Visualizing Urban Accessibility Metrics for Incremental Bus Rapid Transit Projects

by

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Submitted to the Department of Civil and Environmental Engineering
and the Department of Urban Studies and Planning
in partial fulfillment of the requirements for the degrees of

Master of Science in Transportation
and
Master in City Planning
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Abstract

As cities worldwide grow, their residents must be able to traverse urban space in order to access employment, social services, recreation, and other critical activities. Urban accessibility reflects the ease of such access with respect to locations within a city, and it is largely dependent on the city's land use and transport systems. A variety of urban accessibility metrics have been proposed to guide urban policy and planning, but they have not been implemented systematically. Better understood and more widely adopted accessibility measures could help guide complex land use and multimodal transportation planning processes toward more effective and equitable outcomes. Such measures represent a significant departure from the facility, maintenance, and mobility priorities that dominate transportation planning today, opening possibilities for new approaches. In particular, a clearer focus on accessibility could help prioritize and inform the design of bus rapid transit (BRT) projects, which tend to include different potential streetscape, transport, and network improvement options across a wide range of geographic and temporal scales.

This thesis aims to develop a participatory framework built on an open-source, web-based toolkit that transit advocates and planners can use to visualize how urban design and operational characteristics of different incremental BRT scenarios might affect access at a personal level and accessibility at a regional level. Such visualizations can encompass the interaction of these scenarios with pedestrian, local bus, and rail connectivity, as well as regional land use. Built on Open Trip Planner Analyst and other web-based civic engagement platforms, as well as open data such as transit information in the general transit feed specification (GTFS) format, this toolkit is applied to transit performance and accessibility for example projects in two contexts, Boston and Santiago de Chile. Focus groups with transit advocates and planners were conducted in these two settings to evaluate the proposed toolkit. Members of community-based transit advocacy organizations found the toolkit to be both understandable and able to represent some of their key concerns; professional planners thought the toolkit could help them better understand existing operations and proposed projects. These evaluations suggest that the participatory framework developed around this toolkit could be an effective platform for dialogue between planners and community organizations. By connecting individual perspectives on access with broader accessibility metrics, this framework has the potential to build political will for the adoption of equitable accessibility indicators as decision-making metrics.

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Chapter 1

Overview

The proliferation of bus rapid transit (BRT) reflects a broader shift toward more flexible and adaptable urban transportation systems. A spectrum of bus service upgrades, rather than a consistently defined transit mode, BRT is often promoted as an option that can be adapted more easily to a wide range of contexts than rail-based transit. Yet this very adaptability can also undermine public transit because it renders BRT projects prone to the elimination of important transit priority features in car-dominated cities.

When planning such systems, accessibility metrics can be useful indicators that account for the fundamental purpose of transit in a city – providing access to opportunities for the city's inhabitants, and accessibility to labor and patrons for a city's businesses and institutions. Accessibility is a useful concept for assessing the equity impacts of proposed service changes and projects, responding to concerns raised by the environmental justice movement. New approaches to public participation in the planning process, built around open data and open software tools, can encourage the adoption of accessibility metrics in urban transportation planning and use these metrics to promote more equitable outcomes. Stronger participatory platforms built around individual perspectives on access can also enable planners to utilize local knowledge more effectively in adapting transit to local contexts.

1.1 Research Questions, Goals, and Objectives

Core research questions for this thesis revolve around the themes introduced above:

- How could accessibility metrics guide urban transportation service planning and projects?
- What factors limit these metrics from being used more widely in transportation planning and decision-making?
- How well can web-based mapping tools communicate accessibility metrics to planners and to a broader public audience concerned about specific transit projects?

This thesis tests the hypothesis that web-based mapping tools make accessibility metrics easily understandable and provide a platform for transportation and land use officials and community advocates to engage in dialogue. The goal of this work is to demonstrate how new open source tools can be adapted to promote the use of accessibility indicators and drive more participatory mechanisms for transit planning.

Specific objectives to further this goal are to:

- Explain the potential of urban accessibility and transportation equity as interrelated concepts to guide complex land use and multimodal transit planning and decision-making
- Build a web-based toolkit for transit advocates and planners to use in visualizing and understanding accessibility changes induced by bus corridor projects
- Develop and facilitate a participatory inquiry process to encourage the incorporation of local knowledge into corridor planning through the web-based tools
- Evaluate the toolkit and participation process in different contexts

1.2 Organization

The remainder of the thesis is structured as follows:

Chapter 2 defines urban accessibility and details past efforts to measure it. Accessibility is closely related to equity, and transportation equity advocates could benefit from the adoption of more clearly defined accessibility measures.

Chapter 3 offers an overview of bus rapid transit projects, challenges they typically face, and how their incremental implementation can improve urban accessibility through both transport and land use.

Chapter 4 reviews theoretical work on citizen participation in the planning process and outlines how the increased availability of open data and software could catalyze new approaches to meaningful participation.

Chapter 5 situates this theoretical discussion in two contexts, describing salient transportation planning history and the incremental development of BRT in Boston, Massachusetts and Santiago de Chile.

Chapter 6 draws on research on participation and these two contexts to describe the design and customization of an accessibility visualization toolbox called IBRT Accessibility.

Chapter 7 describes how IBRT Accessibility was tailored to audiences in Boston and Santiago and how focus group sessions were used to evaluate the tool.

Chapter 8 synthesizes the findings from these evaluative efforts into broader lessons and recommendations for transportation planning.

Chapter 2

Urban Accessibility

This chapter begins by defining urban accessibility and contrasting it with mobility, a related but distinct concept. Various proposed metrics for quantifying accessibility are compared, and example approaches to depicting these metrics visually are discussed. Access to opportunity is a central theme of transportation equity, and advancing accessibility metrics as measures of transportation system performance has the potential to also highlight and advance equity. The chapter concludes with possible extensions for past work on urban accessibility metrics.

2.1 Definitions

Urban accessibility reflects how easily people at a given location can reach destinations in a city. It extends the notion of accessibility as it is often used in relation to individuals' physical abilities by including:

- other personal characteristics, such as age, gender, income, and vehicle ownership
- transport system characteristics, such as travel times, reliability, available modes, and costs
- land use and activity characteristics, such as job locations, public amenities, and hours of operation

Accessibility as a way of understanding cities has been discussed since the 1950s, and though it has not yet been widely used as a performance measure or decision-making metric in planning, it has seen renewed attention recently.

Hansen (1959, p. 73) defines accessibility as a "measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome spatial separation." For example, the employment accessibility of a given point to area i increases with the number of jobs in area i and decreases with the effort required to travel from the point to area i; the total employment accessibility for the point is then the sum of the accessibility to each of the other areas (Hansen, 1959).

While such a conceptual link between mobility and land use systems is a relatively straightforward and intuitive representation of an important part of urban operations, the divides between traditional urban professions tend to obscure this link:

> Transportation planners make use of performance measures such as freeway level-of-service and average intersection delay; these measures say something about the transportation system, but in isolation, ignoring the larger context. Land use planners focus on activity patterns, looking at characteristics such as density, and tend to ignore links between activities... The concept of accessibility, because it accounts both for the pattern of activities and for the links between activities, provides a basis for making trade-offs between land use and transportation policies that has been sorely lacking. –Handy and Niemeier (1997, p. 1175)

While the above quotation suggests trade-offs, there can also be synergies that an accessibility framework would illuminate. Put another way, accessibility reflects outcomes of the joint transportation and land use system, rather than intermediate measures of the performance of the individual subsystems (McGurrin et al., 2011). Geurs and Van Wee (2004, p. 128) advance a similar concept, defining accessibility as "the extent to which land use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)." They locate accessibility at the center of four travel components: land use, transport, temporal, and individual (See Figure 2.1).

In addition to detailing the different components of accessibility, Geurs and Van Wee (2004, p. 128) emphasize the importance of clear terminology. One of their conventions, which will be followed here, is that "**access is used when talking about a person's perspective [and] accessibility when using a location's perspective**." Access is partly a function of personal characteristics of an individual traveler; these characteristics are aggregated for a

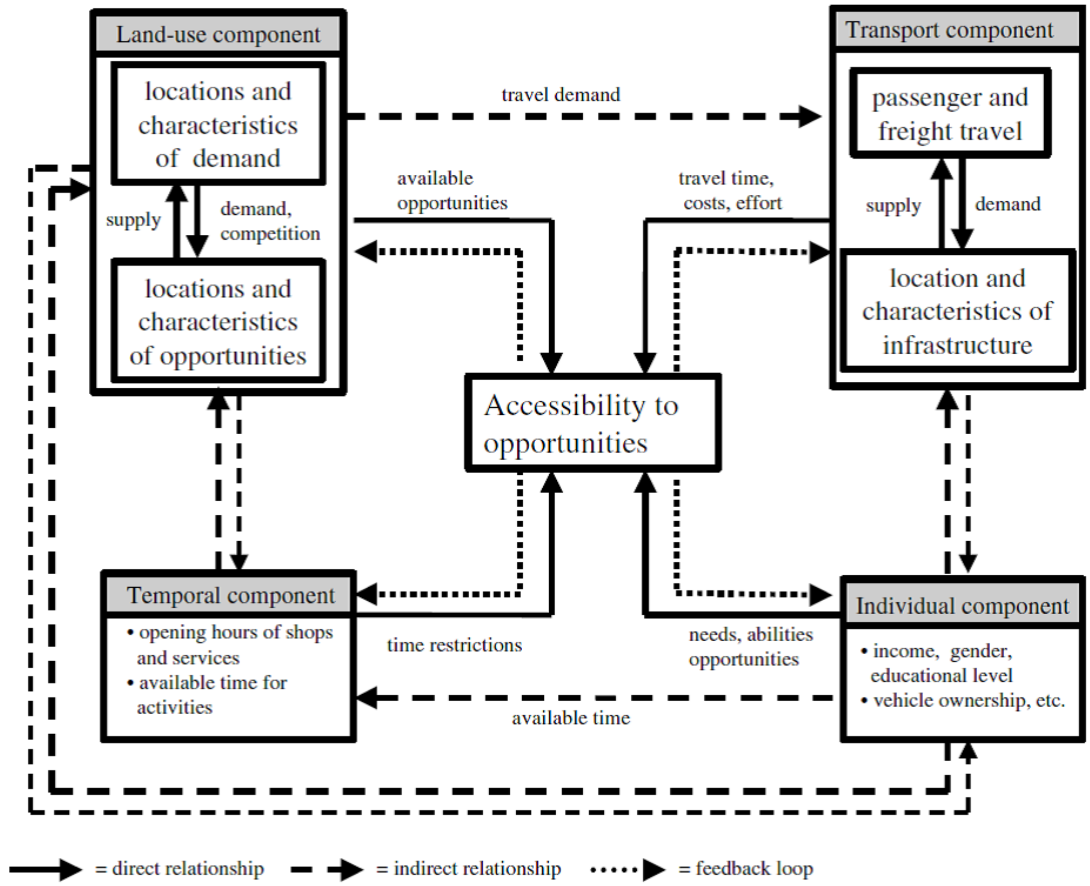

Figure 2.1: Components of accessibility (from Geurs and Van Wee (2004))

representative population of travelers when considering the accessibility of a location. Both increasing the aggregate accessibility of a city's neighborhoods and improving access for its residents should be primary goals of planning the coupled land use and transportation systems.

Accessibility matters to businesses and institutions, which must be able to draw on a broad pool of workers and customers to thrive. Accessibility models have been widely applied, for example, in retail location decisions, and businesses tend to value access to "thick" labor markets facilitated by transit (Bleakley and Lin (2012), Chatman and Noland (2013)). Similarly, improved access results in widened choice-sets for individuals, allowing them additional freedom in optimizing their own decisions about goods, services, recreation, and employment. These widened choice-sets represent improved well-being and are fundamental to building human capital (Zegras, 2011).

2.1.1 Other Types of Accessibility

The preceding discussion has focused on access and accessibility as related to the physical movement of people through urban space, the center of this thesis. While this framework accounts for important dimensions of how city residents are able to take advantage of opportunities and resources, a number of extensions deserve brief mention.

First, accessibility can be applied to the movement of goods and freight as well. If a resident is highly accessible to a good (e.g. via an efficient home delivery system), then her need to be able to reach a store selling this good physically may be reduced. Additionally, shared road space leads to interactions between human and freight mobility systems, often an important consideration in analyzing congestion.

Another extension involves the use of communication technologies. Increasingly, these technologies allow for a representation of a person, rather than the person himself, to move through space and achieve desired goals. Sheller and Urry (2006) consider possible implications of these mobile technologies at length. A clear consensus on how virtual mobility may substitute for or complement physical mobility has not emerged. It is clear, though, that physical access will be an important determinant of urban residents' available opportunities for the foreseeable future.

2.1.2 Relation to Mobility

Planning in the United States has often conflated mobility and accessibility as equivalent goals. Mobility, from an individual's perspective, is the ease of movement through a city regardless of destination. At a more aggregate level, urban mobility can also represent the throughput of a transport network as impeded by capacity constraints (Zegras, 2011); high speeds indicate high levels of mobility, as movement is unencumbered. When mobility alone is a planning effort's objective, the solution will be biased towards high-speed, high-capacity solutions; these solutions may negatively impact urban design and local accessibility concerns, either through heavy mass transit infrastructure or free-flowing highways, for which owning a car is required for access.

In contrast to accessibility, mobility is a function only of a city's transport system. Increasing mobility can be one means to achieving accessibility ends, but the outcome of interest for residents is access to destinations, not individual mobility *per se*. This distinction "highlights the importance of placing higher value on accessibility and less value on high levels of mobility alone" (Ducas, 2011, p. 28). For sustainability more broadly, transit should be designed to provide accessibility, not merely congestion relief and improved mobility for drivers (Paget-Seekins, 2010). Zegras (2011, p. 570) proposes a framework for defining sustainable mobility, in which "accessibility is the goal and mobility is the throughput cost of achieving the goal, where any mobility throughput represents depletion of capital stocks;" in other words, urban transport should maximize well-being, as measured by accessibility, within the constraints of cost, as measured by the resources required to build and operate the mobility system. Where the construction industry has strong political influence, however, political will to consider mobility as the denominator in a sustainable transport index will be diminished.

While increased mobility throughput can potentially improve accessibility, it can also significantly undermine it. Handy (2005, p. 133) argues that equating mobility and accessibility ignores key differences between the two and has led to perverse planning outcomes, explaining, "although planning for mobility can be compatible with planning for accessibility, the traditional focus on mobility in transportation planning in the U.S. has over time helped to decrease accessibility." Sclar and Lönnroth (2014, p. 1) echo this criticism for urban transportation planning internationally:

> The goal of expanding urban transport is to facilitate improved urban access. Yet growing worldwide experience demonstrates that the agencies charged with delivering urban transport increasingly tend to see the continual expansion of mobility as their sole mission. The result is the spread out and socially segregated metropolitan regions...[that] hinder access for the urban population as a whole.

Increased mobility through the expansion of highway capacity, for example, would improve mobility for some drivers; but it could reduce access at a systemic level for drivers (e.g. through Braess's Paradox and induced demand), for public and non-motorized transit users (e.g. through decreased pedestrian and bicycle safety and connectivity), and in the long term by encouraging sprawling development. Furthermore, when accounting for the negative pollution and safety externalities of such a highway expansion, there might be far less costly means of achieving the same improvement in accessibility. Equating any improvement in mobility to an equal improvement in accessibility is highly questionable. Yet, as discussed in Section 2.4, some agencies do just that. Put simply, in comparison to "traditional mobility-based measures of performance,...[e]valuating transportation performance in terms of accessibility allows a more blanced approach to transportation analysis and problem-solving" (Cervero et al., 1995, p. 4).

Though mobility and accessibility are distinct concepts, transportation planners have often failed to differentiate between the two. This failure may be explained partly by the relative ease of collecting data for mobility measures, such as travel speeds and delays compared to uncongested baseline travel times, and a history of allowing such measures to be proxies for accessibility. Improvements in data availability and computing capabilities, however, make the compilation of accessibility metrics more feasible than in the past. A range of such metrics is discussed in the next section.

2.2 Quantifying Accessibility

Many ways to calculate accessibility exist, and the specifics of planning contexts can help determine which metric is most appropriate (Handy and Niemeier (1997), Handy and Clifton (2001)). Geurs and Van Wee (2004, p. 130) offer an overview of criteria that can be used to evaluate possible accessibility metrics; they propose "(1) theoretical basis, (2) operationalization, (3) interpretability and communicability, and (4) usability in social and economic evaluations." Depending on the planning context, appropriate accessibility measures may involve evaluation for different modes, the aggregation of measures to reflect accessibility of populations or locations of interest, or the normalization of measures to facilitate regional comparisons. While many variations exist, the most commonly used approaches to accessibility are based on one of the three basic classes of measures discussed below.

2.2.1 Cumulative Opportunity Metrics

Also called isochrone measures, cumulative opportunities metrics are location-based calculations of how many opportunities can be reached from a location within a given time threshold. The typical cumulative opportunity measure is similar to, for example, the number of jobs accessible in 30 minutes or less. In the example shown in Figure 2.2, the accessibility of location A would be 12, the total number of opportunities reachable within the cutoff time.

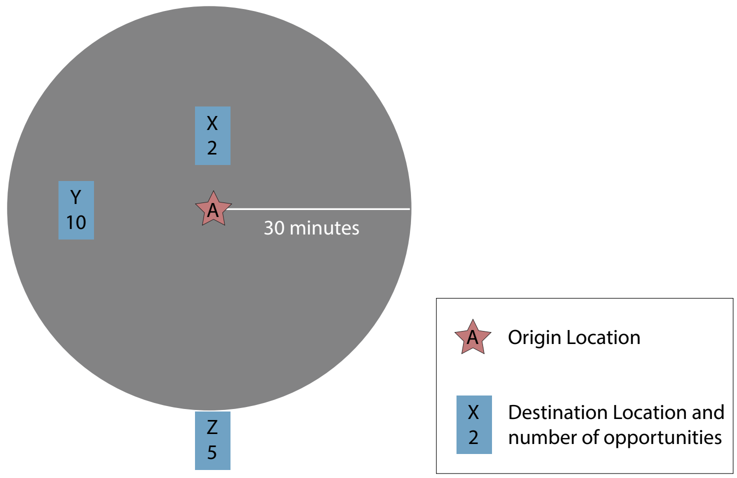

Figure 2.2: Cumulative opportunity metric example

Mathematically, this can be expressed as:

$$A_j = \sum_{i=1}^{N} B_i o_i, \quad B_i = \begin{cases} 1, & C_{ij} \leq T \\ 0, & C_{ij} > T \end{cases}$$

where A_j is the accessibility of zone j, B_i is either 1 or 0 depending on whether the cost of traveling (measured as time, distance, or money) between zones i and j (C_{ij}) is less than a defined threshold value T (e.g. thirty minutes), and o_j is the number of opportunities (e.g. jobs, educational facilities, hospital beds, etc.) available in zone i. This number of opportunities can vary by user (e.g. industry of worker) or time of day (e.g. based on hours of operation) to reflect the personal and temporal components of accessibility.

The main advantage of such measures is ease of interpretation and communication; the units of the measure (e.g. number of jobs) are easily understood. A disadvantage is that these measures are sensitive to the threshold value selected, undermining their theoretical soundness. If a threshold of 30 minutes is selected, for example, then jobs that are 31 minutes away from a given zone would not influence the accessibility score of that zone, even though in reality they could likely benefit residents of that zone. Such measures also fail to account for competition when the opportunities may be limited; for instance, a destination zone with a given number of jobs may not be able to benefit directly more than that number of employees, even if many more people have easy commuting access to that zone.

2.2.2 Gravity-based Metrics

An extension of the cumulative opportunities metric is the gravity-based metric. Instead of ignoring opportunities beyond a set threshold, a gravity-based approach will weight more easily accessed opportunities more heavily than opportunities that are farther or costlier to reach. For example, the number of opportunities at a given destination could be multiplied by 100 over the square of the time it takes to travel there from the selected origin. If this impedance function is used, and if in Figure 2.3, the travel time from A to X is 10 minutes, from A to Y is 20 minutes, and from A to Z is 31 minutes, then the total accessibility score for A will be:

$$A_A = \frac{100}{10^2}(2+)\frac{100}{20^2}(10) + \frac{100}{31^2}(5) = 5.02$$

Because of the weighting, this score is not directly comparable to the cumulative opportunity metric calculated above.

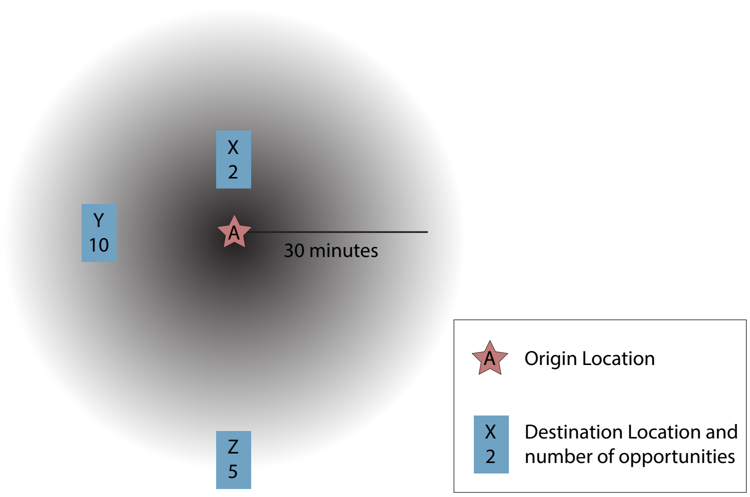

Figure 2.3: Gravity metric example

More generally, this approach can be expressed as:

$$A_j = \sum_{i=1}^{N} f(C_{ij})o_i, \quad f(C_{ij}) = \begin{cases} e^{\theta C_{ij}} \\ \text{or } \frac{1}{C_{ij}^2} \\ \text{or...} \end{cases}$$

where A_j is the accessibility of zone j, C_{ij} is the cost of traveling (measured as time, distance, or money) between zones i and j, $f(C_{ij})$ is a calibrated impedance function of C_{ij} (generally monotonically decreasing, such as a negative exponential), and o_j is the number of opportunities (e.g. jobs) available in zone i. Again, o_j can vary by individual and time.

While these metrics avoid the threshold cutoff problem of cumulative opportunity measures, they are also dependent on behavioral data to estimate an appropriate impedance function and do not have units that are as as meaningful or as easily communicated.

2.2.3 Utility-based Metrics

Person-based accessibility measures rely on detailed socioeconomic and trip characteristics used in specifying utility functions. The denominator of a multinomial logit model, which represents the availability and attractiveness of alternatives, can be specified as:

$$A_n = \ln \left[\sum_{\forall \in C_n} e^{(V_{n(c)})} \right]$$

where A_n is the accessibility for person n, $V_{n(c)}$ is the observable indirect utility of choice c for person n, and C_n is the choice set for person n (Handy and Niemeier, 1997).

Utility-based metrics often have "theoretical and empirical advantages" (Handy and Niemeier, 1997, p. 1178) but are more difficult to calculate and explain than cumulative opportunity and gravity-based metrics. They are also individual-specific, rather than location-specific, so their use in place-based planning generally requires detailed disaggregate data about populations.

2.2.4 Comparing Metrics

Each of these classes of metrics has advantages and disadvantages. Geurs and Van Wee (2004) include an in-depth comparison. For high-level sketch planning, the simplicity of location-based metrics, either cumulative opportunity or gravity, make them more attractive than utility-based ones. Comparing the former two classes of measures, Ducas (2011, p. 149) notes the shortcomings of isochrone measures "when considering opportunities with a spatial distribution that is concentrated in multiple 'lumpy' discrete locations," and instead recommends the use of gravity metrics in her proposed FTA New Starts evaluation criteria. Páez et al. (2013) also caution against using arbitrary thresholds for cumulative opportunity, though they address this problem by using empirically observed maximum travel times, rather than switching to a gravity measure. Despite these cautions, cumulative opportunity measures were selected to form the core of this thesis for their ease of explanation and communication, though an extension to allow for gravity-based metrics would not be onerous.

2.3 Visualizing Accessibility

Various visualization approaches have been developed to represent the multiple spatial and temporal layers of accessibility. A number of these approaches are cataloged below.

Isochrone maps display travel times from a chosen point by a given mode at a given time. They only represent mobility, however, and do not reflect land use. These maps are standard features in proprietary transportation planning tools like Cube and TransCAD. Another early example of the use of geographic information system (GIS) software to generate isochrones for public transit is described in O'Sullivan et al. (2000) (see Figure 2.4). Street (2006) authored a Java application to generate isochrones for the London Underground, using transit schedule data, assumed disruptions, and walking calculations based on Open Street Map. Another tool, Isoscope, is a car and pedestrian isochrone mapping web page that displays isochrones calculated from cellular phone data and Open Street Map, using transparency to show how travel times vary over the course of a day (see Figure 2.5) (http://www.flaviogortana.com/isoscope/).

Figure 2.4: Isochrones from ArcGIS (O'Sullivan et al., 2000)

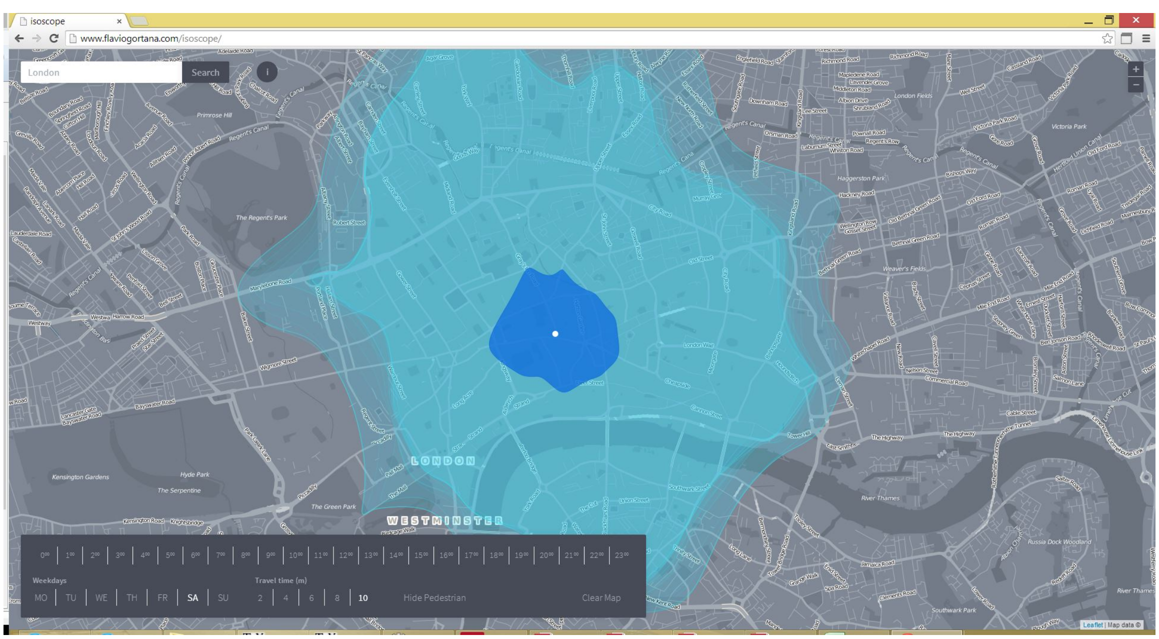

Figure 2.5: Isochrones from Isoscope (http://www.flaviogortana.com/isoscope/)

Combining land use layers with isochrone tools integrates potential destinations, reflecting accessibility instead of just mobility. The resulting maps, produced with transportation modeling and GIS software, are usually chloropleth maps where the color intensity represents the number of opportunities accessible from that region. Examples include calculation of urban accessibility to employees, employment, shopping, recreation (see Figure 2.6), and healthcare facilities (Peralta-Quirós (2013), Ducas (2011), Martin et al. (2008)). Goulias et al. (2013) implemented accessibility calculations based on modeled travel times as an input to an agent-based transportation model for Southern California. Their use of detailed transport network, population, and employment data also allows for extensive filtering by travelers, time of day, and mode, enabling insights into access for specific user types as well as broader accessibility (see Figure 2.7).

