Indicators for Sustainable Mobility

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ITDP

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EXECUTIVE SUMMARY

ITDP developed a suite of indicators that can be used to effectively develop sustainable transportation policies in a city and to measure their effectiveness. These indicators measure a variety of different aspects of sustainable transit and can be broadly grouped into three categories: proximity, access, and city characteristics. Our goal is to provide city officials with the tool necessary to understand transportation conditions and make informed policy interventions that improve sustainable transportation. This report introduces indicators developed by ITDP and tested in 25 cities to measure their sustainable transport systems. The indicators were then analyzed and compared to the Sustainable Transport Mode Share of the cities to draw conclusions from the data.

The indicators developed and measured for this report are as follows:

- Proximity (to transit)
  - People/Jobs/Low-Income Households Near Rapid Transit
  - People/Jobs/Low-Income Households Near Frequent Transit

- Access (to opportunity)
  - Access to Jobs by Sustainable Transit (60 and 30 minutes)
  - Access to Low-Skill Jobs by Sustainable Transit (60 and 30 minutes)
  - Access to People by Sustainable Transit (60 minutes)

- City Characteristics
  - Block Density
  - Weighted Population Density

From this 25-city analysis, we found some interesting results:

- People Near Frequent Transit and Access to Jobs are the indicators that most strongly predict Sustainable Transport Mode Share.
- Cities with the highest shares of People Near Frequent Transit had strong corridors of frequent transit coverage as opposed to disparate islands of coverage.

- While many cities have large percentages of jobs located near frequent transit, only those that also have large shares of their population near frequent transit show high Sustainable Transport Mode Shares.
- When measuring accessibility to jobs, our analysis shows that the total number of jobs that can be reached is more important than the percentage of jobs in terms of influencing Sustainable Transport Mode Share. In other words, when travelers are making decisions about how they choose to get to work, it is more important that they can reach a large number of jobs than a large share of jobs.
- When measuring accessibility to destinations, we found that the 30-minute threshold correlates with Sustainable Transport Mode Share more strongly than the 60-minute threshold, indicating that it may be a more useful threshold for measurement.
- While lower-income residents tend to have greater access to public transit than the overall population, their ability to reach jobs that require less than a high school education is lower than the average job accessibility for the whole population.
- Access to People was established as a reliable proxy measure for Access to Jobs in the United States.

In addition to the trends, patterns, and takeaways from the indicators, this research has prompted further research concerning:

- More granular-level analysis in targeted cities
- Expanded geographic coverage
- Application of similar indicators, such as the ones proposed by the European Commission

We look forward to the opportunity to further explore these indicators, which will facilitate a better understanding of urban transport, monitor progress more efficiently, and lead to improved decision-making tools.

CONTENT

INTRODUCTION

In the United States, transportation accounts for nearly 30 percent of all greenhouse gas emissions[1]. As cities attempt to become more sustainable, it is imperative that they curb those emissions. Encouraging sustainable modes of transportation, such as walking, biking, and taking public transportation, can help cities in their mission to lower transportation-based emissions.

However, if you want to manage something, you first have to be able to measure and understand it. To that end, we have developed a suite of indicators that can be used to effectively develop sustainable transportation policies in a city and measure their effectiveness. These indicators measure a variety of different aspects of sustainable transit and can be broadly grouped into three categories: proximity, access, and city characteristics. Their goal is to provide city officials with the data required to make informed policy interventions that improve sustainable transportation. This report introduces this suite of indicators, developed by ITDP and tested on 25 cities to measure their sustainable transport systems. Following an overview of the indicators and how they are measured, we present the results of the benchmarking and analysis across the following 25 cities, selected to represent a broad geographic range, growing populations, and political momentum toward improving sustainable transportation:

- Albuquerque
- Atlanta
- Boston
- Charlotte
- Dallas
- Denver
- Guadalajara
- Houston
- Indianapolis
- León
- Los Angeles
- Louisville
- Memphis
- Mexico city
- Minneapolis
- Monterrey
- Montreal
- Nashville
- New Orleans
- Ottawa
- Philadelphia
- San Antonio
- Seattle
- Toronto
- Vancouver

1 US EPA, OAR 2015. Fast Facts on Transportation Greenhouse Gas Emissions. Overviews and Factsheets. US EPA. https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions, accessed November 30, 2018.

APPROACH

ITDP endeavors to create indicators that are actionable, scalable, and easily understood. There are many existing indicators of sustainable transit, but a lot of them are developed using indices that become black boxes, offering few discernible actions to improve them. Many current indicators are too complex and require a high level of technical knowledge to fully understand and act upon them. To avoid this problem, the indicators presented in this report are easily understood and replicable, and they can be tied to policy interventions. This can be done by relying on open-source data, which allows the analysis to be replicated even by those who are not able to pay for data or where other forms of data are not available. This report also includes a robust methodology section so that the analysis can be repeated easily. Finally, the indicators do not use indices, which combine multiple pieces of information in a way that is difficult to quickly understand. By making transparent and actionable indicators, analysis can be easily communicated not just to people working within the public transportation sphere but also to city politicians and community advocates.

Easily communicable indicators provide change-makers with data they can use to advocate for improvements. For example, the share of jobs that are accessible in 60 minutes is a straightforward indicator that can be generally understood without a detailed explanation. It is grounded in values that are readily apparent (enabling access to more jobs is positive for a city). A city official, planner, or community advocate can see if a city has a low value for that indicator and use that information to support actions to improve the indicator value (e.g., investing in more frequent transit service). The indicators can be used to project impacts of policies—for example, more frequent transit reduces wait times, which in turn increases the number of jobs reachable in 60 minutes. And applying the indicator in a more granular fashion means it can be used to target improvements in a more equitable manner, such as by focusing on increasing transit frequency in places with the lowest access. This provides data that can inform policy actions to improve public transportation in cities. For this reason, the report includes examples of policy changes for each indicator that are typically related to improving the indicator value. It should be noted that some of the indicators may be in tension with one another, and each city will need to establish its own priorities for taking action. However, our hope is that these indicators provide the tools to help them do so effectively.

INDICATOR OVERVIEW

This section of the report will provide a brief overview of each indicator, highlighting what it measures and why it was selected. The overview will also detail what the indicator measures well and what deficiencies it has. Finally, the overview will provide some examples of policy interventions that can be informed by the indicator.

The indicators are grouped into three broad categories based on what they measure: proximity to transit, accessibility, and city characteristics. The categorization is as follows:

- Proximity to Transit
  - People Near Rapid Transit
  - Jobs Near Rapid Transit
  - Low-Income Households Near Rapid Transit
  - People Near Frequent Transit
  - Jobs Near Frequent Transit
  - Low-Income Households Near Rapid Transit

- Accessibility
  - Access to Jobs by Sustainable Transport (60 and 30 minutes)
  - Access to Low-Skill Jobs by Sustainable Transport (60 and 30 minutes)
  - Access to People by Sustainable Transport (60 minutes)

- City Characteristics
  - Block Density
  - Weighted Residential Density
  - Sustainable Transport Mode Share

PEOPLE NEAR RAPID TRANSIT

People Near Rapid Transit (PNT) is an indicator that measures the percentage of the population that is within a half-kilometer walk of a rapid transit station. This indicator, along with the other proximity indicators, is measured using walking and also includes biking on protected bike lanes. We define “near rapid transit” as being within a roughly 10-minute journey. This is measured in our model using the following parameters. For walking, being “near rapid transit” is defined as living within 500 meters (roughly a third of a mile) of a rapid transit station, which is equal to a 10.41-minute journey walking at 48 meters per minute. When biking on protected bike lanes, being “near rapid transit” is defined as the distance a person can travel in 10.41 minutes at 248 meters per minute. This accounts for faster movement on a bicycle but restricts cycling to protected bike lanes, which have been shown to be used by more people due to the greater sense of safety they provide.

This measure was selected because it can be used as a proxy for accessibility to destinations and it is easy to measure, especially when there is a lack of detailed data. It also helps to illustrate the relationship between population distribution and the coverage of rapid transit services. We hypothesized that when more people live near rapid transit stations, more people will ride transit. However, this indicator only looks at rapid transit, not all transit, and it does not measure the actual ability of people to reach their destinations using the rapid transit. Rapid transit is defined as follows:

- Any Bus Rapid Transit (BRT) corridor or LRT corridor that meets the BRT basics definition in the BRT standard or
- any rail-based transit mode that:
  - is completely grade separated,
  - has off-board fare purchase,
  - operates entirely within a single built-up area with regular spacing,
  - operates at headways of less than 20 minutes in both directions from at least 6 a.m. to 10 p.m., and
  - has cars that are designed to prioritize capacity over provision of seating.

A 10-minute walk/bicycle distance from rapid transit stations was chosen as an appropriate measure of proximity, since research shows it’s a good estimate of how far people are generally willing to walk to rapid, reliable transportation.[2]

As far as policy interventions are concerned, this indicator can be mapped to show where people are not currently served by rapid transit so that the city can build rapid transit to remedy that. Further, it can show where rapid transit is located without population density. In those locations, the government could work to facilitate and encourage more dense development through tools such a zoning changes, subsidies, and other incentives.

2 Federal Highway Administration. Pedestrians and Transit - Safety | Federal Highway Administration. https://safety.fhwa.dot.gov/ped_bike/ped_transit/ped_transguide/ch4.cfm, accessed November 30, 2018.

JOBS NEAR RAPID TRANSIT

Jobs Near Rapid Transit is a measure of the percentage of jobs that are within a roughly 10-minute bike ride or walk of a rapid transit station. Rapid transit is defined the same way as People Near Rapid Transit.

This indicator was selected because it is an effective proxy for measuring accessibility. However, it does not actually measure people's ability to use transit to reach their destinations, it only shows where rapid transit is located near jobs. In addition, it does not incorporate all forms of public transportation, only rapid transit. That being said, better understanding the spatial relationship between jobs and rapid transit is paramount when trying to improve the Sustainable Transport Mode Share of a city. The role of transportation is to move people to their destinations, and the most important trip for many people is the commute to their job. With this in mind, understanding how well rapid transit serves jobs is critical when trying to improve public transit mode shares.

A map of this indicator can show where there are existing clusters of high job density lacking access to rapid transit. It can also show where existing rapid transit is not located alongside high job density. In these two situations, the indicator can be used to indicate where rapid transit improvements can have the most impact as well as where rezoning for denser job growth should be done.

LOW-INCOME HOUSEHOLDS NEAR RAPID TRANSIT

Low-Income Households Near Rapid Transit measures the percentage of the population that makes less than $20,000 a year that lives within about a 10-minute bike ride or walk of a rapid transit station. The figure of $20,000 was selected as it is just below the federal poverty level for a family of three ($20,780) and also because of the way that the census data was aggregated. Rapid transit is defined as transit that operates in a separated right of way–including bus rapid transit, light rail, and metro. More detail is provided in the methodology section.

Low-Income Households Near Rapid Transit was selected as an indicator because it is a measure of equity in a transit system. Low-income households are often the ones that are most dependent upon public transit, as private vehicle ownership can be too costly for them. While this indicator successfully identifies whether rapid transit is serving low-income populations, it does not take into account the cost of living in different cities, and $20,000 is a somewhat arbitrary cutoff. Also, while this indicator assesses whether low-income populations are near rapid transit, it does not assess how well that rapid transit connects those people to jobs and other destinations.

Policy interventions for this indicator include identifying clusters of low-income households that are not within close proximity of rapid transit and building rapid transit to serve them. This also includes building low-income housing in areas that are close to existing rapid transit. This could address equity concerns by improving access to opportunities for low-income populations that are more likely to be dependent upon public transportation and tend to have less access to opportunity than wealthier residents. Increasing access to opportunities can allow these populations to more easily secure jobs and higher incomes.

PEOPLE NEAR FREQUENT TRANSIT

People near frequent transit (PNFT) measures the percentage of the population within a roughly 10-minute bike ride or walk of a frequent transit stop. This indicator could be an effective proxy for measuring access to opportunities by public transportation–the ultimate goal of a transportation system. Frequent transit services can be used throughout the day without referring to a schedule, making them much easier to use than less frequent services. Frequent services also facilitate easier transfers between transit routes. Frequent transit includes rapid transit as well as other transit that does not meet our definition of rapid transit. Stops are defined as frequent if they are served an average of five times an hour (around a 12-minute headway) from 7 a.m. to 9 p.m. on a weekday. We chose to measure stations that are served frequently instead of routes that are run frequently because a stop that is served frequently by different bus routes can provide access to more destinations. Also, many of the cities examined have only a handful of frequent routes, but those routes overlap to form a corridor of frequent service. We measured planned service and not actual performance.

