TTSAT: A New Approach to Mapping Transit Accessibility

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Abstract

Transit agencies have never had an accurate indicator of the extent of their service area based on riders' door-to-door travel time. This is an important gap in knowledge, because travel time is one of the most important factors determining whether or not people will use public transit. This paper presents a powerful new travel time-based method to visualize and analyze transit service coverage—a computer application called the Time-Based Transit Service Area Tool (TTSAT). Unlike other service area metrics, TTSAT incorporates total trip travel time into the transit service area maps it generates. To make these travel-time estimates realistic, TTSAT integrates all segments of a complete, door-to-door transit trip into the trip time calculations. TTSAT's mapping and analysis capabilities offer numerous potential applications for planners, developers, and members of the public working to create transit-accessible communities.

Introduction

An important planning problem for transportation and land-use planners is to evaluate the geographic areas that are "served" by a community's public transit service. Most transit system service coverage analyses use very simplistic methods, such as creating a single map showing the area within a certain distance of the transit routes. This area is then considered to be the effective "service area." The method is easy to apply and visualize, but provides incomplete information. One particular limitation is that the method ignores the key value of time—some transit trips between two points on the route might take so much time as to be unrealistic for most travelers, especially for the choice riders whom many transit operators wish to attract. This paper presents a computer application called Time-Based Transit Service Area Tool (TTSAT), a new and powerful method of analyzing and visualizing transit service coverage that allows planners to incorporate travel time into their assessment of transit service coverage.

Recognizing the problems inherent in trying to assess service coverage at a system-wide level (i.e., for all possible trips on all possible routes), TTSAT instead allows users to determine how well the transit system serves trips to or from a particular location under a given set of assumptions that the user can control. One powerful feature of TTSAT is that it incorporates all segments of a complete transit trip: the user's movement from the trip origin to the transit stop, wait-time for the transit vehicle to arrive, in-vehicle time, and time spent traveling from the disembarkation stop to the user's final destination. A second key feature of TTSAT is that users can set many of the input variables according to their personal preferences. The variables that users can set include the maximum travel-time budget for the complete, door-to-door trip; the maximum acceptable time spent traveling to and from the transit stops; the speed of the travel mode used accessing the transit stops; and the average time spent waiting to board a transit vehicle.

To apply TTSAT to a designated location, a user sets values for the factors described above. TTSAT then calculates and maps the "time-based transit service area" (TTSA) for that point The TTSA is presented on a map showing all locations that a person can reach by transit from the designated location, within his/her given travel-time budget and under the other assumptions that the user has set. (Figure 3 shows a sample of what TTSA maps look like.)

TTSAT's mapping and analysis capabilities offer numerous potential applications for planners, developers, and members of the public working to create transit-accessible communities. As such, TTSAT can support many of the most important issues in contemporary urban planning practice, including smart-growth planning efforts and equity questions, such as ensuring that a community's transit-dependent residents can reach jobs and social services.

At its most basic functionality, TTSAT allows planners to analyze the level of accessibility that a pre-existing transit system provides. Planners also can customize this accessibility analysis to different types of users—someone who walks slowly versus someone who walks quickly, users with different tolerances for their total trip time, or able-bodied users who can walk some distance versus users with limited mobility who cannot walk more than a short distance. In addition to this basic functionality, TTSAT can be used to analyze the effects of changing service characteristics, such as headway times. Thus, TTSAT functions as a modeling tool as well as a descriptive tool.

This paper begins with a brief overview of existing transit service area mapping methods. Then the paper explains briefly how TTSAT operates, including the variables users can set. Next is an overview of how the computer application operates. The following section uses real-world data from the Santa Clara Transit Center in San Jose, California, to demonstrate through three scenarios how planners can use TTSAT to analyze transit service accessibility. The concluding section summarizes the main findings from the research and recommends strategies for improving TTSAT.

The Evolution of Transit Service Area Mapping Methods

A variety of different transit service area measurement methods have been used by planning analysts to measure the spatial area served by a transit system. This section reviews the evolution of different methods that planners have used and explains how TTSAT provides more useful results by adding a time-based component to its methodology.

Early efforts to measure transit system coverage conceived of the system in terms of corridors, or the immediate area along the two sides of the streets along each transit route (see Figure 1a) (Wirasinghe and Vandebona 1987; Chapleau et al. 1987). Transportation planners recognized the inaccuracy of measuring transit service area as corridors, however, since riders cannot get on and off at any point along most transit routes. In response, planners later began to measure the transit service area as a set of concentric polygons located around each transit stop (Figure 1b) (Dufourd et al. 1996; Bruno et al. 1998). In the newer approach, a significant improvement over the corridor models, the potential riders of the system are assumed to be those travelers whose trip origin and destination both lie within one of these polygons. Destinations beyond the polygons are considered too far away from the transit stops to be easily accessible to riders.

