TRANSPORTATION PLANNER'S WEB-BASED ACCESSIBILITY TOOLKIT

FINAL REPORT

Prepared for:

Federal Highway Administration
Office of Planning and Environment
Under Contract No. DTFH61-10-C-00059

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July 9, 2013

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CHAPTER 1: Introduction and Executive Summary

This report describes a project performed with the overall objective of developing simple but powerful analytical tools to support improved transportation planning. These tools are provided in the form of web-based software that calculates the accessibility afforded by existing transport infrastructure and from potential improvements and demographic changes. This accessibility toolkit opens the door to broader consideration of concepts and methods for planning and is available to and usable by a much broader set of planners than those who perform travel demand modeling.

Increased accessibility, which expresses the ease of traveling to desired destinations, is a primary goal of most transportation plans and projects. Accessibility can be measured directly rather than associated with inferior proxy metrics such as vehicle miles or vehicle hours of travel. Accessibility can be measured for both passengers and freight as well as for motorized and non-motorized travel.

The toolkit developed uses only simple, easy to understand measures of accessibility. These are measures of travel time and the destinations that can be reached with differing amounts of travel using auto, transit, bicycle, and pedestrian modes. These measures are intentionally simpler than and rather different from the complex measures encountered in the research literature and in advanced travel demand models.

The toolkit relies on the availability of network datasets for each mode of interest. Planning model data has been used in the project, but it may not usually be detailed enough to satisfy the needs of accessibility measurement. Accurate, complete street networks are what would be the natural solution. These are needed to represent pedestrian travel and to provide the geographic basis for mapping transit routes and providing access and egress to transit. Unfortunately TIGER street centerline files have inadequate topology for routing, have gaps, lack directionality, and are not easily improved. If there are available local GIS files with appropriate detail, these will be a good solution. Otherwise, implementers of the toolkit may not have adequate street files unless they are licensed from private data providers for web use. In data-poor contexts, the usefulness of the accessibility toolkit will be limited.

Even in situations where there is ample and appropriate data, a finding of the project is that substantial data development and preparation will typically be necessary for a successful implementation of accessibility measurement in any region. This is because the granularity of travel demand datasets is often too coarse and also too limited. Also, explicit coding of landmarks and specific facilities will usually be warranted.

Transit accessibility calculation presents several additional challenges which were investigated and addressed in the project. The General Transit Feed Specification (GTFS) data published by nearly every transit operator in the U.S. can be extremely useful, but it also needs appropriate data processing including conflation to an adequate reference street layer.

In the course of the project, numerous technical obstacles to accurate accessibility measurement were encountered and addressed. In order to provide accurate network travel time bands, it was found necessary to compute intersection-to-intersection travel times for each mode. This requires billions of shortest path calculations for even a medium-size region. Fortunately, with fast 64-bit computers these calculations can be performed interactively for road networks. There were also other innovations introduced to improve the calculations and make them fast enough to be computed upon demand.

The software application consists of a front-end web application than runs in popular browsers and provides access to the application and a back-end server that performs the necessary calculations with a version of TransCAD. One free licensed copy of the software will be made available to any U.S. public transportation organization including the U.S. DOT, state DOTs, MPOs, and public transportation agencies.

In the course of the project, the calculator was implemented and tested with data from a number of MPOs and transit properties. In this report, we use data from the Durham-Research Triangle region of North Carolina to illustrate some of the functionality of the accessibility calculator. These data were supplemented by other information to illustrate the workings of the software, but are not representative of current conditions, nor should they be taken to reflect reality.

The project software enables accessibility-based assessments of transportation improvements through the implementation of a web-based accessibility toolkit. At the heart of the toolkit are methods and software enabling calculation of the accessibility associated with transit, pedestrian, and road travel. This application leverages previously developed GIS and transportation software technology. GIS plays a pivotal role in all aspects of the project ranging from data development, accessibility calculations, visualization of benefits, and communication with the public.

It is hoped that the accessibility calculator will be broadly supportive of capacity-building and will find uses in transit planning, tribal planning, public involvement, environmental justice, and visualization. Also, it should provide tools and important insights about the current levels of transportation performance and the impact of transportation improvements. This should be especially useful in addressing issues poorly served by the domain of travel demand models, particularly with respect to use of non-motorized modes and public transportation.

The accessibility toolkit will also help managers and a broader range of stakeholders to perform analysis and to share data and analysis with the public. The application supports Title VI analysis in a more direct, systematic, and useable form than any previous tools. The data and visualization should help planners and stakeholders alike in understanding current travel resources, system performance, and critical problems. It should also help planners communicate with the public in a clear yet substantive manner.

The toolkit is available publicly and is useable by a broad range of stakeholders both inside and outside of the transportation planning community. It complements the traditional types of analysis and can augment the insights available to policymakers. In addition, it can provide analysis capabilities to those who lack access to travel demand forecasting tools or lack the specialized training to use those tools. It is expected that the accessibility toolkit will lead to new conclusions about effective and equitable transportation improvements and that it will contribute to breaking down barriers between jurisdictions and institutions by illustrating the multidimensional impacts and spatial extent of proposed projects. Even when consensus building is impossible, these tools should help provide an objective empirical basis for discussion and negotiation.

CHAPTER 2: Background on Transportation Accessibility

Planners are well aware that narrow objectives limit the possibilities for imaginative and effective transportation planning. The prevalent supporting analytical techniques utilized in planning have an even narrower focus, further limiting consideration of policies, plans, and projects that would be beneficial or producing biased assessments of the associated benefits. Moreover, many projects have localized effects that are simply ignored by travel demand models because they occur within travel analysis zones. More sensitive and more valid measures and analytical techniques are needed for these quite common planning challenges.

Conventionally, traffic-based measures or mobility-based measures are used in place of accessibility measures, but as Todd Litman has written, "Accessibility is the ultimate goal of most transportation and so is the best approach to use." (Litman, 2003, p.1). Accessibility refers to the possibilities of traveling to destination opportunities and the level of service associated with a wide range of travel options. Accessibility can be assessed for both person travel and freight movements and for all modes, not just vehicular modes. Increasing travel options or improving their quality and performance spatially and/or temporally increases accessibility.

While there is an extensive literature on measuring accessibility, there has been no significant penetration of accessibility-based evaluation in the United States for several reasons. First, without tools, application requires too much effort. Second, use of travel demand models for calculating benefits has crowded out simpler, alternative methods. Third, there are implementation barriers to using accessibility measures in transportation planning to be overcome. In this regard, there are a wide range of measures that could be calculated, but many are hard to understand or require data that are not readily available. Also, measures must be correctly indicative of benefits or their use will lead to flaws in the planning process. To improve planning, we need to find simpler but more informative means of understanding transportation goals and approaches for achieving them. The accessibility-based approach, while certainly not a new idea, is increasingly attracting the attention of planning theorists and practitioners and has the potential to be transformational in opening up transportation planning to a better future.

Accessibility Measures

As an initial part of this project, we reviewed prior measures of accessibility for the purpose of identifying those to be implemented in the toolkit. The selection of appropriate accessibility measures was thought to be critical to the success of this effort and a further qualification was that the measures had to be quantifiable for most locations in the U.S. without significant new data collection.

An extensive review performed by UT Austin for FHWA and the Texas DOT some years ago (Bhat et al., 2000) obviated the need for a full historical literature review of accessibility measures, but we examined a focused sample of the numerous more recent publications as part of our evaluation. As suggested by UT Austin, reasonable accessibility measures should have a sound theoretical basis, be readily computable, and have valid empirical sensitivity. Measures can be aggregate or disaggregate either spatially or with respect to trip purpose and/ or traveler characteristics. Also, various measures of impedance can be utilized. These can be congested travel times for roads and scheduled service for transit or be gravity or utility-based measures of attractions and spatial separation that discount opportunities that are at greater distances from travelers' origins.

Our focus in further review was on practical, comprehensible, and computable measures of accessibility with due regard to data availability. From a conceptual point of view, we found several key signposts. Specifically, Krizek and Levinson (2011) had already traversed the path that we wanted to follow and provided guidance that we embraced.

In particular, they have researched and argued for greater use of accessibility measures in planning and enumerated what they refer to as the "5-C's" of effective accessibility measures, which are listed verbatim below.

> **Cumulative –** Accessibility measures need to scale well. They need to apply to a particular address, a neighborhood, or an entire region.
>
> **Comparable –** Accessibility measures need to inform multiple modes on the same continuum and the same scale. In other words, it is ideal to have the associated varying networks, varying travel speeds, and varying impedance functions be as consistent as possible. Comparing an accessibility measure for walking that focuses particular attention on experiential elements (e.g., urban design amenities) with an accessibility measure for auto based solely on travel time presents outstanding challenges.
>
> **Clear –** For the measures to have appeal to various constituents, they need to be understood by them. They need to be transparent in terms of where the data came from, how they were calculated, and what they mean. Politicians and citizens have a hard time relating to phenomena such as log-sum measures or negative exponential distance delay curves.
>
> **Comprehensive –** Accessibility measures need to be able to clearly capture just certain domains of interest—restaurants, for example—or be able to aggregate different types of land uses.
>
> **Calculable –** Finally, it is best for measures to employ data that is readily accessible, available for an entire metropolitan area, and specific enough to capture the fine-grain calculations required for pedestrian travel.

Furthermore, Krizek and Levinson(2011, p. 7) argue that satisfying those "five C's leads to a suggested and specific type of measure to be employed, the 6^{th} C, cumulative opportunity measures of accessibility. "

Cumulative opportunity measures are the number of a particular type of destinations that are reachable within a specific travel time such as 20 minutes. This is inherently reasonable, but only if there is a clear understanding of the nature of the destinations involved and valid, appropriate numerical measures associated with those destinations.

Numerous illustrations of accessibility calculations can be found in the extensive work on accessibility performed by David Levinson's Networks, Economics, and Urban Systems Group at the University of Minnesota. Many of these calculations meet the criteria for this project of being readily comprehended by a broad range of individuals.

In terms of application of accessibility as a key component of transportation planning, British practice stands out where it seems to enjoy a level of attention that is at least as important as travel demand forecasting. It may also be more operational.

Accessibility evaluation is part of the fabric of "evidence-based" planning. One of the benefits cited is the ability to examine all parts of a study area and to compare them and perform evaluation of plan components using consistent and low-cost methodology.

In British practice, accessibility measures the catchment characteristics of a given location and their technical guidance suggests including numerous attributes such as travel time, travel cost, safety, knowledge about travel and service choices and individual characteristics, perceptions, and needs.

Three main categories of accessibility measures are distinguished. These are access measures, threshold measures, and continuous measures. An example of an access measure would be the share of individuals who are within a ten minute walk of a transit stop; this measure can be computed on a small area basis to identify communities that have reasonable transit access and those that do not. An example of a threshold measure would be the share of workers who are within a 45 minute drive of a major employment center. Travel time measurements in terms of the time by specific modes for specific journeys are examples of continuous measures.

It is noted that "these measures can be presented in absolute form e.g. "the total number of individuals or households" or in relative form e.g. "the proportion or percentage of households or individuals. It is further noted that the measures "can be used in combination, to generate two additional forms of quantitative measure: Composite measures and comparative measures" (Department for Transport, p. 7). British guidance also quite reasonably identifies core indicators that are calculated for planning areas using threshold measures and these indicators are tracked through time. An evaluative review of the success of the British approach was beyond the scope of our work, but it would certainly be interesting and may very well be instructive for those advocating similar practices for the U.S.

Perhaps no one has argued more passionately about using accessibility measures in evaluation than Todd Litman. It would be unreasonable to attempt to summarize the breadth or depth of his arguments for accessibility measurement in any simple way, so we recommend that his papers be read by those interested. From the perspective of this project, we attempted to implement key aspects of his ideas and those from thoughtful academics and practitioners that have become engaged in this approach.

Some of these ideas considerably augment traditional approaches to accessibility measurement. The first is explicit multi-modal consideration of the travel opportunities that each available mode affords. The second is use of network-based measurements and, where possible, approximations of door-to-door computations of travel times. The third is assessing costs in economic terms such as transit fares and auto operating costs and also the costs of vehicle ownership and parking. Fourth, Litman advocates a holistic approach to accessibility including all sorts of relevant factors that are typically not considered. This sets the bar very high but it does certainly offer a sensible direction and a sense of the ultimate goal.

Practical realization of accessibility measurement has advanced in recent years although it stills falls short of the recommended methods and goals. From a public policy point of view, transit accessibility is always a focus of interest.

For example, The Metropolitan Policy Program at the Brookings Institute (Tomer et al., 2011) released a massive study on access to public transit services. While this study was limited in many ways, it illustrates how the availability of the general transit feed data can be used to implement transit accessibility calculations for many, if not most, of the metro areas in the country. The study focused on transit accessibility to jobs in the larger metropolitan areas in the U.S. Unfortunately the study used 2000 rather than demographic 2010 data, used centroids for block groups and census tracts rather than point locations or smaller zones, and made other simplifying assumptions about demand.

The study notes that “travel time thresholds are essential to model transportation accessibility. Without a temporal boundary, any destination within reach of transit could be considered accessible”. Yet, Brookings bizarrely used a threshold of 90 minutes for transit trips, but did not consider the travel distances, the nature of the modes involved, or the travel time by auto or even walking. This illustrates the need for more sensitive measures that could help us understand whether a 45-minute trip for a 30-mile trip on commuter rail provides good accessibility while a 45-minute transit trip to travel 5 miles would be considered poor service. Another meaningful alternative would be compare the transit trip time to that by other modes for the same trip.

We would be remiss if we did not note a specific connection between smart growth indicators and measures and those associated with accessibility. In work that we and many others have performed, empirical measures of transit access, walkability, land use diversity, density, and many other measures have been found to be statistically significant determinants of travel behavior. This should not be surprising as accessibility is of consequence and does affect travel choices.

Taken altogether, the literature offers considerable guidance and sets a high bar for a toolkit. We drew inspiration and guidance from these ideas and research.

Our focus in this project was on the computability and understandability of the accessibility measures that are computed. While we wanted to focus on measures that could be provided for a wide range of areas and circumstances, we also felt that the calculator should accommodate a diversity of calculations that might be of interest to the target audience.

Specific Empirical Accessibility Measures

Our approach to this project was based upon the use of accessibility measures that can be understood by transportation planners and citizens alike. In other words, the measures should not require nuanced interpretation or comprehension of complex conceptual matters or assumptions. Based upon this criterion, we intended to use travel time measures as the core metrics to be computed for measuring the accessibility of locations to various types of destinations. These measures are computed from networks appropriate for different modes of travel. There are also counts associated with the number of people, jobs, shopping opportunities, or other entities that are within a given number of minutes from a location or zone. These measures are computed separately by mode. An illustrative list of specific measures is given below.