While this indicator shows who has access to frequent transit, it does not measure whether that transit can allow them to effectively reach destinations or the reliability of the service. Also, because this measure is based on planned service not actual performance, it may not accurately reflect true transit frequency. This could happen in the case of a bus that does not run on time due to traffic congestion, leading to fewer buses per hour. People Near Frequent Transit also helps to illustrate the relationship between population distribution and coverage of transit services. It is important to understand, particularly with regard to the UN Sustainable Development Goal 11.2.1, the proportion of the population that has convenient access to public transportation. In addition, since this indicator measures both walking and biking, it illustrates how bike infrastructure can help to connect more people to transit services. This is discussed more in the analysis section.

As an indicator, People Near Frequent Transit also provides context for some policy interventions. When this indicator is mapped, it shows where there is strong potential for transit-oriented development (TOD) by pinpointing areas that are served well by transit but lack density. Also, the indicator can show which areas are potentially supportive of transit improvements by highlighting densely populated areas that lack frequent transit.

JOBS NEAR FREQUENT TRANSIT

Jobs Near Frequent Transit is a measure of the percentage of all jobs that are within a roughly 10-minute bike ride or walk of a frequent transit stop. This indicator uses the same parameters as People Near Frequent Transit– an average of five departures per hour from 7 a.m. to 9 p.m. However, in terms of analysis, it serves as a corollary to People Near Frequent Transit, in that instead of representing the origins of trips, it represents employment destinations.

This indicator was selected because it shows where jobs are near frequent transit. This is important to measure, as the goal of transportation is to provide access to destinations. Since the journey to work is the one of the most important and lengthy trips for many people, understanding the spatial relationship between jobs and public transit is critical in working to improve public transit. While the indicator is successful in showing that relationship, it does not actually measure the ability of people to use transit to access jobs and instead functions as a proxy for that measurement.

When mapped, this indicator can illustrate where there are job centers that are served by frequent transit and where there are job centers that are not. Similar to the People Near Frequent Transit indicator, this indicator can show potential TOD locations with frequent transit but few jobs as well as areas with high job density but little frequent transit that could support transit improvements. However, this indicator does not show whether or not the jobs that are near frequent transit can be easily reached by many people via transit, as it only represents one side of the origin destination coupling.

LOW-INCOME HOUSEHOLDS NEAR FREQUENT TRANSIT

Low-Income Households Near Frequent Transit is a measure of the percentage of households that are making less than $20,000 that live within a roughly 10-minute bike ride or walk of frequent transit. The figure of $20,000 was selected as it is just below the federal poverty level ($20,780) for a household of three.[3] Household is used as the unit of analysis because the data is aggregated that way by the United States Census.

This indicator was selected to measure the level of equity in access to transit, but due to data restrictions, it was only measured in the United States. Low-Income Households Near Frequent Transit successfully identifies whether or not frequent transit is located near the populations that could potentially benefit the most from it. Low-income households are often reliant on lower-cost public transit due to the high costs of car ownership, including insurance, gas, and upfront purchase costs, which are too great of a barrier for many low-income people to overcome. Therefore, they tend to utilize lower-cost public transit in higher numbers than wealthier residents do. This indicator is a measure of the spatial relationship between the location of frequent-transit stops and the populations that are most dependent upon transit. However, it does not show whether or not the frequent transit can provide access to jobs or other services. Mapping the indicator can reveal the locations of greater populations of low-income households that don't have access to frequent transit.

3 US Department of Health and Human Services. Federal Poverty Level (FPL) - HealthCare.Gov Glossary. HealthCare.Gov. https://www.healthcare.gov/glossary/federal-poverty-level-fpl/, accessed November 30, 2018.

In terms of policy interventions, this indicator can be used for targeted interventions toward low-income populations. One example would be to use this indicator to illustrate where new affordable housing could be located to improve transit access for residents with lower incomes. Another would be to expand frequent service to areas with concentrations of low-income households.

ACCESS TO JOBS BY SUSTAINABLE TRANSPORT

Access to Jobs by Sustainable Transit measures the average of the number of jobs that can be reached within 30 minutes and 60 minutes for each census tract within the area by walking, cycling (on protected bike lanes), and public transit. The number of jobs that each census tract can reach is weighted by the number of people living in the census tract. This gives a better understanding of the experience on the ground than an unweighted average would. This indicator serves as an actual measure of a person's ability to reach potential destinations via sustainable modes of transportation. It is measured assuming a start time of 8 a.m. on a weekday morning, as that is typically at the commuting peak.

The indicator includes the entire city, not just areas that are in close proximity to a frequent transit station. Therefore, it is particularly successful in identifying areas of the city that are not well served by transit. However, the jobs that are accessible by sustainable transit do not necessarily match the jobs available to people of different skills and education levels. For example, in large cities, high-paying office jobs tend to cluster in central business districts typically well-served by transit, while lower-skilled jobs are more spread across the urban area, often with lower levels of transit service.

In terms of policy, this indicator has potential for locating targeted transit improvements to improve accessibility to jobs in the city. It can also be used to determine how best to locate jobs and housing so that access is improved by leveraging the transit network.

ACCESS TO LOW-SKILL JOBS BY SUSTAINABLE TRANSPORT

This indicator is a measure of the average of the number of jobs that require less than a high school education that can be reached by walking, cycling, and public transport within 30 and 60 minutes for each census tract in the area. This indicator was selected as a measure of equity to measure how well the transport system serves the people who are most in need of reliable, affordable transport and who are most negatively impacted by its absence. Typically, jobs that require less education also are lower paying. Lower-income people are more likely to be reliant upon public transportation due to the high upfront costs of car ownership.

To calculate the average number of jobs the indicator is weighted by the number of workers with less than a high school education in that census tract. This allows the indicator to better represent census tracts with high populations of those workers. This indicator was first measured at the 30-minute threshold and assumed a start time of 8 a.m. on a Wednesday, the same as the 30- and 60-minute thresholds for the Access to Jobs indicator. However, after external feedback, when we measured access at the 60-minute threshold, the start time was switched from 8 a.m. on Wednesday to 8 a.m. on Sunday, to better represent when low-skilled workers may be commuting to work. This is because many jobs that require less than a high school education are outside of typical business hours. We selected 8 a.m. on a Sunday as it represented a time when the public transit network for many cities is not running at an optimal level and also a time when many people would still be going to or from jobs. While this prevents some comparison between Access to Jobs by Sustainable Transport and Access to Low-Skill Jobs by Sustainable Transport, it allows for a comparison at the 30-minute level, and it also shows the disparity between peak and off-peak transit performance. Ideally we would measure all indicators at multiple time periods, but we were confined by capacity and time constraints.

This indicator, unlike measuring access to jobs in general, is particularly successful in linking specific populations to the types of jobs they are qualified to fill–when mapped, it has the potential to show which areas of the city lack the transit necessary for them to reach jobs. This indicator lends itself well to policy around specific transit improvements for low-education populations, allowing for nuanced interventions that can connect people to jobs that they are more likely to be qualified for.

ACCESS TO PEOPLE BY SUSTAINABLE TRANSPORT

This indicator is a measure of the average of the number of people that can be reached within 60 minutes for each census tract in the area[4]. To calculate this indicator, the number of people accessible is weighted by the number of people who live in each census tract. This gives a better representation of the access experienced by the average person in the city. This indicator assumes a start time of 8 a.m. on a weekday, as it is during the morning commute. The 8 a.m. start time was also used because it was important that this indicator could be compared to Access to Jobs by Sustainable Transit.

This indicator was developed as a proxy measure of access to jobs and other services for cities where job location and other opportunity location data is not readily available, such as cities in Canada and Mexico.

The policy implications for this indicator mirror those of Access to Jobs by Sustainable Transit. When mapped, this indicator provides a granular survey of accessibility in the city, which allows for spatially nuanced interventions in the quality of transit, and the planning of land uses across a city.

4 This indicator was developed as a proxy for Access to Jobs. While it was determined that the 30-minute threshold for Access to Jobs better predicted Sustainable Transport Mode Share than the 60-minute threshold, this was determined at a late point in the research, and we were unable to recalculate this indicator at the 30-minute threshold.

SUSTAINABLE TRANSPORT MODE SHARE

Sustainable Transport Mode Share serves as an indicator of the percentage of the population that uses public transportation, walking, or biking to commute as opposed to using private motor vehicles. This indicator was selected because it is easily understood and is also an effective way of testing the efficacy of other indicators. Further, it takes into account outside factors, such as the price of gas, whereas the others do not. While it is often difficult to pinpoint which specific policies and circumstances are impacting mode share, it is frequently selected as a target by cities that are trying to reduce private car usage.

While this indicator does not lead to specific policy interventions, it is a way to test the impact that policy interventions have. If a policy intervention is made, mode share can be used to track whether or not it had the intended impact. Mode share is also useful because cities can use it to set targets so there is greater accountability for their decisions. The main downside to using mode share as a target is that it is typically measured infrequently, with the data in this report coming from 2010, for example. It also only includes commuting trips, and while those are important, they only represent a minority of all trips made. This is important, as commute trips tend to be longer and better served by public transport systems, which are often, particularly in the United States, designed for 9-to-5 commutes. Thus commute mode share potentially overrepresents the total use of public transit. As a portion of total trips, commute trips tend to overrepresent the travel of working-age males and underrepresent the travel of children, women, and the poor, who make more noncommute trips. Despite these flaws, mode share data is still the best data available for benchmarking purposes due to its frequent measure and clear methodology.

BLOCK DENSITY

Block Density is a measure of the average number of city blocks per square kilometer of study area. Blocks are defined as developed areas that are surrounded on all sides by publicly accessible pedestrian passages. Blocks serve as a foundation for walkability in urban areas.

A greater density of blocks facilitates shorter, more direct trips and thus encourages walking, cycling, and using public transit as attractive alternatives to driving. As such, Block Density serves as a proxy for connectivity, a key driver of walkability in the city, which correlates with lower fatalities and injuries to pedestrians from vehicle crashes. While Block Density does not take into account the quality of walking infrastructure and environment, it does provide an understanding of the potential for a walkable environment. Block Density is measured instead of the more common indicator of intersection density in an effort to better represent connectivity in areas with many intersections and dead-end streets. This also aligns with other ITDP indicator endeavors, such as *Pedestrians First*, which uses block density as a measure. This metric is best used by employing it with other metrics, such as weighted population density.

Block Density lends itself to several policy implications, though they may take time to manifest in the built environment. The first of these is planning that emphasizes the development of a fine grid of streets to facilitate walking by enabling shorter trips. This is often achieved through the regulation of the subdivision of larger plots of land. Subdivisions that are underpinned by a grid of connected streets will create greater Block Density, while those that are built upon roads that end in cul-de-sacs and dead ends will lead to lower connectivity. While cut-through connections can be made retroactively to create a more connected network, this process is typically very time-consuming, expensive, and politically challenging.

WEIGHTED POPULATION DENSITY

Weighted Population Density is related to the activity potential in an area. To calculate this indicator, density (population/area) is calculated for each census tract, then that density is multiplied by the population of the census tract. The resulting number is then summed for the entire city and divided by the city's total population. This results in an indicator that represents the average experienced density of a person in the city.

This indicator was selected because it is a good proxy for activity at the city scale, but it does not actually measure land use. Greater population density typically means more people living closer to more destinations, which allows for shorter trips that are more easily done by walking, cycling, and using transit. Higher densities are cheaper to serve by high-frequency transit, and higher transit frequencies lead to greater use of transit. However, it is important to note that while density increases the potential for walkable trips, this indicator does not take urban design (such as good sidewalks) or the mixture of land uses into account. Therefore, Weighted Population Density, like many of the other indicators, must be used in conjunction with other indicators to allow for a better understanding of the city.

Policy implications for this indicator include rezoning in ways that allow for denser growth. This indicator also helps to facilitate the location of new services based on where the density in the city is greatest.

