 studied the Chicago Transit Authority (CTA) and found that CTA's fare structure resulted in a “redistribution of income from blacks to whites due largely to distance-related price inequities” (Cervero 1981).

Rock and Zavattero 1979 and Bates and Anderson 1982 studied the equity of flat fare policies by average trip distance by income and ethnic group. Both found that flat fare policies are regressive with respect to income, but neutral with respect to ethnicity (as cited in Martinelli and Medellin 2007). Ircha and Gallagher 1985 in their study, using census data for two urban areas in Canada, found that a flat fare system is “neither efficient nor equitable”. It is not efficient as they fail to recover the costs of the routes that are the most expensive to serve and inequitable as they transfer benefits from lower-income, short-distance, non-peak-period riders to higher-income, longer-distance, peak-period riders.

Transit equity mandates in the United States

Transit equity mandates in the United States stem from the Title VI of the Civil Rights Act of 1964, which requires all federal agencies to distribute federal resources in the most equitable, fairest and least discriminatory manner possible. Title VI states that "no person shall, on the ground of race, color, or national origin, be excluded from participation benefits of, or be subjected to discrimination under any program or activity receiving assistance" (42 U.S. Code § 2000d). This directive for equity was further strengthened by Executive Order 12898 of 1994 mandating all federal agencies to address issues of equity (Welch and Mishra 2013). These equity-related mandates were also implemented broadly through the Transportation Equity Act for the 21st Century (TEA-21) from 1998-2003. These acts mandate that the United States Department of Transportation (USDOT) and the Federal Transit Authority (FTA), both being federal agencies, address issues of equity.

FTA enlists the Title VI requirements and guidelines for local agencies that receive funding from the agency in its Circular C 4702.1B (FTA 2012). Under the circular, transit systems that operate 50 or more fixed route vehicles in peak service and are in an Urbanized Area (UZA) of 200,000 or more in population need to meet the requirements. Some of the requirements under this circular include requirement to notify beneficiaries of protection under Title VI, develop complaint procedures and form, promote inclusive public participation, conduct service equity analyses, provide meaningful access to LEP (Limited English Proficiency) persons, etc.

Another requirement under the circular is a fare equity analysis. It is an assessment conducted by a transit provider to determine whether fare changes, either increases or decreases, will result in a disparate impact on Title VI-protected populations" (FTA 2012). The circular provides a sample analysis; however, local agencies can make adjustments according to local conditions and needs.

Suburbanization of poverty

Studies indicate a trend of suburbanization of poverty across the cities of the United States (Raphael and Stoll 2010, Howell and Timberlake 2014). Atlanta has the largest increase in suburban poverty among the 25 largest metro areas (Lee 2011, ARC 2015). This trend can have implications on the equity impacts of fare structures, different from the results of previous studies in the literature discussed earlier.

Previous study on variable fare structure for MARTA

In 2010, MARTA conducted a "Variable Based Fare Study" where it looked at possible fare structure alternatives for MARTA. The evaluation of the alternative focused on revenue, ridership, technology, cost impacts and Title VI impacts. The study evaluates Title VI impacts based on the method suggested by the Federal Transit Authority (FTA) and assesses the percentage splits of how the change in fare structure affects different groups. However, the report shows the results in consolidated format and does not directly look at the equity issues of the alternative fare structures as compared to current fare structure. The report does not elaborate on the methodology used for analysis and thus I was unable to compare my methodology to that of the study[3].

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[3] I would like to thank Mr. Christopher Silveira, Senior Transit System Project Planner (Acting) at MARTA for his help in accessing information.

Research question

Do people in poverty and minority population, because of changes in geography of poverty, travel longer distances and thus benefit from flat fares, making flat fares more equitable than previously thought?

This paper uses the case of Atlanta and MARTA to answer this question.

Data

The paper uses the 2009-2010 Regional On-Board Transit Survey conducted by the Atlanta Regional Commission (ARC) and its partners for the study. The survey was the largest survey of its kind in the United States with over 50,000 respondents (approximately 10 percent of the region's transit ridership). The survey was completed in January 2010 and covers riders living in 20 different counties and the region's six transit operators: Cherokee Area Transportation System (CATS), Cobb Community Transit (CCT), Gwinnett County Transit (GCT), GRTA Xpress Bus, Hall Area Transit (HAT) and Metropolitan Atlanta Rapid Transit Authority (MARTA).

Analysis methodology

Studies that look at fare structures and their equity impacts are few. Cervero in his paper "Flat versus differentiated transit pricing: what's a fair fare?" analyzes the equity impacts of flat fare systems using on-board survey data. He contrasts RPM/CPM (Revenue Per Mile/ Cost Per Mile) to trip distance, time-of-day and user demographics. Luhrsen and Taylor 1997 created cross-tabulations of different service types with different user groups and used earlier study results to conclude on how inequitable the flat fare is. Farber et al. 2014 assess equity in distance-based fare structures by developing a GIS Decision Support System.

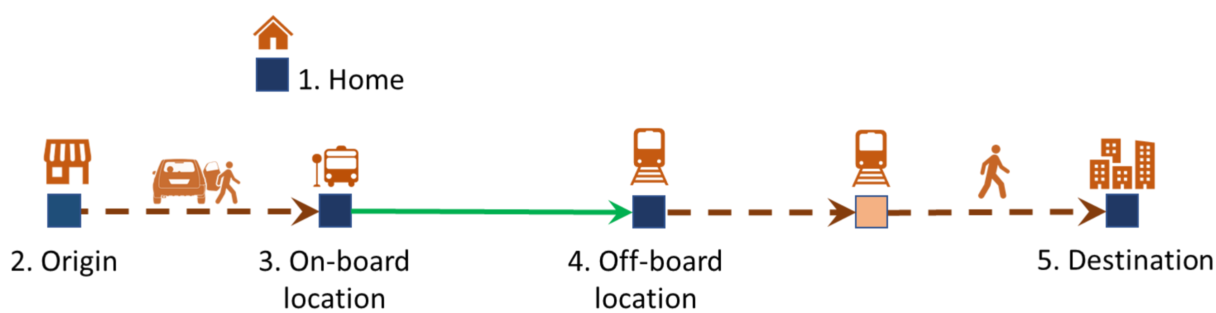
The fare equity analysis as recommended by the FTA calculates relative percent change in average fare for low-income and non-low-income users and minority and non-minority users, based on the existing ridership. In modifications of this methodology, few agencies like Massachusetts Bay Transportation Authority (MBTA) use fare elasticities to calculate the new ridership based on fare elasticities and then calculate the relative percent change in average fare based on the new ridership.

In my analysis, I use the ARC on-board survey data to calculate the route of each respondent. Then, I apply alternative fare structures to these respondents' routes and examine the distribution of fare change among difference groups of commuters: a) income groups, b) racial and ethnic groups and c) gender. In this paper, I analyze distance-based fare system, zone-based fare systems, time-based fare systems and combinations thereof.

The ARC data uniquely identifies each respondent with an ID and the information available for each respondent broadly covers 1) geographic location, 2) trip characteristics and 3) socio-economic characteristics. Appendix 1 provides the data dictionary of the dataset. Among the trip characteristics, the 'time period' variable indicates the time period of the trip, i.e. whether the trip was made during peak hours or non-peak hours. The analysis uses this to calculate the time-based fares.

Five geographic location information variables are available for each respondent record: 1) home location, 2) origin location, 3) on-board location, 4) off-board location and 5) destination location. Figure 5 explains these five locations with an example trip.

Figure 5: Example explaining the geographic location information available in the dataset



Source: Author (Drop-off graphic: MyParkingSign.com 2018; Bus stop graphic: Serre 2018)

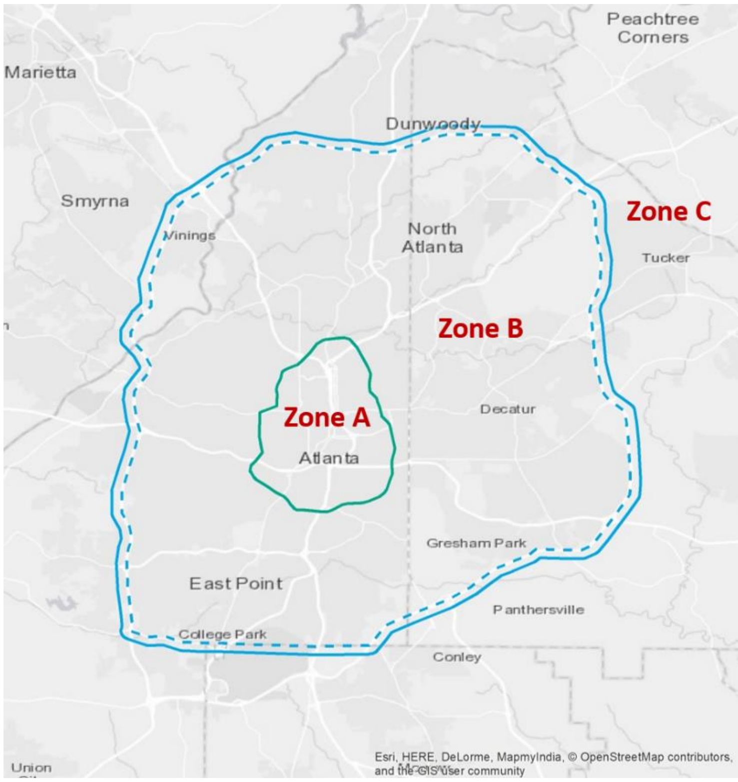
The survey data provides the 'Origin'-'Destination' distance; however, this distance does not accurately measure the distance travelled on public transportation. The distance between origin and on-board location or between off-board location and the destination can be traveled without public transport and thus should not be accounted for in the analysis. Therefore, the first step of analysis is to calculate the route and route distance between on-board location and off-board location.