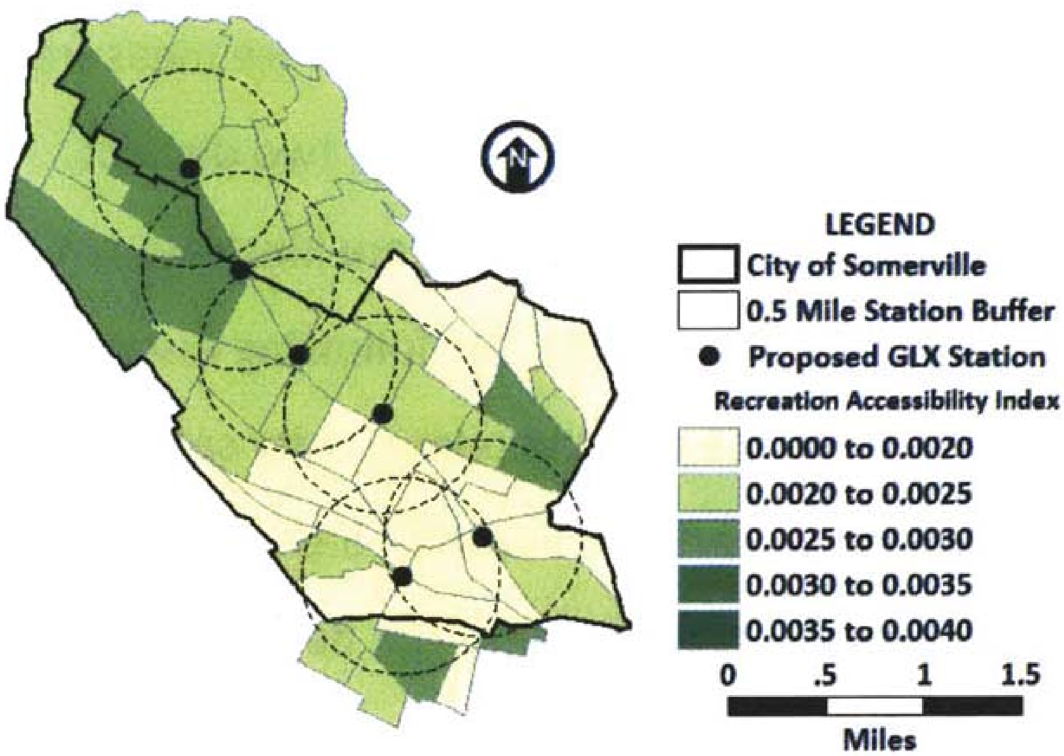

Figure 2.6: Access to recreation opportunities in Somerville, MA (Ducas, 2011)

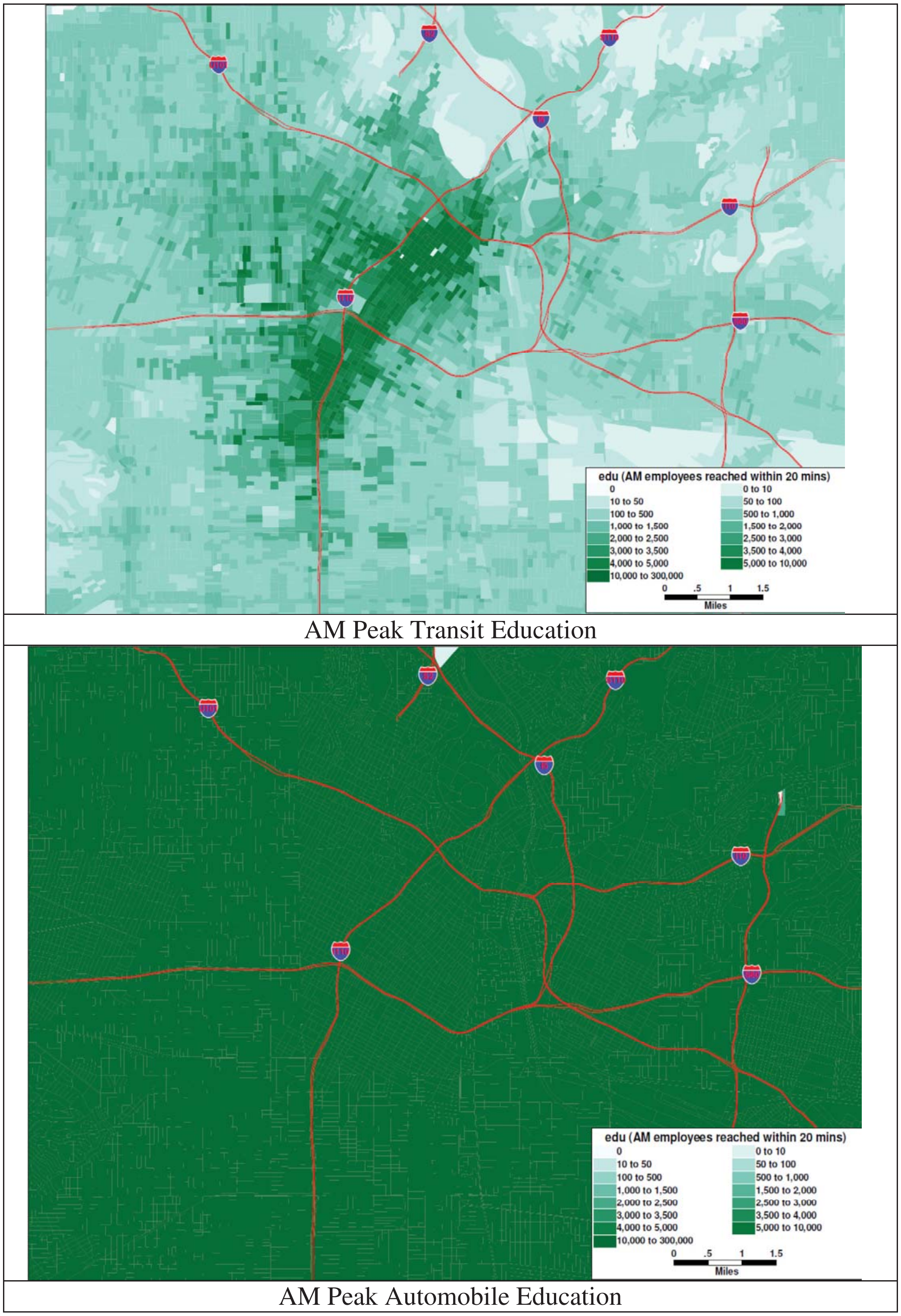

Figure 2.7: Access to education-sector workers by transit and auto in Los Angeles (Goulias et al., 2013)

Páez et al. (2013) developed a web-based tool that uses home-based trips from a household travel survey and a business location dataset to display personalized access maps for the Montreal area (see Figures 2.8 and 2.9). A user creates a profile containing ”age, gender, possession of driver license, income level, main occupation, household type, and mode of travel,” and the tool overlays on a map of relevant businesses a circle representing an access area, based on the average travel distance for that profile in the household travel survey (Páez et al., 2013, p. 108). Their prototype does not yet include transit service or the ability to model the impact of different transit service scenarios on access.

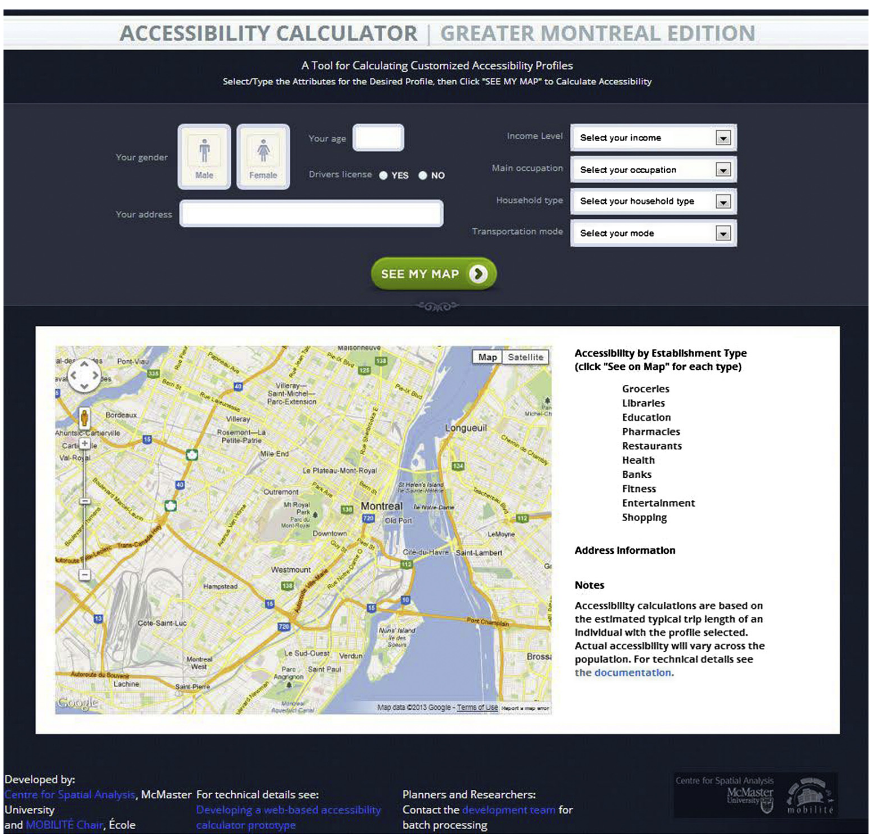

Figure 2.8: Web based calculator (Páez et al., 2013)

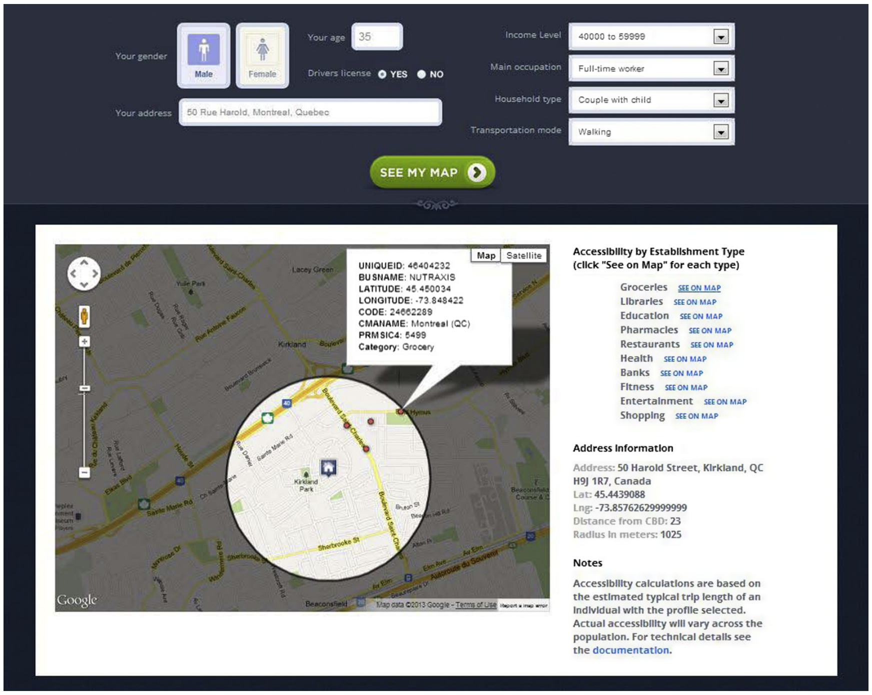

Figure 2.9: Web based calculator (Páez et al., 2013)

2.3.1 Open Trip Planner

Another set of accessibility visualization tools is based on Open Trip Planner, a trip planning and transport analysis suite based on the open data and open-source software philosophy described in Chapter 4. Taking advantage of an Open Trip Planner implementation, the Regional Plan Association developed an online tool that draws on employment locations, transit schedule data, and a mix of auto travel time data, to depict accessibility to employment with extensive options to vary origin location, travel mode, time threshold, industry, and education level (see Figure 2.10). This tool effectively combines the access perspective of an individual traveler with regional transportation and firm location patterns.

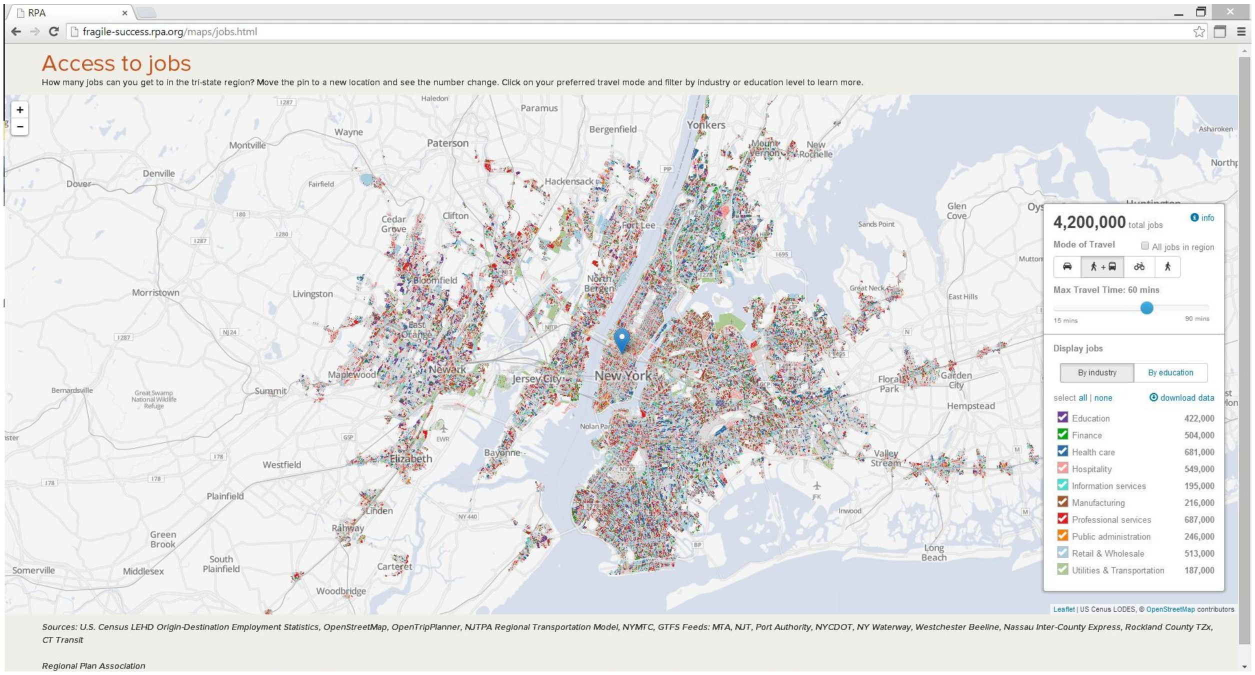

Figure 2.10: Interactive job accessibility mapping tool for the New York region based on Open Trip Planner (Regional Plan Association, 2014)

Owen and Levinson (2014) outline an automated approach to calculating transit accessibility measures that would facilitate the process throughout the United States. Using Open Trip Planner's batch analyst module to process general transit feed specification (GTFS) data (see Chapter 4) and demographics from the Census Bureau, their process for mapping employment accessibility enables rapid approaches to scenario planning (e.g. the employment accessibility impacts of eliminating a bus route – see Figure 2.11). Extensions to this project could include methods to include both transit service for agencies which do not publicly release GTFS data (e.g. most municipal operators in Los Angeles County) and employment figures for states that do not participate in the Census Bureau's LEHD (e.g. Massachusetts).

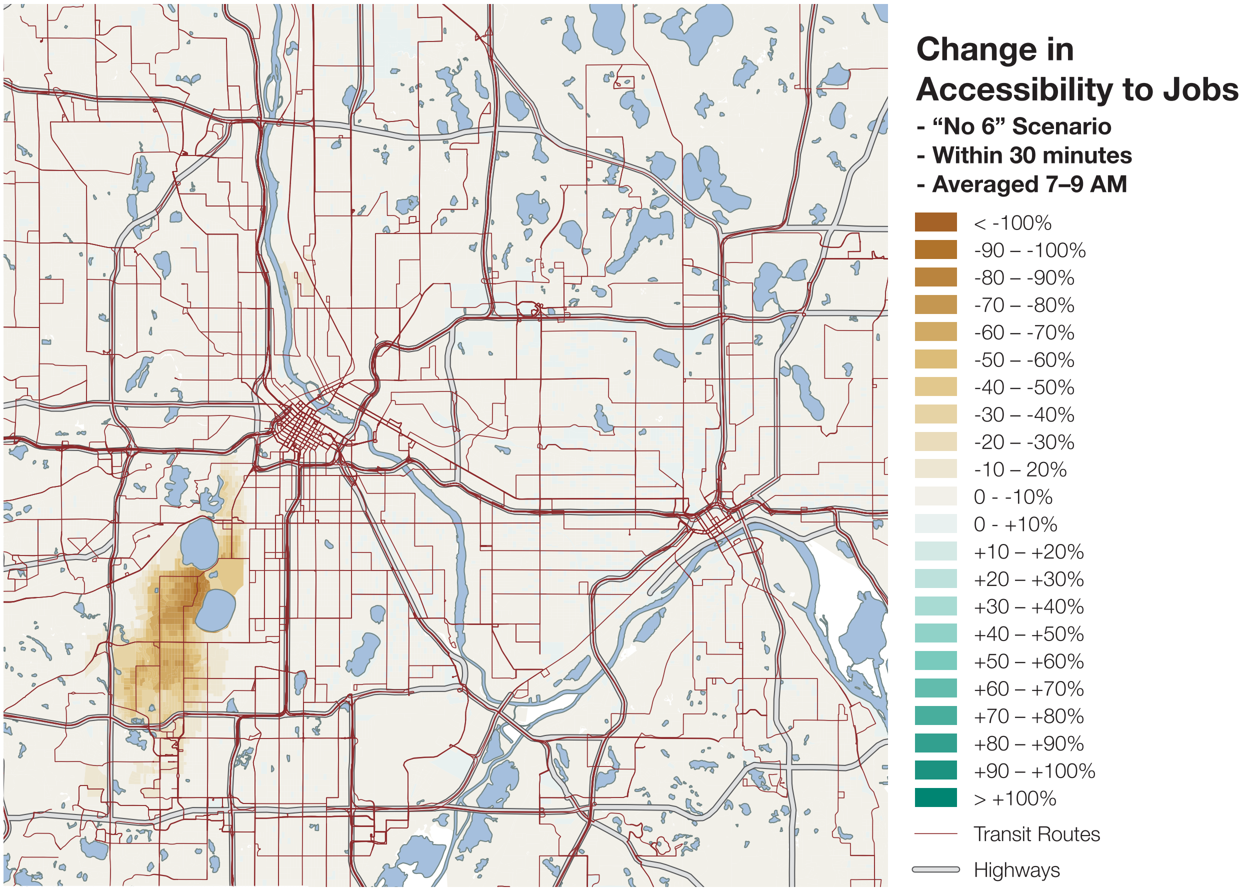

Figure 2.11: Project analysis based on Open Trip Planner (Owen and Levinson, 2014)

These tools clearly represent complex combinations of transport and land use data, but they do not allow for the depiction of attributes of the origin location other than its accessibility score. For example, an uninhabited district of a city might have low accessibility to jobs; the implications of low accessibility for a vacant sector might not be severe, but the fact that the sector is vacant is not depicted through the types of tools listed above, so recognizing it would require contextual knowledge.

Another project using Open Trip Planner, the Open Source Accessibility Toolbox (OSAT), addresses this shortcoming by adding a third dimension to visualizations. In addition to sector color (see Figure 2.12), these tools also represent each sector as a polygon whose extruded height represents an attribute of interest (see Figure 2.13). This attribute could be total population, for example, or populations of interest such as low-income households, households without access to cars, etc. OSAT also has a built-in option to compare the accessibility differences between different modes. Summarizing its features, OSAT's authors explain, "The goal of this new approach is to allow more groups, with some level of software expertise, to conduct accessibility studies using free publicly available data and without expensive software. This opens up such analysis to a much broader array of stakeholders" (https://github.com/Noblis/OSAT).

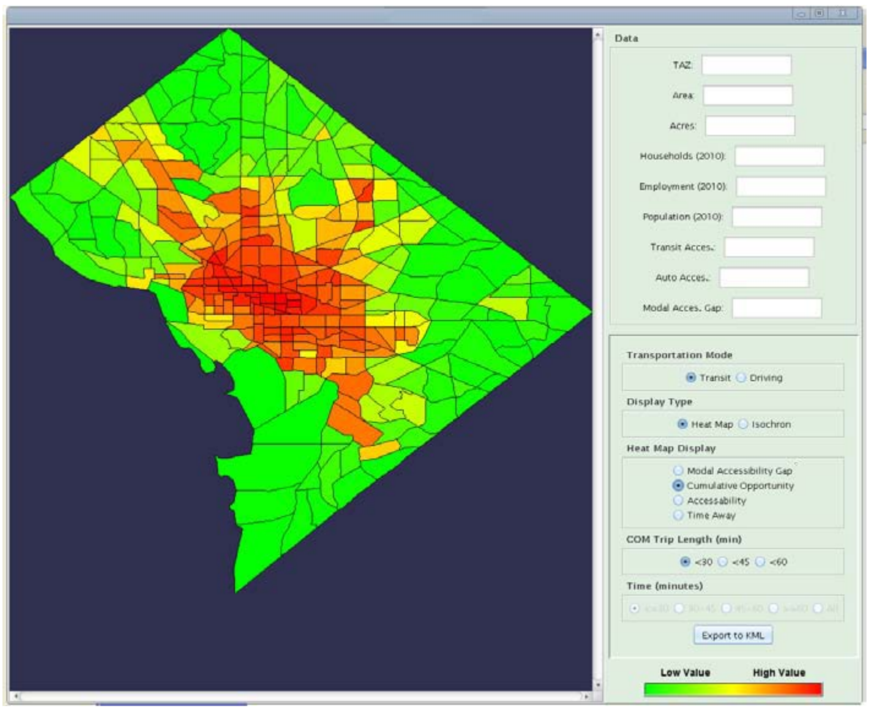

Figure 2.12: Flat OSAT accessibility map for Washington, DC, with display options (McGurrin et al., 2011)

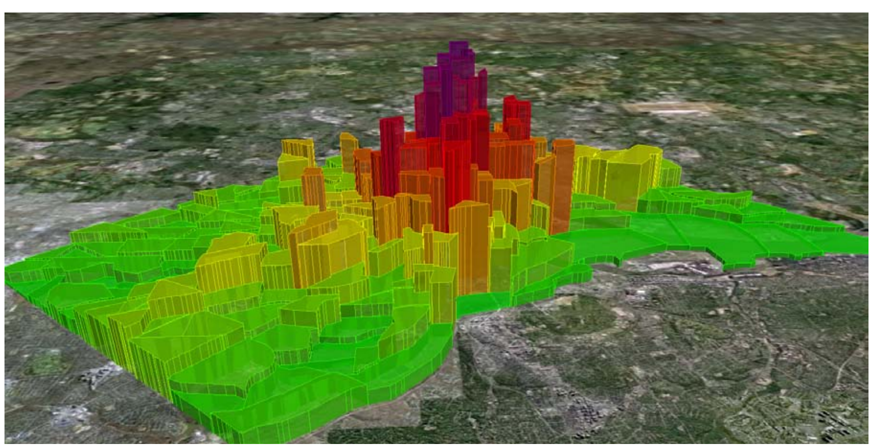

Figure 2.13: 3-D accessibility map representing the number of people (polygon height) who experience each accessibility level (color) (McGurrin et al., 2011)

These tools enable new ways of understanding the complex links between land use and transport. Research is lacking, however, into how to incorporate refined versions of these tools into participation and planning processes (topics considered in Chapters 4 and 6), and few governmental entities have actually adopted accessibility metrics as part of formal decision-making processes.

2.4 Using Accessibility Metrics in Transportation Planning

Highway and transit agencies are generally oriented toward maintenance, state of good repair, safety, and physical facility planning concerns. The focus on these tactical and operational concerns generally outweighs a broader strategic focus on network design and service planning (see Chapter 4 for a discussion of these planning levels). Planning efforts to consider mobility systematically are rare – level of service analyses typically focus on limited corridors and intersections, for example – and accessibility at a regional level is considered even more rarely. The road-building industry, traditionally a strong driver of facility-focused public works projects, has little incentive to advocate for the use of accessibility metrics.

Some metropolitan planning organizations (MPOs) and state departments of transportation have attempted to incorporate some level of accessibility analysis into planning processes, but the accessibility framework has not been consistently adopted for long range transportation planning (Cervero et al., 1995). To analyze the limited attempts that have been made, Handy (2005) proposes an evaluative approach that considers the institution's goals, measures, and strategies. For specific cases, she considers the regional transportation plans of four MPOs in Northern and Central California. Three of the four "do not seem to have articulated for themselves the distinction between planning for accessibility and planning for mobility. The plans do not define these terms, and they do not use them consistently throughout" (Handy, 2005, p. 145). Even though they vaguely cite accessibility as a goal, their strategies reveal a failure to commit to the "notions...that plans can enhance accessibility without increasing mobility and that providing for increased mobility has the potential to reduce accessibility" (Handy, 2005, p. 145-146).

Another example of this confusion between mobility and accessibility can be found in the 2012 Regional Transportation Plan of the Southern California Association of Governments, which combines them into the single goal of "Maximize mobility and accessibility for all people and goods in the region" (Southern California Association of Governments, 2011, p.

13). This combined measure obscures the differences between the two concepts and can lead to the perverse outcomes described previously.

Some transportation agencies do a better job of employing accessibility measures to guide planning. El-Geneidy and Levinson (2006, p. 2) describe the case of the Minnesota Department of Transportation, which "has a mission to: 'Improve access to markets, jobs, goods and services and improve mobility by focusing on priority transportation improvements and investments that help Minnesotans travel safer, smarter and more efficiently' (Minnesota Department of Transportation, 2003). The role of accessibility as a measure of how well MnDOT is reaching its mission is clear." Such explicit adoption of accessibility goal and measures is uncommon among agencies.

Because mobility measures are used more commonly than accessibility measures, and given the biases described in Section 2.1.2, the benefits of transit projects tend to be undervalued relative to road projects in conventional practice. Warade (2007) uses an example project in Chicago to show that such benefits can be substantial, especially when the land use impacts are included in an accessibility analysis. Both Warade (2007) and Ducas (2011) discuss accessibility measures and how they could be used to revise project evaluation for the Federal Transit Administration New Starts funding program.

2.5 Advancing Transportation Equity

Accessibility is a critical concept for achieving not only improved total well-being, but also improved social equity in cities. One of the clearest statements of the fundamental connection between transit, accessibility, and equity comes from Dr. Martin Luther King, Jr., who wrote, "The layout of rapid-transit systems determines the accessibility of jobs to the black community. If transportation systems in American cities could be laid out so as to provide an opportunity for poor people to get meaningful employment, then they could begin to move into the mainstream of American life." (cited in Sanchez (1999, p. 284)). Decades later, however transportation remains divided along racial lines; given the fundamental importance of transportation in facilitating access to opportunities, furthering transportation equity is an important step towards furthering social equity more broadly (Bullard, 2003).

Based on experience in Los Angeles, Carter et al. (2013) propose a definition of transportation equity that consists of three components:

1. Equitable access to quality, affordable transportation options and so employment, services, amenities, and cultural destinations;
2. Shared distribution of the benefits and burdens of transportation systems and investments, such as jobs and pollution, respectively; and
3. Partnership in the planning process that results in shared decision-making and more equitable outcomes for disadvantaged communities while strengthening the entire region.

– Carter et al. (2013, p. 11)

Equitable access and shared benefits are core components of this definition, as is meaningful participation in the planning process (as discussed in Chapter 4).

Despite the long history of calls to include the linked concerns of accessibility and equity in transportation planning, neither of these concerns is meaningfully prioritized in many transportation planning processes or outcomes. Sanchez et al. (2003, p. 10) assert, "Most transportation planners are concerned primarily with the efficiency and cost of transportation, including people's mobility levels and the accessibility of transportation to the most people." In other words, even in the limited cases when accessibility metrics have been adopted as performance indicators, they have been situated in a utilitarian framework that eschews explicit analysis of equity.

2.5.1 Implications of Mobility, Access, and Accessibility for Equity

Mobility-centric planning focuses more closely on system performance than individuals. Nelson (2008, p. 98) argues that, at least in the case of transportation in Portugal, this fact impedes equity: "Policies toward public transportation service provision orient state-owned companies toward mobility (merely providing service) instead of accessibility (providing service for the benefit of users). This represents yet another equity impact on users who are already adversely impacted by a policy bias toward road infrastructure planning and a highly politicized public transportation infrastructure implementation process." More generally, mobility planning neglects the personal and locational components of access and accessibility; a free-flowing highway provides high levels of mobility, but it is unlikely to promote access to opportunities for those without cars or destinations served by the highway.

Accessibility's inclusion of demographic and spatial aspects makes it a better tool for advancing transportation equity. Fan et al. (2012, p. 28) document examples of a transit project inducing "statistically significant gains in accessibility to low-wage jobs [that] stand out from changes in accessibility for the transit system as a whole." Though the congestion reduction and mobility benefits of the project might not be substantial at an aggregate level, it does provide improved access for low-income workers. The inclusion of spatial factors in access and accessibility makes them better suited for analysis of "spatial mismatch" (Sanchez (1999), Zenou and Boccard (2000), Carter et al. (2013), Fol and Gallez (2014)) and environmental justice, a set of issues that had clear equity impacts for lower-income communities of color (Bullard, 2003).

2.5.2 Equity in Theory

A response to the problematic historical pattern of "plans that benefit highly mobile population groups at the expense of the mobility-poor" is to complement the focus on mobility with analyses that reflect equitable personal access and neighborhood accessibility (Fol and Gallez, 2014, p. 66). To do so, they propose three areas of revision to the transportation decision-making process:

> 1. **Defining equity objectives in a comprehensive and effective way** – Our first proposal is to define clearly which equity objectives are being pursued in order to clarify the types of indicators that may be used...
>
> 2. **Combining qualitative and quantitative methods** – ... While the use of quantitative data seems essential when measuring accessibility, qualitative approaches are necessary to understand the real experience of deprived groups or individuals
>
> 3. **Basing transport planning on the principle of needs** – Following Martens (2006), we state that given the importance of mobility and accessibility, transport-modeling approaches – which are implicitly based on the distributive principle of demand – should be based on the principle of need.
>
> – Fol and Gallez (2014, pp. 69-70)

These recommendations echo the priorities of Carter et al. (2013) and explicitly call for a quantitative and qualitative understanding of accessibility. Fol and Gallez (2014, p. 76) also stress Carter et al. (2013)'s emphasis on procedural equity, making the overarching recommendation for "Encouraging community participation in the planning process."

To reduce the gap in "access levels between the most and least mobile," Martens et al. (2012, p. 690) develop the theoretical foundation of principles for the "just distribution of transport investments and services":

> 1. The gap between the areas or neighborhoods with the lowest and the highest level of [accessibility] should remain within a predefined range (space-related or inter-neighborhood equity)
> 2. The gap between car-owning and car-less households residing in the same area or neighborhood should remain within a predefined range (mode-related or intra-neighborhood equity), while
> 3. Aiming to achieve the highest possible average access level across neighborhoods and mode-related groups.
>
> – Martens et al. (2012, p. 689)

They argue that MPOs and agencies have generally ignored these important principles. To rectify conventional practice, they propose an approach that will "guarantee that access is maximized, while ensuring that an acceptable level of access is ensured for all population groups, irrespective of location" Martens et al. (2012, p. 688). Their approach is especially salient because it provides strong links between emerging methodologies for calculating accessibility metrics and a normative framework within which to use such metrics.