AUTO MEASURES

- Travel time by car from or to a point location
- Travel time by car from a set of point locations to a point location
- Travel time by car from a point location to a user-defined area or zone such as a CBD
- Counts of the number of people, jobs, or establishments by type within travel time bands from point locations or zones
- Before and after comparative measures of the above measures, e.g., travel time savings from a point location to a zone or the increase in the number of jobs within a 45 minute drive resulting from an improvement project

TRANSIT MEASURES

- Travel time by best transit mode(s) from or to a point location
- Number of transfers required for the shortest travel time transit path
- Walk distance and estimated travel time for access and egress for the shortest travel time path from one location to another.
- Fare for the shortest travel time path by best transit mode(s)
- Peak and off-peak computations of the above measures
- Counts of the number of people, jobs, or establishments by type within transit travel time bands from point locations or zones
- The above measures for specific transit modes or sub-modes
- Distance to the nearest transit stop
- Counts of the number of people, jobs, or establishments within given walk distances from a transit stop
- Before and after comparative measures of the above transit measures resulting from an improvement project

NON-MOTORIZED MEASURES

- Walk travel time from or to a point location
- Before and after comparison of walk distances and travel times resulting from an enhancement project
- Bicycle travel time from or to a point location
- Percentage of bike path distance and travel time on dedicated bike lanes for the shortest bike path
- Before and after comparison of bike distances and travel times resulting from an enhancement project

COMPARATIVE MEASURES

- Travel time difference between the transit shortest path and the auto shortest path from or to a location
- Travel time differences between walking and using transit from or to a location
- Travel time difference between biking and using transit shortest path from or to a location
- Differences in the number of people, jobs, or establishments by type within the same travel time bands that can be reached by different modes such as auto and transit
- Travel time differences between congested and uncongested auto travel
- Travel time differences between peak and off-peak transit travel from or to a location

CHAPTER 3: The Toolkit Approach

Our approach involved creating a way to calculate accessibility for nearly any region and to do so for auto, transit, bicycle, and pedestrian modes. While this capability resides in TransCAD and in other software, we attempted to create a calculator that that would be easier for planners to use and one that would not require purchasing licenses for proprietary software. The solution takes the form of a web application that provides the user interface and the ability to frame accessibility queries and display maps and tables that provide the requested output. One licensed copy of the TransCAD for the Web software needed to run the web application will be provided gratis upon request to U.S. state, MPO, and public transportation agencies.

Data Needs

While we aspired to produce the most relevant accessibility calculations, we had to deal with the realities of data availability. While there has been a general explosion in geographic data over the last decade, there are also intellectual property restrictions that apply to some of the data that planners use, and these restrictions must be respected. Given the nature of accessibility measures, the calculator requires networks suitable for the analysis of walking, biking, driving, and taking public transit where available.

Early in the project, we considered how to obtain the network data for a broad set of communities. Unfortunately, the U.S. Census TIGER data is not suitable for routing of vehicles, and the cost of proprietary data for web access is prohibitive. We examined OpenStreet Map as a potential source, but found that for the U.S., it suffered from the same topological problems as TIGER. This reinforced our earlier thinking about accessing planning model data as the source of networks for computations of auto accessibility. However, there are opportunities to use some state and local GIS files and their use is accommodated in the calculator. We also approached some data vendors to ask if they would be willing to contribute the limited use of their data without cost but with what would be some marketing benefit to them, but this has not yet borne fruit.

For transit, the wide availability of transit schedule data in the General Transit Feed Specification (GTFS) format provides key raw material needed for calculating transit accessibility. This can sometimes be augmented by information published or made available by transit agencies in other formats. Obviously, if the data are already in TransCAD format, they can be used directly. For walking, one can pre-process the TIGER files to remove freeways and other non-walk links.

Population and employment data are taken from Census sources and also from MPO TAZ estimates that are available for base years and also potentially for future years. The block level SF1 data on residential population is available and we had already processed it for Maptitude and TransCAD users.

Employment data at the small area level is harder to obtain, but the planning model data can be augmented from private sources, local sources, and perhaps with Longitudinal Employer-Household Dynamics (LEHD) data. LEHD data could also be aggregated somewhat, which might make it more reliable.

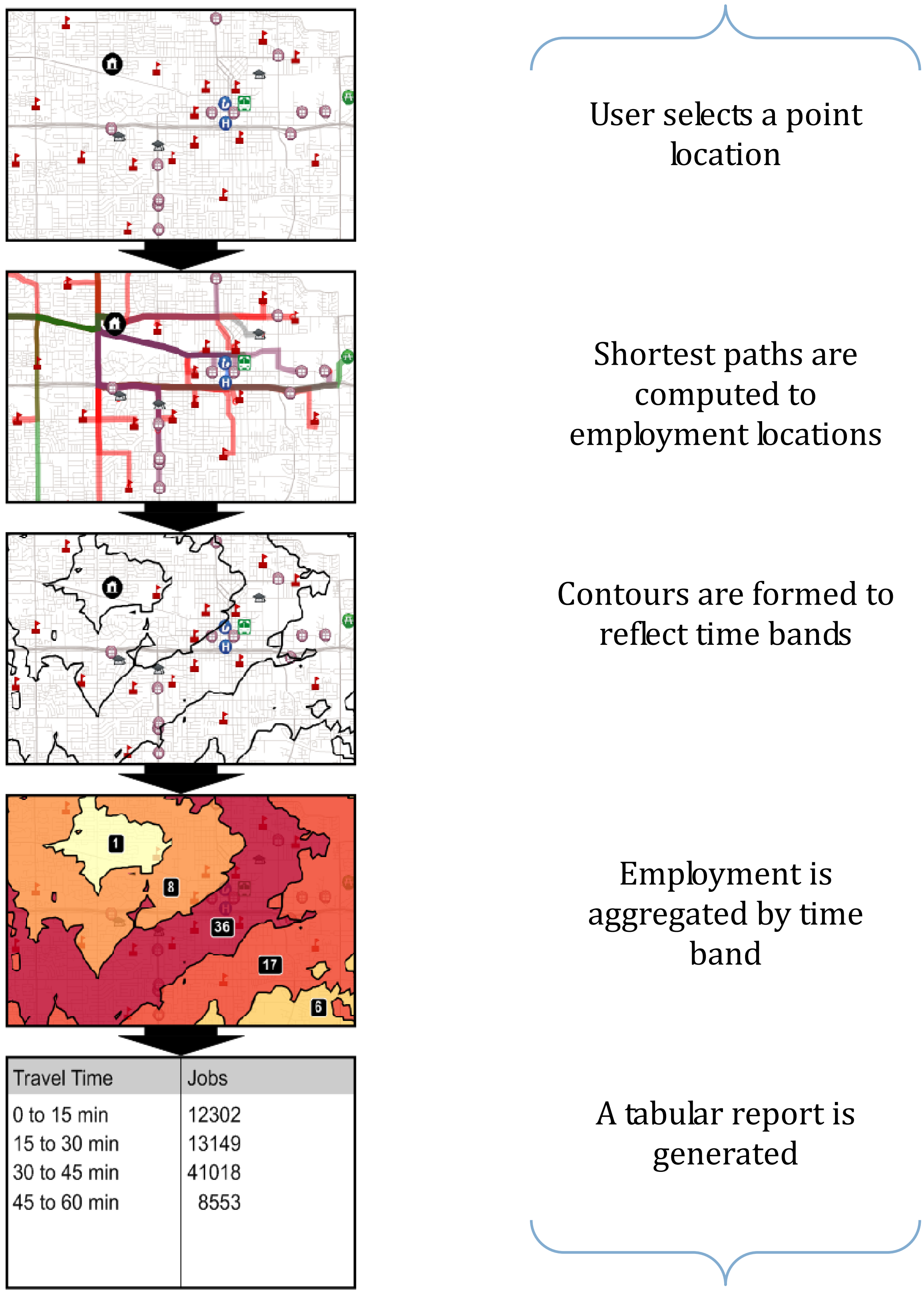
Assessing specific projects or policies requires comparative analysis, which should also be facilitated and simplified. This requires consideration of data that describes future scenarios, which cannot be obtained from readily available sources, so it has to be taken as user input.

Early in the project, we developed a standard set of data file specifications for the application. These are documented in the Appendix as implemented for the North Carolina example that we use in this report.

Computational Approach

From a computational perspective, the accessibility calculators rely on network-based calculations and make use of the best path algorithms in TransCAD. These methods include node-to-node minimum travel time paths. These algorithms are invoked millions upon millions of times to generate the input needed to calculate the areas or network bands associated with specified travel time bands. Networks can be utilized directly or converted from their native form to TransCAD's network format. As necessary, networks can also be developed from geographic line layers with suitable topology using the network builder in TransCAD. For different modal networks and multi-modal networks, there are default settings for measures such as walk speeds to capture all of the components of travel time that will be relevant to computing accessibility. Geo-processing in the form of point-in-polygon and polygon overlay procedures is used to count or sum the relevant demographic measures associated with the specified areas and network bands.

An illustration of the computational procedure appears in the following flow chart, which shows a computation of employment accessibility from a user-selected point location. First, network travel times to employment locations by auto travel are computed. These form the basis for the development of contours representing travel time network bands. Then employment is summed within each travel time band and reported in a table. A further step could be generating cumulative measures of employment by travel time band. Similar procedural steps can be applied for other modes and other accessibility measures. In the next chapter, we provide a discussion of the technical methods that are employed to implement this computational approach.



Travel Time	Jobs
0 to 15 min	12302
15 to 30 min	13149
30 to 45 min	41018
45 to 60 min	8553

Figure 3-1: Flowchart for Employment Accessibility Calculation Procedure

CHAPTER 4: Technical Aspects of Accessibility Calculations

In this chapter, we describe the technical issues we confronted in computing real-world accessibility and the solutions we developed to enable accurate and quick calculations of isochrones bands and demographics. As discussed previously, our original conception was to use planning model data for the calculations, and this may still be the only option for some areas. However, when we investigated further, we found that accessibility calculations and maps were problematic in that they typically failed to provide convincing results. This was due in some measure to the coarseness of the calculations when performed on a zone-to-zone basis, but also due to difficulties in contouring. In particular, the use of sparse networks introduced problems in generating travel time contours especially in outlying areas. There were also problems in computing isochrones in locations where there are water bodies, tunnels, and/or bridges that do not provide the same level of access as ordinary streets. Lastly, we addressed the performance of the polygon overlay operations that are used to compute the demographics for the chosen network bands.

Road Network Travel Time Calculations

To compute auto travel times, the accessibility calculator employs shortest path algorithms on a road network. In our initial experiments with several MPO model networks, we found that the travel times computed from zone to zone gave peculiar results that would be hard to explain to decision-makers or the public. This was the result of several factors, not the least of which were that the planning networks were not sufficiently dense for proper calculations and that destinations or origins of interest were often not at nodes in the network. Landmarks and key service destinations such as hospitals are not commonly represented explicitly in planning networks, although perhaps that should become a good practice in future. Calculating the accessibility to a school or hospital would be a typical request, but when computed using zones and centroids, implausible travel times result.

An illustration of the differences between zone-to-zone planning network bands and street node-t- node network bands are shown in Figures 4-1 and 4-2. These differences are quite significant and definitely will lead to differing results.

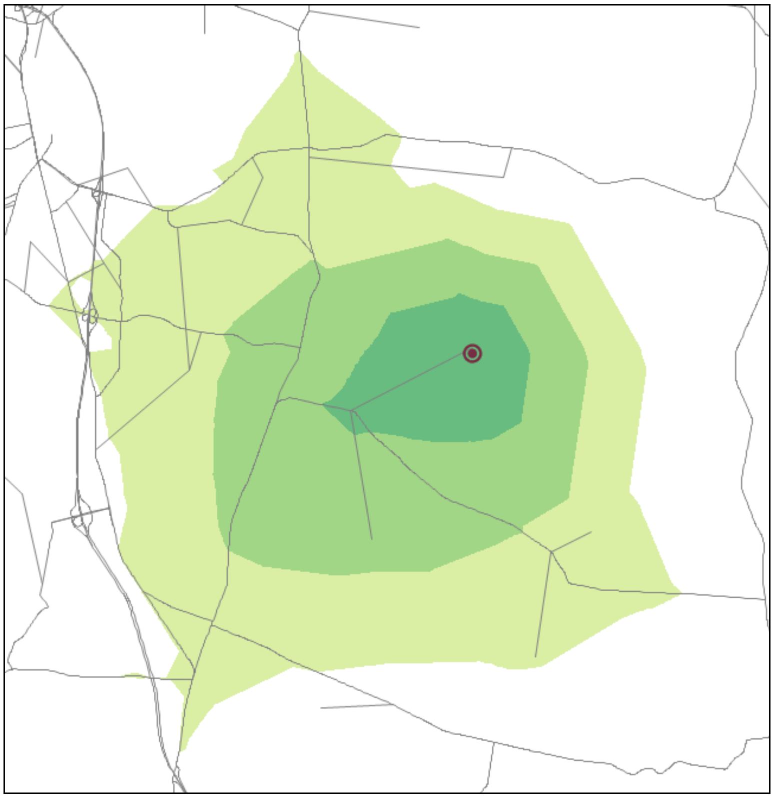


Figure 4-1 Planning Network Bands

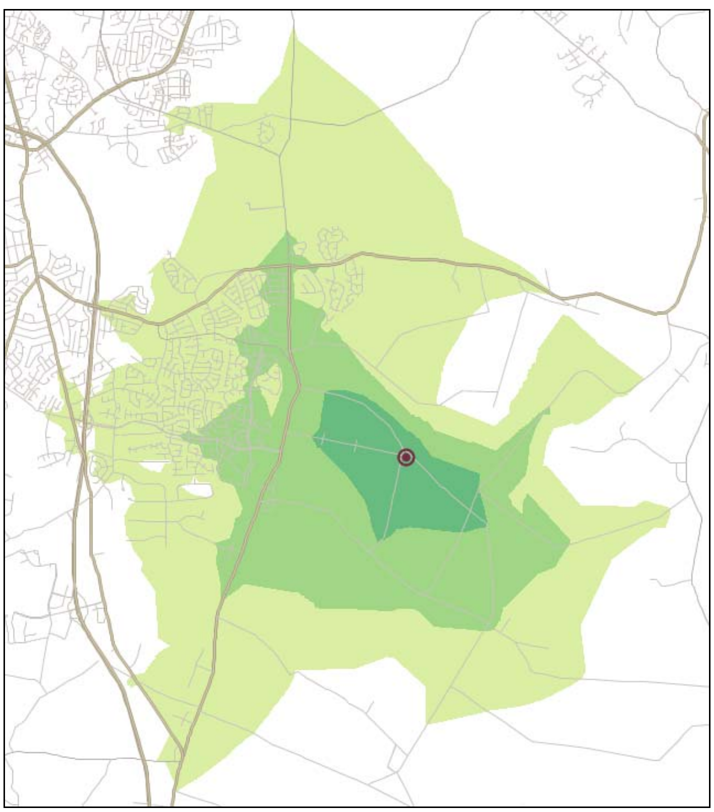


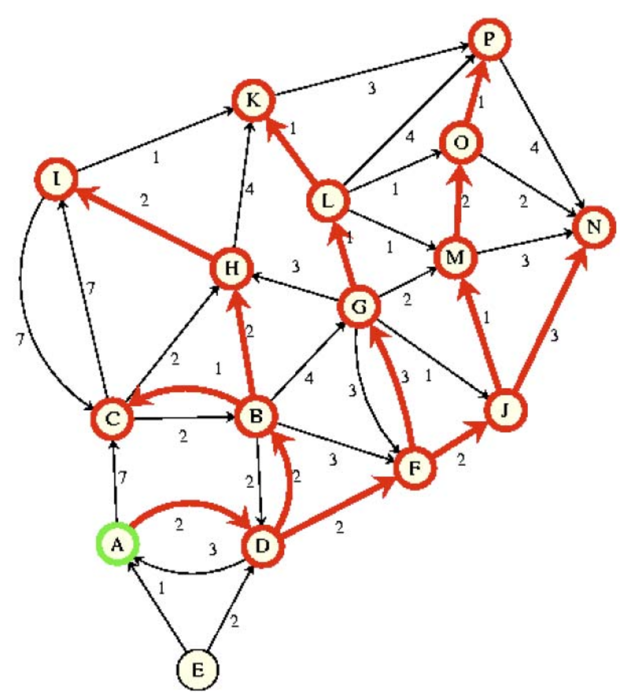
Figure 4-2 Street Level Node to Node network bands

There was also a problem in computing accessibility to or from point locations that were not in the network. To do this on the fly involves augmenting the network or rebuilding it in some fashion, which is time consuming and has other problematic aspects. After some deliberation, the solution adopted was to perform node-to-node shortest paths instead of zone-to-zone paths. When the network is reasonably dense, the nearest node can be used for an origin or a destination that is not in the network. Also, it was determined that in many cases, key landmarks should be explicitly represented as nodes in the road/street network.