First, I filter the data to select only the entries where the respondent participated in the survey (particip ≠ 2) and where the survey was conducted on the MARTA system (SYSTEM = M). Next, I filter the data to exclude records that had missing values for on-board and off-board location (on_lat ≠ *blank*, on_long ≠ *blank*, off_lat ≠ *blank* and off_long ≠ *blank*). The total number of records after filtering is 47,826.

I calculate the routes for this set of records using Open Source Routing Machine (OSRM) script in R programming language. Appendix 2 shows the R Script used for this process. The output of this process is in the form of a shapefile consisting of all the 47,826 route polylines. The attribute table includes the distance of the route. The analysis uses these distances as the basis to calculate distance-based fares.

The analysis uses the zones for the zone-based fares based on the MARTA's variable based fare study of 2010. The three zones are: Zone A - Inside BeltLine, Zone B - Outside BeltLine and Inside I-285 and Zone C - Outside I-285 (See Figure 6).

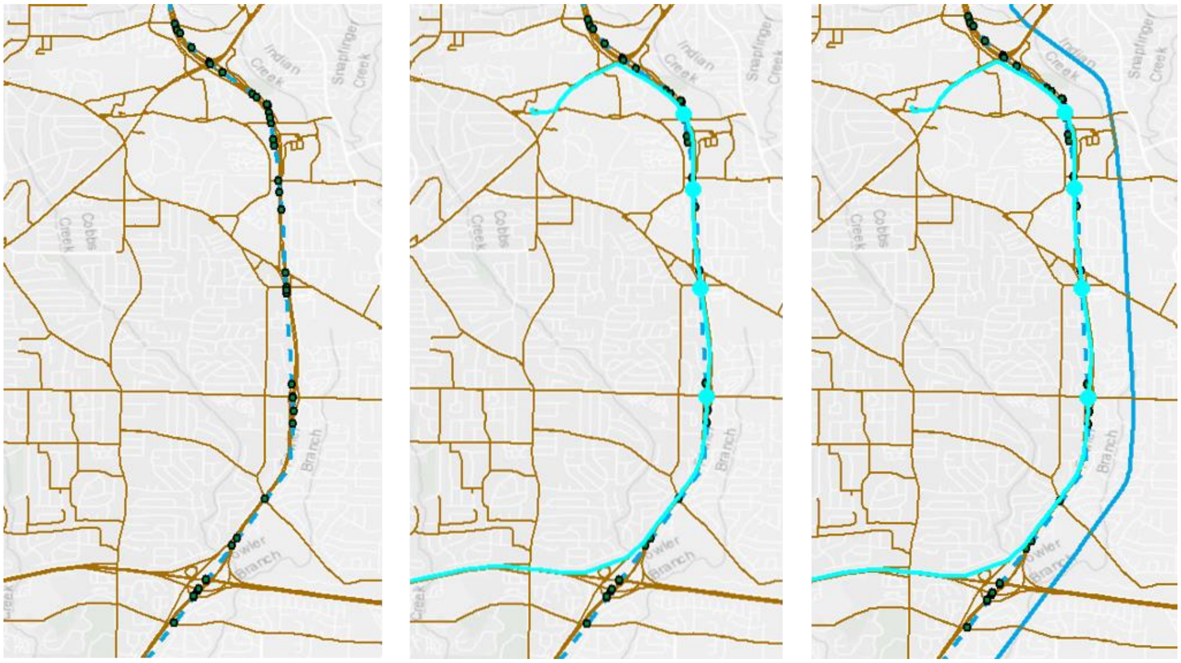
Figure 6: Fare zone map



Source: Author (Base Map: ESRI, Zones: adopted from MARTA 2010)

I calculate the number of zones crossed by each respondent, i.e. the number of intersection points between the routes and the zones on ArcGIS using the 'Intersect' tool with point output. However, the result shows some routes to cross over 15 zones, which is dubious. Further examination shows that these intersection points are created due to the alignment of the Zone C boundary with the I-285, because of which the routes that run along the I-285 intersect the boundary on multiple points (See Figure 7). In order to avoid this, I created a buffer of 0.5 mile along the Zone B-C boundary and expanded Zone B boundary to include this 0.5 mile buffer area (See Figure 6). This solved for most of the errors in the analysis.

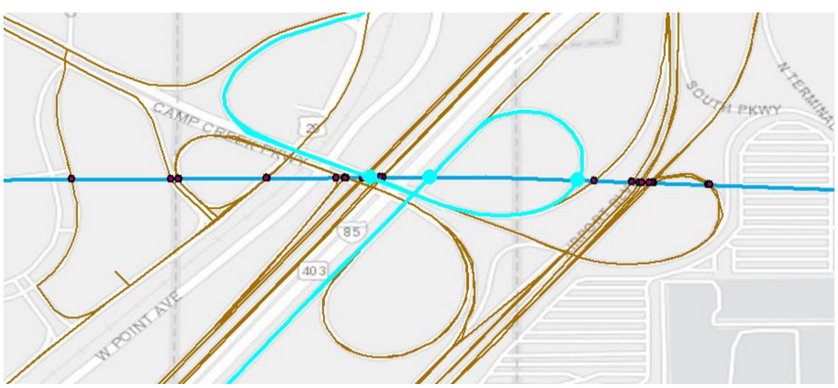
Figure 7: Intersection of route and zone boundary along I-285



Source: Author (Base Map: ESRI)

However, the new results still show some routes to cross over 8 zones. A closer look shows that the issue occurs along road interchanges (See Figure 8). I use the ‘Delete Identical’ tool on ArcGIS, using a XY tolerance of 3miles to clean up the intersection points. The count of the cleaned intersection points equal the number of zones crossed by each respondent.

Figure 8: Intersection of route and zone boundary at road interchanges

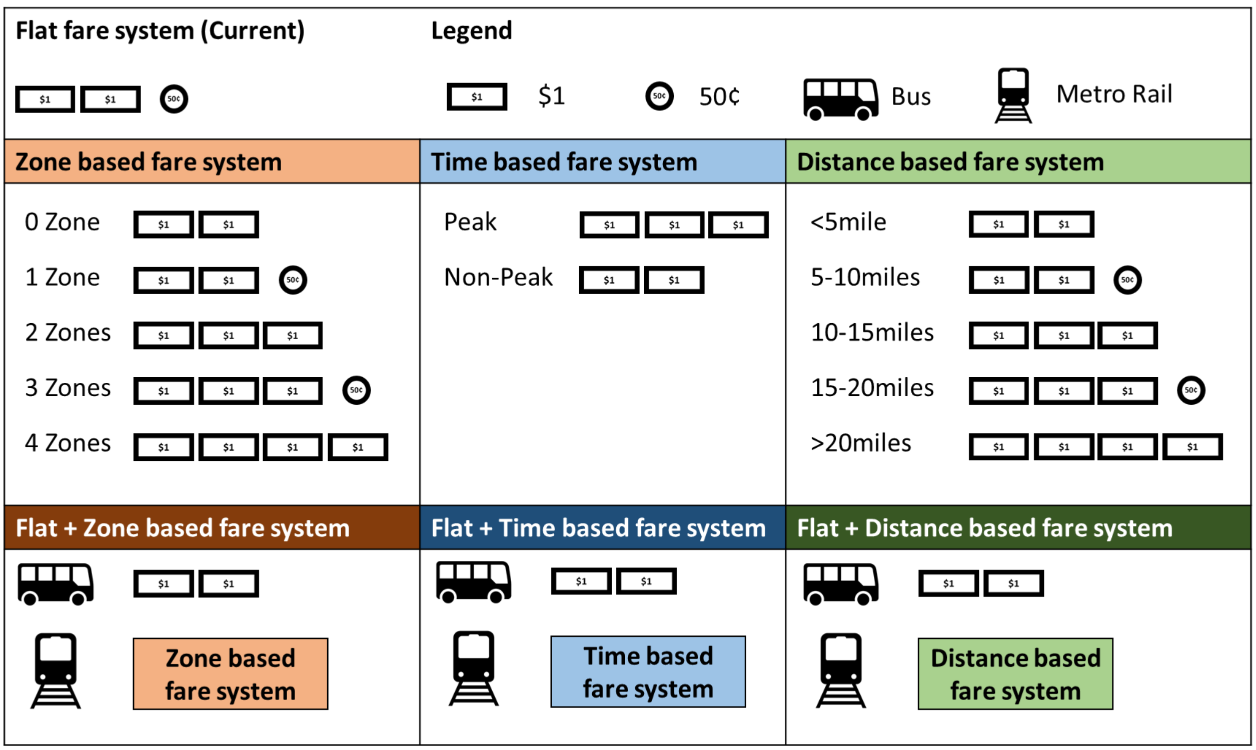


Source: Author (Base Map: ESRI)