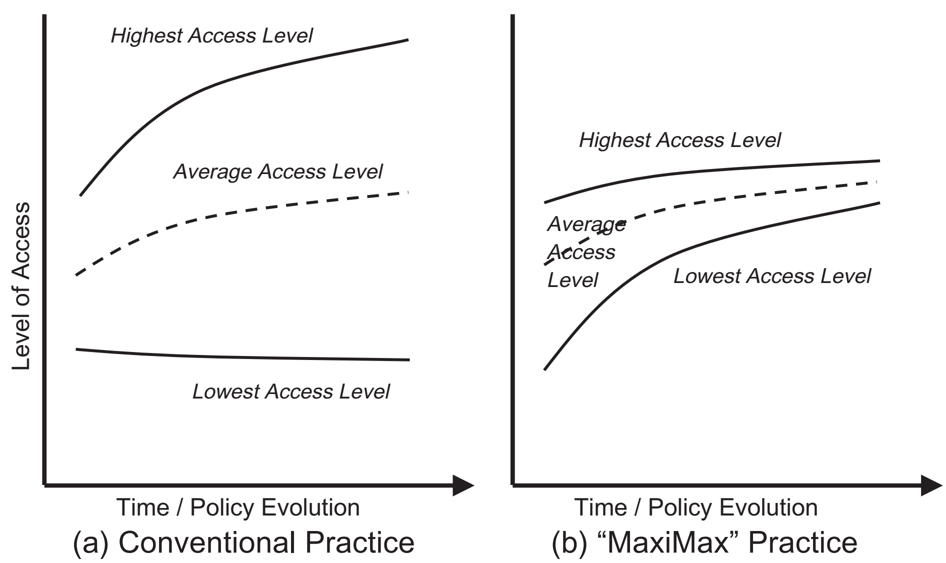

Figure 2.14: MaxiMax approach reduces (Martens et al., 2012)

2.5.3 Equity in Practice

Community-based advocacy groups like the Bus Riders Union in Los Angeles and the T Riders Union in Boston, as well as national think tanks and policy groups, have made practical advances for the equity agenda in recent decades (Bullard et al., 2004). Growing out of "a merging of civil rights and environmental justice efforts," the transportation equity movement has pioneered a number of "promising practices" that are relevant to the work at hand (Raya and Rubin, 2006, p.3), including:

> - **Revise transportation planning models and metrics.** Local transportation systems are often designed to maximize the speed and efficiency of car travel, at the expense of other modes of travel...But low-income and disadvantaged populations have lower auto ownership rates than other groups, so they bear the brunt of poorly designed alternative modes...
> - **Envision the entire region in your planning**...
> - **Attract more transit riders and increase system efficiencies.**...By creating dedicated bus lanes, fewer stops, and priority at traffic signals, the Los Angeles Metropolitan Authority has been able to reduce passenger travel times by 29 percent and increase ridership by 40 percent [in pilot Metro Rapid corridors]...
> - **Foster local activism and coalitions.** In Massachusetts, during the development of the state's 25-year transportation plan, which will direct billions in transportation funding, a coalition of more than 20 community-based organizations, the "Action for Regional Equity Alliance," appealed to the state in 2004 for a more open and equity-focused transportation planning process: for broader public participation mechanisms, longer comment periods, a citizen advisory board, and other improvements
>
> –Raya and Rubin (2006, pp. 6-10)

The connections to accessibility in these practical equity guidelines are clear. Horner and Mefford (2005) reiterate the importance of transit accessibility for equity goals. Their wide-scale "analysis of bus transportation in Austin, Texas demonstrated divergence in the levels of [access] people experienced...Minority residents in this study area may be underserved by the transit system" (p. 211). While these findings are not necessarily generalizable to other cities, the "work has implications for broader accessibility issues," and "conditions of accessibility, especially in minority and low-income neighborhoods, require greater attention and resources" (Horner and Mefford, 2005, p. 211) At a much more detailed level of analysis, Ferguson et al. (2012) demonstrate an equity-driven approach to determining the frequency of bus service.

The design of transit systems across scales, from the bus stop to route service levels to the structure of the entire route network, impacts equity. Accessibility, which also takes these different scales into account, is therefore an important tool for analyzing equity. As Fol and Gallez (2014, p. 77) conclude, “The multidimensional and complex nature of the concept of [access] explains both its capacity to enrich reflection on the social aspects of spatial exclusion, and the difficulties encountered when using it operationally... Accessibility is a component of social justice, and as a precondition for social inclusion it is part of the ‘right to the city’.”

Shifting the frame of public debate from the mobility means of a transportation system to access ends naturally opens broader questions of purpose and values. When a discussion moves from the operational efficiency of a highway or transit line to access to jobs and healthcare, the human impacts of transportation planning are pushed to the forefront. The personal access lens creates an opening for new forms of knowledge, experience, and participation to be included in decision-making (see Chapter 4), which may have positive ramifications for equity.

2.6 Extending Accessibility Metrics

Accessibility metrics amount to a potentially powerful tool for understanding how a city functions. These metrics, especially when supported by visualization tools, have the potential to encompass varying urban subsystems, scales, and user priorities. Within the accessibility framework, various extensions and refinements could foster the wider adoption and impact of metrics, making them more powerful.

The capital investment dominance of transportation planning has led to lack of visibility and public participation in service planning, and lack of a systematic link between service planning and capital planning (see Chapter 4). But access and accessibility are partly functions of service planning outcomes like frequency, capacity, and convenience of service, including intermodal and first-mile/last-mile connectivity. For maximum effectiveness, accessibility metrics should be combined with an emphasis on service planning, and equitable service planning should be a driver of capital investment planning.

Most of the applications cataloged above use schedules or model estimates for travel times. With the growing prevalence of vehicle tracking and sensing technologies, calculations of accessibility can be extended to reflect actual levels of service. Extensions of this nature would account not only for vehicular congestion on roadways, but could also incorporate the effects of transit congestion on riders. An example is lengthened waiting times and correspondingly decreased accessibility experienced when buses are bunched together. Basing accessibility on scheduled, rather than operated service, may bias results by overestimating levels of service and accessibility in core areas with relatively high traffic congestion and transit crowding. Since such areas might tend to be inner-city areas with lower income residents, this bias could be especially undesirable from an equity standpoint. These concerns are somewhat less prevalent for reliable dedicated-guideway transit service; but for bus service, they are often central.

Chapter 3

Incremental Bus Rapid Transit

BRT generally refers to urban bus service enhanced by transit priority and passenger amenity elements (See Table 3.1). Compared to fixed-guideway rail rapid transit with high capital expenses, bus transit tends to be more flexible and fall along a spectrum of service. Enhancements are often phased, with incremental upgrades of a given corridor across time, or the incremental development of a network with phased corridors across a city. Given this tendency towards incremental development, defining BRT is difficult. Especially when a subset of BRT elements are employed, and when projects are phased over time, these projects have faced challenges in responding to varying local conditions and sustaining political will.

Since being popularized by pioneering "surface metro" systems in Curitiba, Brazil and Bogotá, Colombia, BRT has spread across the globe. More than 300 corridors of enhanced bus or bus rapid transit, totaling over 4000 km, are now found in over 150 countries around the world (See Figure 3.1). A majority of these cities have inaugurated service in the first decade of the 21st century (See Figure 3.2), inspired in part by former mayors of Curitiba and Bogotá, Jaime Lerner and Enrique Peñalosa, respectively.

Table 3.1: BRT Elements

Category	Element
Running ways	Bus lane or busway
	Physical separation
	Enforcement
Intersections	Grade Separation
	Signal Pre-emption
	Signal Priority
	Queue Jump Lanes
Stops/Stations	Fare Prepayment
	All-door boarding
	Passenger Amenities
	Level boarding
	Wider spacing between stops
Service	High frequency
	Branding and marketing
	Active monitoring and control
	Real-time passenger information

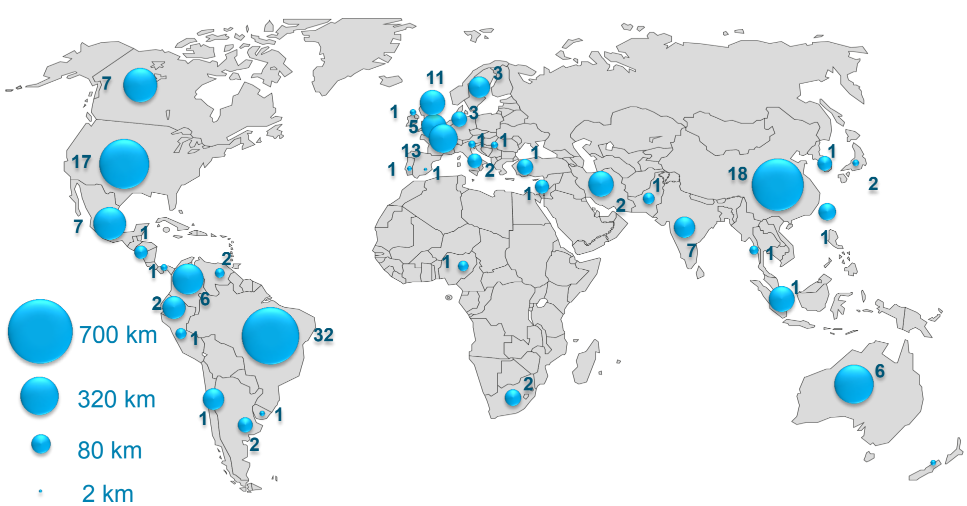

Figure 3.1: Number of corridors and total corridor length by country (Embarq and brtdata.org)

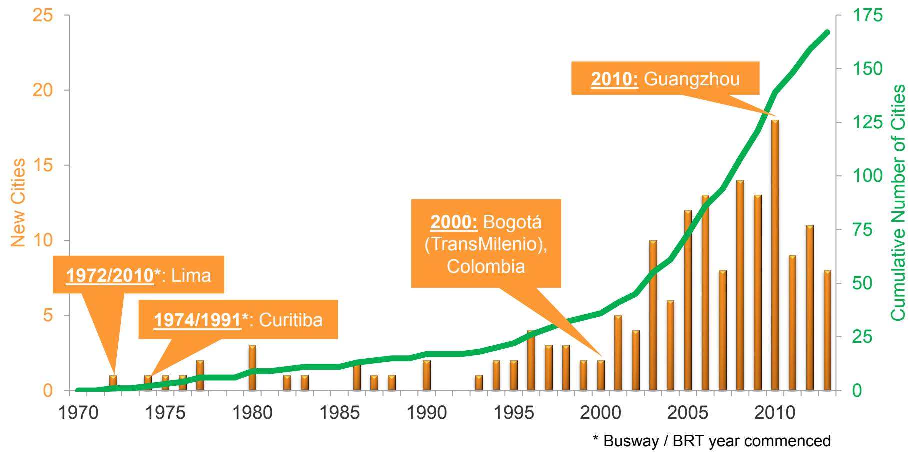

Figure 3.2: Annual inaugurations and cumulative number of BRT and busway systems worldwide (Embarq and brtdata.org)

Especially in cities without highly developed formal transit networks, BRT has the potential to be a disruptive technology. It is a relatively low-cost investment that can drastically alter transportation in a city, not only in its physical manifestation, but also in terms of governance and institutionality. Projects in places as diverse as the United States, Mexico, Chile, South Africa, and India have seen as their primary challenges not questions of transportation engineering, but planning, phasing, and relations with incumbent operators (Schalekamp and Behrens (2010), Flores (2013)).

3.1 Definitions

Early definitions of bus rapid transit stressed system integration and dedicated transit lanes, exemplified by the "surface metro" bus system in Curitiba, Brazil: "The major components of BRT are planned with the objective of improving the key attributes of speed, reliability, and identity. Collectively, as an integrated package, they form a complete rapid-transit system" (TRB, 2001). TCRP 90 (2003b, p. S-1) modifies earlier definitions by specifying "a flexible, rubber-tired form of rapid transit that combines stations, vehicles, services, running ways, and ITS elements into an integrated system with a strong identity." In 2002, the US Department of Transportation's Federal Transit Administration vaguely defined BRT as "a combination of facility, systems, and vehicle investments that convert conventional bus services into a fixed-facility transit service, greatly increasing their efficiency and effectiveness to the end user" (FTA, 2002).

A more concise and widely agreed upon definition of bus rapid transit is elusive. It is clear from these diverse definitions, and from the increasingly wide range of contexts in which BRT is implemented, that BRT is less a well-defined mode than a collection of tools to provide a spectrum of improved bus service. Bus rapid transit corridors consist of combinations of various design elements related to running ways, intersections, stations, and service, as summarized in Table 3.1.

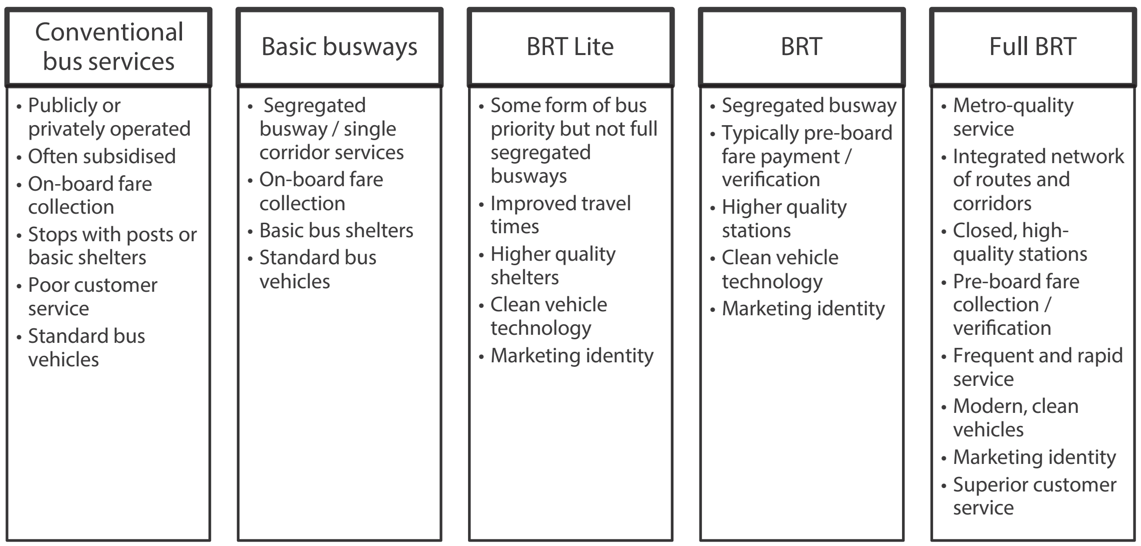

Figure 3.3: Spectrum of bus services (adapted from Wright and Hook (2007) in Boncompte and Galilea (2013))

This flexibility has led to efforts to characterize BRT within a broader spectrum of bus services (see Figure 3.3) as well as different sets of terminology to describe this spectrum, including hybrid BRT, rapid buses, low-level BRT, and high-level BRT (Kline and Forbes, 2012); bus semi-rapid transit (Vuchic, 2002); and incremental BRT (Niles and Callaghan, 2010), among others. The latter will be used here to describe systems and corridors that are evolving towards integrated networks of full-featured BRT.

On one hand, incrementalism can be a major advantage of BRT. In contrast to capital-intensive heavy rail systems, BRT corridors can be developed incrementally and improved iteratively. As Niles and Callaghan (2010, p. 51) assert, "BRT is ... a bundle of characteristics subject to implementation in many combinations, with additional variations possible in the speed of rollout. The incremental character is a fundamental strength: It allows geographic (where), temporal (when), qualitative (what), and sequential (how) flexibility in implementation to match agency goals and constraints." TCRP 90 (2003a, p. S-7) cites incremental implementation of BRT as an "opportunity to demonstrate BRT's potential benefits to riders, decision makers, and the general public, while still enabling system expansion and possible upgrading." Rodriguez (2003) concurs regarding the appropriateness of incremental BRT, especially in settings with limited financing and political acceptance.

On the other hand, this flexibility creates a number of liabilities and challenges related to system and service planning. In particular, some BRT advocates argue that labeling such a wide range of projects as BRT will dilute the mode's image and undermine support for future projects (ITDP, 2013).

Additionally, project proponents might implement only the most expedient features, even if other combinations of features could provide more substantial benefits. An early report cautioned, "A successful BRT project...requires the entire range of rapid-transit elements and the development of a unique system image and identity...Corners should not be cut merely to reduce costs" (TCRP 90, 2003a, p. 8). Yet many projects with lofty promises based on BRT's "rapid transit" image end up cutting the corridor elements required for improved service and falling short of those promises.

When viewed through an accessibility lens, improving bus frequency and reliability through select tactical elements might be more preferable than upgrading already well-performing bus lines to "full BRT." In any case, accessibility metrics should allow more transparency in the decision-making about how to improve bus service.

Specific BRT elements, and research into their impact on travel times, are described below.

3.2 Improved Mobility through BRT Upgrades

One of the strongest potential arguments in favor of BRT over higher-speed, higher-capacity heavy rail is that for a given amount of capital investment, a much broader area of the city can benefit from mobility and accessibility gains facilitated by BRT elements. Research and popular attention on BRT has revolved largely around the benefits of these tactical corridor elements, such as signal priority, dedicated lanes, and stop infrastructure. Understanding the performance impact of these elements is an important step towards understanding the potential for BRT to influence accessibility.

3.2.1 BRT Corridor Design Elements

Chapter 4 of TCRP 118 (2007), "Component Features, Costs, and Impacts," details different options for running ways, stations, vehicles, service, and branding. TCRP 118 (2007) also suggest the following "typical effects" on running time of BRT elements:

Table 3.2: Typical Effects of BRT Running Way Components

	Component	Estimated Effects	Savings Compared to Base
Off-street	Elevated	64 kph, 0.9 min/km	2.8 min/km
	Some grade separation	56 kph, 1.1 min/km	2.7 min/km
	At-grade	40 mph, 1.6 min/km	2.3 min/km
On-street	Median arterial busway	21 kph, 2.8 min/km	0.9 min/km
	Bus lane	20 kph, 3.1 min/km	0.7 min/km
Traffic treatments	Queue bypass		6 sec/int
	Curb extension		4 sec/int
	Transit Signal Priority		5 sec/int

(TCRP 118, 2007, p. 5-6)

ITDP's BRT Standard discusses these elements and uses them to suggest a scoring system for BRT corridors (ITDP, 2013). Multiple studies have documented the corridor performance impacts of these individual BRT elements in greater detail. Agrawal et al. (2012) describe different design and management approaches for bus-only lanes in London, Los Angeles, New York, Paris, San Francisco, Seoul, Sydney. Similarly, Liao (2012) quantifies the travel-time benefits of traffic signal priority for a route in Minneapolis. Determining the impact of stop treatments such as level boarding and fare prepayment on dwell times is relatively straightforward, and a summary of estimates for these impacts is available in TCRP 100 (2003)).

Other studies focus on specific BRT projects with combinations of elements. Recent examples include evaluation reports of the Los Angeles Orange Line (National Bus Rapid Transit Institute, 2011) and New York's Select Bus Service (Barr et al. (2010) and Barr et al. (2012)). Such evaluations describe in detail infrastructure and service improvements and subsequent performance and ridership gains.

While travel time benefits have been reported for many BRT projects, the reliability benefits have been reported less consistently. Some evidence suggests that these benefits can be substantial. For example, "Schedule adherence as measured by variability in bus travel times and arrival times at stops improves significantly with transit signal priority (TSP) application. In Seattle, along the Rainier Avenue corridor, bus travel time variability was reduced by 35%. In Portland, OR, TriMet avoided adding one more bus to a corridor by using TSP and experienced up to a 19% reduction in travel time variability. In Vancouver, the travel time variability decreased about 40%" (TCRP 118, 2007, p. 4-32).

To distill these complex interactions into a clearer understanding of performance and accessibility gains that may arise through reduced travel times, attempts at modeling BRT operations have been undertaken.

Empirical models include Vincent et al. (2010), which relies on agencies' survey responses about 119 routes in the United States to estimate a running time model. The candidate independent variables are station density, presence of dedicated bus lanes, use of low floor buses, presence of queue jump lanes, total weekday boardings, number of doors used for boarding, transit signal priority density, headway, and route length. The model is estimated for both AM Peak, PM Peak, and Combined Peak periods. Separate models are also estimated with and without the Los Angeles routes because of particularities with these routes' signal priority systems.

As expected, station density and route length have significant positive impacts on running time. Similarly, the significant positive coefficients for low and no dedicated bus lanes suggest that corridors without extensive dedicated lanes will have services with higher running times.

Analytical models also provide insight into the links between corridor design and performance. As part of her analysis of the relative effectiveness of BRT elements, Rodriguez (2003) employs deterministic models for running time and waiting time. Applying this analysis to a corridor in Chicago, she recommends a phased implementation approach, with increases in stop spacing, signal priority, and preferential lanes in the short term, and off-board fare collection in the long term.

A third class of models includes simulations of BRT operations. Bayle (2012) uses microsimulation to investigate the effect of running ways, stations, vehicles, fare collection, ITS technologies, and service and operating plans on a BRT corridor in Sydney. Notable results include an estimated 5.7% increase in speed for public transit at the expense of 16.8% increase in driving time for other users.

While transit agencies will likely be interested in these tactical performance improvements in themselves, the ultimate goals for sustainable transit should be increased ridership and accessibility (as argued in Chapter 2). Documented links between BRT elements and these broader benefits are more tenuous. Better understanding and communication of how these elements translate into broader accessibility gains could inform advocacy groups' efforts to improve service from an access perspective while at the same time building their membership base.

3.3 Improved Accessibility through Land Use

Bus rapid transit can serve as a catalyst for new transit-oriented development (TOD). Improved accessibility at a given location increases land values, since people will be willing to pay more to use that location, up to the amount of reduction in travel expenses. Land values around new transit may also increase due to improved productivity and agglomeration benefits (Chatman and Noland, 2013). The increased land values in turn tend to produce denser development; when this development is well integrated with urban design and policy, the resulting mixed-use, walkable development is successful TOD. The role rail systems play in encouraging denser, mixed-used development has been well-documented (Arrington and Cervero, 2008), and emerging evidence suggests that BRT can also catalyze such development. Densification and land use changes can increase accessibility per unit mobility. In short, through TOD, well-planned BRT corridors can create accessibility improvements that go far beyond the improved mobility that comes from reduced travel times.

Studies of Bogotá's TransMilenio system have found BRT station access premiums are capitalized in residential property values. Rodriguez and Mojica (2009) consider the network effects of BRT extension and find that "access to BRT implies 13-15% premium for residential properties." Rodríguez and Targa (2004), however, note that network effects in Bogotá are not strong and could be offset by proximity to the corridor and, presumably, the associated noise and pollution. In Seoul, Cervero and Kang (2011) find a premium for residential property values of 5-10% within 300 meters of BRT stop and premium for non-residential property values of 3-26% within 150 meters of BRT stop.

Anecdotal evidence suggests that developers' interest in bus systems in the United States is strong. In interviews with developers in Minnesota, Fan and Guthrie (2013) find that the flexibility of bus systems is sometimes favored over LRT in part because "employers focus more on current transit options in site selection than on proposed future options."

In Oregon, Nelson et al. (2013) find "the Eugene-Springfield market responded...quickly to the EmX BRT system" and go on to generalize that "even in the cities with a relatively low level of infrastructure, BRT is viewed as permanent when there is a clear long-term commitment by the transit agency." In a study of Boston's Silver Line Washington Street corridor, Perk et al. (2013) estimated the residential property value premium attributable to the new corridor was up to 7.6%. Some of this premium may reflect streetscape and urban design improvements in addition to mobility improvements. Evidence from these diverse contexts suggests that BRT can in fact drive the capitalization of accessibility improvements required for successful transit-oriented development.

In short, the construction of a BRT corridor can spark transit-oriented development through the capitalization of accessibility benefits. When comprehensive policy packages are implemented to support transit-oriented development around a corridor, the wider economic impacts can be substantial. The self-reinforcing dynamics of these wider economic benefits may even reach a point where the capacity of a heavy rail line is required. The increasingly recognized power of BRT to catalyze redevelopment helps explain its rapid global proliferation.

3.4 Case Studies - Challenges of Planning

Cities employ two general tracks to developing BRT. Some have focused initially on a limited number of new dedicated corridors that can eventually be expanded to a network, while others have focused on upgrading a wider existing network of bus routes through limited forms of transit priority. Both tracks involve shared planning challenges, as discussed in the case studies below.

3.4.1 Bogotá: Corridors to Network

Bogotá's Transmilenio is a paragon of BRT. The system "has achieved enormous success in terms of efficiency and ridership with a limited infrastructure and operational cost" (Bocarejo et al., 2013, p. 78). The first corridor, on Avenida Caracas, was opened in December 2000, with a daily ridership of 14,000; by the completion of the second phase in 2007, average daily ridership of the system had grown by a factor of 100, and in 2011 it reached 1.7 million (Hidalgo et al., 2013). In 2013, a third phase consisting of two corridors and integrated local, non-BRT service was inaugurated, but this phase has encountered significant organizational and institutional hurdles. These difficulties reflect the challenges replicating a model of closed, high-capacity corridors widely throughout the city.

The first two phases of Transmilenio were, in some respects, a revolutionary intervention. Space in wide, auto-dominated avenues was taken for public transit, allowing for the construction of high-capacity transit corridors capable of moving more than 40,000 passengers per direction per hour. At the same time, special attention was paid to streetscape design and options for non-motorized transportation (see Figure 3.4). These initial phases had 114 stations, and 663 km of routes, as shown in Figure 3.5.

Figure 3.4: Transmilenio buses leaving Las Aguas terminal on the Eje Ambiental

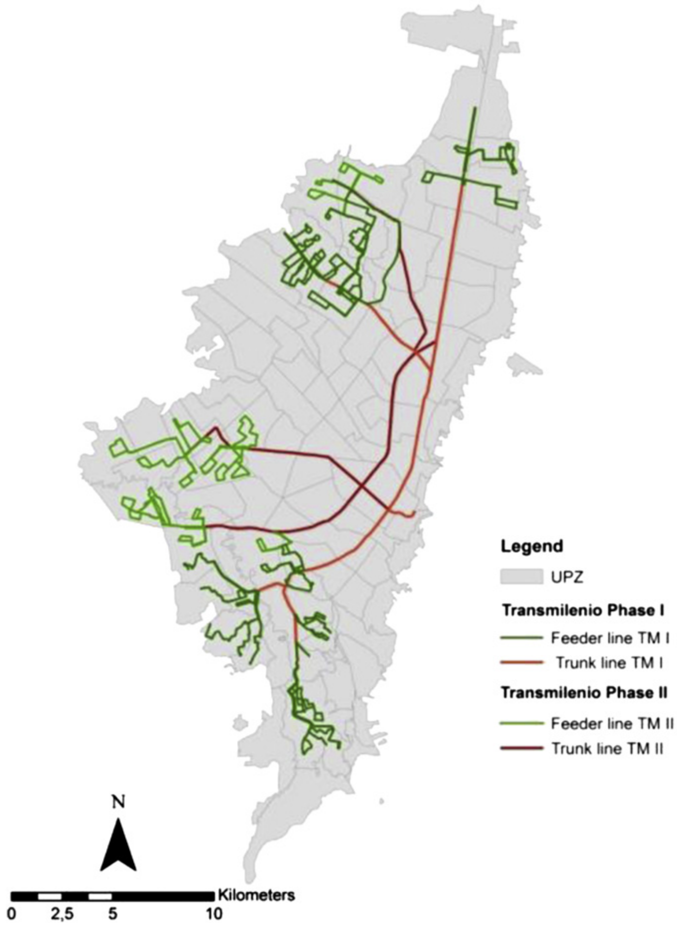

Figure 3.5: Phases I and II of Transmilenio

In a city the size of Bogotá, however, these initial phases did not serve a majority of transit trips, let alone all trips. In 2010, nearly three quarters of transit trips in Bogotá were still made with the pre-existing informal bus system that provided much broader coverage than the special dedicated BRT infrastructure. Phase III was conceived of as a way to bring more riders into the integrated system, not only through two new corridors and the system's first downtown interchange depot, but also through integrating the previously loosely regulated, atomized owners into a unified system called SITP.

Phase III faced a new set of challenges that delayed its inauguration and frustrated riders. Progress on approving and building the new corridors was halting, especially as discussions of a long-planned Metro system led some to question the value of BRT. Phasing for the Airport and Carrera 10 corridors was not ideal, with the seventeen new stations and two new corridors basically unused, or used by other traffic (see Figure 3.8), for an extended period of time before full service began in 2013. Even when service started, the need for a separate farecard belied the promises of a fully integrated system. Further delays have arisen as SITP attempts to incorporate atomized operators into a formal network that complements Transmilenio. This integration was initially planned to begin in 2011, but was not actually launched until a year later. Kash and Hidalgo (2014, p. 107) identify “awareness, expectations, and aspiration gaps between transit users and planners, as well as equity concerns” that may exacerbate these integration delays, and they suggest that better public participation approaches could mitigate these gaps.

Figure 3.6: SITP bus in Bogotá

Figure 3.7: Limited service on Carrera 10 during preliminary operations of Transmilenio Phase III

Figure 3.8: Private vehicles using the Phase III bus lanes

Participatory tools for understanding accessibility could help address some of the challenges that the effort to expand Transmilenio has encountered. While the attention paid to streetscape and urban design around corridors has been beneficial in Bogotá, it could be complemented by accessibility measures that might quantify and help communicate the broader benefits of corridors as they are replicated to create a network. In short, the growing pains of this BRT exemplar support the need for improved participatory processes and understanding of regional project benefits.

3.4.2 Los Angeles: Network and Corridors

Los Angeles County Metro inaugurated the Metro Rapid bus network in 2000 and the Orange Line, an exclusive busway corridor, in 2006. In 2010, freeway express routes along two corridors were consolidated into a new incremental BRT service, the Silver Line. Unlike the

Bogotá case, in Los Angeles, these rapid bus and BRT corridor efforts were largely separate projects.

Metro Rapid

While proposals from as early as 1948 called for a countywide bus rapid transit system (see Figure 3.9), experience with incremental BRT projects in Los Angeles did not begin in earnest until the June 2000 inauguration of the Metro Rapid Demonstration Program's two corridors, Wilshire/Whittier and Ventura Boulevards.