METHODOLOGY

The indicators developed as part of this research endeavor were calculated primarily using ArcGIS, and the majority of them were calculated using the ArcGIS network analyst extension. All of the data used in this process was free of cost. The road data was collected from OpenStreetMaps, and the GTFS data was collected from TransitFeeds and from various transit agencies. United States population and income data was from the United States Census American Community Survey 2015 three-year estimates. US job data was from the 2015 Longitudinal Employer Household Dynamics survey, also from the United States Census. Canadian population data was from the 2011 Canadian Census, and Mexico population data was from the 2010 Mexican Census. In addition to the open-source data, city boundaries were used to define the extent of the city, and the urban extents were defined using urban boundaries from the Global Rural Urban Mapping Project (GRUMP). GRUMP delineates urban boundaries using the National Oceanic and Atmospheric Administration's nighttime lights data set and buffered settlement centroids. GRUMP was selected because it represents urban extents more accurately than Metropolitan Statistical Areas typically do. Also, it is a global data source, which allows the results to be compared at a global scale and for the analysis to be replicated at that scale. Detailed methodologies for each of the indicators can be found below.

PEOPLE/JOBS/LOW-INCOME HOUSEHOLDS NEAR RAPID TRANSIT

People Near Transit is defined as the percentage of people living within 500 meters of a rapid transit station. To calculate this indicator, first a network data set was created using OpenStreetMaps road data, which is open source and also available across a broad range of geographies around the globe. While there are some flaws in the data because it is crowdsourced, the street network is fairly comprehensive for most large cities around the world; there can be some missing sections in smaller cities in lower-income countries, though.

Once the network data set has been generated, point data representing the location of rapid transit stations is used to generate service areas on the network. The points are located on the network on the street closest to the point's latitude and longitude. These service areas represent the areas that are within 500 meters of the station points. The service areas are generated as a single polygon so that service areas that are close together merge instead of overlapping.

Once the service areas have been generated, they are overlaid on top of census data. The service areas are then used to clip the census data to find the areas that are within the service area. This is done using the ArcGIS intersect tool with the ratio policy of the census data layer turned on for the population field. The resulting file is then summed to find the total number of people in the service area. The ratio policy is used so that if only a portion of the census tract is within the service area, only a portion of that census tract's population will be counted. For example, if a census tract has 100 people living in it and 43 percent of the census tract is within the service area, only 43 people will be counted as living within the service area. This allows for a better estimate for the indicator.

PEOPLE/LOW-INCOME HOUSEHOLDS/JOBS NEAR FREQUENT TRANSIT

The near frequent transit indicator is defined as the number of people, low-income households, or jobs that are within 500 meters' walking on the street network or a 10.41-minute journey biking on the protected bike lane network of a transit stop that is frequently served. A station is defined as frequently served if a bus, train, or other form of transit stops there an average of five times an hour between 7 a.m. and 9 p.m. on a weekday. The first step for calculating this indicator is creating a network data set of streets, using OpenStreetMap data, and protected bike lanes which were collected from city and state governments, or by hand tracing in google maps. In generating the network data set, speeds must be assigned to the streets and the bike lanes. The streets have a walking speed of 48 meters per minute and the bike lanes have a biking speed of 248 meters per minute.

Once a network data set has been generated, it is necessary to determine which transit stops in a city are frequent and which are not. This is done using GTFS data and the Count Trips At Stops tool from the BetterBusBuffers toolset developed by Melinda Morang at ESRI. Frequent stops can be selected from the tool's output based on the average trips per hour column. After a new feature class has been created using the selected features, they are loaded as locations in the network data set and service areas are created. The service areas are 500 meters for walking; for the indicator that includes biking, they are 10.41 minutes, which is equal to about 500 meters walking at 48 meters per minute or biking at 248 meters per minute.

Once the service areas have been generated, they are used to clip census data on population, income, or jobs, depending on which variation of the indicator is being calculated. The clips are performed using the intersect tool, with a ratio policy turned on for the feature being clipped. This results in a file that is just the census tracts that are within that service area. The final step is to sum the fields for population, low-income households, or jobs.

ACCESS TO JOBS/LOW-SKILLED JOBS/PEOPLE BY SUSTAINABLE TRANSIT

Access to Jobs by Sustainable Transit can be defined as the average number of jobs that can be reached from a census tract within 30 or 60 minutes on a weekday morning at 8 a.m. This number is weighted by the population of the census tract–greater importance is given to census tracts that are heavily populated than to those that are not.

The first step in calculating this indicator is to build a network data set with the city's roads, public transit lines, and bike lanes. This is done by using ArcGIS network analyst, along with Melinda Morang's Add GTFS To A Network Dataset toolset. The streets have a walking speed of 48 meters per minute and the bike lanes have a biking speed of 248 meters per minute.

Once a network dataset has been generated, it is necessary to calculate the centroid of each census tract using the Polygon to Point tool in ArcGIS. Once this is done, the centroids can be loaded into the network dataset. They will snap to the closest road feature in the network.
Once the locations have been loaded into the network, it is necessary to solve for the service areas. The parameters for this are as follows for Jobs Accessible in 60 Minutes and Access to People. A travel time of 60 minutes, with one way turned off, on Wednesday at 8 a.m., with Travel From selected. Also, it is necessary to prevent the service areas from being generated on the transit lines and for the service areas to be overlapping so that there is a service area for each location. For the 30-minute threshold the parameters are the same, except that instead of 60 minutes, 30 minutes was used. For the low-skill jobs accessible within 60 minutes indicator, the parameters are the same, except a time of 8 a.m. on Sunday is used. At the 30-minute threshold for low-skilled jobs, the start time was 8 a.m. on a Wednesday.

Once the service areas have been generated, they can be used to clip job data. This is done using the Intersect tool, as it allows for the job data to be clipped for each census tract service area, so jobs can be counted for more than one census tract. The resulting file's attribute table is then exported to a .txt file using the table-to-table conversion tool.

When the .txt file has been generated, it is run through a code written in Python using the pandas and numpy modules. For the total number of jobs accessible in 60 minutes indicator, the code uses the feature ID of the service areas and the number of total jobs field to create a .txt file with a total number of jobs for each feature ID. For the low-skill jobs indicator, the code does the same, except that it uses the field that counts the jobs that require less than a high school education. The feature ID is then used to join the .txt file to the original census tract file that was used to create the census centroids.

Once the .txt file has been joined to the census tract file, it is necessary to weigh the number of jobs by the population. To do this, each census tract's population is multiplied by the number of jobs that can be reached from that census tract. This number is then summed for the whole area and divided by the total population. The resulting number is the final indicator.

For low-skilled jobs, the methodology is the same, except that an additional .txt file is generated that contains the number of workers in a census block who have less than a high school education. This is done by running the residential area characteristics LEHD data set through a Python script that uses pandas to sum jobs by census tract by searching the first 11 digits of the 15 digit FIPS code. The resulting .txt file is joined to the census tract file along with the file containing the number of low-skill jobs that each tract can reach. Instead of weighting that indicator by total population, it is weighted by the number of workers with less than a high school education.

For Access to People, once the service areas have been generated, they can be used to clip population data. This is done using the Intersect tool, as it lets the population data be clipped for each census tract service area, allowing population from a census tract to be counted for more than one service area. The resulting file's attribute table is then exported to a .txt file using the Table to Table conversion tool.

Once the .txt file has been generated, it is run through a code written in Python using the pandas and numpy modules. The code uses the feature ID of the service areas and the population fields to create a .txt file with a total number of people for each feature ID.

This .txt file is then joined to the original census tract file used to create the census tract centroids using the feature ID field. Once it is joined, the population and the total number of people who can be reached in 60 minutes are multiplied for each census tract. This number is then summed and divided by the total population. The resulting number is the indicator.

BLOCK DENSITY

Block Density is defined as the number of blocks per square kilometer of the urban area. This indicator is calculated using OpenStreetMap data and urban boundary or city boundary data, depending on the scale at which it is being calculated.

The first step in calculating this indicator is collapsing the roads to eliminate features like traffic circles or slip lane islands. This is done using the Collapse Road Details tool. Once those features have been eliminated, the Merge Divided Road tool is used to generate center lanes for roads that have a median. Finally, the line to polygon tool is used to generate polygons in the negative space between the roads. Once these polygons have been generated, they are deleted if they are less than 1,000 square meters or larger than 1,000,000 square meters. Finally, the blocks are counted and then divided by the total area of the urban area to determine the number of blocks per square kilometer.

WEIGHTED POPULATION DENSITY

Weighted Population Density is calculated using population data from the 2015 United States ACS data for US cities and from the Canadian and Mexican censuses for Canadian and Mexican cities, from 2011 and 2010, respectively. The density is calculated for each census tract by dividing the population by the area, then the density for each census tract is multiplied by the population in that tract. The resulting number is then summed for the city or metropolitan area and divided by the total population for that area. The resulting number is the Weighted Population Density.

RESULTS AND ANALYSIS

The charts below illustrate the results for each indicator and each city. The results will be discussed individually in brief and then analyzed as they relate to both one another and mode share. Unless otherwise stated, the results are for the city scale, not the metropolitan scale. Correlations are used throughout this report to better understand the relationship between indicators and Sustainable Transport Mode Share. Correlations are shown in scatter plots comparing an indicator to Sustainable Transport Mode Share. Each scatter plot has a trendline and an r^2 value between 0 and 1. The trendline shows how the data should plot out according to the correlation. The r^2 value shows how well the data fits the trendline, giving an indication of how strong the correlation is. A higher r^2 value indicates a stronger correlation. A correlation does not necessarily indicate a causal relationship, but it does give insight into how two different indicators relate to each other. These r^2 values should be taken with some skepticism, however, due to the small sample size. Typically, a minimum sample size of 30 is recommended for statistical analysis like this, and these correlations range from 17 to 21 data points. A small sample size could overemphasize the results of some of the cities, leading to correlations that are either stronger or weaker than a larger sample size would show. The r^2 values are included in the chart because they give the reader some insight into how well correlated a given indicator is with Sustainable Transport Mode Share and are not necessarily meant to be statistically rigorous. This relationship is important in providing context to the data; making it more easily communicated and understood. The r^2 values, sample size, and p values can be seen in more detail in table 1 in the appendix.

These indicators were measured at both the city and the metropolitan scale, and both results are shown for some indicators. For all of the indicators, results were higher at the city scale than they were at the metropolitan scale, which was expected. However, the analysis focuses on the city scale, as the data was more reliable at that scale, as it was a more constrained environment. At the metropolitan level, there are often multiple transit agencies in operation, including at least six in metropolitan Atlanta[5] and nearly 50 fixed route carriers in metropolitan Los Angeles[6]. However, while we have tried to be as comprehensive as we can, it is possible that we missed some transit agencies that operate in the periphery of metropolitan areas, or that a smaller city or town in a metropolitan area has transit that does not have GTFS data available. In order to avoid drawing conclusions based on data that could be incomplete, the analysis in this report focuses on the city proper.

5 Atlanta Regional Commission. Transit in the Atlanta Region. ARC. https://atlantaregional.org/transportation-mobility/transit/transit-in-the-atlanta-region/, accessed November 30, 2018.

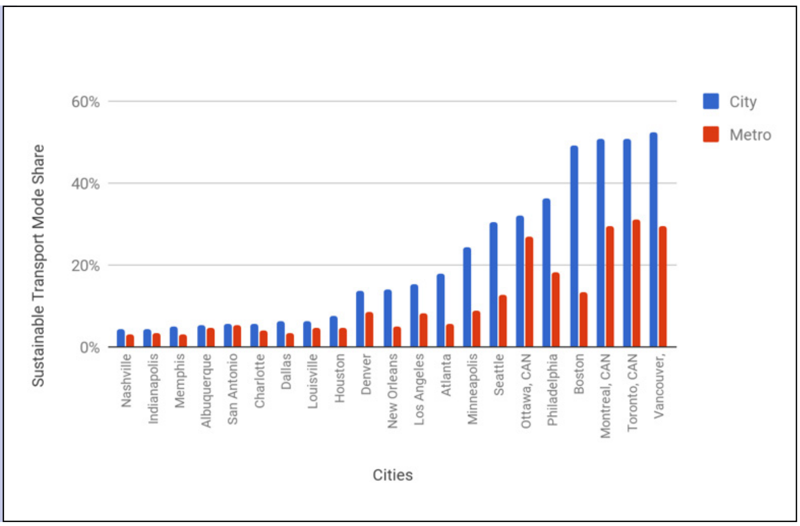
6 Los Angeles Metro. Other Carriers. LA Metro. https://www.metro.net/riding/getting-started/other-carriers/, accessed November 30, 2018.