Alternative fare structures applied

The paper applies six alternative fare systems to the data; Figure 9 shows the details of each system. The alternatives draw from MARTA's variable based fare study. The fares range from $2 to $4 and are a combination of dollars and 50cents. The fare does not breakdown further beyond 50 cents, as that would be difficult to pay with cash. The fares range from -0.5dollars from the current fare to +1.5dollars, providing savings to certain groups of commuters while increasing fares for another. The combination of increase and decrease in fares also ensures that the revenue is anchored around the current situation.

Figure 9: Alternative fare structures applied



Source: Author

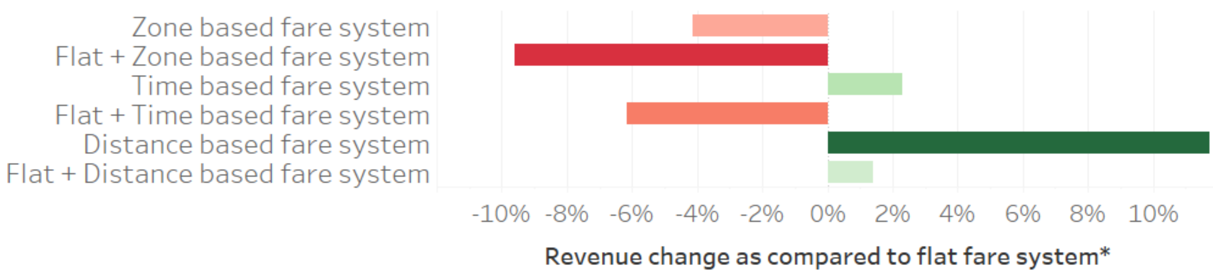
I apply these alternative fare structures to the trips of the respondents, based on the distance, time and zone variables calculated earlier and calculate the fare change applied to each respondent. The next section examines these fare changes and the differences in them for various groups: by income, race/ethnicity and gender.

Results

The analysis shows that alternative fare systems reduce the fares for lower income groups more than for higher income groups (refer Figure 11). An exception to this is that with the time based fare system, flat + time based fare system and flat + distance fare system, the lowest income group (people with less than $5,000 income) pay a little more (1-3%more) than the next income group (people with income between $5,000 and $9,999.

The discussion on fare change is incomplete without looking at the revenue generated through the system. Figure 10 shows the differences in the revenue generate by each of the alternative fare systems as compared to the revenue generated by the existing flat fare system, for the trips in the data.

Figure 10: Difference in revenue generated by alternative fare systems as compared to that by the existing flat fare system



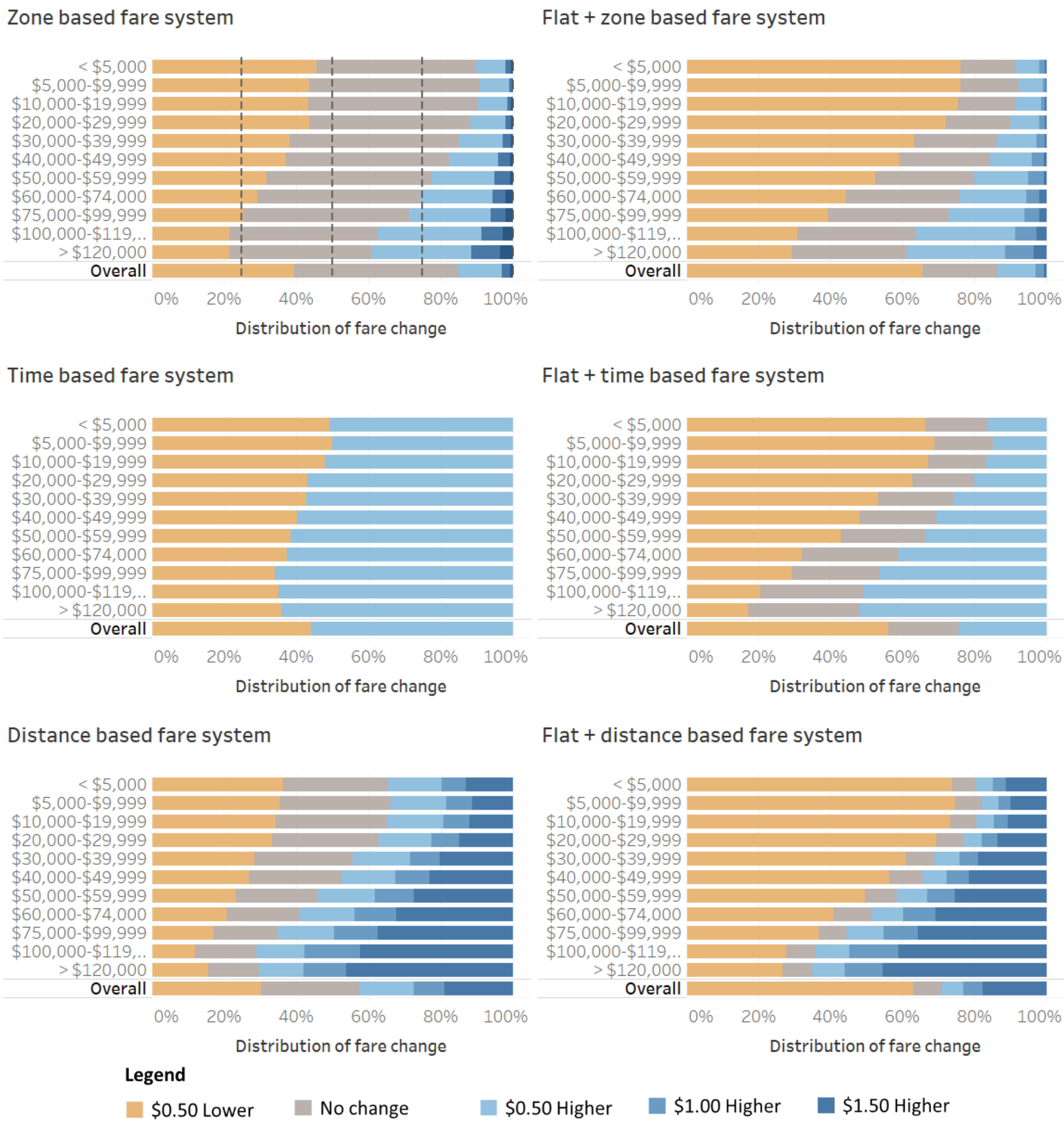
*Revenue generated by flat fare system for trips in the data = $119,565.00

Source: Author

We can see that some of the alternative fare systems, such as the distance based fare system, time based fare system and flat + distance based system can provide higher revenue than the current system and the lower income groups will bear lower increase in their fares, compared to the higher income groups.

The distribution of fare change shows that the current flat fare structure subsidizes the fares for a large proportion of the higher income groups as compared to lower income groups.