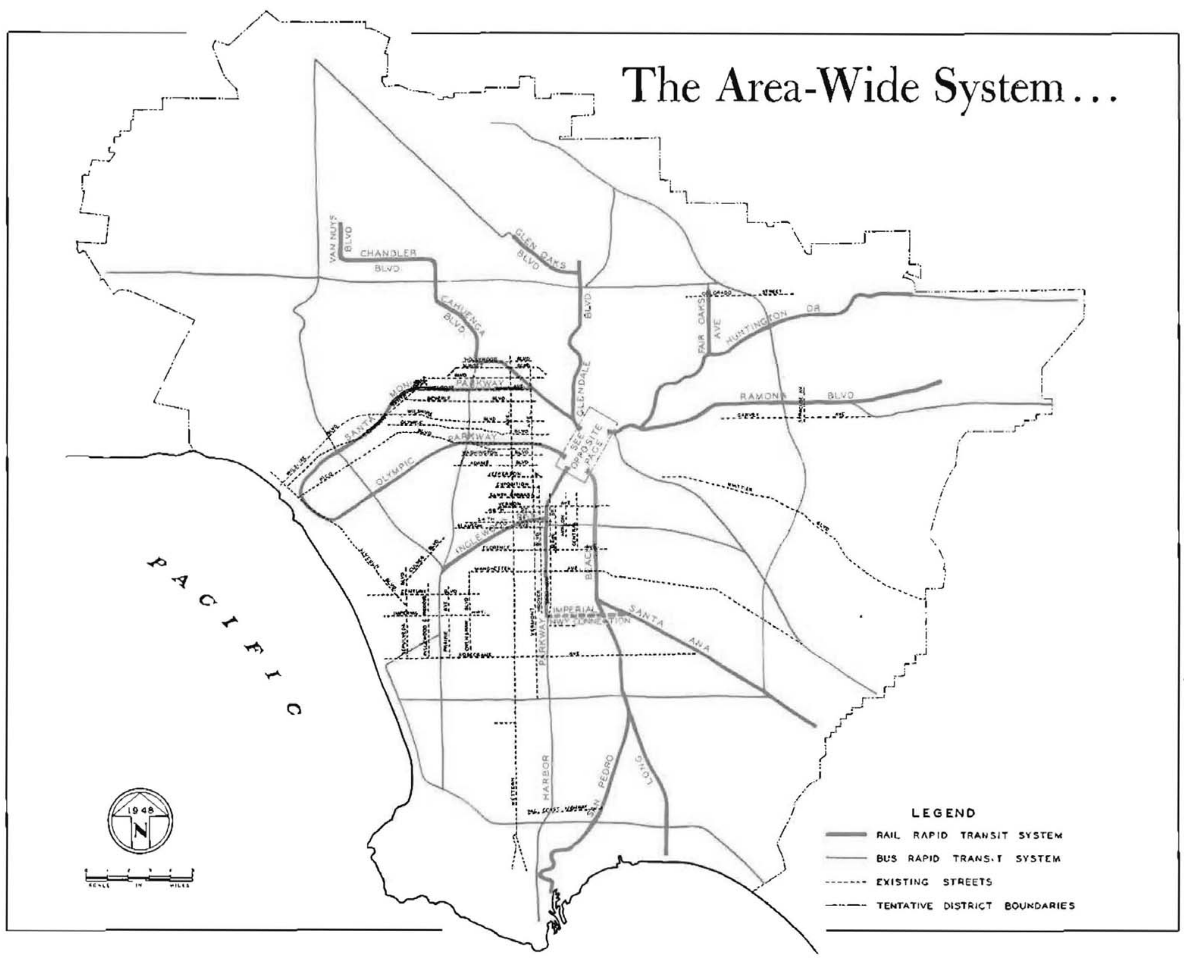

Figure 3.9: 1948 "area-wide system" proposal that includes a "bus rapid transit" for Los Angeles

These Metro Rapid lines were designed as limited stop overlay services with improved stops, active signal priority, headway-based schedules, and a distinct brand. When approving these projects, the Metro Board of Directors explicitly endorsed the notion of incrementalism, suggesting that future phases could make the system in Los Angeles approach Curitiba's full BRT (see Figure 3.10).

CURITIBA KEY ATTRIBUTES	Metro Rapid Phase I Demonstration	Metro Rapid Phase II Expanded System
1. Simple Route Layout	Yes	Yes
2. Frequent Service	Yes	Yes
3. Headway-based Schedules	Yes	Yes
4. Less Frequent Stops	Yes	Yes
5. Level Boarding and Alighting	Yes	Yes
6. Color-coded Buses and Stations	Yes	Yes
7. Bus Signal Priority	Yes	Yes
8. Exclusive Lanes	No	Yes
9. Higher Capacity Buses	No	Yes
10. Multiple Door Boarding & Alighting	No	Yes
11. Off-Vehicle Fare Payment	No	Yes
12. Feeder Network	No	Yes
13. Coordinated Land Use Planning	No	Yes

Figure 3.10: Planning Metro Rapid as a first step towards Curitiba-style full BRT (LACMTA, 2002)

LACMTA (2002) details early results of this demonstration phase. Active signal priority and increased spacing between stops improved commercial speeds by up to 29% in the case of the Wilshire corridor, and the Rapid brand was well-received by passengers. Ridership increased by 42% with only a 22% increase in revenue hours for Wilshire, and by 27% with an 81% increase in revenue hours for Ventura. The productivity increases on the Wilshire corridor were enabled partly by the improved reliability stemming from the signal priority system. TCRP 118 (2007) estimated these operating savings to be $3.3 million annually, translating to a benefit-to-cost ratio in excess of 11:1.

The evaluation of the Demonstration Program recommended building on its success: "Together with the introduction of the additional Curitiba model attributes, expansion of the Metro Rapid network is appropriate" (LACMTA, 2002, p. 16). While the network was expanded, the additional "Curitiba model" BRT features were not added.

Signal priority has improved travel time and reliability, but the lack of other BRT features has limited these improvements. The 720 Rapid takes up to 2.2 times longer to traverse its route during peak hours as compared to an uncongested base running time, indicating how limited transit priority is (see Table 3.3). Visualizing the accessibility implications of this difference in travel time could help make the case for substantial improvements in transit priority.

Instead of improving on the initial corridors, LA Metro prioritized the extension of the rapid network brand in subsequent phases (see Figure 3.11). The lack of improvement, coupled with expansion to corridors with lower frequencies, diluted the Rapid identity. On the other hand, this approach allowed for improvements to be made flexibly and experimentally across the network. Rapid routes that do not meet ridership (such as the 920 Rapid Express on Wilshire) or average trip length criteria have been eliminated and resources reallocated to other bus routes.

Figure 3.11: The Metro Rapid network on a map of frequent service (LA Metro)

Table 3.3: Running Time Performance Indicators for Selected Los Angeles Metro Service

Corridor	Route	Ratio of peak to off-peak running time
Wilshire-Whittier	720	2.2
Vermont	204	1.9
Vermont	754	1.6
Orange Line	901	1.2
Silver Line	910	1.3

Orange Line

Callaghan and Vincent (2007) and Flynn et al. (2011) provided detailed evaluations of the Orange Line corridor in Los Angeles' San Fernando Valley. Planning for fixed guideway service along this former Southern Pacific Railroad corridor began in the mid-1980s, but local opposition to rail alternatives prevented progress until a BRT alternative was proposed in the 1990s. Though the right of way had been owned by the Southern Pacific, Pacific Electric operated interurban service along the tracks to Van Nuys Boulevard then continued west on separate tracks one mile to the north. Interurban commuter service ran until 1952.

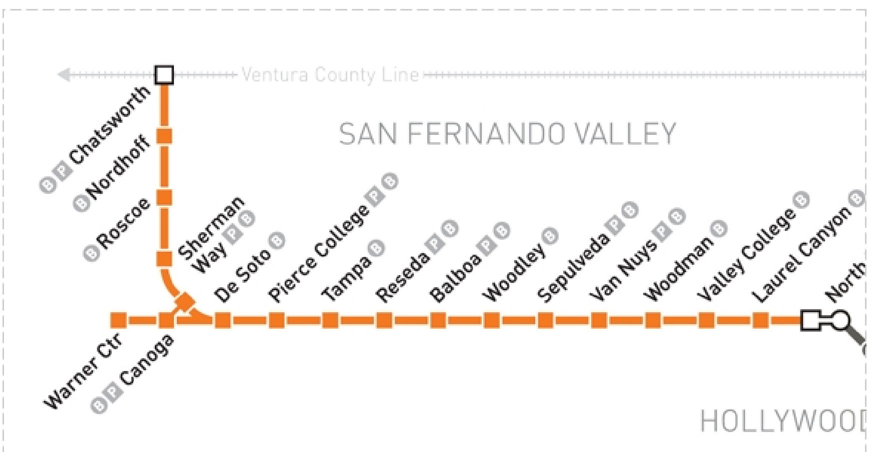

Figure 3.12: Metro Orange Line (LA Metro)

The available right of way allowed the Orange Line to be constructed as an exclusive busway for the vast majority of its length between the employment hub at Warner Center and the Red Line's North Hollywood terminus. Dedicated right of way is conducive to highly reliable service, with a low peak to off-peak running time ratio of 1.2 (see Table 3.3). Relatively high quantitative reliability indicators are reinforced by strong rider perceptions of reliability fostered by the lane dedication and signal priority. A well-designed signal preemption system for grade crossings improves both travel times and headway regularity. Signage at grade crossings emphasizes transit priority (see Figure 3.13).

Figure 3.13: Sign warning drivers of Orange Line busway crossing

According to Flynn et al. (2011), more than 72% of Orange Line passengers who previously drove alone perceive the Orange Line to be the same or better in terms of travel time. The Orange Line still has higher end-to-end travel times than driving, but the difference is lower than for most other LA Metro bus lines. High levels of reliability, as well as the Orange Line's connection to the Red Line subway, which helps provide competitive overall trip times, help drive the perception that transit travel times are lower than driving times.

The Orange Line has experienced sustained ridership increases, even as systemwide bus ridership has remained flat, it has approached capacity limits sooner anticipated. Flynn et al. (2011) found that in March 2009, 20% of peak period trips exceeded Metro's load standard at Van Nuys. With continued ridership growth since then, as well as the inauguration of the Chatsworth extension, capacity is certainly a concern for the corridor. The Orange Line's signal priority system allows for buses to pass at most every 3 minutes, limiting capacity to approximately 1,500 passengers per direction per hour. Increasing denied boardings suggest that this capacity is being approached. Improved accessibility metrics might help inform the needed update and service adjustment process.

Silver Line

In late 2009, five freeway express routes operating along Interstates 10 and 110 were consolidated and rebranded as the Silver Line. The off-freeway portions were truncated and turned into local feeders for the new trunk line, which ran from the six existing Harbor Transitway stations, through street stops in downtown, to the four existing El Monte Busway stations. New vehicles and liveries were introduced, accompanied by a concerted marketing effort connected with the ExpressLanes HOV to HOT conversion, and frequencies and ridership have been increasing dramatically in the intervening four years (see Figure 3.15).

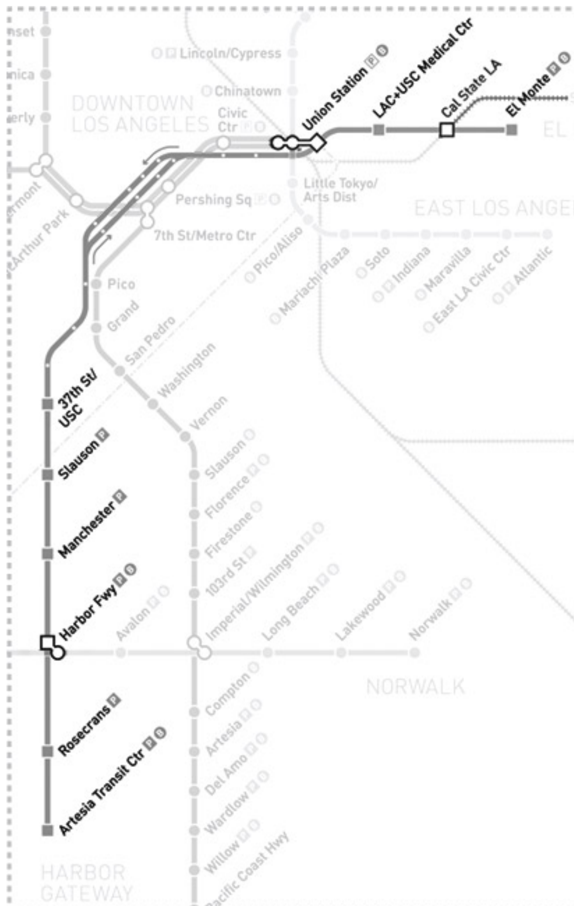

Figure 3.14: Metro Silver Line (LA Metro)

Before implementation, studies suggested that 10 to 15% of passengers at the Harbor Gateway and El Monte transitway entrances were through passengers. Assuming all of these passengers continued taking the truncated local services and transferring to the new Silver Line trunk service, a 10 to 15% increase in unlinked boardings would be expected for a constant level of linked boardings. As seen in Figure 3.15, this baseline was surpassed about 18 months after the project's implementation. Anecdotal evidence suggests that many passengers actually drove to the trunk terminals instead of continuing to use the truncated routes as feeders, implying that the baseline number of unlinked boardings would be lower, and the increment in riders over this baseline higher. While these complications make a precise quantification of ridership increase difficult to obtain, ridership clearly has responded well to improved frequencies and a simplified service pattern.

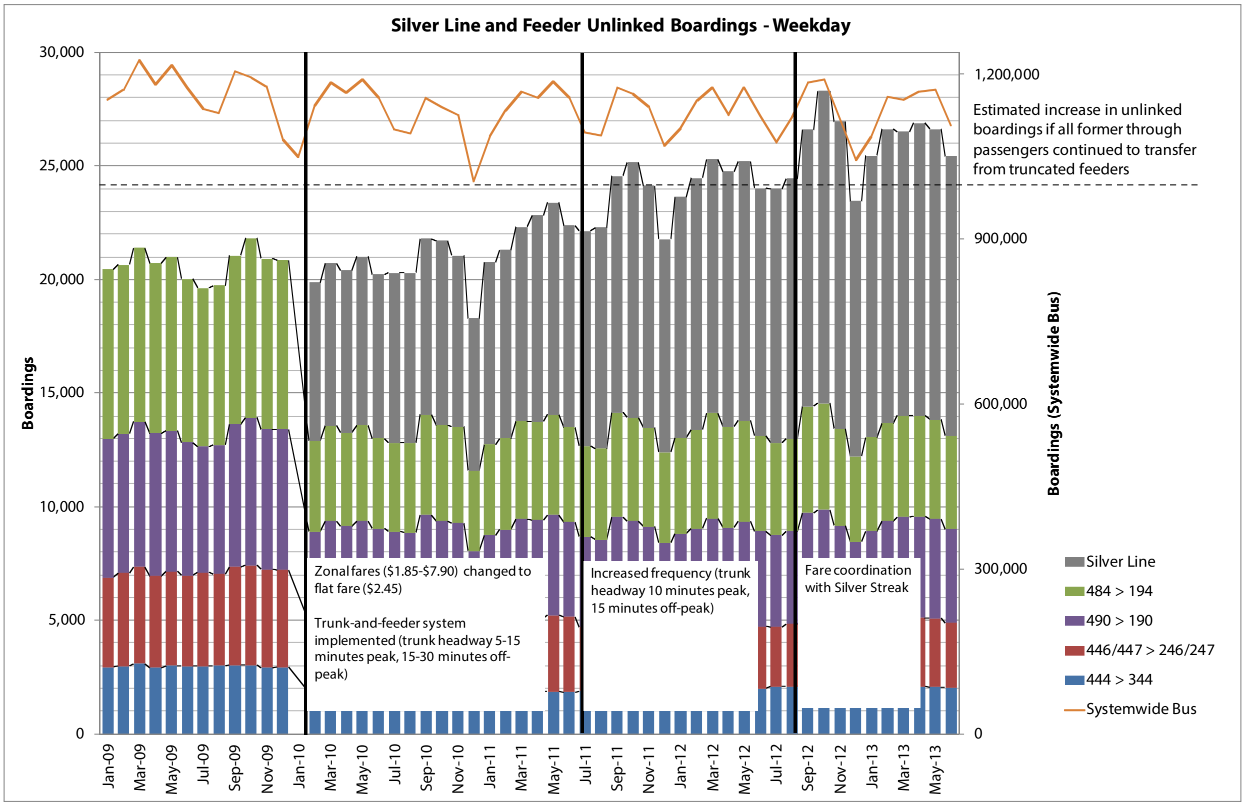

Figure 3.15: Trends in Silver Line and systemwide bus ridership (data from LA Metro)

Bus ridership systemwide has dropped 2.9% over the same period. Some station improvements have been made, but it could be assumed that on balance, with the inconvenience caused by construction, especially at El Monte station, the effect of these improvements on ridership would be negligible. Service simplification, branding, and advertising have likely played a central role in increasing ridership.

Future Projects

LA Metro is considering BRT as a mode for a number of corridors currently in planning. Progress is also being made on improvements to the Wilshire Boulevard project after earlier efforts were curtailed:

> In May 2007, the Los Angeles City Council...made a decision to pursue...peak period end-to-end bus lanes, which clearly met the corridor objectives to reduce bus congestion, improve passenger travel times and average bus speeds, minimize parking space removal, and improve the mode shift from automobile to bus. In August 2007, the demonstration project was temporarily suspended by the Los

> Angeles City Council until the one-mile segment could be integrated into a larger bus lane project.
>
> – LACMTA (2010, p. 2-3)

After the Rapid corridor's inauguration in 2000, it took seven years for a peak-hour dedicated lane pilot program to start, and the pilot was short-lived. The first stage of the promised "larger bus lane project" was not inaugurated until 2013. The lengthy delays in achieving even modest lane priority measures antagonized transit advocates and reduced momentum that had been building after the implementation of early Rapid corridors. Planners' emphasis on travel time savings, which were substantial for the project as a whole, left them open to counterarguments from individual residents and businesses concerned about parking and driveway access; they made arguments that travel time savings at the block or segment level were not substantial enough to justify dedicated lanes. A stronger emphasis on reliability and expanded access to opportunity might have made the importance of continuous dedicated lanes clearer and possibly protected the project from death (or at least extended unnecessary delays) by a thousand cuts. Once again, clear accessibility metrics could have helped improve the transparency of decision-making and build political support.

3.4.3 New York: Network

In New York City, the MTA has been developing a rapid bus network branded as Select Bus Service (SBS), but does not have plans for fully separated BRT corridors. They have intentionally avoided labeling SBS as BRT, in part to avoid unrealistic expectations of improved service. Five corridors, shown below with their years of inauguration, are currently operational:

- Fordham-Pelham, BX12 SBS – 2008
- 1st/2nd Avenues, M15 SBS – 2010
- 34th St., M34/M34A SBS – 2011
- Hylan-Richmond, S79 SBS – 2012
- Webster, Bx41 SBS – 2013

Barr et al. (2010) and Barr et al. (2012) provide detailed descriptions of BX12 SBS and M15 SBS implementation and results, including ridership statistics and explanations of how travel time reductions were achieved. The SBS corridors have been notable for ridership gains even as systemwide bus ridership is trending downwards.

One of the strengths of the SBS network is its brand's consistency across corridors and between vehicles and infrastructure. SBS corridors are announced on subway trains, and transfers between the SBS and subway lines are free.

Four of the corridors operate with preboard fare collection and proof-of-payment system based on stop kiosks that accept cash or MetroCard payment in return for a printed receipt (See Figures 3.16 and 3.17). Random inspections check that passengers have proof-of-payment receipts printed within an acceptable time period. This system allows for all doors to be used for boarding, significantly reducing dwell times. Dwell times for the BX12 and M15 SBS services dropped by approximately 40%, and fare evasion actually dropped slightly on both routes (Barr et al. (2010) and Barr et al. (2012)).

The S79 SBS does not have preboard fare collection because dwell time was determined not to be a major cause of delays along this less densely populated corridor in Staten Island.

Overall, SBS has struck an appropriate balance between the advantages of BRT's flexibility, both spatially and temporally, and a strong system image. This has allowed progress to be sustained over the past five years, building momentum for projects that may be more contentious (e.g. the proposed M60 SBS along 125th St.).

Figure 3.16: Substantial stop amenities and fare prepayment systems at the South Ferry terminus of the M15 SBS

Figure 3.17: Similar SBS fare prepayment infrastructure in a more confined space along 34th St.

3.4.4 Boston: Corridors to Network

After two initial corridors bundled together with the designation of the Silver Line BRT in the early 2000s, multiple initiatives in Boston are now employing some of the lessons learned from these corridors to advance bus improvements around the network. These efforts are discussed in Chapter 5.

3.4.5 Santiago: Network to Corridors

Santiago took the opposite approach, envisioning first a city-wide network of upgraded bus service. The framers of Transantiago explicitly "discarded [Transmilenio] as a model for Santiago since it only promised to reach a few main corridors, leaving the rest of the city untouched;" instead, they "wanted a 'global intervention,' something akin to Curitiba's Rede Integrada de Transporte (RIT), except at a much grander scale" (Flores, 2013, p. 233). But seven years after its inauguration, Transantiago still lacks some of the dedicated corridor infrastructure that was initially promised. Chapter 5 offers a more detailed description of BRT development in Santiago.

3.5 Conclusion

These examples suggest that, whether moving from initial full BRT corridors to a broader network, or from a broad conventional bus network to upgraded infrastructure in select corridors, BRT projects face a common set of challenges. In the former case, such as in Bogotá, initial phases focus on streetscape and urban design, which may make for successful interventions in select areas, but provide little insight into the institutional and regional complexities of a broad, integrated network. The tactics of designing dedicated corridors for wide rights of way, like Avenida Caracas in Bogotá or the Orange Line in Los Angeles, may be minimally applicable to more narrow, constrained corridors; yet these tactics comprise a core part of the expertise that has been developed around BRT, so they may be applied in other settings despite limited prospects for success. On the other hand, cities that have tried to start from a broad network perspective, like Santiago, have realized the need for effective corridor infrastructure and redoubled their focus on the tactical elements of corridor design. Both approaches would benefit from a better ability to understand how in-street infrastructure and operations relate to broader mobility and accessibility goals.

In contrast to capital-intensive heavy rail projects, which tend to concentrate well-understood mobility and accessibility benefits in relatively narrow corridors, BRT projects tend to have benefits that are more diffuse. The emphasis on geographically distributed benefits often arises from intentional policy decisions to create a regional, integrated network, but it can also be a result of less intentional transportation capacity and funding factors. Street-running BRT has lower capacity than heavy rail, so in many cases, it is more appropriate for lower density sectors where the benefits will correspondingly be less concentrated. In the United States context, as federal capital funding for transportation projects declines, metropolitan areas are increasingly establishing locally-based revenue streams. A political consequence of this shift is the need to distribute projects throughout a metropolitan area, favoring smaller-scale, more distributed projects. Without attention to the impacts of these smaller projects, there may be a greater risk of missing opportunities to improve regional accessibility. This risk may be more acute when projects are phased over time.

Planners' and advocates' focus on the tactical BRT elements of streetscape and bus operations has not generally been clearly connected to broader strategic urban development goals. As a framework that explicitly considers the interlinked transport and land use systems, accessibility can help expand this focus and strengthen arguments for bus priority. As Straatemeier (2008, p. 135) argues, "Planning for accessibility signals a shift from a planning which focuses on transportation network efficiency to a planning which focuses on the 'network' position and development potential of places in the urban network." The next chapter discusses how to encourage such a shift by opening a meaningful participation process to transit advocates.

Chapter 4

Open Participation, Data, and Software

As described in the preceding chapter, incremental BRT projects have promise but are often beset by common challenges. These challenges can be overcome with consolidated political will and an understanding of local context informed by strong sense of place. Yet traditional transportation planning frameworks, coupled with international BRT boosterism, have in some cases left little room for local contextual knowledge. A participatory framework that values local knowledge can incorporate important insights into incremental BRT planning in ways that the traditional transportation planning process is not designed to.

Along these lines, Fischer (2000, p. 2) argues that “participatory forms of inquiry...have the potential to provide new knowledge – in particular local knowledge – that is inaccessible to more abstract empirical methods.” This chapter begins with a critique of such “abstract empirical methods,” which form the basis of traditional transportation engineering and planning approaches. It then discusses more open participation frameworks, and how such frameworks can be enabled and enhanced by new open software and data tools.

4.1 Levels of Transportation Planning

Transportation planning takes place at multiple time horizons, as suggested in Figure 4.1. In an integrated planning process, these levels should be well coordinated, but in practice they often are not, due to institutional factors.

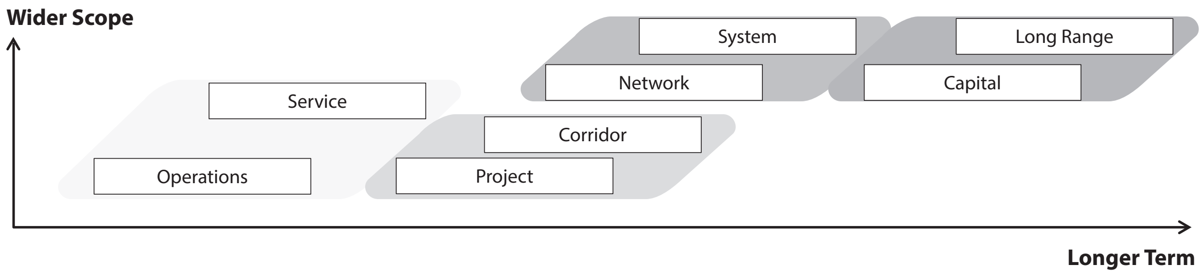

Figure 4.1: Planning levels

Operations can be planned at short time horizons, responding to unforeseen circumstances. For transit, service planning typically takes place on a quarterly or yearly timeframe to respond to seasonal variations in demand. For facilities, a service planning focus considers maintenance and upgrading to meet revised design and level of service standards.

New or expanded infrastructure is considered at the project/corridor level, where benefit-cost calculations are typically applied. Benefits of these projects often include travel time savings accrued through new service reduced congestion. The use of benefit-cost analysis can become increasingly cumbersome for larger, more complex projects. The National Environmental Protection Act, the Clean Air Act and Amendments, Section 4(f) parkland protections, the Americans with Disabilities Act, and Title VI of the Civil Rights Act all add additional dimensions of analysis for transportation projects in the US. Multicriteria analysis is now often used for projects to determine whether they are worthwhile, and how they compare to other candidate projects.

A multi-corridor, and potentially multi-modal perspective comprises the network/system planning level. In the United States, these plans are partly a response to federal mandates requiring continuing, comprehensive, and cooperative transportation planning.

Project and network planning should also be informed by a larger capital programming and long-range planning process. Ideally, such a process matches the most desirable projects in certain categories with funds over time, helping to prioritize action with political goals. Financing considerations, such as costs and revenue sources, are included in this process. A capital plan is a typical example of a programming document that should guide and be guided by project evaluation criteria across different project types. This level of planning is also appropriate for the political determination of the broader vision, goals, and objectives for the transportation system. Yet in some cases, broader programs may be simply a compilation of individually designed projects rather than a coherent, strategic plan. Overall, the traditional approach to transportation planning has "focused almost exclusively on analysis and evaluation, with the visioning process, program and/or project implementation, and system monitoring (i.e., assessing how well the system is performing) occurring outside the planners purview" (Amekudzi and Meyer, 2005, p. 35). This focus on project-based analysis and evaluation, rather than an integrated perspective across these planning levels, comes from a historical tendency towards privileging technical understandings of projects and a public works orientation. It also implies that understanding of accessibility is likely to be fragmented.

In theory, public participation can be incorporated into any of these levels of planning, though experience suggests that it has been most prevalent at the project/corridor level, where residents respond to proposals with a clear, direct impact on their neighborhoods.

4.2 Traditional Frameworks for Public Participation

Historically, attitudes toward public participation in urban transportation planning can be characterized as a "predict-provide" approach, in which demand is forecast through a set of technical assumptions, then infrastructure is built to satisfy that demand with little regard for public input (Kenworthy, 2012, p. 6). The environmental movement in the United States, starting in the 1960s, helped add more checks on transportation planning through environmental laws requiring public input. Yet even this framework, characterized as a "decide-announce-defend" approach, can be skewed and leave little room for meaningful public participation. These two models, which dominated transportation planning in the 20th century, are discussed below.

4.2.1 Predict and Provide

In the first half of the 20th century, transportation planning was based on a technical, rational-scientific framework that sought to forecast demand through quantitative methods and expert engineering judgment, then build infrastructure designed to handle such demand with little consideration for other input or perspectives. This framework, exemplified in the era of the construction of the Interstate Highway System in the United States, and its associated "transport planning methods and practices, based on what has been derogatorily termed a 'predict and provide' computer modeling approach (which treats traffic as a liquid), have helped to evolve the automobile-dependent city" (Kenworthy, 2012, p. 6). The biases in favor of expanding highway capacity for automobiles are embedded in both the broad philosophy and technical details of this framework, and in many cases these biases continue unabated today (Krishnamurthy, 2012).

This bias is persistent in part because it is masked by the purported rationality and expertise of analytical approaches. Regarding the larger neopositivist, rational-scientific planning approach, Fischer (2000, p. 17) elaborates, "In pursuit of the most efficient problem-solving strategies...experts appear to objectively transcend partisan interests. Their technical methodologies and modes of decision making are said to be 'value neutral.'" Contesting this ostensible neutrality is a difficult task, because expert knowledge is required to decode the discourse of engineering reports and plans, and even with such expertise available, there are few avenues for public participation available in this framework.

The masking of biases by expertise and analytic approaches is not only symptomatic of highway planning, but also of market-based transportation planning more broadly. Privately provisioned transit services, whether in the early days of streetcar suburbs or in recent neoliberal bus network projects like Santiago's Transantiago bus system, often rely on analytical models to predict ridership and provide an optimal amount of service. Optimizing based on a narrow set of assumed quantitative inputs can render the implemented service inflexible and vulnerable to unforeseen circumstances. Such was the case of Transantiago, which experienced the "big bang," detailed in Chapter 5. Here it is sufficient to note that "Public participation in this enormous process was almost non-existent. The government decided not to publicize the details of the system before it was ready...The government should clearly have been more receptive to user feedback and previous operators' experience" (Muñoz and Gschwender, 2008, p. 52). Partly because the expertise-driven approach was not structured to incorporate important non-expert knowledge of the local context, the resulting theoretically efficient project collapsed when it faced actual implementation.

The predict-provide framework, while based on important early advances in modeling, is on its own minimally capable of responding to the complexity of urban development and institutions. Kane and Del Mistro (2003, p. 113) assert, "The rational comprehensive model of thinking is less useful today, due to the increasing complexity of the transport planning exercise; the rejection by the public of the transport planner as 'expert'; and the highly political nature of transport planning." The technocratic approach was deemed appropriate for mid-20th century highway infrastructure conceived of as rigid and durable, yet the social and environmental consequences of this narrowly quantitative approach (Krishnamurthy (2012) and Kenworthy (2012)), the subsequent degradation of this infrastructure (Spicer, 2011), and the understanding of cities as complex systems, call into question this approach. Especially for incremental BRT projects, which supposedly contrast with traditional transport projects in their adaptability and sensitivity to local conditions (see Chapter 3), the need for planning frameworks that incorporate knowledge beyond the narrowly quantitative inputs of the predict-provide approach is clear.

