Evaluating the Accessibility of Residential Areas for Bicycling and Walking using GIS

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Approval Sheet

The thesis is submitted in partial fulfillment of the requirements for the degree of

Master of Science, Civil Engineering

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Author

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Thesis advisor

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Accepted for the School of Engineering and Applied Science:

Dean, School of Engineering and Applied Science

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Abstract

Accessibility, or the ease of travel between two locations, is an appropriate measure for walking and cycling because of the heavily constrained nature of walking and cycling trips. Much attention has been focused in recent years on the connection between the built environment and the transportation system. This relationship is especially relevant for walking and cycling as literature has shown that spatial layout and infrastructure design are significant factors in the ability to make walking and cycling trips. Unfortunately, a quality method does not exist to quantify walking and cycling accessibility. Most accessibility measures have concentrated on the macro level while walking and cycling by nature occurs mainly at the micro level. The few attempts at measure micro-scale accessibility have serious drawbacks.

This thesis synthesized recent research on the connection between the built environment and transportation to develop a new accessibility measure that can identify areas conducive to walking and biking. This measure, the Pedestrian and Cycling Accessibility Measure (PCAM), is based on the concept of the “3Ds,” or density, diversity, and design. Corresponding to this research, the PCAM first considers the proximity of residential areas to specific destinations within walking and biking ranges (density) and the mix of destinations immediately surrounding these destinations (diversity). This part of the PCAM demonstrates the potential for walking and biking trips in a given area. Once this analysis is complete, the physical design of the pedestrian and cycling infrastructure (or lack thereof) are examined to determine if the necessary infrastructure is in place to support the potential walking and biking travel (design).
After developing the PCAM, a geographic information system (GIS) was used to implement the measure and display the results. The PCAM was applied to the Charlottesville/Albemarle region of Virginia to demonstrate the results of the analysis and the capabilities of GIS for calculating and displaying accessibility. The GIS results show that this analysis presents a large amount of detail over the study area and can be displayed in a variety of ways. The regional maps give an overview of accessibility for the study area showing that it is highest in the high-density, mixed-use areas. Any point on the map can be queried to reveal how the PCAM score was calculated for that specific point. Map layers can also be used for more in-depth calculation such as subtracting the actual infrastructure design from the potential accessibility to reveal areas in need of infrastructure improvements.

While there were some limitations to the analysis due to unavailable or inadequate data, the GIS application proved to be an ideal environment for measuring accessibility. GIS is well suited to handle the spatial nature of the data and the number of calculations necessary to calculate the PCAM. The mapping features of GIS and ability to view the underlying data for the maps allow the results to be presented in a number of useful ways.
Acknowledgements

I would like to thank the many people who assisted with technical aspects of this thesis and provided invaluable feedback. First I’d like to thank Scott Kreissler for his hard work and expertise with the GIS application of the PCAM and Chris Gensic for much of the Charlottesville/Albemarle data. Next I would like to thank David Phillips for his extensive help with GIS, Bruce Dotson for help with the RAI and giving feedback on the thesis, and Bruce Appleyard for helping me focus my topic early on. Finally, thanks to my examining committee of Lester Hoel, John Miller, and Mike Demetsky for seeing me through this process, giving insightful feedback on the thesis, and especially for putting up with me over the unusual path I took to my degree.
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CHAPTER 1. Introduction

Accessibility is a term commonly used by urban planners and transportation professionals to describe the ease of travel between two locations. Thus, accessibility implies both the need to reach a particular destination and the means to reach that destination. Accessibility is different from mobility. Mobility is a measure of the availability and quality of given transportation options but is not destination specific. For example, creating a new network of bicycling trails through the countryside increases mobility by making it easier and faster for people to bicycle through the countryside. But this does not address accessibility as no destinations are involved. The creation of a new network of bicycling trails that connect residential areas to schools, shops, and jobs increases accessibility by improving both the ability to bicycle and the ease of reaching destinations. This thesis will focus specifically on local, or neighborhood, accessibility.

Much attention has been focused in recent years on the built environment and its impact on accessibility. This relationship is especially relevant for walking and cycling as low-density suburban growth patterns have made these modes difficult if not impossible for little more than social or recreational travel. Even in the most disconnected environments it is still feasible to reach most any destination by automobile if one is available. Certainly automobile travel is more accessible with shorter distances and less congestion but most drivers are willing to tolerate long distances and roadway hassles en route to their destinations. On the other hand, walking and cycling are far more limited by the distance people are physically able and willing to travel and by the presence or lack of facilities such as sidewalks or bike lanes that facilitate travel and
safety. While it may be possible to walk five miles to work, few are willing to expend the time and energy necessary to make that trip.

Walking and cycling travel has well-documented benefits. More walking and cycling trips result in fewer automobiles on the roadway, thus freeing up capacity for those trips that cannot be feasibly made by a non-automobile mode. Walking and cycling are beneficial for both the environment and the individual by being pollution-free travel modes and also a good form of exercise. And socially, the ability to walk and cycle to destinations reduces automobile dependence and provides transportation choices, especially beneficial for those without easy access to a vehicle or transit. This is not to say that walking and cycling are better than any alternative, as automobiles, transit, and other modes all have their own substantial benefits. But these are significant reasons for promoting walking and cycling as two of many transportation options.

Accessibility is an appropriate measure of walking and cycling opportunities because of the emphasis on the destination and mode of travel. Since the walking and cycling realms are limited by distance as mentioned above, these modes are only feasible if desirable destinations lie within an acceptable range. The presence of these destinations creates the potential for walking and cycling. Then the infrastructure can be analyzed to determine if it is appropriate for each possible mode choice to those destinations. High local accessibility and its individual related measures of the built environment (land use, land use mix, density, etc.) have been found to correspond to increases in walking and biking travel by Kockelman, Steiner, and others.1,2
1.1 Purpose

This thesis will synthesize recent research on the connection between the built environment and transportation to develop a new accessibility measure that can identify areas conducive to walking and biking. This measure will be referred to as the Pedestrian and Cycling Accessibility Measure or PCAM. The framework for the PCAM is based on the work of Cervero and Kockelman who have studied the impacts of the “3Ds,” density, diversity, and design, on travel choices. Corresponding to this research, the PCAM is proposed that will first consider the proximity of residential areas to specific destinations within walking and biking ranges (density) and the mix of destinations immediately surrounding these destinations (diversity). This part of the PCAM will demonstrate the potential for walking and biking trips in a given area. Once this analysis is complete, the physical design of the pedestrian and cycling infrastructure (or lack thereof) will be examined to determine if the necessary infrastructure is in place to support this potential walking and biking travel (design).

After developing the PCAM, a geographic information system (GIS) will be used to implement the measure and display the results. The amount of computation necessary to complete the PCAM analysis over a large area requires a substantial amount of automation to complete, which GIS is well-suited for. The PCAM will be applied to the Charlottesville/Albemarle region of Virginia to demonstrate the results of the analysis and the capabilities of GIS for calculating and displaying accessibility.
1.2 Potential uses

The PCAM could be used in a number of applications to help guide decision-making. Below are two examples of potential uses for the measure. Additional uses could include guiding future residential development, identifying non-residential needs, etc.

