"DEVELOPMENT OF A COMPREHENSIVE, MULTI-MODAL TRAVEL ACCESSIBILITY INDEXING SYSTEM AT THE TAX PARCEL LEVEL"

prepared for

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By

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Executive Summary

Trip generation models are often used in transportation planning models and traffic engineering studies to convert land use activities such as households and employment locations into trip productions and trip attractions. These models usually include a linear or non-linear regression format relating the size of land use activities (such as number of households or number of jobs) to the corresponding number of trips. A limitation of regression-based trip making models is that they typically do not allow quantitative, statistically valid adjustments accounting for specific design characteristics which may have a significant effect on trip making behaviors to and from potential, proposed, or planned land use developments. In particular, a measure of the opportunity to reach destinations based on proximity is missing. For instance, if trips performed by walking or biking are being considered, one naturally expects that available destinations in the locale will factor into an estimation of expected trips. .

Accessibility measures the ease of reaching valued destinations. Ease of reaching destinations here primarily means that destinations are available in a proximity to a particular location of interest on the map, and that proximity is evaluated by estimates of travel times from the location to the destinations. The paths between origins and destinations are the roads, sidewalks, trails, bikeways and other paths provided by the existing or proposed transportation facilities. Ease of use and a measure of ease of use starts first with existence of destinations and travel times to those destinations along available paths. Travel times and paths depend on the travel mode of interest (bike, walk, transit, car). To support current applications at DelDOT, walking and biking were of primary interest.

An available path from origin and destinations with a particular travel time is only a part of the information that would be used to determine if trips of a certain type would be made. A measure of the accessibility of a destination could also address the quality or other amenities of the path. For instance, a store would be considered more accessible by walking if sidewalks were available instead of walking in the street. A path that included sidewalks and walk signals at intersections would be considered to be a path that offers a higher level of service. Bike trails and road shoulders would make a destination more accessible (ease of reaching) by bicycle than a road where a bicyclist would have to be within traffic flow. There are other features involved related to the decision to travel by a particular method (travel mode choice). For instance the level of crime in an area, lighting, and the attractiveness of the environment would influence whether someone would walk to a particular destination. Such features definitely would affect the ease of reaching a destination but are beyond the scope of this research. Here we are focused on a measure that first can capture the availability of destinations and travel time while also taking into account basic levels of service offered by the path. The methodology presented takes into account the presence of sidewalks, trails, and shoulders but not the more comprehensive evaluation of “Walkability”, a measure of how friendly an area is to walking.

This research addresses limitations of regression-based trip generation models by developing a comprehensive accessibility measure and process able to evaluate travel behavior at the tax parcel level. The research focuses on identifying the degree to which proximity to individual modes, the quantity and quality of those modes, and locational factors affect trip rates and travel at the tax parcel level. The primary objective of the research is to develop a GIS-based evaluation process able to access levels for auto, transit, bike, and pedestrian modes in Delaware. The process was developed at the tax parcel level because:

1) Tax parcels are the "geography" of the economy in that people typically travel between residential tax parcels and employment-based (non-residential) tax parcels.
2) GIS data exists in Delaware at the tax parcel level to support this research including zoning, land use, land cover, number of housing units, and estimates of the number of jobs.
3) Modal data such as statewide GIS layers exist to support this research including road centerlines and transportation facility inventory data, transit routes and stops, bike routes & trails, and pedestrian sidewalks.

The research developed a process allowing transportation analysts in Delaware to evaluate the degree to which potential or proposed system improvements for each of the road, transit, bike, and pedestrian modes in a given study area might affect the individual accessibilities for each mode and how they affect the overall accessibility. There are a number of ongoing and potential investments in bike and pedestrian facilities that could benefit from measures of accessibilities to available destinations.

Origin and destination data and travel network models developed by CADSR enable the calculation of accessibility measures for various modes or level of service (LOS) under consideration. Origin data consisted of housing locations take from a statewide tax parcel based land use file. Destinations were compiled from place data maintained by CADSR and by place data available on the internet from sources such as Google. Paths were provided by travel network layers consisting of roads, trails, sidewalks, paths and transit facilities. A statewide route-able road center line file developed by CADSR from DelDOT centerline and linear referencing system standards was used extensively.

The principle accessibility measure shown in this report was built around the number of destinations available within a specified travel time and could support analysis of any travel mode. The organization of the information and use of optimum path utilities was demonstrated for walking and biking, and a statewide origin-destination matrix was developed for walking trips and for walking trips that included sidewalks. This is a Cumulative Opportunity approach that specifies the number of destinations available within a given travel time. The origin-destination matrices were generated for all place types but can be used to analyze specific categories of destinations, such as Schools, Recreation, and Food Shopping.

The research outlines a functional information system framework that can be further developed to serve many applications. Primary data resources needed are a sets of origins and destinations, and travel network model that accurately specifies paths available for any given trip for each travel mode, (walking, biking, transit, car). Certainly there is a need for improvement of these resources, particularly for detailed studies, but with what is available very useful statewide accessibility measures can be developed that are immediately useful as demonstrated.

Literature and Relevant Topics on Accessibility

An examination of the literature and information related to accessibility was conducted. Much of the literature addresses accessibility more from a standpoint of service to those with disabilities, or broad assessments used for estimations of mode split. A few examples especially relevant to the calculation of an accessibility measure based on proximity and travel times are presented in this section.

Victoria Transport Policy Institute, Todd Litman
"Evaluating Accessibility for Transportation Planning"

Victoria Transport Policy Institute's paper entitled "Evaluating Accessibility for Transportation Planning" is an excellent report that discusses the concept of accessibility, how it can be incorporated in transportation planning, factors that affect accessibility, and how accessibility can be evaluated.

Accessibility is defined as peoples' ability to reach desired goods, services, activities, and destinations. Litman argues that improving accessibility and reducing accessibility costs can help achieve many economic, social and environmental objectives and is the ultimate goal of most transportation activity. Therefore transportation planning and evaluation should be based on accessibility rather than traffic-based (vehicle movement) or mobility –based (people and goods movement) which tend to favor automobile transportation over other modes. Optimal planning requires more comprehensive accessibility analysis and a variety of methods must be used to reflect different impacts, scales, and perspectives. Accessibility based planning techniques are still new and practitioners are still learning how to apply them to specific decisions.

Many factors affect accessibility, including people's transport needs and abilities, the quality and affordability of transportation options, the degree to which various links and modes are connected, land use patterns, and the quality of mobility substitutes. Some of these factors tend to be overlooked or undervalued in conventional transportation planning, such as; non-motorized travel demand, alternative mode service quality, user information, integration, affordability, prioritization ,and the value of inaccessibility. (Litman 2012) This paper provides a comprehensive view of accessibility by presenting factors that affect it and strategies for improvement. Two examples of this are the following tables from the report that summarize factors affecting accessibility and accessibility improvement strategies.

"Evaluating Accessibility for Transportation Planning" provides a very good overall picture of accessibility considerations and includes a discussion of various land use factors that affect accessibility including density, mix, connectivity and walkability. Land use geometries and layouts are discussed to compare accessibilities.

Figure 1, Summary of Factors Affecting Accessibility from Victoria Transport Policy Institute, "Evaluating Accessibility for Transportation Planning", Table 6, Todd Litman

Table 6 **Summary of Factors Affecting Accessibility**

Name	Description	Current Consideration
Transport Demand	The amount of mobility and access that people and businesses would choose under various conditions (times, prices, levels of service, etc).	Motorized travel demand is well studied, but nonmotorized demand is not. Travel demand is often considered exogenous rather than affected by planning decisions.
Mobility	The distance and speed of travel, including *personal mobility* (measured as person-miles) and *vehicle mobility* (measured as vehicle-miles).	Conventional transport planning primarily evaluates mobility, particularly vehicle mobility.
Transportation Options	The quantity and quality of access options, including walking, cycling, ridesharing, transit, taxi, delivery services, and telecommunications. Qualitative factors include availability, speed, frequency, convenience, comfort, safety, price and prestige.	Motor vehicle options and quality are usually considered, using indicators such as roadway level-of-service, but other modes lack such indicators and some important service quality factors are often overlooked.
User information	The quality (convenience and reliability) of information available to users on their mobility and accessibility options.	Frequently considered when dealing with a particular mode or location, but often not comprehensive.
Integration	The degree of integration among transport system links and modes, including terminals and parking facilities.	Automobile transport is generally well integrated, but connections between other modes are often poorly evaluated.
Affordability	The cost to users of transport and location options relative to incomes.	Automobile operating costs and transit fares are usually considered.
Mobility Substitutes	The quality of telecommunications and delivery services that substitute for physical travel.	Not usually considered in transport planning.
Land Use Factors	Degree that factors such as land use density and mix affect accessibility.	Considered in land use planning, but less in transport planning.
Transport Network Connectivity	The density of connections between roads and paths, and therefore the directness by which people can travel between destinations.	Conventional planning seldom considers the effects of roadway connectivity on accessibility.
Roadway Design and Management	How road design and management practices affect vehicle traffic, mobility and accessibility.	Some factors are generally considered, but others are not.
Prioritization	Various strategies that increase transport system efficiency.	Often overlooked or undervalued in conventional planning.
Inaccessibility	The value of inaccessibility and isolated.	Not generally considered in transport planning.

This table indicates factors that affect accessibility and whether they are currently considered in planning.

