SSM - Population Health 29 (2025) 101753

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: www.elsevier.com/locate/ssmph

Transit bus access to healthy, affordable food: A novel geographic information system (GIS) and community-informed analysis

Ric Bayly[a,b,*], Jennifer Pustz[b], Thomas J. Stopka[b], Jay Metzger[c], Mary C. Waters[d]

[a] *Tufts University Friedman School of Nutrition Science and Policy, 150 Harrison Ave, Boston, MA, 02111, USA*
[b] *Public Health and Community Medicine, Tufts University School of Medicine, 136 Harrison Ave., Boston, MA, 02111, USA*
[c] *Center for Health Data and Analysis, Rhode Island Department of Health, 3 Capitol Hill, Providence, RI, 02908, USA*
[d] *Department of Sociology, Harvard University, 33 Kirkland Street, Cambridge, MA, 02138, USA*

ARTICLE INFO

Keywords:
Transit
Bus
Food access
Food security
GIS
Equity
Low-income

ABSTRACT

Good nutrition reduces the risk of chronic disease, but many vulnerable populations do not have equitable access to healthy food. People who are lower-income, non-White, older, or disabled, have increased likelihood of not owning a vehicle and of being dependent on public buses to source healthy, affordable food. Our study took place in three municipalities targeted by the Rhode Island Department of Health for equity-focused interventions. Our methodology aimed to overcome limitations of prior analyses of public transit food access. We determined healthy food sources, stratifying their affordability with market basket pricing data and community input. Using a geographic information system (GIS), we identified the transit bus service areas of the sources. Our novel approach included employing a fixed bus wait time, determining bus travel times based on schedule combined with historical data, and determining acceptable travel times through a community leader survey. We analyzed access by subgroups including those experiencing poverty, older adults, those without cars, and those with disabilities. We found that 45% of the population in the most urban municipality had bus access to discounted healthy food, and no one in the two less urban municipalities did. Bus access to six food pantries was limited to 15%–28% of the population. Our approach, combining spatial analysis informed by surveys and community input, can increase the ease and accuracy of analyzing bus access to healthy, affordable food and is replicable in other regions and extensible to other types of destinations and services and to rail transit.

1. Introduction

More than half (51.8%) of the U.S. adult population had at least one chronic medical condition in 2018 (Boersma et al., 2020). Good nutrition lowers the risk of chronic disease, including obesity, diabetes, ischemic heart disease, and total cancer (Afshin et al., 2019; Miller et al., 2020). Yet healthy food (which we will define as minimally processed food) access is not equitable in the U.S. for many who are lower-income, minority, older adults, or have disabilities (Schwartz et al., 2019; Vaudin et al., 2022; Walker et al., 2010).

Further, dependency on public transit and inequities in healthy food access are associated with an increased risk of food insecurity (Bonanno & Li, 2015), which affects 10.2% of U.S. households (Coleman-Jensen et al., 2022). Households with incomes below 185% of the poverty threshold, or with a household member who is either Black/non-Hispanic or Hispanic, have higher rates of food insecurity: 26.5%, 19.6%, and 16.2%, respectively (Coleman-Jensen et al., 2022). At the same time, low-income and non-White households, as well as individuals with disabilities, are more dependent on public transit than the average household or individual (Anderson, 2016; Brumbaugh, 2018; Oak Ridge National Laboratory, 2019).

1.1. National-level food access assessment tools

The U.S. Department of Agriculture recognizes the need to access healthy food and has developed two tools to measure it, yet neither takes into account public transit access. The Food Environment Atlas (Economic Research Service, 2023) is an interactive map that displays the numbers of food store types, from supercenters to convenience. Comprehensive, selectable parameters include distance, vehicle

* Corresponding author. Department of Public Health and Community Medicine, Tufts University School of Medicine, 136 Harrison Avenue, Boston, MA, 02111, USA.

E-mail address: ric.bayly@tufts.edu (R. Bayly).

https://doi.org/10.1016/j.ssmph.2025.101753
Received 23 December 2023; Received in revised form 19 December 2024; Accepted 8 January 2025
Available online 13 January 2025

ownership, seniors, food assistance programs, diabetes and obesity, race and ethnicity, and income. This map's estimates of physical access are at the county level and do not take into account road networks or transportation modes, reducing the utility of this tool at the community level.

The second ERS tool, the Food Access Research Atlas (Economic Research Service, 2024), estimates and displays low-income census tracts (33% of households with low-income) that have low-access to food stores. However, this tool cannot estimate the food access of the many low-income households found in communities with fewer than 33% low-income households.

1.2. Transit versus automobile or walking access assessment

To meet the needs of policy makers, public health officials, and others at the local level, researchers have developed multiple methodologies to analyze the spatial relationship of where people live to where they can acquire food. While automobile access is almost always evaluated in spatial access assessments, only a small number of studies have examined public transit access. The paucity of transit access analyses may be due in part to the predominance of the car as the preferred access mode in high-income countries but may be in part related to the analytical challenges involved in calculating transit access.

The roots of these challenges are two-fold: the multi-modal nature of transit travel, most frequently walking combined with bus, and the need to incorporate fixed transit schedule and inflexible route information into analyses. Car, walking, and biking modes are analyzed with the freedom to select a departure time without regard for the effects of schedule and fixed routes, and without the need for accommodating mode transition effects such as wait times at transit stop and transfer points. The ability to depart unconstrained by an external schedule and to travel without changing mode (i.e., solely by car or on foot), make analyzing car or walking travel much simpler, and potentially more accurate, than analyzing travel by public transportation. Driving and walking service areas of food sources can be determined in a straightforward manner within Geographic Information Systems (GIS).

1.3. Multiple dimensions of accessibility and equity issues

Further, when contemplating the multiple dimensions of travel access to healthy food, additional considerations and challenges arise apart from the spatial-analytical questions that may be addressed by GIS. Car, public transit, and walking vary greatly in their inherent burdens, including, for transit users, exposure to walking effort, carrying effort, weather, traffic, and waiting. Further, financial considerations affect access to healthy food in terms of the cost of transportation and the affordability of the food that is physically accessible. Costs related to these factors include not only time, money, and stress, but personal physical costs associated with weather and disabilities. All these costs increase the level of disparity for transit users who, frequently, are already vulnerable (Vedovato et al., 2022). The challenges of dependency on public transit for access to food, as well as jobs, services, education, and recreation, are a particular burden for those who are already disadvantaged by their socioeconomic or immigrant status, race, ethnicity, age, or disabilities (Aaronson et al., 2012; Klein et al., 2023).

Unsurprisingly, use of a car provides far more access to groceries than use of public transit (Leuthart et al., 2022; Widener, 2017). Surveys of food access have found 10%–11% of low-income respondents were dependent on buses for food shopping (Mabli, 2014). Although car ownership in low-income families has risen over the years, both being carless and using transit still tend to be mostly associated with low income (Brown, 2017). Also, access to healthy food for low-income households may be affected by the often transient nature of car ownership, where periods of carlessness may alternate with periods of car ownership (Klein et al., 2023).