SUSTAINABLE TRANSPORT MODE SHARE

Sustainable Transport Mode Share is included in the indicators as a measurement of behavior among travelers in a city and can be used to identify cities that have higher rates of sustainable transportation use. Those cities can then be analyzed to identify commonalities in their indicator results to determine what leads to greater use of sustainable transport. We can use Sustainable Transport Mode Share in our analysis as a dependent variable of sorts by comparing it to the different indicators that were measured. This way we are able to identify which of the measures best correlate with higher usages of sustainable transport. This also allows us to identify commonalities between the cities that had the highest Sustainable Transport Mode Shares and begin to draw conclusions based upon those commonalities, even when there is not enough evidence of statistical correlation. This can frame future research endeavors. However, it is important to recall that Sustainable Transport Mode Share includes only commute trips and not all trips that are made.

The Sustainable Transport Mode Share of each of the cities in our analysis can be seen in Chart 1 below. We were unable to find official government mode share data for the cities in Mexico. The five cities with the highest Sustainable Transport Mode Share are Vancouver (52.3%), Toronto (50.8%), Montreal (50.7%), Boston (49.3%), and Philadelphia (36.2%). Only looking at cities in the United States, the highest Sustainable Transport Mode Shares aside from Boston and Philadelphia include Seattle (30.3%), Minneapolis (24.3%), and Atlanta (17.8%). These cities, because of their high sustainable modes, are often called out in later analysis. It is also worth pointing out that all of the cities had higher mode shares than the metropolitan areas did. This finding is not surprising given the general increase in sprawling, car-dependent development that comes with greater distances from the city center.

Chart 1. Sustainable Transport Mode Share 2010



WEIGHTED RESIDENTIAL DENSITY

The results for Weighted Residential Density can be seen in Chart 2. Greater density facilitates transit ridership by allowing more people to be located near transit stops. Many of the cities that score highest on this indicator are the highest-scoring on the rest of the indicators as well. Boston, Philadelphia, Seattle, and Minneapolis have the highest Sustainable Transport Mode Shares of the US cities that were included in this analysis, and they also have some of the highest results on this indicator, as do the Canadian cities. In all of the cities included in the analysis, Weighted Residential Density is higher in the city proper than in the metro area as a whole. This is to be expected, as cities tend to sprawl more and become more suburban in their design as you move from the city center to the edges of the metro area. Weighted density has one of the highest correlations of all of the indicators analyzed in this report. This correlation can be seen in Chart 3 below and suggests a strong relationship between Weighted Residential Density and Sustainable Transport Mode Share.

Chart 2. Weighted Density

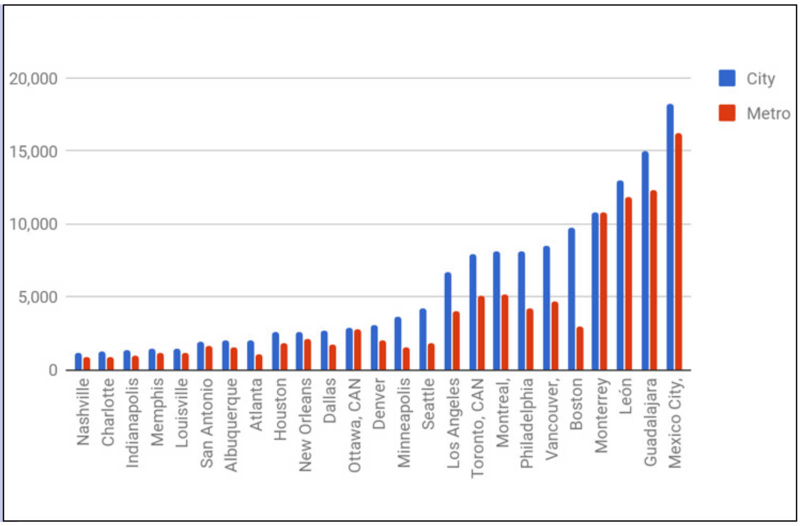
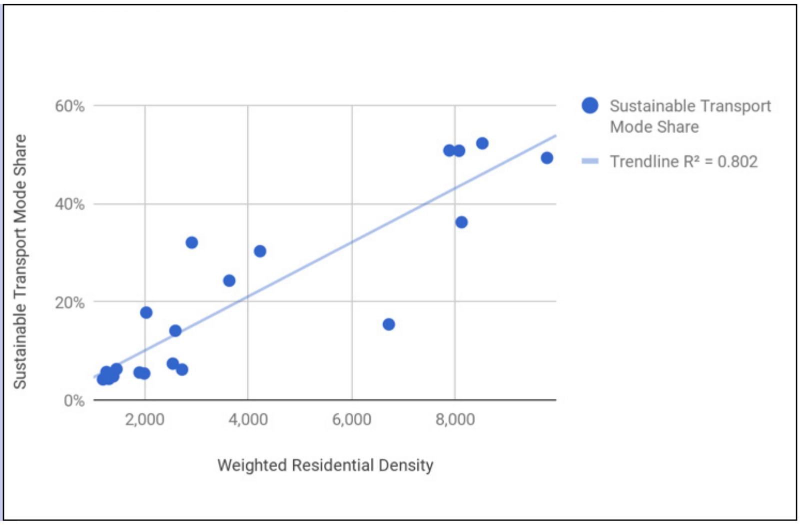


**Chart 3.
Weighted Residential Density and Sustainable Transport Mode Share**

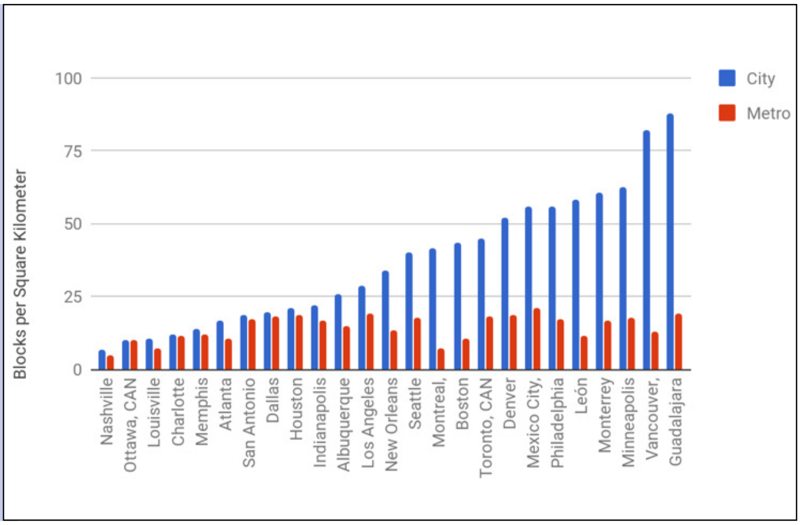


BLOCK DENSITY

The results for Block Density can be seen in Chart 4. They generally mirror the results from Sustainable Transport Mode Share, with Canadian cities having high block densities and Philadelphia, Boston, and Minneapolis doing well too. Two outliers are Denver and Ottawa. Denver overperformed on this indicator relative to its mode share, meaning that its Block Density was higher than would be expected based on its Sustainable Transport Mode Share. Ottawa's low result for Block Density is due to the city's geography–large swaths of land to the west, northwest, and south of the city are largely agrarian or undeveloped. However, since those areas are still within the city boundary, they are included in the Block Density analysis. This is different from many cities, particularly those in the United States, that are increasingly suburban and less well connected as you move out from the city center. Instead of being surrounded by suburbs, Ottawa is surrounded by farms. Nashville's city geography also disadvantages it on this indicator, which helps explain its performance on this indicator. However, it is less of an outlier, as it has a similar performance on all of the indicators.

Chart 4 also includes the Block Density of the metro areas in addition to the city proper. In every city except Ottawa, the Block Density is higher in the city proper than it is in the metro as a whole. This is an expected result, as many of the cities included in the analysis have higher levels of sprawl as you move farther from the city center. This result mirrors the one seen in the Weighted Population Density indicator.

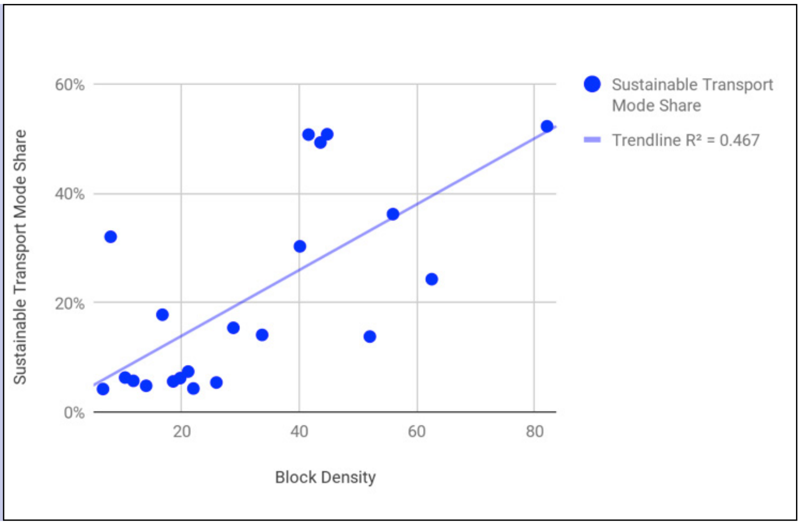
Chart 4. Block Density



All of the cities that had a Sustainable Transport Mode Share over 20 percent had 40 blocks per square kilometer or higher, excluding Ottawa. While there is not necessarily a known ideal number of blocks per square kilometer, shorter blocks are associated with higher levels of walkability, so generally speaking, having more blocks is better. Short blocks should allow for more direct routes to destinations. Higher walkability in cities is a crucial to increasing mode shares for sustainable forms of transportation, as many sustainable modes, such as public transportation or bike share, require commuters to first walk from their homes to the transportation. This relationship can be seen in Chart 5 below, which shows the relationship between mode share and Block Density in the cities where both of those pieces of data were available. While the correlation between Block Density and Sustainable Transport Mode Share is not strong, it does suggest that the increased Block Density in these cities is responsible for greater amounts of walking and other forms of sustainable transport in them.

While there is a great degree of variation between different cities at the city level, there is much less variation at the metropolitan level. In the Mexican cities this is likely due to more informal settlement and fewer paved and mapped roads at the periphery of the city. However, in the cities in the United States and Canada, this likely reflects urban sprawl more than anything else. As distance increases from the center of the city, it is more likely that the street grid will be less connected and more suburban in its design, as typified by heavy use of cul-de-sacs, limited street connectivity, leapfrog development, and widely spaced arterial roads. These patterns lead to very low block densities. So even for cities like Minneapolis that have high Block Density at the city level, the metropolitan result is dragged down by the low Block Density of suburbs and exurbs in the metropolitan area.

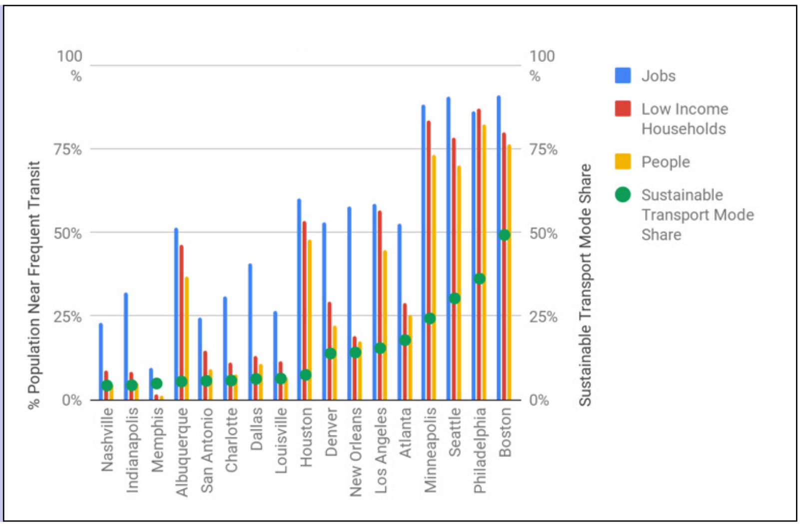
Chart 5. Block Density and Sustainable Transport Mode Share



PROXIMITY TO FREQUENT TRANSIT

The results for all of the Proximity to Frequent Transit indicators can be seen in Chart 6. These indicators are analyzed individually and then together in the paragraphs that follow. Sustainable Transport Mode Share has also been included in Chart 6 for context related to the analysis.