Figure 2, Potential Accessibility Improvement Strategies from Victoria Transport Policy Institute, "Evaluating Accessibility for Transportation Planning", Table 6, Todd Litman

Table 12 **Potential Accessibility Improvement Strategies** (VTPI 2006)

Factors	Improvement Strategies
Access and Mobility Demand	Use research to better understand people's accessibility and mobility needs, preferences and abilities, and use social marketing strategies to develop better options that respond to these demand, and to encourage consumers to choose more efficient and equitable options.
Basic Access and Mobility	Prioritize transportation improvements and activities to favor access to goods, services and activities considered most important to society.
Mobility	Improve traffic speed and capacity, such as improving and expanding roadways.
Transportation Options	Improve the convenience, comfort, safety, reliability, affordability and speed of transport options, including walking, cycling, automobile, rideshare, taxi, carshare and public transit.
User Information	Improve the quantity and quality of user information regarding travel and location options, including signs, maps, brochures, websites and telephone services. Special attention can be given to providing convenient information on alternative modes and efficient locations.
Integration	Improve connections between different modes and destinations, such as more integrated information, fares, walkability, baggage transfers, automobile and bicycle parking.
Affordability	Improve the quantity and quality of affordable modes (walking, cycling, ridesharing, public transit, taxi and telework), and improve housing affordability in accessible locations.
Mobility Substitutes	Improve the quantity and quality of telecommunications and delivery services that substitute for physical travel.
Land Use Factors	Improve land use accessibility by increasing density and mix, in order to create activity centers and urban villages that contain the appropriate combination of housing, jobs and services within convenient walking and cycling distance.
Transport Network Connectivity	Improve road and path connectivity to allow more direct travel between destinations, including special shortcuts for non-motorized travel where appropriate.
Roadway Design and Management	Improve roadways to increase traffic flow (for example, by reducing the number of driveways), to favor higher occupant vehicles, and to improve walking and cycling conditions.
Prioritization	Use mobility and parking management strategies to favor higher value trips and more resource-efficient vehicles, and to encourage more accessible land use development.
Improve Payment Systems	Better road and parking pricing methods reduce transaction costs and increase the feasibility of implementing pricing reforms to increase overall transportation system efficiency.
Inaccessibility	Where appropriate, limit mobility and accessibility.

This table indicates various ways to improve accessibility. Current transport planning practices tend to focus on just a few of these strategies, which limits the scope of solutions considered.

Figure 3, Best Practices for Evaluating Accessibility from Victoria Transport Policy Institute, "Evaluating Accessibility for Transportation Planning", Table 6, Todd Litman

Best Practices

Below are recommendations for best practices when evaluating transportation and accessibility.

- Transportation should be evaluated based on *accessibility* in addition to *mobility*.
- Accessibility evaluation should consider all factors that may affect access, including people's needs and abilities, the availability and quality of various access options, land use factors, network connectivity, mobility substitutes and land use patterns.
- Transport planning should identify specific accessibility *constraints* in a particular situation (specific people, times, locations, types of travel, etc.). For example, traffic congestion may be a major constrain in some situations, while in others the constraint is inadequate user information, poor walkability, or high financial costs.
- Accessibility evaluation should give special consideration to the access needs of disadvantaged groups, including people with disabilities and low incomes. The quality of their access can be evaluated relative to average accessibility levels.
- Accessibility evaluation should account for qualitative factors such as user convenience, comfort, affordability, security and consumer preferences.
- Accessibility evaluation should account for the quality of modal integration, such as the quality of connections between modes.
- Accessibility analysis should consider various perspectives, including different individuals, groups, locations and activities.
- Analysis should consider ways that improving one form of access may reduce other forms, such as the tendency of wider roads and increased vehicle traffic to reduce pedestrian access, and the reduction in vehicle traffic speeds from traffic calming.
- Special consideration should be given to providing basic access and mobility, recognizing that certain types of access are particularly valued by society.
- Special consideration should be given to walkability because pedestrian access is important on its own, and supports other modes including ridesharing, public transit and automobile parking.
- Transportation planning should account for the benefits of inaccessibility and the external costs of vehicle traffic. Transportation policies should limit access and mobility when doing so preserves valuable social or environmental amenities.
- Transportation planning should consider a wide range of strategies for improving accessibility, including improvements to vehicle traffic, alternative modes, mobility management, mobility substitutes and more accessible land use.
- Transportation and land use planning should be integrated to optimize access. For example, land use policies should encourage clustering in areas that have good walking and cycling conditions, and good transit service.
- Transport planning should use neutral language that does not favor automobile transport over other modes, as illustrated in the box below.

"Low-Stress Bicycling and Network Connectivity" , Mineta Transportation Institute Report 11-19, Maaza C. Mekuria, Peter G. Furth, Hilary Nixon, May 2012

The paper discussed previously, covers many of the factors that affect accessibility. Clearly proximity to destinations is only one factor to be considered. When considering the suitability of an area for bicycling or walking, any measure or rating to account for that suitability needs to include a way of examining and classifying the types of access provided by the path between origins and destinations. For instance, it could be found that there are a large number of destinations within walking distance of a particular place using existing roads or trails, but considerably less destinations accessible using paths that included sidewalks or safe intersections. Certain features of a path would encourage or discourage walking or biking and an approach to describing and classifying features of paths is very useful and germane to considerations of whether or not to build facilities. Research has demonstrated that Americans have varying levels of tolerance for traffic stress, which is a combination of perceived danger and other stressors associated with riding a bike close to motor traffic. Traffic danger is considered to be the chief impediment to bicycling and a classification of cyclists by level of tolerance for traffic stress is considered more appropriate than a skill-based classification scheme. "Low-Stress Bicycling and Network Connectivity" provides a description of how streets and crossings can be classified according to the level of traffic stress as it applies to examining bike routes, and presents a user-oriented bicycling network definition. The approach could be generalized to walking or other modes of travel. The classification is somewhat like a Level of Service (LOS) that various routes would provide.

"Low-Stress Bicycling and Network Connectivity" proposes classifying road segments by one of four levels of traffic stress. Level of traffic stress 1 (LTS 1) is meant to be a level that most children can tolerate; LTS 2, the level that will be tolerated by the mainstream adult population; LTS 3, the level tolerated by American cyclists who are "enthused and confident" but still prefer having their own dedicated space for riding; and LTS 4, a level tolerated only by those characterized as "strong and fearless." Where a population will tolerate only streets with a certain level of traffic stress, the stress of a route is determined by its most stressful link, not an average. "Islands of low-stress connectivity" within land development is discussed pointing out that land use configurations often have many clusters of low stress road links but require the use of high-stress links to get from one island to another. (Mecuria, Faith,Nixon 2012)

Connectivity is a critical aspect of a bicycling network. An evaluation of connectivity can involve consideration of a path using only links that do not exceed a given level of stress. At a given stress level two points in a network may be connected in this sense but may be so circuitous or add so much additional travel distance that most people would consider them effectively unconnected. Research in the paper proposes a methodology that also includes defining an acceptable level of detour. An acceptable level of detour to avoid more stressful routes was considered to be around an additional 25% or the trip distance considered.

Barriers to low-stress connectivity have three general types. One is natural and man-made barriers that require grade-separated crossings such as freeways, railroads, and creeks, whose crossings tend to be widely spaced and are often adapted to high traffic volumes and therefore carry high stress. A second is arterial streets whose cross streets lack the combination of a low-stress approach and a safe crossing. Often, the only safe crossing provisions are at traffic signals, where the cross streets themselves have high stress, often because of turning lanes that are added on the intersection approaches. A third kind of barrier is breaks in the neighborhood street grid, a common feature of newer developments that force traffic, including bicycle traffic, to use arterials to access the local streets.

"Figure 4, Levels of Traffic Stress from Table 1 of "Low-Stress Bicycling and Network Connectivity" , Mineta Transportation Institute, May 2012

Table 1. Levels of Traffic Stress (LTS)

LTS 1	Presenting little traffic stress and demanding little attention from cyclists, and attractive enough for a relaxing bike ride. Suitable for almost all cyclists, including children trained to safely cross intersections. On links, cyclists are either physically separated from traffic, or are in an exclusive bicycling zone next to a slow traffic stream with no more than one lane per direction, or are on a shared road where they interact with only occasional motor vehicles (as opposed to a stream of traffic) with a low speed differential. Where cyclists ride alongside a parking lane, they have ample operating space outside the zone into which car doors are opened. Intersections are easy to approach and cross.
LTS 2	Presenting little traffic stress and therefore suitable to most adult cyclists but demanding more attention than might be expected from children. On links, cyclists are either physically separated from traffic, or are in an exclusive bicycling zone next to a well-confined traffic stream with adequate clearance from a parking lane, or are on a shared road where they interact with only occasional motor vehicles (as opposed to a stream of traffic) with a low speed differential. Where a bike lane lies between a through lane and a right-turn lane, it is configured to give cyclists unambiguous priority where cars cross the bike lane and to keep car speed in the right-turn lane comparable to bicycling speeds. Crossings are not difficult for most adults.
LTS 3	More traffic stress than LTS 2, yet markedly less than the stress of integrating with multilane traffic, and therefore welcome to many people currently riding bikes in American cities. Offering cyclists either an exclusive riding zone (lane) next to moderate-speed traffic or shared lanes on streets that are not multilane and have moderately low speed. Crossings may be longer or across higher-speed roads than allowed by LTS 2, but are still considered acceptably safe to most adult pedestrians.
LTS 4	A level of stress beyond LTS3.

"Low-Stress Bicycling and Network Connectivity" establishes a stress criteria for road segments in order to classify the network and bases considerations on:

- Physically separated bikeways
- Bike lanes
- Speed limits or prevailing speed
- Bike lane blockage
- Lane widths
- Signalized versus non-signalized intersections
- Presence and configuration of right turn lanes at intersections.

University of Minnesota Center for Transportation
"Access to Destinations Study"

One of the major efforts in the nation dealing with accessibility is the University of Minnesota Center for Transportation "Access to Destinations Study". "The Access to Destinations Study encompassed a set of carefully designed research projects (11), each under the direction of University of Minnesota researchers with specific expertise in the areas under investigation. The projects were organized according to three research components: understanding travel dimensions and reliability, measuring accessibility, and exploring implications of alternative transportation and land-use systems. In separate projects, researchers refined methods for calculating auto and non-auto travel times. They developed methods for describing how our accessibility is changing, including a set of performance measurements that can be used to analyze historic land-use and travel time data. By focusing on accessibility, rather than on simple congestion measures the study changed the question from "How fast is traffic moving"? to "How easily are people reaching places they need or want to go?". (El-Geneidy 2004)

Findings of the ongoing study noted that while until this last decade congestion had been steadily worsening, the actual ease of reaching destinations in the Twin Cities areas has been getting better-all over the region. Accessibility has improved also via walking, biking, and public transit, but the striking findings are the improving access by automobile and discovering that land-use changes and increased development densities explain most of the improvement. Researchers mapped modes of travel in relation to the dominant destinations most people have. They analyzed the attributes of destinations that would affect which mode of travel people would ordinarily choose. They probed more deeply into the interactions between changes in land use and the mode people chose for access to their destinations. They also produced a new Web-based tool that policymakers and transportation managers can use to analyze the likely effects of new transportation investments on accessibility. The Web interface also features a number of predefined maps and allows users to create their own maps and select up to three filters, including year, travel mode, trip purpose, and type of destination (www.atd.houstonng.net). The new approach is in understanding how people use the transportation system and how transportation and land use interact, and research was divided into three major research components: Understanding Travel Dimensions and Reliability, Measuring Accessibility, and Exploring Implications of Alternative Transportation and Land-Use Systems.