1.2.1 Identify areas to focus limited funding for pedestrian and cycling infrastructure.

This PCAM can first identify areas with high potential accessibility and then determine whether adequate pedestrian and cycling infrastructure already exist. Areas with large discrepancies between potential accessibility and actual infrastructure should be targeted for infrastructure improvements. The North Jersey Transportation Planning Authority used a similar strategy using the “pedestrian potential index” based on employment density, population density, land use mix, and street network density.3

1.2.2 Identify areas that provide an array of transportation choices.

For the real estate field, the PCAM has a variety of potential applications. Certain customers may view transportation choice as a desirable feature of a location and therefore accessibility could be promoted by real estate agents. Additionally, accessibility could be used by lenders as one of the criteria for determining areas that qualify for a Location Efficient Mortgage.4
1.3 Methodology

This thesis synthesized prior research to create a new accessibility measure for
determining areas supportive of walking and cycling travel and then demonstrated this
measure with GIS. The thesis involved the following tasks:

1. Conduct a literature review of accessibility indices, modal choice, and the
   connection between transportation and the built environment
2. Develop the Pedestrian and Cycling Accessibility Measure
   a. Select two existing local accessibility measures in the literature for
      reference
   b. Identify additional factors that contribute to accessibility
   c. Create scoring system for the PCAM
   d. Revise and improve the PCAM based on feedback from researchers and
      professionals
3. Demonstrate the PCAM through a GIS application
   a. Collect destination, density, and infrastructure data as needed for the
      PCAM analysis
   b. Input data and analysis methodology to create a GIS-based case study of
      the PCAM for the Charlottesville/Albemarle region
   c. Present results and examples both graphically and numerically to
      demonstrate the capabilities of the GIS application
4. Revise the PCAM based on the case study and develop conclusions on the
   reproducibility and usefulness of such a measure
The two main objectives of this thesis are to develop a new measure of pedestrian and cycling accessibility (the PCAM) and to demonstrate this measure through a GIS application. Validating the results is beyond the scope of this thesis. Although measuring transit accessibility at a micro level has substantial merit, analysis of transit accessibility is also beyond the scope of this thesis.
CHAPTER 2. Literature review

2.1 Built environment-transportation research

In the study by Cervero and Kockelman on the 3Ds, density was taken to relate to population, employment, and accessibility to jobs. Diversity involved measures of land-use mixing, dissimilar land-uses, activity-center intensities, proximity to retail uses, and vertical land-use mixing. Design measured characteristics of the streets, pedestrian and cycling infrastructure, and site design. This study and a more recent study by Cervero both determined that these three variables significantly influence mode choice, although design factors are usually weaker than density or diversity.

Several other researchers have identified these three factors as having a role in modal choice and vehicle miles traveled (VMT). Frank and Pivo found that increases in employment density, population density, or land-use mix lead to reductions in single-occupant vehicle usage and increases in transit use and walking. Holtclaw et al. determined that VMT and auto ownership are strong functions of density while they are a weak function of pedestrian and bicycling friendliness, meaning that a significant relationship exists for both comparisons but that VMT and auto ownership are far more sensitive to density than to pedestrian and bicycle friendliness. Ewing et al. found an inverse relationship between density, mixed use, and a central location and vehicle hours traveled per person.

Criterion Planners/Engineers and Fehr & Peers Associates completed a study in 2001 that estimated the elasticities of density, diversity, design, and destinations on vehicle trips and vehicle trip miles. The elasticites were developed based on the data presented in over 40 studies on the behavior between land-use and travel behavior. This
elasticity table has been reproduced in Table 2.1 below. This table and the above literature have all found statistically significant relationships between the transportation system and the built environment but the influences are fairly small in magnitude. For example, according to Table 2.1, increasing the density of an area by 1% will result in a 0.043% reduction in vehicle trips.

<table>
<thead>
<tr>
<th></th>
<th>Vehicle Trips</th>
<th>Vehicle Miles Traveled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>-0.043</td>
<td>-0.035</td>
</tr>
<tr>
<td>Diversity</td>
<td>-0.051</td>
<td>-0.032</td>
</tr>
<tr>
<td>Design</td>
<td>-0.031</td>
<td>-0.039</td>
</tr>
<tr>
<td>Destinations</td>
<td>-0.036</td>
<td>-0.204</td>
</tr>
</tbody>
</table>

A substantial body of research also exists that does not backup the above findings. Crane and Crepeau, Boarnet and Sarmiento, Krizek, and others have found that the relationships between density, diversity, or design and transportation choice or usage are for the most part insignificant. The inconsistencies in the literature on the transportation impacts of the built environment create a dilemma for continuing research and policy implementation. As neither side has proven its case conclusively, these inconsistencies should not halt continuing work in this area. Common sense alone leads to the conclusion that walking and biking trips are more likely to occur in locations with shorter travel distances and safer, higher quality infrastructure connections. Until this statement is proven otherwise, it will remain beneficial to promote built-environment design that is intended to increase pedestrian and cycling accessibility.
2.1.1 Distance to destinations

Data from the 2001 National Household Transportation Survey were selected for use in this index because this is a well-established source of national data. From the raw online data, the average distance for biking trips is calculated as 1.91 miles and the average walking trip is calculated as .74 miles. Assessment of the built environment within a 1 mile range is consistent with Cervero and Radisch who found that neighborhood characteristics have the strongest effect on non-work trips under a mile in length.

2.1.2 Type of destinations

The common method of analyzing the attractiveness of a destination is through employment numbers or square feet of retail space. This makes data collection and analysis simpler while providing a decent representation of the availability of jobs or services. But for the level of detail needed in this index, information about the specific type of destination was needed. A list of desirable locations is available in the study by Banerjee and Baer that indexes 79 potential destinations to have in close proximity to the home. Each destination is associated with a value from +1.0 to –1.0, where higher scores indicate more desirability.

2.1.3 Design

Besides the general influence of density and diversity on modal choice, it is important to look at specific characteristics of bicycling and walking and the design of their infrastructure to determine what conditions are the most desirable. In fact, Moudon
et al. determined that density, land-use mix, and income cannot sufficiently predict pedestrian volumes but adding site design to those factors substantially increases the predictive power.\textsuperscript{18} Research in this area is made difficult by the amount of subjectivity involved in assessment of cycling and pedestrian infrastructure and with the wide variety of personal attitudes towards the use of these two modes. A growing body of research exists that attempts to bring some clarity to this subject.

\textit{2.1.4 Bicycling}

Landis et al. identified six factors that improve the cycling level of service based on the response of 150 participants following an on-road cycling experience. The participants were most interested in having a bike lane or paved shoulder, more space between bikes and vehicles, low vehicle speed and volume, good pavement condition, and a small amount of on-street parking.\textsuperscript{19} These results are backed up by the FHWA’s Bicycle Compatibility Index which also adds residential development as a more desirable roadside feature than commercial development.\textsuperscript{20} A bicycle-intercept survey conducted by Shafizadeh and Neimeier found that the biggest reason for not cycling is the lack of dedicated biking facilities.\textsuperscript{21}

\textit{2.1.5 Walking}

Landis et al. conducted a similar study on pedestrian characteristics and found that the four most important items are the presence of sidewalks, the lateral separation of pedestrians and vehicles, the lack of physical barriers or buffers, and low vehicle volume and speed.\textsuperscript{22} Shriver compared the travel behavior of residents in four Austin, Texas
neighborhoods, two of which were traditional with higher density, mixed-use, and
gridded streets while the other two were modern with lower density, mostly residential
use, and cul-de-sacs. In the more accessible traditional neighborhoods, walk trips are
short, frequent, utilitarian, and include more secondary activities per trip. The most
important design attributes were found to relate to density and diversity with the presence
of sidewalks and aesthetics of less importance. The most significant constraints to
walking trips include long distances, the need to reach too many different destinations in
one trip, traffic, and the presence of a major road.23

1000 Friends of Oregon created the Pedestrian Environment Factor (PEF) for use
in the model created for Making the Land-Use, Transportation, Air Quality Connection
(LUTRAQ), the alternative land-use and transportation proposal for Washington County.
This factor included measures of the ease of street crossings (width, signalization, and
traffic volumes), sidewalk continuity, local street characteristics (grid or cul-de-sac), and
topography. It was found that as the PEF increases, VMT will decrease.24

2.2 Existing accessibility measures

Unfortunately, most current accessibility measures do not take all of the above
characteristics into account and are therefore inadequate for the needs of pedestrians and
cyclists. These measures typically include only macro-scale measures that pertain to
regional travel by auto or transit modes. A thorough review of accessibility measures can
be found in the literature review by Bhat et al.16 There are some notable exceptions such
as the measures by Dotson and the Essex Planning Officers Association which look in
detail at the connections of individual developments to nearby destinations.25,26 While
these measures provide an innovative basis for measuring local accessibility, they both suffer from an over-emphasis on design characteristics and subjectivity.