Chart 6. Proximity to Frequent Transit

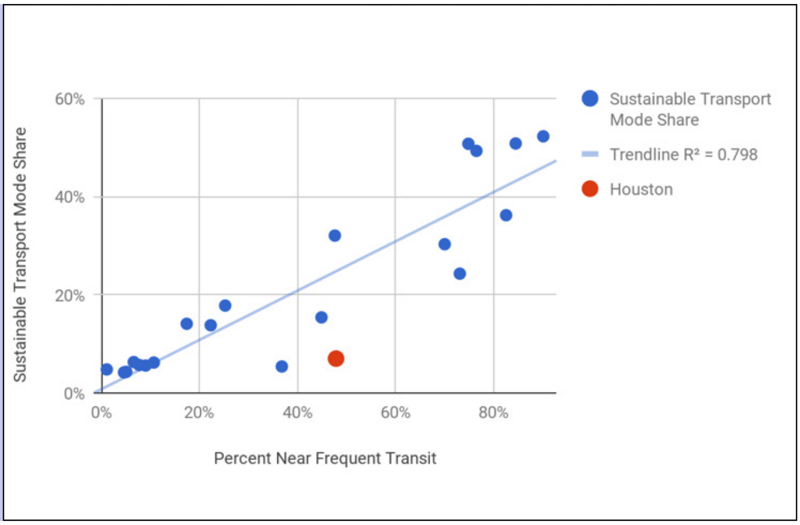


PEOPLE NEAR FREQUENT TRANSIT

People Near Frequent Transit measures the percentage of the population that is within a 500-meter walk or about a 10-minute bike ride of frequent transit service. This shows the coverage of transit that can be used reliably, even when transfers are required. It also acts as a proxy for access to destinations. We used it to compare cities and highlight the potential for bicycle access to extend the reach of transit. In our research, we found that this correlates strongly to Sustainable Transport Mode Share (see Chart 7 below).

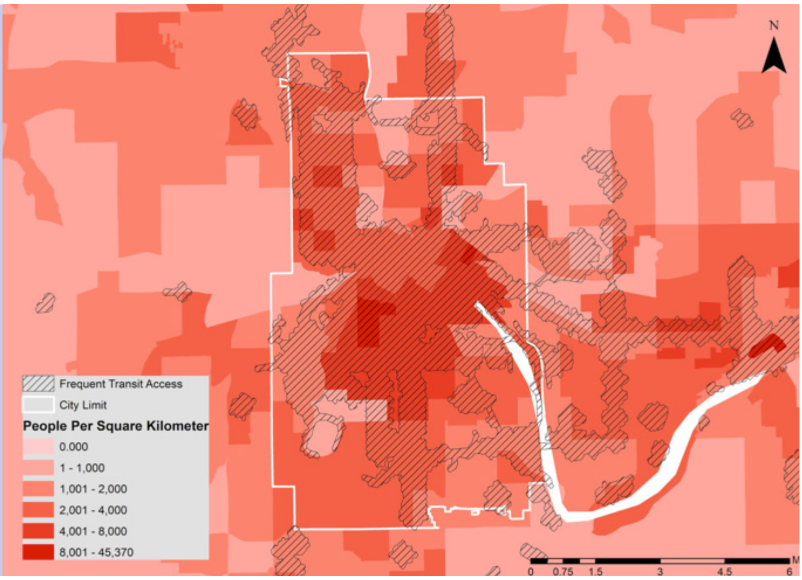
While the reason for such a strong correlation could be explained in a number of ways, the authors of this report hypothesize that it is due to the importance of frequency in transit decision making. A commuter may prefer a bus or train that runs more frequently so that if the transportation schedule is disrupted, their commute is only impacted a little. This allows more flexibility in their commute, so that they can rely on transit, even as more people have frequently shifting work schedules. While more research is needed to better understand this relationship, this correlation highlights the importance of having frequent transit. It is worth noting that Houston is included in this correlation, even though the mode share data was collected before the city's bus network redesign. Houston has been highlighted in red in the chart. When Houston is removed from the correlation, it is stronger, with an r^2 of .85.

Chart 7. People Near Frequent Transit and Sustainable Transport Mode Share



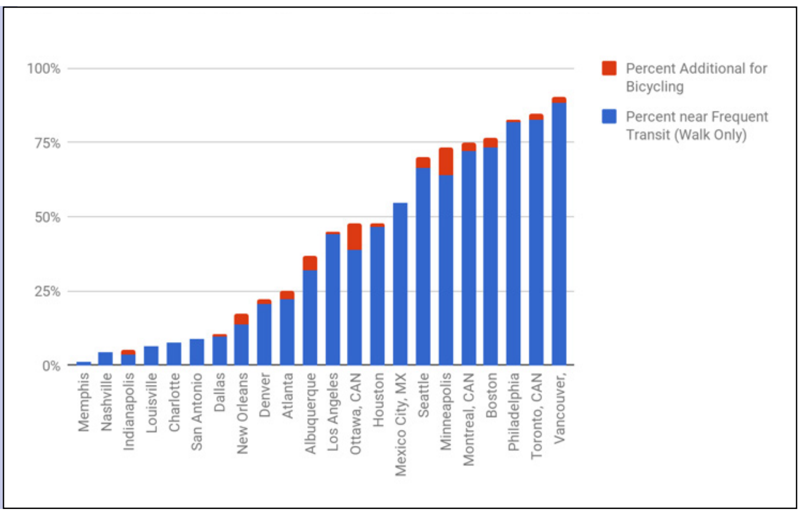
Further analysis of this indicator at the city level reveals that cities with well-defined corridors of frequent transit–as opposed to cities with scattered islands of coverage–perform well on the Proximity to Frequent Transit indicators, suggesting that cities should focus on developing corridors to meet mode share targets. Minneapolis, for example, recently expanded light rail service and has an established grid of frequent transit routes that connect the city, which are reflected in their strong results on the indicator. This can be seen in Map 1.

Map 1. Minneapolis People Near Frequent Transit



This indicator, along with the other Proximity to Frequent Transit indicators, also highlights the impact that good bike infrastructure can have on accessibility to transit. In Minneapolis, for example, the population near frequent transit is 9 percent higher, rising from 64 to 71 percent, when bike infrastructure is included in the analysis. The 9 percent increase from bike infrastructure means that 35,700 more people can reach frequent transit stops in 10 minutes or less on physically protected bike lanes. This increase is depicted in Chart 8 by the red bar stacked on top of the blue. This suggests cost-effective ways of increasing access to transit by building out protected bike lanes and connecting existing protected bike lanes to transit. Understanding the connection between this increase and bicycle mode share might be an interesting point of analysis for future research projects.

Chart 8. % People Near Frequent Transit (W+B) – Cities



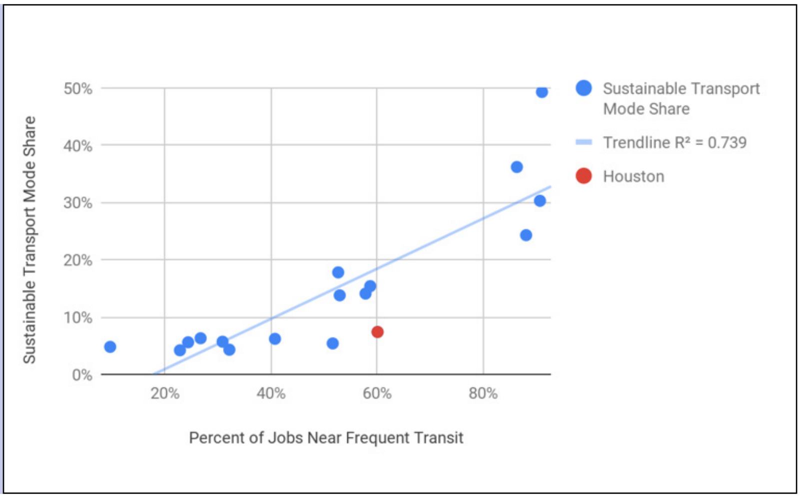
Unfortunately, job and income data was not readily available in Canadian or Mexican cities, and only one of the Mexican cities, Mexico City, had GTFS data, so many of the indicators were not able to be applied in those cities. When People Near Frequent Transit was applied in Mexico City, the results placed the city in the upper half of all the cities analyzed, scoring higher than Houston but lower than Seattle. While this is somewhat surprising given that Mexico City has a fairly robust transit system, it's position relative to US cities like Minneapolis and Seattle is possibly due to its physical size. Mexico City is covers more than 570 square miles, whereas Minneapolis is only about 50 square miles. Another potential explanation is Mexico City's informal settlements, which are less likely to be served by formal transit service but are also very dense in population. In Canada, population, GTFS, and mode share data were all available, so the People Near Frequent Transit indicator was able to be calculated for all of the Canadian cities. On the whole, Canadian cities had high results for the indicators, with the exception of Ottawa, which had average results relative to all of the cities analyzed. All of the Canadian cities had Sustainable Transport Mode Shares higher than 30 percent, and they all had People Near Frequent Transit higher than 30 percent. Ottawa, the Canadian city with the lowest results on the People Near Frequent Transit indicator, still had 38 percent of its population near frequent transit and 32 percent of its Sustainable Transport Mode Share represented by sustainable modes. These results suggest the importance of locating frequent transit near population centers.

JOBS NEAR FREQUENT TRANSIT

Jobs Near Frequent Transit measures the percentage of jobs in the city that are located within a 10-minute journey of a frequent transit stop. The results show a similar pattern as People Near Frequent Transit, with many of the same cities having the highest results. It is worth noting here that while the distribution of the cities is similar to that of the People Near Frequent Transit indicator, the actual percentages are much higher in this indicator. For example, only about 4 percent of the population in Nashville lives near frequent transit, but almost 22 percent of the jobs in the city are located near frequent transit.

Of the cities that had Sustainable Transport Mode Shares higher than 15 percent, all except Atlanta had both high people near transit and high jobs near transit, with over 40 percent for both. In addition, all except for Atlanta also had relatively high Weighted Population Densities of at least 3,500 people per square kilometer. Additionally, cities with the worst Sustainable Transport Mode Shares, such as Nashville (4.2 percent), Indianapolis (4.8 percent), and Memphis (4.2 percent), all had Jobs Near Frequent Transit percentages below 30 percent and People Near Frequent Transit results below 5 percent. While further analysis is required to better understand why Atlanta is an outlier, the results of this analysis would suggest that higher shares of Jobs Near Frequent Transit generally correlate with higher Sustainable Transport Mode Shares. Chart 9, which shows the correlation between Jobs Near Frequent Transit and Sustainable Transport Mode Share, helps to illustrate this point. Since this analysis did not include enough samples to accurately do multivariate regressions, we cannot statistically measure the relationship between Jobs and People Near Frequent Transit and Sustainable Transport Mode Share. Instead, we will highlight some examples of this pattern. Collecting more data points and doing more robust statistical analysis of the relationship between Jobs and People Near Frequent Transit and Sustainable Transport Mode Share is an area of potential future research.

Chart 9. Jobs Near Frequent Transit and sustainable Trnasport Mode Share



The necessity of having both jobs and people near frequent transit is underscored when looking at cities that have high shares of their Jobs Near Frequent Transit but do not have high residential densities or high rates of their population near frequent transit. One good example of this is Dallas, which has nearly 40 percent of its Jobs Near Frequent Transit but less than 10 percent of its people. Its Sustainable Transport Mode Share is only 6.2 percent. In fact, of the 16 cities assessed using both metrics, all but one, Memphis, had over 20 percent of its Jobs Near Frequent Transit, but only six had more than 15 percent of their mode share using sustainable modes. Of the cities that had Sustainable Transport Mode Shares of less than 10 percent (Nashville, Dallas, Albuquerque, Charlotte, Houston, Indianapolis, Louisville, Memphis, and San Antonio), all but Albuquerque and Houston had People Near Frequent Transit scores of less than 10 percent. This suggests that while frequent transit is located near many of the jobs in these cities, it is not located near people. This mismatch could explain the low mode shares for those cities. Again, further and more robust statistical analysis is needed to determine if there is a strong correlation.