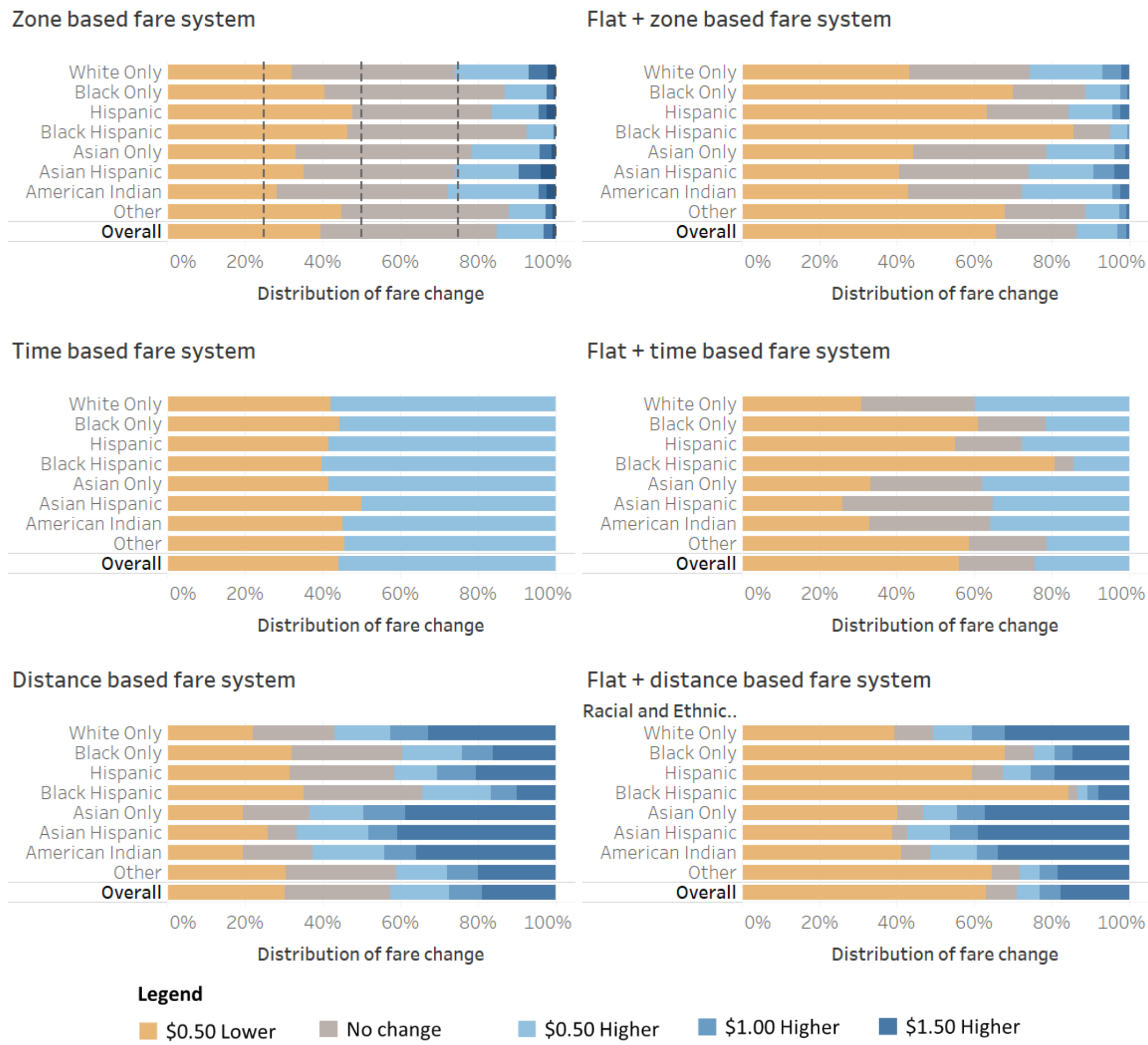
Figure 11: Distribution of fare change by income group for the alternative fare structures



Source: Author

Similar to Figure 11, Figure 12 shows the distribution of fare change by racial and ethnic groups. All the alternative fare systems decrease the fare for higher number of non-White people (minority), with a few exceptions, compared to White non-Hispanic people (White only). The difference is significantly higher in the systems that are a combination of flat fare system, especially for Black and Hispanic groups, with large savings for these minority groups. This indicates that these minority groups use bus more than other groups, consistent with the previous literature on this topic. However, some groups like the American Indians and Asian Hispanics face a higher burden in some alternative fare system scenarios and we need to be mindful of this.

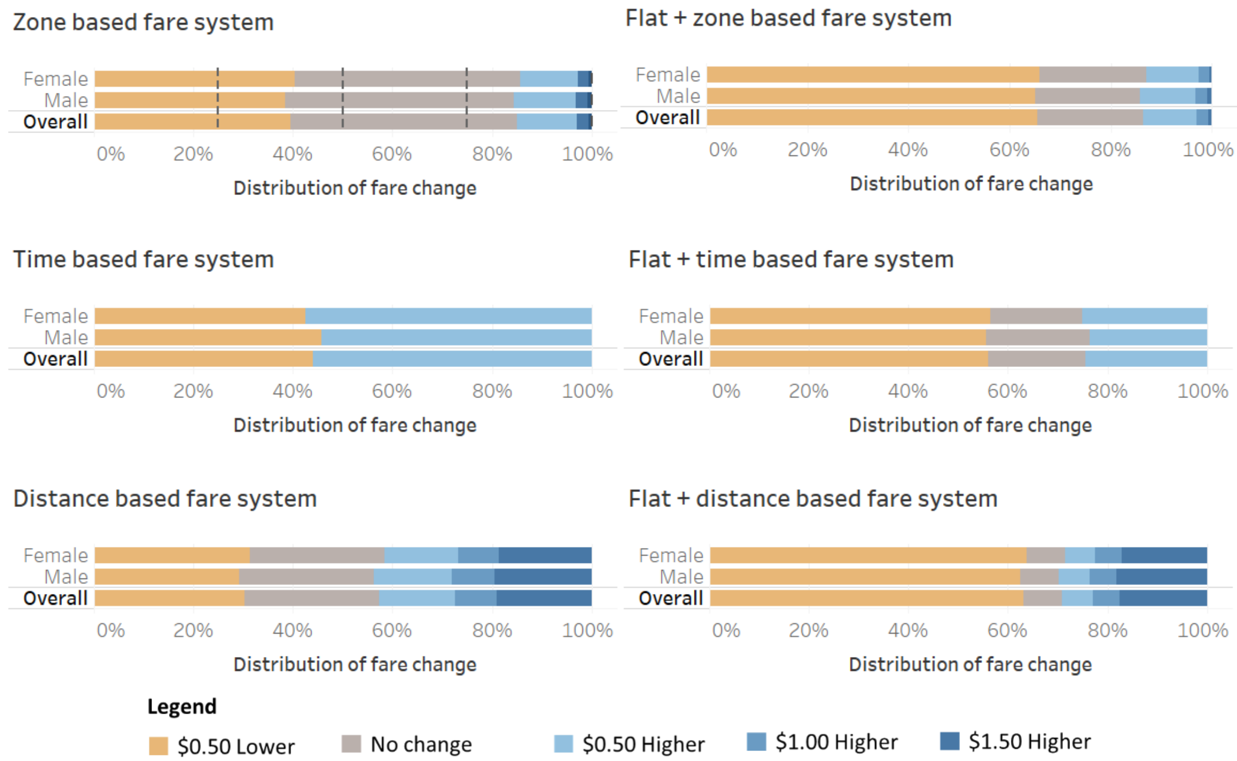
Figure 12: Distribution of fare change by racial and ethnic group for the alternative fare structures



Source: Author

Next, we look at the distribution of fare change by gender in Figure 13. There is no significant difference in the change in fares faced between the two genders.

Figure 13: Distribution of fare change by gender for the alternative fare structures



Source: Author

Limitations

A major limitation of this study is that the analysis does not consider the effect of transfers in the trips in the data. The respondent in the data might have had a prior transfer before or a future transfer after the trip captured in the data, however the analysis does not consider this. Currently, MARTA has a system of free transfers for up to four transfers within a 3-hour period (transfers cannot be used for roundtrips). This has implications as lower-income and minority groups might be making multiple transfers; thus, the differentiated/variable fare structures must account for this.

Another limitation of this study is that the rCarto script uses vehicle routing in its algorithm and not public transit routing. This might have affected the distances and the number of zones crossed for some of the respondent trips.

One of the technical limitations is that if a route goes in and out of a zone within a short distance, the route is not exactly crossing zones; however, the analysis counts this crossing. The analysis does remove at least one of the intersection points by using the delete identical tool but is not equipped to remove both the points, in some instances.

Additionally, the study does not consider the induced demand for MARTA trips, and its composition, due to the change in fare structure (and the decrease in fares) in the analysis. Factors such as ease of use, ease of understanding fares, technology needs, technology costs, etc. are also critical in deciding the optimal fare system and need to be considered.

The recently passed 'The ATL' legislation talks of integrating the various public transit systems in the Atlanta region and bringing them to a common fare collection platform and possibly a common fare system (Green 2018). This development calls for the analysis to include all the trips made by the various transit systems in the region, available in the data.