Node-to-node shortest paths require considerably more computation than those encountered in planning model practice. For example, in our Triangle Region example, this results in an increase from millions of shortest paths to roughly 6 billion paths. Fortunately, with efficient algorithms and modern computers affording sufficient memory and multi-threading, these calculations from any one point to all other points are easily computed.

To achieve high-performance calculation for the accessibility calculator, we pre-built network files from the line geographic files that are used to perform shortest paths in fractions of a second from any origin node in the database. The shortest path method used for this is known as a label-correcting method that will build a tree of shortest paths tree from one origin. This shortest path tree enables the creation of network bands from any origin node in the network.

The problem of creating the bands to a destination node, however, requires the calculation of tens of thousands or even hundreds of thousands of shortest paths, one from each node in the network to the destination node.



1 shortest path calculation required for bands **from** node A to all the other nodes (15)

15 shortest path calculations required to create bands **to** node A

Figure 4-3: Forward or Reverse Shortest Path Tree

This would result in very high run times and would render the network band tool too slow for a web application. To overcome this problem we utilize a function in the TransCAD macro language that reverses a network on the fly. The benefit of the reversed network is that it enables the calculation of a shortest path tree to a node from all other nodes in the database with a single shortest path calculation. In the current implementation of the accessibility calculator bands can be calculated to and from points using this technology.

Figure 4-4 illustrates another set of problems that we faced. In the figure, we show a road network band created on an accurate NAVTEQ network for the Boston area from a point in downtown Boston. As one can see, various areas in water are marked as accessible. Moreover, bridges and tunnels provide more accessibility than can be delivered given their limit access and egress points. Also, there were strange islands of accessibility divorced from the main time band.

Figure 4-4 Network Band from central Boston

As a check to see if we were missing something fundamental, we tried similar calculations in other software. For example, we tried Microsoft's Map Point with the results shown below for a 5-minute band from central Boston. Clearly these results were even worse than ours and suggested that we needed to develop our own solution if we could.

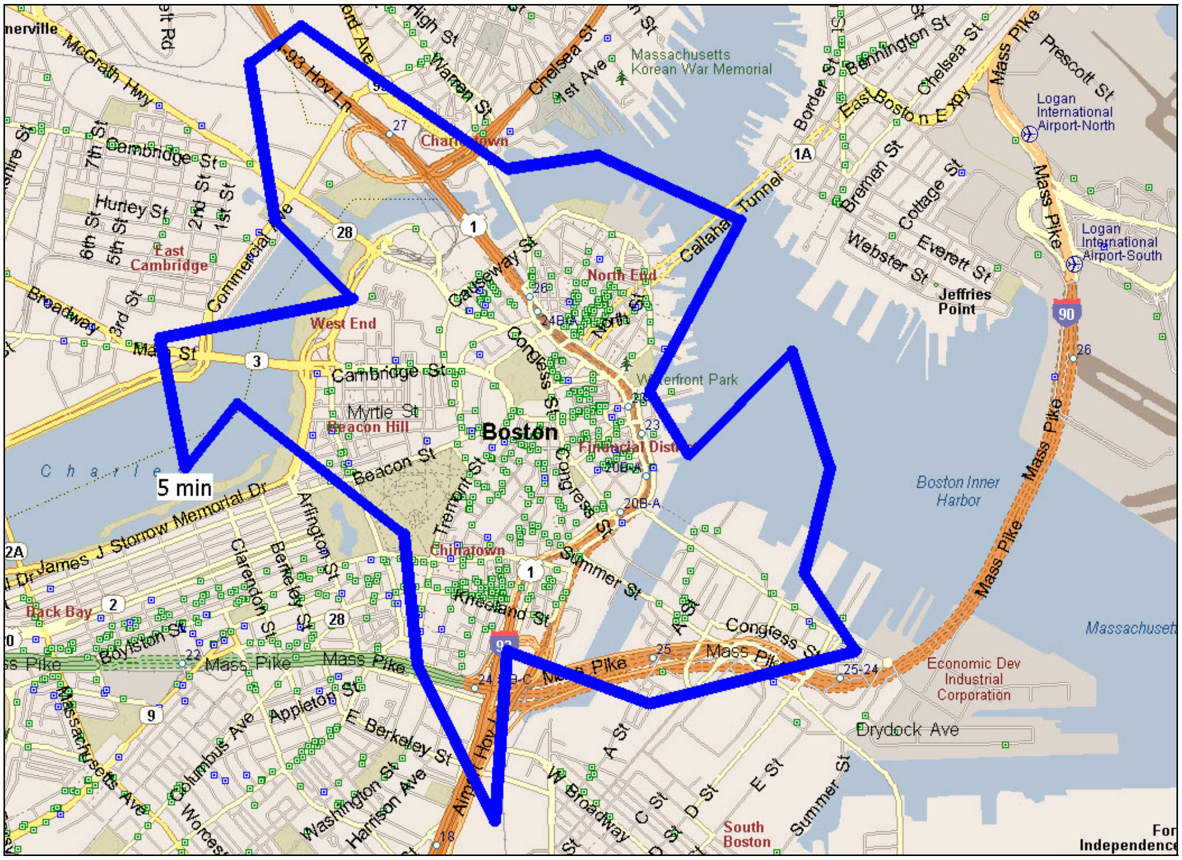


Figure 4-5 5-minute band in Microsoft Map Point

To address some of these issues, we added the technology of masking exclusion areas to eliminate inaccessible points from the solutions generated. This was relatively straightforward by means of polygon selection and/or creation in the TransCAD GIS. A similar approach was taken to exclusion of outside boundary edges which was efficacious once we realized that the strange islands were artifacts of the contouring algorithm when there were too few points through which to draw the contours at the periphery of the outside network band. It is also useful for dealing with areas with inaccessible terrain and National and state park areas.

While the advantage of this approach is considerable, it cannot be a fully automated process. Consequently, it adds to the data preparation required for each region.

An illustration of the effectiveness of the improved approach to computing network bands is presented in Figures 4-6 and 4-7 that follow. In the first figure we show 3 travel time bands of 5, 10, and 15 minutes each without any masking of exclusion areas. In the second figure, we exclude inaccessible areas. The differences are clearly evident in the maps.

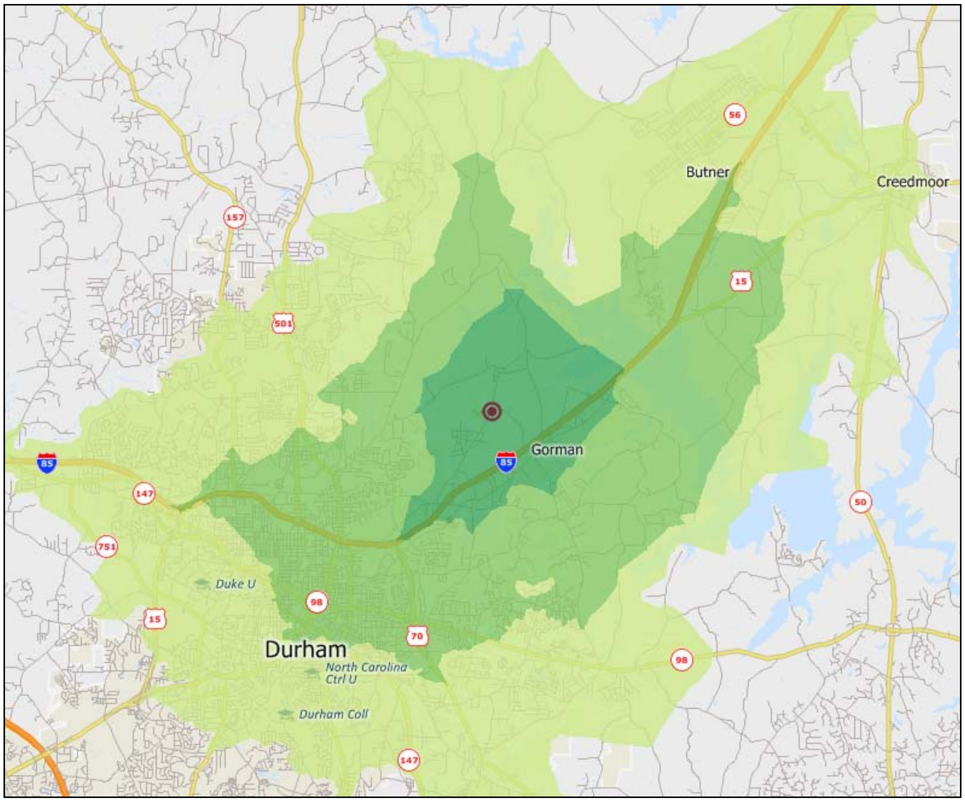


Figure 4-6 Five, Ten, and Fifteen Minute Drive Time Bands without Exclusions

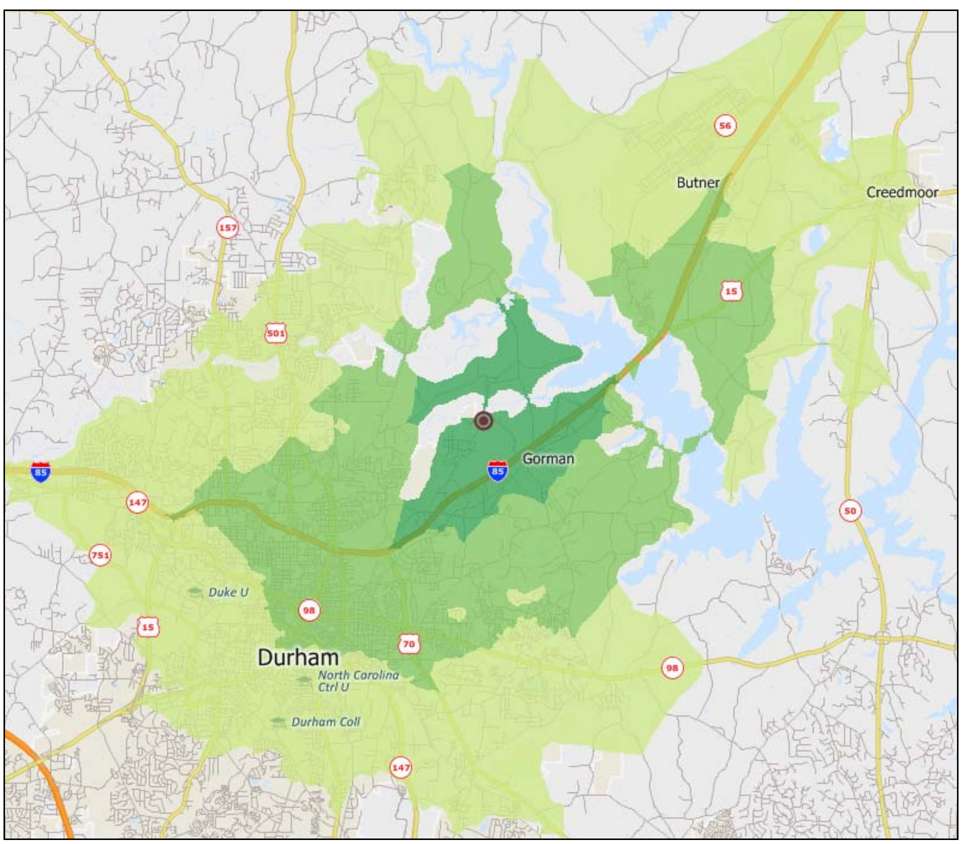


Figure 4-7 Network bands with exclusion areas

Network Bands for Non-motorized Modes

For non-motorized modes, the same basic technology is employed in computing travel times. Separate networks can be used for bicycle and pedestrian modes or the same network can be used with different travel time fields for the non-motorized modes and exclusion sets for the inappropriate links such as interstate highways. Default travel speeds for walking and biking can be used, and these can also be adjusted for specific types of facilities.

Care must be taken to properly identify the road links that are suitable for walking as well as other facilities such as walkways and paths that provide the critical connectivity of pedestrian networks. When we were experimenting with calculating walk accessibility, we found it necessary to augment our network with paths such as those through Boston Common, which are heavily used by foot traffic.

In most areas, it will be useful to have much broader street coverage for non-motorized modes than for the auto mode. Also, the presence of sidewalks and bike lanes would be appropriately tagged in the GIS line layer from which the modal networks are built.

Transit Network Travel Time Calculations

A somewhat different strategy was selected for computing public transport accessibility. While the principle of computing transit shortest paths is similar in concept to computing auto shortest paths, the transit networks use walk links to provide access, egress, and interline connectivity. In TransCAD, there are some very flexible and full-featured transit pathfinding methods, and any of these can be used on a public transport network to compute transit accessibility. Thus the accessibility calculator can accommodate computation of first weights for overlapping service as well as take fares into account should that be desired. It can also make use of schedule-based shortest path calculations in addition to the methods commonly utilized in planning models.

The point of departure is creation of a public transport network from data on public transportation routes, stops, and schedules along with the set of roads and streets that travelers can use as part of their trip. This information can be taken directly from some travel demand models, but it can also be developed independently.

An important source of data for computing transit accessibility are the General Transit Feed Specification (GTFS) data feeds made available by a high percentage of transit operators in the U.S. Originally known as the Google Transit Feed Specification, these data are used by Google and others to provide transit customer information on how to travel from place to place.

TransCAD imports GTFS data and during the project we investigated the GTFS feeds for a number of metropolitan areas, and we researched the usefulness of these data for accessibility calculations. GTFS tables provide key information on routes by ID, transit trips by route, and route stops, which are geolocated. Optional information can include the geographic shape of the route. A stops times table gives the times at which each transit trip is scheduled to arrive at each stop. There are also other tables that provide fare and schedule information.