1.4. Prior transit access to healthy food studies

Transit access to healthy food studies have aimed to overcome some inherent spatial-analytical challenges by employing newer GIS tools (Lytle & Sokol, 2017) and improved, albeit at times complex, methods (Abel & Faust, 2018). Grengs (2001), Burns and Inglis (2007), Larsen and Gilliland (2008), Farber et al. (2014), Widener et al. (2015), Abel and Faust (2018), and Leuthart et al. (2022) all have measured access to food via bus using GIS analyses. General Transit Feed Specification (GTFS), a worldwide standard for distributing transit schedule data, is typically favored in GIS analyses and was employed in the well-cited papers of Farber et al. (2014) and Widener et al. (2015).

One of the primary limitations of these prior GIS-enabled studies of transit access to healthy food is lack of certainty regarding transit travel time burden. This limitation results in diminished accuracy and potentially less utility of access analyses in formulating policy and interventions. An early study did not consider travel time (Grengs, 2001), and another considered travel time only as converted to distance for the bus but not the walking component of the analyzed trips (Larsen & Gilliland, 2008), although for most riders bus stops are accessed by walking.

Critically absent have been methods to fully control variations in travel time due to variations in wait times at bus stops. Wait times are a necessary component of bus travel and can greatly diminish the reach of a bus service area in studies with a fixed maximum acceptable travel time to access a food source or other service. Leuthart et al. (2022) did not use wait times. Farber et al. (2014) incorporated wait times with the assumption that a rider's arrival at a bus stop was uncoordinated with the bus schedule, contributing to bus-to-next-bus fluctuations of up to 34 min in travel time between the two points offered as an example in their study. These fluctuations translated into variations of many miles in the traveled distance of buses within a set time. Thus, the assumption of the lack of schedule-coordinated behavior on the part of passengers can greatly inflate or deflate a food source service area (or any other type of destination's service area) dependent on whether the theoretical traveler with an allotted amount of travel time arrives at the originating stop just after or just before the bus departs.

To reduce uncertainty in their estimates of travel time, and thus service area size or accessibility indicator, Farber et al. (2014), Widener (2017), and others took the approach of measuring total travel time at intervals over a portion of the day. However, the results were then averaged, decreasing their accuracy by assigning an unspecified amount of time to waiting that would otherwise be available for bus travel.

Analysts have combined defined walk zones (Fan & Li, 2019) and transit stop wait times in studies that are not focused on food source access. For instance, Benenson et al. (2011) created a custom software module for a popular GIS. It circumvented inflating/deflating service areas, caused by passenger arrivals at the bus stop just after or just before bus departure, by allowing input of a maximum wait time and cancelling any trip that would exceed the maximum.

Several teams of investigators (Abel & Faust, 2018; Farber et al., 2014; Larsen & Gilliland, 2008; Widener et al., 2015) enhanced the travel time accuracy of their analyses (Li et al., 2022) by adding walk times to and from bus stops using realistic street routes – network analysis – instead of the simpler method of drawing Euclidean distance buffers to create service areas around the stops. Conversely, most studies of bus access to healthy food in the literature have employed the centroid of a spatial unit such as a Traffic (Transportation) Analysis Zone or a Census Block or Tract as their origination point for analysis, a less precise determinant of population access than simply using a GIS to extract population from a service area overlay.

Discrepancies between bus schedules embedded in GTFS data and real-life performance on those bus routes might add to imprecision in estimating service areas. Recognizing this, instead of using GTFS data, Leuthart et al. (2022) employed a small sampling of three bus rides to calculate an average speed of bus travel for their analysis in

Bloomington, Indiana.

Finally, a general limitation of accessibility studies has been the lack of data to quantify or define acceptable travel time cost. Providing a range for policymakers and others to consider, Farber et al. (2014) and Widener (2017) use an array of travel times in 10 or 15 min intervals, respectively, to categorize their results.

1.5. Our approach

In this paper, we examine the geographical and transportation aspects of transit bus access to healthy food, stratified by affordability. Our study took place in Rhode Island in three Health Equity Zone municipalities, designated and targeted by the state's Department of Health for equity-focused interventions. The city of East Providence and the towns of Warren and Bristol extend southeast from the city of Providence along the border of Rhode Island and Massachusetts. The three municipalities have differing degrees of urban and suburban relationships to the city of Providence, providing the opportunity to examine healthy food access by bus across a range of environments.

Similar to some other studies (Burns & Inglis, 2007; Farber et al., 2014; Grengs, 2001; Larsen & Gilliland, 2008), we report demographic and socioeconomic data for those served by bus access to healthy food. Our methods were designed to overcome complexities and limitations of prior analyses of public transit access to healthy, affordable food.

2. Methods

2.1. Data collection

To perform our access analysis, we first identified a mean acceptable round-trip bus travel time, which we calculated from responses to a questionnaire distributed to leaders of the three communities for which a healthy food access analysis had been requested. These community members were leaders of food pantry and free-meal non-profits, as well as Head Start, senior, assistance for people with disabilities, and other community-based organizations. In addition to recommended travel time limits, the community leader questionnaire also collected comments on issues related to accessibility and evaluations of the affordability of food stores.

The community leader responses provided characterizations of the cost of shopping for food at local supermarkets, which we used to rate the affordability of these retailers. The affordability ratings were used to validate the price rankings of the retailers based on a market basket of nine food items from an in-store survey (see Supplement for survey details). The stores were ranked on the basis of total cost of the market basket items and also index ranked with a value of plus one for each item that was more costly than the median for that item and a value of minus one for each item that was less costly. To identify those retailers providing an acceptable offering of healthy food, the food retailer survey also quantified the variety of fresh and canned fruits and vegetables and frozen vegetables available in each store (see Supplement for details of retailer identification methods and qualifying criteria). We included fresh, frozen, and canned since, depending on the item, each of these forms can deliver the highest nutrient content, with frozen or canned often at lower cost than fresh (Miller & Knudson, 2014; Rickman et al., 2007).

A food pantry survey was used to identify pantries offering fresh produce on a weekly basis, the qualifying criteria for a pantry's inclusion in our spatial analysis (see Supplement). Data for this survey were collected with web searches and via phone.

2.2. Coordinated bus stop arrival

Little research has investigated the propensity of bus travelers to coordinate their arrival time at a bus stop with the expected arrival of a bus. However, Fan and Machemehl (2009) found that at a headway (the spacing between transit vehicles) of 11 minutes or more, passenger behavior transitioned from almost random arrival at bus stops to becoming somewhat more coordinated with bus arrivals. In our study area with six bus routes of a range of lengths and patterns through urban, suburban, and low-density areas, an examination of bus schedules indicated the average headway was longer than in a typical strictly urban area.

We made the inclusive assumption that travel time for shopping was constrained by other time demands on the shopper and, to reduce travel time, shoppers with limited time would coordinate their arrival at a bus stop with a bus. Shoppers cannot control the bus schedule or easily control where they live relative to a food source, but they can largely control their arrival time at a bus stop to coordinate with a bus arrival. The assumption is not that coordination is universal among shoppers but that it is available to anyone who wants to reduce their travel time. The effect of a fixed wait time on the service areas that we calculated would be to expand them, as more of the travel time could be attributed to bus movement instead of bus stop waiting. The assumption of coordination is strengthened with the growing use of smartphone bus transit apps, available for at least 295 transit systems (Bian et al., 2023) including Rhode Island Public Transportation Authority (RIPTA), the only mass transit service in Rhode Island. Getting bus schedule and live-tracking information is especially easy with ubiquitous smartphone map apps such as Google Maps (Google, Mountain View, CA) and Apple's Maps (Apple, Cupertino, CA). These apps, which have greatly increased in usage since the Fan & Machemehl, 2009, study, also incorporate walking times, allowing for close coordination with bus arrivals.