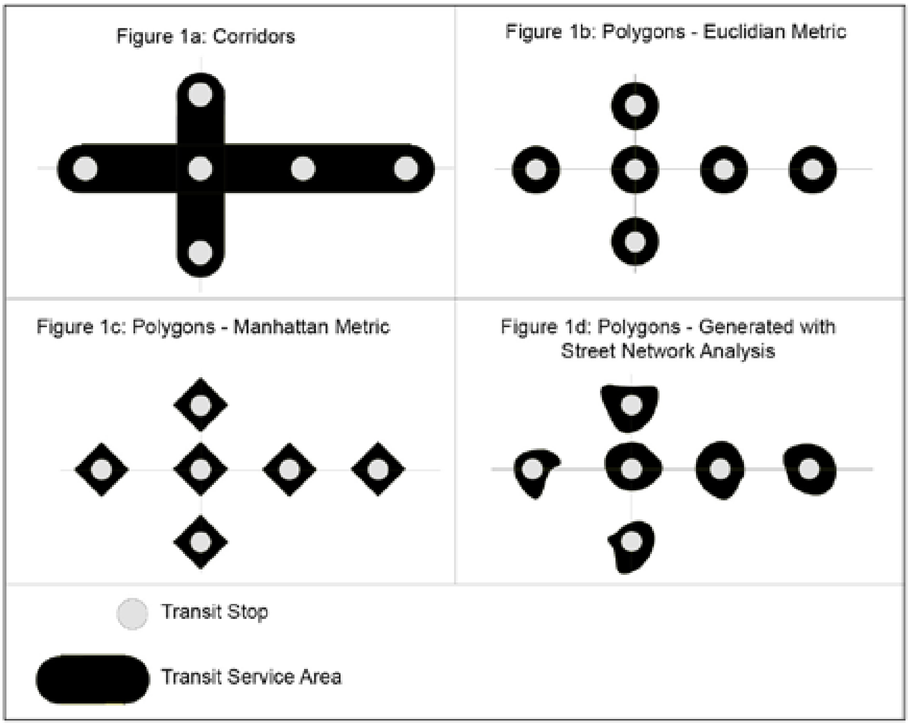

Figure 1. Four Methods to Measure Transit Service Areas

The polygons can be drawn using two different methods. The Euclidian metric encloses each stop in a circle, assuming people can walk freely from the transit stops—as the crow flies—without being blocked by buildings or other physical barriers (Figure 1b). The Manhattan metric, by contrast, attempts to simulate walking behavior more precisely by acknowledging that people are not crows who can fly over physical barriers. As a simplification, it assumes that people access transit stops by walking along a perfect street grid (of strictly eastern-western and northern-southern streets), and that the travelers will make only one right-angle turn. In the Manhattan metric, the service area drawn around a transit stop is typically a diamond (Figure 1c).

The Manhattan method still leaves much to be desired, however, since, in reality, many transit stops are not located in the middle of a perfect grid street network.

With the development of modern computer software, planners now can draw transit service areas more precisely using network analysis and GIS software (Kimpel et al. 2006). Figure 1d shows the transit service area as the locations around a transit stop that can be reached by walking a set maximum distance along the actual street network that surrounds a transit stop.

The introduction of network analysis produces much more accurate maps showing the service area around individual transit stops, but these maps stills ignore a key factor: time. The maps don't indicate whether this service area can be reached within a predetermined travel-time budget. TTSAT, by contrast, creates maps that represent the places travelers can access within a chosen travel-time budget, taking into account the time needed for all segments of a transit trip.

Figure 2 illustrates the conceptual difference between a transit service area map generated by traditional methods and the time-based transit service area generated by TTSAT. In both cases, the traveler boards the transit vehicle at stop A. The traditional methods of generating service areas produce polygons of the same area around all the stops. The TTSAT method, by contrast, shows that the more remote transit stops have smaller service area measurements, since travelers with a maximum acceptable time-budget will have less time to access destinations around the more distant stops.