4.2.2 Decide, Announce, and Defend

For transportation planning, the environmental movement of the 1960s and 1970s led to new statutory requirements to incorporate public comment and comprehensive planning. This marked a shift from the predict-provide framework, in which plans and designs were shielded from public comment or criticism by their elevated status as expertly derived optimal solutions. Legislation such as the National Environmental Policy Act required planners to publicly release project and network plans and formally seek public input on them. This environmental review process, combined with new environmental protections, provided a basis for successful challenges that have halted numerous transportation projects.

While these requirements for public participation are an important step, many argue that they do not do enough to build meaningful feedback into the planning process. Instead, nominal participation requirements are merely a box to be checked before moving to implementation, and the resulting process has been caricatured as "decide, announce, defend," in which a project is decided by experts and subsequent *de rigueur* public feedback can do little to modify the proposal. The widely cited "ladder of citizen participation" proposed by Arnstein (1969) encapsulates this critique (See Figure 4.2). Unless the general public actually has the power to shape outcomes, participation processes run the risk of being forms of manipulation or tokenism. She emphasizes,

> "There is a critical difference between going through the empty ritual of participation and having the real power needed to affect the outcome of the process... Participation without redistribution of power is an empty and frustrating process for the powerless. It allows the powerholders to claim that all sides were considered, but makes it possible for only some of those sides to benefit."
>
> – Arnstein (1969, p. 217)

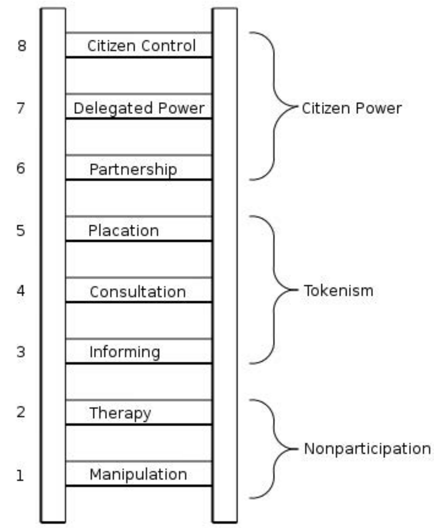

Figure 4.2: Ladder of citizen participation (Arnstein, 1969)

In terms of participation, the environmental review process requires little more than informing and consultation, rungs three and four on this ladder. Required mitigation and political concerns arising from the public consultation may push participation towards the next rungs of placation and partnership, that is, moving from announcing a design to defending it.

Even in processes where there is a genuine desire to incorporate public feedback, reliance on traditional expertise may complicate participation. The decide-announce-defend framework still relies on technical modeling, privileges quantitative inputs, and involves jargon; just like in the predict-provide framework, these factors complicate non-expert participation and mask biases. Outreach materials are often comprised of technical documents that require a certain level of formal education to understand. Fischer (2000, p. 18) explains, "Because of the fundamental differences in the legitimacy and power of their respective languages – technical versus everyday language – the interaction between technocratic planners and the members of the local community tends to give shape to an unequal communicative relationship, or what Habermas (1970a) has described as 'distorted communication.'" Unless significant resources are dedicated to training, communications, and intentional responses to "the diverse communication codes and subtle power relations that shape face-to-face encounters," delegated power and citizen control, the apex of Arnstein's ladder, are difficult to achieve (Briggs, 1998, p. 1).

The difficulties inherent in achieving meaningful public participation can diminish trust between governmental planners and civil society. Citizens and transportation advocacy groups recognize the hollowness of participation structures; to maintain active constituencies and avoid having their missions co-opted, they often resort to civil disobedience and refuse to buy into established participation scaffolds. Groups relevant to the Santiago and Boston contexts are discussed in greater detail in Chapter 5, but a few points about their critique of the contemporary decide-announce-defend model are worth mentioning here. These groups generally come from a community organizing, environmental and social justice perspective and are skeptical of official information and analyses. Fischer (2000, p. 121) explains, "One of the most innovative features of the environmental justice movement's efforts to empower citizens and thus revivify democracy has been the effort to help local citizens understand their own needs and interests...Rather than merely accepting information provided by scientists and other technical experts...the movement assists communities in a variety of ways to collect and interpret their own information." Yet a decide-announce-defend participation model is not structured to value such independently collected and interpreted information.

Centro Alerta, an organization that seeks to build common space for leftist social and political groups in Santiago, lays out the following critique in its Campaign against Transantiago: "Technocracy does not understand the needs of flesh-and-bone people, and the entrenched establishment in the State does not have any other interest than our exploitation...In this context, a response that comes from them is either disingenuous or part of the same trick" (Centro Alerta, 2013, p. 10). In this view, engaging with a nominal participation process would only serve to add legitimacy to a fundamentally flawed system.

The frustration and antagonism reflected in these positions affects not only the participants, but also the planners, who grow more entrenched in their practice. In an adversarial climate, traditional analyses of limited corridor projects can be announced and defended more easily than broader network projects that may require new forms of analyses. Facing antagonistic audiences, planners are likely to retreat from broad strategic visions and eschew new metrics and ways of evaluating projects. The impulse to "defend" turns planners away from seeking new ways to incorporate local knowledge. Though advances gained by the environmental movement put important checks in place on the previously dominant predict-provide framework, the framework that has replaced it is subject to many of the same weaknesses with respect to participation. Innes and Booher (2004, p. 419) go so far as arguing that "legally required participation methods in the US not only do not meet most basic goals for public participation, but they are also counterproductive, causing anger and mistrust." New forms of participation in the transportation planning process are needed.

4.3 Open Participation

Scholars of participation have called for new conceptualizations of meaningful participation that challenge the decide-announce-defend model. Innes and Booher (2004, p. 419), for example, argue that "participation should be understood as a multi-way set of interactions among citizens and other players who together produce outcomes." Sharing the power to "produce outcomes" with citizens implies a new way of valuing their experience and knowledge.

4.3.1 Local Knowledge

The lack of meaningful participation in contemporary planning means officials may miss important local knowledge that can make designs more responsive and robust. Fischer (2000, p. 194) defines this local knowledge as knowledge that "does not owe its origin, testing, degree of verification, truth, status, or currency to distinctive professional techniques, but rather to common sense, casual empiricism, or thoughtful speculation and analysis." Other urban theorists concur on the importance of such contextually-situated knowledge, with Sassen, for example, emphasizing "knowledges that the non-recognized experts have" (panel discussion at Kevin Lynch Award, MIT, February 6 2014). The implication is not only that non-recognized experts have access to important perspectives on local context, but also that experts are incapable of or are trained to avoid understanding problems from these perspectives. Fischer (2000, p. 35) summarizes, "Although citizens need experts, the experts...themselves need citizen assistance much more than their professional ideologies have acknowledged."

Local knowledge is crucial for understanding the personal dimensions of accessibility described in Chapter 2. Fol and Gallez (2014, p. 76) state more generally, "Not only does the issue of accessibility need to be explicitly addressed in transportation planning, it also must be discussed with the concerned groups. The planning process can greatly benefit from hearing the citizens' point of view, which must be recognized as a real form of expertise." Facilitating structures that include this "real expertise," often through settings that value qualitative and narrative sharing rather than just quantitative data produced by recognized experts, should be a primary goal of revised participation frameworks.

At the same time, "citizen control" begs the questions of *with which citizens*, and *based on* *what analytical tools and information*, can discussion with officials provide a more meaningful process and set of outcomes.

4.4 Open Data and Software

New digital data, networks, and software tools offer the promise of better including local knowledge in a way that can transform public participation (Evans-Cowley and Hollander, 2010). Open data and open-source software are both central to such a transformation. The combination of open data and open software allows for web-based tools that can reduce the costs of participation, drastically expanding planners' access to local knowledge, with caveats about those with limited internet access or literacy. At the same time, new tools for efficiently processing and interpreting urban data, whether collected through a participatory process or otherwise, can spark new ways of representing and discussing projects. Both of these facets lend themselves to iterative planning; reduced costs of soliciting and processing feedback mean that such feedback can be sought over a number of revised proposals.

Open data generally refers to accurate official datasets organized in an easily used digital format, available for free download and freely licensed distribution and use. To improve data access and accountability, government entities are increasingly adopting open data policies and statutes (Code for America; Sunlight Founation; Open Knowledge Foundation).

Collaboratively defined open standards are also emerging as a way to structure these data across contexts. An illustrative example is the general transit feed specification (GTFS). Originally the Google Transit Feed Specification, a file organization system established to load transit agency schedules and network information into Google Maps, GTFS is now an open de facto standard which an open community of online contributors maintains and updates (Wong, 2013). GTFS has enabled hundreds of transit agencies around the world to release their schedules as open data, and the shared format means software written for one city is easily adaptable to another, facilitating widespread public use and analysis of these data. The open approach to the standard means that extensions, for example to represent real-time information or informal transit networks (Eros et al., 2014), can be developed in a collaborative way to reflect new perspectives on service attributes to include.

Members of the public can also modify open data or author their own in the same format, then use the same suite of applications that have been developed for the official data feeds. Following Superstorm Sandy in New York City, for instance, members of the public were able to rapidly create GTFS feeds that represented the state of transit service as the system shut down, reopened, and recovered. These feeds could then be used in trip planning and accessibility measuring applications in the same way that the official MTA GTFS feeds could.

Standards for open data, along with standardized application programming interfaces (APIs) that allow for consistent ways of using these data, encourage the development of software applications. The One Bus Away project, for instance, built an API that uses GTFS data to enable the distribution of transit schedule information to smartphone apps. When this software is based on an open-source philosophy, the potential benefits for meaningful participation multiply. Making the source code for a software project available under an open license implies the software can be freely distributed and modified. It also implies that all calculations and assumptions within the software are subject to public scrutiny. Granted, a certain level of familiarity with computer science may be required for an individual to understand or modify the code, but having the code available is a major evolution from the black box approaches typical of proprietary systems used in historical transportation modeling.

As alternatives to costly propriety software, free open-source software is more readily accessible to governments and organizations with limited financial resources. Open-source software has met some resistance in governmental settings, due to a combination of established procurement procedures, perceived security concerns, and relatively less developed documentation. In addition to the increased training and technical support required by these factors, there is also the perception that updates and patches for open-source software tend to be less reliably developed than proprietary solutions. On the other hand, active user communities for open-source software projects often provide adequate technical support, guidance, and updates. Overall, the relative ease of access to open-source tools means they have the potential to be a common tool used by both professional planners and community groups. Making the software used by professional planners freely available to community groups could be a major step towards facilitating non-recognized expert input into the planning process.

More generally, online collaboration, GIS, and data visualization tools are leading to the fusion of the data collection, analysis, and representation steps of project planning. Previously, these three steps were conducted in distinct phases with different tools; a road project would first be based on surveying, then geometric calculations would be performed, and the final design would be presented through maps and plans. In contrast, today's software, driven by widely available open data and APIs, is moving towards unified platforms that handle all of these functions. Collaborative mapping projects, for example, allow for the identification of existing conditions, computation of relevant metrics, and the tracking of solutions in the same platform. Consolidating these functions online makes the entire platform easy to share and distributes "the means of thinking" (Rahman (1993) cited in Fischer (2000, p. 178)) about a city. When this platform is open-source and used to shape understanding of cities, then the means of production of knowledge about a city can be widely distributed, potentially reshaping power dynamics in a city.

4.4.1 Examples of Collaborative Online Mapping and Visioning

Numerous online tools now allow for collaborative mapping of urban conditions. Fix My Street is one example of a purpose-built site that allows users to submit requests for municipal services (see Figure 4.3).

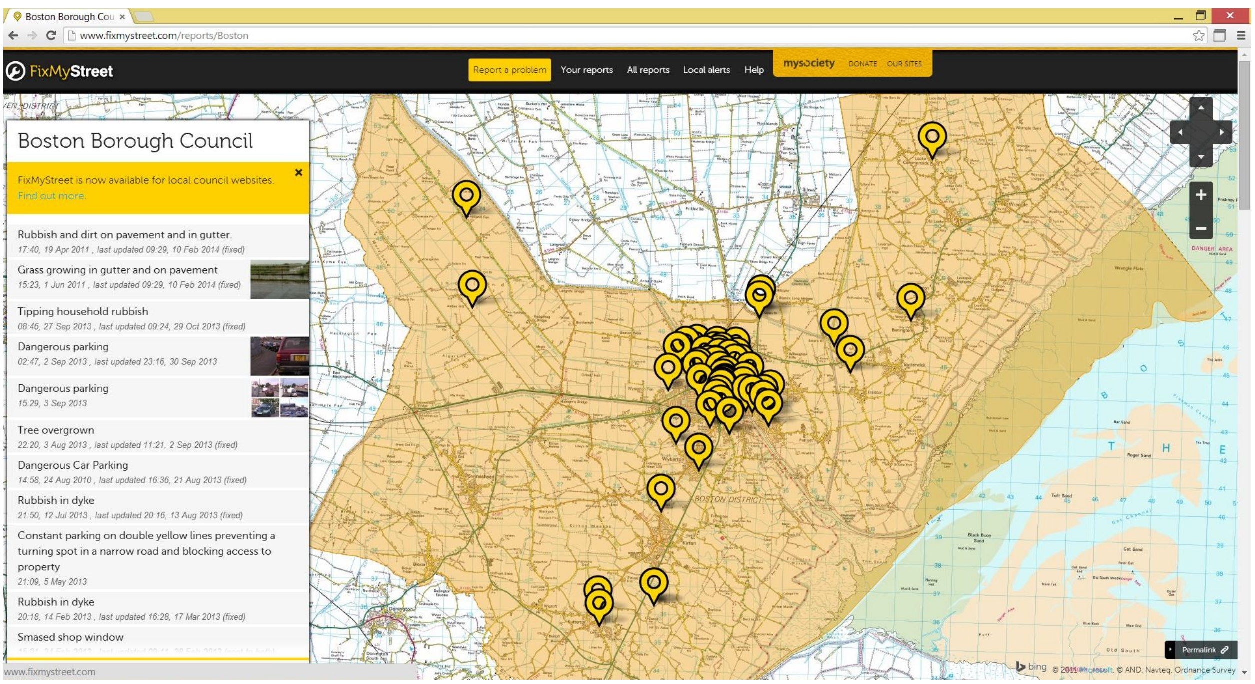

Figure 4.3: Online platform for submitting complaints to municipal agencies in Boston, UK (fixmystreet.com)

Other tools allow not just for the representation of existing conditions, but also visions for what urban space could be. StreetMix, developed as an open-source project through Code for America, is one such example. Its drag-and-drop interface allows users to create easily understandable street sections (see Figure 4.4). Since the source code is freely available, anyone with software experience can customize it for a specific geographic setting or project and add educational information about street design features like bike lanes, bus lanes, or tree canopies. A street redesign project could use this tool to allow users to generate, share, and vote on designs. This richly participatory process would be a far different experience than a public hearing in which a predetermined street design was presented to an audience with little ability to dynamically modify the design. While a powerful tool for street-level urban design, Streetmix does not currently include robust tools to understand how traffic and transit operations would be affected by proposed design, so models based on proposed cross-sections would still likely be run by experts. Integrated accessibility measurement tools could add this essential component to the local urban design focus that currently tends to dominate at the neighborhood level.

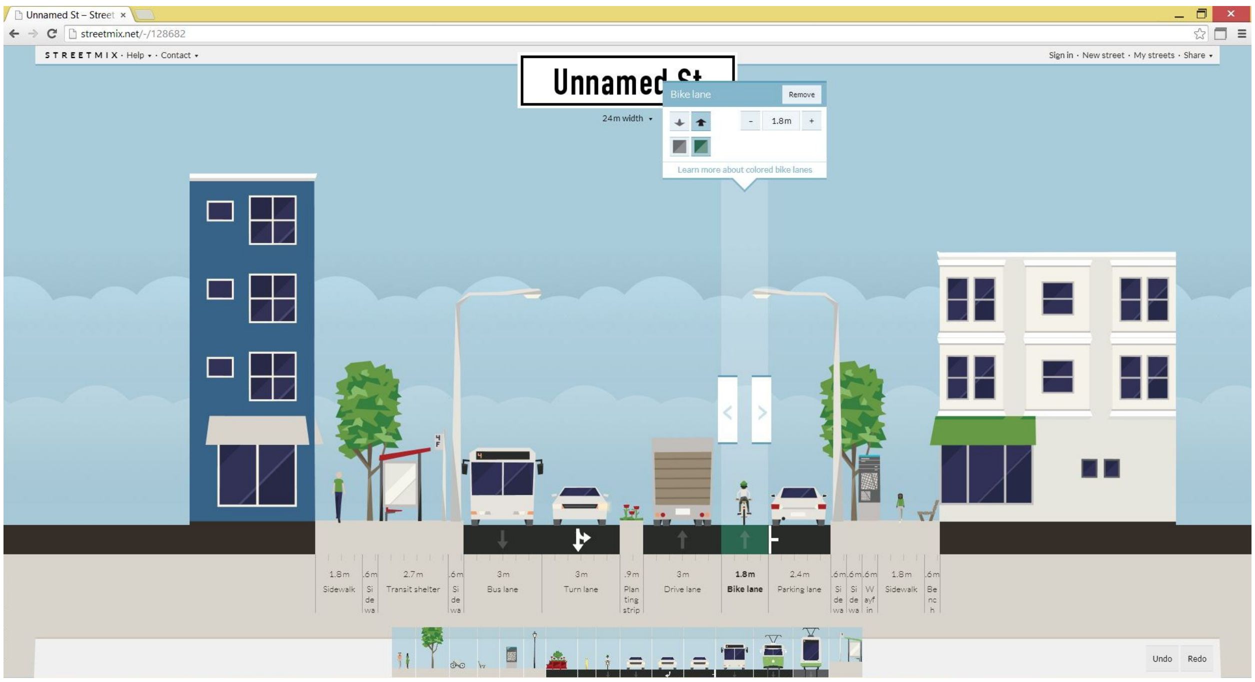

Figure 4.4: Streetmix Interface (streetmix.net)

Online tools are also being used in participatory budgeting projects. The Participatory Budgeting pilot in New York City, for instance, includes an online map that allows residents to view and vote for proposed capital improvements. This six-month version of the pilot program was underway in 2013 and 2014 in ten council districts, with a budget of $14 million. The web interface facilitates communication and voting, but extensive in-person programming is also an important component.

In Brazil, the Prefectural Government of São Paulo has implemented an online platform, called Gestão Urbana SP, for dissemination of information and documents about current projects, news and live broadcasts, and innovative participation tools. Introduced as part of a legislated revision of São Paulo's Strategic Master Plan, this site is now seen as a platform for ongoing engagement. The site includes various applications that "are launched periodically for collaboration in different phases of projects, allowing for the submission of proposals" and encourages residents to "take advantage of this electronic channel, and make together the São Paulo that the people want" (gestaourbana.prefeitura.sp.gov.br). In its first year of use for the Strategic Master Plan revision, the site was part of an outreach process that involved 56 in-person meetings with nearly 20,000 participants. Through these meetings and the online portal, which allowed users to post their diagnoses of urban problems and their proposals for interventions (see Figure 4.5), 8,800 comments on the Plan were submitted.

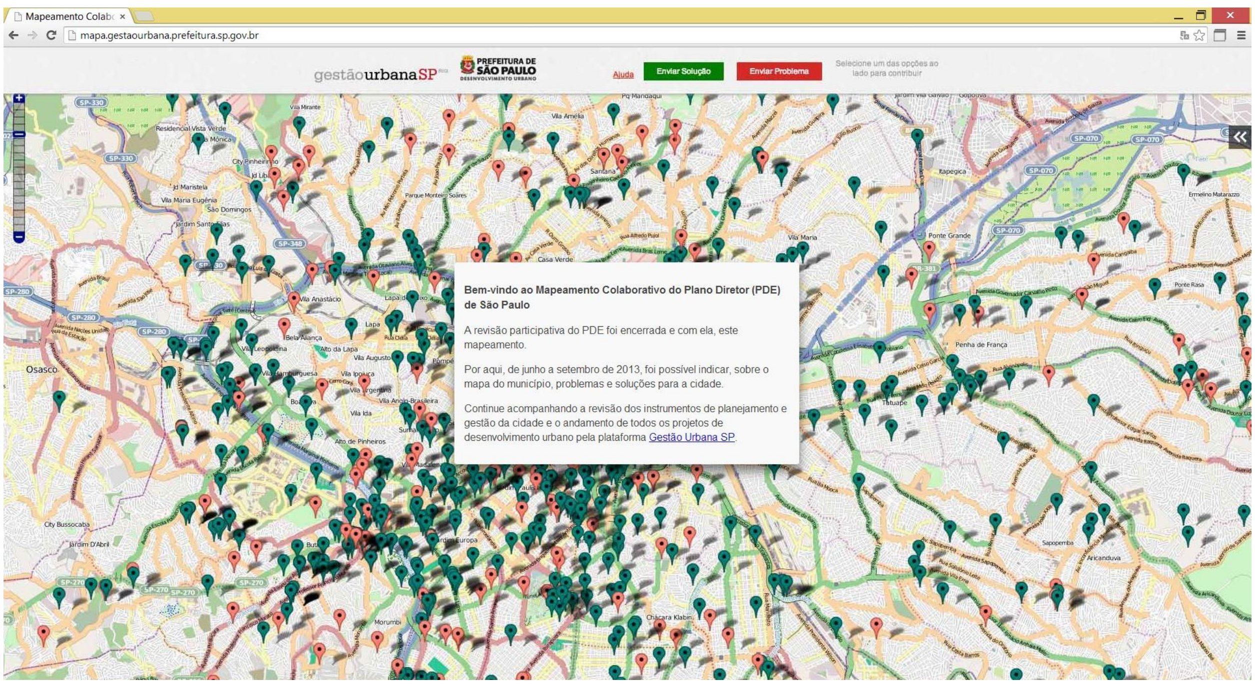

Figure 4.5: Online platform for collaborative mapping of urban "problems and solutions" in São Paulo (Prefeitura de São Paulo, 2013)

Many of these collaborative mapping and geographic visualization sites are based on Open Street Map, a user-generated mapping system. An alternative to commercial mapping platforms, Open Street Map relies on users to input street networks, using GPS traces and published open data, as well as other urban infrastructure and land uses. It epitomizes open data and open software in that it is both freely accessible and modifiable. These sites often make use of open-source code, such as Leaflet, a javascript mapping library. Without open-source tools like One Bus Away, Leaflet, GTFS, and Open Street Map, the journey planning and accessibility analysis features of Open Trip Planner, which are at the core of this thesis and described further in Chapter 6, would not exist.

The proliferation of open data and open software open an unprecedented opportunity to promote more open participation frameworks. The use of these tools accordingly warrants additional research.

4.5 Conclusion

This chapter has described three frameworks for participation in the transportation planning process. The first, predict-provide, privileges technocratic analysis and discounts the value of contextual, everyday knowledge. Today's dominant model, decide-announce-defend, seeks to incorporate public feedback, but in many cases it can exacerbate conflicts and preclude the meaningful incorporation of non-expert ideas. An emerging model of open participation leverages open data and open software to make planning substantially more collaborative, allowing non-recognized experts to also have a say in projects in an open dialogue with each other and officials. Table 4.1 summarizes the features of these three frameworks as they were defined in this chapter.

Table 4.1: Transportation Planning and Participation Frameworks

	Predict-Provide	Decide-Announce-Defend	Open Participation
Planning Level	Service/Operational, Project/Corridor, Network/System	Service/Operational, Project/Corridor, Capital/Long Range	Service/Operational, Project/Corridor, Network/System, Capital/Long Range, Wider urban systems
Analytical Tools	Empirical modeling, quantitative data	Empirical modeling, quantitative data, cost-benefit analyses	Quantitative data, qualitative data, collaborative mapping, interactive visualizations
Representational Tools	Reports, engineering plans	Plans, outreach materials, static visualizations	Collaborative mapping, interactive visualizations
Authors	Recognized Experts	Recognized Experts	Recognized and non-recognized experts
Feedback Mechanisms	External to planning process	Limited in duration and scope	Ongoing and iterative

To reiterate, part of the power of open data and open software driven participation is the merging of analytical and representational tools. That is, online platforms can offer a space for the sharing and representation of local knowledge, which in turn becomes the basis of analysis and subsequent project proposals.

While open participation uses virtual tools, it is a complement to, rather than a substitute for, interpersonal interactions. The examples of internet-informed planning processes described in the previous section still rely on robust facilitated in-person meetings; these tools, however, have the potential to dramatically remake the dynamics of in-person participation. Well-designed open participation tools can open in traditional public meetings a liminal space, in which both planners and members of the general public are removed from their accustomed roles and engage in a shared dialogue around a shared tool. Seen this way, the key challenge is less in the technical coding of these tools and more in building participation structures around them.

A hallmark of such participation should be iterative planning. These tools, which enable the elaboration and evaluation of a range of sketch scenarios with unprecedented speed and flexibility, allow design to be an ongoing, collaborative, incremental process at all levels of transportation planning, from service planning to long-range planning, rather than a static one in which professionals are inclined to defend rigid final designs. For infrastructure projects that claim benefits of flexibility and adaptability, like incremental BRT, such iterative planning that can integrate successive gains of local knowledge is key.

Performance management is an emerging model to replace the traditional project- and infrastructure-focused framework with more effective, integrated, and iterative planning. The performance management framework (see Figure 4.6) aligns well with the accessibility measures discussed previously, increasing the potential improvements these measures could make on traditional approaches to system planning, project and program evaluation, and financing.

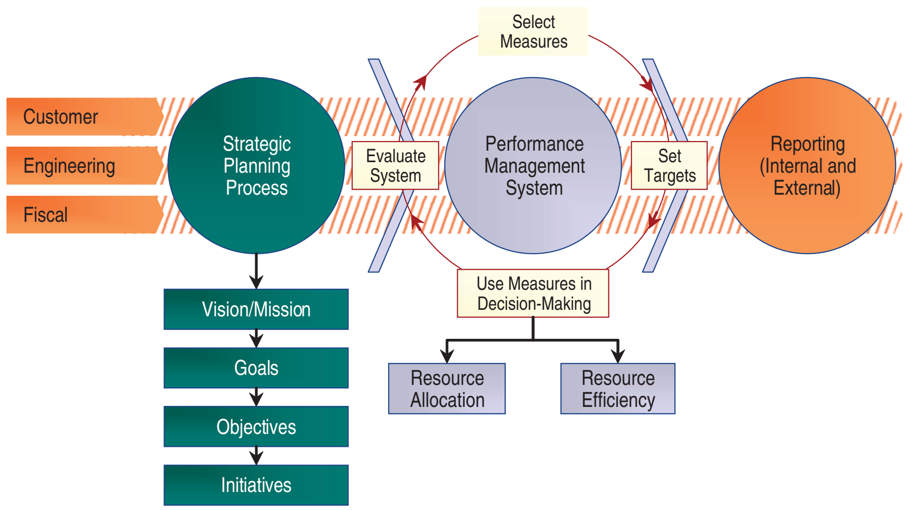

Figure 4.6: Performance management structure (Cambridge Systematics and High Street Consulting Group, 2010)

Performance management relies on the use of measures that represent customer experience. As discussed previously, accessibility measures can be an ideal way to represent user concerns intuitively. More generally, performance management requires an intentional strategic planning process that considers the vision, mission, and goals of the transportation system (Cambridge Systematics and High Street Consulting Group, 2010). Accessibility measures are informed by the values the public holds regarding what opportunities they should be able to access and could be the basis of this process. Incorporating these measures into decision-making and project evaluation would help establish a stronger link between the broader strategic planning process, specific projects, and detailed service planning.

Open participation holds promise for the adoption of accessibility measures. As argued in Chapter 2, the traditional focus in transportation planning on mobility and network efficiency disregards travelers' destinations and the personal dimensions of accessibility. Tools that lower the cost of considering such personal factors could encourage the adoption of accessibility measures, with potential resulting equity benefits.

These equity outcomes would be in addition to the procedural justice inherent in affording affected populations the power to impact decision-making. As Kinsella (2004, p. 85) writes, "The ideal form of public expertise is technical competency acquired and used directly by affected citizens. Such competency need not, and cannot replace the more specialized knowledge of technical or policy professionals, but it can provide members of the public with an adequate foundation for genuine dialogue with these specialists." The relevance of this enhanced communication process to the lives of much of the public can be dramatically strengthened through a shift in emphasis to service planning, with the potential for quick action, and as a newly emphasized basis for capital planning.

Questions of participation, and how it can be more effectively encouraged and incorporated into planning across temporal and spatial scales, are relevant for practitioners globally. Brownill and Parker (2010, p. 276) underline "the necessity of widening the geographical focus of debates on participation to broaden the critical perspectives that emerge from such comparisons (Watson, 2009)." The following chapter establishes such a comparison through the discussion of two distinct contexts for planning incremental BRT projects.

Chapter 5

Trial Contexts

Two distinct contexts, Boston and Santiago de Chile, were briefly mentioned in Chapter 3 and will be examined more fully here. Boston and Santiago are characterized by different urban, political, and institutional conditions, and comparing the two responds to the call to widen "the geographical focus of debates on participation" (Brownill and Parker, 2010, p. 276) discussed in the previous chapter. For each city, background on both incremental BRT projects and active transportation and equity advocacy groups is provided. New opportunities for the introduction of an accessibility-focused participation framework in each context are also considered.

5.1 Boston

Boston is the capital of the Commonwealth of Massachusetts and the largest city in the New England region. The metropolitan area has a population of 4.6 million residents and is facing numerous urban transportation planning challenges. The regional transportation agency, the Massachusetts Bay Transportation Authority (MBTA), is responsible for bus lines as well as light, heavy, and commuter rail trains. Much of the system's core infrastructure was built a century ago, and the MBTA has a history of underinvestment in maintaining this capital.