The ultimate goal researchers had was the development of a matrix that both describes and potentially predicts how people access destinations by different modes. In this matrix the columns reference the most common destinations people have – employment, shopping, schools, parks. Then in rows, the available modes of travel are listed. Using travel time as a filter, the matrix paints a picture of the capacity of different modes to facilitate the choices people make to get to their destinations.

The University of Minnesota study addressed different ways to measure access and reports include detailed examples of the following methods.

- Cumulative Opportunity is an approach that calculates the number of opportunities that can be reached in a specific period of travel time
- Gravity- Gravity measures evaluate access in terms of the "cost" of getting there (travel time) , and like Newton's law of gravity, nearby things exert stronger attraction than those far away.
- Place Rank- This measure accounts for the number of opportunities that an individual foregoes in a zone to reach an opportunity in another zone. For example, a high ranking would be awarded to a destination that attracts more workers from zones that have high numbers of jobs.

The Access to Destinations research indicated that little is known about how far people will actually travel to reach a variety of destinations and what differences there may be among those types of destinations. Most walking trips involved distances of 1.86 miles or less but a third of trips exceed a mile. For bicycling, longest trips were for recreation, personal entertainment, or fitness. The longest trips were work trips. Workers like proximity to work but also highly value affordable homes and land. Trip length varies significantly by trip purpose. Transit users seem to have a time budget. If it takes more time to get to a transit connection the tendency is to use transit for shorter hall trips. Models used in the research treat land use outcomes as a function of the interaction between transportation networks and urban land markets. When decisions get made about the location and intensity of new uses of urban land, some measure of accessibility seems to be the thread that ties together the decision dynamics.

WALKSCORE.COM

Much of the interest in accessibility in Delaware has to do with evaluation of current or proposed pedestrian and bicycling facilities, and also as a factor in models of travel mode split. A goal of this research is to develop accessibility measures and a most relevant resource that has emerged is the web site and related services of WALKSCORE.COM. At this site, users can enter an address, and a "walkability" rating of the area is provided with references and maps of destinations in the area. The score is based on a patent pending algorithm that classifies types of destinations and their proximity, and awards points based on the proximity of those destinations to produce a rating in the range of 1 to 100. Ranges of the walk score can be interpreted as shown in figure 5 on the next page that is provided by WALKSCORE. WALKSCORE uses a variety of data sources for destinations including Google, Education.com, Open Street Map, and Localeze. (http://www.walkscore.com/methodology.shtml) WALKSCORE also provides a wide range of data that can be used for analysis and web API's that programmers can use in developing web sites that can incorporate WALKSCORE capabilities.

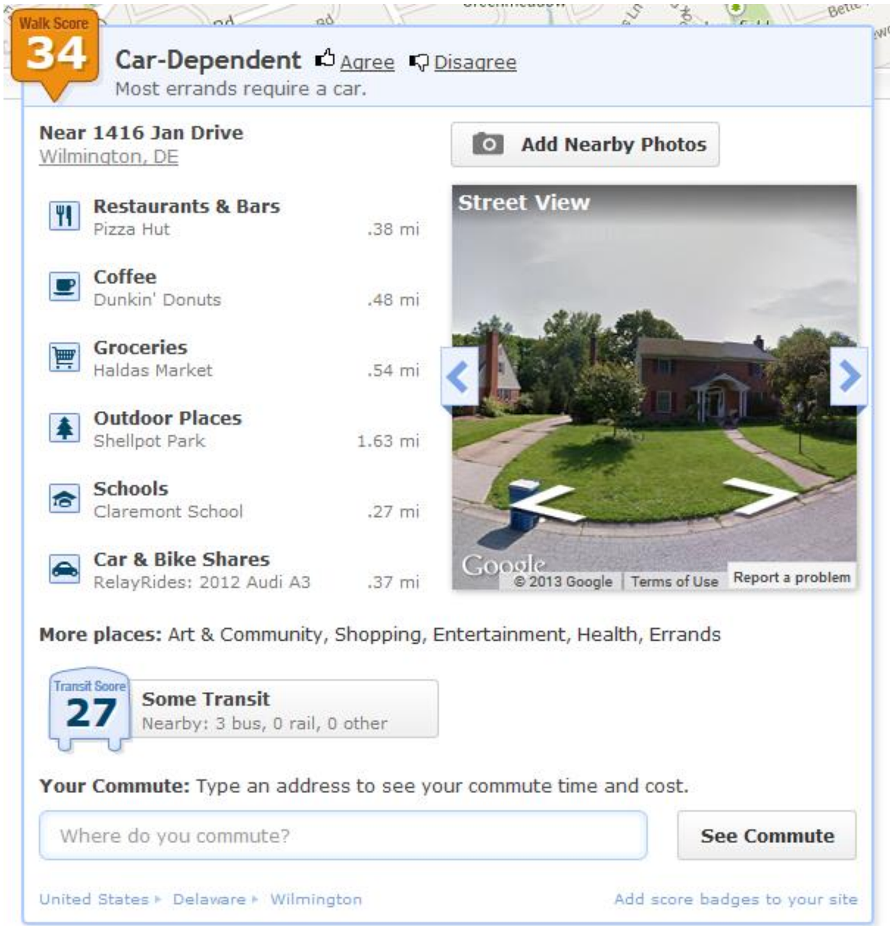
Figure 5, WalkScore Explanation of Scoring (www.walkscore.com)

Walk Score®	Description
90–100	**Walker's Paradise** Daily errands do not require a car.
70–89	**Very Walkable** Most errands can be accomplished on foot.
50–69	**Somewhat Walkable** Some errands can be accomplished on foot.
25–49	**Car-Dependent** Most errands require a car.
0–24	**Car-Dependent** Almost all errands require a car.

A Bike Score is available that measures whether an area is good for biking and is calculated by measuring bike infrastructure (lanes, trails), hills, destination and road connectivity, and the number of bike commuters. A Transit Score is also available that is generated by summing the relative "usefulness" of nearby routes, where usefulness is defined as the distance to the nearest stop on the route, the frequency of the route, and type of route.

Walkscore provides valuable indicators that can be applied in a number of areas, real estate, tourism, and land use planning for instance. Scores are based on available data and of course that is the main source of its limitations. Anyone examining a familiar area might notice omissions of some destinations. At the time of this report WALKSCORE does not address various amenities of the walking or safety or the quality of the walking path. The proximity to destinations may be the direct line between origin and destination, "as the crow flies", and may not factor in some physical barriers. It does not appear to take into account hazards of intersections that would need to be crossed to get to some destinations. Computer mapping technology is advancing rapidly and there is continually more accurate data being produced, so WALKSCORE is expected to get more refined and accurate. Various WALKSCORE utilities available such as commute reports, transit availability views, and maps of referencing local features of interest are very useful now and are expected to get better.

Figure 6, Typical Output from a WALKSCORE.COM



Project Plan

Project Goals

Goals of this project are to develop:

- a statewide measure of accessibility focused on pedestrian and bicycle travel that can be used in travel demand modeling, and evaluation and prediction of usage of bicycle and pedestrian facilities.
- a GIS based analysis routine or process able to quantify the relative access level of each tax parcel for each of four modes with emphasis on walking biking and transit access, resulting in a generalized or composite accessibility index.
- an accessibility measure that can be regenerated using GIS tools available to DelDOT Planning as various investments and scenarios are considered
- a process allowing analysts to quickly evaluate the degree to which potential improvements for each mode in a given study area affect the individual accessibility for each mode and overall accessibility, and how bike-ped improvements affect accessibility of individual tax parcels, subdivisions as a whole , and wider communities.
- a tool to prioritize potential improvements to facilities.

Previous studies of accessibility have for the most part employed data at the level of available Census geography, census tracts and census blocks. Travel demand forecasting in Delaware is moving toward models that are at the tax parcel property level and this project will take advantage of detailed land use information. This project is focused on piloting specific and repeatable procedures to develop accessibility measures and on identifying data needs to support those procedures.

Project Plan

Briefly stated the approach in this work is to:

- Develop origin data
- Develop place/destination data
- Develop a network capturing the paths between origins and destinations
- Develop network travel impedances that can correspond to travel by various modes (walk, bike, car) and can capture available level of service associated by those modes.
- Employ software to examine proximity of housing to destinations to produce origin-destination matrixes from which an accessibility measure can be developed in terms of the number of destinations that can be reached under specified conditions. Accessibility measures will be associated with points on the map at the tax parcel level.
- Outline methods to improve data and accessibility measures.
- Demonstrate development and use of the accessibility measures.