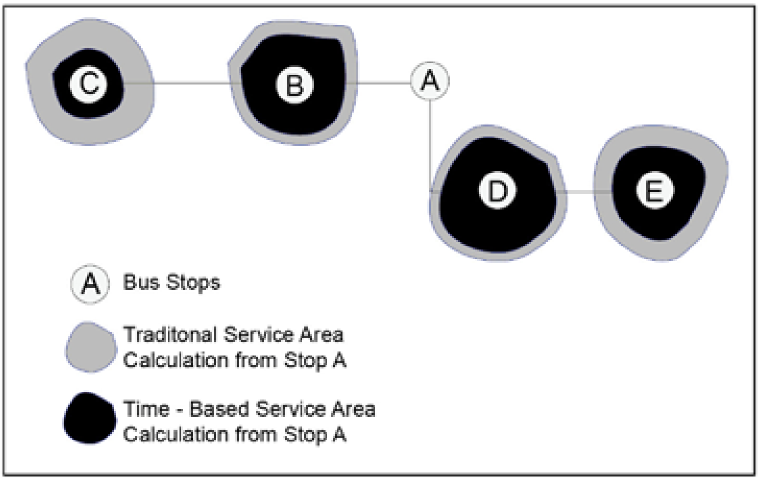

Figure 2. Transit Service Areas Generated by Traditional Methods vs. TTSAT

How TTSAT Functions: An Overview

TTSAT produces TTSA maps using a set of procedures that combine functions from both ESRI's ArcGIS suite version 9.2, for the geographical computations using a street network map, and Microsoft Access 2007, for computations related to a database containing the transit route information. This section of the paper explains the basic process through which TTSAT generates the TTSA maps. It discusses the variables the user may set and the series of six steps through which the application produces the TTSA maps.

First, the TTSAT user must set the trip origin or destination point around which the TTSA map will be created.[1] Then, the user has the option to set customized values for several variables:

- **Maximum total travel-time budget**: The maximum time passengers are willing to spend for the whole trip, including time spent traveling to the transit stop where they catch the transit vehicle, time waiting for the transit vehicle, in-vehicle time, and time spent traveling between the transit stop where they disembark and the final destination. The TTSA map will show all locations that can be reached within the maximum total travel time.
- **Maximum acceptable transit stop access time**: The maximum time passengers are willing to spend traveling from their trip origin to the transit stop where they catch the bus or train.
- **Transit stop access speed**: The speed at which passengers travel from their trip origin to the boarding stop. TTSAT uses a default speed of 2.05 miles/hour, but users can set a different speed if they walk more slowly or quickly, or if they use other travel modes, such as cycling.[2]
- **Maximum acceptable destination access time**: Similar to the acceptable transit stop access time, this is the maximum time passengers are willing to spend traveling from the transit stop where they disembark to the final trip destination.
- **Final destination access speed**: Similar to the transit stop access speed, the destination access speed is the speed at which passengers travel to their final destination after disembarking from the transit vehicle. TTSAT uses a default speed of 2.05 miles/hour.
- **Waiting-time-to-headway ratio**: This variable determines the estimated time passengers will wait for a bus or train once they arrive at the stop.

TTSAT uses a default value of 0.5, assuming that people on average wait half as long as the scheduled service frequency.

Once these variables have been set, TTSAT is ready to create the TTSA map for a given trip origin point. The application does so in six discrete steps:

1. **Find all accessible transit stops**. These are the transit stops that passengers can reach within the maximum acceptable stop access time chosen, moving at the chosen transit stop access speed.
2. **Find all accessible transit routes**. These are the bus or train routes that stop at the accessible stops identified in Step 1.
3. **Calculate the remaining available travel time at each disembarkable stop**. TTSAT calculates the remaining available travel-time budget at each stop where passengers could conceivably disembark. This time is calculated by subtracting from the maximum total travel time the following time values:
   - The time passengers spend traveling from the trip origin to the accessible transit stop where they board the bus or train.
   - The estimated time passengers spend waiting for the transit vehicle at that stop.
   - Passengers' in-vehicle time.
4. **Identify the "reachable" stops that passengers can access within the maximum total travel time**—that is, all transit stops for which the time calculated in Step 3 is greater than zero.
5. **Identify all portions of the street network that passengers can reach within the remaining available trip time**. For every reachable stop, TTSAT uses ArcGIS's network analysis function to identify the portion of the street network that passengers can reach within the remaining available travel time.
6. **Merge all reachable areas into a complete time-based transit service area (TTSA) map**. By merging all portions of the street network that can be reached within the remaining available travel time calculated in Step 5, TTSAT generates a map showing all possible locations that passengers can reach via a single transit trip from the chosen trip origin.

Applying TTSAT to the Santa Clara Transit Center

This section demonstrates how planners can use TTSAT to calculate and visualize TTSAs as part of the transit service planning process, using as an example the bus service available near the Santa Clara Transit Center (SCTC). The SCTC is an important transit hub in San Jose, California. It is served by Caltrain commuter rail, the Altamont Commuter Express rail service, Amtrak, and light rail and bus routes operated by the Santa Clara Valley Transportation Authority. To simplify the exercise, the scenarios below generate TTSA maps incorporating data only from the 11 bus lanes running nearest the SCTC.