2.3. On-bus travel time calculation

We chose a 5-min wait time as a reasonable wait-margin at both the originating and the store/pantry bus stops. Five minutes also represents the average wait for passengers arriving at a stop with a headway of 10 min.

Next, we subtracted the 10 min wait total (5 min wait in each direction) and the 10 min round-trip walk to and from the originating bus stop from the total acceptable round trip travel time determined from our community input. The remaining time was the allotted time for the bus itself to travel and, in the case of two pantries and one supermarket that were not located adjacent to a bus stop, for additional walking to occur.

2.4. Bus travel extent calculation

GTFS, originally called Google Transit Feed Specification, was developed by Google in 2005 (Fan & Li, 2019). Google Maps bus transit travel times are based on bus schedules specified in GTFS data provided by transit systems, including RIPTA, and moderated by historical traffic data and live traffic updates detected from bus GPS trackers and other sources. We used Google Maps to determine the travel extent of buses in an allotted amount of time, relative to supermarkets and pantries. To eliminate the effect of any unusual live traffic delays, such as those caused by accidents or road construction, we selected a past Wednesday at noon for our analyses. This limited the Google Maps data to that provided by GTFS and historical records. We confirmed that the most recent two past Wednesdays returned the same result.

For our three communities, Google Maps displays both inbound and outbound bus stops. For each supermarket and pantry, we recorded the originating bus stop located at half the allotted bus travel time away (allowing for the round trip) from the destination store or pantry. We found the corresponding bus stop location in our GIS in order to plot the maximum extent of the service area extending along that bus route. Most stores and pantries in our three municipalities had one adjacent route and so a service area extending in two directions. Three stores had two or three passing routes and so service areas extending in up to six directions.

One store and one pantry were distant enough from a bus route that all the allotted time for travel (bus and walking combined) would be required for walking from, and back to, the closest bus stop to the food source. The second pantry that was not directly adjacent to a bus route required walking time from the stop to the store and back and thus had a reduced service area because of the shortened on-bus time.

We tested crossing bus routes to see if the ability to transfer buses would expand service areas. However, the uncontrolled wait-times at the transfer points (bus-to-bus close timing coordination is not typically feasible) consumed too much of the total travel times to expand the service areas.

2.5. Service area and demographics determination

Employing street network analysis in our GIS, we determined the walking zones around all the bus stops which could reach a discount supermarket, a discount or a regular supermarket, or a food pantry, in the allotted bus travel time as identified in Google Maps. The service areas for each store or pantry were comprised of the sum of all the 5-min walking zones around each food-accessing bus stop.

After we created service areas for qualifying food stores and pantries, we calculated estimates, within a GIS, of the general populations and demographic subgroups within those service areas. We used U.S. Census Bureau 2020 Decennial data and 2018–2022 American Community Survey 5-year estimates, apportioning population to the service areas from Census blocks and block groups, respectively.

3. Results

3.1. Community questionnaire

The community questionnaire received a 100% response rate from the 14 community leaders who received it. The mean acceptable round-trip travel time by bus to access healthy food was 36 min. By comparison, the mean acceptable round-trip time by car to access healthy food was 18 min half of the acceptable bus travel time. Of the 16 supermarkets serving the three communities for those with car access, only 11 were on bus routes within or from communities. Of these bus-accessible supermarkets, two were described by respondents as expensive, two were described as most affordable, and seven were characterized as medium-priced.

Comments on transit bus access discussed issues of carrying groceries, access to bus stops, and mobility challenges. One respondent noted that *"Seniors are not able to do a large shopping at one time since they have to carry the bags themselves."* Another said *"If you have a car, it is [the]easiest way to access food. It is a system designed for drivers."* One community leader who uses a wheelchair identified many issues for many shoppers:

> "Although many of us live on a bus route it's not always feasible traveling to and from supermarkets. Try living with a disability. If you are allowed to take a small travel cart onto the bus often you have trouble getting it on and off the bus and are in the way of other patrons, so a lot of bus drivers will refuse you service if you try. Many of the bus routes do not go to where there are less expensive markets, and if you want to go to one of them you have to walk quite far. If you find sales in different locations, it's not worth the effort and extra expense of travel time. Also, the weather is a factor – rain, snow, extreme heat – keeps many people from making the hike to the bus. Sometimes bus routes are a couple of blocks away. If this is the only choice you have, making your way to the market usually means going two-three times a week. There are many people who have to take taxis just to get their groceries home, which is expensive. Most often we are elderly or disabled and must shop on our own, consuming much of our day. When I'm told how lucky I am to be on a bus route, I like to tell people what I must go through to get a few days of groceries, and I prefer to use my electric wheelchair and lug my groceries home on the footrest of my chair."

3.2. Food retailer and pantry surveys

Following identification of 69 food retailers serving our three study communities, we found no convenience, corner, or dollar store met our criteria for a healthy food provider. Our in-store survey found that all supermarkets met the criteria for good quality, healthy food. Market basket pricing identified two of these supermarkets as expensive (Table 1). At $30.77, the most expensive store's market basket cost more than double that of the least expensive store. These two expensive stores were eliminated from analysis as not meeting the affordability criterion. Of the remaining nine, the two in the most affordable ("discounted") category had market basket costs of $14.89 and $20.10, and the seven in the medium-priced category had market basket costs ranging from $23.27 to $24.79. Our affordability categorizations were closely validated by perceptions in the community survey.

We identified 10 food pantries serving our three study communities, six of which met our criteria as a healthy food provider because they offered fresh fruits and vegetables weekly or better.

3.3. Bus access analysis

In East Providence, 45% of the population had public bus access to one, and only one, of the two local discount supermarkets (Fig. 1, Table 2). Two other discount supermarkets nearby in Massachusetts were not accessible by bus. No one in Warren or Bristol had bus access to discounted food.

In East Providence, 63% of residents had bus access to a regular or discount supermarket, while 28% in Warren and 19% in Bristol did (Fig. 2, Table 2).

Access to food pantries by bus was 21% in East Providence, 28% in Warren, and 15% in Bristol (Fig. 3, Table 2).

Shoppers living within bus access of an affordable supermarket or a pantry in East Providence or Warren typically could access two of each healthy food source. Some in East Providence had bus access to three affordable supermarkets. Shoppers in Bristol who had bus access to an affordable healthy food source had access either to a single supermarket two towns over or to the single food pantry in town, but not both.

Table 1
Market basket pricing of eleven bus-accessible supermarkets.

Community	Community perception of store's affordability	Index pricing of the 9 market basket items vs. median	Total $ cost of the nine items
East Providence	affordable	−7	14.92
East Providence	affordable	−5	20.10
Bristol	medium	5	23.27
Seekonk, MA (East Providence adjacent)	medium	5	23.27
East Providence	medium	5	23.27
Bristol	affordable	0	24.45
East Providence	medium	2	24.79
Barrington, RI (between East Providence and Warren)	medium	2	24.79
East Providence	medium	2	24.79
Providence (East Providence adjacent)	expensive[a]	2	27.48
Bristol	expensive[a]	7	30.77

[a] The two expensive supermarkets were excluded from analysis.