An important limitation is that GTFS does not include any provision for any information about the lines (streets, rail links, etc.) on which the routes run. If route trip shapes are provided, they often seem to be generated by GPS. This means that the same route's shape may vary from trip to trip by the amount that the GPS varies. Also, the shapes consist of a single chain from the beginning to the end of a trip. There is no information provided for where one shape might match or intersect with others. Shapes are frequently repeated. In an urban area, roads carrying multiple routes may end up with tens of shapes representing the same stretch of road.

Some aspects of GTFS limitations are illustrated below in a sequence of figures produced from the GTFS feed for the Washington DC Metro area transit system. Figure 4-8 shows the route traversed by the N6 bus.

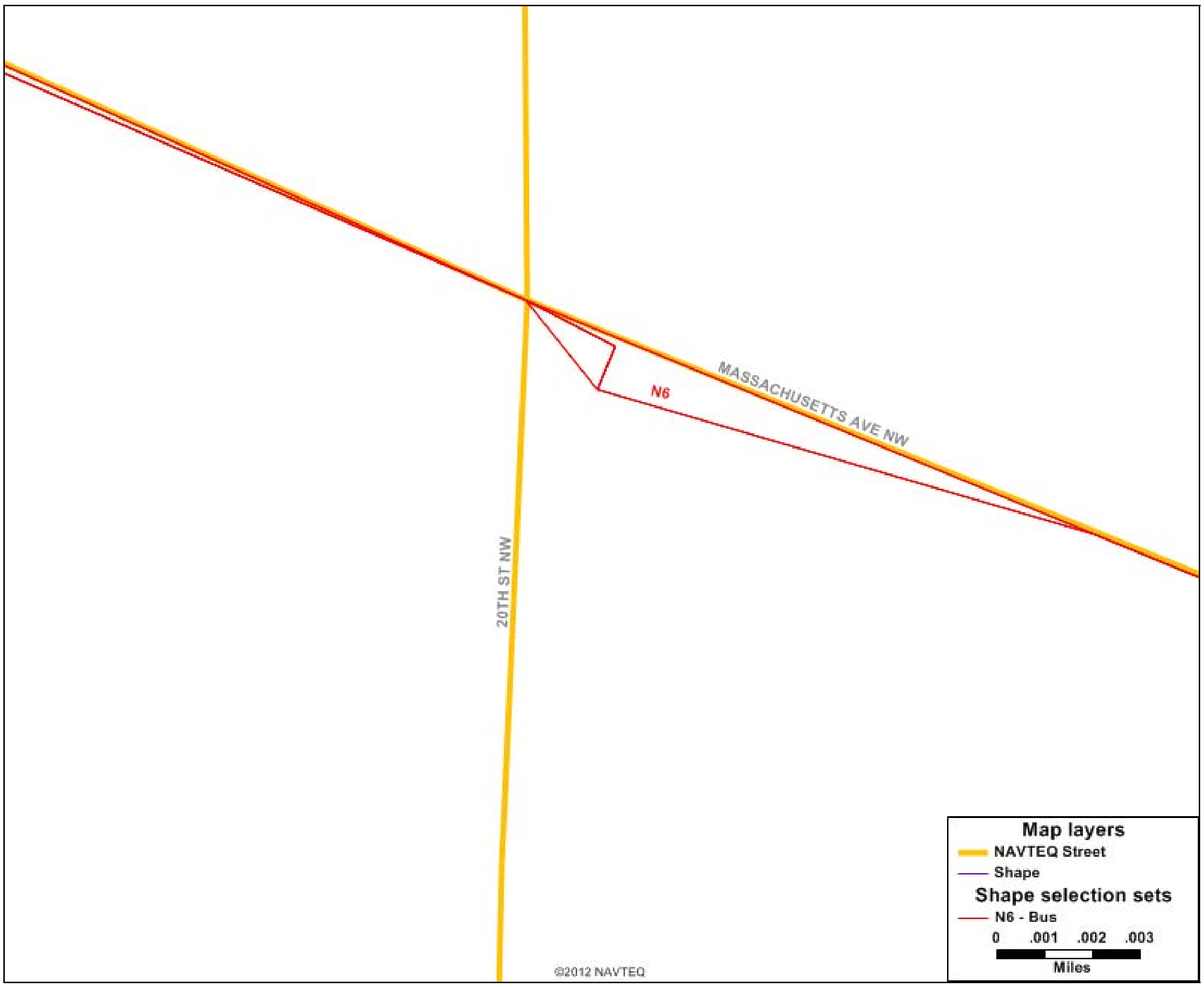


Figure 4-8 Several trips of the WMATA N6 bus inbound

In Figure 4-9, we can see that the shape for WMATA route 5A follows the streets but only for a portion of the route. In the other portion the route is represented as a straight line between stops.

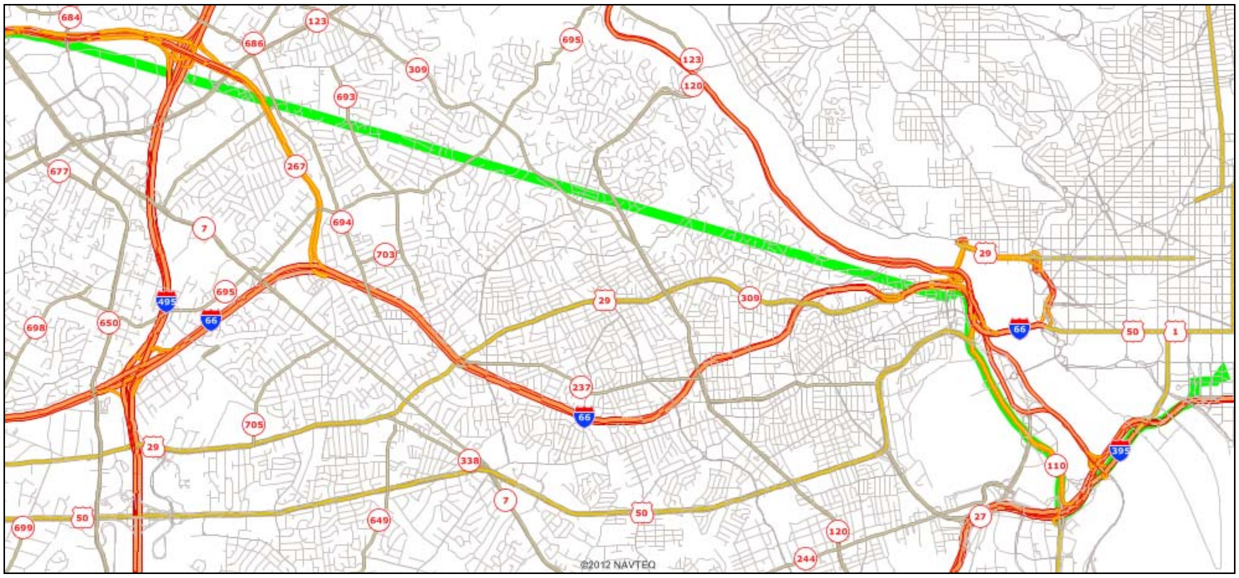


Figure 4-9 WMATA Route 5A

Not only are the route shapes inaccurate, we also found that there was no verification that the stops were actually located on the route shape. A typical example is shown in Figure 4-10, in which the supplied shapes do not include many of the stop locations.

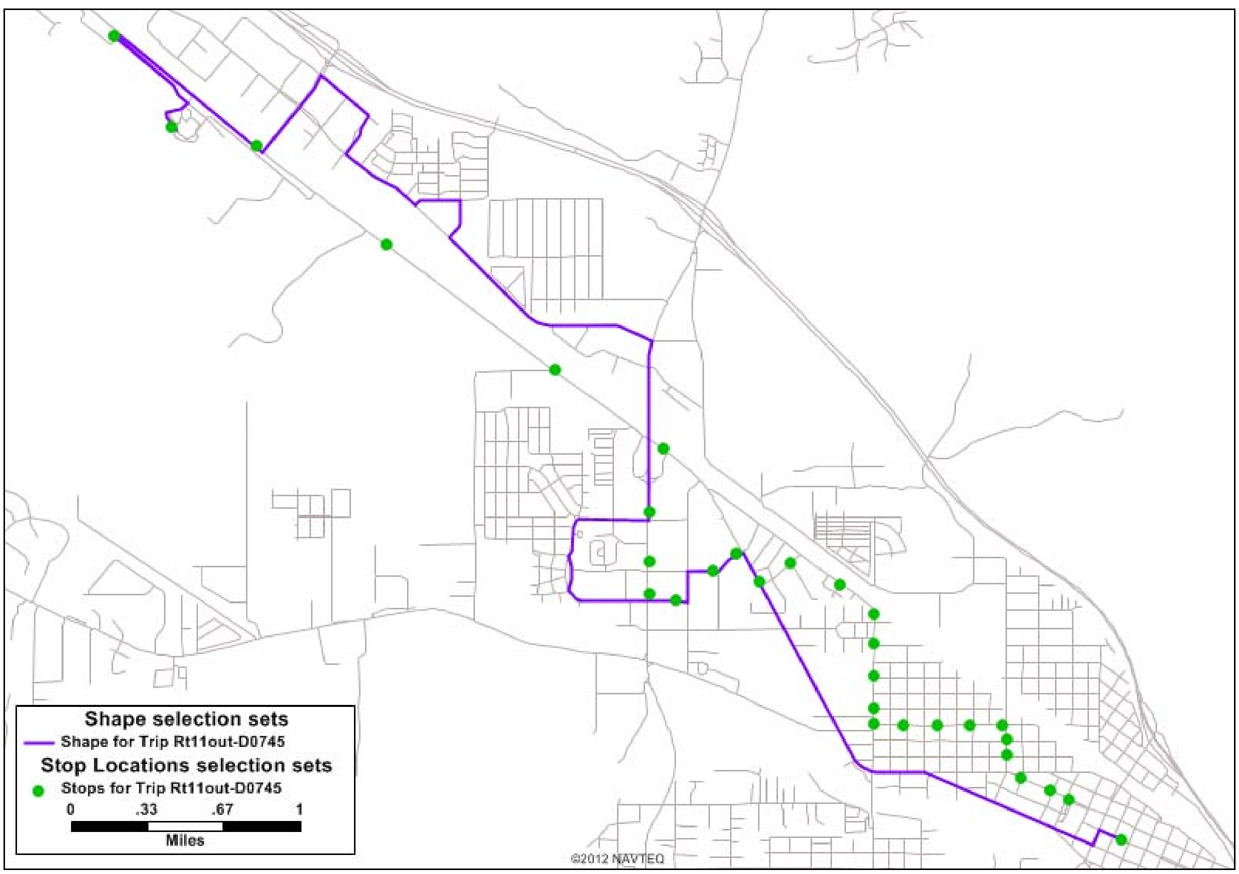


Figure 4-10 Stop locations along a route

Our conclusion from this investigation was that to make GTFS useful for accessibility calculations, we would have to associate it with the correct geography.

Making GTFS useful involves several steps, which we researched in the course of the project. The first of these is to establish a reference street layer on which to place the routes and stops. This needs to be topologically and directionally correct to facilitate route link identification. The second step is to conflate the GTFS routes to the reference street layer.

Conflation is a GIS operation in which a more accurate geographic layer is substituted for a less accurate one. This can be automated to some degree, but typically requires some manual inspection and editing to be fully realized.

During the project, we experimented with conflation of transit networks for a variety of areas. Figure 4-11 shows a conflated network for the Pittsburgh, PA area. We found that conflation could be done successfully when we used NAVTEQ street layers, which meet reasonable standards of geographic accuracy and connectivity. In each case, a few hours of editing was necessary after the conflation program was run. From these exercises, we concluded that GTFS conflation was quite viable, but that it would only make sense for entities that had suitable NAVTEQ licenses or other accurate street networks available

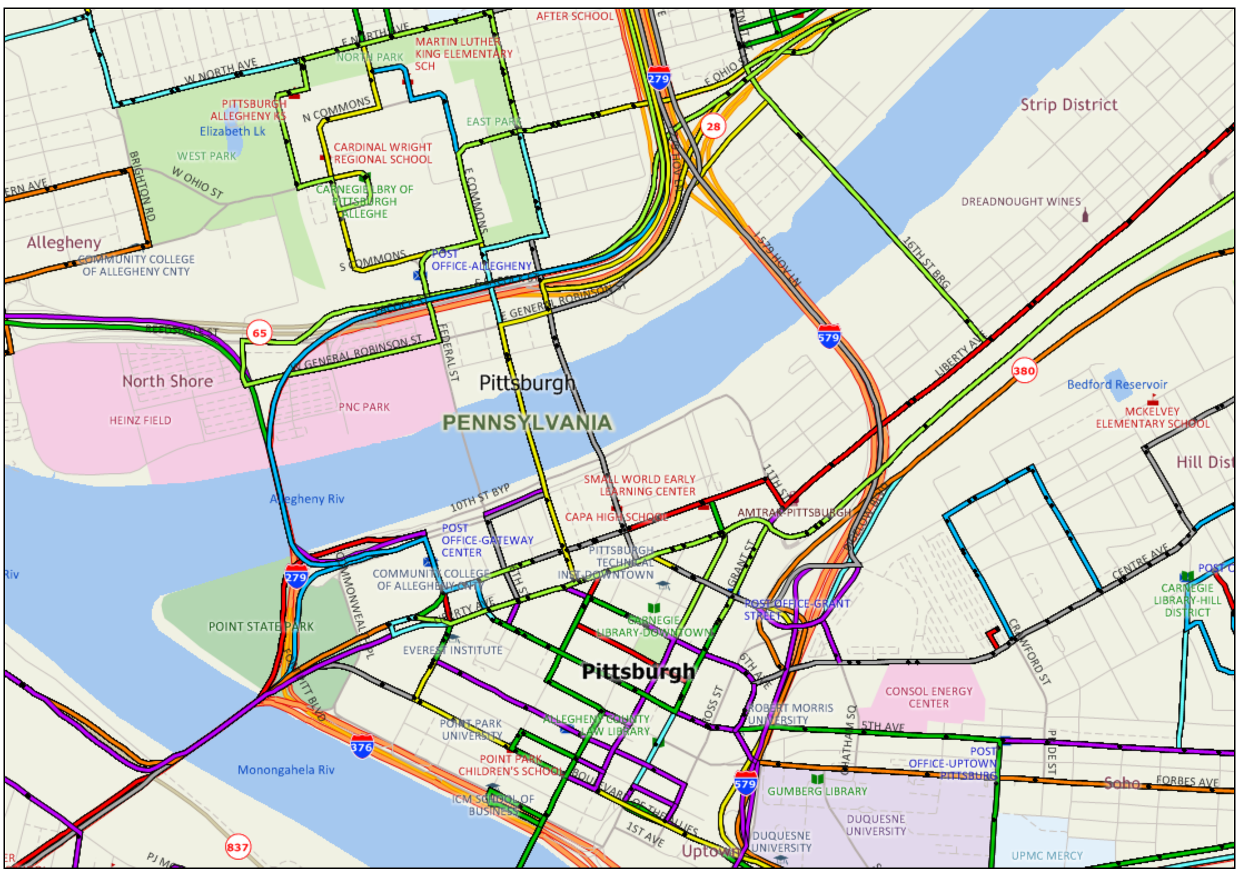


Figure 4-11 Example of a Conflated Transit Route System

As discussed above, the streets are also needed to provide place-to-place connectivity on the transit system. When that is done, the transit pathfinding is quite a bit more accurate than when it is attempted from GTFS alone with only very approximate access, egress, and transfer times.