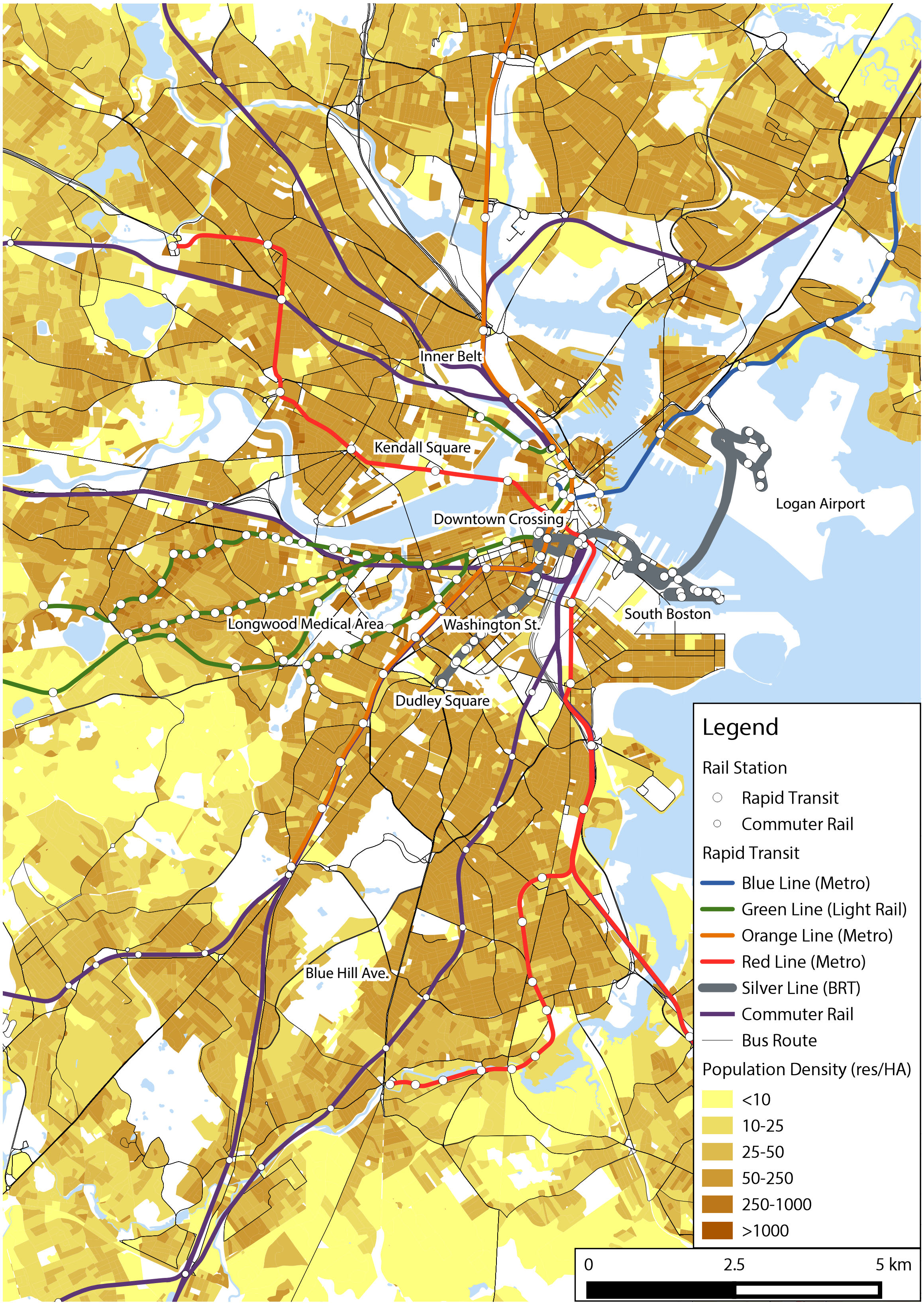

Figure 5.1: Boston Region

5.1.1 Incremental BRT Development

In 1994, the MBTA introduced three limited stop services with a distinct brand. These new Crosstown routes, CT1, CT2, and CT3, initially ran only on weekdays and were meant to be the first phase in a larger effort to implement a circumferential transit corridor called the Urban Ring. That project subsequently lapsed, so increased stop spacing remained the only incremental BRT feature present in Boston until the 2002 opening of the Silver Line.

Silver Line

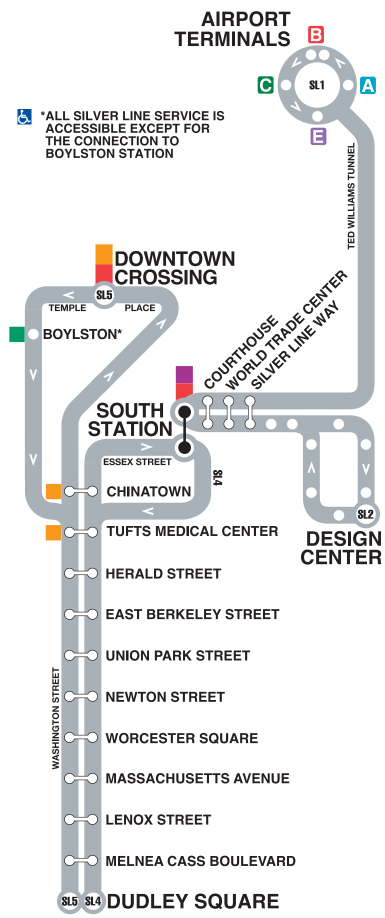

Figure 5.2: Silver Line branches (MBTA)

The first phase of the Silver Line to open, currently designated as SL5, opened in 2002 along Washington Street in Boston. The lack of new major infrastructure required allowed it to open before the Waterfront Corridor, which ran through a new tunnel and had a planning and construction timeline extending back to 1987. The Waterfront Corridor consisted of SL2 service to the South Boston Waterfront and SL3 service to City Point starting in 2004, with SL1 service to Logan Airport added in 2005. A proposed third phase would have connected the two corridors, allowing for through running from Washington Street to South Station in a bus tunnel, but that project has been postponed indefinitely. Since then, SL3 service was been eliminated due to low ridership, and the SL4 was added to provide service from the Washington Street corridor to South Station. Buses running on the surface through the congested downtown restrict capacity and reliability, a reminder of the risk entailed in incremental BRT's reliance on sustained political will.

Washington Street

FTA (2005) provides an evaluation of the Silver Line Washington Street corridor. Low household vehicle ownership rates are prevalent along the corridor, and large numbers of passengers board from feeder buses serving Dudley Square. Most boardings and alightings occur at the terminals. The urban context surrounding the corridor was heavily influenced by the elevated Orange Line, which operated in the corridor until 1987, when it was shifted northwest to its current alignment. The Washington Street corridor was designed to replace this rapid transit line; BRT was promoted as a promising new mode, and the Silver Line became one of the first BRT demonstration projects in the United States.

The corridor is one of the MBTA's highest in terms of ridership and productivity, with average weekday boardings increasing from 13,000 in the year of inauguration to over 18,000 in 2012. FTA (2007) found, however, that 83% of corridor riders used the Orange Line or other MBTA service prior to the corridor's inauguration, indicating somewhat limited success in attracting new riders, but clear responsiveness to improving service quality for existing customers.

Though 92% of the corridor's length consists of nominally dedicated lanes, allowed right turns and parking limit their effectiveness. Enforcement was also relatively weak in the corridor's early years, furthering riders' perceptions that these lanes were ineffective. More importantly, the portions of the corridor without dedicated lanes, near the Downtown Crossing and Dudley Square terminals, are often subject to congestion, while the portion with dedicated lanes had little congestion when it was inaugurated. Additionally, institutional complications hindered the operation of transit signal priority at the four intersections where it was installed.

Figure 5.3: End of the Silver Line's dedicated lanes, approaching congested Dudley Square

Without meaningful transit priority elements, service in the corridor is subject to unreliable running times, and in turn, unreliable headways. Cham (2006) details the causes of this unreliability. According to her analysis, the ratio of a day's maximum to minimum running time is 1.5 as scheduled, and 1.7 in reality. Peak period running times 70% greater than the uncongested baseline suggest that the BRT features have not been effective in minimizing the impact of traffic on operations.

Compounding the unreliable running times are poorly managed headways at terminals, which Cham (2006, p. 134) suggested were "the major cause of unreliability on this route." Bunching propagates these delays, leading to peak period headway coefficients of variation of 0.28 for the segment from East Berkeley to Temple, and 0.26 from East Berkeley to Dudley. According to Cham (2006, p. 119), "The coefficient of variation shows that many buses operate with much lower or much higher headways, creating reliability problems for both operations and passengers. Headway variability increases as buses traverse the route (variability is higher in the outbound direction) and over the day until after the PM peak period (coefficient of variation is highest in this period)."

Passengers accustomed to the reliable rapid transit service to downtown previously provided by the elevated Orange Line prior to 1987 today face longer in-vehicle travel times, and, more importantly, less reliable service. Though these changes are offset by the significantly greater number of opportunities near the realigned Orange Line, light rail advocates claim the promises of BRT were not met, referring to the project as "The Silver Lie" and undermining support for future incremental BRT projects.

Waterfront

FTA (2007) is an evaluation of the Silver Line Waterfront corridor, which provides access to Logan Airport and the South Boston waterfront. The Waterfront corridor runs for part of its length in an exclusive busway tunnel but is still subject to signal delays, congestion, and circuitous routing in other segments. According to data provided in Cao et al. (2013), peak period running times are 18% greater than uncongested baselines. At the primary signalized intersection for the corridor, where the buses cross D Street, round trips currently experience a median delay of 1.5 minutes during the midday; this intersection also contributes to headway variability for the Silver Line, but problems could be mitigated through use of a restricted highway ramp and managed bus platooning (Cao et al., 2013).

Combined ridership on the three Waterfront services was approximately 15,000 average weekday boardings in 2009, and ridership has been growing steadily since then, a reflection of both new real estate development and fare policy (see Figure 5.4). Most of the corridor's riders transfer to or from heavy rail at South Station. All-door boarding has been implemented for the airport line, with a combination of fare-prepayment at stations and free boarding at the airport terminal stops, which helps reduce unreliability due to dwell times.

5.1.2 Proposed Projects

As described above, subsequent phases of the Urban Ring circumferential transit project and the Silver Line have officially been put on hold indefinitely. Another proposed incremental BRT project, improvements to Route 28 and the Blue Hill Avenue Corridor, was rejected based on community feedback. Residents and state lawmakers especially questioned the rushed process behind the proposal. The first guideline of TCRP 90 (2003b, p. 1-6), "Early and continuous community support from elected leaders and citizens is essential," was not well heeded, leaving the bus corridor project on thin ice. While bus service in the corridor was

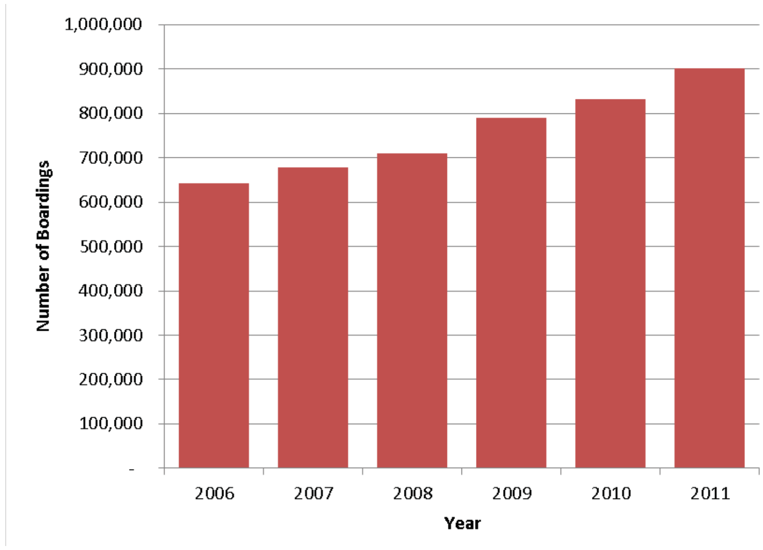

Figure 5.4: Annual SL1 boardings at Logan Airport (Cao et al., 2013)

a prime candidate for incremental upgrades, community members and elected officials were skeptical of a hastily unveiled, disruptive full BRT proposal when light rail activists continue to feel that the Silver Line has met its promises. A separate project, adding a branch to the Silver Line Waterfront corridor that would extend north to the City of Chelsea, has much stronger prospects and is advancing through the environmental review process. Dubbed the Silver Line Gateway corridor, this new service would largely follow a portion of the Urban Ring's proposed alignment. Though the Urban Ring project was officially canceled in 2008, the resurrection of this segment of it offers another example of the sometimes extended timelines in the incremental development of BRT.

Boston's history with these corridors highlights the promise incremental BRT holds for flexibly fostering transit-oriented development. At the same time, it provides a cautionary tale about focusing on individual BRT projects without developing a wider network approach, continuity in image, clear and relatable communication of benefits, and building sustained momentum for bus priority projects.

5.1.3 Advocacy Groups and Equity

One of Boston's oldest transportation advocacy groups is the T Riders Union (TRU), a project of the environmental justice community organization Alternatives for Community and Environment. TRU's core focus is transit-dependent riders and transportation equity, and one of its formative campaigns was against the Silver Line Washington Street Corridor, which they viewed as inadequate replacement for a heavy rail line that had been moved away from Washington Street. TRU's mission today is broader:

> The T Riders' Union (TRU), a program of ACE, organizes public transit riders to build a unified voice and movement for better public transportation in Greater Boston, Together, we develop and implement strategies to improve the quality of public transit. Our focus is on transit dependent communities neighborhoods that are predominantly people of color and/or lower-income, where residents are likely to not own cars and therefore depend on public transit to get to work, school, recreation, and shopping.
>
> We have joined together to demand our fair share of service because the MBTA and the state have failed to meet the needs of riders in lower-income neighborhoods and neighborhoods of color. Buses are unreliable, crowded, and slow, and continue to pollute the air we breathe with dirty diesel exhaust, causing asthma and other health problems. Better public transit will alleviate these health problems and help combat climate change by cutting down on waste and pollution.
> – ace-ej.org/tru

In short, TRU demands improved transit accessibility, especially for neighborhoods with transit-dependent populations. They focus on the various components of accessibility, from the individual, as exemplified by their Youth AffordabiliT and anti-fare-hike campaigns, to the temporal, as seen in their advocacy for improved off-peak and early morning service (see Figure 5.5).

TRU is also part of a broader transportation justice coalition in Greater Boston called On the Move (OTM). Formed in 2000 as an alliance of transit, livable streets, cycling, housing, and community development advocacy organizations, OTM's stated goal is "an environmentally sustainable and socially just transportation system that is integral to the preservation and creation of livable communities." In 2013, responding to repeated threats of MBTA fare hikes and service cuts, as well as concerns about housing affordability and gentrification-driven displacement, with its first regional Transportation Equity Summit. This series of workshops involved policy discussions, collective mapping, and public art that considered how discursive and narrative arguments, which privilege "local knowledge" (as discussed in Chapter 4), could be incorporated into the transportation planning process. The short-term fare hike and service cut concerns of this summit were addressed later in 2013 by a state funding bill, but the systematic concerns about affordability, accessibility, environmental

Figure 5.5: T Riders Union protest of proposed fare increases and service cuts

justice, and gentrification remain. In concert with aligned campaigns like Transportation for Massachusetts and Public Transit, Public Good, OTM continues to work on these issues.

5.1.4 Opportunities

A number of recent developments have opened a space for new approaches to transportation planning in the Boston region. The state funding legislation passed in 2013 allowed the MBTA and transit advocates to transition from a crisis management mode toward a more reflective, visioning process. The MBTA's general manager has repeatedly called for a "People's Plan" to assess the MBTA's vision and objectives. The capital planning process may be one avenue for such a reassessment. As part of a recently unified Massachusetts Department of Transportation, the MBTA has for the first time submitted a capital budget in conjunction with the other state agencies representing highway, maritime, and aviation modes. The capital plan calls for performance measures to prioritize projects and gauge outcomes. While the currently proposed measures are mobility-focused and leave much to be desired, there is now a framework to propose accessibility measures that could potentially be used to prioritize projects across modes.

Increased attention being paid to buses, in part through the MBTA's Key Bus Routes

Initiative, has the potential to carry through these strategic and capital planning processes, though, as the omission of bus maintenance funding from the initial capital budget draft suggests, such attention is by no means guaranteed. Another set of changes relates to Boston's new mayor, a change after the 21 year Menino administration. The new mayor has promised a transportation planning review, the first to be conducted in the City of Boston in more than two decades. At the same time, a working group of planners, consultants, and community leaders has been working to take advantage of experience from other cities and develop a proposal for more BRT corridors in Boston.

These opportunities may set the stage for a watershed moment in transportation planning for Boston. The opportunity can be substantially enhanced by broadening the planning focus to include service planning, and the development of understandable accessibility metrics to facilitate communication within and among communities, city agencies, and the MBTA.

5.2 Santiago

Chile's capital is home to more than six million people. The region has an extensive public transit network, including 108 Metro stations serving five lines and the Transantiago bus system (see Figure 5.6). Politically, Chile's emergence from the Augusto Pinochet dictatorship (1973-1990), and the implications of this experience for civil society in the social awakening and economic growth the country is now experiencing, create unique challenges for transportation planning projects.

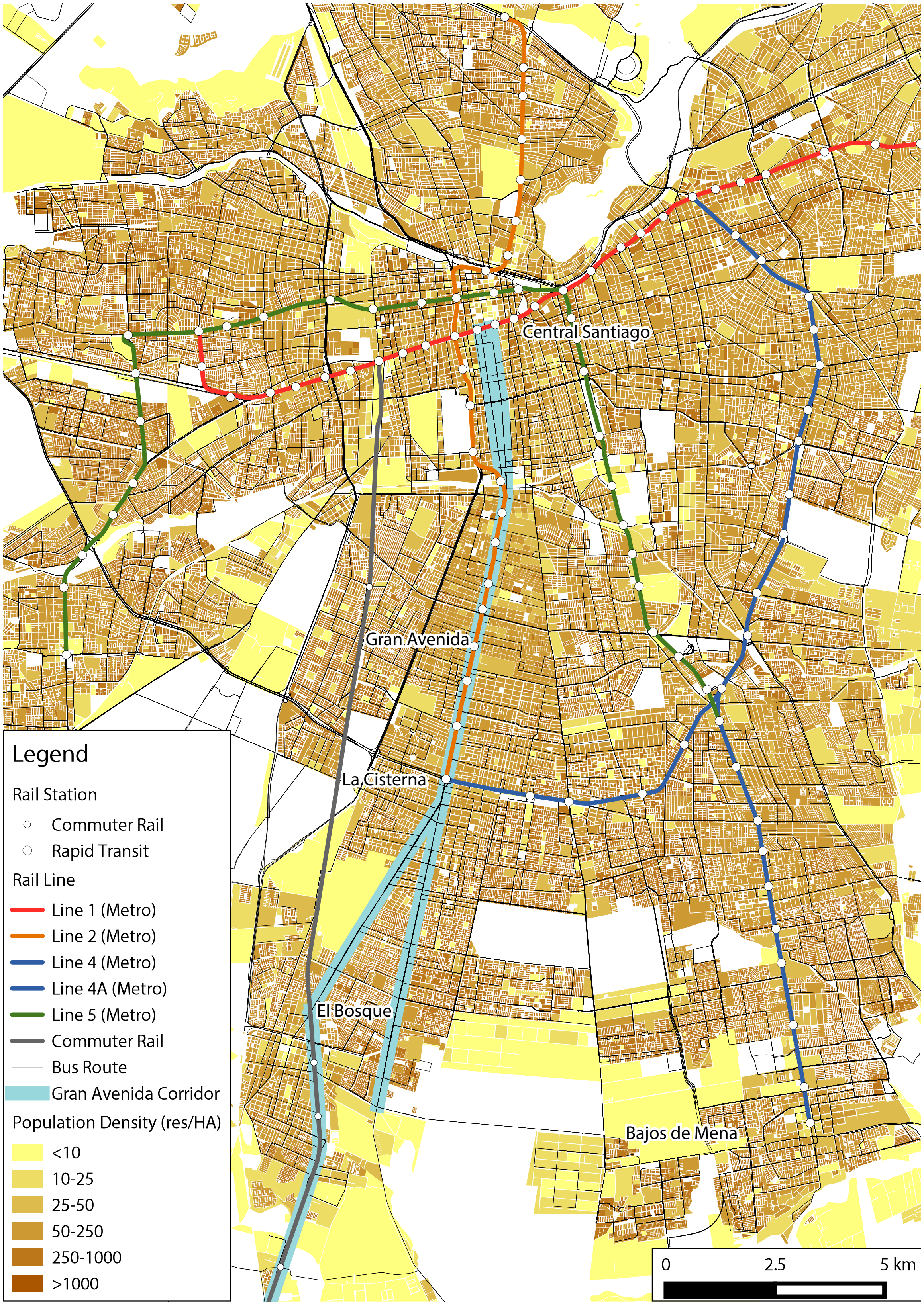

Figure 5.6: Santiago Region

5.2.1 Incremental BRT Development

As noted in Chapter 3, Santiago's bus network, Transantiago, was initially conceived as a completely integrated system, in contrast to the initial limited corridors of Transmilenio in Bogotá (Flores, 2013). The original proposal called for 284 km of bus-only corridors, but when operations began in 2007, only 7 km of priority facilities were available. The lack of priority infrastructure, along with other lapses in planning, led to collapse of the privately provisioned service when it was inaugurated (Muñoz and Gschwender, 2008). Today, authorities are still working gradually to implement the BRT elements required to improve the system's operation, with only 100 km of exclusive infrastructure built. They increasingly believe that efficient operations enabled by significant corridor infrastructure are key, from both the user perspective and the perspective of financial sustainability of the system.

Santa Rosa

Santa Rosa, a major artery that connects dense public housing developments in the southern periphery of Santiago with the downtown core, is an illustrative example of the challenges Transantiago has faced. Determined to avoid reducing vehicular capacity, designers of the Santa Rosa corridor instead resorted to widening the avenue to provide improved transit accessibility for the region's southern districts. This decision led not only to the expropriation of abutters' property, but also to a resulting cross-section that has been compared to a runway (see Figure 5.7).

The poor urban design surrounding the corridor added to neighborhood resistance. Compounding these complications was a complicated contracting structure. Unlike many of the other Transantiago corridors, Santa Rosa was under the direction of the national Ministry of Public works, and the concession scheme they created for construction and maintenance led to conflict and further delays. In part because of these conflicts, the corridor infrastructure is not continuous, leading to lost time and decreased reliability all along Santa Rosa. Clearer communication of benefits and closer attention to urban design might have strengthened the political will to build a complete, integrated corridor.

Figure 5.7: Santa Rosa Transantiago corridor (R. Forray)

Gran Avenida

Running parallel to Santa Rosa, Gran Avenida is a 21 km. long north-south axis of greater Santiago traversed by 25 bus routes. While average bus speeds are relatively high along the corridor (15-20 km/hr during the afternoon peak, 25-30 km/hr at night), congestion in the segments close to the center of Santiago slows travel times and degrades service reliability for the rest of the corridor. Bus-only lanes exist in segments of the corridor, but, like the Silver Line Washington Street Corridor in Boston, lax enforcement means parked cars often block the lanes. The national government put forward preliminary proposals to upgrade segments of Gran Avenida to BRT corridors, but strong community opposition forced them to agree to study the extension of a Metro line to cover a greater portion of the axis instead. Local officials argue that a Metro would better address some of the capacity constraints faced by current bus service, and, more importantly, better preserve some of the area's trees and urban design features.

Alameda-Providencia

A project that gained traction in 2013 was the redesign of the Alameda-Providencia corridor, one of Santiago's most iconic avenues, through the heart of downtown. The corridor currently consists of segregated shoulder lanes for buses and taxis; the proposed project would convert these to median lanes with new stations. This project would facilitate major improvements to the pedestrian realm in the center of the city. Concerns about the equity implications of such a major investment in a downtown area that already has abundant transit infrastructure could be evaluated by modeling the improvements in trips that could be expected for riders who board buses using these corridors in outlying, lower-income areas.

5.2.2 Advocacy Groups and Equity

Compared to groups in Boston, advocacy groups in Chile tend to have fewer opportunities for formal participation and to resort to more adversarial tactics. Fernández and Ordóñez (2007, p. 15) cite three key factors in their diagnosis of civil society in today's Chile, which has been conditioned by the Augusto Pinochet dictatorship (1973-1990): "the persistence of a general weakness of public participation, particularly in relation to public administration...; the absence of institutionalized spaces of participation...; [and] instrumentalized and pre-defined relationships with civic society, which further contribute to inhibiting rather than strengthening the autonomy and involvement of citizens in public administration." The lack of space for interaction between the government and civic society has led to massive, widespread protests, and transportation advocacy groups are not exempt from this adversarial climate.

One coalition of populist groups, Centro Alerta, ran a pro-fare evasion campaign in 2010. With the slogan "Transanfiasco - this is robbery!" the group articulated critiques of the neoliberal philosophy of Transantiago's private operators, created a storytelling program about riders' experiences, and questioned why riders should pay for inadequate service (see Figures 5.8 and 5.9). Direct and confrontational, the campaign brought attention to the experiences of riders and to questions of equity and affordability.

The approach taken by a new Coalition for Just Transport in Santiago has been slightly less adversarial, but they are still direct in their critique of transport planning in Chile: "The current way of addressing transport needs no longer works" (Quijada, 2014, p. 2). Driven largely by a well-established environmental community organization called Ciudad Viva (Sagaris, 2010), the Coalition is committed to advocating for the "creation of integrated

Figure 5.8: Fare evasion campaign - "Why pay for something so bad?" (Centro Alerta, 2013)

transport systems, whose driving purpose is to support equity and social and environmental justice, using the rich array of tools that current knowledge - everyday and technical - makes available for these ends" (Quijada, 2014, p. 2). Specific issues addressed by the Coalition include planned Metro extensions, opposition to new urban highways, and transparency in the contracting of transit service. More fundamentally, they question the lack of participation in transportation planning:

> "Whether you like it or not" – That has been the form in which the government, in these almost 25 years of democracy, defines transport projects and communicates them to the citizenry. Behind closed doors, the minister and his consultants and friends dictate what should be done in our city, whether we who live here like it nor not. Informed only through the press, each one of us realizes what these initiatives are. Then we understand what they want to do with our neighborhoods, our streets, our money, and our form of life. Then protests arise, where we can complain that what they have decided for us is not what we desire. We

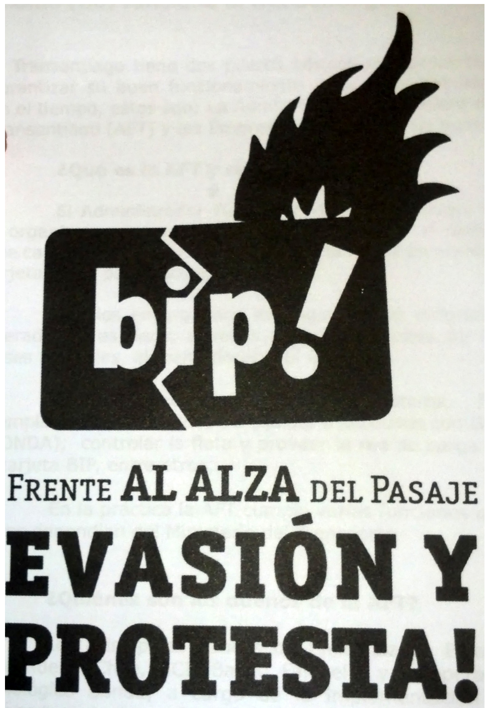

Figure 5.9: Fare evasion campaign - "In the face of fare increases, evade and protest!" (Centro Alerta, 2013)

> propose alternatives, thinking that we're confronting reasonable people whose job is to strive for our well-being, only to see that they deny us. We who have formed the Coalition for Just Transport have differences in certain things, but we all agree that we are the citizens who should decide the fate of our city. – Quijada (2014, p. 2)

The emergence of groups like the Coalition for Just Transport reflects the desire and need for enhanced forms of participation in the Chilean context.

5.2.3 Opportunities

Ciudad Viva, especially through its Active Neighborhoods Network, is now being directly consulted on BRT corridor planning, such as the Gran Avenida and Alameda-Providencia examples mentioned earlier. Their expertise in participatory mapping (Sagaris, 2010), in conjunction with other collaborative mapping projects in Santiago like the BiciMapa cycling map, could make significant strides for participation in these projects.

In March 2014, a new national government took office in Chile. New leaders in the Ministry of Transport, Transantiago, Santiago Metro, and the regional intendancy mark a major transition and the opportunity to put new accessibility metrics into place for regional transportation decision-making. Such metrics have considerable potential given that in the next three years, Santiago will be opening two new Metro lines, which will almost certainly be the impetus for a restructuring of the bus network, and a potential shift in focus to include service planning.

Taken together, these opportunities could be a step towards new planning paradigms and the mandate for participation in Chile articulated by Fernández and Ordóñez (2007, p. 15) – "to open institutional participation channels, in a way that gives spaces for the public to play a relevant role in programs and projects that could benefit them, thus strengthening the fragile but necessary relationship between public administration and civil society."

5.3 Conclusion

Both Boston and Santiago, despite having different urban forms, histories, and political structures, have been the setting for highly contentious bus projects in the last decade. New opportunities in both of these contexts open the possibility for rethinking BRT and reframing transportation planning, at system, project, and service levels, in terms of accessibility and equity.

Chapter 6

Designing Accessibility Visualization Tools for Participatory Inquiry

New tools to measure and communicate accessibility have the potential to substantially improve urban transportation planning. This potential is especially promising for complex incremental BRT projects with high degrees of spatial and temporal flexibility, and in contexts that may be re-envisioning how transit works. Building participatory structures around these tools may be one way to maximize their impact, as well as the associated sustainability and equity benefits of moving away from technocratic mobility measures. This chapter describes the development of IBRT Accessibility, a new toolkit based on the open-source Open Trip Planner platform and designed to foster deliberative participatory inquiry for incremental BRT projects and urban transportation planning more broadly.

6.1 Assessment of Existing Tools

Multiple existing tools to visualize urban accessibility are cataloged in Chapter 2.3. These tools allow for sophisticated representation of the various dimensions of accessibility. Both the visualizations and the metrics that underlie them can be assessed with the criteria established by Geurs and Van Wee (2004, p. 130): "(1) theoretical basis, (2) operationalization, (3) interpretability and communicability, and (4) usability in social and economic evaluations."

In terms of the first criterion, the tools mentioned previously are theoretically acceptable, generally based on cumulative opportunity measures calculated from scheduled transit service and widely used shortest path algorithms. Extending these tools to use gravity-based metrics, as discussed in Chapter 2, could be desirable and relatively straightforward if the relevant decay functions are available. More accurate network speeds, whether achieved through empirical measurements or models that include congestion effects, would also improve the theoretical soundness of these tools. The existence of the tools demonstrates the operationalization (2) of the underlying metrics, and the web interfaces are interpretable and communicable (3). Their usability in actual evaluations (4) seems promising, but this criterion has been the subject of relatively little critical research. In most cases, these tools have been published online as thought- and discussion-provoking ways to visualize urban systems, but without detailed guidance on how they might be used in evaluations or participatory settings.