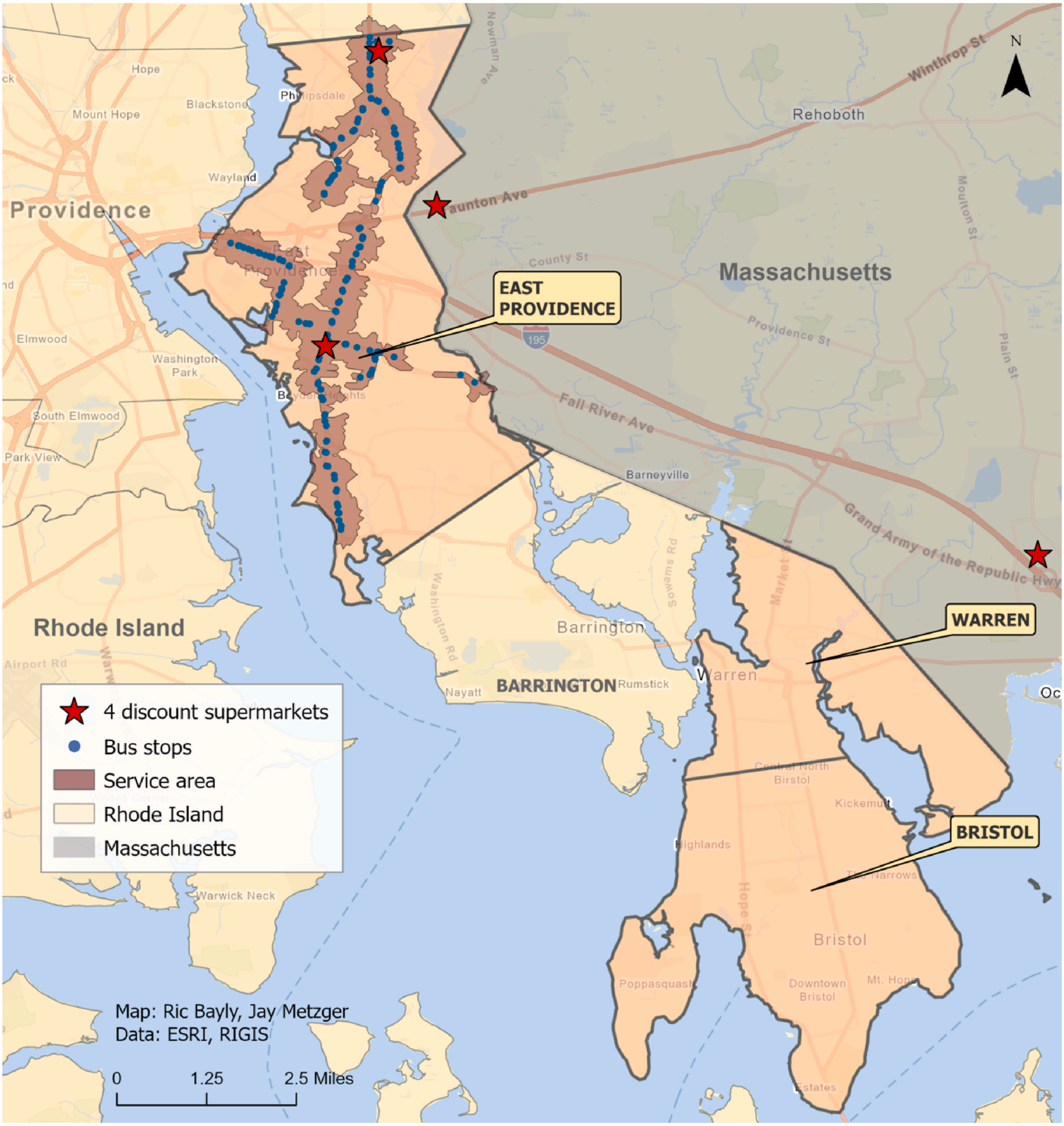

Fig. 1. Transit bus service areas for discount supermarkets: East Providence, Warren, Bristol (Rhode Island.).

3.3.1. *Access by demographic subgroups*

With some significant exceptions, affordable healthy food access via public bus did not tend to vary much across subgroups compared to the general population (Table 2). In East Providence, access for the general population and those in poverty, 65 years and older, White, living in households with a disability or households without a vehicle, was 43% (± 4%) for discount supermarket access and 63% (± 3%) for discount or regular supermarket access. Food pantry access was 20% or 21% for all groups, including the general population, except households without a vehicle, which had 15% access. In Warren and Bristol households without a vehicle were twice as likely as the general population to be near a bus stop with access to affordable supermarkets/pantries (60% vs. 28% and 36%/35% vs. 19%/15%, respectively), and individuals experiencing poverty in those communities were also more likely to have bus access to both affordable and free healthy food (47%/46% and 24%, respectively.) Neither Warren nor Bristol had any access via bus to discount supermarkets.

Those 65 and older, White, and households with a disability, had access to regular supermarkets and pantries similar to the general populations in Warren and Bristol. In Warren, all groups had 27%–32%

Table 2
Population and households with bus access to healthy food sources.

Municipality	Access of subgroups: counts and (%) of total subgroup population			Total subgroup population counts and (%) of total population
	Discount Supermarkets	Discount and Regular Supermarkets	Food Pantries	
East Providence				
Population[b]	21,339 (45)	29,667 (63)	9958 (21)	47,107
Households (HH)[b]				21,035
Poverty[c]	2345 (47)	3278 (65)	1023 (20)	5039 (11)
65+ [b]	4846 (43)	6876 (60)	2251 (20)	11,396 (24)
White[a b]	15,866 (44)	22,057 (61)	7693 (21)	36,076 (77)
HH w/disability[c]	2591 (46)	3692 (66)	1112 (20)	5599 (27)
HH w/o vehicle[c]	653 (39)	1114 (66)	249 (15)	1676 (8)
Warren				
Population[b]	0 (0)	3163 (28)	3130 (28)	11,147
HH[b]				5087
Poverty [c]	0 (0)	536 (47)	532 (46)	1149 (10)
65+ [b]	0 (0)	754 (27)	747 (27)	2821 (25)
White[a b]	0 (0)	2933 (29)	2903 (29)	10,141(91)
HH w/disability [c]	0 (0)	422 (32)	420 (32)	1311 (26)
HH w/o vehicle [c]	0 (0)	336 (60)	334 (60)	557 (11)
Bristol				
Population[b]	0 (0)	4297 (19)	3286 (15)	22,493
HH[b]				8779
Poverty [c]	0 (0)	350 (24)	352 (24)	1468 (7)
65+[b]	0 (0)	1182 (20)	981 (17)	5787 (26)
White[a,b]	0 (0)	3795 (19)	2984 (15)	20,060 (89)
HH w/disability [c]	0 (0)	338 (19)	284 (16)	1737 (20)
HH w/o vehicle [c]	0 (0)	142 (36)	138 (35)	390 (4)
Total population	21,339 (26)	37,127 (46)	16,374 (20)	80,747

Notes.
[a] White includes non-Hispanic and Hispanic. Data.
[b] ESRI estimates based on 2020 U.S. Census.
[c] American Community Survey, 5-year, 2022.

access for both regular supermarkets and pantries, and in Bristol 19% or 20% for regular supermarkets and 15%–17% for pantries.