An alternative to using GTFS is to use a pre-built route system in TransCAD or the equivalent that can be imported from other planning model software as long as it is suitable for street node-to-street node transit shortest path calculations.

Given the additional complexity involved in transit pathfinding, with its many parameters and features, the computational burden is significantly higher than it is for the auto mode. In fact, we felt that it was undesirable to do the calculations in real time when web queries are made. Consequently, we developed a faster computational approach.

In this approach we pre-compute the transit shortest paths and store the resulting travel times in matrices. Each cell of the matrix will contain the total travel time between the origin node row and the destination node column. The total travel time includes all the travel time components of the transit shortest path such as waiting time, in vehicle travel time, transfer times, etc. In the case of the North Carolina Capital Area Metropolitan Planning Organization database this resulted in matrices with over 78,000 rows and columns, one for each node in the database. Public transportation matrices are in general sparse because many nodes in the database are not in the public transportation service area.

Network bands from an origin are then calculated by reading a complete row of the matrix, while network bands to a destination are calculated by reading a complete column of the matrix. For computational efficiency, the web accessibility calculator works with two copies of the same matrix, one saved as a row major matrix (enabling fast access of a complete matrix row) and the second one as a column major matrix (enabling fast access to a complete matrix column). With this strategy, transit travel time bands are rapidly generated in response to web queries.

Isochrone Contouring Approach

Network bands representing equal travel times or isochrones are computed using a contouring algorithm in TransCAD. The contours, of course, are only a means to approximate the area covered in a time band as the travel times are only measured on the network unless an off-network time component is included.

In sparse areas, the method used to generate the contours can give peculiar results. To increase accuracy of the bands, we interpolate impedance values for points along each road segment that is not a bridge, tunnel or ferry. In the interest of speed of computation, we drop all points that have impedance values that are barely higher than the maximum band required. To this set of points, we add points around bodies of water and assign them a value that is greater than the maximal travel band required to ensure that water areas are dropped.

Computing Demographics with Polygon Overlay

Essential to computing measures of accessibility is the ability to calculate the number of jobs, people, or destinations within a given modal network band. This is done by counting locations with a point-in-polygon function or by performing a polygon overlay by intersecting each network band with a polygon layer that has small area data on population, employment, or other measures of interest. Polygon overlay is a GIS operation that we used for computing the demographics for any isochrones. This is more accurate than marking area layer objects such as zones as either in or out of a travel time band. The small area layer will be a TAZ layer or a Census block, block group, or Census tract database.

Early in the project, we learned that the polygon overlay would be time-consuming and would make users impatient. We quickly discovered that part of the problem was the highly detailed nature of the polygon boundaries that we were using. This can be seen in the example below where the dark squares are the shape points for some polygons.

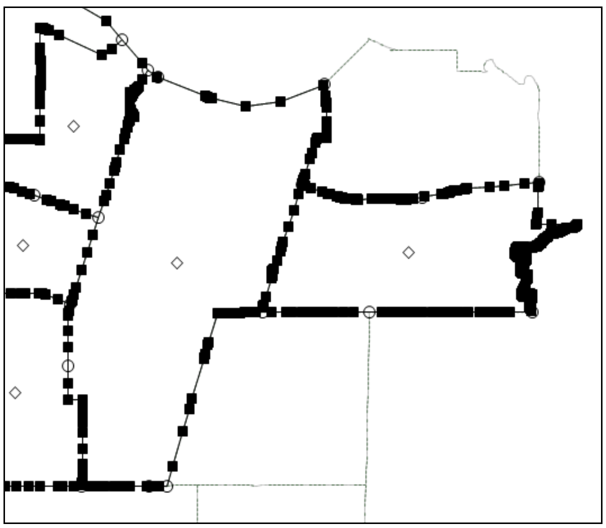


Figure 4-12 Polygons Before Simplification

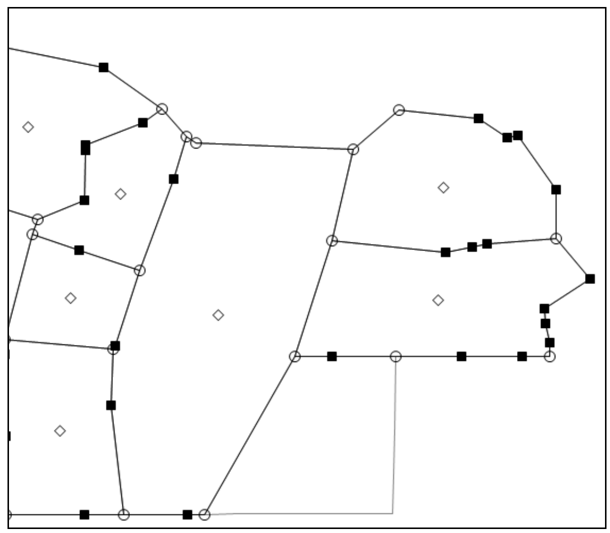


Figure 4-13 After Polygon Simplification

Due to the nature of the demographic approximations associated with polygon overlay, there is little reason to expect that simplification would exact any significant compromise in the calculations performed. Yet it produces a dramatic speedup in the calculations. So polygon simplification has become a useful and necessary aspect of the data preparation for the accessibility calculator.

CHAPTER 5: Accessibility Web Application Software

In this chapter, we describe the work we've done to develop the web application and demonstration site, including the back-end and the front-end component. We developed each component of the web site with two goals in mind: firstly that it should be possible to install and setup a new site, region, or scenario relatively quickly, and secondly that is should be easy to navigate by end users.

Overview

The application is designed to provide a simple user interface to a powerful accessibility calculation engine. The principal functional requirements on the end user side are illustrated in Figure 5-1. In addition to performing the accessibility calculations, the user interface needs to support comparisons of scenarios and the sharing of results.

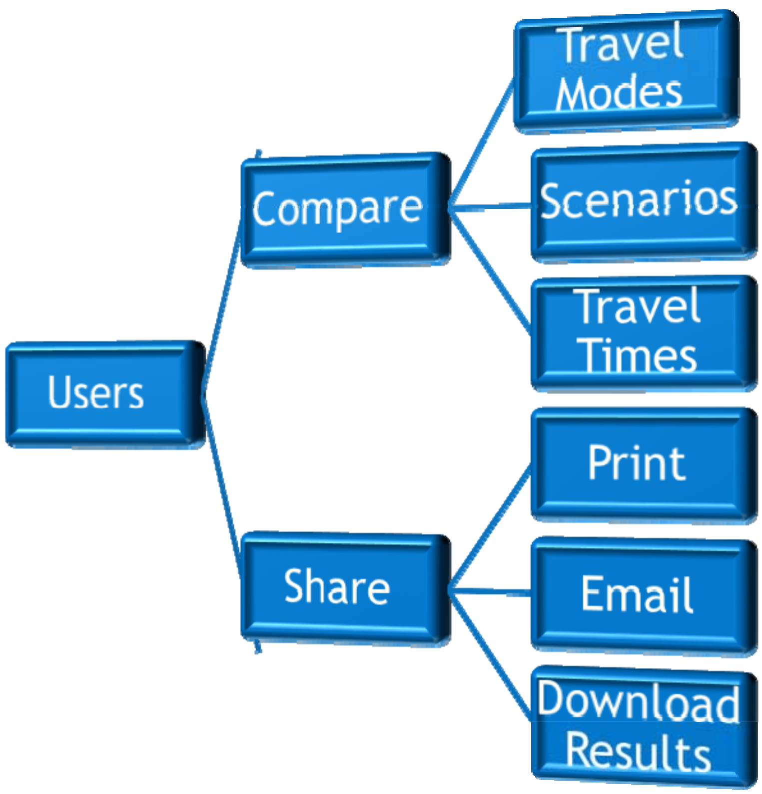


Figure 5-1 User Functionality Requirements

Tools are also required to administer and maintain the application as it might be hosted by a state or regional transportation agency or by their consultants. These functions are illustrated in Figure 5-2 and include the ability to add scenarios, update key data elements, and add different regions. This functionality has been implemented and is part of the application.

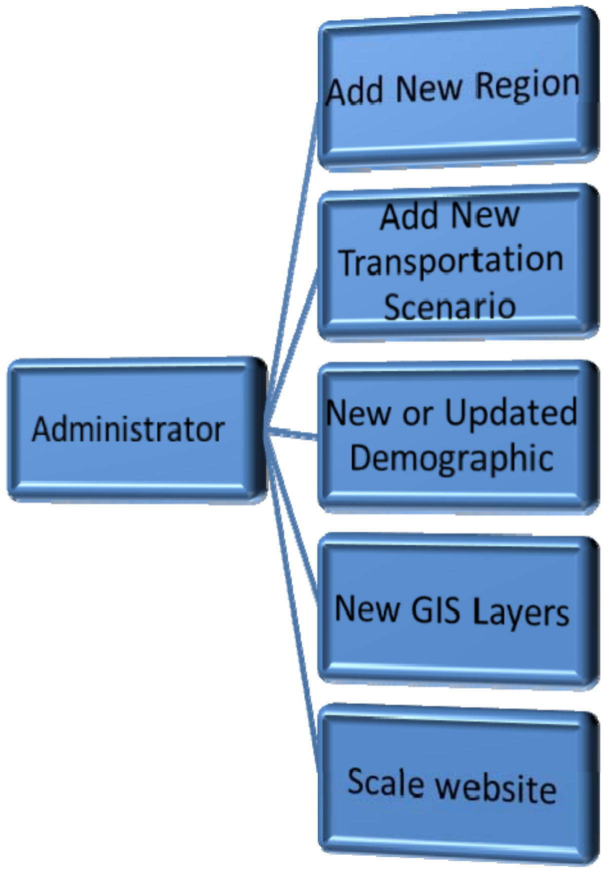


Figure 5-2 Administrator Functional Requirements

The User Interface

A primary consideration in the design of the user interface was to make it easy for users to formulate and execute accessibility queries. To achieve this end, we iterated over a series of design revisions. At the outset, we organized the web site with a vertical panel aligned to the left of the screen and a full screen map (see Figure 5-3). The panel is used to select the map functions. Each design revision added a function to the web site (e.g., Scenarios, Gallery, Compare). We also made a variety of changes to the application to provide enhanced performance.

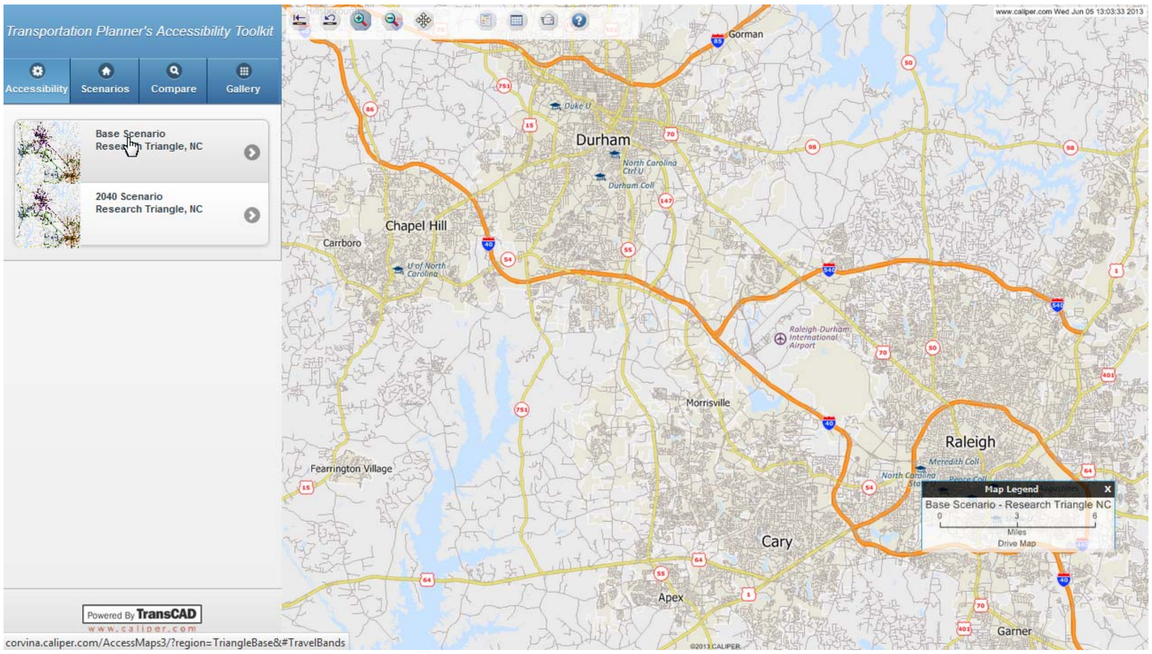


Figure 5-3 User Interface Panel and Map Display

We introduced the Scenarios tab to support creating maps for different geographic and demographic contexts. Scenarios are added offline by the web site administrator. Each scenario corresponds to a specific data set and particular network conditions (e.g., existing conditions, 2040 projected improvements). While the process of creating the appropriate data set for each scenario is not trivial, adding a scenario to the web site is simple. It consists of adding a single JavaScript file that list the geographic data and the numeric parameters used for that scenario and adding one item to the list of scenario names in HTML.

The Gallery is a list of pre-computed travel time maps with thumbnails to aid in map selection as shown in Figure 5-4. We introduced this function to provide immediate gratification to first-time users. They can see what a travel time map looks like for different travel modes by simply choosing an existing map, which they can explore further. Also, the run time for creating a travel time map may be long (e.g., 20 seconds). Being able to see what a map looks like immediately is an important aspect of this site. The Gallery maps are created and stored once by the web site administrator by using the web site and calling some Javascript functions. There is no limit in the number of maps that can be computed and stored in advance. The Gallery provides a simple way to cache frequently requested maps.