The focus of this work, then, will be to implement an accessibility visualization toolkit that builds on these already-developed tools through a process of interpersonal dialogue.

6.2 Goals for a Participatory Accessibility Visualization Toolkit

With the strengths and shortcomings of existing visualization tools in mind, the following goals were considered when developing IBRT Accessibility:

Table 6.1: Goals for toolkit features

Develop stronger links between personal and regional lenses on accessibility
Better reflect actual conditions
Foster mutual learning
Highlight the equity implications of accessibility measures
Compare benefits of different projects

The goals summarized in Table 6.1 are discussed in detail below.

Develop stronger links between personal and regional lenses on accessibility. The toolkit should have a unified interface that links trips with which individual riders are familiar to regional accessibility patterns. It should foster an understanding of how personal experiences of and narratives about access are shaped by, and can be used to calibrate, broader accessibility measures; in other words, it should complement the focus on mobility with the spatial and individual perspectives that also comprise accessibility (Fol and Gallez, 2014).

Better reflect actual conditions. Current tools are based on transit service as it is scheduled, not as it is actually operated. Actual operations generally result in degraded accessibility due to congestion, unreliability, and crowding. Rigorous quantitative solutions to this shortcoming, such as using archived vehicle locations from GPS tracks as inputs to the accessibility tools, are one approach. Such technical approaches would still have shortcomings; for example, even if bus bunching were reflected in vehicle location data, denied boardings would not be. Moreover, increasingly involved technical solutions might do little to inspire non-experts' trust in the tools. Instead, allowing participants' input to modify the assumed transit performance would give participants a sense of buy-in, since they could immediately see their experience reflected in the tool. Incorporating feedback into service planning and actual operations could be a relatively quick, though not immediate, way for a transit agency to establish credibility and build confidence.

Foster mutual learning. The toolkit should allow users to learn about the possibilities and constraints of transit projects, specifically BRT features and how they relate to the urban landscape, from precedents and recognized experts. More importantly, it should allow the recognized experts to learn from the local knowledge of the participants, through both discussion and through the logging of their queries that can be analyzed later. Allowing users to save and share their input and results would facilitate mutual learning among the participants, as well as other interested parties.

Highlight the equity implications of accessibility measures. The visualizations should draw attention to populations, not just areas, underserved by transit. It can also correct for the current overstating of access in areas of poor reliability by updating schedule data to more accurately reflect operated service.

Compare benefits of different projects. Projects of interest to planners and advocacy groups should be able to be represented, evaluated, and compared with the tool.

Combined, these goals promote the collaborative formulation of projects and their evaluation. If met, they could help ground debates about transportation planning in "local realities and citizen interpretations rather than would-be 'objective realities' designed by analysts sitting behind desks" (Fischer, 2000, p. 187). They would foster the open participation advanced in Chapter 4 by valuing local knowledge and breaking down the masks of rational expertise.

Situating these visualization tools within a facilitated process can help advance equity goals. Highlighting populations with low levels of access can help improve outcomes, and at the same time, these goals help advance procedural equity, "partnership in the planning process that results in shared decision-making" (Carter et al., 2013, p. 11).

6.3 Proposed Toolkit: IBRT Accessibility

To address these goals, a version of Open Trip Planner was customized for the contexts described in the previous chapter, and to include relevant aspects of incremental BRT.

6.3.1 Modules

Three Open Trip Planner modules are at the core of IBRT Accessibility. In all of these modules, example incremental BRT projects could be toggled on and off to show the projects' impacts through the lenses of individual trips, regional mobility, access, and accessibility.

The first is a web-based journey planner, the core original functionality of Open Trip Planner. With two clicks, this module allows a user to see the fastest routing options between two points drawn on a map. Additional options regarding time, date, and mode of the trip are easily configured. This core interface was extended to include user-settable wait time parameters and links to information about BRT and street design.

Another mobility-focused feature of Open Trip Planner is the analyst module, which uses the same web interface to map isochrones showing travel time at a specified time by a specified mode from a specified point. By itself, these isochrones represent mobility. Land use layers were then superimposed to shift the focus towards access and accessibility, which is a function of both mobility and land use.

The final Open Trip Planner module utilized was the batch analyst, which can output rasters quantifying accessibility metrics for cells throughout the city. Due to computing time (30-45 minutes for intermediate-sized cities and network on a laptop computer), this is not yet available through a web interface, but the maps could reasonably be created before a meeting, or during a meeting using cloud computing resources.

Screenshots of all three of these modules, as customized for the trial contexts, are included in Chapter 7.

6.3.2 Setup

The following steps were followed to setup the tool:

1. Download Open Trip Planner from the Github repository and configure it in the Eclipse Integrated Development Environment
2. Download Open Street Map road network extracts for the appropriate geographical extents
3. Download GTFS feeds for the transit agencies in question
4. Extend the GTFS feeds to represent scenarios by adding new routes and trips
5. Build the Open Trip Planner routing graph, combining the road network, transit network, and transit schedule data
6. Customize the javascript-based user interface and Java-based back-end by adding features and translations
7. Export web archive files from the Eclipse IDE and upload them to a server running Apache Tomcat

The tool is available online at http://transitlab.mit.edu/ibrt

6.4 Proposed Structure for Facilitated Workshop

The guiding concept for the proposed workshop is deliberative participatory inquiry: "an ongoing and iterative process requiring two-way communications, such deliberation focuses on 'how problems are defined and understood, what the range of possible solutions might be, and who should have the responsibility for solving them' (Reich 1990, 7)." (Fischer, 2000). Deliberative dialogue has mutual learning as a key objective:

> When an inclusive set of citizens can engage in authentic dialogue where all are equally empowered and informed and where they listen and are heard respectfully and when they are working on a task of interest to all, following their own agendas, everyone is changed. They learn new ideas and they often come to recognize that others' views are legitimate. They can work through issues and create shared meanings as well as the possibility of joint action. They can learn new heuristics. –Innes and Booher (2004, p. 428)

The process and outcomes that Innes and Booher (2004) describe align well with the goals desired for the proposed workshop. Small, collaborative groups can work together to advance equity and learn the new heuristic of accessibility metric-based project evaluation and planning. The agenda presented below seeks to encourage these outcomes for such a small group in a 90 minute workshop.

6.4.1 Introductions

To establish trust, all participants are asked to introduce themselves briefly and share why they are interested in transit. Additional introductory questions asked of the group serve as "problem setting." Fischer (2000, p. 185) explains, "Problem setting is fundamentally normative and qualitative. In technical analysis, values and goals are taken as given; in problem setting, analysis focuses on their identification and discovery." Example problem-setting questions for this workshop include:

- What is the purpose of a transit system?
- How is it decided to improve transit service? How should it be?
- How is it decided whether or not to build a project? How should it be?

These broad questions open space to explore the values and goals with which participants approach transit projects. Effective facilitation will emphasize the provision of access as the purpose of transit, and equitable accessibility gains as the guiding decision metric for projects.

6.4.2 IBRT Accessibility Demonstration

Participants are then introduced to the web-based IBRT Accessibility tool. Using a projector or shared screen, the facilitator demonstrates the interactive trip planning module, including its trip calibration features, then participants are given the opportunity to try it on their own computers. The facilitator invites participants to discuss trips they typically make and how well they think these trips are represented through the tool. Infrastructural tactics, such as bus-only lanes, are then introduced as possible ways to reduce trip times in the context of users' journeys. A similar process of guided learning and discussion is used with the interactive analyst module and its isochrone maps. Example land use layers are then superimposed, the concept of accessibility is introduced, and results from the batch analyst are discussed.

6.4.3 Debrief

To conclude the workshop and crystallize some of the mutually learned lessons, participants are guided through a discussion of how other transportation projects and service changes might be proposed and ranked. They are also asked to consider sharing with their social networks samples of the corridors they configured, and the impact of these configurations on their trips. Finally, opportunities for additional analysis and action are considered.

6.5 Conclusion

The workshop structure proposed in this chapter is the antithesis of the typical public hearing, in which information flows one way, from the officials to the audience. Both enabled by the visualization software tools, and as a way to build political will for more widespread adoption of the guiding accessibility metrics that underlie the tool, this joint learning exercise could be an effective new approach to participation around urban transportation planning. Further developing, testing, and implementing this approach would require significant preparation and resources. The evaluation effort described in the following chapter is one step in this direction.

Chapter 7

Evaluating IBRT Accessibility

Boston and Santiago de Chile, the two contexts described in Chapter 5, were used to evaluate the IBRT Accessibility toolkit and the proposed participatory inquiry process built around it. Pilot versions of the web interface were developed and tested with focus groups in both cities. These focus groups followed the agenda outlined in Chapter 6, with minor additions of background information about participatory tools and accessibility frameworks, as well as meta-questions about the tool and the process. Salient points from these evaluative efforts are included below.

7.1 Boston

7.1.1 Interface Customization

Two potential incremental BRT corridors of interest were included as options in the Boston version of IBRT Accessibility – the western half of the Urban Ring, and Blue Hill Avenue. Special trips for these routes were appended to the GTFS files used to build the graph for this instance, and options related to these special trips were added to the web interface. The interface for the trip planning and analyst modules is shown in Figures 7.1 and 7.2. The trip planning module is similar to other widely used trip planners, showing suggested routings, services, and times for a selected origin and destination. The analyst module depicts travel time isochrones from the blue marker; points within the green area, for example, are accessible within 30 minutes via the specified mode at the specified departure time.

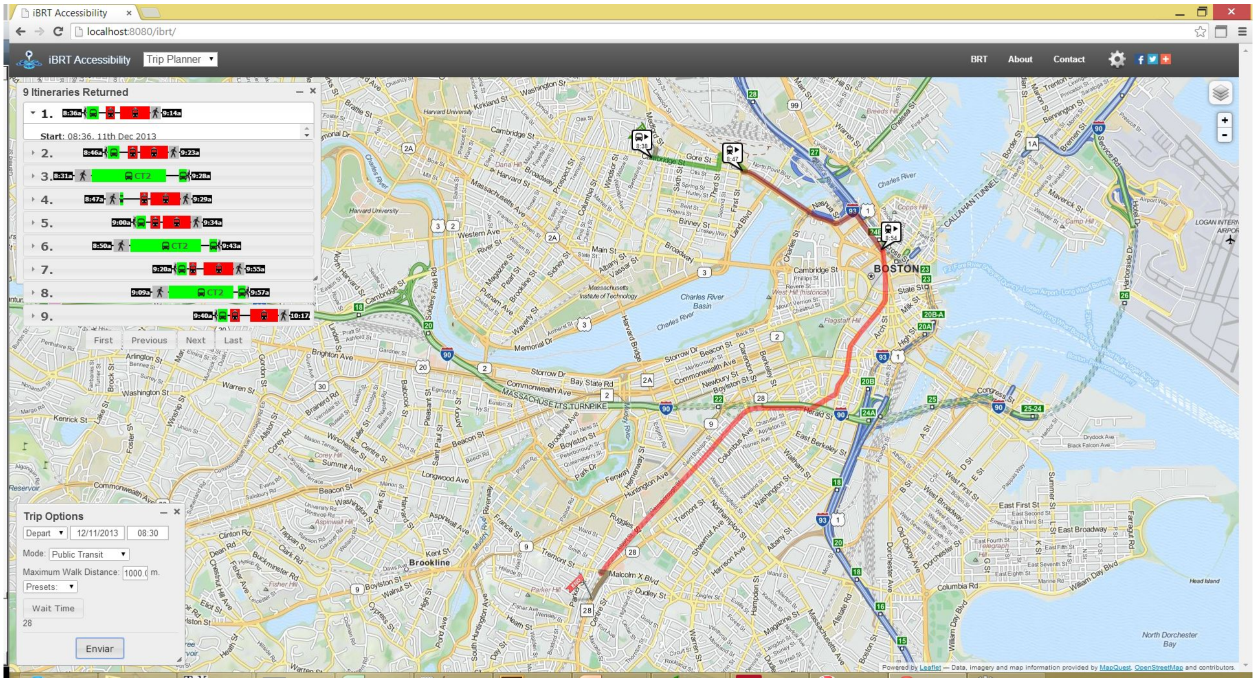

Figure 7.1: Trip planning module - Boston

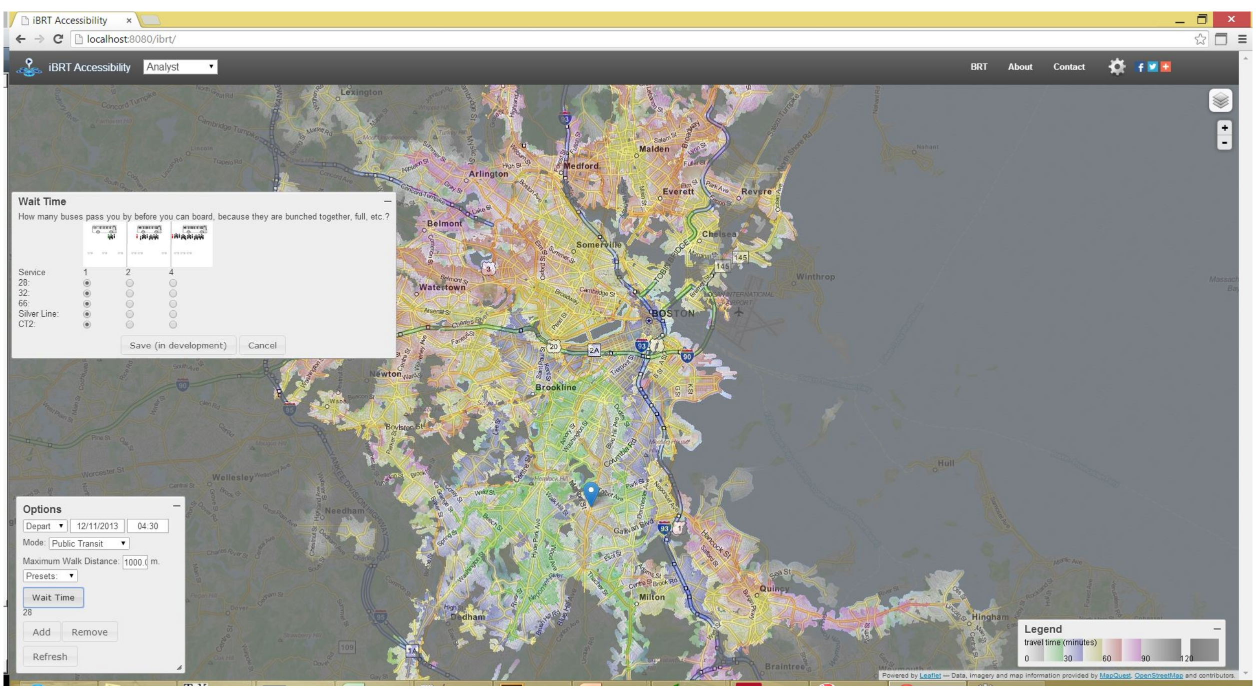

Figure 7.2: Isochrone module - Boston

7.1.2 Sample Results

In general, the trip planning and isochrone modules performed well. Some unexpected results were encountered using the isochrone mapping module, likely due to Boston's relatively dense transit network and the associated large number of possible alternatives. There were also some incorrect results for early morning departures; these anomalies suggest that the initial waiting time is not reflected well in the isochrone maps. Another possibility is that the provided GTFS file's use of both full trips (specified for MBTA services) and frequency-based trip patterns (specified for Massport shuttle services) led to unexpected behavior in the waiting or travel time calculations.

The example land use layer chosen as a destination for accessibility calculations was simply number of employees per block according to Census Transportation Planning Package 2010 Part 3. The results of sample cumulative opportunity measure processing are shown in the figures below. Figure 7.3 shows, for each approximately 80 meter by 80 meter grid cell, the number of jobs accessible from that cell for a traveler departing at 8:00 AM via existing public transit service. Figure 7.3 depicts the same calculation with the addition of BRT service on the western half of the Urban Ring corridor (shown in yellow). In both of these figures, the high concentration of jobs in Downtown Boston leads to prominent nodes of high accessibility along Boston's radial transit lines. Figure 7.5 shows the difference between the preceding two figures, that is, the accessibility gains attributable to the added service. Major employment accessibility gains occur in the northern half of the corridor, reflecting reduced travel times from these brownfield areas (e.g. Assembly Square and the Inner Belt district of Somerville) to the job centers of Kendall Square and the Longwood Medical Area, as expected. Notable gains also occur in areas west and south of the corridor itself, reflecting the importance of connecting services. Understanding these gains could be an important step towards building political will among constituents beyond the physical footprint of the corridor.

These maps are limited, though, in their reliance on specific departure time (8:00 AM) and journey time cutoff (45 minutes). The "continuous accessibility" approach developed by Owen and Levinson (2014) would address the first shortcoming. It would also be relatively straightforward to convert these cumulative opportunity maps to gravity-based maps, which would not be reliant on a hard journey time threshold.

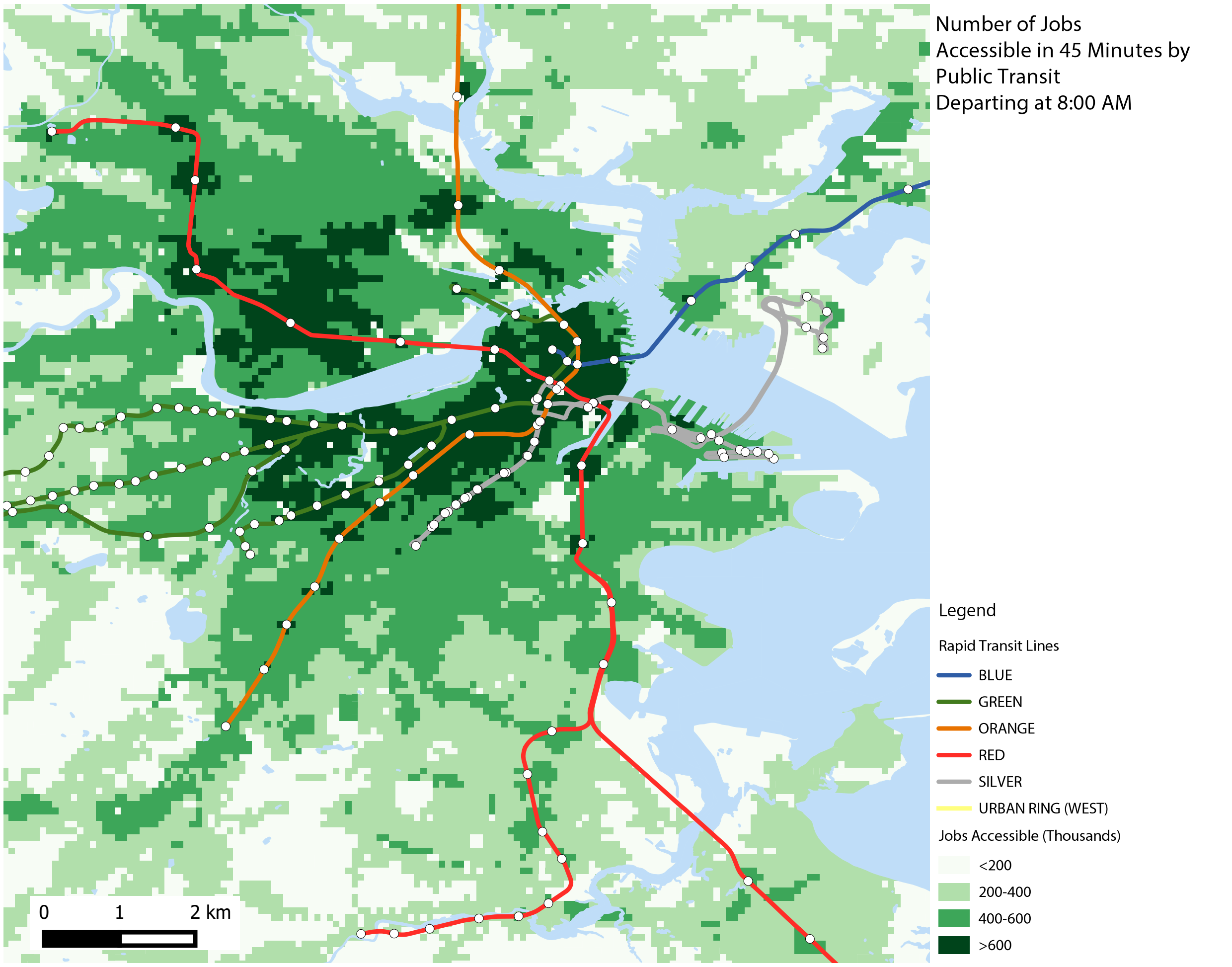

Figure 7.3: Accessibility to Jobs in Boston, current service

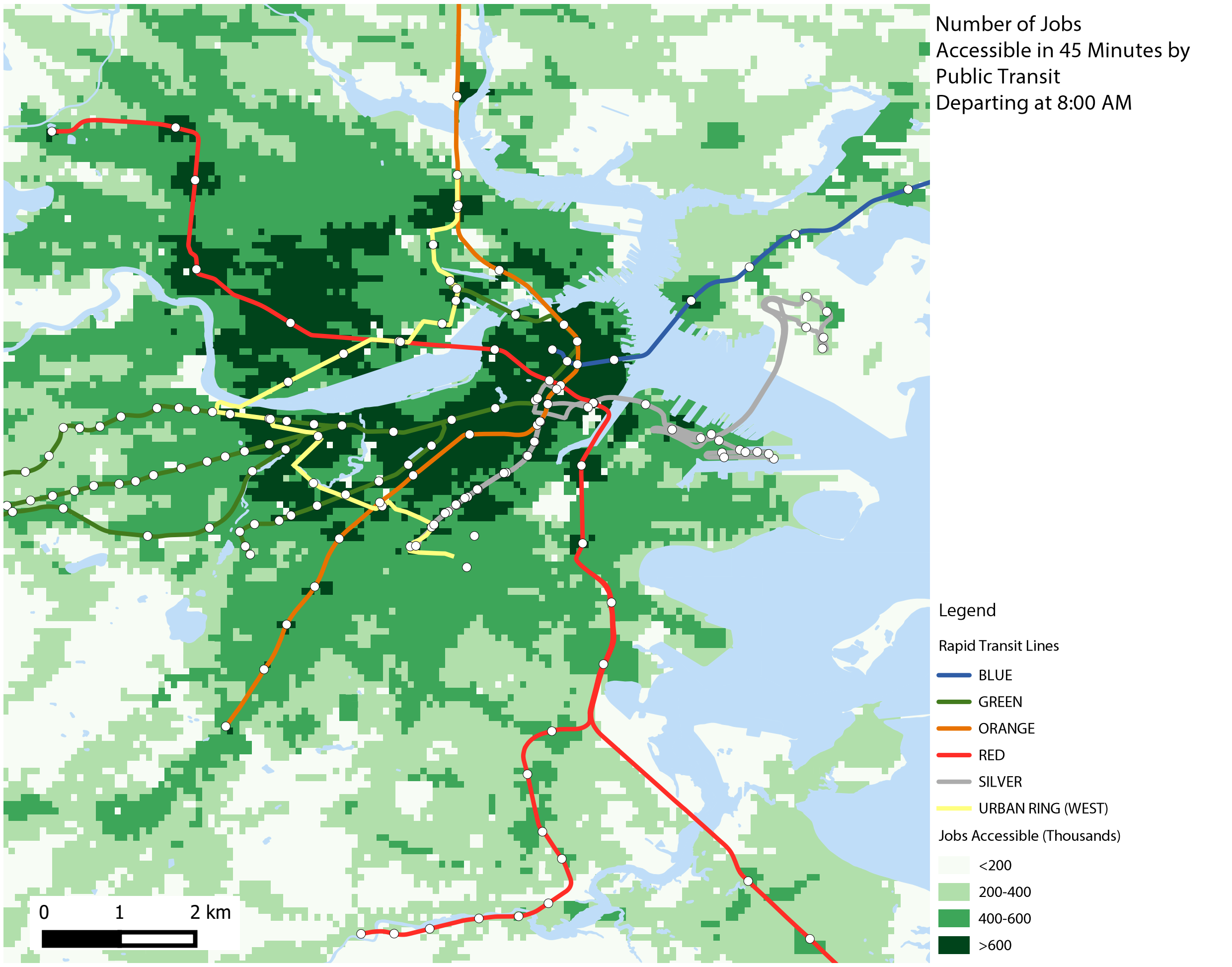

Figure 7.4: Accessibility to Jobs in Boston, adding the western portion of the Urban Ring

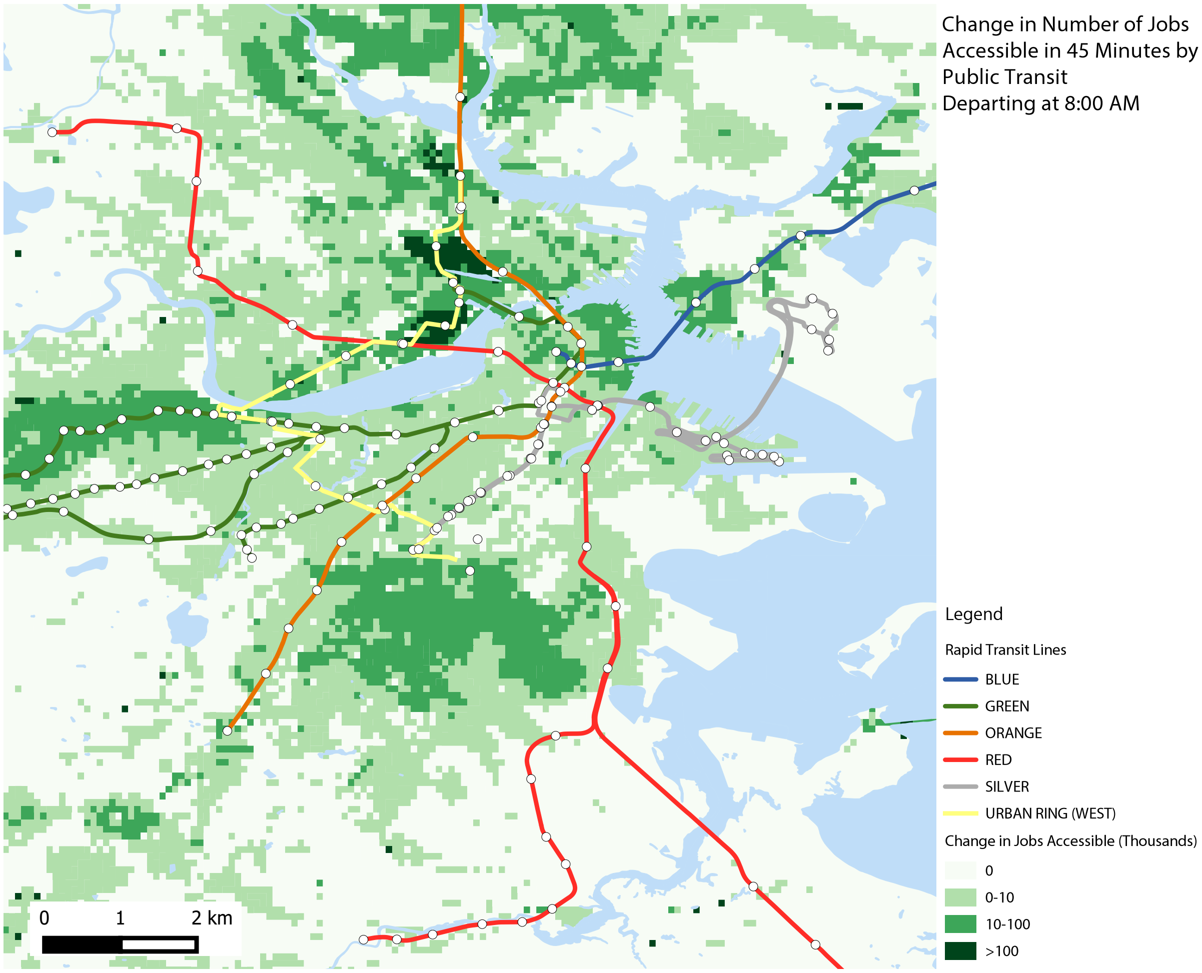

Figure 7.5: Change in accessibility to Jobs in Boston with the western portion of the Urban Ring

7.1.3 Focus Groups

The interface was tested with about ten participants at a strategic planning meeting for T Riders Union (TRU) in Boston. Introductions and broad conversations about transit had been conducted before the IBRT Accessibility session; since the participants all knew each other, and "problem setting" had already been conducted, the introductory part of the focus group agenda was only briefly covered. Background on participatory tools included a demonstration of a very preliminary version of Transit Mix. Participants were especially enthusiastic about this tool, which provides rough estimates of bus operating costs based on a drawn route and assumed headway and span of service, since many of TRU's proposals center on added bus service.

In general, the web components of the toolkit were agreed to be powerful and understandable.

In the demonstration of the isochrone module, the difference between the distance coverable via transit and via walking was compared, reflecting the reduced mobility residents face when they are unable to afford MBTA fares. A longtime resident of a Boston neighborhood seeing skyrocketing commercial development suggested we use the tool to critique claims about this development being beneficial to nearby residents. Indeed, the isochrones suggested that despite geographic proximity, sparse transit service meant that workers were farther in terms of travel time than many had realized.

A number of possibilities for future action were discussed. First, TRU would be interested in seeing accessibility maps calculated based on operated, rather than scheduled service. Such an undertaking could be relatively straightforward extension of this work given the MBTA's GTFS-RT API, and it could powerfully illustrate the impact of dropped trips and unreliable service on their membership base. Another campaign they are exploring is improved early morning service. The tool's adjustable time of day options would be conducive to an analysis supporting this campaign, but some inconsistencies were found with it, as described previously. A final idea shared by an attendee was to simply print hard copies of Figure 7.3 and use it as a flier for recruiting new TRU members. In her opinion, the map was clear and could spark the interest of potential members who live in neighborhoods with low accessibility. This point served as an important reminder about ways to distribute the results of these tools to people who do not use the internet extensively.