Framework for Calculating Accessibility

Analysis Environment

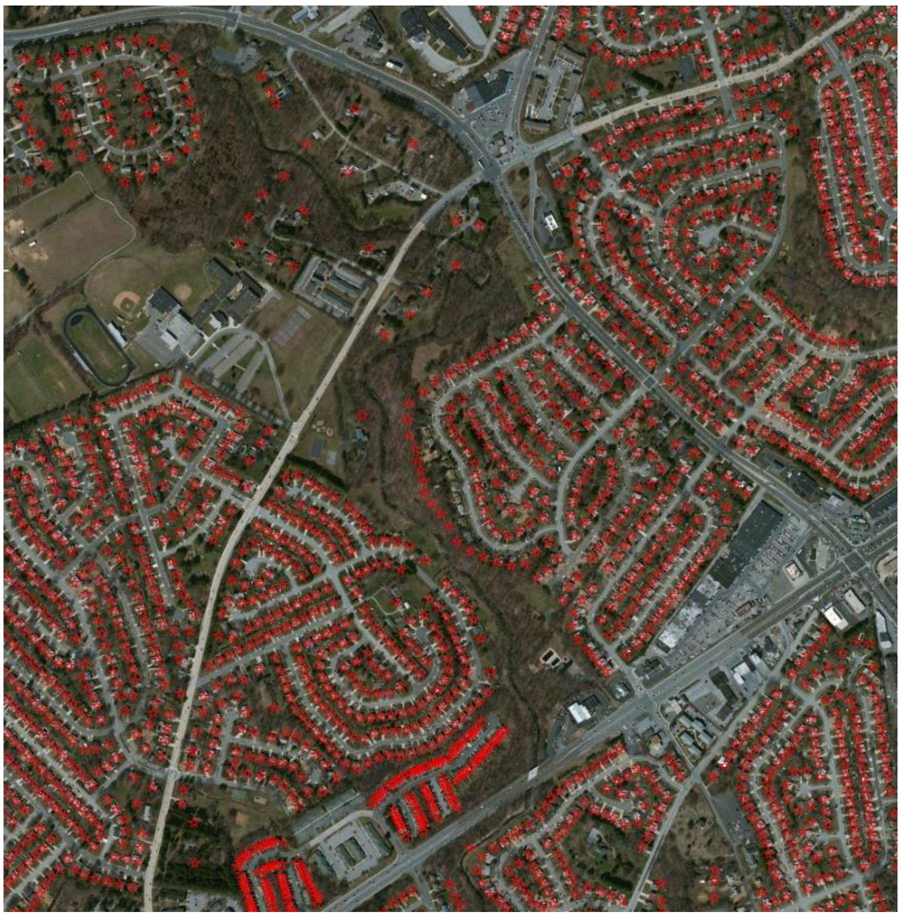
This project focuses on outlining a process that can be repeated and is based on information systems that are available to DelDOT. The State of Delaware currently maintains licenses for ESRI software including ArcMap, ArcCatalog, ArcSDE, ArcGIS Server and various extensions the most important of which is Network Analyst. DelDOT staff have made large investments in GIS based around this software and staff have developed considerable expertise, so ESRI software was selected as the tool to accomplish goals of this project. Utilities referenced here and data entities such as the "network dataset" use terminology and functions within ESRI products.

The primary software utility used is the Origin – Destination Cost Matrix feature in ESRI's Network Analyst Extension. Given a specified set of origins and destinations, the utility will calculate all distances or travel times between those origins and destinations as calculated along the length of an available network path. The network is a composite of roads, transit routes, trails, and sidewalks and junction points between these linear features and for each path segment a number of different impedances, given in terms of travel time or distance, are specified in relation to the mode under analysis. For example one travel time could be associated with car travel using posted speed limits, while another impedance could be specified for walking at an estimated speed of three miles per hour. Travel modes can be mixed in the analysis so for instance a transit trip could be comprised of a walking portion to the bus stop and a transit route portion, and a door-to-door travel time could be estimated.

Origins – Housing

The goal is to develop an accessibility measure for points on the map and the approach was to use the tax parcel location of built housing units and empty lots as the origin points. The focus was on access of residential areas to destinations. Public lands, commercial properties, utilities, agricultural preservation lands, and other non-housing land uses were not included in the origins under study. Previous research by CADSR developed a statewide tax parcel based land use that was used to allocate housing projections and this data set was available for this project. For this type of analysis it is possible to simply specify points on the map with no reference to the locations of tax parcels/properties. A distribution of an accessibility index could be developed from a lattice of points spaced at a particular resolution. Having the origins tied to actual tax parcels though is in line with current travel demand modeling efforts and has a number of very real advantages including references to addresses, property value, actual residential housing distributions, realistic access points to the road network, and a range of other related and useful data. For each housing unit location the number of destinations available is calculated within a specified distance. An example of these origin points is shown in the next figure. Each location is typically a single family unit. In some cases a tax parcel location represents a multi-unit entity like an apartment or condominium complex, and if one was estimating the number of housing units in proximity to a particular destination this would need to be taken into account.. In a case where it was more important to determine the population and demographic within proximity to a destination rather than the number of housing units, available census and survey data could be used to estimate populations characteristics.

Figure 7 Example of Parcel Based Housing Layer
Locations of tax parcels in red



The main process used to estimate a proximity variable is the development of an origin destination cost matrix as described below. The original motivation for this study was to determine a factor that could be used to model mode choice. The choice of walking or biking or transit has much to do with the proximity of destinations to travel to and having some measure of the proximity to destinations is needed in models. For a GIS analysis, the calculation of the proximity of origins to destinations typically provides at the same time a measure for calculation of destinations to origins, so the process can be used for both sides and the demographic and housing information is preserved in these tax parcel point based origins and destinations.

Destinations – Point Place File

Measures of accessibility would be calculated for various types of destinations, such as accessibility to schools, employment, shopping, or recreation. Depending on the application there will be various classifications and selection of destinations. A state wide Delaware place file was developed from CADSR GIS libraries, tax parcel based land use, and locations of places of interest as presented in Google. As shown in the figure on the next page, the various types of places were then grouped into categories that reflect larger categories of land use as often used in transportation studies. The set of places used in this project are detailed and work very well for initial development of an accessibility measure. State wide, there were approximately 30,000 destinations considered. Once one examines any particular place category from any source for a particular locale, omissions, placement errors, and other errors can be observed. An up to date and detailed place file serves many planning applications, and continued maintenance and review can provide a great resource.

All destinations cannot be considered the same when looking at accessibility. Being close to grocery stores would usually be considered better than being near karate studios. People would usually ride a bicycle to a recreational area or job rather than to an auto repair facility or medical center. Selecting subsets from destination collections and focusing in on appropriate travel modes is necessary. Establishing an accessibility score(s) that is a composite of proximity measures to various types of destinations would be useful.

Figure 8 Example of density of Places in Elsmere, Delaware
Places shown as red triangles

Figure 9 Place Categories

Home
Tax parcel data
Apt-condo
Trailer parks
Rv-mobile
elderly

Work
Any category

ShortStop
Conveniencestore
gas

Store (Basics)
Pharmacy 1
Grocery
laundry
conveniencestore

Store (General)
Art (gallery)
Departmentstore
Shopping center
clothing
electronics/computers
liquor
movie rental
art
jewelry
florist
books
bicycle
furniture
homegoods
hardware
clothing
bakery
tobacco
pets
deserts
healthfood
computers
homegoods

Bank or Post Office
Bank-atm
Postoffice

Child Care

School
School
Education
university

Drop off/pick up

Social- Recreation
Park 3%
Recreation
Bar
museum

Community
association
social service
pool
political
government
library
funeral
institute
fire
housing
police
communications
parking
prison
union
senior center

Places
Cemetery

Eat out
Restaurant 4%
Café

Health
Medical 11%
Hospital
Therapy
Health 4%

Place of worship 5%

Utilities
Communications
waste
utility
water
energy

Transportation
bus hub
Airports
Transit – stops 4%
stations
Transportation
train

Barber – hairdresser
Beauty

Other
Establishment 22%
Business Services
Company
Auto
Services
Systems
Associates
Enterprise
Foodbusiness
Finance
Legal
Lodging
Realestate
Insurance
Catering
Buildingservices 2
Roofing
Security
Storage
Cleaning
Security
Electrician
Contractors
Landscaping
Locksmith
Accounting
Shipping
Travel Agenc

Creation of the Modeling Network for Walking and Biking

The following types of paths are considered for the analysis:

- Roads, large and small that can be used by cars
- Paths that can be used by bicyclists
- Paths for walking
- Transit stops and routes
- Proposed paths and connectors

These were integrated into a multimodal network model that includes rules for valid travel between the path types. Some of these paths can be shared, for instance bicycles share the road with cars and sometimes paths with walkers. Path finding requires roads and trails to have correct connectivity and flow direction (as with one way streets and car traffic).

Previous research by CADSR developed a state wide road centerline file, here called the DELRS centerline, that includes an identification and linear referencing system, and that was built to preserve standards used by DelDOT in the last decades. This file makes it possible to integrate a variety of traffic and performance data for use in the accessibility analysis. For instance, DelDOT road inventory data could be used to locate roads with shoulders, as was done in the functional classification map described below, which would be important when examining less stressful bike routes. Having a standard routing network available also helps in incorporating intersection data. The DELRS includes all roads large and small and is broken down into segments that are typically from intersection to intersection.

Another helpfl resource is a detailed GIS layer provided by DelDOT that was designed to establish functional classifications for roads. The functional classification map was useful in categorizing roads in terms of volume and usage and included the location of sections of roads that had shoulders or sidewalks. In this functional classification layer, attributes of road sections are referenced by using route identifiers and beginning and end mile points, in a standard linear referencing scheme used by DelDOT over the last few decades. Figure 10 below shows a sample of what the functional categorization might look like. Following that figure is a map where road sections are colored depending on the presence of a shoulder. This can provide detail when examining paths for bicycling in terms of where shoulders or sidewalks drop off. In figure 11, roads sections are colored red according to whether they have adjacent sidewalks. Other attributes could be added to this network, including a measure of crime or safety, presence of lighting, path condition, and any other factor that would want to be included in an analysis or selection of paths. The information from the functional class map was combined with the DELRS network to form a routable network that could be used for walking and biking.

Figure 10 Portion of the DelDOT Functional Classification Map

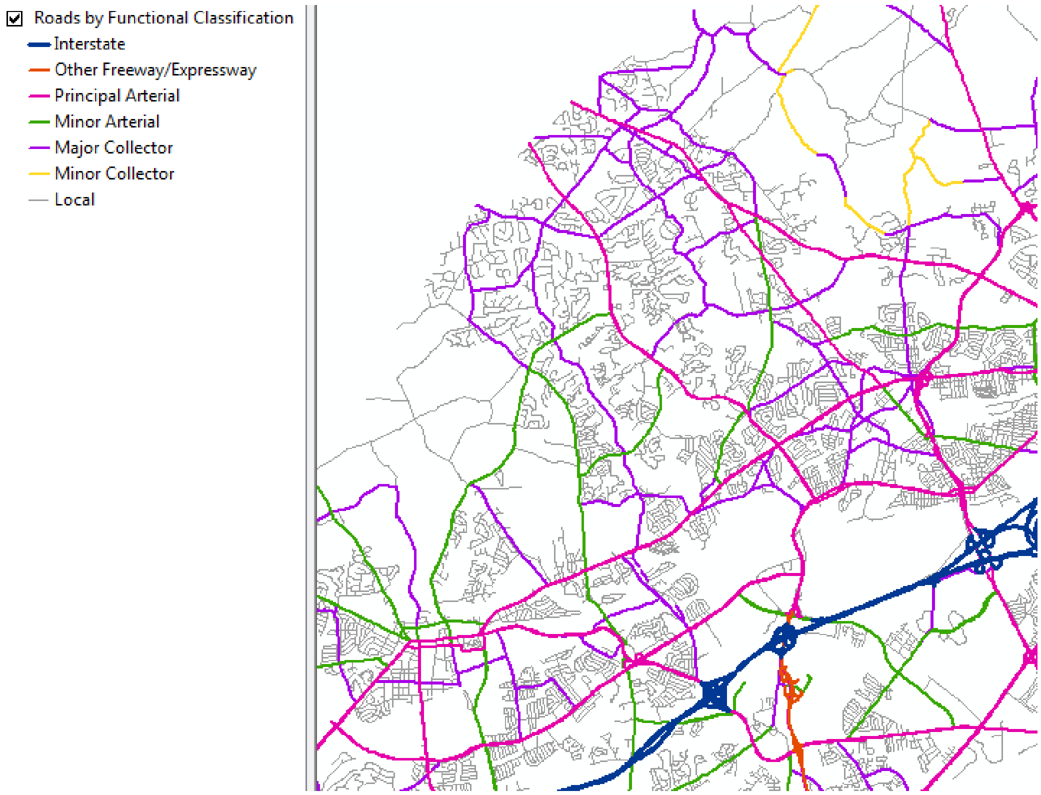


Figure 11 Example of a map showing presence of a road shoulder (Green = no shoulder, Yellow = 1 or 2 foot shoulder, Red = 3 foot or greater shoulder)