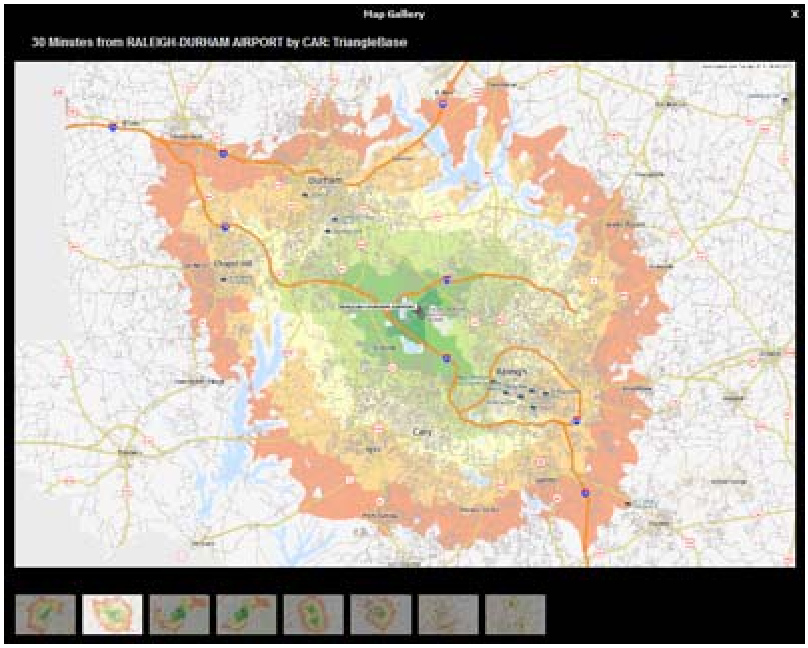


Figure 5-4 Map Gallery

The Accessibility tab is used to create a travel time map for different modes and different parameters. We decided to split the time-consuming process of calculating accessibility metrics by breaking the process into two shorter steps. A user can first create the travel time contours via the “Create Map” button, and if satisfied with the map, subsequently choose “Compute Measure” to get a tabular report (Figure 5-5). Each of these steps takes an average of 10 seconds, resulting in a more responsive web site.

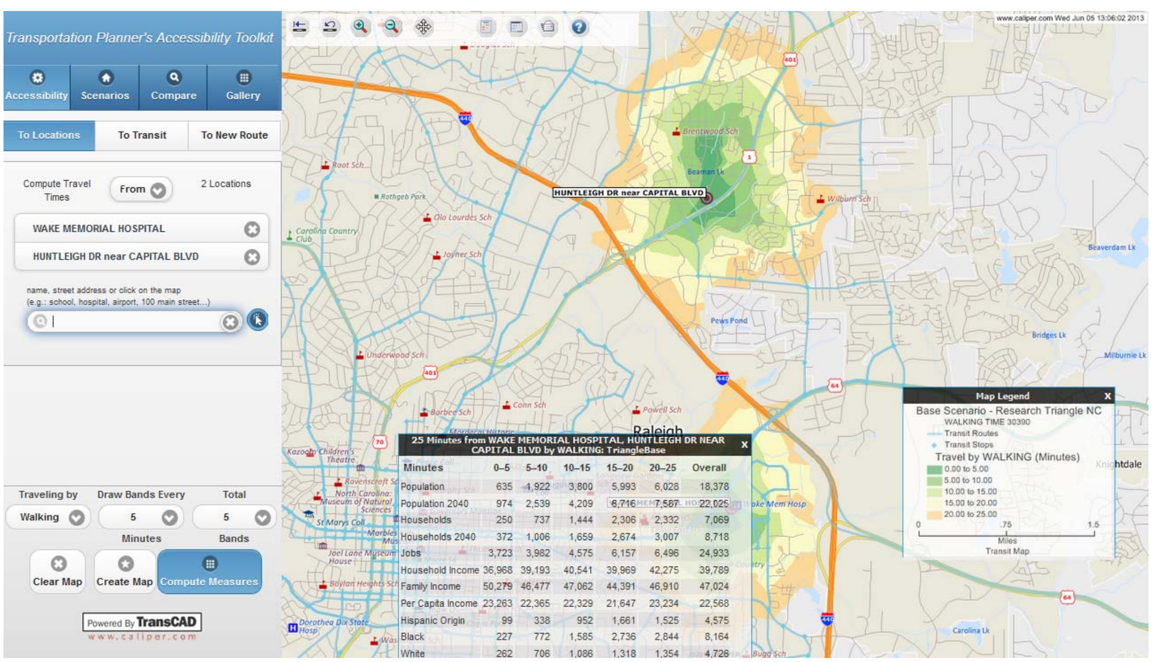


Figure 5-5 Overlay Demographics

A key function of the web application is the ability to compare different maps via the “Compare” tab. There are two ways to compare maps. The first one is side-by-side as shown in Figure 5-6, and the second one is to combine them on the same map as shown in Figure 5-7. When they are presented side-by-side, the two map windows can be synchronized to display the same exact location and extent. The “Combine” function overlays two different maps for a common time interval, highlighting regions that are accessible in one map and not the other, and comparing the different accessibility measures in a single table.

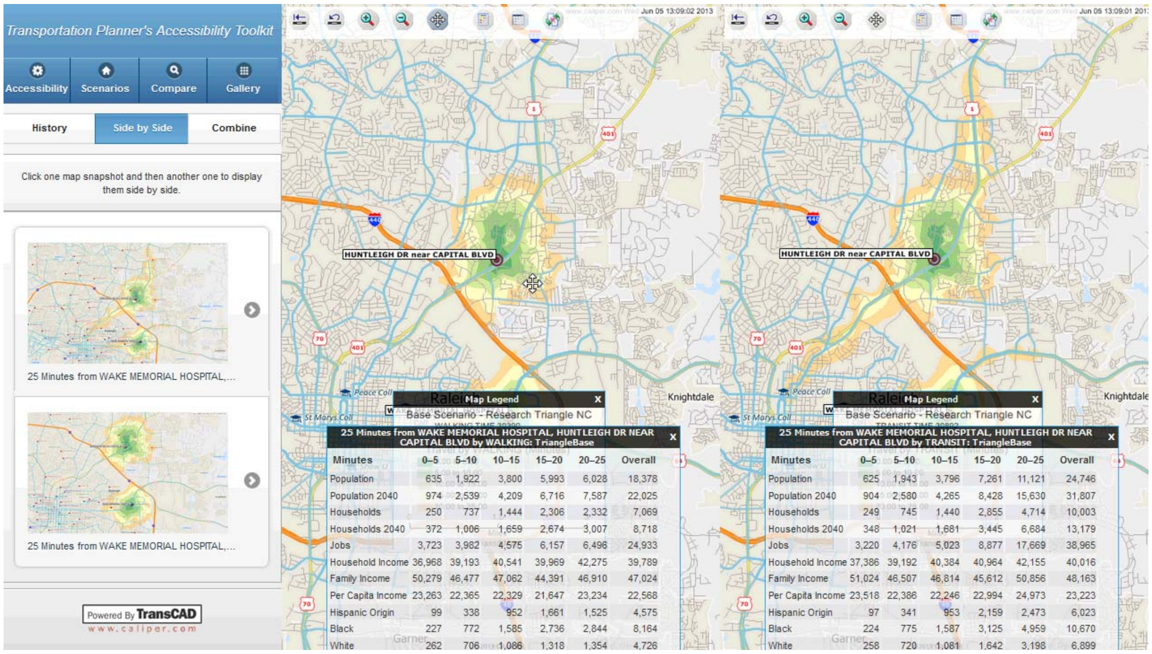


Figure 5-6 Side-by-side comparison

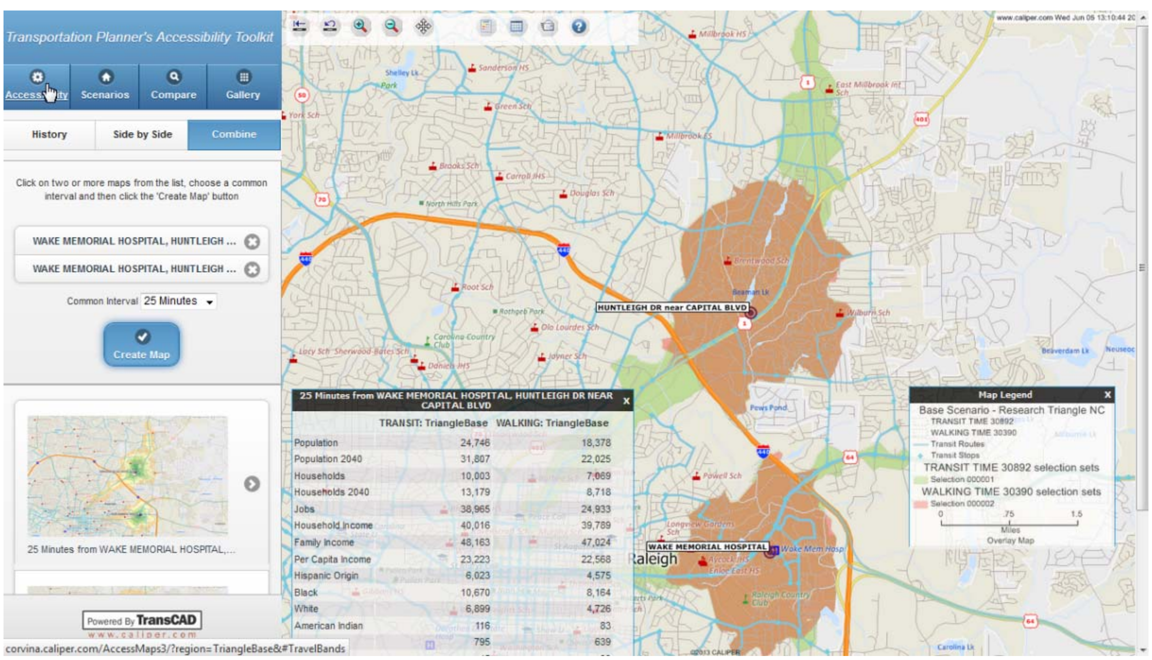


Figure 5-7 Combined Comparison View

In addition to the map gallery, previously computed maps appear in the "History" list. The web site attempts to "remember" as much as possible the maps that the user creates, and computes a specific map only once.

On the client side, this is accomplished by storing information about each map in the browser local storage, a functionality that is available in the latest version of all browsers. This has the advantage that a user may close the web browser and come back to the web site a few days later, and the history of his or her most recent maps and map locations will be presented.

On the server side, we have implemented a cache manager that uses the server local file system. The web site administrator can delete the cache folder when appropriate.

Another aspect of web development was the selection of thematic mapping styles to facilitate comprehension and comparison of results. While the end user cannot choose what colors are displayed on the thematic maps, it is possible for the web site administrator to choose all the map layer display styles and colors using the TransCAD desktop application. We think this is a good solution that provides some level of customization, while ensuring that all maps can be compared and shared with a common display standard.

The application will let the users download the data in several different forms. The most basic download option is by saving the map image as a raster image file in any of the image file formats such as png, jpg, and gif. The numerical results from calculations will also be provided as data tables in spreadsheet format. Advanced users can download the resulting contour layer and related data in geographic vector format as either Esri shapefiles or Keyhole Markup Language (KML). The application will not offer a complete download of all the other input layers in the displayed map since the size of these datasets can be rather large. The downloaded files will include the geometry of the contours and the accessibility measures for each contour.

A User's Guide was prepared for the web application and it is provided in the Help system that is incorporated in the software.

Front-End Software Architecture

The application front-end is written in HTML and JavaScript, and supports being viewed by many different browsers, in either Windows or Mac.

We tested the application with the following browsers: Internet Explorer 8, 9,and 10, Google Chrome, Mozilla Firefox and Apple Safari.

While the application consists of several JavaScript modules and libraries, we developed the top-level application functions by encapsulating them into a single documented JavaScript module called ToolkitApp.js. This single module, called toolkit.app, has this set of functions:

- switching the current region or scenario
- redrawing the map at a specific bounding box (center lon/lat, width and height)
- panning, zooming and recentering the map image

- adding or removing origins by choosing them from a list
- adding or removing origins by clicking on the map
- validating the input travel time HTML form
- computing the travel time contour map
- printing the current map
- clearing the annotation and the contour theme on the map
- managing the history of contour maps
- displaying two contour maps side-by-side
- synchronizing the location and extent of two maps

The web site look and feel can be customized by modifying the HTML templates, the CSS (Cascade Style Sheet) files and the Jquery plugin themes that are included in the application.

Back-End Software Architecture

The web site back-end, running on a multicore Windows Server, is organized into two layers: a thin ASP.NET application layer, and a pool of GIS server instances. The ASP.NET application layer delegates all the GIS computations to a pool of GIS servers - TransCAD for the Web instances, each one running on a server core.

For the ASP.NET application layer, we developed a Cache component that is responsible for storing and retrieving travel time contour maps. The Cache supports the history function of the web site. After a contour map is created, the user can access it again on the web page via the history tab. The ASP.NET application attempts to retrieve the contour map response from the cache. If the map response is not found in the cache, then the application forwards the request to one of the TransCAD for the Web instances. The temporary folders managed by the cache may be flushed by the web site administrator on a regular basis.

For the GIS server layer, we improved the functionality of TransCAD for the Web to better support computing travel band contour maps on multiple instances, and drawing very large map images. For this web application, TransCAD for the Web can draw full screen map images in desktop browsers with large monitors.

Setting Up Scenarios

We developed the web site back-end so that it is relatively simple for a web site administrator to add and remove scenarios to a web site.

The web site is organized into scenarios. Each scenario defines a specific MPO area of study and transportation model data set. Typically, different scenarios may correspond to different geographic data sets, different numeric parameters, or even different areas of study. A single web site should include at least one scenario.

For example, to add a base year scenario for a Boston transportation model, first the administrator would copy all the relevant geographic data sets needed by TransCAD into a specific data folder (e.g., C:\Projects\Data\Boston).

Second, the administrator will edit a single JavaScript configuration file that stores all the parameters for that scenario (e.g., c:\WebSite\Application\BostonData.js).

The parameters in the JavaScript configuration file for one scenario include:

- List of maps to use to calculate travel times (one for each travel mode).
- For each travel mode, which geographic layers and matrix datasets are used to compute travel times.
- Which Census overlay area layer to use and the list of numeric variables to compute.
- Default values of all the numeric parameters used in the calculations.
- Which file to use in the list of landmarks.

Demonstration Example

During the course of the project we implemented accessibility calculations for a number of regional test cases. We also experimented with transit accessibility calculations in some other areas including Miami, Pittsburgh, and Boston. In the project, we demonstrated the use of the accessibility toolkit utilizing data provided for the Triangle Region of North Carolina graciously provided by the Durham-Chapel Hill Carboro (DCHC) MPO.

Two scenarios were built for the Research Triangle region of North Carolina, which includes the cities of Raleigh, Durham, and Chapel Hill. Base-year and 2040 scenarios were derived in part from the TransCAD models of the Durham-Chapel Hill-Carboro (DCHC) MPO. Street data were obtained from a shapefile obtained from North Carolina DOT, and future-year highways and key transit streets were merged from the 2040 model. Display layers were cropped from TransCAD's bundled TIGER datasets. Transit networks were extracted from the two demand models and were conflated to the NCDOT street layers. Demographic data were also extracted from the TAZ layers of the two model scenarios, while additional attributes were added to landmark point features. For example, the estimated number of hospital beds was added to each hospital, enabling the calculation of the number of hospitals as well as the number of hospital beds in each generated travel band. Neither we nor the DCHC MPO vetted these data and they should be regarded as illustrative as opposed to definitive. Further details on the input data files are provided in Appendix B.