2.2.1 Real Accessibility Index

Students and faculty at the University of Virginia’s School of Architecture created the Real Accessibility Index under the direction of Dr. Bruce Dotson.\textsuperscript{25} This index is intended for use as a multi-modal transportation evaluation tool that analyzes the accessibility of individual neighborhoods in Charlottesville City and Albemarle County based on the private automobile, public transportation, bicycling, and walking. Suggestions are made in the report that allow the locality to prioritize improvements in an attempt to achieve a more balanced transportation system.

For each mode, the proximity of services, employment, recreation, etc. within a mode-specific distance threshold is used to account for 3/5 of the total score. Destinations are weighted by placing them into categories of frequent, regular, and occasional use. The remaining 2/5 of the score is broken down into several factors representing the design of the area, such as sidewalk provision, surface quality, and lighting. This scoring system has been reproduced in Table 2.2 on the following page.
Table 2.2. The scoring system for the Real Accessibility Index

<table>
<thead>
<tr>
<th>Automobile Links</th>
<th>Frequent Use links</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Use links</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Occasional Use links</td>
<td>5 (30)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interior Access</th>
<th>Parking</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of access points</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Pavement Markings</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Signage</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Speed controls</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Lack of congestion</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Road Width</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Road surface condition</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Debris/litter</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Snow removal</td>
<td>1 (20)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pedestrian Links</th>
<th>Frequent Use links</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Use links</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Occasional Use links</td>
<td>5 (30)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Provision of sidewalks</th>
<th>1 per 10% coverage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crosswalks</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Clear walks (obstacle-free)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Handicapped Access</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Calm Traffic</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cleanliness</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Weather protection</td>
<td>1 (20)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bicycle Links</th>
<th>Frequent Use links</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Use links</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Occasional Use links</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Racks at destinations</td>
<td>5 (30)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interior Access</th>
<th>Lanes on major streets</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calm traffic</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Clear of debris/obstacles</td>
<td>5 (20)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transit Links</th>
<th>Service available</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time open</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Days open</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Buses per hour</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td># of routes available</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Provision of maps/info</td>
<td>2 (30)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interior Access</th>
<th>Platforms</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benches</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Shelters</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Crosswalks</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Handicapped Access</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Trash Bin</td>
<td>1 (20)</td>
<td></td>
</tr>
</tbody>
</table>

While this index and the analysis for each neighborhood are extremely detailed and constructive for pointing out the transportation needs in each neighborhood, the
usefulness of such an index is limited for broader use. First, 2/5 of the total score is used to measure details of design within the neighborhood where published research cannot support such a large point allocation to a design measure. Design has been found to have a minor to no impact on transportation behavior except for recreational and social trips.\textsuperscript{5,23} Second, the design characteristics are only analyzed within the neighborhood, which again really only makes an impact on recreational and social trips, and not between the neighborhood and destinations. Third, there is little guidance on what the point values for each item mean, such as what conditions constitute a 0-2 score for the “lighting” value. Finally, the index does not take into account direct travel costs or the diversity of services available at a particular destination, both which have been proven to have an impact on mode choice.\textsuperscript{6}

2.2.2 Essex Planning index

The Essex Planning Officers Association in the United Kingdom created a similar index as part of a report on calculating developer contributions to support sustainability of the transportation system as a result of new development.\textsuperscript{26} The goal of this index is to create an accurate and standard way of measuring the accessibility of all common modes of transportation in medium to large developments. The factors in the index are meant to measure not only the actual accessibility but also the perceived accessibility.

Points are given to different factors relating to public transportation, biking, walking, private vehicles, and powered two-wheelers. For each mode, factors such as time, distance, cost, and elements of design are used. Far more factors contribute to the accessibility score in the Essex index than the \textit{Real Accessibility Index}. The major
additions in the Essex index include marketing, incentive programs, and the needs of people with mobility impairments. This index is intended for use at any type of development and the score can be compared to a benchmark score for each development type, size, and location. Finally, this score can be converted to the financial contribution necessary to improve the transportation system to the pre-determined level to allow development. The tables needed to apply this index take up over 20 pages, so only one example from this index is reproduced in Table 2.3 below.

Table 2.3 The scoring system for off-site pedestrian facilities in the Essex Planning index

<table>
<thead>
<tr>
<th>Accessibility element</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
</tr>
<tr>
<td>No direct pedestrian route to the site</td>
<td>0</td>
</tr>
<tr>
<td>Identifiable direct pedestrian route to the site</td>
<td></td>
</tr>
<tr>
<td>Route is signed</td>
<td></td>
</tr>
<tr>
<td>Route is adequately lit</td>
<td></td>
</tr>
<tr>
<td>Route is well used and safe</td>
<td></td>
</tr>
<tr>
<td>Footway width</td>
<td></td>
</tr>
<tr>
<td>No footpath</td>
<td>0</td>
</tr>
<tr>
<td>Footpath present, but does not connect to site</td>
<td>0</td>
</tr>
<tr>
<td>Less than 1.2m</td>
<td>0</td>
</tr>
<tr>
<td>1.2-1.5m</td>
<td>3</td>
</tr>
<tr>
<td>1.6-1.8m</td>
<td>5</td>
</tr>
<tr>
<td>Over 1.8m</td>
<td>10</td>
</tr>
<tr>
<td>Footway Quality</td>
<td></td>
</tr>
<tr>
<td>Uninterrupted by services</td>
<td></td>
</tr>
<tr>
<td>If required – Seating</td>
<td></td>
</tr>
<tr>
<td>Adequate street lighting</td>
<td></td>
</tr>
<tr>
<td>Dropped kerbs where required</td>
<td></td>
</tr>
<tr>
<td>Continuity of footway</td>
<td></td>
</tr>
<tr>
<td>Tactile paving where required</td>
<td></td>
</tr>
<tr>
<td>Footpath on desire lines</td>
<td></td>
</tr>
<tr>
<td>Sign posting</td>
<td></td>
</tr>
<tr>
<td>Litter bins</td>
<td></td>
</tr>
</tbody>
</table>

As the previous sentence may have implied, this measure is highly detailed but even more daunting to complete. It also suffers from problems of subjectivity. This is tough to avoid with the nature of a micro-scale index, but with proper guidance, this subjectivity could at least be reduced. The emphasis in this index is strongly towards
design as well. Although it varies between modes, typically \( \frac{3}{4} \) of the available points deal with design elements while only \( \frac{1}{4} \) address the proximity and attractiveness of destinations. Because this index is intended not just for residential developments but for any type of development, points are generally assigned based on the number of people within a distance threshold to a particular destination, which is really only meaningful for non-residential development. There is one section within pedestrian accessibility that specifically addresses residential developments, but even here the treatment is fairly rudimentary.

### 2.2.3 Conclusions on current micro-scale accessibility measures

These two accessibility measures show great promise but leave room for improvement in two major areas. The first is in the distribution of points in a scoring system. Although design elements do have an impact on transportation behavior, the relationship is far less strong than implied by these two indices. More of an emphasis needs to be placed on the proximity and attractiveness of the destinations themselves rather than the detailed elements of the path to reach those destinations. Second, subjectivity cannot completely be avoided, but action should be taken to minimize its effect. Subjective factors may be necessary and beneficial to a micro-scale measure of accessibility as long as standard guidance exists on how to score each factor. That guidance was not present with either of the two reviewed accessibility measures.
CHAPTER 3. Development of the PCAM

The PCAM is based on the variables previously described as the 3Ds or density, diversity, and design. In this thesis, density is defined as residential accessibility, or the number of destination opportunities within the pedestrian or bicycling range from the home. Diversity is defined as destination accessibility, or the availability of additional destination opportunities within a ¼-mile range of a specific destination. The term design will continue to be used throughout the thesis and refers to the presence and quality of the pedestrian and cycling infrastructure. Appendix A contains a graphical version of the analysis developed in this chapter. Reference to this chart may help to illustrate the proposed calculations.