A Note About Linear Referencing and the Combination of Network Data

This provides an excellent example of the usefulness of linear referencing systems. Each of the 43,000+ segments in the DelDOT functional classification includes the route identifier and the beginning and end mile point based on DelDOT's linear referencing system. The segmentation that appears is specific to the data that is mapped to the segments, and segmentation generally occurs where information that is kept along the roadway changes. Information such as the shoulder width or whether there is a sidewalk or a different functional class. This works perfectly for the functional classification network and is a valuable and detailed picture of realities on the roadway. The data added by the functional class layer of most interest is the functional classification, the right and left shoulder widths, and the right and left presence of a sidewalk fields. But this creates a segmentation scheme that doesn't generally correspond to how other transportation information such as speed or volume might be allocated to the network.

The DELRS Centerline, is built on the same standard linear referencing system and therefore it is very easy to map linear referenced functional class data onto DELRS Centerline data. The DELRS Centerline includes several pieces of useful identification information, is a more common segmentation scheme to examine traffic and other data, and has gone thru a few iterations to insure connectivity and "routability". A union operation was performed on the DELRS and the functional class map creating a representation that included the break points of both layers. All categorical data such as the functional class designation number is preserved in this union process.

Travel by Car Network

The original plan was to use the DELRS road centerline file for routing of car traffic and include separate path files for walking, biking, transit, and other paths to form the multimodal network. For applications in this project though it was decided where possible to build the network developed for walking and biking on the same network path file for cars. As a union of the DELRS and the Functional Classification Map, the resulting walk and bike network contained all of the same information and roads of the DELRS centerline file, the only difference is the added segmentation detail needed to incorporate shoulder, sidewalk, and functional class information. Increased segmentation would not be a good idea if the results of the paths were fed directly into a list of directions referencing travel between each and every small segment, but to simply accumulate travel time and costs it works well and preparation of the impedances (travel times) is simpler.

Transit Network

Examining transit accessibility in this project is confined to measures of distance to the nearest bus stop. Bus Stops were included in the multimodal network. A network of transit routes was also included and could be used to develop estimates of travel time by transit, but in this project the time to fully prepare the transit route network was not available.

Other Paths

There are a number of dedicated trails and greenways that can be used by bicyclists and pedestrians that are not part of, or adjacent to roadways. A map layer for these were provided by DelDOT and prepared and served as available paths for walking or biking trips. Several path layers can be used in a multi-modal network using ESRI GIS software. Connectivity can be established between various types of paths where useful. For instance a set of walking paths could be joined to a transit bus route.

An additional map layer called a connector layer was useful. The connector file is used to add additional connections not shown or missing from the car, bike, walk, trails, or transit networks. An example of a connector would be a line representing a walking path that people use or could use to access a shopping center near the back of a neighborhood. This is a layer that could be edited frequently as new paths are discovered or proposed. Results of the analysis can change if paths for pedestrians or cyclists are missing, such as driveways into shopping centers and crossing points for major highways. Addition of these other available paths is important when doing detailed analysis.

Accessibility Measures as Related to Paths

The more one examines the development of accessibility measures, the more encompassing the term “accessibility” can get. Accessibility ratings can become detailed composite scores based not just on distance to available origins but also the quality of the path that involves a range of amenities and considerations. For example when developing an accessibility measure for a walk trip to destinations within walking distance, the measure could be specified in various ways taking into account more considerations, for example:

- Number of destinations within walking distance (any path)
- Number of destinations within walking distance where walking is on sidewalks
- Number of destinations within walking distance with sidewalks, that only includes paths with crosswalks or pedestrian signals
- Number of destinations within walking distance that include sidewalks, pedestrian signals at intersections or crosswalks, and areas that have low crime rates and have pleasant environmental amenities.
- Number of destinations within walking distance that include sidewalks, pedestrian signals at intersections or crosswalks, and areas that have low crime rates, no impediments for the disabled, and have pleasant environmental amenities.

In a similar way, an accessibility measure to destinations by bike could involve a range of considerations such as safety, presence of shoulder or dedicated bike paths, traffic speeds and volumes, and particular configurations encountered at intersections. Considering the wide array of conditions that might make a trip more walk or bike friendly, corresponds to the type of decisions that come into play when one is deciding whether to walk or use their car (mode split decision). If a person has to walk in the street on a particular path or cross a dangerous intersection to get to some particular destination, that destination could certainly be considered less accessible. At the time of this project, an accessibility measure was needed by DelDOT for immediate use in travel demand applications and consideration of bicycle and pedestrian facilities. This research begins with an approach that could be developed to generate a statewide measure within a framework that could first produce a basic measure of proximity to destinations, using available software and data. The framework provides for added complexity in the data used and how the accessibility is defined.

Impedances and Level of Service

The primary measure of accessibility in this research is based around the number and type of destinations that are within a particular travel time such as a 10 minute walk or a 20 minute bicycle ride. Optimum paths are built to destinations from the origin of interest, and the time it takes to get to those destinations from available paths is tabulated. To accomplish this, impedances in terms of travel time in minutes were associated with path segments throughout the network model that was developed. For each segment there are "to" and "from" time values for transversal by walking, biking, car, and transit. Incorporated into the impedances are valid movements for each mode. For instance cars cannot use a bike trail. Walkers cannot use Interstate 95. Cars cannot go the wrong way on a one-way street, though walkers can. Accessibility measures are developed for each mode, "By Car" or "By walking" or "By Bicycle" and each mode has a different time estimate incorporated into the impedance based on average walking or bicycle speed, or speed limit. Procedures are run to find the optimum route between origins and destinations and the impedances in terms of time are summed across the route.

When examining accessibility the "quality of the path" is an important factor to consider especially when one is evaluating facilities. This can be thought of as a level of service. For instance a path that includes sidewalks, lighting, and crosswalks offers a higher level of service to pedestrians than one without these amenities. For those in charge of locating and building pedestrian and bicycle facilities there is definitely a belief that the facilities will be used depending on a variety of amenities that encourage walking or bicycling, and an accessibility calculation and specification needs to be able to view benefits offered by, as viewed here, differing levels of service. An accessibility measure should be able to be specified relative to a particular quality of path, for instance accessibility to destinations by paths with sidewalks, or roads with safer biking features.

The level of service (LOS) approach here is inspired by the work by Mineta Transportation Institute in defining levels of stress for bicyclists. Path segments can be assigned a level of service or classification for pedestrian or bicycle travel, and this can be incorporated into a network impedance in the analysis. Accessibility "ByWalk" in this research includes any path or street to the destination, whether it has a shoulder or sidewalk or not. But another impedance could be developed such as "By Walking Path"where only paths that have sidewalks, shoulders, or very low traffic can be traversed. This is useful. For instance, it could be determined that numerous desirable destinations are in walking distance of a particular origin, but it could be shown that most of these destinations would not have sidewalks available. This then would be an indication of a good place to put sidewalks and facilities to encourage more walking trips. The accessibility analysis allows for this type of focus on the quality of the path.

In developing a measure of accessibility based on proximity to destinations, levels of service were suggested and incorporated into path impedances for walking and bicycling, as shown in the figure on the next page. These levels of service serve as a way to qualify the path and of course could get much more complicated as other factors such as safety, road geometry, and details of turning movements of intersections were considered. The methodology presented here could incorporate additional features to address a broader measure of accessibility. The presence of sidewalks, dedicated paths, functional classification of roads, and presence of shoulders were considered to be the most basic and influential features for walking and bike trips.

Intersections

Notably missing from demonstrations of the approach taken is the extent that intersections are considered. An intersection is generally defined as the place where two or more distinct path segments meet or cross. In network modeling this is typically referred to as a node or junction and can be factored into the determination or quality of the optimum path. The characteristics of intersections have an impact on accessibility for pedestrians and are certainly a major consideration, for example, the safety of students walking to schools. Often the most stressful portion of the path for bicyclists is at intersections where roads with shoulders or bicycle lanes merge with turning lanes at intersections leading to a greater interaction with traffic and often some confusion. In this project, time did not allow for the development of intersection characteristics in examining accessible paths. No such statewide intersection file was available and would have to be constructed based on traffic speeds, volumes, available lanes, signals, and intersection geometries. Once such data is compiled inclusion of an intersection file is straightforward and the approach outlined here would allow for accessibility measures that take into account intersections. The primary way this is done is to establish turn tables for each intersection to manage the data and include it in calculation of optimum paths.

Origin-Destination Cost Matrix Calculation

The Origin-Destination (OD) cost matrix function within ArcGIS in the Network Analyst software extension provides a very valuable and flexible tool to calculate a cost matrix between multiple origins and destinations. Minimum impedance paths, typically in units of time (minutes) are determined and tabulated. Various costs can be associated with path segments and junctions. Total time costs can be calculated between origins and destinations. For instance trip length can be determined as well as trip time. An estimated time for waiting at a bus stop or other such transfer costs can be incorporated into the total trip time. Fuel and vehicle costs and accumulation of other costs can be accumulated for paths.