For easier data management, we organized all the data by scenario folders. Each scenario represents an alternative for each area of study. For example, in the Triangle NC region we can compare travel times between the base scenario and a 2040 scenario. Each scenario has its own network data set. To simplify data management, a scenario (2040) specifies a parent scenario (Base) and only lists the parameters that differ between the two scenarios.

The preparation of this dataset gave us further insight into the difficulties of assembling the appropriate data for multi-modal accessibility calculations. It took several person weeks for the work described above, and we believe that similar or greater levels of effort will be required for each regional application unless licensed data such as that from NAVTEQ or TeleAtlas can be utilized. The reason for this is quite simple. MPO travel demand models do not utilize enough geographic detail to be sufficient for accessibility calculations, especially for modes other than driving. More detailed walk networks and explicit representation of oft-frequented destinations such as hospitals, schools, and shopping malls will usually be needed.

In this first example, we examine the accessibility of a location to two major hospitals in the Raleigh-Durham area. Figure 5-8 shows the panel used to generate accessibility queries and the map history shows that accessibility bands have been computed for auto and transit access to either hospital. As would be expected, the 30-minute access area for transit is significantly smaller than that for driving. This is seen more clearly in Figure 5-9 which shows a side-by-side comparison at the same map scale.

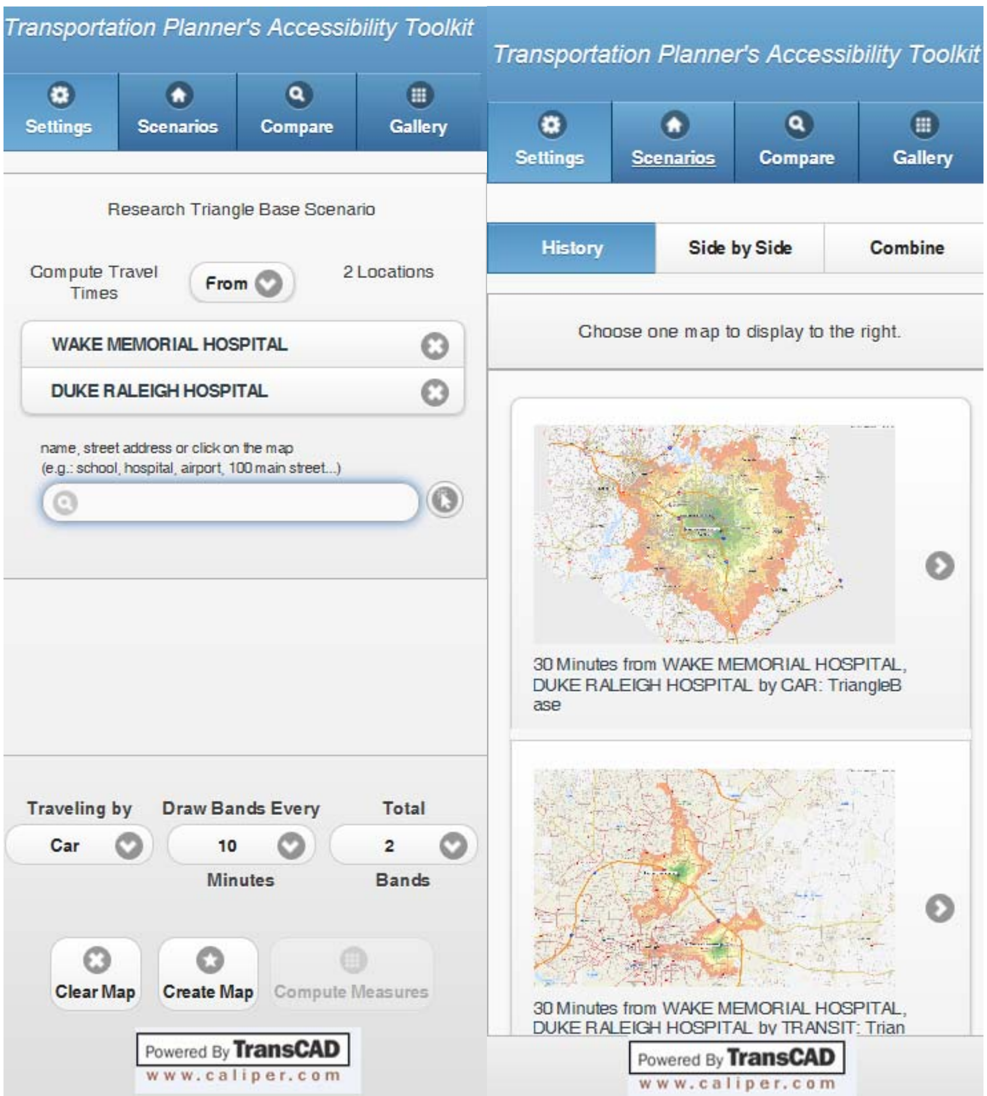


Figure 5-8 Application Interface

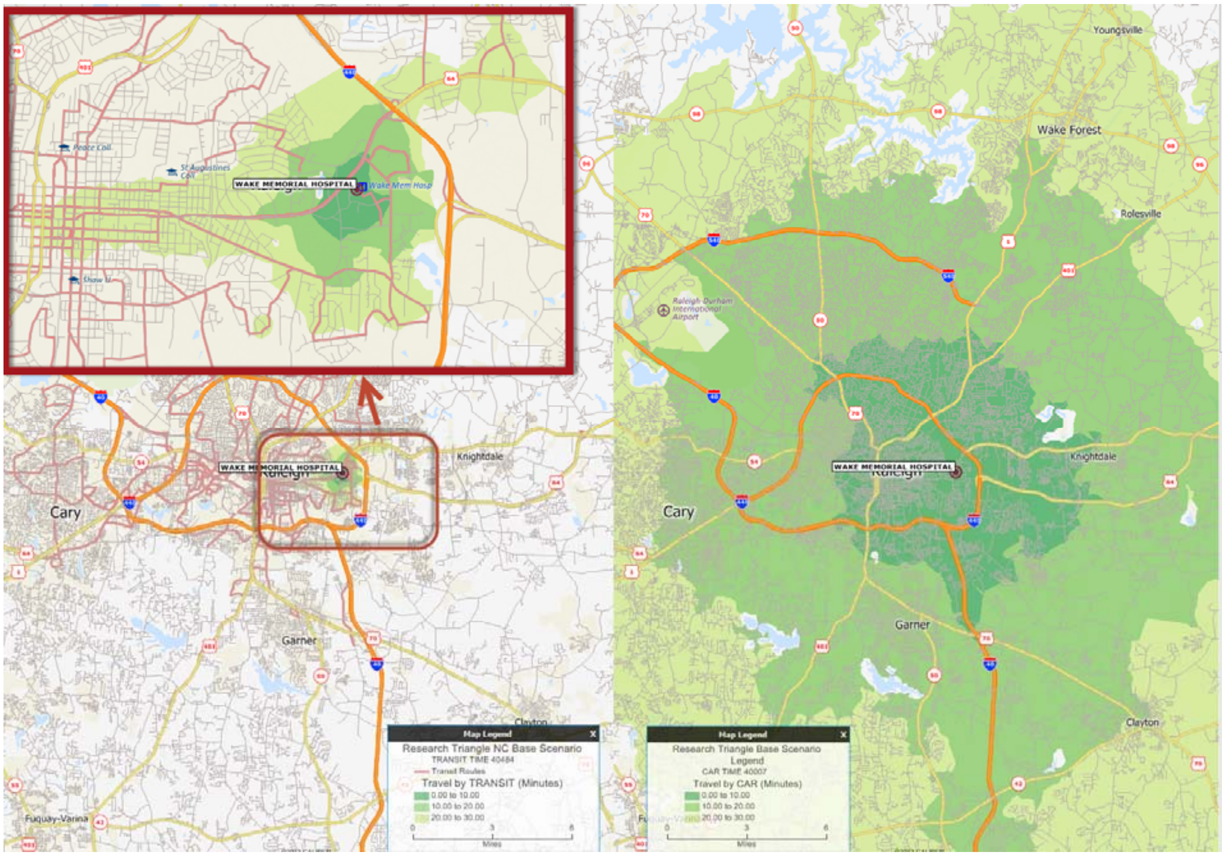


Figure 5-9 Side-by-side comparison of transit and auto accessibility to hospitals

30 Minutes from WAKE MEMORIAL HOSPITAL, DUKE RALEIGH HOSPITAL by TRANSIT: TriangleBase

Minutes	0–5	5–10	10–15	15–20	20–25	25–30	Overall
Population	668	1,497	2,468	4,714	9,665	16,996	36,008
Population 2040	1,306	2,373	3,313	6,828	14,111	23,594	51,525
Households	169	494	978	2,104	4,469	7,441	15,655
Households 2040	500	960	1,388	3,028	6,324	10,725	22,925
Jobs	5,213	6,499	8,075	11,100	15,622	56,233	102,742
Household Income	39,158	36,877	42,897	45,505	53,213	45,097	43,791
Family Income	30,392	30,477	42,276	49,526	63,858	76,962	48,915
Per Capita Income	23,271	21,899	25,028	26,240	30,507	29,486	26,072
Hispanic Origin	329	564	798	1,131	1,305	1,860	5,987
Black	164	528	1,052	1,931	3,126	6,089	12,890
White	153	362	550	1,491	4,937	8,508	16,001
American Indian	3	6	9	17	33	74	142
Asian	12	21	36	96	190	327	682
Other Race	2	3	4	7	16	31	63
Multiple Races	2	7	16	35	54	96	210
Hospital	1	—	—	—	—	—	1
Hospital Beds	870	—	—	—	—	—	870

Table 5-1 Demographics by transit time band

Tabular output from the overlays of 5 minute bands for public transit appear in Table 5-1. This is a standardized report produced by the web application.

A side-by-side comparison of access within 30 minutes to these hospitals by car and by public transit is shown in Table 5-2. The narrow reach of public transit is clearly seen in this analysis. One can also see that while there will be dramatic growth by 2040, most of it will take place in areas not well-served by transit.

30 Minutes from WAKE MEMORIAL HOSPITAL, DUKE RALEIGH HOSPITAL

	CAR: TriangleBase	TRANSIT: TriangleBase
Population	1,094,991	36,008
Population 2040	1,940,341	51,525
Households	416,422	15,655
Households 2040	761,707	22,925
Jobs	977,564	102,742
Household Income	62,007	43,791
Family Income	72,716	48,915
Per Capita Income	30,614	26,072
Hispanic Origin	111,201	5,987
Black	256,847	12,890
White	655,097	16,001
American Indian	5,542	142
Asian	57,625	682
Other Race	2,565	63
Multiple Races	5,495	210
College/Univ	10	1
Grocer	0	0
Hospital	2	1
Hospital Beds	1,136	870

Table 5-2 30-minute travel band demographics by transit and car

An important use of the toolkit is likely to be support for Section VI analysis of transit accessibility. While it was straightforward to identify the ¼-mile service area for any one transit stop, we realized that it would be unduly tedious to have to separately query each stop on a route or every stop on every route within a given region. Consequently, we added functionality to the calculator to make it easy to peform these computations. In Figure 5-10, we show the 10-minute walk access band to one specific route in Durham.

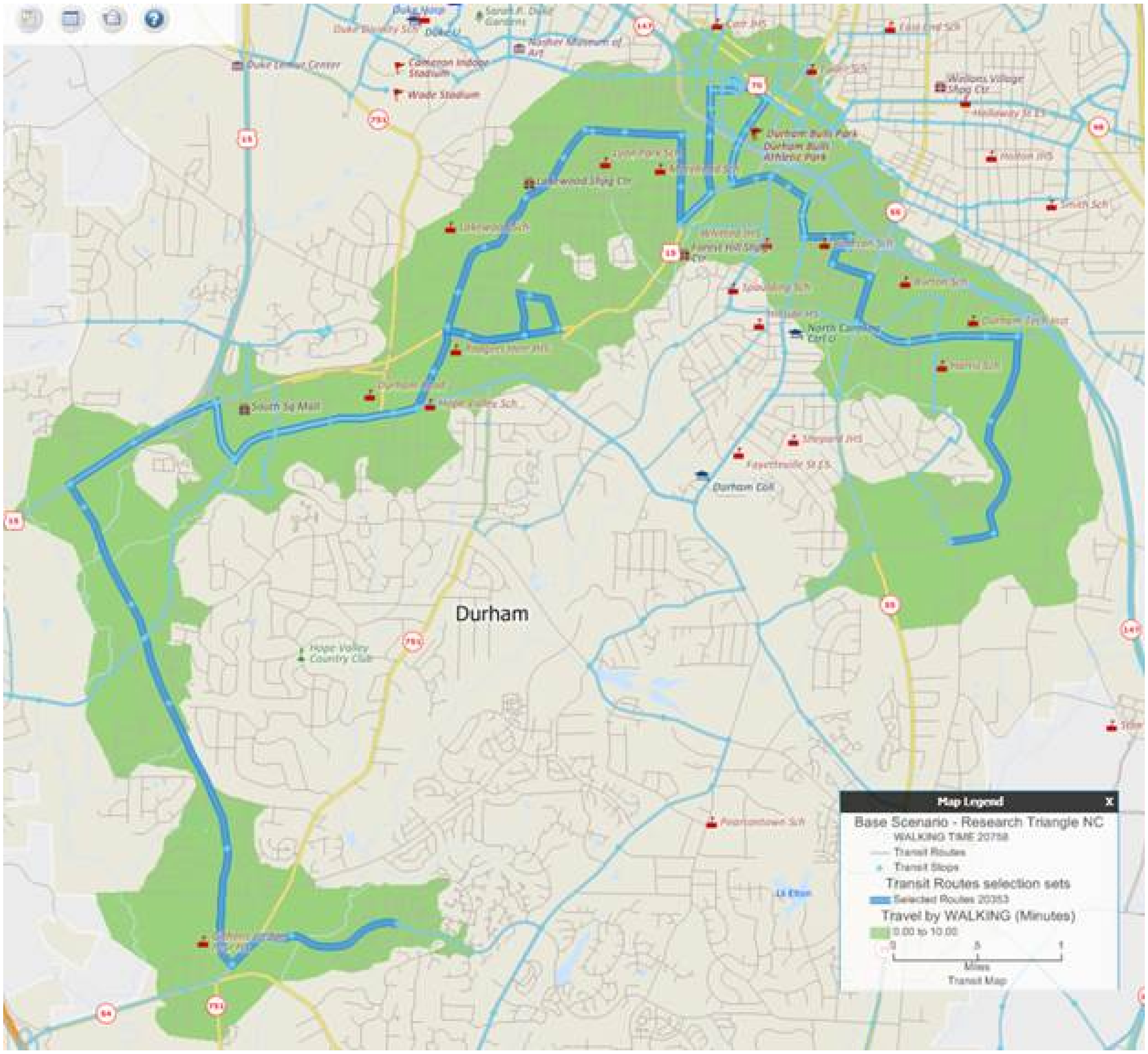


Figure 5-10 10-minute access band around Route 10-8 IB: Woodcroft-Durham Tech

Below, in Figure 5-11, we illustrate the entire service area covered by ¼ mile access to a transit stop in the region. In Table 5-3, which show the demographics computed for this area.