Three scenarios are presented in this section, each illustrating a different aspect of TTSAT's ability to precisely calculate how changing the input variables leads to changes in the TTSA. For each scenario, a TTSA map is created, and the SCTC's bus accessibility is analyzed in multiple ways. One technique is simple visual inspection of the TTSA maps. In addition, bus accessibility is analyzed by calculating the number of destination bus stops a rider can access within the total travel-time budget, as well as the percentage change in the areas of the TTSAs. Each scenario concludes with a discussion of some planning implications suggested by the analysis.

Scenario 1: Variable Total Travel-Time Budgets

Figure 3 shows how the TTSA changes when travelers change their maximum travel-time budgets from 30 to 60 to 90 minutes. The scenario assumes that all other input factors remain constant—the traveler walks at a rate of 2.05 minutes on either end of the bus trip itself, the maximum acceptable walking time on either end of the in-vehicle trip is set at 15 minutes, and the waiting-time-to-headway ratio is set to 0.5.

One finding that is obvious from the map, especially from the TTSA for the 30-minute trips, is that the TTSA around reachable stops shrinks as travelers disembark at stops farther from the SCTC. This shrinkage occurs because travelers have a smaller remaining share of the total travel-time budget when they disembark farther from the SCTC. Such a result is intuitive, but TTSAT visually represents this finding in a way that viewers can easily grasp.

Figure 3 also shows that the expanding service area eventually reaches a cap. For example, the height of each horizontal strip appears to yield to a cap. This occurs because the maximum size of the service area that can be generated for any reachable bus stop is capped by the 15-minute maximum acceptable destination access time.