Once the multimodal network file is created, the focus is in developing various impedance values to be associated with each segment or portion of a road or trail. For instance one impedance value that all path segments had was the amount of time it took to traverse it by walking. Another impedance value was developed for when the question was accessibility to destinations by paths that only included sidewalks. Each road segment was attributed as to whether a sidewalk was present. Road segments that did not include sidewalks were barriers that could not be crossed (infinite impedance) and were removed from paths that could be available. The same approach can be applied to biking.

Figure 12 Path Levels of Service for Bike and Walk

Walking Level of Service A
Dedicated Trail or
Sidewalk
And
No Intersection crossed without pedestrian signal/crosswalk/crossing guard

Walking Level of Service B
Dedicated Trail or
Sidewalk or
Local street or
Presence of a Shoulder on any street other than an Interstate
And
No Interstate

Walking Level of Service C
Walk Anywhere but Interstate

Biking Level of Service A
Dedicated Bikeway or
Sidewalk or
Local street

Biking Level of Service B
Dedicated Trail or
Sidewalk or
Local street or
Presence of a Shoulder on any street other than local
And
No Interstate

Biking Level of Service C
Bike anywhere but Interstates

Origin and destination matrices can get very large and the time to process the data can in some cases be measured in days or longer. A couple hundred thousand housing origins and thirty thousand destinations were studied statewide. This project demonstrated that for Delaware a state-wide measure for walking and bicycling could be produced without much difficulty and be processed within several hours if certain cut offs were introduced. For instance, for a measure addressing accessibility by walking, if only destinations within a 10 minute walk are considered then the solution becomes more manageable. “Destinations reachable by car within a 10 minute car ride” on the other hand is a much bigger calculation. Even so, by breaking the processing down into smaller pieces and using additional computing resources, and having some distance cut offs, it would seem that for an area the size of Delaware a solution in most cases is a realistic expectation.

The output of the Origin-Destination Cost Matrix routine is a table where each record is an origin-destination pair that includes the distance along the path, the travel time, and links to the origin tax parcel data and the destination place data. Other information can be added to the table such as travel time by other modes or an accumulation of any other type of cost involved with the travel from the origin and destination. An example of another accumulated cost could be when looking at transit trips. The walk to the bus stop takes time, there is time in transit, and then there is time from the destination bus stop to the final destination. In addition, another cost that would be part of the trip would be the time the rider waited at the bus stop and this could be accumulated with other travel costs in the OD matrix. By creatively associating information with portions of the path, it is possible to get more information about the path. For instance if portions of the path have sidewalks, a statistic could be generated as part of the process that gave the percentage of the walking trip distance where sidewalks were available. Or for a bike trip, the percentage of the trip that included bike paths or shoulders.

The Origin-Destination matrix once calculated can be used repeatedly once it is produced. For example, all trips from all housing locations to all destinations in Kent County produces a matrix of over 2 million records for destinations reachable within a 10 minute walk. That includes all places and all types of places and the table can be aggregated to produce a table showing the number of destinations of all categories that are reachable at every housing location. If however one is only interested in a particular place type like "food stores" for instance, records that contained only that type of place category could be selected and an aggregation could be created using the same matrix that would show the number of food stores that are reachable at specific housing location. Once all origins and destinations are processed using a particular scenario (walking, biking, car, walking with sidewalks, bike paths of low stress, etc) the matrix only needs to be reprocessed if the available paths change somehow or the travel times (impedances) are adjusted.

This research was particularly focused on the calculation of an accessibility index for a distribution of origins. The resulting Origin-Destination matrix could be used in another way. Instead of aggregating on origin locations, records could be selected for a particular destinations, a park for instance, and the table could be aggregated on the destination to estimate the number of housing units or population within a 10 minute walk (bike, car, etc). Often there is a particular destination in mind and a planner will want to know the accessibility to housing or populations of that specific destination.

Developing an Accessibility Index

With the origins, destinations, and paths in place and the Origin-Destination Matrix produced for a given travel mode or level of service, the question next is the form of the accessibility index or score. The University of Minnesota study addressed different ways to measure access. One method, the simplest, is the Cumulative Opportunity approach that calculates the number of opportunities that can be reached in a specific period of travel time. As simply the sum of destinations of interest within proximity of particular origins, this measure can be produced directly from the Origin-Destination Matrix. Questions concerning this approach are around what destinations should be used or if there are particular weights that should be applied to specific destinations. For example at one location there is 1 school, 2 grocery stores, a shopping center with 10 stores, and 5 stores of miscellaneous commercial use, 1 bank, and 1 state park within walking distance which sum to a total of 20 destinations available from that location. At another housing location there are 10 doctors offices, 4 stores of miscellaneous commercial use, 1 funeral home, 3 government offices, 1 cemetery, and 1 barber shop, which sum to 20 destinations. That is actually the type of variety in destinations that occurs. Based on a very raw cumulative opportunity score the 2 locations are equal. While both locations are within walking distance of 20 destinations the accessibility in terms of “usefulness” would seem different. For instance people don’t usually walk to doctor’s offices and they are usually of a specialized nature, and hopefully people don’t visit funeral homes and cemeteries often. On the other hand someone might visit a grocery store or park or bank frequently. Detailed tax parcel or community level studies would benefit from some way of ranking or weighting destinations to produce an accessibility score.

In the case of examining a large category like “Employment/jobs within a 20 minute drive”, an accessibility score based on an accumulation of destinations is useful. For instance, one location might be in proximity to 1000 jobs, another 10,000 jobs, and another 20,000 jobs. At a large area planning scale such figures would say a lot about opportunities available. Where you could further classify employment locations and proximities into categories of employment like Manufacturing, Service, Finance, and Government, a cumulative opportunity approach could be more useful. The larger the populations and areas addressed, the better a raw cumulative opportunity measure would be. The approach outlined in this report can be used for large or small areas, and for all travel modes,

A method for the calculation of accessibility can factor in distance to destinations. Analogous to the inverse square relationship between force of gravity and distance, the affect on the accessibility measure of a particular type of destination could get less as the distance becomes greater. Gravity models are used in travel demand forecasting routines and in some accessibility measures. The origin and destination matrix calculation used in this project includes the distance of the path between origins and destinations, so a measure could be developed that was a function of distance.

Examples of Accessibility Calculations

A Review of the Multimodal Network Setup

The following layers participate in a multimodal network used in this project:

- Bike/Walk/Car network based on DELRS
- Paths – paths and greenways for walking and biking
- Transit Stops
- Transit Routes
- Added Paths – An edit layer used to add additional paths to study scenarios
- Turn Table for Bike/Walk/Car

A turn table was incorporated into the network model but was not populated in this project but is vital when one needs to factor in the characteristics of intersections.[*]

Impedances/Travel Time

All line layers participating in multimodal network model include impedances for walking, bicycling, car travel, and transit and this makes it possible to use all of the paths from streets, trails, bike paths, and transit paths The primary impedance used is the time in minutes it takes to traverse a section of the path. Where speed is in miles per hour and road section lengths are in meters:

$$\text{Travel Time in Minutes} = \text{Distance / Speed}$$
$$\text{Distance (meters) / (Speed(mph) * 1609.3 / 60)}$$

It was assumed that average walking speed is 3 mph and bicycling speed was 12mph.
No statewide map layer that includes average speeds for all roads is available for Delaware. Car travel times on sections of roads was approximated using functional classification. For car travel speeds used were:

- Interstate 60mph
- Freeway and expressway 60mph
- Principal Arterial 45mph
- Minor Artreial 40mph
- Major collector 35mph
- Minor Collector 35mph
- Local 30mph

[*] Turn tables capture flow at intersections. When a traveler enters an intersection, they could take a left or right turn, go straight thru the intersection, or make a U-turn, and there are differing time costs for each movement. For cars, on average right turns would offer less impedance than going straight or turning left at an intersection. Bicyclists and pedestrians also encounter time costs at intersections and this could be in minutes, or associated with other measures. For instance safety ratings or levels of service could be associated with the ease at which pedestrians can cross a street.

As discussed previously, each path segment has an initial direction and a FROM_TO impedance and a TO_FROM impedance for each travel direction. A negative value of impedance is used to prohibit travel in a particular direction so for example for car or bicycle travel on one way streets the TO_FROM impedance is negative one (-1). However, the walking TO_FROM impedance on a one way street is not -1, walking is permitted in both directions of a one way street. As another example, walking and bicycling impedance on Interstate 95 is -1. For a transit trip, riders would use a walk impedance to get to bus stops, and from there the impedance is related to the transit route time. By selectively prohibiting travel thru assignment of impedances based on travel mode (car,bike,walk,transit) and travel time based on features of the path (i.e, sidewalks present, bike path available) it is possible to calculate proximities and accessibility measures with respect to levels of service. Those levels of service defined for this project are

Walking LOS C – Walk anywhere along roadway or other path, 3 miles per hour no walking on expressways or interstates
WalkingLOS B - Walk only if there's a sidewalk on either side, or trail, or local street or shoulder (> 2 feet) and no walking on expressway or interstates.
Walking LOS A - Walk only if there's a sidewalk or dedicated path
Bike LOS C – 12 mph, bike most anywhere on roadway or paths, no biking on one way streets, no biking on interstate or expressways
Bike LOS B - There must be a shoulder (>2feet) or sidewalk if not a local street, or designated bike way or dedicated trail
Bike LOS A - Designated Bikeway or trail, or sidewalk or a subdivision local road.
Transit LOS B – Walk to and from transit stops on any path available
Transit LOS A – Walk to and from transit stops only where sidewalks are available or on local subdivision streets.

Calculating an accessibility measure based on various levels of service can be very useful in supporting multimodal planning and facility planning.

There is only one impedance used for cars in this research based on a very rough estimate of travel speeds. However, impedances are based on expected speeds and travel times, and of course average car travel times vary depending on time of day, day of week, and holidays. Where more detailed data can support it, one can imagine a number of impedances for car travel being established depending on when travel occurs.

Example 1, Accessibility to Destinations By Walking LOS C

As a first example we will look at an area near the town of Elsmere in New Castle County, Delaware as shown in the aerial photography below. The place file are the destinations that will be considered as shown as green triangles in figure 13, and built housing units will be the origins as shown with green dots. . An accessibility measure based on the number of destinations within walking distance will be calculated. In this example the path considered will be along any roadway or path corresponding to Walking LOS C.