Conclusion

Public transit is the lifeline for the transit captive riders who largely have lower incomes and belong to the minority population. Flat fare structure for transit remains inequitable, despite the observed suburbanization of poverty. All alternative differentiated fare structures reduce transit fares for a sizeable number of low-income and minority riders. Some of these fare structures can also increase the revenue for the transit agency.

The reductions in transit fares for low-income and minority riders are more significant in fare structures which are a combination of flat fare for bus trips and differentiated for train trips. Such combination systems are also easier to implement as applying a distance-based or zone-based fare structure is more difficult for buses than trains. Transit agencies should consider these equity impacts and make the initial effort to create and implement a differentiated fare structure, keeping in mind the long-term benefits.

References

42 U.S. Code § 2000d. "Prohibition against exclusion from participation in, denial of benefits of, and discrimination under federally assisted programs on ground of race, color, or national origin".

Altshuler, Alan A. 1969. "Transit subsidies: by whom, for whom?" *Journal of the American Institute of Planners* 35 (2):84-89.

Andrle, Stephen, Janet Kraus, and Frank Spielberg. 1991. "Lessons from the Broome County Distance-Based Fare Demonstration: Effects of Zone Fares and Off-Peak Discounts on Ridership, Revenue, Pass Sales, and Public Opinion." *Transportation Research Record* 1297:50-56.

APTA. (American Public Transportation Association). 2007. "A profile of public transportation passenger demographics and travel characteristics reported in on-board surveys." Washington DC. May 2007.

ARC. 2015. Suburbanization of Poverty in Metro Atlanta: An Update. Atlanta Regional Commission. http://documents.atlantaregional.com/enewsletters/2015/regional-snapshot/january/foodstamp_poverty.pdf.

Beirão, Gabriela, and JA Sarsfield Cabral. 2007. "Understanding attitudes towards public transport and private car: A qualitative study." *Transport policy* 14 (6):478-489.

Bocarejo, S Juan Pablo, and H Daniel Ricardo Oviedo. 2012. "Transport accessibility and social inequities: a tool for identification of mobility needs and evaluation of transport investments." *Journal of Transport Geography* 24:142-154.

Buehler, Ralph, and John Pucher. 2012. "Demand for public transport in Germany and the USA: an analysis of rider characteristics." *Transport Reviews* 32 (5):541-567.

Camporeale, R, L Caggiani, A Fonzone, and M Ottomanelli. 2017. "Quantifying the impacts of horizontal and vertical equity in transit route planning." *Transportation Planning and Technology* 40 (1):28-44.

Cervero, Robert. 1981. "Flat versus differentiated transit pricing: what's a fair fare?" *Transportation* 10 (3):211-232.

Chen, Xumei, Guoxin Lin, and Lei Yu. 2005. "Evaluation analysis on an integrated fare initiative in Beijing." *Journal of Public Transportation* 8 (3):2.

City of Madison. 2017. "Low Income Pass." accessed 27 November 2017. https://www.cityofmadison.com/metro/fares/lowincomepass.cfm.

Daskin, Mark S, Joseph L Schofer, and Ali E Haghani. 1988. "A quadratic programming model for designing and evaluating distance-based and zone fares for urban transit." *Transportation Research Part B: Methodological* 22 (1):25-44.

Delbosc, Alexa, and Graham Currie. 2011. "Using Lorenz curves to assess public transport equity." *Journal of Transport Geography* 19 (6):1252-1259.

Delmelle, Elizabeth Cahill, and Irene Casas. 2012. "Evaluating the spatial equity of bus rapid transit-based accessibility patterns in a developing country: The case of Cali, Colombia." *Transport Policy* 20:36-46.

Farber, Steven, Keith Bartholomew, Xiao Li, Antonio Paez, and Khandker M Nurul Habib. 2014. "Social equity in distance based transit fares." Transportation Research Board 93rd Annual Meeting.

Frankena, Mark. 1973. "Income distributional effects of urban transit subsidies." *Journal of Transport Economics and Policy*:215-230.

FTA. 2012. "Title VI Requirements and Guidelines for Federal Transit Administration Recipients". FTA C 4702.1B USDOT. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_Title_VI_FINAL.pdf.

FTA. (Federal Transit Administration). 2014. "National Transit Database: National Transit Summaries and Trends 2013." USDOT. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/2013_NTST_Storylines.pdf.

Garrett, Mark, and Brian Taylor. 1999. "Reconsidering social equity in public transit." *Berkeley Planning Journal* 13 (1).

Giuliano, Genevieve. 2005. "Low income, public transit, and mobility." *Transportation Research Record: Journal of the Transportation Research Board* (1927):63-70.

Graham, Peter. Research Report ITLS-RR-10-01 of the Institute of Transport and Logistics Studies, University of Sydney. 2010. "Cash or prepay? Motivations for passenger payment."

Green, Josh. 2018. Georgia passes landmark legislation for regional transit; prepare for ‘The ATL’. *Curbed Atlanta*.https://atlanta.curbed.com/2018/3/30/17180118/georgia-marta-transit-atl-legislation-regional-network.

Haas, Peter M, Carrie Makarewicz, Albert Benedict, Thomas W Sanchez, and Casey J Dawkins. 2006. "Housing & transportation cost trade-offs and burdens of working households in 28 metros." *Center for Neighborhood Technology* 2.

Hine, Julian, and J Scott. 2000. "Seamless, accessible travel: users’ views of the public transport journey and interchange." *Transport Policy* 7 (3):217-226.

Howell, Aaron J, and Jeffrey M Timberlake. 2014. "Racial and ethnic trends in the suburbanization of poverty in US metropolitan areas, 1980–2010." *Journal of Urban Affairs* 36 (1):79-98.

Ircha, Michael C, and Margaret A Gallagher. 1985. "Urban transit: equity aspects." *Journal of urban planning and development* 111 (1):1-9.

Kable. 2018. Fish-eye Breeze fare gates. Railway Technology.

Krumholz, Norman. 1982. "A retrospective view of equity planning Cleveland 1969–1979." *Journal of the American Planning Association* 48 (2):163.

Lee, Sugie. 2011. "Analyzing intra-metropolitan poverty differentiation: causes and consequences of poverty expansion to suburbs in the metropolitan Atlanta region." *The Annals of Regional Science* 46 (1):37-57.

Ling, Jui-Hsien. 1998. "Transit fare differentials: A theoretical analysis." *Journal of advanced transportation* 32 (3):297-314.

Lovely, Mary E, and Daniel Brand. 1982. *Atlanta transit pricing study: moderating impact of fare increases on poor*.

Luhrsen, Kurt F, and Brian D Taylor. 1997. "The high cost of flat fares: an examination of ridership demographics and fare policy at the los angeles MTA." *University of California Transportation Center*.

MARTA. (Metropolitan Atlanta Rapid Transit Authority). 2010. "Variable Based Fare Study." Atlanta. June, 2010.

Martinelli, David, and Leonel Medellin. Mid-Atlantic Universities Transportation Center, Region III. 2007. "Assessment of Bus Transit Equity in Two Metropolitan Areas."

McKenzie, Brian, and Melanie Rapino. 2011. *Commuting in the united states: 2009*: US Department of Commerce, Economics and Statistics Administration, US Census Bureau Washington, DC.

MyParkingSign.com. 2018. "Drop Off or Pick Up Sign." https://www.myparkingsign.com/drop-off-pick-up-only-sign/sku-k2-0614

Nuworsoo, Cornelius, Elizabeth Deakin, and Aaron Golub. 2012. "Equity Impacts of Transit Fare Proposals: A Case Study of AC Transit." Journal of the Transportation Research Forum.

Nuworsoo, Cornelius, Aaron Golub, and Elizabeth Deakin. 2009. "Analyzing equity impacts of transit fare changes: Case study of Alameda–Contra Costa Transit, California." *Evaluation and Program Planning* 32 (4):360-368.

Oram, Richard L. 1979. "Peak-period supplements: The contemporary economics of urban bus transport in the UK and USA." *Progress in Planning* 12:81-154.

Parry, Ian WH, and Kenneth A Small. 2009. "Should urban transit subsidies be reduced?" *The American Economic Review* 99 (3):700-724.

Pucher, John. 1981. "Equity in transit finance: Distribution of transit subsidy benefits and costs among income classes." *Journal of the American Planning Association* 47 (4):387-407.

Pucher, John. 1982. "Discrimination in mass transit." *Journal of the American Planning Association* 48 (3):315-326.

Pucher, John. 1983. "Who benefits from transit subsidies? Recent evidence from six metropolitan areas." *Transportation Research Part A: General* 17 (1):39-50.