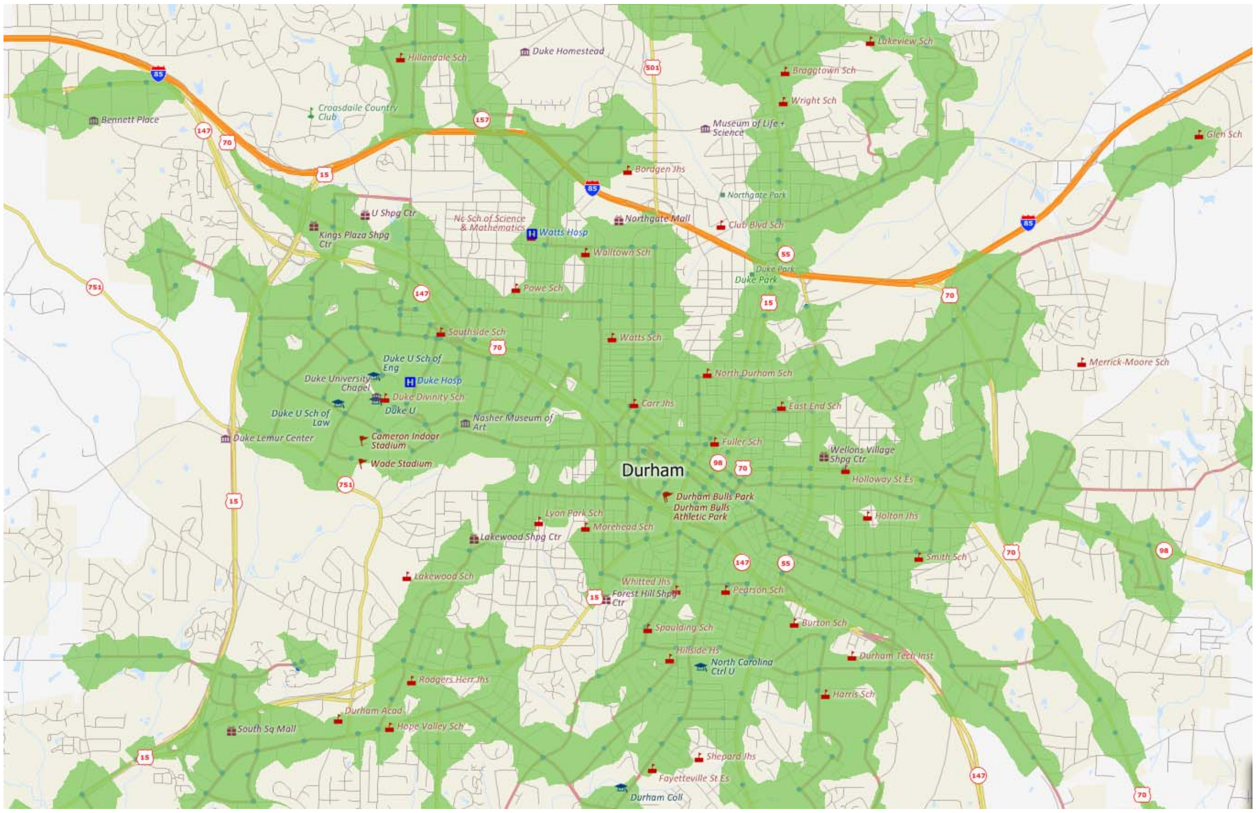


Figure 5-11 Quarter mile transit stop access service area

As we computed, only about 16% of the region falls within that service area. Only 13% of the white population is within the ¼ access area, but 22% of hispanics and 24% of blacks in the region are with the ¼ mile service area.

Field	Value (1/4 mile)	Whole Region	Percentage
Population	277,384	1,641,484	16%
Hispanic Origin	38,514	169,924	22%
White	129,845	1,000,210	13%
Black	88,460	370,809	24%
American Indian	1,294	8,984	14%
Asian	16,751	79,224	21%
Median Income	43,027	60,785	
Avg. Per Capita Income	25,795	30,379	
Median Family Income	59,037	73,080	

Table 5-3 ¼ Mile Transit Access Demographics

The ability to perform these transit calculations quickly and easily should be a useful aid for transit planners.

CHAPTER 6: Conclusions and Recommendations

This project has produced a web-based toolkit for computing transportation accessibility. In the course of the project, our initial belief that simple accessibility measurements can make a meaningful contribution to transportation planning was considerably reinforced. While at the outset we believed that the calculations themselves would be straightforward, we soon learned that existing approaches to accessibility measurement have many undesirable properties and may not adequately capture significant local variations in transportation levels of service.

Through a series of methodological enhancements, we have been able to produce accessibility calculations that can, with appropriate data, stand the scrutiny of planners and citizens. These calculations require a more fine-grained approach than is typically found in travel demand models and make use of intersection-to-intersection travel time calculations for motorized, non-motorized, and public transit modes. An immense amount of computing involving billions of road and transit network shortest paths per query can be profitably employed to generate accurate travel time isochrones for entire regions of interest. We found it necessary to deal with the vagaries of geography including water bodies, inaccessible terrain, tunnels, and bridges, all of which pose challenges to creating plausible accessibility maps. These difficulties can be overcome using a mix of technical adjustments and data strategies that we developed during this project.

We were also able to find ways to improve the performance of the calculations so that accessibility maps could be generated in the small amount of time that interactive web users would typically expect. This makes use of the toolkit more agreeable and makes it possible to use it interactively in public meetings.

Data limitations are a constant problem in transportation planning and analysis and remain so for calculating transportation accessibility. Accurate, routable street databases are necessary for meaningful calculations, and these are not widely or freely available in the United States. GTFS data offer enormous potential for mapping and analyzing public transport in the U.S, but they, too, require correct placement on a reference street layer to be fully useful. Also, some amount of manual quality control and editing is a necessary part of any proper accessibility assessment. Consequently, we have concluded that some significant data preparation will be required to produce successful applications of the accessibility toolkit. On a positive note, this will be much less of an effort than is required for travel demand modeling and it certainly is justified for that application as well.

We foresee uses for the toolkit in transit planning, bicycle and pedestrian planning, environmental justice, smart growth analysis, travel demand model support, performance monitoring, and public outreach. Transit planning applications include

- Market Analysis
- Identification of Service Geography
- Point to point level-of-service (LOS) measures
- Comparisons with auto LOS
- User benefit mapping

Non-motorized planning applications include bike lane network design, pedestrian facility design and sidewalk mapping, and assessing the role of non-motorized modes in enhancing transit service connectivity.

Environmental justice applications include facilitation of Title VI calculations, identification of under-served transit markets, and analysis of the distribution of incremental user benefits by income and ethnicity.

The toolkit can be used to produce measures integral to smart growth planning and assessment. It can also be used to visualize the impact of smart growth planned infrastructure on place to place travel times.

Travel demand model support applications include quality assurance and quality control of model, modal networks. In particular, the accessibility maps can reveal problems with free-flow and congested travel speeds as well as insufficiently connected or insufficiently dense networks. The introduction of landmark databases can aid in the identification and modeling of special generators, which do not always get the attention that they deserve in regional models. Various travel model components can make use of and benefit from explanatory variables that are accessibility metrics. Smart growth and transit access measures can generally be profitably employed in model choice model estimation and evaluation. Lastly, the mapping and visualization of scenarios and their model inputs and outputs can be helpful in reducing empirical errors in models.

Tools are not of consequence unless they are put to use. It will be interesting to see if planners gravitate toward accessibility measurements and assessments, or whether these concepts and their implications are found to be annoying complications.

Experience with applications of the toolkit in future will undoubtedly suggest refinements and needed additional features. Fortunately, the architecture of the application is easily modified and extended so hopefully it will gain in its utility in subsequent applications.

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APPENDIX: Data Preparation for the Triangle Example

The accessibility calculator requires the following geographic files:

- Street layer for drive, walk and bike network bands
- A public transportation route system or a GTFS data feed for the transit network bands
- A TAZ or other polygon layer with the attributes that will be calculated inside of the bands
- A point landmark database used for locating origins and destination as well as a source of data to be counted inside each of the returned network bands (number of jobs, hospitals, government offices, etc.).
- Other geographic files used for display and reference such as water areas, railroads, landmark areas, urbanized places, etc.)

Street Files

The street files used for the drive, walk, and bicycle network bands should be a rather dense file because the use of sparse, planning type networks or the use of artificial links such as centroid connectors or public transportation supporting links (zone access, zone to park and ride, transfer links) will result in undesirable artifacts in the network bands. It is also very important to have street layers with correct directionality information. In addition to the geometry, travel time estimates by time of day and by mode are needed to build the TransCAD network files that will be used for the band creation.

The walk network bands are created using only walkable links, therefore the database has to include a field that marks links as walkable or not. In many regions the street file is in reality a multi-modal layer that includes roads and railroad tracks if there is a subway or light rail system in the region. Rail tracks, interstate highways, some bridges and tunnels are not allowed for pedestrians; they should be clearly marked as such. The network file for the walk bands ignores the directionality of the links.

The roads that can be used for bike paths should also be clearly marked to build a network for the bike network bands. In our example we assume that the bikes follow the link directionality. We use bike speeds to calculate the link travel times.

To avoid band anomalies around special links such as bridges, tunnels and ferry lines, these should be marked as such. Each line layer in TransCAD can include character fields that clearly mark these links as bridges, tunnels or ferry lines:

NAME	BOSTON QUINCY	N WASHINGTON ST	CROSS ST
Bridge	N	Y	N
Frontage	N	N	N
Paved	Y	Y	Y
Private	N	N	N
Ramp	N	N	N
Rotary	N	N	N
Tunnel	N	N	N
Ferry	Y	N	N

Figure A-1: Road Type Field

For the Triangle region data we calculated travel time speeds assuming bike speeds of 10.5 mph, walk speeds of 3 mph and auto speeds at the posted speed limits.

Required Street Fields:

Name	Type	Description
ID	Integer sequence	Unique identifier of each link. Used to join tabular and spatial data.
Length	real	The length of each link (can be derived)
ANode	integer	The ID of the node from which the link originates
BNode	integer	The ID of the node at which the link terminates
Direction	integer (-1, 0, or 1)	Indicates the allowable direction(s) of travel, as follows: -1 One-way travel from B to A 0 Two-way travel 1 One-way travel from A to B
StreetName		Name of the street (or rail line, etc.), used for display purposes.
ABDriveTime	real	Travel time by car from A to B
BADriveTime	real	Travel time by car from B to A
AB_IVTT	real	In-vehicle travel time by transit from A to B
BA_IVTT	real	In-vehicle travel time by transit from B to A
Functional Class	int or text	Functional classification of the link (e.g., collector street, highway, ramp, subway, pedestrian path). Used for display and to determine whether cars, bikes, or pedestrians are allowed.
Bridge*	boolean, bit, or int	Flag indicating whether the link is a bridge
Tunnel*	boolean, bit, or int	Flag indicating whether the link is a pedestrian-restricted tunnel (e.g., a car or rail tunnel beneath a body of water)
RailOnly*	boolean, bit, or int	Flag indicating whether the link is traversed by rail only. (E.g., heavy rail, subway, or dedicated light-rail lines, but not streetcar lines operating in mixed flow.)
Ferry*	boolean, bit, or int	Flag indicating whether the link is a ferry route

* Bridge, Tunnel, RailOnly, and Ferry links are flagged because people cannot directly access the areas that abut them.

The node geographic file contains the points at which street segment links terminate or intersect. A node table is required for each link table.

Required Node Fields:

Name	Type	Description
ID	Integer sequence	unique identifier of each node. Referenced by the link records that about it.
Centroid	boolean, bit, or int	Flag indicating whether the node is a centroid
DriveNode	boolean, bit, or int	Flag indicating whether the node lies at the beginning or end of a link that is traversable by car (can be derived)
WalkBikeNode	boolean, bit, or int	Flag indicating whether the node lies at the beginning or end of a link that is traversable by pedestrians or cyclists (can be derived)
TransitNode	boolean, bit, or int	Flag indicating whether the node lies at the beginning or end of a link that is traversed by a transit route (can be derived)

Transit Files

Several approaches to create the public transportation networks were explored. The one that provided the best result consisted in moving the transit route system provided by the MPO to the denser street layer. The process we used for this move consisted in exporting the MPO route system to the GTFS format using TransCAD' s support for GTFS files. The resulting GTFS files were subsequently imported onto the dense street layer file.

The transit route file contains lines and attributes for each transit route (e.g., bus routes, rail lines, ferry lines).

Required Route Fields:

Name	Type	Description
ID	Integer sequence	Unique identifier of each route.
Mode	int or text	The mode of route (e.g., bus, subway, commuter rail, ferry)
Headway	real	Time in minutes

The transit stop geographic file contains points for each transit stop (e.g., bus stop, rail, ferry station, etc.) of each route. If multiple routes serve the same physical stop location, a separate stop record is required for each.

Required Stop Fields:

Name	Type	Description
ID	Integer sequence	Unique identifier of each stop.
Route	integer	ID of the route that this stop serves
Sequence	integer	The ordinal value of the stop within the route. E.g., a sequence of 5 denotes the fifth stop in the route.

The resulting route system and the walkable portion of the underlying street layer are used to build a transit network, the building block for the transit shortest path and transit network band calculations. The settings we used for the transit network for this case study included among others the following settings:

- Allow very high total trip costs
- Allow very high transfer, access, and egress times
- Set all cost weights to 0 (only the time components of the paths are being taken into account)
- Disable all penalties

Once the network is properly set a transit shortest path matrix from all walkable nodes to all walkable nodes is calculated. This matrix is then used to calculate the transit network bands.

Exclusion Areas

To increase the accuracy of the network bands an exclusion area that defines the regions where travel bands cannot be created should be built. An example of such a layer is shown below:

Figure A-2: Exclusion layer for Triangle Region

The exclusion layer includes all areas beyond the scope of the region, major water areas, and large regions that are not accessible by the travel modes analyzed such as large National parks.

TAZ Layer and Landmarks

The zone is an area geographic file that contains the polygons and related attribute data that will be used to calculate demographic information (e.g., transportation analysis zones (TAZ), Census block groups, or other areas for which demographic data are included). The zone layer determines the boundaries of the region area of study.

Required Zone Fields:

Name	Type	Description
ID	Integer sequence	May be generated by Caliper if missing from input data
Census, Employment, & Travel Count Data Fields	Integer or real	Numeric fields containing counts of residents, jobs, housing units, or any other demographic data to be included in the travel time table output

The landmark file is a geographic point file with the name and location of points of interest or landmarks that can be used for origins or destinations for the travel bands (e.g., schools, hospitals, malls, transit stops).

Required Landmark Fields:

Name	Type	Description
ID	Integer sequence	May be generated by Caliper if missing from input data
Longitude	real	Longitude
Latitude	real	Latitude
Name	String	Landmark name (required)
Type	String	Landmark type (optional)
Count	integer	Number of elements (hospital beds, jobs, etc.)