Figure 13, Example Area Near Elsmere Delaware

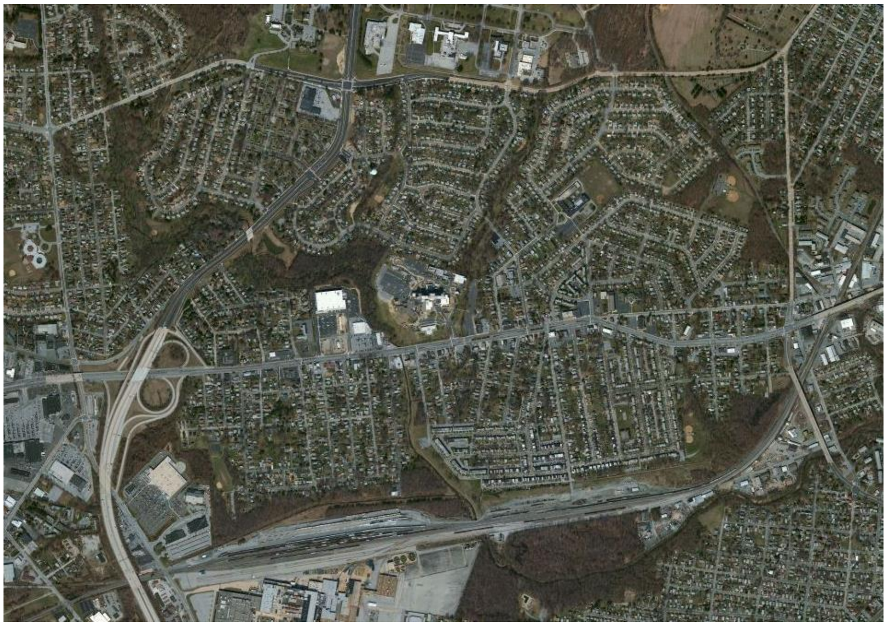


Figure 14 Parcel points and Destinations for Example 1 (Places shown as green triangles)

All categories of place are used in this example. Walking speed is assumed to be 3 mph and the path taken could be any road or path available, even if there is no shoulder or sidewalk. Origins are housing units as represented by the centroids of properties as available from tax parcel maps. The OD Matrix utility in ArcMap Network Analyst is run and produces a origin destination matrix for all origins to all destinations where the distance between is a 10 minute (½ mile distance) or less walking trip. The origin/destination table is then aggregated on origins to get the number of destinations assigned to each origin and that is the variable that is mapped in figure 15 using colorations of the points. This provides a visual distribution that is linked to actual property records and forms a basic measure of accessibility. A map and table for number of destinations within a 10 minute walk was created for all areas in Delaware and provided to DelDOT to be used with travel survey data to predict distributions of mode choice.

Figure15 Number of destinations within a 10 minute walk (LOS C) at the location of each housing unit.

Example 2, Consideration of the effects of a new path

Research was paticularly focused on accesibility for pedestrians and bicyclists for work DelDOT is doing in travel demand forecasting. Recently there is increased support and funding for pedestrian and bike facilities so an accessibility measure could be very useful there as well. As an example of how the approach demonstrated could be used, consider the same area in the previous example. The bulk of the destinations are on the main road in the central part of the area (Kirkwood Highway). Perhaps if a path was created as shown in red in the figure below that would link the northern properties with the destinations below, this will increase the number of destinations within a 10 minute walk for that group.

Figure16 Consideration of the addition of a new path (in red)

This is perhaps a good example of the types of areas that could be considered for bike/ped facilities. Room for a path may be available on the grounds of the VA hospital and on the east side is a shopping center in addition to the destinations on the main road. The proposed path was added to the multimodal network used in analysis and the OD matrix function was performed again and the result is shown in figure 17. The main result as expected was to make more destinations available to those properties in proximity to the top of the new path. And for those properties the number of destinations available at a 10 minute walk roughly doubled. The effect though is otherwise not significant, total OD pairs for the entire study area only changes by a ½ a percent with the introduction of the new path While on the aerial photography the new path does not seem very long, it is actually around 600 meters, a little over a third of a mile. A 10 minute walk at 3 mph covers a half a mile so the number of new origins now within a half mile is of course limited.

Figure17 More detailed view of the path considered

Figure18 Estimated result of adding a new path

The new path would be expected have a bigger effect in making new destinations accessible if the northern properties were a bit closer to the destination on the main highway to the south.   Or perhaps, what if the distance cutoff was not a 10 minute walk, but a 15 minute walk?   First of all, without the new path, using the same ranges, as before many of the properties would then be accessible to destinations at the higher range (figure 19). Introduction of the path has a similar effect as before and only seems to effect those properties that are at the top and left of the new path. The effect of the new path also is minimized because northern properties can access destinations to the south within a 15 minute walk by paths available to the east.

Figure 19 Estimated result of adding a new path, 15 minute walk

Example 3, Restrict Types of Places under Consideration

Previous examples used all categories of places in the place file used in this project . Once the origin-destination table is generated for all places it is a simple matter examine results for a subset. For instance if more if shopping was of interest categories SHOPPING CENTER, STORE, SHORT STOP (convenience stores), and SHOPPING CENTER could be selected.

Figure 20, Number of stores within a 10 minute walk from each housing unit location

Example 4, Consideration of the quality of paths. Northeast Delaware Comparison of Walk LOS A and Walk LOC C

Maps on the next page show a comparison of the results when estimating the number of destinations within a 10 minute walk for Walk LOS A and Walk LOC C. Walk LOS A is walking only where sidewalks exist.

Figure 21, Number of destinations within a 10 minute walk, any path, Walk LOS C
Dark Green 1-7, Light Green 8-16, Yellow 17-35, Orange 36-104, Red 105 and greater
All Destinations, North East New Castle County, Delaware.

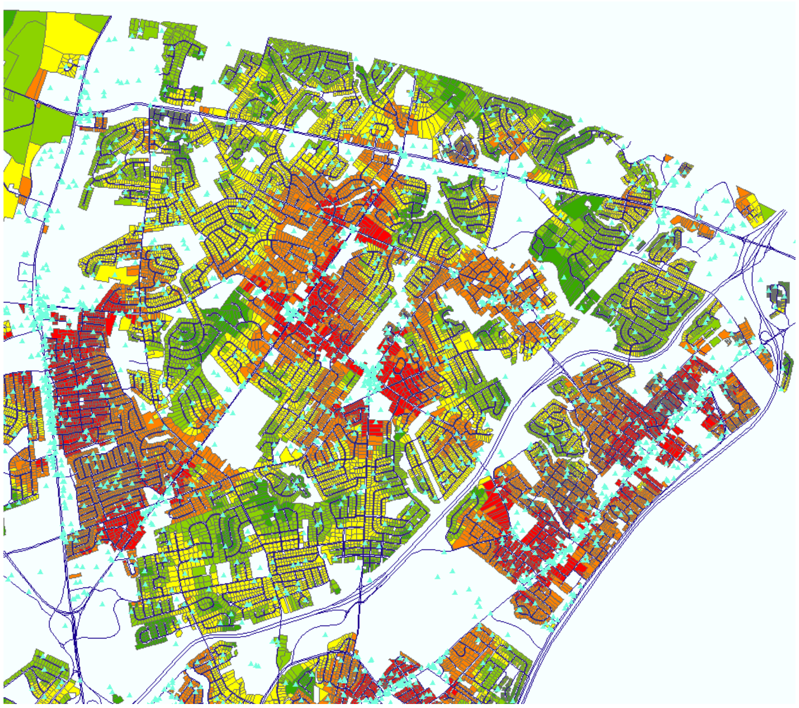
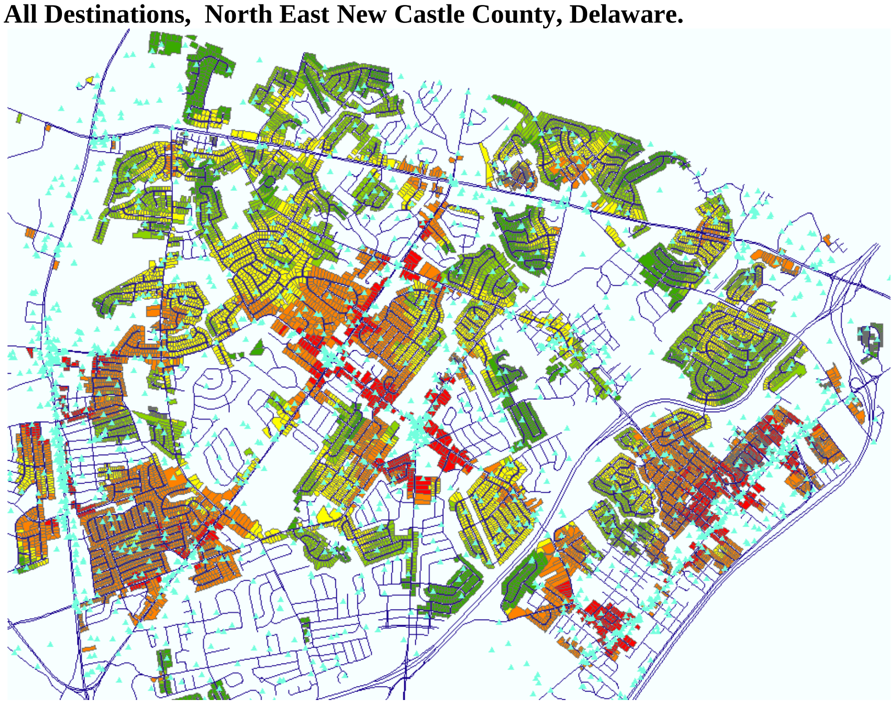