Pucher, John, Chris Hendrickson, and Sue McNeil. 1981. "Socio-economic characteristics of transit riders: some recent evidence." *Traffic Q.;(United States)* 35 (3).

Pucher, John, Anders Markstedt, and Ira Hirschman. 1983. "Impacts of subsidies on the costs of urban public transport." *Journal of Transport Economics and Policy*:155-176.

Raphael, Steven, and Michael A Stoll. 2010. *Job sprawl and the suburbanization of poverty*: Metropolitan Policy Program at Brookings Washington, DC.

Sánchez, Thomas W, Rich Stolz, and Jacinta S Ma. 2003. Moving to Equity: Addressing Inequitable Effects of Transportation Policies on Minorities. Cambridge, MA: The Civil Rights Project at Harvard University.

Santos, Adella, Nancy McGuckin, Hikari Yukiko Nakamoto, Danielle Gray, and Susan Liss. U.S. Department of Transportation. 2011. "Summary of travel trends: 2009 National Household Travel Survey." Washington DC.

Serre, Marc. 2018. "Bus Stop." The Noun Project. https://thenounproject.com/term/bus-stop/2246/#.

SFMTA. 2017. "Lifeline (Low Income) Pass." accessed 27 November 2017. https://www.sfmta.com/getting-around/transit/fares-passes/low-income-lifeline-pass.

Soberman, Richard M, and Heather A Hazard. 1980. *Canadian Transit Handbook*: University of Toronto-York University, Joint Program in Transportation.

Tait, JJ. 1979. Social Equity and the Automobile. In *Role of the Automobile Study*. Ottawa, Ontario, Canada.

Taylor, Brian D, and Eric A Morris. 2015. "Public transportation objectives and rider demographics: are transit's priorities poor public policy?" *Transportation* 42 (2):347-367.

Taylor, Kendra C, and Erick C Jones. 2012. "Fair fare policies: pricing policies that benefit transit-dependent riders." In *Community-based operations research*, 251-272. Springer.

Tsai, Feng-Ming. 2009. *Optimizing fare structure and service frequency for an intercity transit system*: New Jersey Institute of Technology.

U.S. Bureau of Census. 2000. Summary File 3(SF3).

USDOT. 2009. "National Household Travel Survey." Federal Highway Administration. http://nhts.ornl.gov.

USDOT. 2013. "Commuting to Work." accessed 15 November 2017. https://www.bts.gov/content/commuting-work.

Wabe, J Stuart, and Oliver B Coles. 1975. "The short and long-run cost of bus transport in urban areas." *Journal of Transport Economics and Policy*:127-140.

Wachs, Martin. 1989. "US transit subsidy policy: In need of reform." *Science* 244 (4912):1545-1550.

Wardman, M, and J Hine. Working Paper, 546, 1–50. 2000. "Costs of interchange: a review of the literature. Institute of Transport Studies, University of Leeds."

Welch, Timothy F, and Sabyasachee Mishra. 2013. "A measure of equity for public transit connectivity." *Journal of Transport Geography* 33:29-41.

White, PA, and AF Neal. 1960. "The problem of the peak." *Journal of the Institute of Transport*:275.

White, Peter. 2016. *Public transport: its planning, management and operation*: Taylor & Francis.

Appendix 1: Data dictionary

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
id_aok_new	Unique ID number
gis_id	ID number for GIS
surv_id	ID number from original field work
sur_date	Date Survey Was administered
sur_time	Time Survey Was Administered
	Code Value 1 = Before 6am
	Code Value 2 = 6am-6:59am
	Code Value 3 = 7am-7:59am
	Code Value 4 = 8am-8:59am
	Code Value 5 = 9am-9:59am
	Code Value 6 = 10am-10:59am
	Code Value 7 = 11am-11:59am
	Code Value 8 = 12pm-12:59pm
	Code Value 9 = 1pm-1:59pm
	Code Value 10 = 2pm-2:59pm
	Code Value 11 = 3pm-3:59pm
	Code Value 12 = 4pm-4:59pm
	Code Value 13 = 5pm-5:59pm
	Code Value 14 = 6pm-6:59pm
	Code Value 15 = 7pm or later
sur_durat	Time Survey Took To Be Completed
sur_rte	Route or Station Name (MAR=MARTA, CCT=COBB, GCT=Gwinnett, CTRAN=Clayton, HAT=HALL, CAT=Cherokee, RAIL STATION CODES Shown in worksheet 4 - see tab below)
	Airport=S7
	Art Center=N5
	Ashby=W3
	Avondale=E7
	Bankhead=P1
	Brookhaven=NE8
	Buckhead=N7
	Chamblee=NE9
	Civic Center=N2
	College Park=S6
	Decatur=E6
	Dome/GWCC/Phillips/CNN=W1
	Doraville=NE10
	Dunwoody=N9
	East Lake=E5
	East Point=S5
	Edgewood/Candler=E4
	Five Points=5P
	GA State=E1
	Garnett=S1
	Hamilton E Holmes=W5
	Indian Creek=E9
	Inman Park=E3
	Kensington=E8
	King Memorial=E2
	Lakewood/Fort McPherson=S4
	Lenox=NE7
	Lindbergh=N6
	Medical Center=N8
	Midtown=N4
	North Avenue=N3
	North Springs=N11
	Oakland City=S3
	Peachtree Center=N1
	Sandy Springs=N10
	Vine City=W2

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
	West End=S2
	West Lake=W4
particip	Did the person [articipate in the entire survey
	1=YES
	2=NO
or_typ	Type of Place the Trip Begin
	Code Value 1 = Your HOME
	Code Value 2 = Your WORK
	Code Value 3 = Store/Retail Place
	Code Value 4 = Restaurant
	Code Value 5 = School/Daycare
	Code Value 6 = Hospital/Doctor
	Code Value 7 = Recreation Place
	Code Value 8 = Bank/Other Office
	Code Value 9 = Another home
	Code Value 10 = Place of Worship
	Code Value 11 = Hotel
	Code Value 12 = College/University (student only)
	Code Value 13 = Airport (passenger only)
	Code Value 14 = Other
or_name	Name of Origin
or_adr_int	Was the origin address and exact address or intersection
	Code Value 1 = Exact Address
	Code Value 2 = Intersection
or_lon	Origin Longitude
or_lat	Origin Latitude
or_add	Origin address if complete address given
or_str_1	1st street given for origin if the respondent provided an intersection
or_str_2	2nd street given for origin if the respondent provided an intersection
or_int	origin intersection
or_city	origin city name
or_cnty	origin county code (see codes on the next worksheet)
	1=FULTON
	2=DEKALB
	3=COBB
	4=GWINNETT
	5=CLAYTON
	6=CHEROKEE
	7=HALL
	8=BARROW
	9=BARTOW
	10=CARROLL
	11=COWETA
	12=DOUGLAS
	13=FAYETTE
	14=FORSYTH
	15=HENRY
	16=NEWTON
	17=PAULDING
	18=ROCKDALE
	19=SPALDING
	20=WALTON
	21=OTHER
or_zip	origin zip code
	Code Value 99999 = Not Provided
frst_bustrn	Was this the first bus or train the rider used on this trip?
	Code Value 1 = Yes
	Code Value 2 = No
frm_bustrn_1	Did the rider use a bus or train 1st to get this the current bus or train
	Code Value 1 = Bus