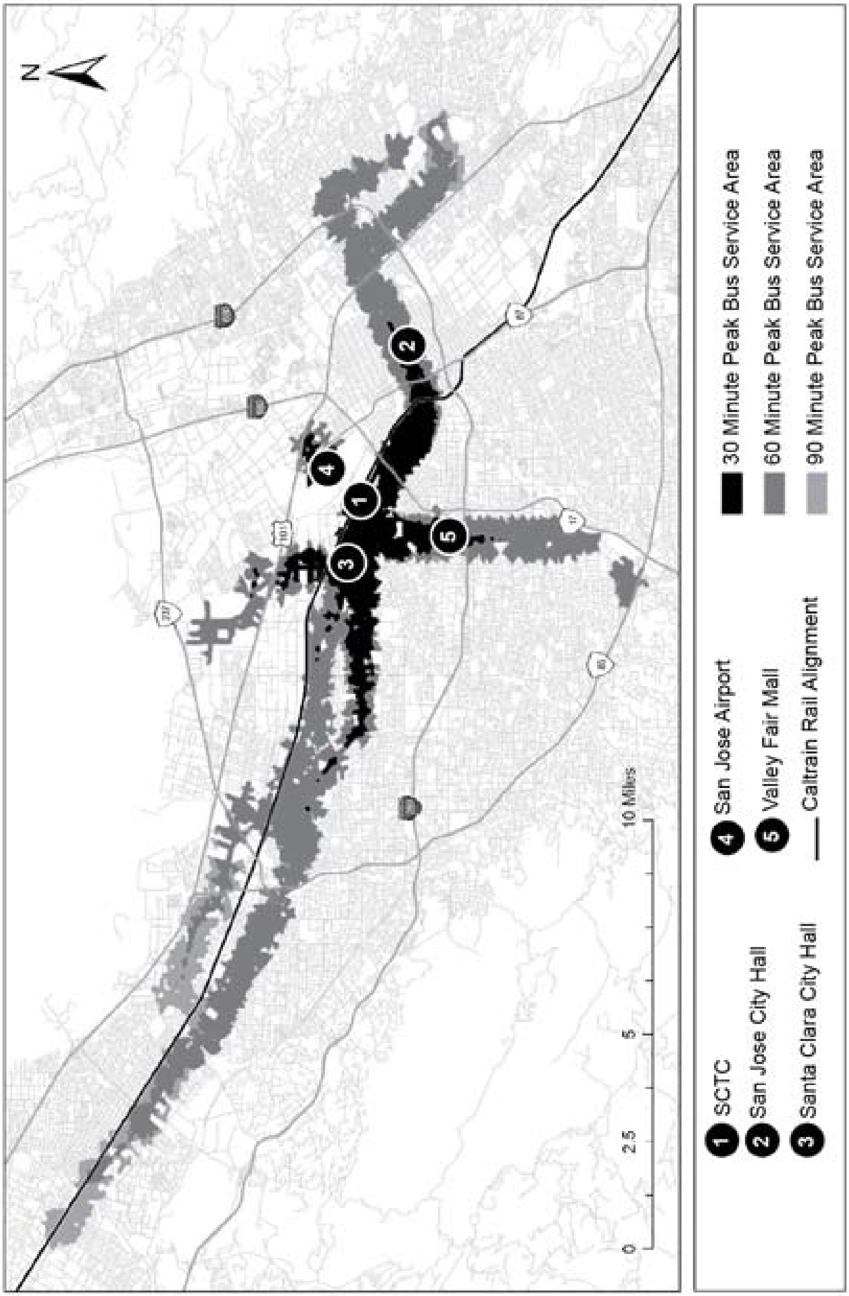

Figure 3. Thirty-, Sixty-, and Ninety-Minute Peak-Hour Bus Service Areas for the Santa Clara Transit Center

Finally, the map shows that the size of the TTSA and number of reachable destinations increases significantly as the maximum total travel time increases. The east-west strip becomes longer as the maximum total travel time increases, because now travelers have more time to spend on a bus trip from the SCTC.

Using GIS software, users can easily calculate how the area of the TTSA changes as the total travel time changes. Compared to the TTSA for the 30-minute trip, the TTSA increases by 379 percent for travelers with a 60-minute total travel-time budget and by 443 percent for travelers with a 90-minute total travel-time budget. Users can also measure the change in accessibility by counting the number of destination bus stops that travelers can reach under the different travel-time budgets. Here, the number of stops is 114 for the 30-minute trip, 280 for the 60-minute trip (a 146% increase), and 399 for the 90-minute trip (a 250% increase over the number of stops in the 30-minute trip).

Scenario 2: Changes in the Frequency of Transit Service

One of the key service variables that transit operators control is the frequency with which transit vehicles arrive at a stop, a variable also referred to as the service headway. Factors that can influence the service headway include peak and off-peak schedules (service is usually less frequent in the off-peak period), varying levels of traffic congestion (congestion that delays transit vehicles may increase the time passengers wait for the bus or train, mimicking the effect of less frequently scheduled service), or simply the decisions that operators make to increase or decrease the scheduled service frequency.

For this scenario, TTSAT assumes that passengers, on average, wait one-half the length of the service headway. Under this assumption, if vehicles come less frequently—for whatever reason—then passengers will wait longer to board the transit vehicle and will have less time remaining out of their total travel-time budget for the other segments of their trip. As a result, the TTSA shrinks when service headways increase. Figure 4 illustrates this principle by comparing the TTSA for the SCTC during peak and off-peak service, assuming a 30-minute total travel-time budget. Except for comparing peak and off-peak service, all other TTSAT variables are held constant.

Inspecting the map in Figure 4 shows that peak-hour service allows travelers to reach a considerably larger territory around the stops on one of the north-south lines. The peak-hour service along this line has considerably shorter headways than the off-peak service, generating the much larger peak-hour TTSA. However, along