Houston is an outlier here, having high People Near Frequent Transit, Low-Income Households Near Frequent Transit, and high Jobs Near Frequent Transit, and a decent Weighted Residential Density. However, Houston still has a low Sustainable Transport Mode Share of 7.4 percent. This can likely be attributed to how recent its bus network redesign was–the Sustainable Transport Mode Share statistics are from 2010, well before the bus network redesign. It will be important to track Houston into the future to see the impacts of its bus network redesign. When you remove Houston from the data set, the correlation between Jobs Near Frequent Transit and Sustainable Transport Mode Share becomes stronger, improving from an r^2 of .73 to .78.

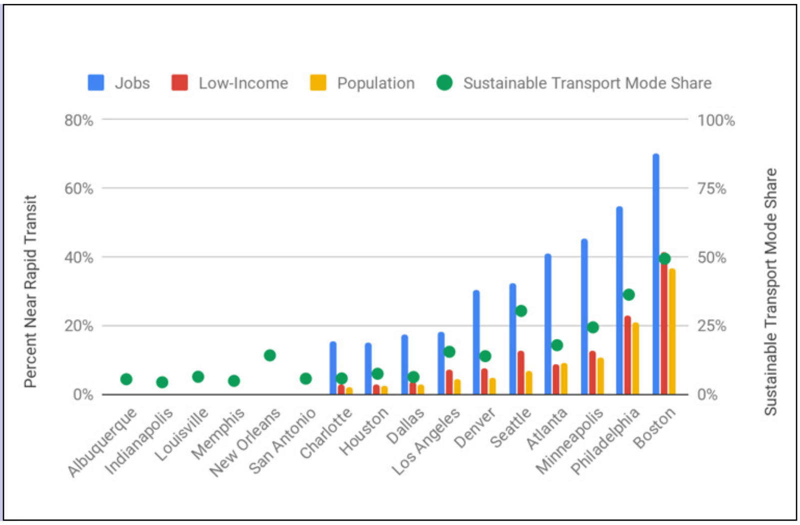
LOW-INCOME HOUSEHOLDS NEAR FREQUENT TRANSIT

Low-Income Households Near Frequent Transit was selected as an indicator of equity in frequent transit distribution. If the percentage of People Near Frequent Transit in a city is dramatically different than the percentage of Low-Income Households Near Frequent Transit, it would indicate that the transport system does not service the whole city equitably. The anticipated pattern in these cities was one of frequent transit underserving lower-income populations. However, that was not the pattern that was observed. Instead, in all of the cities where this indicator was measured, there was a greater percentage of Low-Income Households Near Frequent Transit than the percentage of the population as a whole, which can be seen in Chart 6. This indicates that low-income households were better served by frequent transit than the whole population was. The largest gaps for this were seen in Los Angeles (11.7%), Minneapolis (10.5%), and Albuquerque (9.7%), where the percentage indicates the additional percentage of low-income households that are close to frequent transit over total population with such access. This pattern is potentially explained by the generally greater concentration of lower-income residents in central parts of American cities, where densities tend to be higher and transit services tend to be more robust. Potentially further contributing to this condition are car-centric Not In My Back Yard (NIMBY) politics, in which wealthy residents in lower-density neighborhoods view public transit negatively and use their political power to prevent frequent transit stops from being located in their neighborhoods. The combination of these forces could explain the higher share of Low-Income Households Near Frequent Transit in many cities.

PROXIMITY TO RAPID TRANSIT

Typically, the Proximity to Rapid Transit results mirror the trends of the Proximity to Frequent Transit results. Rapid transit tends to be near large shares of the jobs in cities, but not large shares of the population. However both jobs' and people's proximity to rapid transit correlate well with Sustainable Transport Mode Share. Chart 10 depicts the results for the Rapid Transit Proximity indicators. The results for Jobs Near Rapid Transit can be seen in blue, and the low-income households and Population Near Rapid Transit are depicted in red and yellow, respectively. Some of the cities included in this study do not have rapid transit, so those cities have a result of zero. Also, job and income data was not readily available for the cities in Mexico and Canada, so only People Near Rapid Transit is shown for those cities.

Chart 10. Proximity to Rapid Transit



A clear pattern can be seen in this chart: Rapid transit is largely located near job locations and is much less likely to be located near population centers. However, our analysis shows that both Jobs Near Rapid Transit (Chart 11) and People Near Rapid Transit (Chart 12) correlate well with Sustainable Transport Mode Share. By analyzing how well the indicators fit the model based on the correlation between People Near Rapid Transit and Sustainable Transport Mode Share, we can see interesting patterns. The cities that overperform are Montreal, Toronto, Vancouver, New Orleans, and Seattle, which had higher Sustainable Transport Mode Shares than would be anticipated based on their percentage of People Near Rapid Transit. However, these cities also have extensive frequent transit networks that complement their rapid transit or, in the case of New Orleans, function without it. While there is not enough data to draw conclusions, it is possible that these cities overperform in the correlation between People Near Rapid Transit and Sustainable Transport Mode Share because they have such strong bus networks. Seattle is probably the best example of this. Seattle's People Near Rapid Transit is only 6.7%, whereas their People Near Frequent Transit is 70% (see chart 13). Seattle has a higher Sustainable Transport Mode Share than would be expected based on its People Near Rapid Transit, possibly because it has a high People Near *Frequent* Transit result. Also, the two cities that underperform in the correlation are Boston and Philadelphia, the two cities with the highest People Near Rapid Transit scores. This may indicate that a stronger frequent transit network could increase their Sustainable Transport Mode Share even higher.

Chart 11. Population Near Rapid Transit and Sustainable Transport Mode Share

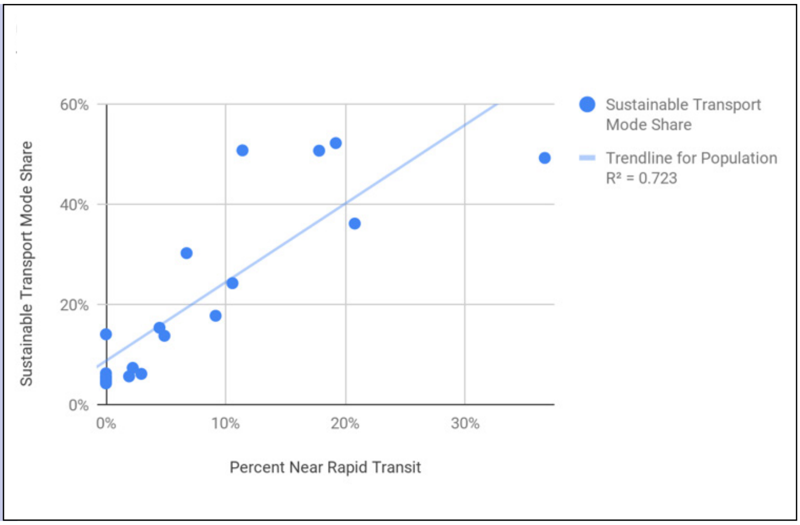
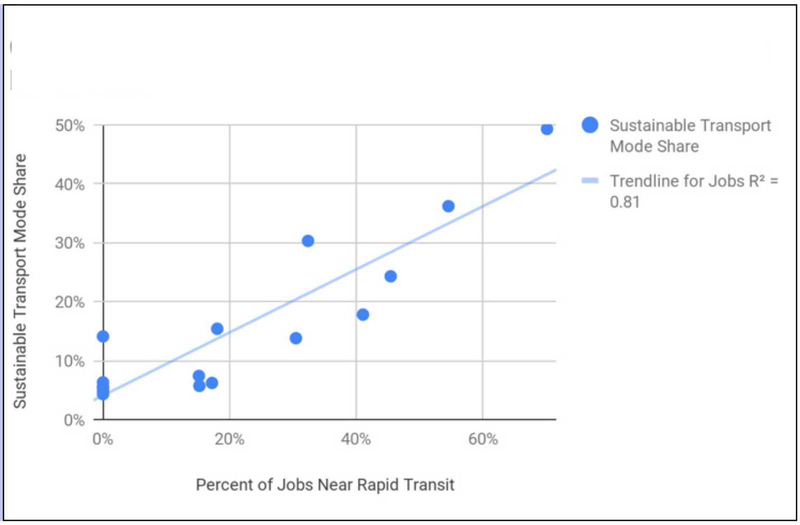
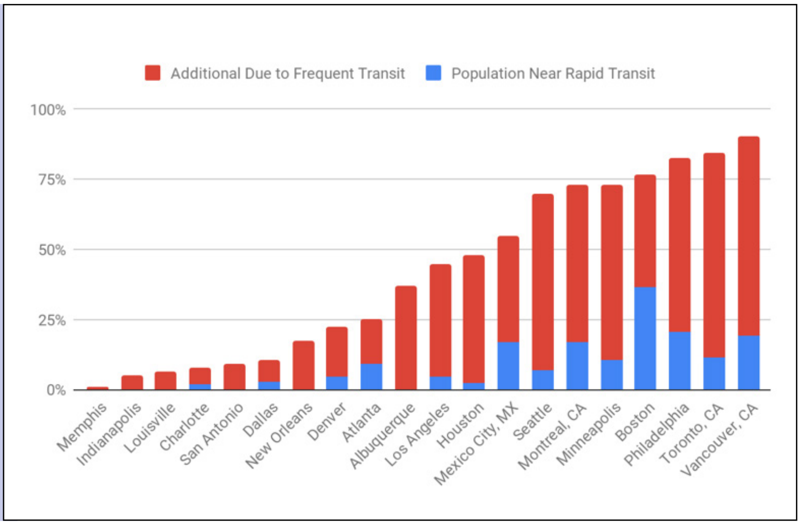


Chart 12. Jobs Near Rapid Transit and Sustainable Transport Mode Share



There is a strong correlation between Jobs Near Rapid Transit and Sustainable Transport Mode Share. Cities in the analysis tended to have higher numbers and shares of their jobs near rapid transit than people near rapid transit. This stronger correlation with mode share makes sense, as mode share data is collected on commuting trips. Therefore, this analysis is limited in trying to understand how well rapid transit serves other types of trips. Of the cities without rapid transit, only New Orleans had a Sustainable Transport Mode Share higher than 10%. This is possibly due to the compact nature of New Orleans. However, this correlation is limited by its small sample size, as it only includes the 16 cities in the United States.

Chart 13. Proximity to Rapid Transit vs. Frequent Transit



JOBS ACCESSIBLE BY SUSTAINABLE TRANSPORT

Jobs Accessible by Sustainable Transport revealed many of the same patterns as the other indicators, with Seattle, Minneapolis, and Philadelphia taking the top spots. However, Albuquerque placing in the top four on this indicator does buck the trends of earlier indicators. Albuquerque likely does well on this indicator because of its history of regional planning policies designed to connect communities by public transport, even when those communities are built at a relatively low density. In general, though, higher-density communities allow public transportation to be more effective, as transportation can more easily serve smaller areas. The results for this indicator are shown for the 30-minute threshold in Chart 14 and for the 60-minute threshold in Chart 15.