3.1 Destination value

Thirteen destinations were selected from the list published in the Banerjee and Baer study. The highest-ranking destinations were selected as well as “place of work” due to the significant amount of travel made on the work journey. Some items in the list were removed because they did not qualify as destinations (street lights, walkways, etc.) or because factors much stronger than proximity influence their use (religious facilities and doctor’s offices). Others were combined due to similar usages (neighborhood park, a court for games, and playground were combined into park). In these cases, the median desirability value was selected. All of the selected destinations were weighted relative to the others to determine the percentage of the destination value to be allocated. The list of destinations is displayed in Table 3.1 on the following page with their desirability value and weighting value.
Table 3.1. Selected destinations with desirability and weighting values.

<table>
<thead>
<tr>
<th>Destination</th>
<th>Desirability</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drugstore</td>
<td>0.91</td>
<td>0.091</td>
</tr>
<tr>
<td>Grocery store</td>
<td>0.91</td>
<td>0.091</td>
</tr>
<tr>
<td>Library</td>
<td>0.91</td>
<td>0.091</td>
</tr>
<tr>
<td>Post office</td>
<td>0.85</td>
<td>0.085</td>
</tr>
<tr>
<td>Small food store</td>
<td>0.79</td>
<td>0.079</td>
</tr>
<tr>
<td>Park</td>
<td>0.78</td>
<td>0.078</td>
</tr>
<tr>
<td>Bank</td>
<td>0.77</td>
<td>0.077</td>
</tr>
<tr>
<td>Dry cleaner</td>
<td>0.76</td>
<td>0.076</td>
</tr>
<tr>
<td>Beauty/barber shop</td>
<td>0.75</td>
<td>0.075</td>
</tr>
<tr>
<td>School</td>
<td>0.72</td>
<td>0.072</td>
</tr>
<tr>
<td>Friend's place</td>
<td>0.72</td>
<td>0.072</td>
</tr>
<tr>
<td>Restaurant</td>
<td>0.7</td>
<td>0.070</td>
</tr>
<tr>
<td>Place of work</td>
<td>0.44</td>
<td>0.044</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10.01</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>

Determining the proximity from the home to the above specific destinations was fairly straightforward except for “friend’s place” and “place of work.” For these two, it was necessary to find the number of people and number of jobs available within the local area. The presence of people in the immediate area increases the accessibility for social trips and the presence of jobs increases the accessibility for work trips while both serve as proxies for additional shopping, services, and other local opportunities. Frank and Pivo found thresholds for employment and population densities above which SOV usage begins to decline and is replaced by transit and walking trips. This threshold for employment density is 20-30 jobs/acre and for population density is 13-18 people/acre. The midpoint of each of these ranges was increased by 50% to determine the maximum for the range of densities analyzed. This means that points will be awarded for employment densities from 0-38 and population densities from 0-23. Densities above these ranges will be awarded the maximum number of points.
3.2 Operationalizing residential accessibility

The average distances for walking and biking cited in Section 2.11 were increased by roughly 50% to determine a maximum distance for awarding points, which results in a 3-mile maximum for biking and a 1-mile maximum for walking. Using these ranges, the following formulas were used to measure the various dimensions of residential accessibility. “Specific destinations” refers to all locations from Table 3.1 except for friend’s house and place of work. The formulas are applied separately for walking and biking opportunities and ignore any opportunities outside of the 1-mile (walking) and 3-mile (biking) ranges. The highest possible result for each formula before the weighting is applied is 1. For example, even if the population density is more than 23 people per acre, additional points will not be awarded above 1. If more than one of the same type of specific destination is found within the walking or biking range (ex. two grocery stores), only the nearest destination will be used for the calculation. This analysis can begin at any point in space but is intended for use at a current or potential residential location.

**Equation 3.1**  
Specific destinations (walking) = \( \left(1 - \frac{\text{distance (miles)}}{1 \text{ mile}}\right) \times \text{weighting} \)

**Equation 3.2**  
Specific destinations (biking) = \( \left(1 - \frac{\text{distance (miles)}}{3 \text{ miles}}\right) \times \text{weighting} \)

**Equation 3.3**  
Population density = \( \left(\frac{\text{density (people)}}{23 \text{ acre}}\right) \times \text{weighting} \)

**Equation 3.4**  
Employment density = \( \left(\frac{\text{density (jobs)}}{38 \text{ acre}}\right) \times \text{weighting} \)
3.3 Operationalizing destination accessibility

For all of the specific destinations listed in Table 3.1, the surrounding destinations were also analyzed. For this measure, a value of .25 miles was used as the maximum range to determine the number of additional destinations accessible from a major destination. The same formulas listed in Section 3.2 are applied again from every specific destination found within the 1-mile and 3-mile ranges. The only difference is that the area of analysis is reduced to a ¼-mile range from each specific destination to reflect the ability to walk to additional destinations from the first.

\[
\text{Specific destinations (both)} = \left(1 - \frac{\text{distance (miles)}}{.25 \text{ miles}}\right) \times \text{weighting}
\]

\[
\text{Population density} = \left(\frac{\text{density} \left(\frac{\text{people}}{\text{acre}}\right)}{23}\right) \times \text{weighting}
\]

\[
\text{Employment density} = \left(\frac{\text{density} \left(\frac{\text{jobs}}{\text{acre}}\right)}{38}\right) \times \text{weighting}
\]

3.4 Operationalizing design characteristics

Finding a way to include design in the analysis was especially tricky due to the availability of data and subjective character of many design factors. Unlike the residential and destination accessibility measures that could be replicated anywhere, the calculation of design in this project is specific to the Charlottesville/Albemarle region.

The design measures, at their most basic level, repeated the residential accessibility measures at a much greater level of detail. Whereas the residential
accessibility measures used line of sight with no regard for what may be on that line between origin and destination, the design measures include the road, sidewalk and bike lane infrastructure, and the presence of busy roads. As with the calculation of residential accessibility, specific destinations within the pedestrian and biking ranges are searched for. Only this time, the maximum range is modified based on the following constraints (detail on the scoring system for design, written with a GIS-base analysis in mind, can be found in Appendix B):

- Must follow the road network
- Traveling without sidewalks/bike lanes costs twice as much
- Traveling along busy roads results in as much as a doubling of travel cost
- Crossing busy roads results in as much as a complete barrier to travel

3.5 Aggregating residential accessibility, destination accessibility, and design

The equations above set every part of the accessibility measure equal to 1 prior to the application of a weighting. This weighting is used to assign higher values to the more desirable specific destinations and to differentiate between the value of the three categories of residential accessibility, destination accessibility, and design. Based on the review of literature, especially on the Index® 4D Method, it is reasonable to apply 40% of the total score to residential accessibility, 35% to destination accessibility, and 25% to design. In the end, the scores will be aggregated together to achieve a possible maximum of 100 points for each analysis point. The analysis is run twice to come up with two separate scores based on pedestrian accessibility and cycling accessibility.
In the description of the steps for calculating the final score, it will be assumed that the analysis if being conducted for pedestrian accessibility. First, the residential accessibility equations are applied at each analysis point. There are thirteen different calculations occurring for residential accessibility corresponding to the thirteen destinations in Table 3.1. Eleven correspond to specific destinations while the other two are for calculating population and employment density. The weighting for each of these thirteen equations is dependent on the desirability of each destination (see Table 3.1 above) and the overall value of residential accessibility. The weightings were determined by the formula below:

\[
\text{Equation 3.6} \quad Desirability_i \times \frac{\text{Residential accessibility value}}{\sum_{i=1}^{13} \text{Desirabilities}}
\]

Where:

- Desirability = the value from Table 3.1
- \( i \) = the destination being analyzed
- Residential accessibility value = 40

The thirteen individual scores are then added together to determine the residential accessibility score out of a maximum of 40 points.