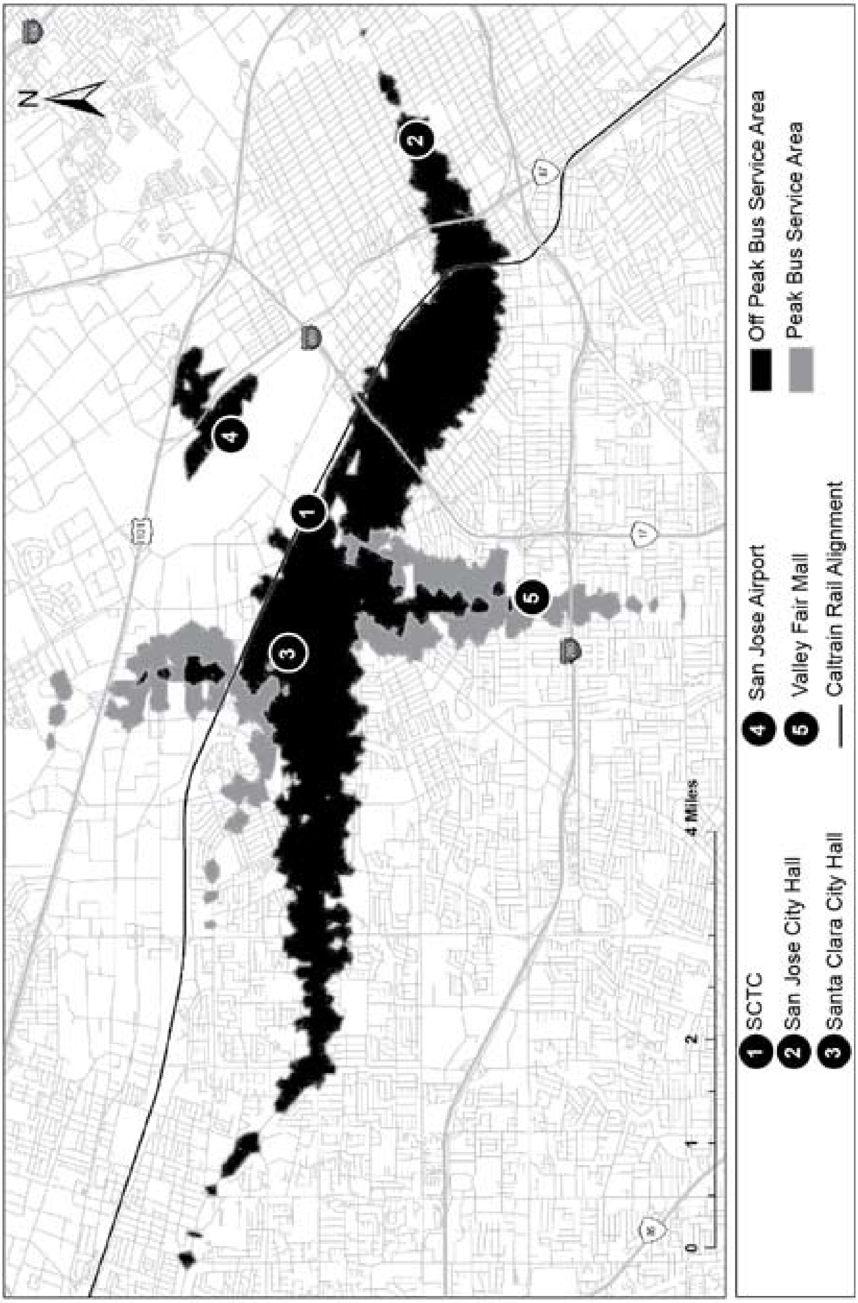

Figure 4. Thiry-Minute Peak and Off-Peak Hour Bus Service Areas for the Santa Clara Transit Center

the east-west routes, the peak-hour service is only marginally more frequent than the off-peak service, so the TTSA for the peak-hour service is only marginally bigger than the off-peak service TTSA. Looking at the entire TTSA map, the TTSA for the peak service period expands by18 percent, as compared to the TTSA during the off-peak period. The number of reachable destination stops also grows from 80 in the off-peak period to 114 during the peak period, a 42 percent increase.

Planners can use the results of modeling exercises like this one to check how much they will impact accessibility between popular origins and destinations if they change scheduled service frequencies. Using this scenario as an example, planners can inspect the TTSA map to check if the bus service provides good access to specific locations likely to attract transit riders. Figure 4 confirms that both peak-hour and off-peak bus service allow passengers to reach job-rich downtown San Jose within 30 minutes (downtown is located next to the San Jose City Hall, item number 2 on the map.) However, the Valley Fair Mall (number 5 on the map), a major regional shopping center, can be accessed in 30 minutes only during peak-hour bus service. Figure 4 shows that the mall lies slightly beyond the black area on the map, which is the 30-minute reachable area during the off-peak hours. Since many people visit shopping centers during weekends or other times that are traditionally off-peak hours for transit service, local planners might use this finding from the TTSAT analysis to support plans to add more frequent off-peak service so that patrons could have faster access to the mall on weekends.

Scenario 3: Walking vs. Biking as Transit-Access Modes

Although walking is the most common mode people use to access bus stops, bicycling is another alternative. Figure 5 shows the 60-minute bus service area of the SCTC for passengers using three different access modes:

- Walk-Only: Passengers walk on both ends of the bus ride.
- Bike-and-Walk: Passengers bike to the stop where they board the bus, park the bicycle near the bus stop, and walk from their disembarkation stop to their final destination.
- Bike-and-Bike: Passengers bicycle on both ends of the bus ride (these passengers would bring their bicycles on the bus).

For all three cases in this scenario, the maximum acceptable transit stop access time and destination access time are set at 15 minutes each, and travelers are estimated to walk at 2.05 miles per hour and to bicycle at 13.68 miles per hour.[3]