Chart 14. Average Jobs Accessible in 30 Minutes

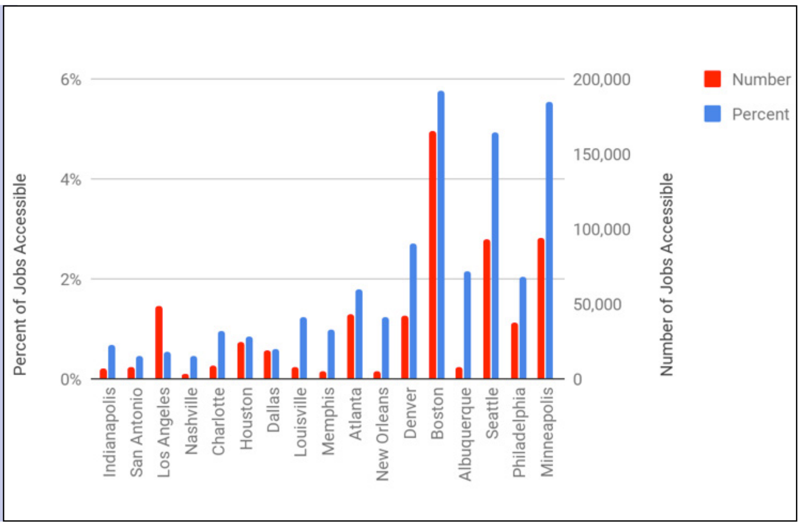
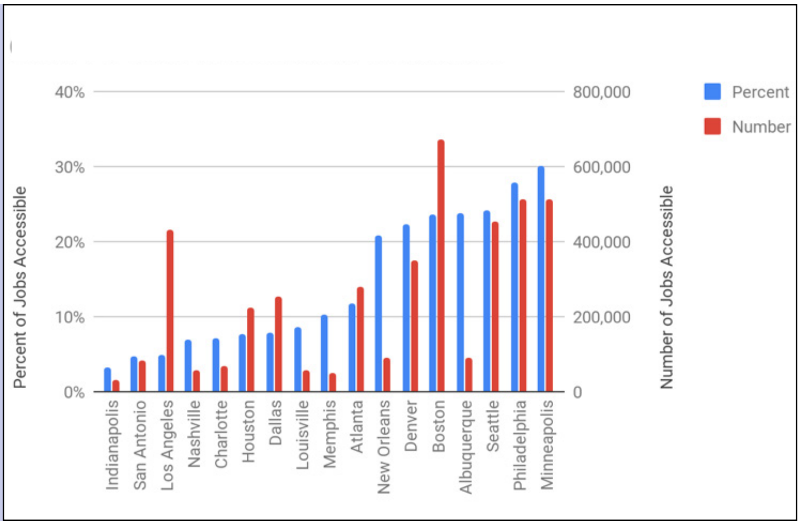


Chart 15. Jobs Accessible in 60 Minutes



It is important to note on this indicator that having a low percentage does not necessarily indicate poor accessibility. For example, in Los Angeles, only about 4 percent of jobs can be reached in an hour, but that number is nearly half a million jobs. Understanding both the percentage and the number is critical, because even if residents cannot reach a large share of the jobs, they are still able to access a large number of opportunities. This is especially important to note in very large, polycentric cities such as Los Angeles, as some people can only access one or two of the job centers and not all of them. Also, our research suggests that the number of opportunities that can be reached is of greater importance than the share of opportunities that can be reached as far as travel choice is concerned. This is illustrated by the two correlations depicted in charts 16 and 17. The first shows the correlation between the share of jobs that can be reached in 60 minutes and Sustainable Transport Mode Share. Surprisingly, this correlation is not particularly strong. However, the second chart depicts a much stronger correlation between the number of opportunities that can be reached and the Sustainable Transport Mode Share. The comparison of these two correlations suggests that when travelers are making decisions about how they choose to get to work, it is more important that they can reach a large number of destinations than a large share of destinations.

Chart 16. Jobs Accessible in 60 Minutes and Sustainable Transport Mode Share

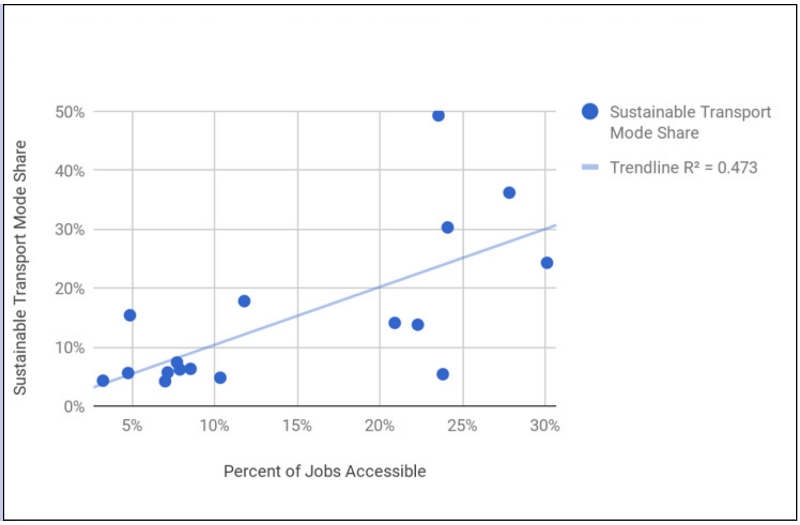
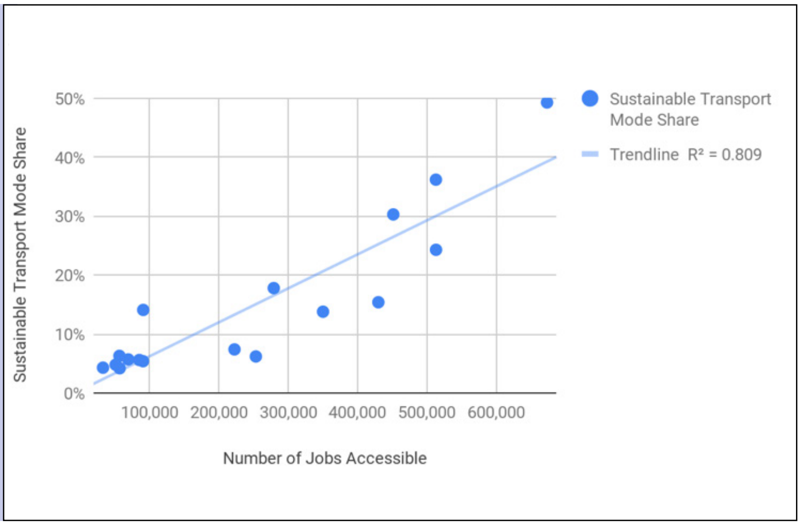
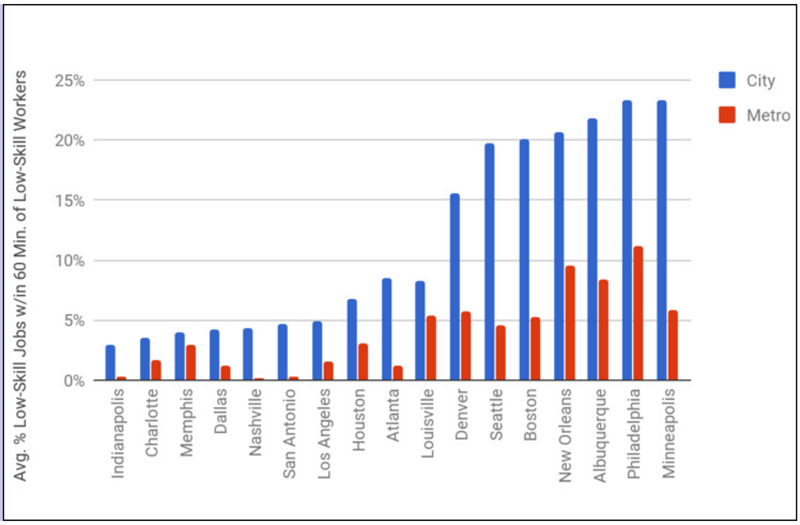


Chart 17. Jobs Accessible in 60 Minutes and Sustainable Transport Mode Share



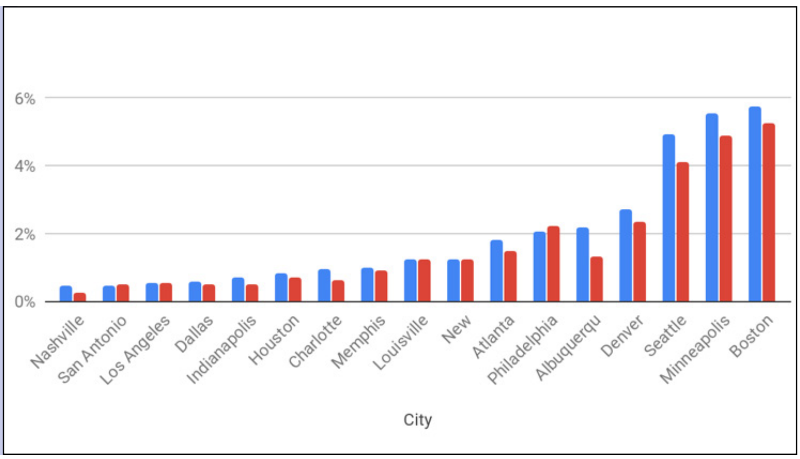
Many of the patterns that presented themselves in the Jobs Accessible in 60 Minutes indicator are also present in the low-skill jobs accessible indicator. The top-ranking cities are the same, albeit shuffled around a bit, and the large gap between cities with high results and cities with low results remains.

Chart 18. % Low-Skill Jobs Accessible in 60 Minutes



However, one key difference is the noticeable gap between the share of all jobs accessible and low-skilled jobs accessible. This gap has two possible explanations. The first is that the methodology for this indicator is based on a travel time on a Sunday morning–this likely produces smaller polygons of accessibility for each census tract because of limited transit functionality in most cities at that time. However, that time was selected intentionally due to the atypical (i.e., not 9-to-5) work schedules that often accompany low-skilled labor. The other possible explanation is that low-skilled jobs and/or low-skilled workers are not as well served by transit as other jobs are. However, at the 30-minute time threshold, the indicator was measured at the same time for both all jobs and low-skilled jobs, meaning that they were both measured at the same start time of 8 a.m. on a Wednesday. The comparison between the two 30-minute threshold indicators can be seen in Chart 19. The same pattern of worse access for low-skilled jobs is also seen at the 30-minute threshold, even though they are measured at the same start time.

Chart 19. Percent of Jobs Accessible vs. Percent of Jobs Requiring Less than a High School Education Accessible



Based on the indicators of proximity to frequent transit, which showed that low-income households had greater access to frequent transit than the population as a whole, it would appear that there is a spatial mismatch between transit reaching low-income households and actually connecting them to jobs (which are presumably those that require less education) relative to the population as a whole. However, further research will be required to better understand this relationship and its causes and potential solutions. This relationship is depicted in the chart below.

30-. VS 60-MINUTE ACCESS COMPARISON

Access to jobs was measured at both the 30- and the 60-minute threshold. This was done because there was little consensus over what time was most appropriate. In the United States the average one-way commute time is 26.1 minutes. This was the basis of the 30-minute selection. Transit should be competitive with the average commute time. After some external feedback, this was extended to 60 minutes, mainly because performance was so poor at the 30-minute threshold. Also this indicates a popular expectation that transit will and should take a commuter double to triple the time to make a trip as the commute would with a car.

Both the 30- and 60-minute indicators correlate with Sustainable Transport Mode Share, but the 30-minute indicator has a stronger correlation when comparing the percentage of jobs accessible. These correlations can be seen in Chart 16 and Chart 20. The 30-minute indicator has a much higher correlation, which suggests that it may be a better indicator of what drives Sustainable Transport Mode Share choices than the 60-minute threshold. **However, the strongest correlation can be seen when looking at the number of jobs accessible instead of the percentage**. This can be seen in charts 17 and 21. When comparing the raw number of jobs that can be reached with the Sustainable Transport Mode Share, the 30-minute and 60-minute indicators both correlate strongly, with little difference between the two. Considering that the share of jobs correlated more strongly at the 30-minute threshold and that there was little difference in the correlations for the number of jobs, there is a strong case that 30 minutes is a more suitable indicator of accessibility than 60, and that it is more valuable to measure the number of jobs accessible than the percent of jobs accessible