Next, every additional destination within a ¼-mile range of each specific destination is analyzed for its destination accessibility. The same calculations are repeated again, only this time from the specific destinations rather than from the analysis points. Twelve calculations are performed at each destination, as there is no need to search for a second occurrence of the same destination (it is irrelevant to search for
additional grocery stores within a ¼-mile radius of a grocery store). The weightings for
destination accessibility were determined by the following formula:

**Equation 3.7**

\[
\text{Desirability}_i \times \text{Desirability}_j \times \frac{\text{Destination accessibility value}}{\sum_{i=1}^{12} \text{Desirability}_i} \times \frac{1}{\sum_{j=1}^{12} \text{Desirability}_j}
\]

Where:

- Desirability = the value from Table 3.1
- \( i \) = the destination found within pedestrian range of an analysis point
- \( j \) = each additional destination being analyzed
- Destination accessibility value = 35

The twelve individual scores are then added together to determine the destination
accessibility subtotal for each destination found with pedestrian range of the analysis
point in the previous step. When this has been repeated for every destination found
within pedestrian range of the residential accessibility analysis, the subtotals are all added
together to determine the total desirability score out of a maximum of 35 points.

The design score is computed using the same calculations for residential
accessibility and destination accessibility as above but based on the road network and
modified by the factors listed in Section 3.4. The weightings for the residential
accessibility portion of design are calculated with Equation 3.6 but with a residential
accessibility value of 13.3. The weightings for the destination accessibility portion of
design are calculated with Equation 3.7 but with a destination accessibility value of 11.7.
Adding these two portions together results in a maximum design score is 25 points.

Finally, the three individual scores can be added together. The aggregation of residential accessibility, destination accessibility, and design can total a maximum score of 100 points.
CHAPTER 4. Measuring accessibility through a GIS application

Esri’s ArcGIS 8.0 was used to develop a semi-automated application to analyze the pedestrian and cycling accessibility of a regional area. Primarily using the Spatial Analyst extensions, a 50-foot grid was placed over the region so that residential accessibility, destination accessibility, and design could be measured from each point on the grid. After discussing the development of the GIS application for the Charlottesville/Albemarle region, several examples of use of the PCAM will be demonstrated.

4.1 Case study

The Charlottesville/Albemarle region of Virginia was used as the test area for the GIS application. This region was chosen because of the familiarity to the author, the availability of required data, and for its diversity of development. Over a small area, the development ranges from areas that appear to be highly pedestrian and cycling accessible such as the downtown, to areas with lots of development but poor connections such as Route 29, to areas that are completely rural. For the purposes of this case study, only a 130 square mile area centered on Charlottesville city was analyzed, although the accessibility analysis can be run over any area for which the necessary data exists. Figure 4.1 on the following page shows a map of the studied portion of the Charlottesville/Albemarle region.
Figure 4.1  Map of the portion of the Charlottesville/Albemarle region analyzed in this case study.
4.1.1 Base data

Before work could begin on the GIS application, many data layers were required in order to perform the analysis. Population and employment data were needed at a fine-grained level, preferably by parcel, in order to determine the densities around each grid point. Block-level census data were used here to determine a rough estimate of population density as that was the most detailed data available for the region. It was not possible to acquire employment data at a reasonably fine level, as much of that data is private and was only available commercially at a cost of $600-$1000 for the Charlottesville Metropolitan Statistical Area. Without this data it was not possible to calculate employment density but this has little overall impact on the results. Employment density is roughly 4% of the total PCAM value. While the addition of employment density would strengthen the analysis, using 96% of the PCAM components will still result in a representative analysis.

Data on roads, sidewalks, bike lanes, and traffic characteristics were available from local agencies. These data were used in the design portion of the analysis for determining the ease of reaching destinations within a reasonable range of each grid point. While the sidewalk and bike lane data were useful, the traffic data could not be used as the data was not compatible with the rest of the accessibility data. It is impossible to quantify exactly how much the lack of traffic data affects the PCAM. The level of traffic volume is used to modify the components of the PCAM in the design portion and is not a direct component of the PCAM. Regardless of the exact impact, the literature identifies traffic volume as a major factor in the ability to walk or cycle so this data is certainly useful if it is available.
Each of the destinations in Table 3.1, aside from “park,” “friend’s place,” and “place of work,” are associated with a standard industrial classification code, or SIC code. These codes range in length from 2 to 8 digits with increasing detail on the business as the length of the code increases. A database with the SIC codes for these destinations spatially encoded would provide an ideal reference for determining the location of the above destinations within the pedestrian and cycling ranges. A list of the destinations in Table 3.1 matched with the relevant SIC codes for each can be found in Appendix C.

This point data was difficult to acquire as detailed data on specific businesses is usually not made public. There are several providers of this data that will charge a fee based on the number of entries required or for a subscription to a database. A subscription-based database called ReferenceUSA was used to acquire the data necessary for this GIS application. This database provided information on location (address and latitude/longitude), SIC codes, number of employees, yearly earnings, etc. The latitude/longitude was geocoded from the address so the locations were not exact in all cases. Some manually editing of the point data was necessary to improve the accuracy of the application.

At this point, the base map contains point data for each destination listed in Table 3.1, the road network, population data by block group, sidewalks, and bike lanes. The destination points are displayed below in the base map in Figure 4.2. The two most obvious areas of concentrated destinations are along the Route 29 corridor and the Main Street to downtown corridor. For purposes of simplicity, the case study write-up will demonstrate the pedestrian analysis only. The differences between the pedestrian and
cycling analyses are the greater range of travel for cyclists and the use of bike lanes in the analysis rather than sidewalks. The maps displaying the results from the biking analysis can be seen in Appendix D.

Figure 4.2 Base map showing the specific destination point data.
4.1.2 Residential accessibility

To calculate residential accessibility, the first step is to find the presence and proximity of destinations within a 1-mile range of each grid point. To accomplish this task, 1-mile buffers were generated around every destination. From each destination, the distance can then be measured from the destination to each grid point within the 1-mile range. This is repeated for all destinations. At this point at each grid point it is known which destinations are within the 1-mile range of each grid point and exactly what the distance is to each destination. If more than one of the same type of destination are found within the 1-mile range (ex. two grocery stores), only the closest destination will be used in the calculation. Using the raster calculator, each destination is then weighted according to Equation 5.6 and then added together. An example of this analysis is demonstrated in Figure 4.3. In the example, the buffer rings become lighter after each ¼-mile of distance away from the analysis point (the green star in the figure) until they disappear completely at 1 mile away. The 1-mile range includes ten destination points of four different types (small food store, restaurant, school, and beauty shop). The closest destination of each of these four types has been highlighted with a yellow circle surrounding it. Moving clockwise from zero degrees, the analysis reveals that Vinegar Hill Grill is 0.12 miles away, Coletti’s Hair Salon is 0.31 miles away, Greenbrier Elementary School is 0.73 miles away, and Market Rio Road is 0.71 miles away.
The population density was also measured from each grid point using the census block-level population. For each block group, the population density was calculated. Then each block was converted to a raster and each cell within a given block was assigned the population density value for the entire block. The blocks were smoothed together by using an averaging function for the nearest neighbors to each raster cell. Finally, the population density value was then weighted and added to the calculation for specific destinations above to develop the map displayed in Figure 4.4. The residential accessibility scores ranged from 0-32 out of a maximum of 40.
For each of the accessibility maps displayed here, the areas of highest accessibility are the darkest and the color becomes lighter as accessibility decreases. The colors indicate relative accessibility to the other locations on this map, not accessibility relative to the maximum possible score. These maps were generated to best differentiate between locations on this map, not to serve as an index for comparing to other regions.