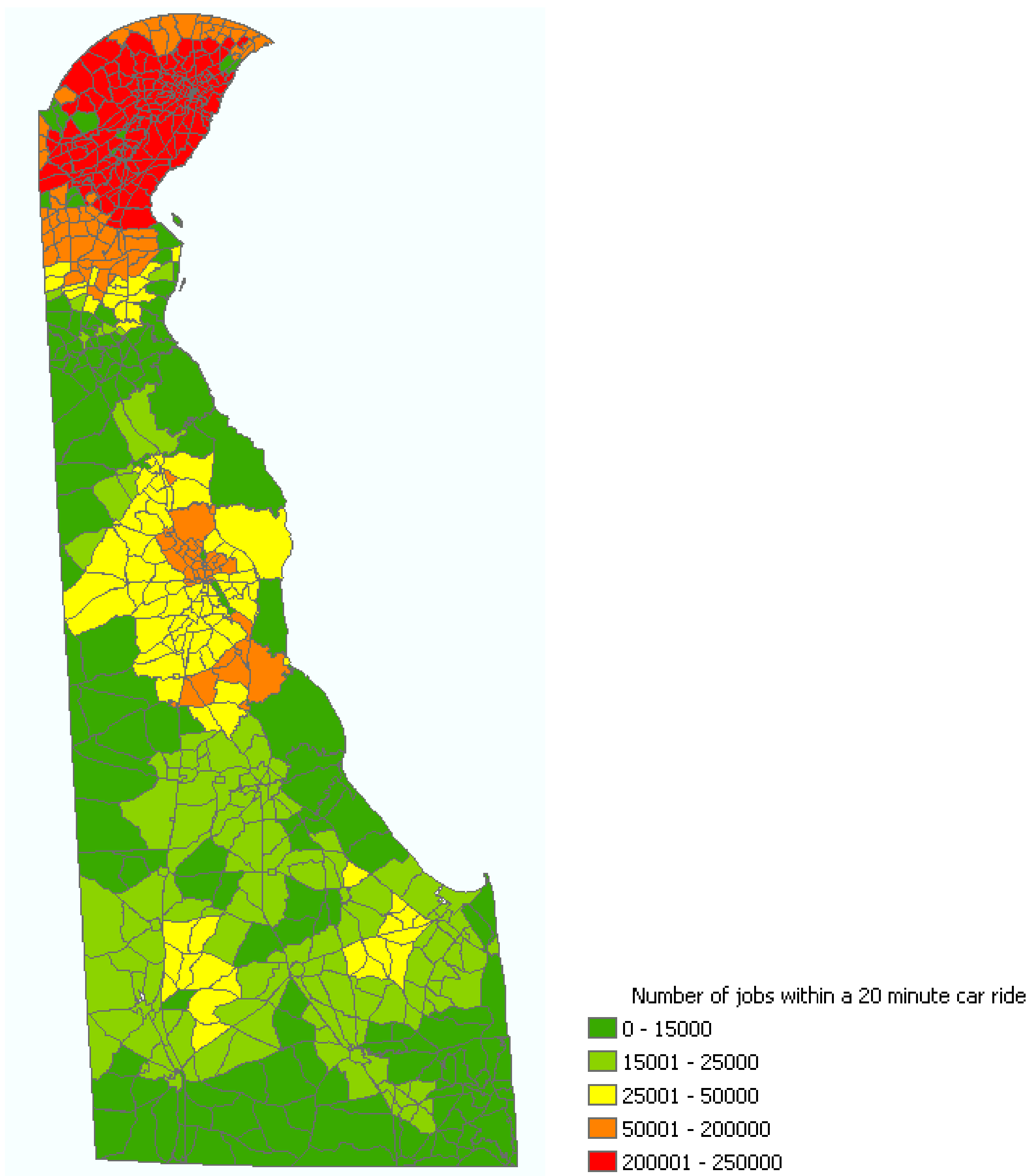
Figure 22, Number of destinations within a 10 minute walk using sidewalks, Walk LOS A
Dark Green 1-7, Light Green 8-16, Yellow 17-35, Orange 36-104, Red 105 and greater
All Destinations, North East New Castle County, Delaware.



Example 5, Number of jobs within a 20 minute Car Trip

In previous examples origins were the location of single family housing units and destinations were from the statewide place file. Other origins and destinations could be used with the path files used in the project. There are 730 traffic zones in Delaware used to organize demographic data. Estimates of population and employment by traffic zone were provided by the Metopolitan Planning Organization (MPO) covering New Castle County, Delaware and Cecil County Maryland (WILMAPCO) . Using centroid locations of traffic zones for origins and destinations the number jobs within a 20 minute car trip could be generated to examine th e proximity of jobs.

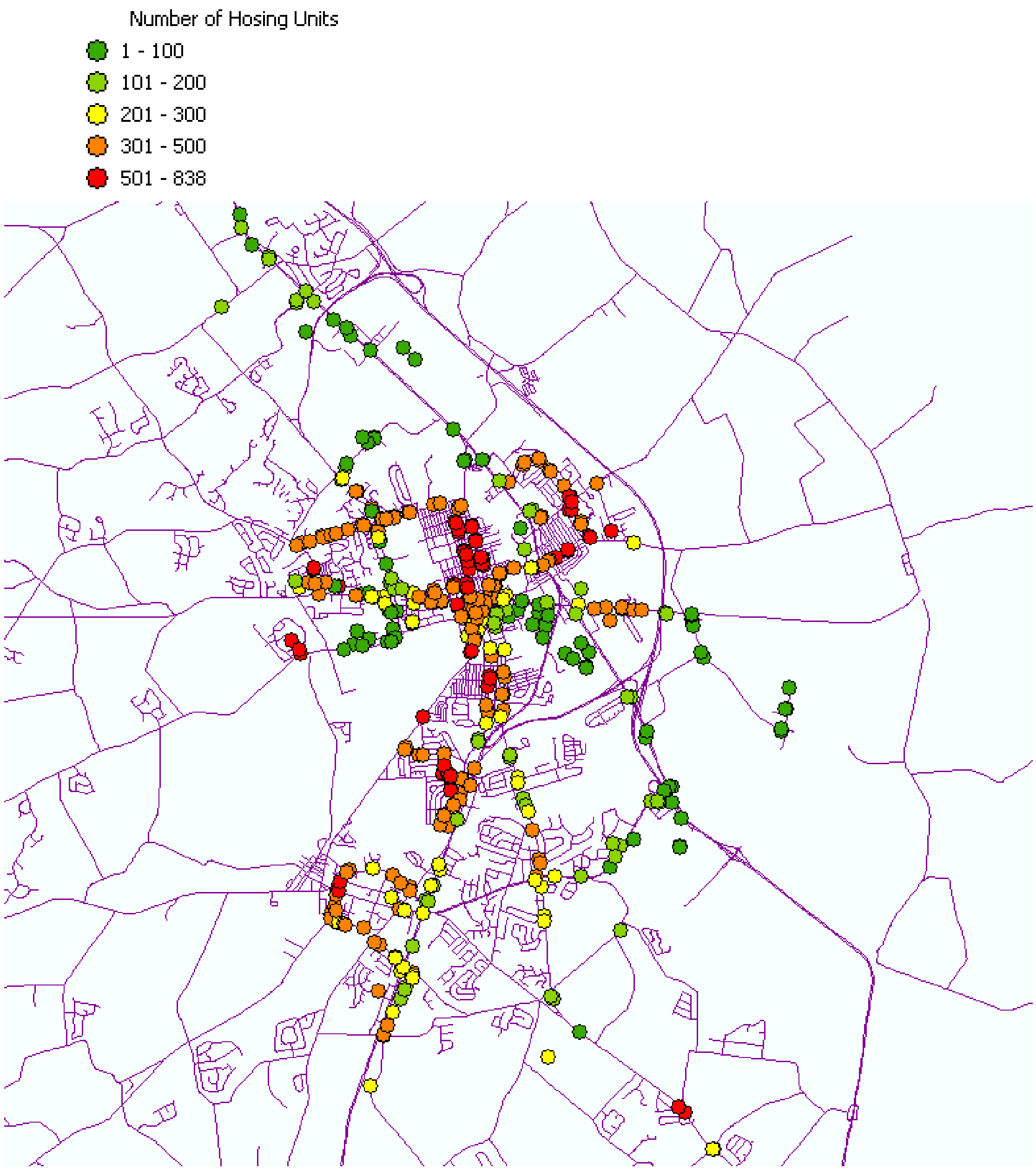
Figure 23 Number of jobs within a 20 minute car ride at the Traffic Zone level



Example 6, Number housing units within 10 minute walk to bus stops

The number of housing units within a 10 minute walk from/to a bust stop is easily calculated and the result shown on the map below. This type of analysis could be used to examine the number of housing units or people that can access any destination or facility.

Figure 24 Number of housing units within a 10 minutes wallk for each bus stop Area around Dover Delaware



Summary

The research outlines a functional information system framework that can be further developed to serve many applications. Primary data resources needed are sets of origins and destinations, and a travel network model that accurately specifies paths available for any given trip for each travel mode, (walking, biking, transit, car) for each level of service of interest.

A statewide accessibility factor based on the number of destinations available within a 10 minute walk was created and additional statewide measures can be generated for other modes. This has immediate application to the modeling of travel demand and examination of land use toward evaluating multi modal facilities. Incorporation of levels of service of paths allows for evaluation of the effect of facilities.

The initial state of data resources allows for the creation of useful measures immediately. Additional consideration should be focused the way destinations are categorized and in improvements to the underlying network model. In particular the network must better reflect available driveways and paths in proximity to land use, and pedestrian street crossing points. The features of intersections relative to how they serve different travel modes would be an important addition to the network model. Thru the implementation of turn tables, intersection data and features can be included in origin-destination analysis. Turn tables also support the management and access of traffic data (volumes, speeds) at intersections. The analysis supports the examination of accessibility by transit routes and work needs to be done to incorporate transit routes into the network model.

The methods presented demonstrate a means to quantify the populations that can be served by multimodal facilities. Analysis could be further streamlined and automated to efficiently study a range of scenarios.

Accessibility addressed in this study is focused on developing factors that measure the availability of destinations. Accessibility in a broader sense can address and is affected by safety, roadway design, affordability, environment, and a range of other factors. The approach here can address some of these by associating them with portions of available paths.

The accessibility index developed is fairly simple being based on the cumulative number of destinations available within a given travel time. As the origin-destination matrices generated include distance use of gravity model effects and more sophisticated means of weighting distance and particular land uses are possible.

Analysis for specific types of destinations or travel purposes (shopping, school, work, etc) has been demonstrated. Improvement and categorization of place files will produce more meaningful results. Where a composite measure is developed for varied types of destinations, a means to weight destinations is needed to generate a score. All destinations in place files are not equal in their desirability or usage. Development of factors used with destinations is suggested. Examples of such factors include trip attraction measures as commonly used in travel demand forecasting, and employment at each destination, Origins used in this analysis were single family housing units but origins are not all the same either. Consideration of the population served, profiles of population and travel behavior, and weighting factors associated with multi-unit facilities could improve results significantly.

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