Another set of demonstration sessions was conducted with transportation planning professionals and non-profit leaders. Unfortunately, in one of these sessions, the web interface's interactive components were unavailable because of an internet connectivity issue. Nonetheless, users' reactions were generally positive and raised some additional considerations. A number of professionals and activists agreed that for the accessibility to employment maps, segmentation by the type and education requirements of jobs was crucial. In the context of project-specific discussions, the audience was inclined to read the accessibility maps, even for the base level of accessibility, as the gains attributable to a project. Clearer ways to distinguish between maps that show base-line levels of accessibility and project benefits should be investigated. Another point raised by an activist was the power of these maps in addressing gentrification. In his view, unaffordability and displacement are already foregone conclusions for many central neighborhoods; the accessibility maps show that the outlying neighborhoods to which many of these residents are pushed have minimal accessibility via transit, which could further exacerbate the challenges these residents face.

7.2 Santiago

7.2.1 Interface Customization

The interface used for testing in Santiago is shown in Figures 7.6 and 7.7. In both the trip planning module and the isochrone module, users can toggle service on the primary trunk routes on Gran Avenida. Due to an artifact of the version of Open Trip Planner used at the time, and the frequency-based GTFS file released by Transantiago, waiting times are not included in travel times or isochrones, a major limitation.

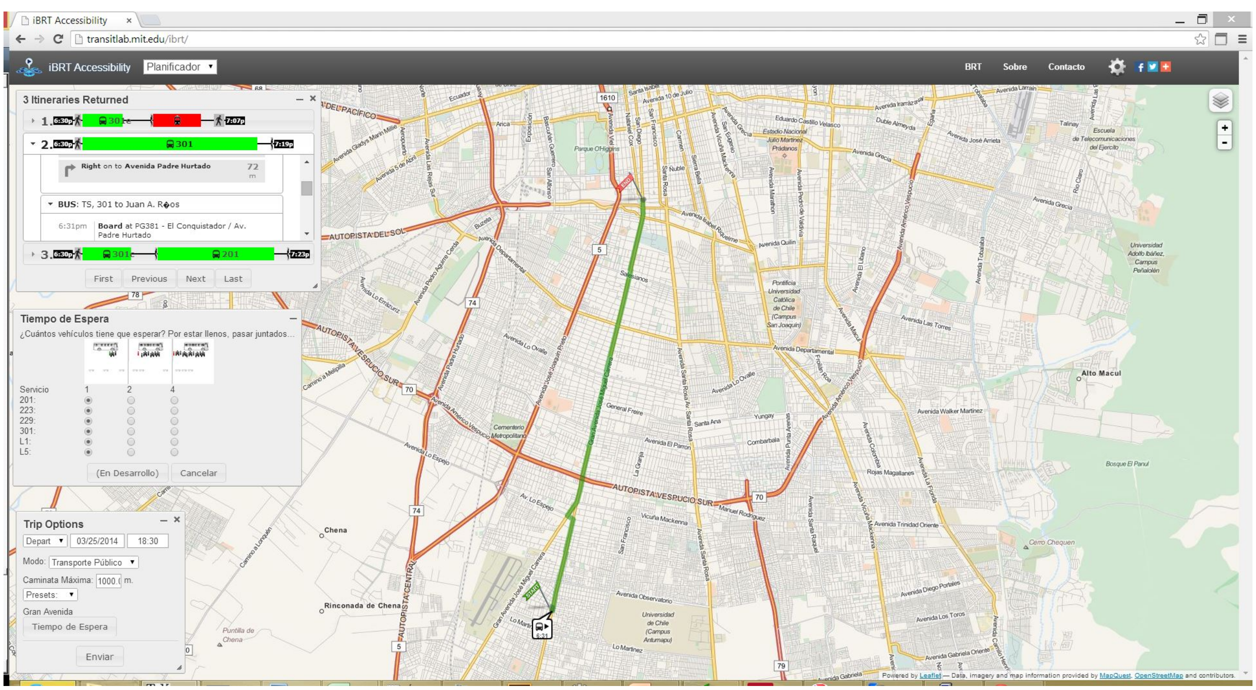

Figure 7.6: Trip planning module - Santiago

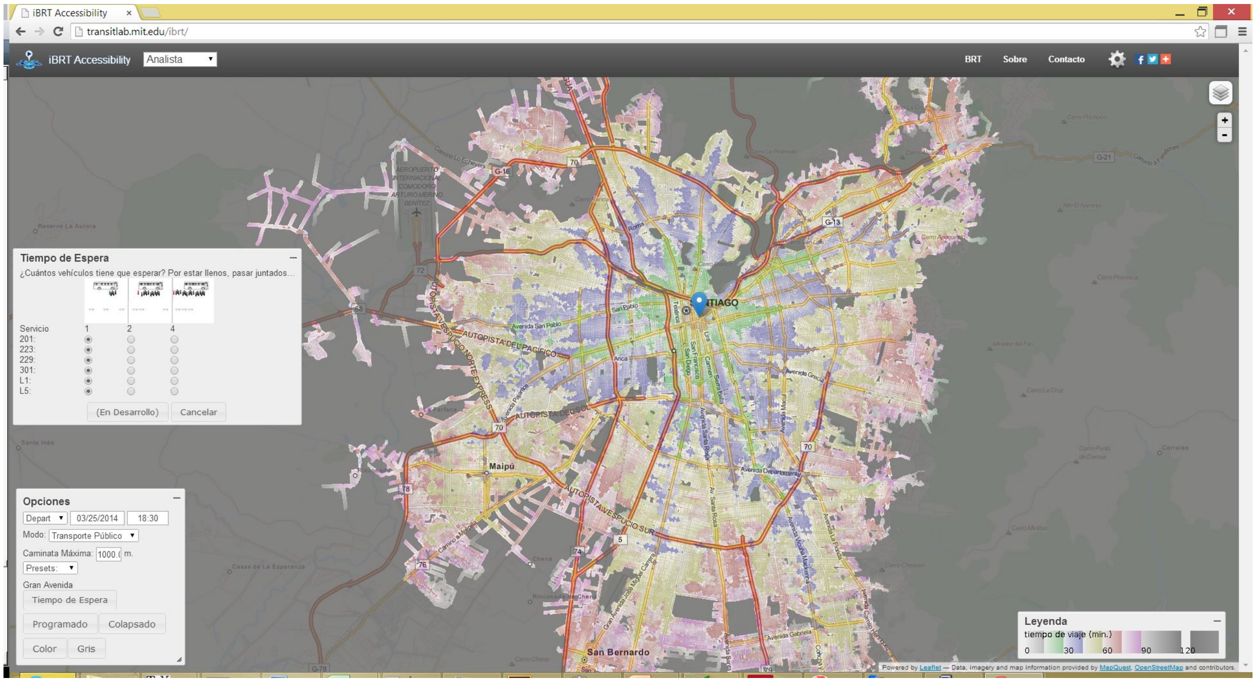

Figure 7.7: Isochrone module - Santiago

Pharmacies were selected as a representative destination land use for the access and accessibility calculations. While recent job location data are not publicly available for Santiago, pharmacy locations have been released on the national government's open data portal (http://datos.gob.cl) and represent an important type of destination for many residents. They also tend to be located near other commercial services, so they may be an appropriate proxy for access to broader services. These pharmacy locations were superimposed (as green dots) on a modified, transparency-based version of the isochrone module to portray gravity measures visually (see Figures 7.8 and 7.9). In Figure 7.9, more easily visible areas are easier to access, reflecting available walking infrastructure and transit service. Notably, there are pharmacies located closer to the green origin marker that are harder to reach than pharmacies that are farther away by distance.

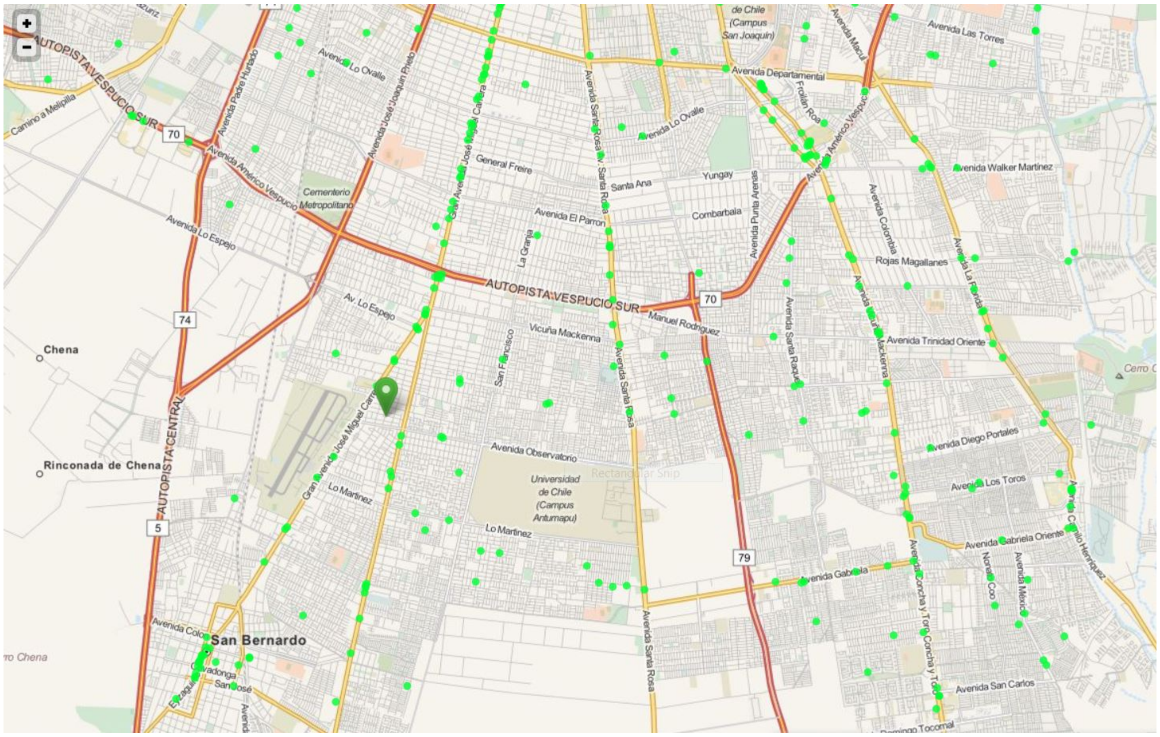

Figure 7.8: Pharmacy locations south of Santiago

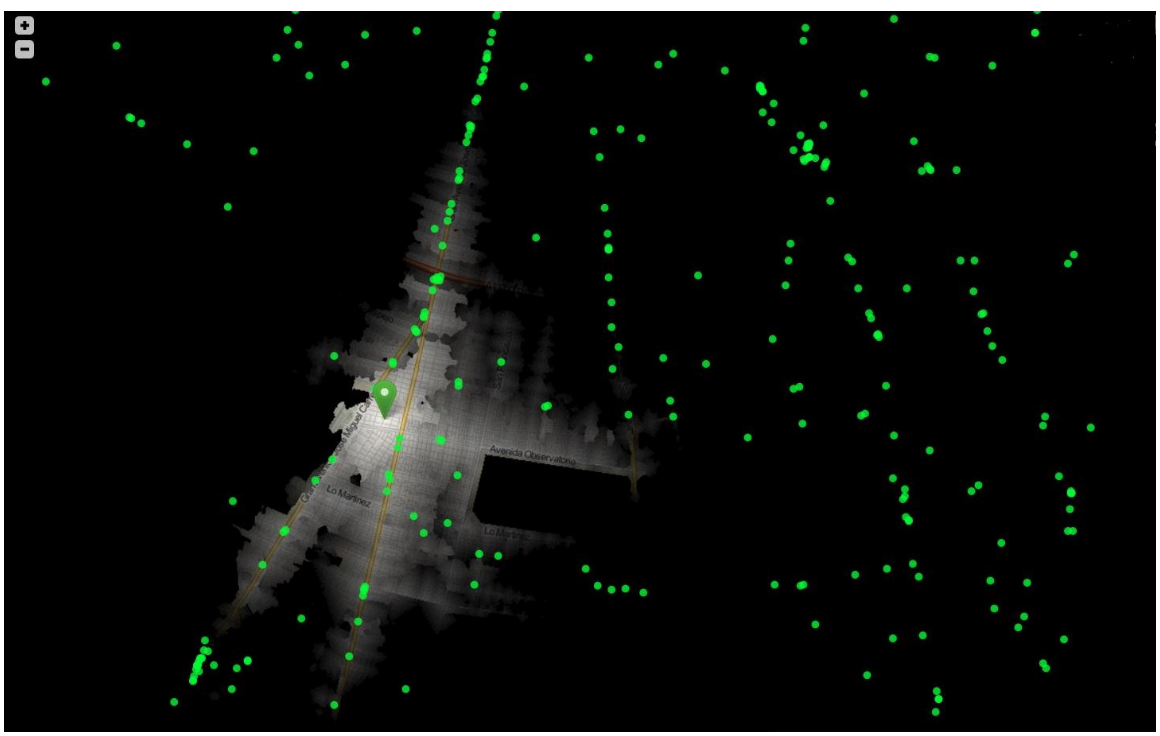

Figure 7.9: Pharmacy locations south of Santiago with travel time gradient overlaid

7.2.2 Sample Results

In addition to ignoring wait times because of the frequency-based GTFS input file, the results from Santiago are also biased due to an approximation made in the calculation of GTFS inter-stop running times. In calculating these times for a route, the agency uses the average commercial speed for the route's entire length, resulting in scheduled running times that are unrealistically short for congested segments and unrealistically long for uncongested outlying areas.

Despite these possible biases, the basic patterns of accessibility to pharmacies can be clearly seen in Figure 7.10. High degrees of accessibility are seen around the rail network as well as some primary arterials with abundant bus service and commercial development (e.g. Gran Avenida in the south of the city, Avenida Independencia northwest of the city center, and Avenida Los Condes in the northeast).

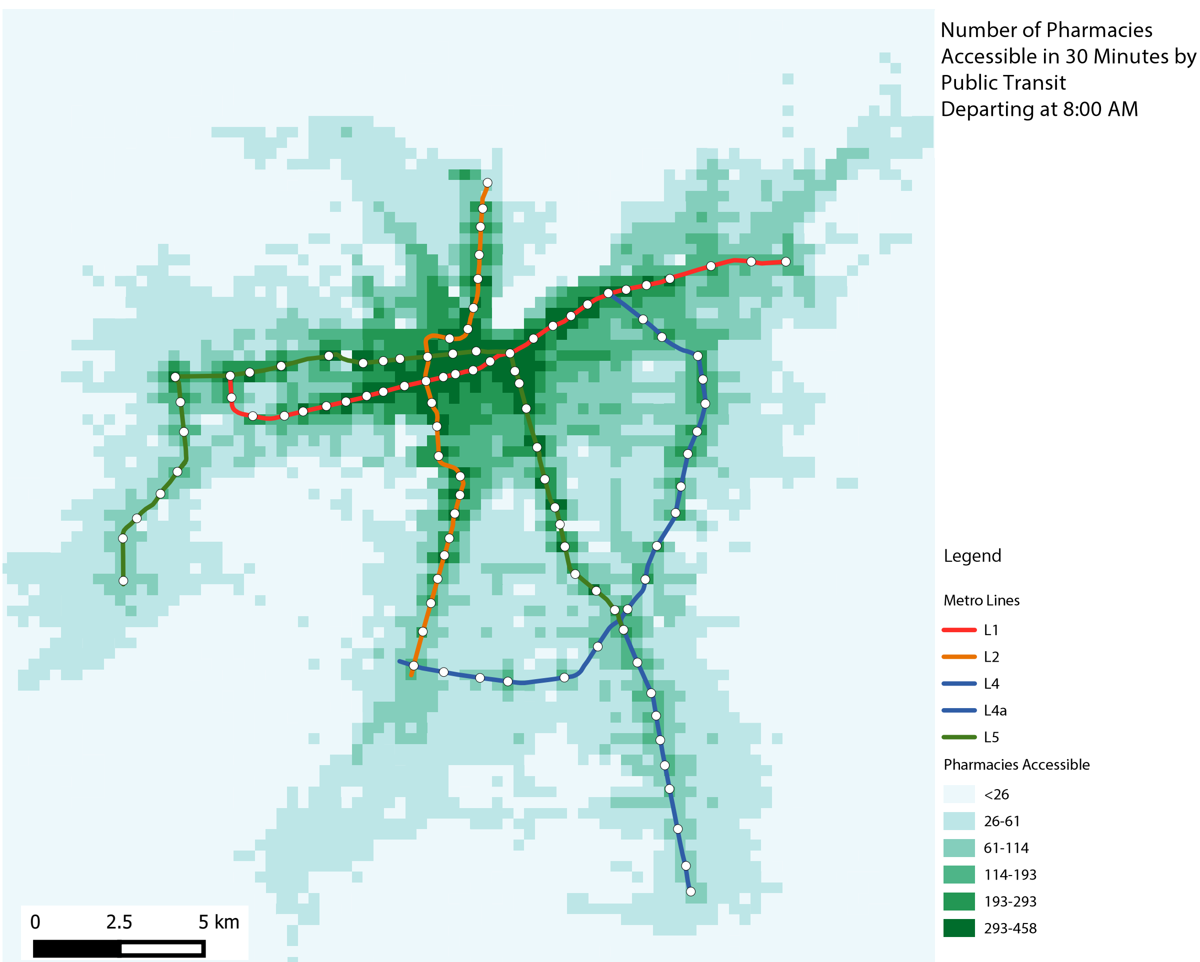

Figure 7.10: Accessibility to Pharmacies in Santiago

7.2.3 Focus Groups

Eight affiliates of the Coalition for Just Transport attended a focus group session at the offices of Ciudad Viva in Santiago. The introductory conversation about the purpose of public transit system raised some important points about the Santiago context. One response, that public transit exists to "order the city," speaks to experience with loosely regulated atomized operators that is more recent, and in the case of colectivo taxis, still extant. Another participant defined the purpose of a transit system as allowing people to move and participate in the city at reasonable cost and within reasonable time. This response made for a smooth transition to the theoretical discussion of mobility, access, and accessibility, and the overview of participatory tools (e.g. Streetmix, discussed in Chapter 4) and the open data sources used to construct the tool (Open Street Map and data from the national government's open data portal).

Conversation continued as the workshop shifted towards the IBRT Accessibility Demonstration. A great deal of time was spent on the under-developed trip planner, with the agreement that to be a robust feedback tool about users' experiences, it would need more development and thinking about the attributes of trips that matter to riders. Users were excited about seeing the benefits of modal integration between bikes and transit (e.g. by modeling bike parking at transit stations and allowing for bikes to be used as a feeder mode) through both the trip planning and isochrone modules. One participant expressed the sentiment that the visualizations of connectivity benefits could "drive real intermodality." The discussion of the equity concerns apparent through the analyst module was engaging, with participants highlighting specific zones like Bajos de Mena. Participants understood, but were generally less engaged with the accessibility maps, noting that equity concerns could be seen clearly enough through relative isochrone sizes for different origins.

Participants were also enthusiastic about taking action moving forward. Some of the group's leaders began discussing the compilation of a regional diagnostic report that could be presented to the Metropolitan Public Transport Directorate, and the notion that "this is a tool to fight with the authorities." In terms of comparing different projects, they were cautious about ranking investments across modes. Portraying the accessibility benefits of a highway extension, for example, would require careful analysis of auto ownership. A number of attendees expressed a strong interest in a drag-and-drop method for sketch planning of routes that could be input into Open Trip Planner, similar to the Transit Mix approach.

Multiple demonstration sessions with current and former Transantiago employees were also conducted. They all regarded it as a useful tool worth further development. In particular, one planner noted that it was helpful for seeing the entire system in one view, since much of the data about Transantiago's contracted service is otherwise distributed across a large number of spreadsheets. They also reiterated an interest in seeing how isochrones and accessibility would change if they showed actually operated service. One planner with extensive international experience had ideas on how the tool could be used by public and private entities in other cities in South America, especially because it links the tactical and strategic levels of planning so well. He highlighted the possibility of using Open Trip Planner Analyst to calculate return on investment for corridor infrastructure projects. He also suggested that in other South American cities, supposed experts, who disregard local knowledge and expertise to the detriment of the transit projects, would do things totally differently if they used a tool like this.

Chapter 8

Lessons for Participation and Planning

In general, focus group participants identified a wide range of uses for the pilot toolkit developed. Testing the toolkit with audiences in two different cities allowed for the identification of some larger conclusions. Findings from the focus groups are synthesized with respect to the goals for the tool and to concerns about participation and planning more broadly. Areas for future research and recommendations for planners and advocacy groups are then discussed.

8.1 Findings

The implementation of the tool is considered in relation to the goals outlined in Chapter 6:

Table 8.1: Toolkit goals assessment

Goal	**Degree Met**
Develop stronger links between personal and regional lenses	Fully met
Better reflect actual conditions	Unmet
Foster mutual learning	Partially met
Highlight the equity implications of accessibility measures	Fully met
Compare benefits of different projects	Partially met

The assessments summarized in Table 8.1 are detailed below:

Develop stronger links between personal and regional lenses on accessibility. This goal was met well. Conversations in the focus groups revealed a clear understanding of the tool and how it could be used to represent trips common to riders' everyday experiences as well as broader concerns of advocacy groups.

Better reflect actual conditions. Due to unforeseen software issues described in the previous chapter, this goal was not fully realized. The pilot interface for adjusting waiting time was not well-received either, though it did prompt helpful discussions of what performance measures mattered most to transit riders.

Foster mutual learning. Definite potential to meet this goal was seen in evaluations. Even though the focus groups were not conducted with both planners acting in an official capacity and members of the general public in the same audience, both audiences expressed strong interest in the tool. It is anticipated that a dialogue including both officials and non-expert participants in the same session would be well-received and fruitful.

Highlight the equity implications of accessibility measures. This goal was successfully met. While it may partly reflect the orientation of the advocacy groups in attendance, in both Boston and Santiago, participants noted the clear appearance of transit deserts in areas with vulnerable populations, as well as the power of such graphics in campaigning for equity.

Compare benefits of different projects. While very few projects were actually evaluated in this thesis project, the potential for groups to generate and evaluate proposals with limited technical assistance was clear. Another possibility is the option to visualize possible synergies between projects; advocates might be able to show that building a combination of projects could have network benefits that are more than the sum of their individual benefits.

These findings suggest that, when supplemented by participatory visualization tools, accessibility metrics can be readily understood and included more widely in transportation decision-making. The equity implications and the connections to personal experience and local knowledge of these metrics were readily apparent to planners and concerned citizens alike.

For planners, the lower cost of open source tools and their natural alignment with open participation can be strong arguments for adopting tools like Open Trip Planner. Its capabilities to quickly generate visualizations, while possibly not as robust or feature-rich as proprietary software, could be useful tools for highly underconstrained, scenario exploration problems like bus network development.

These advantages may not be strong enough to convince established bureaucracies to implement new tools, so equity and advocacy groups may need to develop concerted campaigns for more open participation in capital and service planning. Such campaigns could be supported by tools that effectively link broader mobility and accessibility metrics with the local knowledge and perspectives on access that might appeal more strongly to these groups' membership bases. By establishing a platform for shared inquiry that could be used in regular capital or service planning meetings, a more fully developed process based on the pilot explored in this thesis may have the potential to foster a less adversarial and more productive relationship between planning agencies and advocacy groups.

This process did encounter a number of limitations of open data and software. The assumptions used to create the Transantiago GTFS feed reduce its accuracy in the applications discussed here. Though the next feed released will reportedly have more precise inter-stop running times, without receiving revenue for this open data feed, the incentives for Transantiago to invest in this effort are reduced.

8.2 Future Research

Significant development efforts are underway for Open Trip Planner, and a major update is expected in the near future. The Open Trip Planner Analyst Roadmap outlines much of the development planned in the coming years.

A number of areas of future research connected to Open Trip Planner stand out. The basic framework already developed could accommodate a number of extensions through modified GTFS-like inputs. To organize a discussion of such extensions, the two dimensions of service abstraction (ranging from actually operated to planned) and representation (e.g. the verbose format of listing every trip versus using parameters to represent multiple trips) are proposed, as shown in Figure 8.1.

In Quadrant I of Figure 8.1, standard GTFS feeds, which are verbose representations of scheduled service, formed the basis of Open Trip Planner's initial development. Functionality

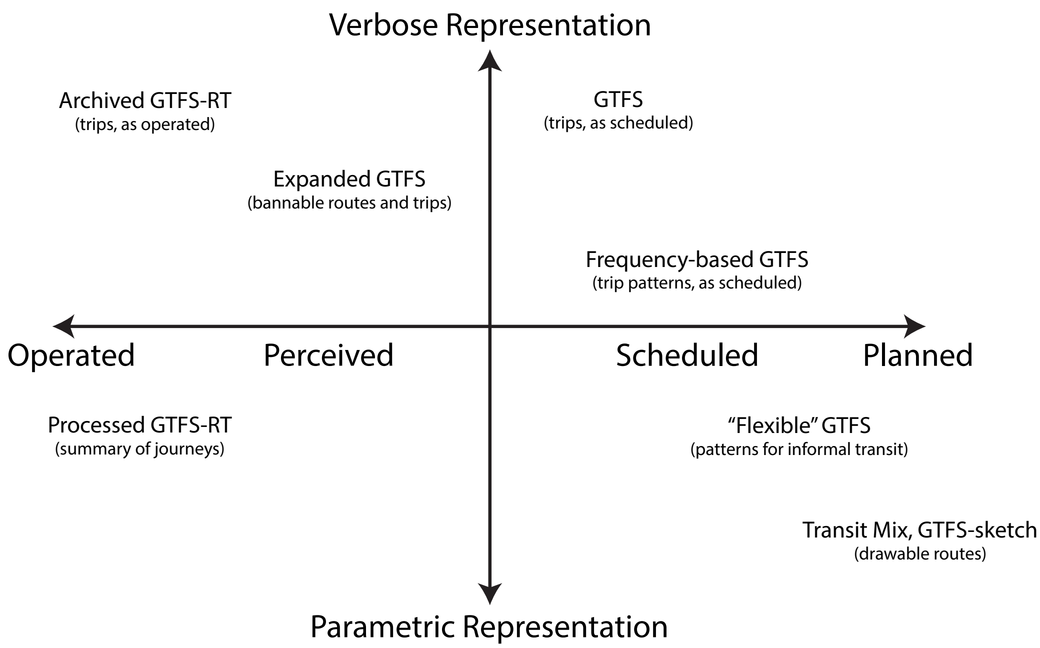

Figure 8.1: Potential transit network inputs for Open Trip Planner Analyst

is limited for frequency-based GTFS feeds, which specify pattern trips and headways in each scheduling period, rather than every individual trip. The pilot version of IBRT Accessibility, which allowed users to calibrate service based on a rudimentary expanded GTFS feed, was a step towards Quadrant II. A more robust approach, which was advocated by participants in both Boston and Santiago, would use GPS data about actual operations in the GTFS-RT format. Real time updates are being incorporated into the trip planning module of Open Trip Planner, but significant effort would probably be required to systematize the archiving and analysis functions implied in Quadrants II and III. Less effort would be required to import "Flexible" GTFS or GTFS files representing sketch planning, but creating these files will remain cumbersome until Transit Mix or a similar user-friendly GTFS editor is fully developed. The release of such an editor would be a major step forward for this research, since participants would be able to imagine services on their own instead of being limited to a predetermined set of scenarios generated before a meeting.

Other possibilities for future research include more rigorous visualizations and metrics that account for origin population, as the OSAT approach mentioned in Chapter 2 does. Appropriate aggregation by origin population would allow for regional accessibility to be represented by a single number, which could then be an indication of the regional impact of service changes or transportation projects. Making the batch analyst functions available through a web interface like the other two modules might be a useful extension that grows more feasible with declining cloud computing costs.

8.3 Conclusions

Overall, this work supports the hypothesis that web-based mapping tools make accessibility metrics easily understandable and could provide a platform for transportation and land use officials and community advocates to engage in constructive dialogue. Mobility, access, and accessibility visualization tools made the overlap between transport system, land use, activity, and individual components clearly understandable for the diverse participants on the focus groups conducted; these findings may not be generalizable to users with lower computer or formal spatial literacy. Nonetheless, these tools have the power to impact transportation and possibly land use planning, especially if they are adopted as common tools by both planners and civic groups. This thesis has considered these tools in relation to bus projects, but they could easily be extended to the consideration of other modes.

The toolkit and participation process developed around it form a framework within which the accessibility benefits of different projects could be compared, not only in the aggregate, but also for specific populations of concern. Such analyses could be the basis for operationalizing the accessibility equity principles articulated by Martens et al. (2012). Instead of evaluating project benefits on the basis of travel time savings, transportation projects could be compared on the basis of access gains for low-income families. Other possible extensions include the calculation of an access Gini coefficient to compare how equitable the transport and spatial systems of different cities. Comparing accessibility benefits across all modes to implement this equity-driven model might represent a threat to entrenched "concrete commons" interests; while actually implementing an accessibility-based decision-making framework would require substantial political will, advocacy groups' use of these visualization tools might help build it.

Nearly twenty years have elapsed since Cervero et al. (1995) called for "the aggressive use of accessibility indicators as part of the long-range transportation planning process" (p. 4). Adopting accessibility indicators as a basis for not only long-range planning, but also planning all the way down to the levels of service and operations, would make it a fundamental concept for performance management that reflects users' experiences and priorities. At the same time, the technocratic origins of accessibility metrics deserve scrutiny. Without concerted efforts to pursue meaningful public empowerment, the inherent biases of and institutional structures around such technocratic metrics might in the end only serve to co-opt everyday riders' concerns.

If a commitment is made to accessibility-based evaluation, informing accessibility measures through a robust participatory process would be a step upwards on the citizen participation ladder of Arnstein (1969). Even without such a commitment, the participatory inquiry enabled and encouraged by responsive, interactive, open-source tools promises to remake participation processes. As tools like Street Mix, Transit Mix, and Open Trip Planner mature, the relative advantages in technical subject areas conferred by professional training will likely decrease, opening the door to more interaction and meaningful participation in public meetings. As Fischer (2000, p. 259) argues, these tools, and methods of participation are already mature enough for this shift: "Throughout the twentieth century, scientific and technical experts have in effect largely set themselves off from the general citizenry...Emerging practices of participatory inquiry...appear to be the methodological extension of Dewey's call for a more collaborative relationship between citizens and experts. In this respect, the contemporary problem seems to be less a question of methods than one of the political will to introduce and experiment with such practices on a larger societal scale."

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