Of the 11% of individuals in poverty in Warren, 47% had bus access to a regular supermarket and 46% to a pantry, compared to the 28% bus access to both types of healthy food sources for the general population. Of the 27% of households in Warren without a vehicle, 60% had bus access to both a regular supermarket and a pantry, again compared to 28% for the general population. For the 8% of individuals in poverty in Bristol, 24% had bus access to both a regular supermarket and a pantry, compared to 19% and 15%, respectively, in the general population. Households without a vehicle are 4% of the households in Bristol, but 36% of them have bus access to a regular supermarket and 35% of them have bus access to a pantry.

4. Discussion

We developed an approach to estimate transit bus service areas for food retailers and pantries that was novel in multiple ways. We controlled variability in bus stop wait times by working from a specified wait time; we measured bus travel distances for a given time allowance, using a combination of GTFS and historical data; and overall acceptable travel times were based on community input. We mapped walking-defined service areas around bus stops with GIS road network analysis. Using surveys, we determined stores and pantries meeting a threshold of healthy food, then stratified them according to affordability by collecting market basket data and community input. Our methods can be applied to evaluating access to other types of services, in other geographical areas, and to rail transit.

We incorporated a community-provided acceptable round trip time and accounted for bus stop wait and walk times. We assume passengers will coordinate their walking arrival at originating stops with the arrival of a bus. Bus travel distance within a time allotment was determined with enhanced accuracy over other methods using Google Maps. The walking service area around originating bus stops was calculated using a GIS street network. Further, using community input and market surveys, we identified healthy food sources in four categories of affordability: free (pantries), discount, regular price, and expensive.

Our use of qualitative and quantitative community-based data to inform spatial analysis is, to our knowledge, unique in the food access literature. However, Díez et al. (2017) similarly used GIS, in-store surveys, and community voices in their assessment of the healthiness of the food environment in a low-income neighborhood in Madrid. The interpretation of their findings was enriched by the use of Photovoice, with community members critiquing their food environment through a camera lens. The voices of our community leaders were heard through our survey, stating, for example, that without a car older adults and others could not do a large shopping trip. One respondent indicated that many bus drivers will refuse service to passengers with loaded carts, a decision that is backed by RIPTA rules prohibiting unfolded shopping carts (Rhode Island Public Transportation Authority, 2024).

Generally, urban East Providence had the most bus access to affordable supermarkets, followed distantly by Warren and then Bristol, both of the latter not having any access to discount supermarkets. Bus access to food pantries was low throughout the three communities. Not many differences were found in bus access between the subgroups in our analysis and the general population, although people living with poverty were more likely to live on a bus route with affordable healthy food access in Warren, and, to a degree, in Bristol. More notably, in Warren, of the 11% of households without a vehicle, 60% of those were on bus routes with access to free or affordable healthy food. One-third of the 4% of households with no vehicle in Bristol similarly had bus access to free or affordable healthy food, suggesting that in both communities bus access might influence choice of residence location for those without a vehicle.

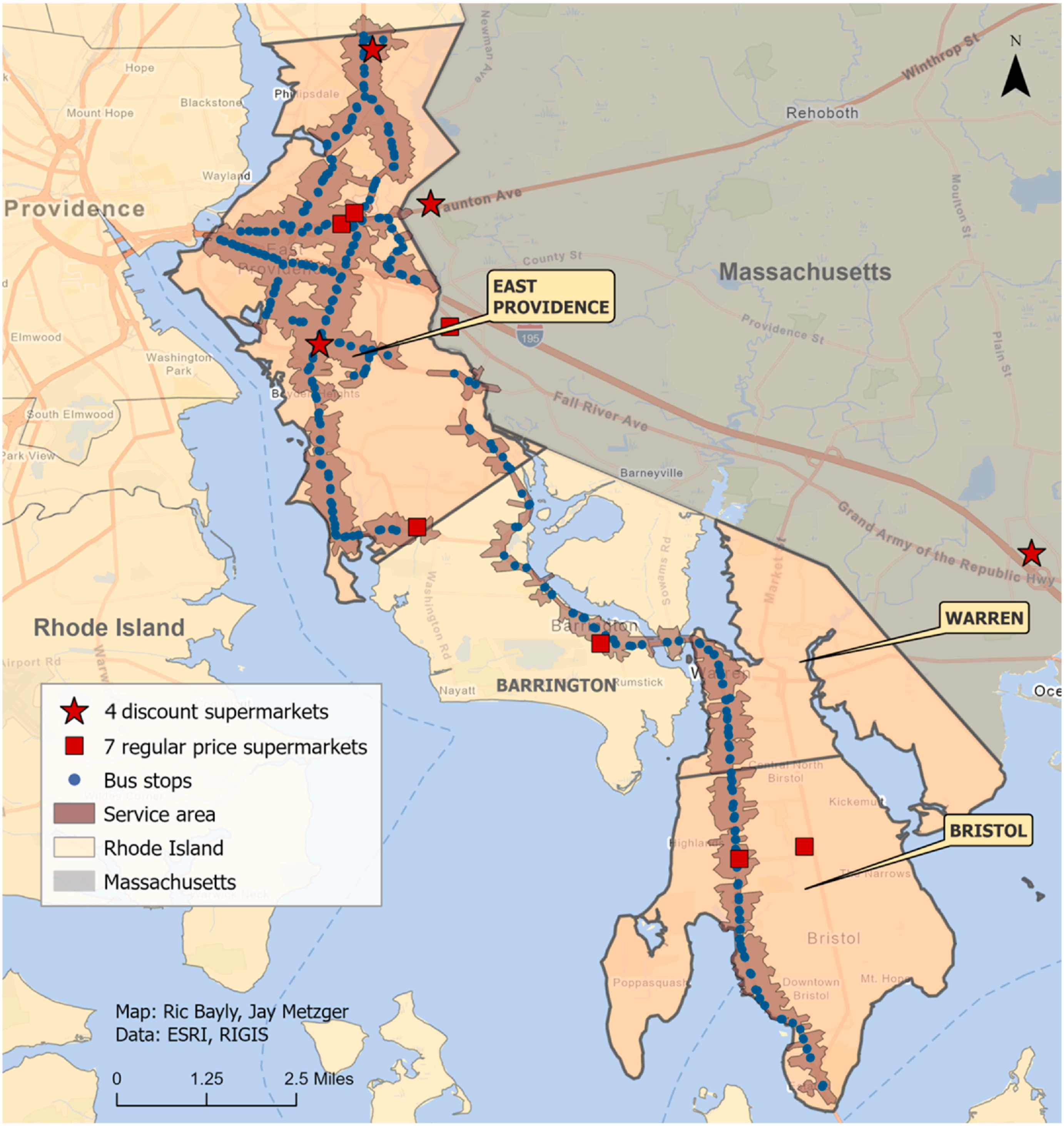

Fig. 2. Transit bus access to regular and discount supermarkets, combined: East Providence, Warren, Bristol (Rhode Island.).