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
	Code Value 2 = Train
frm_bus_1	1st BUS transfer FROM
frm_trn_1_on	1st RAIL transfer ON FROM
frm_trn_1_off	1st RAIL transfer OFF FROM
frm_bustrn_2	Did the rider use a 2nd bus or train before getting to current bus or train
	Code Value 1 = Bus
	Code Value 2 = Train
	Code Value 3 = No
frm_bus_2	2nd BUS transfer FROM
frm_trn_2_on	2nd RAIL transfer ON FROM
frm_trn_2_off	2nd RAIL transfer OFF FROM
frm_bustrn_3	Did the rider use a 3rd bus or train before getting to current bus or train
	Code Value 1 = Bus
	Code Value 2 = Train
	Code Value 3 = No
frm_bus_3	3rd BUS transfer FROM
frm_trn_3_on	3rd RAIL transfer ON FROM
frm_trn_3_off	3rd RAIL transfer OFF FROM
frm_grtr3_bus_trn	Did Rider have more than 3 transfers to get to current bus or train
	Code Value 1 = Yes
	Code Value 2 = No
mode_to_transit	How did rider get from start point to first bus/train used
	Code Value 1 = Rode in a vehicle for part of the trip and walked/biked the rest of the way
	Code Value 2 = Was dropped off at a bus/train station
	Code Value 3 = Carpooled/vanpooled with others and parked near the bus stop/train station
	Code Value 4 = Drove alone and parked near the bus stop/train station
	Code Value 5 = Walked all the way to the bus stop/train station
	Code Value 6 = Bicycled all the way to the bus/train
or_wlk_dist	How far did the respondent walk from the origin to transit
	Code Value 1 = < 1/8 mile (less than 1 block)
	Code Value 2 = 1/8 mile (1-2 blocks)
	Code Value 3 = 1/4 mile (3-4 blocks)
	Code Value 4 = 1/2 mile (5-8 blocks)
	Code Value 5 = 3/4 mile (9-12 blocks)
	Code Value 6 = 1 mile
	Code Value 7 = 1.5 miles
	Code Value 8 = 2 miles or more
or_wlk_time	Time in minutes to walk from origin to Transit
to_prk_ride_acc	Location where person parked if the person parked a car
on_lon	ON Longitude for the location where the person boarded the bus/train
on_lat	ON Latitude for the location where the person boarded the bus/train
where_on	ON location with address or description of the boarding location
pid_on	ON reference GIS reference ID code
on_stop_seg	Code for the Stop or Segment on a route where the rider GOT ON
	Airport=S7
	Art Center=N5
	Ashby=W3
	Avondale=E7
	Bankhead=P1
	Brookhaven=NE8
	Buckhead=N7
	Chamblee=NE9
	Civic Center=N2
	College Park=S6
	Decatur=E6
	Dome/GWCC/Phillips/CNN=W1
	Doraville=NE10
	Dunwoody=N9

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
	East Lake=E5
	East Point=S5
	Edgewood/Candler=E4
	Five Points=5P
	GA State=E1
	Garnett=S1
	Hamilton E Holmes=W5
	Indian Creek=E9
	Inman Park=E3
	Kensington=E8
	King Memorial=E2
	Lakewood/Fort McPherson=S4
	Lenox=NE7
	Lindbergh=N6
	Medical Center=N8
	Midtown=N4
	North Avenue=N3
	North Springs=N11
	Oakland City=S3
	Peachtree Center=N1
	Sandy Springs=N10
	Vine City=W2
	West End=S2
	West Lake=W4
off_lon	OFF Longitude for the location where the person boarded the bus/train
off_lat	OFF Latitude for the location where the person boarded the bus/train
where_off	OFF location with address or description of the boarding location
pid_off	OFF reference GIS reference ID code
off_stop_seg	Code for the Stop or Segment on a route where the rider GOT OFF
	Airport=S7
	Art Center=N5
	Ashby=W3
	Avondale=E7
	Bankhead=P1
	Brookhaven=NE8
	Buckhead=N7
	Chamblee=NE9
	Civic Center=N2
	College Park=S6
	Decatur=E6
	Dome/GWCC/Phillips/CNN=W1
	Doraville=NE10
	Dunwoody=N9
	East Lake=E5
	East Point=S5
	Edgewood/Candler=E4
	Five Points=5P
	GA State=E1
	Garnett=S1
	Hamilton E Holmes=W5
	Indian Creek=E9
	Inman Park=E3
	Kensington=E8
	King Memorial=E2
	Lakewood/Fort McPherson=S4
	Lenox=NE7
	Lindbergh=N6
	Medical Center=N8
	Midtown=N4
	North Avenue=N3

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
	North Springs=N11
	Oakland City=S3
	Peachtree Center=N1
	Sandy Springs=N10
	Vine City=W2
	West End=S2
	West Lake=W4
transfer	Will rider transfer to another bus or train
	Code Value 1 = Yes
	Code Value 2 = No
to_bustrn_1	Will rider transfer to a bus or train 1st?
	Code Value 1 = Bus
	Code Value 2 = Train
to_bus_1	1st BUS transfer TO
to_trn_1_on	1st RAIL transfer ON TO
to_trn_1_off	1st RAIL transfer OFF TO
to_bustrn_2	Will rider transfer to 2nd bus or train?
	Code Value 1 = Bus
	Code Value 2 = Train
	Code Value 3 = No
to_bus_2	2nd BUS transfer TO
to_trn_2_on	2nd RAIL transfer ON TO
to_trn_2_off	2nd RAIL transfer OFF TO
to_bustrn_3	Will rider transfer to 3rd bus or train?
	Code Value 1 = Bus
	Code Value 2 = Train
	Code Value 3 = No
to_bus_3	3rd BUS transfer TO
to_trn_3_on	3rd RAIL transfer ON TO
to_trn_3_off	3rd RAIL transfer OFF TO
to_grtr3_bus_trn	Will rider tranfer to more than 3 buses or trains
	Code Value 1 = Yes
	Code Value 2 = No
mode_frm_transit	Mode of access from last bus or train used for this trip
	Code Value 1 = Will ride in a vehicle for part of the trip and walk/bike the rest of the way
	Code Value 2 = Be picked up by someone at the bus stop/train station
	Code Value 3 = Carpool/vanpool with others to my destination
	Code Value 4 = Drive alone to my destination
	Code Value 5 = Walk all the way my destination
	Code Value 6 = Bicycle all the way to my destination
dest_wlk_dist	Distance will walk from transit to destination
	Code Value 1 = < 1/8 mile (less than 1 block)
	Code Value 2 = 1/8 mile (1-2 blocks)
	Code Value 3 = 1/4 mile (3-4 blocks)
	Code Value 4 = 1/2 mile (5-8 blocks)
	Code Value 5 = 3/4 mile (9-12 blocks)
	Code Value 6 = 1 mile
	Code Value 7 = 1.5 mile
	Code Value 8 = 2 miles or more
dest_wlk_time	Time the rider will walk to destination as reported by rider in minutes
frm_prk_ride_acc	Where did rider park his/her car?
dest_typ	Destination Type of Place
	Code Value 1 = Your HOME
	Code Value 2 = Your WORKPLACE
	Code Value 3 = Store/Retail Place
	Code Value 4 = Restaurant
	Code Value 5 = School/Daycare
	Code Value 6 = Hospital/Doctor
	Code Value 7 = Recreation Place

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
	Code Value 8 = Bank/Other Office
	Code Value 9 = Another home
	Code Value 10 = Place of Worship
	Code Value 11 = Hotel
	Code Value 12 = College/University (student only)
	Code Value 13 = Airport (passenger only)
	Code Value 14 = Other
dest_name	Name of Destination
dest_adr_int	Did the person provide the exact address or intersection for Destination
	Code Value 1 = Exact Address
	Code Value 2 = Intersection
dest_lon	destination longitude
dest_lat	destination latitude
dest_adr	Destination address if complete address given
dest_str1	1st street given for destination if the respondent provided an intersection
dest_str2	2nd street given for destination if the respondent provided an intersection
dest_int	destination intersection
dest_city	destination city name
dest_cnty	destination county code (see codes on the next worksheet)
	1=FULTON
	2=DEKALB
	3=COBB
	4=GWINNETT
	5=CLAYTON
	6=CHEROKEE
	7=HALL
	8=BARROW
	9=BARTOW
	10=CARROLL
	11=COWETA
	12=DOUGLAS
	13=FAYETTE
	14=FORSYTH
	15=HENRY
	16=NEWTON
	17=PAULDING
	18=ROCKDALE
	19=SPALDING
	20=WALTON
	21=OTHER
dest_zip	destination zip code
	Code Value 99999 = Not Provided
breeze_card	Did the respondent use a Breeze card?
	Code Value 1 = Yes
	Code Value 2 = No
TYPE_OF_FARE	Type of fare paid
	Code Value 1 = 1-Day Pass
	Code Value 2 = 7-Day Pass
	Code Value 3 = 10 Trip Pass
	Code Value 4 = 20 Trip Pass
	Code Value 5 = 30-Day Pass
	Code Value 6 = 31-Day Pass
	Code Value 7 = 40-Ride Pass
	Code Value 8 = Half-Fare 65+
	Code Value 9 = Half-Fare 10-ride
	Code Value 10 = Half-Fare Out of District
	Code Value 11 = Local to Express Upgrade
	Code Value 12 = Round-Trip Fare