Chart 16. Jobs Accessible in 60 MInutes and Sustainable Transport Mode Share

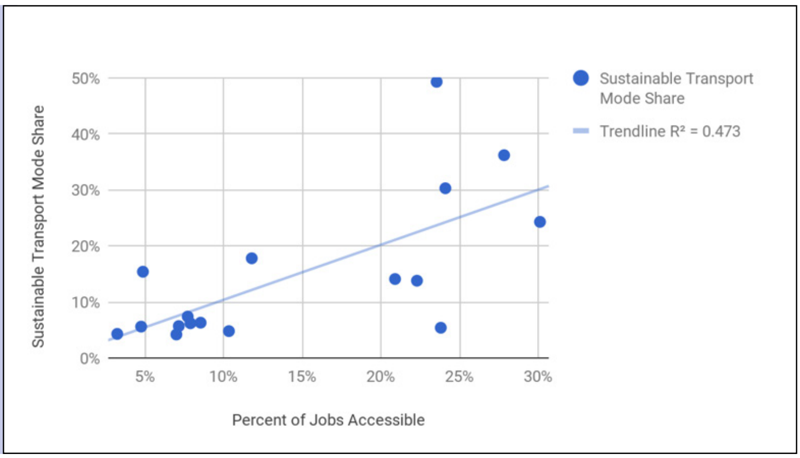


Chart 20. Jobs Accessible in 30 Minutes and Sustainable Transport Mode Share

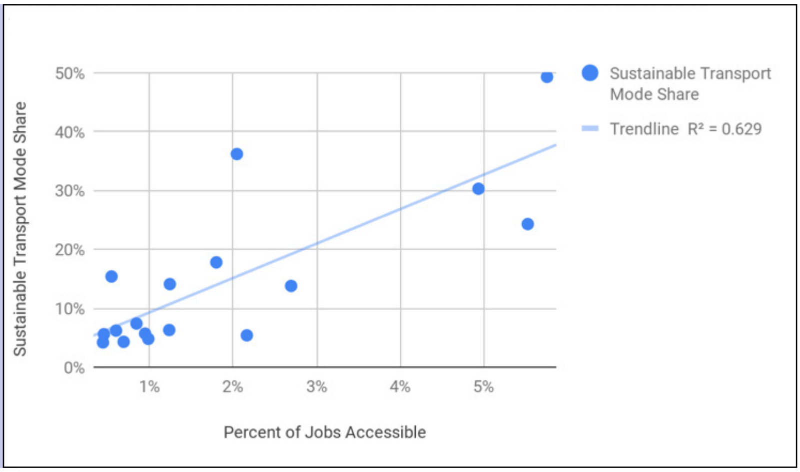


Chart 17. Jobs Accessible in 60 Minutes and Sustainable Transport Mode Share

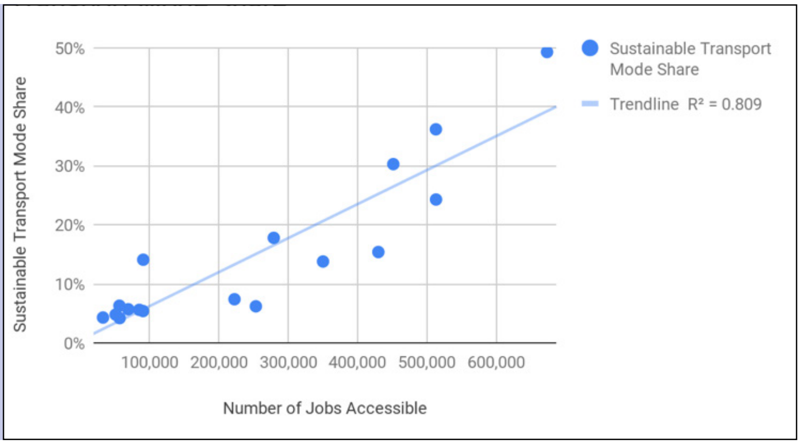
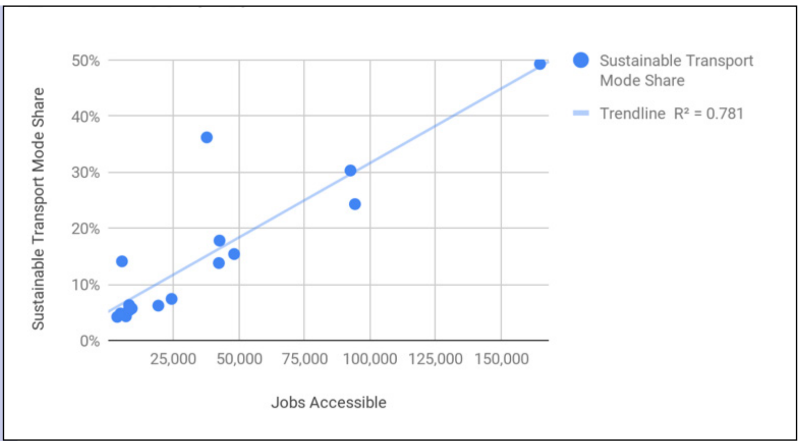


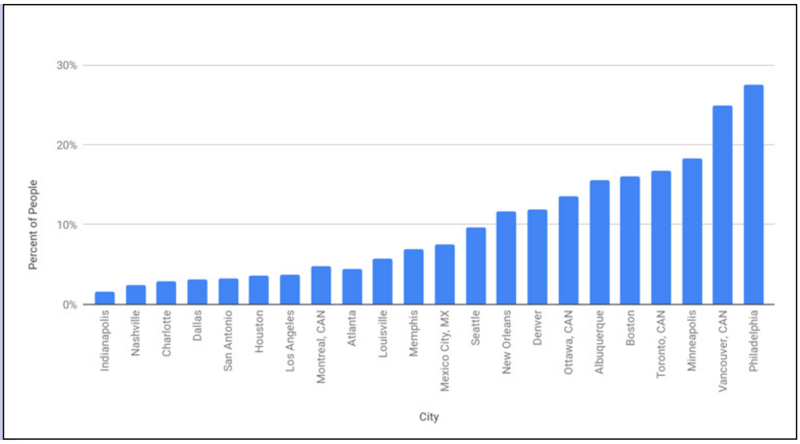
Chart 21. Jobs Accessible in 30 Minutes and Sustainable Transport Mode Share



PEOPLE TO PEOPLE: POTENTIAL PROXY

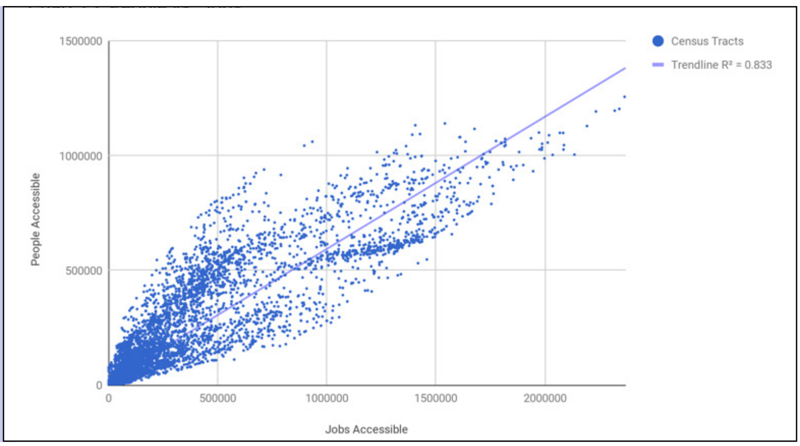
Though we were not able to calculate access to jobs or access to low-skilled jobs in Canada and Mexico because of a lack of job data, we were able to calculate a different indicator of accessibility: Access to People. The results for this indicator can be seen in Chart 22, below. All of the Canadian cities had high access to people results with the exception of Montreal, and the one city in Mexico with GTFS data, Mexico City, also had high results.

Chart 22. Access to People (60 Minutes)



We compared the results from Access to Jobs to Access to People for 11,797 census tracts across 16 cities in Chart 23. This analysis showed that there was a strong correlation between access to jobs and access to people. Based on the results, we determined that access to people serves as a suitable proxy for access to jobs in the US, and potentially elsewhere.

Chart 23. People vs. Jobs



KEY RESULTS

This report presented a suite of 12 indicators for benchmarking sustainable transit in 25 different cities across North America. These indicators are intended to provide a clear and actionable overview of sustainable transit. While these indicators were applied only in North America, with a focus on the United States, they can be applied in other geographies where data is available.

However, there are some limitations to these indicators that are worth keeping in mind. The first is that they are data dependent. For example, all of the frequent transit indicators and the access indicators require GTFS data for calculations. While GTFS data is becoming more and more widely available, it is still not available in all cities. Also, in most cases, GTFS does not include informal transit networks, although this is changing, as can be seen by the work of the Digital Matatus Project and Where Is My Transport. This is especially important in the context of the global south. Another limitation is that the indicator results for any given city are only as accurate as the data they use. For example, if the schedule that the GTFS is based on is not accurate to the reality on the ground, then the indicator will not reflect the reality in the city either. Another place where the data dependency causes potential problems is with Sustainable Transport Mode Share. Mode share data is collected infrequently: The data used in this analysis is from 2010, and since we are using GTFS data from 2017, this can cause strange outliers in some of the indicators. One good example of this is Houston. Houston had high results on People Near Frequent Transit, Jobs Near Frequent Transit, and Low-Income Households Near Frequent Transit. However, these did not match with the city's low Sustainable Transport Mode Share. This is likely because Houston did a bus network redesign in 2015. The impacts of the redesign are included in the GTFS but not in the Sustainable Transport Mode Share data, as it is from before the redesign occurred.

Those limitations aside, GTFS data has enabled us to do research that has been too complex to do at scale in the past. Indicators such as frequent transit proximity and access to jobs, while possible to compute without GTFS data, were previously so convoluted and disparate in their calculation across different cities that this type of benchmarking effort would have been prohibitively time-consuming and difficult to compare. This is particularly true of the indicators of access. GTFS allows us to measure transportation's ability to bring people to opportunity in a much more holistic way than was previously possible. As we've seen, access to jobs has a strong correlation with Sustainable Transport Mode Share, which suggests that it is a strong determinant in whether or not commuters choose sustainable modes. GTFS has allowed us to develop advanced indicators that provide a better understanding of cities' transit systems.

This benchmarking endeavor and the subsequent analysis have resulted in a number of key takeaways. The indicators that had the strongest correlations with Sustainable Transport Mode Share are People Near Frequent Transit and Jobs Accessible in 30 Minutes by Sustainable Transport. These indicators are both measures of access to destinations in the city, which is the goal of transportation, so correlation with Sustainable Transport Mode Share is expected. The indicators of proximity to frequent transit also allowed us to better understand the degree to which protected bicycle lanes can expand access to frequent transit. This analysis also revealed a gap between Low-Income Households Near Frequent Transit and People Near Frequent Transit. Contrary to expectations, low-income households had slightly better access to frequent transportation than the population as a whole did. However, the analysis also revealed that at the 30-minute threshold, accessibility to jobs that required less than a high school education was worse than for all jobs. This suggests that while there was better access to transportation for low-income populations, the transportation does not provide access to low-income jobs very well compared to the job access provided to the total population. This analysis also showed that both frequent and rapid transit are more likely to be colocated with jobs than with people, even though our analysis also shows that people's proximity to transit, both frequent and rapid, also correlates strongly to higher sustainable transport use. Finally, we were able to test the ability of access to people to function as a proxy for access to jobs. Our analysis showed a strong correlation between the two, suggesting that access to people is a suitable proxy, at least in the United States. This is beneficial finding that may help to measure access in places where jobs and other destination data may not be widely available.

In addition to the trends, patterns, and takeaways from the indicators, this research has prompted further research concerning

- More granular-level analysis in targeted cities
- Expanded geographic coverage
- Application of similar indicators, such as the ones proposed by the European Commission

We look forward to the opportunity to further explore these indicators, to facilitate a better understanding of urban transport, better monitoring of progress, and better decision-making tools.

APPENDIX

Table 1, below, shows the sample size (n), p-value, and r^2 value for all of the correlations shown in the report. The sample size (n) varies between 17 and 21 depending upon how many cities had the requisite data available for the correlation. The correlations based on job related indicators have a sample size of 17 because the Canadian cities did not have job data readily available. The p-value is a measure of the significance of the variable as an effective predictor. The r^2 values depicted in the table are slightly different than those shown in the charts in the report. This is because the values in the body of the report were calculated in the making of the charts, using Google Sheets. The r^2 values below were calculated in ArcGIS via an exploratory regression. The exploratory regression presents adjusted r^2 values that are typically lower because the regression is calibrated to reflect model complexity.

Table 1

INDICATOR CORRELATED WITH MODE SHARE	n	P-VALUE	r^2
People Near Rapid Transit	21	.05	.71
People Near Frequent Transit	21	.05	.79
Jobs Near Rapid Transit	17	.05	.80
Jobs Near Frequent Transit	17	.05	.72
Access to Jobs in 30 Minutes %	17	.05	.60
Access to Jobs in 60 Minutes %	17	.05	.44
Access to Jobs in 30 Minutes #	17	.05	.77
Access to Jobs in 60 Minutes #	17	.05	.79
Block Density	21	.05	.43
Weighted Population Density	21	.05	.79

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