Our market basket pricing results indicate the potential of low-priced food to provide significant savings (Table 1). The cost of the basket at the least expensive retailer was less than half that of the same basket at the most expensive retailer. Therefore, a shopper with limited income can use a discount supermarket to, in effect, increase access to healthy food. Lower-income households, including those receiving food assistance benefits, tend to buy food at a supermarket that is not the closest one to their residence, using a car to get there (Ver Ploeg et al., 2015). Over half the respondents to the 2012 SNAP Food Security Survey cited low prices as their primary reason to choose a food store over one "close to home, convenient, easy to get to" (Mabli, 2014). Because of longer travel times, off-route locations, and other inconveniences associated with bus use, bus-dependent shoppers may have less opportunity to choose a supermarket based on affordability, compared to car-enabled shoppers.

Although access to multiple stores or pantries may reduce inequities in acquiring affordable healthy food for bus users, the largest increment in access occurs when the number of bus-accessible destinations increases from zero to one. Therefore, for this study, we used a simple threshold to define access consisting of residence in the bus service area of one affordable, healthy, food store or pantry. As Geurs and van Wee

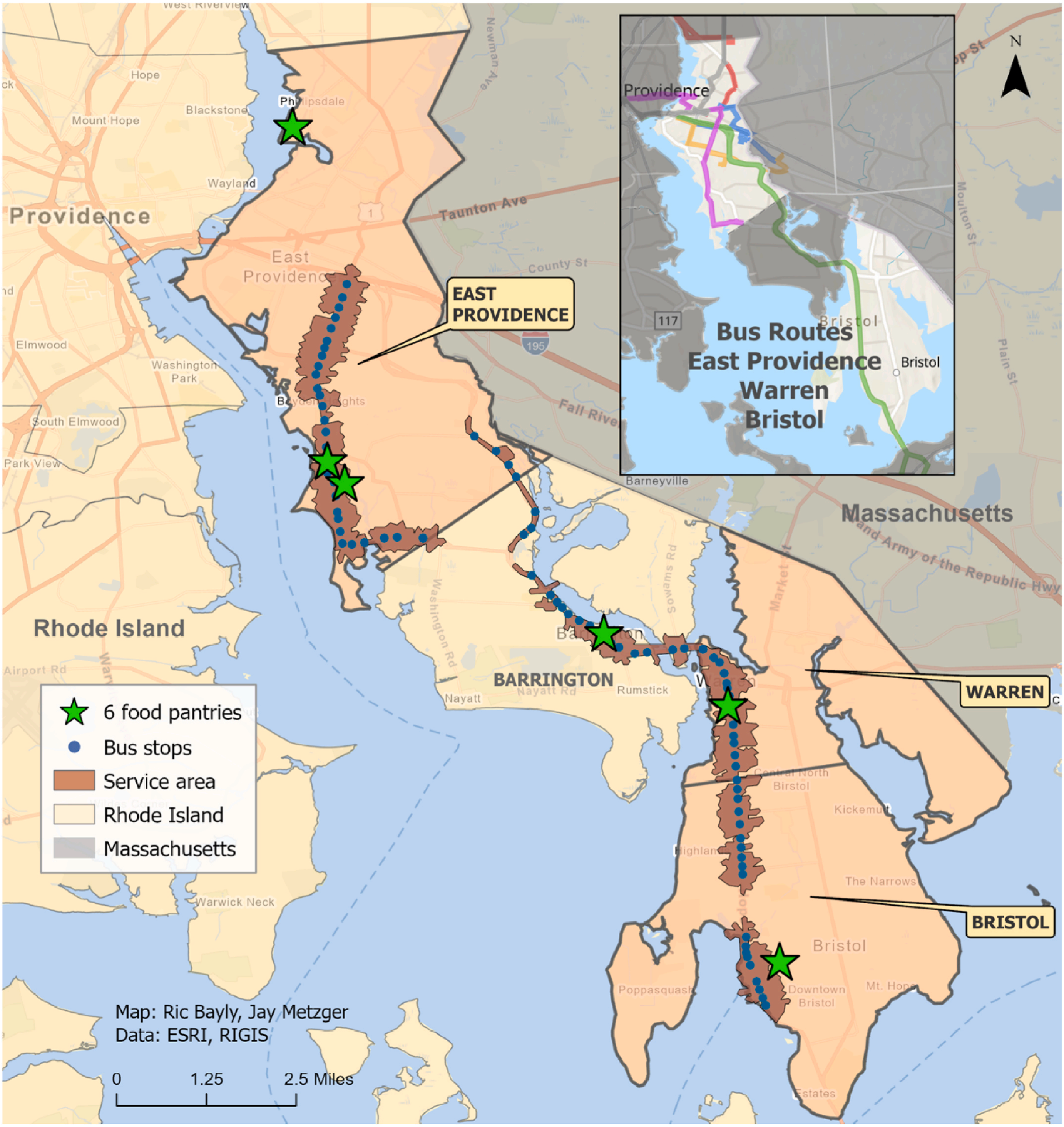

Fig. 3. Transit bus access to food pantries and bus routes: East Providence, Warren, Bristol (Rhode Island.).

(2004) noted, accessibility is a concept with a range of complexity, depending on the type of access and whether the perspective of the analysis is from the typically more complex individual (person-based) viewpoint or the destination (location-based) viewpoint, the latter characterizing our study. Fortunately, transit use, because of the limitations it presents (and despite the complexities inherent in analyzing a schedule-based, fixed route service), lends itself to a tightly focused analysis that can be easier to interpret, such as the narrow, linear service areas generated in our analyses.

We noted there were only two discount supermarkets in the entire study area, both in East Providence and not accessible by bus from Warren or Bristol. All three municipalities did have a discount food retailer nearby across the state border in Massachusetts, providing cost-savings options only for those with car transportation and underlining the inequities for those who were bus dependent.

While analysts comparing transit to car access to healthy food have been careful to employ equal travel time allotments for both modes (Burns & Inglis, 2007; Widener, 2017), when surveyed, community leaders from the three Health Equity Zones reported an expectation of a maximum 18-min round trip travel time reasonable for car shoppers, compared to a maximum 36-min round trip for bus shoppers. Low-wage earners who must shop by bus do not necessarily have more time to do so than higher earners who might be more likely to shop by car. The top 10% of earners in 2021 worked an average of only 4.4 h per week more than the 42.2 h per week of the lowest 10% of earners (Bureau of Labor Statistics, 2022). Although bus users likely plan more travel time to shop, on average, than car users, this is not because bus riders have less value attached to their time than car owners but instead reflects the realities of bus versus car travel.

Older adults typically give up driving as they age, sometimes gradually, retaining a car as an emblem of waning independence (Schwanen & Páez, 2010). Those without a car have been found to be at increased risk for food insufficiency (Fitzpatrick et al., 2016). As the baby boomer cohort ages, with the growth in riders 65 and older increasing 41% between 2009 and 2017 compared to 18% for those 21–35 years old (Oak Ridge National Laboratory, 2019), bus access to affordable healthy food for older adults should be a heightened concern.