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
	Code Value 13 = Single One-Way Fare
	Code Value 14 = Student Weekly Pass
	Code Value 15 = U-Pass Faculty/Staff
agency_fare	Agency issuing the fare
	Code Value 1 = MARTA
	Code Value 2 = GRTA
	Code Value 3 = C-TRAN (CLAYTON)
	Code Value 4 = CCT (COBB)
	Code Value 5 = HALL
	Code Value 6 = GWINNETT
	Code Value 7 = OTHER
	Code Value 8 = CHEROKEE
	Code Value 9 = DON'T KNOW
hh_veh	Number of vehicles available to the household
	Code Value 0 = Zero
	Code Value 1 = One
	Code Value 2 = Two
	Code Value 3 = Three or more
veh_access	Could the rider have used one of the vehicles today
	Code Value 1 = Yes
	Code Value 2 = No
hh_persons	Number of people in household
	Code Value 1 = One
	Code Value 2 = Two
	Code Value 3 = Three
	Code Value 4 = Four
	Code Value 5 = Five
	Code Value 6 = Six or more
hh_adult	Number of adults in household
	Code Value 1 = One
	Code Value 2 = Two
	Code Value 3 = Three
	Code Value 4 = Four
	Code Value 5 = Five
	Code Value 6 = Six or more
hh_employ	Number of employed persons in household
	Code Value 0 = Zero
	Code Value 1 = One
	Code Value 2 = Two
	Code Value 3 = Three
	Code Value 4 = Four
	Code Value 5 = Five
	Code Value 6 = Six or more
employed	Are you employed?
	Code Value 1 = Yes
	Code Value 2 = No
work_already	Have you been to work already today?
	Code Value 1 = Yes
	Code Value 2 = No
work_ltr	Are you going to work later today?
	Code Value 1 = Yes
	Code Value 2 = No
student	Are you a student?
	Code Value 1 = Yes
	Code Value 2 = No
school_already	Have you been to school already?
	Code Value 1 = Yes
	Code Value 2 = No
school_ltr	Are you going to school later today?
	Code Value 1 = Yes

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
	Code Value 2 = No
driver_lic	Do you have a driver's license?
	Code Value 1 = Yes
	Code Value 2 = No
age	What is your age
	Code Value 1 = under 18
	Code Value 2 = 18-24
	Code Value 3 = 25-34
	Code Value 4 = 35-44
	Code Value 5 = 45-54
	Code Value 6 = 55-64
	Code Value 7 = 65+
income	What is your annual household income?
	Code Value 1 = Below $5;000
	Code Value 2 = $5;000-$9;999
	Code Value 3 = $10;000-$19;999
	Code Value 4 = $20;000-$29;999
	Code Value 5 = $30;000-$39;999
	Code Value 6 = $40;000-$49;999
	Code Value 7 = $50;000-$59;999
	Code Value 8 = $60;000-$74;000
	Code Value 9 = $75;000-$99;999
	Code Value 10 = $100;000-$119;000
	Code Value 11 = $120;000 or more
hispanic	Is the person Hispanic
	Code Value 1 = Yes
	Code Value 2 = No
race_ethn	What is the person's race
	Code Value 1 = White
	Code Value 2 = Black/African American
	Code Value 3 = Asian
	Code Value 4 = Other
	Code Value 5 = American Indian
eng_ability	How well could the person speak English
	Code Value 1 = Very Well
	Code Value 2 = Somewhat Well
	Code Value 3 = Not Well at All
gender	What was the person's gender
	Code Value 1 = Male
	Code Value 2 = Female
HOME_ADDRESS_OR_INTERSECTION	Did the person provide the exact address or intersection for the HOME
	Code Value 1 = Exact Address
	Code Value 2 = Intersection
home_lon	home longitude
home_lat	home latitude
home_adr	home address if complete address given
home_str1	1st street given for home if the respondent provided an intersection
home_str2	2nd street given for home if the respondent provided an intersection
home_int	home intersection
home_note	note regarding the location of the person's home if applicable
home_city	home city name
home_cnty	home county code (see codes on the next worksheet)
	1=FULTON
	2=DEKALB
	3=COBB
	4=GWINNETT
	5=CLAYTON
	6=CHEROKEE
	7=HALL
	8=BARROW

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
	9=BARTOW
	10=CARROLL
	11=COWETA
	12=DOUGLAS
	13=FAYETTE
	14=FORSYTH
	15=HENRY
	16=NEWTON
	17=PAULDING
	18=ROCKDALE
	19=SPALDING
	20=WALTON
	21=OTHER
home_zip	home zip code
	Code Value 99999 = Not Provided
origin_taz	TAZ for the ORIGIN
destination_taz	TAZ for th DESTINATION
home_taz	TAZ for the HOME
boarding_taz	TAZ for the boarding location
alight_taz	TAZ for the alighting location
transit_op	Transit Operator
trip_purpose	Transit Purpose Code
BUS_Transfers_reported	Number of bus transfers reported by the respondent
RAIL_Transfers_reported	Number of rail transfers reported by the respondent (transfers at five points, ashby, and lindbergh were not reported)
Total_Reported_Transfers	Total number of transfers reported by the respondent
UNREPORTED_Rail_Transfers	Number of unreported RAIL transfers at five points, ashby, and lindbergh
TOTAL_TRANSFERS	Total number of transfers (reported and unreported)
survey_od_dist	Distance from the origin to the destination in miles
qc_flag	Quality control flag
	1=Meets contractual requirements AND passed all QA/QC checks
	2=Meets contractual requirements, had minor deficiencies in the QA/QC tests, but the record I generally acceptable
	3=Met contractual completeness requirements but there were major errors in the reported data
Problem_Descrip	Description of the reason a record received a qc_flag of 2 or 3
Time_Period	Period of the day when survey was conducted
	A=AM Peak (6:00am-9:59am)
	P=PM Peak (3:00pm-6:59pm)
	N=Non Peak hours (all other hours)
Link_trp_WGT_FACTOR	Linked trip weighting factor (1/1+#reported transfers)
Unlinked_WGT_Factor_RAW	Weighting factor for UNLINKED trips
Unlinked_WGT_Factor_RAIL_Multiplier	Adjustment to expand the number of rail trips to the regional total; this factor accounts for cells that were not represented
Unlinked_WGT_Factor_ADJUSTED	This weighting factor will expand the database to the regional total
RAIL_BUS	Was this survey administered on a Train or Bus
	R=Rail (train)
	B=Bus
SUR_RTE_ALPHA	Name of the Station or the Transit Agency Code
SUR_RTE_NUM	Bus Route Number
RECORD_USE_CODE	Useability Code for the Survey Record
	1=Fully Usable, included in data expansion
	2=meets contractual requirements but was not used in data expansion for minor reasons
	3=Survey record was complete, but the data was generally not acceptabel, the data in this record has useful demographic data
	4=Record was not complete (missing income data, missing one or more addresses)
	5=Short Trip record that contains ON and OFF data

ARC On-BOARD SURVEY CODEBOOK

Field Name	Description and Codes
	6=Dummy records added to similate trips between rail stations that were not captured in the survey
FINAL_WGT_FACTOR_NAME	Unique Name for Data Expansion Purposes The first set of letters identy the route or rail station, the next letter identifies the boarding location, the next letter identifies the alighting location, the last letter identifies the time of day
id_aok_new	Unique ID number

Appendix 2: R Script to find shortest route

R Notebook: "Shortest Route"

Reference Code: https://github.com/rCarto/osrm

Clear global environment at any point in time (as needed)

````
```{r}
rm(list=ls())
```
````

Installing required libraries

````
```{r}
install.packages("osrm")
install.packages("cartography")
install.packages("GISTools")
install.packages("rgdal")
```
````

Loading required packages

````
```{r}
library(osrm)
library(cartography)
library(GISTools)
library(rgdal)
```
````

Setting working directory

````
```{r}
setwd("C:/Users/pooja/OneDrive - Georgia Institute of Technology/1. Option
Paper/Figuredoutdata")
getwd()
````
````

````
```
````

Loading data with geographic information (latitude and longitude)

````
```{r}
marta_rail_bus<-read.csv(file="MARTA_BusRail_id.csv",header=TRUE,sep=",")
```
````

Finding shortest route path for the data points (output as SpatialLinesDataFrame)

````
```{r}
route_path <- osrmRoute(src=marta_rail_bus[1, c("u_id","on_lon","on_lat")],
                 dst=marta_rail_bus[1, c("u_id","off_lon","off_lat")],
                 sp=TRUE,overview="full")
for(i in 2:nrow(marta_rail_bus))
{
route_path <- rbind.SpatialLinesDataFrame (route_try_path, osrmRoute (src=marta_rail_bus [i,
c("u_id","on_lon","on_lat")],
dst=marta_rail_bus[i,c("u_id","off_lon","off_lat")],
sp=TRUE,overview="full"))
Sys.sleep(0.5)
}
```
````

Writing SpatialLinesDataFrame to shapefile

````
```{r}
fp=file.path("C:/Users/pooja/OneDrive - Georgia Institute of Technology/1. Option
Paper/Figuredoutdata")
writeOGR(route_path, fp, layer="route", driver="ESRI Shapefile", verbose=TRUE)
```
````
````