Figure 4.4  A map showing the areas within pedestrian range of destinations.

4.1.3 Destination accessibility

From each destination point, ¼-mile buffers were generated to determine if additional destinations could be found within walking range from the original destination. Similar to the methodology used above for residential accessibility, the presence of and
distance to each additional destination, excluding a second instance of the original destination, was recorded and allocated to the original destination. The raster calculator was then used to weight the value of each additional destination and aggregate them. Population density was again recorded and added to this score. Finally, this score was allocated to each grid point within the 1-mile range of the original destination. This was repeated for every destination point. An example of this analysis was conducted in Figure 4.5. The destination accessibility scores ranged from 0-17 out of 35 maximum.

Figure 4.5  A map showing the areas within pedestrian range of a mixture of destinations.

At this point, the residential and destination accessibility have been calculated in ignorance of the infrastructure design. The map shown in Figure 4.6 shows the aggregate
of these two analyses. The darkest areas on this map indicate the areas with the highest potential for walking trips. The scores for residential plus destination accessibility ranged from 0-49 out of a maximum of 75. The following section will reanalyze the entire area based on the quality of the existing infrastructure.

![Pedestrian accessibility map showing the areas of highest potential for walking trips.](image)

**Figure 4.6** A pedestrian accessibility map showing the areas of highest potential for walking trips.

### 4.1.4 Design

This analysis used the connectivity of the road network and the presence of sidewalks to determine the path required to reach each destination. In its simplest form, the design analysis measures the network path from each grid point to destination (for residential accessibility) and from destination to destination (for destination to
accessibility) whereas the earlier analyses conducted only an “as the crow flies” type of analysis. Travel on a sidewalk results in a distance bonus while travel without a sidewalk results in a distance penalty. The residential and destination accessibility methodology above was repeated here except for the use of a 1-mile range on the road network as opposed to a 1-mile straight-line buffer around each point. This difference is demonstrated in Figure 4.7 below.

Where with the 1-mile buffer analysis there were 10 specific destinations found within the pedestrian range, the lack of network connectivity results in only 3 specific
destinations of one type found through the network analysis. Vinegar Hill Grill, Coletti’s Hair Salon, and Greenbrier Elementary School are all further than one mile away by following the available paths. Only Market Rio Road remains inside the reasonable pedestrian range, at a distance of 0.89 miles on the network. The map of accessibility that takes into account the existing infrastructure is shown in Figure 4.8. The design scores ranged from 0-16 out of a 25 point maximum. Note that this analysis can only be conducted along the road network due to the capabilities of Spatial Analyst in ArcMap. Therefore, the display shows only accessibility in a 50-foot buffer alongside the roads. Because of this limitation, pedestrian or bicycle trails that were not within the 50-foot buffer were not included in the analysis. This was only a minor issue because there are very few trails of this type in the study area and they are generally used for recreation only. It may be possible to include non-adjacent trails in the analysis using Network Analyst but this ArcMap extension was not readily available and was not pursued as it would add very little to this particular case study.
Figure 4.8 A pedestrian accessibility map showing the areas with the best infrastructure to destinations.

4.1.5 Results

Finally, the residential accessibility, destination accessibility, and design can all be aggregated to reveal the final accessibility map. Figure 4.9 shows the final results of the PCAM analysis. The scores range from 0-64 out of a maximum of 100 points.
The map indicates two major areas of accessibility: downtown Charlottesville and the Route 29 corridor. These are the locations in this region with the highest concentration of destinations, as indicated earlier in Figure 4.2. Accessibility gradually decreases with increasing distance from the downtown and decreases more rapidly with movement away from the Route 29 corridor. To look more in depth at what is occurring on this map, four locations within the region will be focused on. In Figure 4.10 a green star and a red number indicate these four locations.
Point 1 is located on Commonwealth Circle, a location just off of Route 29 but without direct access to Route 29. Point 2 is on Charter Oaks Drive which has access to Rio Road, connecting Route 29 and the downtown. Point 3 is on Shamrock Road just off of Jefferson Park Avenue, one of two major off-campus student housing locations. Point 4 is located on Market Street just north of the Downtown Mall, the hub of downtown activity in Charlottesville. Table 4.1 gives a breakdown of the PCAM scores for each of these four locations.
Table 4.0.1  A comparison of PCAM scores for the four test locations.

<table>
<thead>
<tr>
<th>Point</th>
<th>Location</th>
<th>Residential Accessibility</th>
<th>Destination Accessibility</th>
<th>Design</th>
<th>Total</th>
<th>Design percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Commonwealth Drive</td>
<td>24</td>
<td>10</td>
<td>10</td>
<td>43</td>
<td>58%</td>
</tr>
<tr>
<td>2</td>
<td>Charter Oaks Drive</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>10%</td>
</tr>
<tr>
<td>3</td>
<td>Shamrock Road</td>
<td>16</td>
<td>3</td>
<td>10</td>
<td>29</td>
<td>98%</td>
</tr>
<tr>
<td>4</td>
<td>Market Street</td>
<td>31</td>
<td>13</td>
<td>16</td>
<td>60</td>
<td>71%</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>40</td>
<td>35</td>
<td>25</td>
<td>100</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 4.1 displays the number of points awarded for residential accessibility, destination accessibility, design, and the total. Design percentage demonstrates the difference between the “as the crow flies” and network analyses based on an equal weighting for each. A high percentage indicates that the destinations within pedestrian range are easily accessed by the current infrastructure, while a low percentage indicates either poor network connections or a lack of sidewalks.

Point 1 is located in close proximity to many diverse destinations on the Route 29 corridor. The somewhat circuitous route required to reach 29 and the lack of sidewalks brings down the design value somewhat. Point 2 scored poorly in every category. Few destinations are accessible from this location and are mainly or a single type. The circuitous route and lack of sidewalks place all of these potential destinations outside of the reasonable pedestrian range. Point 3 scored well for residential accessibility but because the destinations were only of a few types in this area, the destination accessibility score was low. Point 3 had the highest design percentage because the destinations are all accessible by sidewalk through an almost directly straight connection. Point 4 scored the highest in every accessibility category due to its downtown location. Many diverse destinations are located in close proximity to point 4 with well-designed connections.
4.2 Examples of use

In Section 1.2, two potential uses were identified for applying the PCAM. In this section, examples will be shown from the Charlottesville/Albemarle case study on how the results can be used to apply to each of these potential uses.

4.2.1 Identify areas to focus limited funding for pedestrian and cycling infrastructure.

In the first two portions of the analysis, residential and destination accessibility, the goal is to rate areas on the proximity and mix of services, population, and employment within walking and biking range. The combination of these two measures results in the potential of an area to support walking and cycling in an “as the crow flies” type of analysis. The third portion of the analysis, design, actually looks at the paths from origin to each possible destination, thereby rating the area on the infrastructure of the walking and cycling environment.

Subtracting the score of the design-based analysis from the “as the crow flies” analysis, a simple function within ArcGIS, results in the difference between the potential and actual ratings of each area. Determining areas that have the largest relative differences between potential and actual ratings are the ones that could most benefit from improvements to the pedestrian and cycling infrastructure. Looking back at each component of the design score can reveal whether the problem is a lack of connected streets, a lack of sidewalks, the presence of a difficult street crossing, etc. The map shown in Figure 4.11 demonstrates this type of analysis for the Charlottesville/Albemarle region.
Just glancing at this map can be deceptive. It appears that downtown Charlottesville shows a major discrepancy between potential accessibility and actual accessibility. The problem is that these results are significantly skewed by the presence of destinations. Even though the downtown is already fairly well designed, the presence of so many possible destinations in the area means that significant improvements can still be made to reach those destinations. But in reality, this would require direct paths cutting across city blocks in may cases, which will not practically be made.