Also of particular concern, community members with disabilities are more likely than others to be low-income and to use public transit (Kwon & Akar, 2022). Echoing findings in other studies, when use of a bus is the only option, the community members in our study identified physical limitations, weather, street walkability to bus stops, and limitations in both the amount of food that can be carried on a bus and affordable healthy food source options as special challenges for both community members with disabilities and older adults (Coveney and O'Dwyer, 2009).

Using public buses to access healthy food is a burden that falls disproportionately on disadvantaged groups such as low-income households, older adults, and those with disabilities. When transportation choice is restricted to public transit for these groups, publicly authorized transit planners, who must commonly weigh financial concerns against concerns in pricing, route, schedule, and infrastructure planning, must pay particular attention to the equity balance. Enhanced transit connectivity for high-poverty and minority areas should be the aim, avoiding subpar connectivity as might be found in some urban areas in the United States (Wyczalkowski et al., 2020).

Our analysis was subject to limitations involving the employment of several normative measures, including an acceptable maximum travel time, reflecting a judgement of how long shoppers are willing to travel on a bus for healthy food; an assumption of the motivation and ability of shoppers to use bus schedules, albeit supported by evidence; and a bus stop wait time allowance. However, the study was strengthened by use of a behavior-based, or positive, accessibility measure in the form of Google Maps bus travel times based on GTFS and historical data. Further, to the degree that the community leaders who defined the acceptable maximum travel time based their collective judgment on observed behavior in their communities and the degree to which the prior evidence supported the assumption of bus coordination behavior, these aspects of our analysis can be held to reside in a gray zone between the normative and positive. As pointed out by Páez et al. (2012), the behavior-based positive informs the normative, and the result provides a more solid basis for the formulation of policy and programmatic action.

Future research should investigate transit passenger wait-time tolerance and behavior relative to arrival at transit stops coordinated with a bus or train. Research is also required to weigh perceptions and behavior surrounding reasonable acceptable travel times for driving, bus, and walking across different types of communities and environments, urban and rural.

5. Conclusion

With the use of a fixed wait time for bus service and combined GTFS and historical data for bus travel time, our methods offer a way to more accurately and consistently define service areas for destination points like healthy food sources. The specification of all travel time components and the accuracy of measurement allows clear interpretation of the results. The validity of our analyses was increased using community-generated data to set the travel time parameters and stratify food providers by affordability. Our methods can be easily extended to other transit-based access analyses.

Healthy food is important to reducing the risk of chronic disease and other negative health outcomes. Policy makers, transportation planners, and political and health leaders committed to promoting healthy, affordable, equitable, food environments should incorporate the use of public transit. With an understanding of the limitations and barriers transit presents, particularly for those in greatest need, such as older adults and those living with poverty or disabilities, access for all can be improved.

CRediT authorship contribution statement

Ric Bayly: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jennifer Pustz:** Writing – review & editing, Conceptualization. **Thomas J. Stopka:** Methodology, Writing – review & editing. **Jay Metzger:** Writing – review & editing, Methodology, Conceptualization. **Mary C. Waters:** Writing – review & editing, Methodology, Conceptualization.

Declaration of funding

No financial support was provided for this research.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Critical guidance and input were provided by leaders of the Health Equity Zones of East Providence, Warren, and Bristol, Rhode Island, Director Rita Capotosto. Mariana Arcaya provided important suggestions guiding the development of this study. Reece Lyerly advised on data collection and community engagement and Shikhar Shrestha on GIS analysis. Alissa Ebel provided guidance on the manuscript. We especially thank our anonymous reviewers for their comments and suggestions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2025.101753.

Data availability

The data that has been used is confidential.

References

Aaronson, D., Agarwal, S., & French, E. (2012). The spending and debt response to minimum wage hikes. *The American Economic Review, 102*(7), 3111–3139. https://doi.org/10.1257/aer.102.7.3111

Abel, K., & Faust, K. (2018). *Modeling food desert disruptors: Impact of public transit systems on food access* (Vols. 362–372). https://doi.org/10.1061/9780784481295.037

Afshin, A., Sur, P. J., Fay, K. A., Cornaby, L., Ferrara, G., Salama, J. S., Mullany, E. C., Abate, K. H., Abbafati, C., & Abebe, Z. (2019). Health effects of dietary risks in 195 countries, 1990–2017: A systematic analysis for the Global burden of disease study 2017. *The Lancet, 393*(10184), 1958–1972.

Anderson, M. (2016). *Who relies on public transit in the U.S.?* Pew Research Center. https://www.pewresearch.org/short-reads/2016/04/07/who-relies-on-public-transit-in-the-u-s.

Benenson, I., Martens, K., Rofé, Y., & Kwartler, A. (2011). Public transport versus private car GIS-based estimation of accessibility applied to the Tel Aviv metropolitan area.

The Annals of Regional Science, 47(3), 499–515. https://doi.org/10.1007/s00168-010-0392-6

Bian, J., Li, W., & Lee, C. (2023). Current practices and emerging trends of transit apps for fixed-route bus services in the US. *Journal of Public Transportation, 25*, Article 100052. https://doi.org/10.1016/j.jpubtr.2023.100052

Boersma, P., Black, L., & Ward, B. W. (2020). Prevalence of multiple chronic conditions among US adults, 2018. *Preventing Chronic Disease, 17*. https://doi.org/10.5888/pcd17.200130

Bonanno, A., & Li, J. (2015). Food insecurity and food access in US metropolitan areas. *Applied Economic Perspectives and Policy, 37*(2), 177–204.

Brown, A. E. (2017). Car-less or car-free? Socioeconomic and mobility differences among zero-car households. *Transport Policy, 60*, 152–159. https://doi.org/10.1016/j.tranpol.2017.09.016

Brumbaugh, S. (2018). *Travel Patterns of American Adults with disabilities* (issue Brief, September 2018). *Bureau of Transportation Statistics U.S. Department of Transportation*. https://doi.org/10.21949/1524180

Bureau of Labor Statistics. (2022). *Current population survey* U.S. Census Bureau. https://www.census.gov/programs-surveys/cps.html.

Burns, C. M., & Inglis, A. D. (2007). Measuring food access in Melbourne: Access to healthy and fast foods by car, bus and foot in an urban municipality in Melbourne. *Health & Place, 13*(4), 877–885. https://doi.org/10.1016/j.healthplace.2007.02.005

Coleman-Jensen, A., Rabbitt, M. P., Gregory, C. A., & Singh, A. (2022). Household food security in the United States in 2021 (Economic research report, ERR-309). *Economic Research Service U.S.Department of Agriculture*. https://doi.org/10.22004/ag.econ.329072

Coveney, J., & O'Dwyer, L. A. (2009). Effects of mobility and location on food access. *Health & Place, 15*(1), 45–55. https://doi.org/10.1016/j.healthplace.2008.01.010

Díez, J., Valiente, R., Ramos, C., García, R., Gittelsohn, J., & Franco, M. (2017). The mismatch between observational measures and residents' perspectives on the retail food environment: A mixed-methods approach in the Heart Healthy Hoods study. *Public Health Nutrition, 20*(16), 2970–2979.

Economic Research Service. (2024). *Food access research Atlas*. U.S. Department of Agriculture. Retrieved October 28, 2024 from https://www.ers.usda.gov/data-products/food-access-research-atlas/.