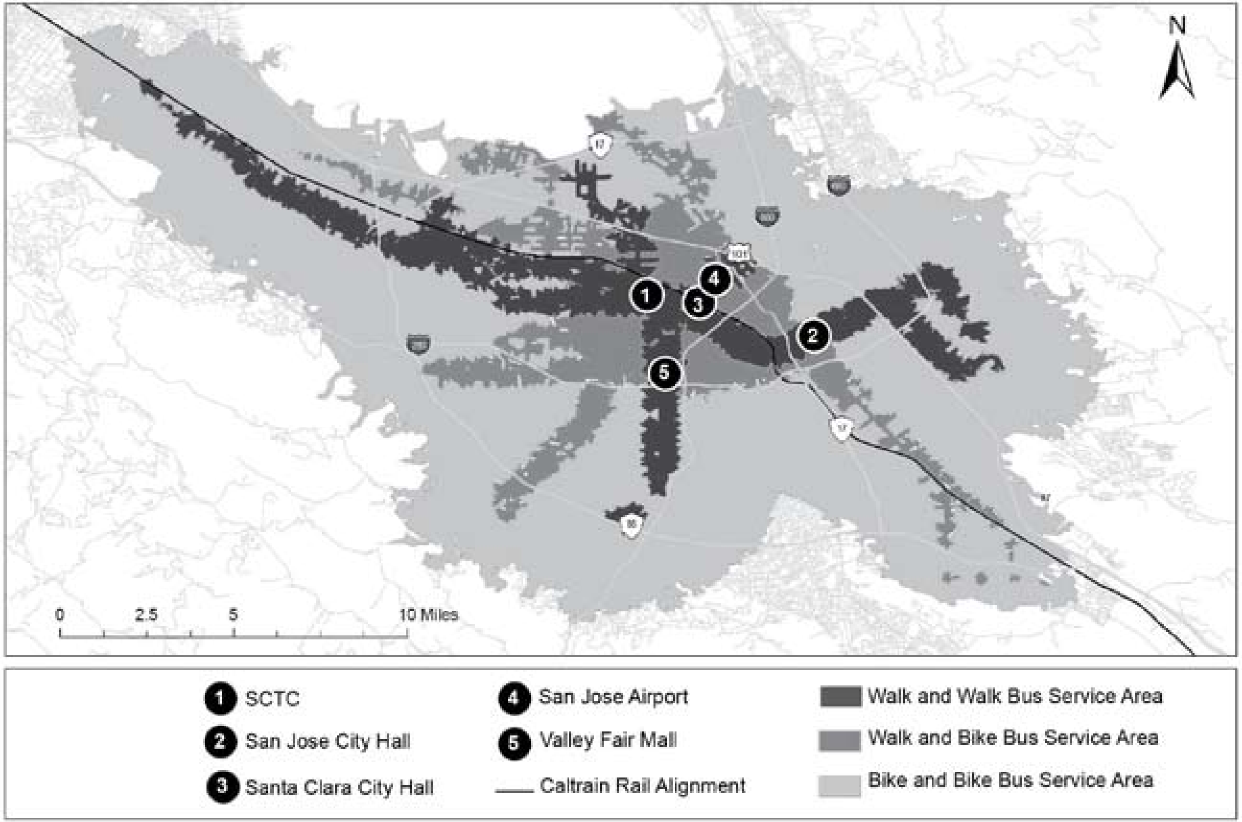

Figure 5. Sixty-Minute Peak-Hour Bus Service Areas for the Santa Clara Transit Center, by Different Access/Destination Modes

Visually inspecting Figure 5 shows that when people bicycle as an access mode, the TTSA is significantly larger than for people who walk to and from bus stops. Calculating the precise change reveals that the peak TTSA increases by 108 percent when the access mode switches from walking to bicycling. The TTSA increases even more dramatically—by 740 percent—for passengers using a bicycle at both ends of the bus trip.

The increased TTSAs are partially explained by the fact that bicycling significantly increases the number of accessible stops where travelers can catch the bus and the number of accessible routes; both factors increase the number of reachable (destination) bus stops. For travelers who walk to the stop where they wait for the bus, only 17 bus stops are accessible from the SCTC within 15 minutes, compared to 566 bus stops accessible to travelers who bicycle to a bus stop. Also, travelers who bicycle to the bus can access 11 routes, compared to the 5 routes accessible to passengers walking from the SCTC. Once passengers are on board the bus, the number of reachable disembarkation stops is 737 for those who bicycle to the bus, compared to 280 for those who walk.

The data generated from this scenario provide evidence to support the argument that transit operators and local governments should seriously consider steps to facilitate bicycle use by bus riders as a way to increase accessibility for transit patrons. Local city and county planners could install bicycle parking near transit stops, and the Santa Clara Valley Transportation Authority could provide ample and convenient bicycle racks on all the agency's buses. These relatively inexpensive steps could bring substantial increases in accessibility, as illustrated by the 740 percent jump in the size of the TTSA for the all-bike versus all-walk access modes in this scenario.