Of more significance are areas such as the one shown in Figure 4.12. There are several streets (primarily Westview Road, Field Road, and Fendall Terrace) approaching
Route 29 from the southeast that do not connect to Route 29. A major regional retail center, the Barracks Road Shopping Center, is located on the far side of Route 29 from these streets. The path required to reach the Barracks Road Shopping Center from these streets place it outside of the acceptable pedestrian range for residents of these streets. A pedestrian connection between these streets to Route 29 would significantly increase the accessibility of the location.

Figure 4.12 An example of a location with high potential accessibility but low actual accessibility.
4.2.2 *Identify areas that provide an array of transportation choices.*

This is the most straightforward of these selected examples. A quick solution to this issue is simply by scanning the accessibility map for walking and for cycling and locate areas with the highest PCAM ratings. Referring back to the use of this application as a marketing tool for real estate will take this analysis one step further to a more practical application.

Assume a couple is relocating to the Charlottesville-Albemarle region and has narrowed down their housing possibilities to four locations based on their price range, what is available, and other personal factors. With all else being equal, the couple would like to live in the location that is the easiest to walk to services, as they do not own a vehicle. The four test locations used in section 4.1.5 will again be used in this example. The realtor informs the couple that the Market Street location just outside of the downtown mall has the highest accessibility with its easy connections to many downtown destinations. The Commonwealth Circle and Jefferson Park Avenue locations have decent accessibility while the Charter Oaks Drive location has very little accessibility. Based on this new information, the couple selects the Market Street location and doesn’t have to worry about their lack of an automobile.

The PCAM can also be used for a related application calculating the value for a Location Efficient Mortgage. Currently the Location Efficient Mortgage calculation uses population density and access to transit as the two major criteria. Higher densities do often represent areas that are walkable and bikeable. But the use of only these two criteria would neglect areas of lower densities that do have a variety of destinations located nearby with adequate infrastructure connections. Adding public transit measures
to the PCAM would result in a measure well suited for calculating a Location Efficient Mortgage.
CHAPTER 5. Implementation

This section will address what needs to be done in order to move the PCAM from its present state to a real-world application. For this example, the Thomas Jefferson Planning District Commission (TJPDC) will be used as the agency looking to implement the PCAM. The TJPDC is a regional planning agency that attempts to link transportation, land use, the economy, and the environment. The TJPDC serves the City of Charlottesville, the County of Albemarle, and additional counties that were not included in the Chapter 4 case study.

The Jefferson Area Bicycling and Walking Advisory Committee (JABAWAC) would be the end user of the PCAM for identifying pedestrian and cycling needs in the area. According to the TJPDC website:

JABAWAC works to identify obstacles to safe pedestrian travel and remove them. This may include physical barriers, such as lack of facilities, unsafe road crossings, poor lighting, or lack of curb cuts, or may be policy issues, such as funding for new or improved facilities. The committee researches funding opportunities to help build the necessary infrastructure, and reviews local and state codes and policies to identify areas which could be improved to better facilitate creation of a safe pedestrian environment in our region…. JABAWAC reports to the MPO and Rural Transportation Committees and assists them in creating comprehensive multi-modal transportation plans.

The PCAM is ideal for the JABAWAC’s goal of identifying hindrances to pedestrian and cycling travel in the area. The PCAM automates the identification process and can prioritize possible improvements according to the improvements that will have the
greatest possible impact on walking and cycling travel. There are several ways that the PCAM must first be improved before the JABAWAC could use it. These will be discussed below.

5.1 Validation

Validation of the scoring system and weighting values was beyond the scope of this thesis but is a necessary step prior to implementation of the PCAM. Each portion of the PCAM was in some way based on previous published work and the references to the primary sources for the scoring and weighting values are listed in Table 5.1 below.

<table>
<thead>
<tr>
<th>PCAM component</th>
<th>Source</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component weightings</td>
<td>Index 4D Method</td>
<td>10</td>
</tr>
<tr>
<td>Pedestrian/bike range</td>
<td>2001 National Household Transportation Survey</td>
<td>14</td>
</tr>
<tr>
<td>Destination accessibility range</td>
<td>Travel Demand and the 3Ds</td>
<td>5</td>
</tr>
<tr>
<td>Desirability values</td>
<td>Beyond the Neighborhood Unit</td>
<td>17</td>
</tr>
<tr>
<td>Pedestrian design</td>
<td>Pedestrian Level of Service</td>
<td>22</td>
</tr>
<tr>
<td>Bike design</td>
<td>Toward a Bicycle Level of Service</td>
<td>19</td>
</tr>
</tbody>
</table>

It would be quite difficult to quantitatively assess the potential of an area to accommodate walking and cycling travel, as is measured in the residential and destination accessibility components of the PCAM. A subjective analysis would be necessary in order to determine potential accessibility and could also be used to determine actual accessibility. Surveys could be conducted to ask residents of various areas how they feel about the ability to walk and cycle in different neighborhoods in their area, as was used by Krizek in the Central Puget Sound. This could address current destinations that they are able to walk or bike to as well as discussing the conditions that impede them from currently making other possible trips.
The survey would be used to evaluate the importance of each component of the PCAM as listed in Table 5.1 above. These questions should be designed such that they collect information concerning what conditions are necessary for people to make walking or cycling trips so that the potential accessibility can be determined. For example, in order to validate the component weighting, the following question might be asked:

On a scale from 1 to 10 (with 10 being the highest), rate the following conditions on their importance towards your ability to make a walking trip-

1. A destination is located within a reasonable distance from your home. \((\text{residential accessibility})\)
2. You can easily reach several destinations in a single trip. \((\text{destination accessibility})\)
3. The path to your destination is direct and safe (due to the presence of sidewalks, light traffic, etc.). \((\text{design})\)

Or for the desirability values:

On a scale from 1 to 10 (with 10 being the highest), rate the following destinations according to how much you would like for a particular destination to be located within walking range of your home-

1. Drugstore
2. Grocery store
3. Library
\((\text{Etc...including additional destinations beyond those that were listed in Table 3.1})\)

This survey should be distributed to at least two hundred (but preferably more) randomly selected households throughout the Charlottesville/Albemarle area in order to get a representation of walking and cycling needs for the area.

There should also be a separate survey that gets more directly at the actual accessibility of an area. This could be in the form of a travel diary that records the details of walking and cycling trips taken by a household for one week. For each trip, the respondent would need to record trip length, destination or destinations, and some notes on portions of the trip that were positive (e.g. continuous sidewalks) or negative (e.g. crossing a busy street). This survey should be distributed to at least one hundred
households in at least four different locations (with a variety of conditions) around Charlottesville/Albemarle. As weather is not a factor in the PCAM, both surveys should be distributed during the spring or fall when respondents will be influenced the least by current conditions while filling out the survey.

After receiving the completed surveys, the responses would need to be compiled into a format that will be easy to analyze such as in Microsoft Excel. Assume that 60 of the potential accessibility surveys were returned. For the example of the component weighting, the average response was:

1. 7.6 (residential accessibility)
2. 3.4 (destination accessibility)
3. 8.1 (design)

To convert these numbers to an aggregate scale of 100% (as is used in the PCAM), simply divide the response for an individual component by the sum of the responses for all three components and multiply by 100. For residential accessibility:

\[
\frac{7.6}{7.6 + 3.4 + 8.1} \times 100 = 39.8 \%
\]

The revised weightings for each component should be as follows:

1. 40% (residential accessibility)
2. 18% (destination accessibility)
3. 42% (design)

The weighting for residential accessibility was already correct, but the destination accessibility weighting was overestimated by 17% while the design weighting was underestimated by 17%. Each question can be analyzed similarly in order to modify the scoring of the PCAM to best fit the characteristics of this specific area.
The impact of such an adjustment in the scoring would result in a substantial change in the PCAM results. Table 5.2 below shows the total PCAM scores from the four test locations used earlier as well as the updated scores reflected the new component weighting.