Economic Research Service. (2023). *Food environment Atlas*. U.S. Department of Agriculture. Retrieved October 28, 2024 from https://www.ers.usda.gov/data-products/food-environment-atlas/.

Fan, W., & Li, Y. (2019). Using general transit feed specification (GTFS) data as a basis for evaluating and improving public transit equity. *Center for Advanced Multimodal Mobility Solutions and Education at the University of North Carolina at Charlotte*. https://rosap.ntl.bts.gov/view/dot/61594/dot_61594_DS1.pdf.

Fan, W., & Machemehl, R. (2009). Do transit users just wait for buses or wait with strategies? Some numerical results that transit planners should See. *Transportation Research Record, 2111*(1), 169–176. https://doi.org/10.3141/2111-19

Farber, S., Morang, M. Z., & Widener, M. J. (2014). Temporal variability in transit-based accessibility to supermarkets. *Applied Geography, 53*, 149–159. https://doi.org/10.1016/j.apgeog.2014.06.012

Fitzpatrick, K., Greenhalgh-Stanley, N., & Ver Ploeg, M. (2016). The Impact of food deserts on food insufficiency and SNAP participation among the elderly. *American Journal of Agricultural Economics, 98*(1), 19–40. https://doi.org/10.1093/ajae/aav044

Geurs, K. T., & van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport Geography, 12*(2), 127–140. https://doi.org/10.1016/j.jtrangeo.2003.10.005

Grengs, J. (2001). Does public transit counteract the segregation of carless households? Measuring spatial patterns of accessibility. *Transportation Research Record, 1753*(1), 3–10. https://doi.org/10.3141/1753-01

Klein, N. J., Basu, R., & Smart, M. J. (2023). Transitions into and out of car ownership among low-income households in the United States. *Journal of Planning Education and Research, 0*(0). https://doi.org/10.1177/0739456x231163755

Kwon, K., & Akar, G. (2022). People with disabilities and use of public transit: The role of neighborhood walkability. *Journal of Transport Geography, 100*, Article 103319. https://doi.org/10.1016/j.jtrangeo.2022.103319

Larsen, K., & Gilliland, J. (2008). Mapping the evolution of 'food deserts' in a Canadian city: Supermarket accessibility in London, Ontario, 1961–2005. *International Journal of Health Geographics, 7*, 16. https://doi.org/10.1186/1476-072X-7-16

Leuthart, K. R., Palde, L. P. R., Babb, A. M., Healey, B. P., & Knudsen, D. C. (2022). Examining public transportation in healthy food access research. *Journal of Hunger & Environmental Nutrition, 17*(2), 245–260. https://doi.org/10.1080/19320248.2021.1905129

Li, J., Peterson, A., Auchincloss, A. H., Hirsch, J. A., Rodriguez, D. A., Melly, S. J., … Sánchez, B. N. (2022). Comparing effects of Euclidean buffers and network buffers on associations between built environment and transport walking: The Multi-Ethnic Study of Atherosclerosis. *International Journal of Health Geographics, 21*(1), 12. https://doi.org/10.1186/s12942-022-00310-7

Lytle, L. A., & Sokol, R. L. (2017). Measures of the food environment: A systematic review of the field, 2007–2015. *Health & Place, 44*, 18–34. https://doi.org/10.1016/j.healthplace.2016.12.007

Mabli, J. (2014). SNAP participation, food security, and geographic access to food. *Prepared by Mathematica Policy Research for the Food and Nutrition Service at the U.S. Department of Agriculture*. https://www.fns.usda.gov/research/snap/measuring-effect-snap-food-security.

Miller, S. R., & Knudson, W. A. (2014). Nutrition and cost comparisons of select canned, frozen, and fresh fruits and vegetables. *American Journal of Lifestyle Medicine, 8*(6), 430–437. https://doi.org/10.1177/1559827614522942

Miller, V., Webb, P., Micha, R., & Mozaffarian, D. (2020). Defining diet quality: A synthesis of dietary quality metrics and their validity for the double burden of malnutrition. *The Lancet Planetary Health, 4*(8), e352–e370. https://doi.org/10.1016/S2542-5196(20)30162-5

Oak Ridge National Laboratory. (2019). *Transit Trend analysis: 2017 National household transit survey*. Federal Highway Administration U.S. Department of Transportation. https://nhts.ornl.gov/publications.

Páez, A., Scott, D. M., & Morency, C. (2012). Measuring accessibility: Positive and normative implementations of various accessibility indicators. *Journal of Transport Geography, 25*, 141–153. https://doi.org/10.1016/j.jtrangeo.2012.03.016

Rhode Island Public Transportation Authority. (2024). How to ride: Rules of riding. https://www.ripta.com/how-to-ride/.

Rickman, J. C., Barrett, D. M., & Bruhn, C. M. (2007). Nutritional comparison of fresh, frozen and canned fruits and vegetables. Part 1. Vitamins C and B and phenolic compounds. *Journal of the Science of Food and Agriculture, 87*(6), 930–944.

Schwanen, T., & Páez, A. (2010). The mobility of older people : An introduction. *Journal of Transport Geography, 18*(5), 591–595.

Schwartz, N., Buliung, R., & Wilson, K. (2019). Disability and food access and insecurity: A scoping review of the literature. *Health & Place, 57*, 107–121.

Vaudin, A. M., Moshfegh, A. J., & Sahyoun, N. R. (2022). Measuring food insecurity in older adults using both physical and Economic food access, NHANES 2013-18. *J Nutr, 152*(8), 1953–1962. https://doi.org/10.1093/jn/nxac058

Vedovato, G. M., Ali, S. H., Lowery, C. M., & Trude, A. C. B. (2022). Giving families a voice for equitable healthy food access in the wake of online grocery shopping. *Nutrients, 14*(20), 4377. https://www.mdpi.com/2072-6643/14/20/4377.

Ver Ploeg, M., Mancino, L., Todd, J. E., Clay, D. M., & Scharadin, B. (2015). *Where do Americans usually shop for food and how do they travel to get there? Initial findings from the National Household Food Acquisition and Purchase Survey* (Economic information Bulletin, number 138). *Economic Research Service U.S.Department of Agriculture*. www.ers.usda.gov/publications/eib-economic-information-bulletin/eib138.

Walker, R. E., Keane, C. R., & Burke, J. G. (2010). Disparities and access to healthy food in the United States: A review of food deserts literature. *Health & Place, 16*(5), 876–884. https://doi.org/10.1016/j.healthplace.2010.04.013

Widener, M. J. (2017). Comparing measures of accessibility to urban supermarkets for transit and auto users. *The Professional Geographer, 69*(3), 362–371. https://doi.org/10.1080/00330124.2016.1237293

Widener, M. J., Farber, S., Neutens, T., & Horner, M. (2015). Spatiotemporal accessibility to supermarkets using public transit: An interaction potential approach in Cincinnati, Ohio. *Journal of Transport Geography, 42*, 72–83. https://doi.org/10.1016/j.jtrangeo.2014.11.004

Wyczalkowski, C. K., Welch, T., & Pasha, O. (2020). Inequities of transit access: The case of Atlanta, GA. *Journal of Comparative Urban Law and Policy, 4*(1), 654–681.