Conclusions

Summary of Main Findings

The primary goal of this research was to develop and demonstrate a new and more useful method to measure the geographic area served by a transit line or network. TTSAT is a prototype of such a tool, one that takes the approach of analyzing the transit service area for trips to and from a particular location. A key improvement of TTSAT compared to other service area measurement methods is that TTSAT incorporates time, allowing users to set the maximum acceptable trip time. Also, TTSAT integrates all segments of a complete transit trip into the trip time calculations: passengers' movement from the trip origin point to the transit stop, wait-time for the transit vehicle to arrive, in-vehicle time, and time spent traveling from the disembarkation stop to the passengers' final destinations. By incorporating all aspects of the trip, not just in-vehicle time, TTSAT produces quite realistic estimates of travel time. Finally, TTSAT users can customize the TTSA maps they generate by specifying details of passengers' expected travel behavior, such as their walking speed or the maximum time they are willing to spend going to and from the transit stops.

The second research goal was to demonstrate the types of analyses TTSAT users can perform that might improve transit and land-use planning. The scenarios presented in the previous section illustrate a sample of the types of analysis possible with TTSAT. For example, a transit planner using TTSAT can analyze how different assumptions about travelers' behavior or the frequency of transit service will change the TTSA for a particular location. This modeling capability can help transit planners and community members to identify the most useful service improvements. To give another example, applying TTSAT to the SCTC shows both visually and quantitatively the changes in bus accessibility that occur when the bus service frequency changes or when assumptions about travelers' behavior change. TTSAT users can also easily calculate the change in the number of reachable stops and the total area of the TTSAs.

Recommendations for Future Improvements to TTSAT

This paper demonstrates the basic capabilities of TTSAT as currently developed. However, the application could be improved in many ways to generate more precise results, improve the operational efficiency (and reduce the calculation time), and finally and most importantly, make the tool available to a much wider range of users. The paper concludes with four recommended improvements.

The first recommendation is to increase the precision of TTSAT's output by in-putting very precise transit route schedules and street network information. Creating accurate TTSA maps requires extremely accurate input data, both for route schedules and the underlying digitized maps. Many transit operators do not produce schedules that estimate arrival times at each stop, but only estimate arrival times at a few major stops. Planners wanting to use TTSAT for their analysis should work with their transit operators to develop the most precise possible route schedules. In addition, the TIGER/Line street network files do not produce accurate pedestrian and bicycle routes because they include only vehicle-accessible streets. If TTSAT managers use a street network map that includes pedestrian and bicycle paths, as well as streets accessible by vehicles, then TTSAT can more accurately calculate the shortest routes for people going to and from transit stops.

A second recommendation is to make TTSAT's output more precise by including more factors in the internal calculations. For example, the time travelers spend walking or biking to boarding stops could be better estimated if street-crossing behavior were included. Another method to increase precision would be to incorporate sophisticated traffic models to estimate the in-vehicle time under different traffic conditions

Third, TTSAT could be redesigned to execute its calculations more efficiently, either by recoding some of the underlying calculations or by incorporating different GIS and database applications. As currently designed, TTSAT produces maps relatively slowly. The exact time needed varies greatly, depending on the number of transit routes and the size of the geographic area under consideration, but the maps shown in this paper each took between 5 and 30 minutes to produce.

Finally, and most important of all, TTSAT should be redesigned to create a more user-friendly interface. Ideally, the application would be redesigned so that anyone could use it, including members of the public with no technical expertise. Creating an interface that anyone could use would make TTSAT useful in numerous settings. TTSAT could be used at public meetings or charrettes, allowing participants to test out how choosing different values for the variables would change accessibility. Participants could, for example, see how much service frequency would need to be increased to achieve the community's desired level of accessibility.

Ultimately, a version of TTSAT could even be included in the transit trip planning websites available to the public over the internet, such as the Transit Trip Planner available at the Metropolitan Transportation Commission's "511.org" website or Google Transit (*http://www.google.com/transit*). People moving to a new neighborhood could then use these websites to check if a potential housing unit would allow them to commute to work by transit within their personal travel constraints of time or access speed. Or, to give other example, retailers considering new locations for their businesses could check to see if it a sufficient number of customers could conveniently access those locations by transit. In the public sector, planners citing a major facility such as a hospital or job training center could check potential sites to see what geographic areas would be accessible to transit riders, using different travel time budgets and other inputs.

To obtain a report with complete details on TTSAT, contact the authors.

Acknowledgements

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Endnotes

[1] The TTSA maps show transit accessibility around a single point. The maps show an area that is both those places a transit user may access when departing from that point and all the locations from which a user can depart to access that same central point.

[2] The default walking speed is set according to recommendations from the Federal Highway Administration (2007) and Montufar et al. (2007).

[3] The bicycle speed represents the average reported speed from a survey of 5,577 bicycle commuters (Rose and Marfurt 2007).

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