<table>
<thead>
<tr>
<th>Point</th>
<th>Location</th>
<th>Original Total</th>
<th>Revised Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Commonwealth Drive</td>
<td>43</td>
<td>46</td>
</tr>
<tr>
<td>2</td>
<td>Charter Oaks Drive</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Shamrock Road</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>4</td>
<td>Market Street</td>
<td>60</td>
<td>65</td>
</tr>
</tbody>
</table>

The creation of a survey, distribution of surveys, compilation of data, and analysis of results would take at least 100 hours of work but would be highly dependent on the method used to distribute, conduct, and collect the survey.

5.2 Additional data

Many additional items could be added to the design analysis to make the PCAM more useful for the JABAWAC. Topography, traffic, lane widths, barriers to travel, bike parking, pavement quality, sidewalk quality, lighting, and transit stops are among factors that could be considered. Traffic and road data does exist but it will take significant work to convert them to a format compatible with the PCAM analysis. There are also some additional pedestrian and cycling pathways that are not aligned with the roadways so they were not included in the case study. Although these are typically only used for recreational travel, they should be included for a more thorough analysis of the area. The addition of employment data, if it could be reasonably acquired, would also allow for the calculation of employment density. Table 5.3 below summarizes the possible additions
to the PCAM with an evaluation of how difficult the data would be to acquire and the impact the additional data would have on the results.

<table>
<thead>
<tr>
<th>Additional item</th>
<th>Difficulty</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>topography</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>traffic volume/speed</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>barriers to travel</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>bike parking</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>pavement quality</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>sidewalk quality</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>lighting</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>transit stops</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>employment</td>
<td>high</td>
<td>high</td>
</tr>
</tbody>
</table>

The addition of transit stops as a destination would be rather simple with a moderate impact, as the GIS data already exists and access to transit increases the range of travel for those without an automobile. The top four items and employment all result in an impact roughly equivalent to the difficulty of acquiring the data. The addition of traffic volume and speed would add much to the analysis but would take considerable work to convert the existing data to be compatible with the rest of the PCAM data. It would be possible to add traffic data only on some of the major roads such as Route 29, Preston Avenue, Jefferson Park Avenue, etc. that are known to be difficult to cross. Increasing the detail on infrastructure quality and lighting would be of a low priority because data collection would be very difficult and subjective without adding much to a general analysis, although sidewalk quality is incredibly important for some segments of the population such as the handicapped (see customization in Section 5.5). The amount of work needed to add data elements would be dependent on the number of data elements added, ranging from just a few hours for a low difficulty item (transit stops) to over 40 hours for a high difficulty item (traffic data). Some elements, such as employment, may
be immediately available but must be purchased. Note that any additional data collection also would require some rewriting of the GIS application to incorporate the new data.

5.3 Addition of transit measures

Adding ways to measure the accessibility of public transportation or other non-vehicle modes could certainly enhance the usefulness of the PCAM, even though it may be somewhat outside the scope of the JABAWAC. As the PCAM is intended for determining accessibility at a local, or neighborhood, level, the addition of any modes that are primarily useful at the neighborhood level would be beneficial. Including transit measures would require a substantial amount of additional work. This would involve researching and creating a scoring system for the factors that influence the use of transit, the collection and addition of transit data (stop locations, routes, frequency, cost, etc.) into the GIS application, programming the transit analysis into the GIS application, and validation of the transit measures. The addition of transit measures would likely require at least 120 hours of work.

5.4 Automation

To conduct the analysis in this project, a large amount of manual work was necessary. Once all of the necessary data was input into the GIS application, each component of the analysis was carried out in separate steps before aggregating over the region to determine final scores. This sequence of steps could be refined and programmed in a way that would allow anybody at the TJPDC to conduct the analysis in
one step following the necessary data input. Automating the PCAM analysis might take 40 hours of work for somebody comfortable with scripting in GIS.

5.5 Customization

The PCAM as developed here was designed in a way to meet the needs of the general population. This limits its usefulness for specific individuals with needs different than the ones proposed here. For example, the range of travel may depend on age or physical ability while the need for specific destinations certainly varies from person to person. A way to customize the analysis for a person’s particular needs would significantly increase the usefulness of this application. The JABAWAC could conduct different analyses for the needs of children, the elderly, the handicapped, or others. Adding this to the GIS application may take 40 hours of work for someone experienced in programming an interactive GIS interface.

5.6 Use of the PCAM

After validation and the addition of data or functionality to the PCAM, the JABAWAC can now apply the PCAM to the TJPDC region. The estimates for additional time needed to complete each step have been summarized below:

- Validation – 100 hours
- Additional data – varies from a few hours to 100+ hours
- Addition of transit measures – 120 hours
- Automation – 40 hours
- Customization – 40 hours
Following the example in Section 4.2.1, the infrastructure design map can now be subtracted from the potential accessibility map in order to reveal the areas with the greatest differences (and therefore the areas that would benefit the most from infrastructure improvements). A list of the top twenty improvements could be made and investigated more in depth for feasibility and cost. Finally, recommendations can be made by the JABAWAC to the metropolitan planning organization on the projects that should receive funding.
CHAPTER 6. Conclusions, Recommendations, and Further Research

6.1 Conclusions

The PCAM was created from a synthesis of literature on the relationship between the built environment and transportation and from making improvements on current accessibility measures. Although the scoring system and factors were not validated almost every part of the measure and the weighting values were based on published research. The resulting equations and aggregation logically appear to be a decent measure of accessibility.

The PCAM was ideal for its use in a GIS application. As every aspect of the accessibility could be measured spatially, the only significant issue was locating the data in a useful form. With the proper data, coding the methodology developed in this thesis into ArcGIS was fairly straightforward. The results from the case study seem to be reasonable based on the author’s knowledge of the region. The analysis methodology was not created specifically for the Charlottesville/Albemarle region. The GIS analysis can be reproduced in any location where the necessary data are available.

The example maps and the use of the data in the examples revealed several potential applications for this accessibility measure. The regional maps provided an adequate analysis of the entire region. For individual locations, the maps were less useful as they showed little detail. With all of the underlying data available, it is possible to see exactly how each score was computed and what aspects of the built environment are needed to improve accessibility. It would be beneficial to make this information more readily available to the casual user.
Several problems limit the accuracy of the analysis. As mentioned earlier, the point destination data were geocoded based on the businesses address and are therefore not necessarily located exactly where it should be. For the design analysis, all destinations needed to be located within a 50-foot buffer of the road to be included. This created additional inaccuracy for the point data as some points had to be relocated to fit inside of this buffer. The presence of additional road data, such as driveways and parking lots, would alleviate this problem.

The sidewalk data were taken from planimetrics were not complete. As a sidewalk passed a driveway or parking lot entrance, the sidewalk would appear to end and then begin again further down the road, even though the sidewalk may be continuous for an entire block in reality. Various other problems with the planimetric data also resulted in some missing segments of the sidewalk.

The population and employment data also presented problems. The population data was only available at the block level that was not as fine-grained as would be desired. Because no employment data was available at a reasonable level of detail, employment density could not be calculated.

The presence of a scoring system allows for easy comparison between locations within a region or between several different regions. The quantitative results are ideal for the decision-making process, as subjective analysis at times cannot be used to make substantive arguments. As demonstrated in the examples in Section 4.2, the nature of the results makes them useful for prioritization of transportation improvements, real estate decisions, or other applications.
6.2 Recommendations

If the pre-implementation tasks are followed, the GIS-based PCAM can be a useful tool for a variety of applications. It is recommended that all of the pre-implementation tasks are carried out by a third-party in order to minimize the additional work that an end-user would need to do to make the PCAM useful. A more general validation procedure could be accomplished to verify the weighting and scoring systems. End-users would then have the option to use the general validated results or to develop more specific results for their area of interest. The GIS-application should be made much more user friendly through automation of the PCAM analyses and the creation of a front-end interface that would require minimal GIS knowledge to use. At this point, it end-users would only need to add minor customizations to make use of the PCAM.

6.3 Further research

Completing the pre-implementation tasks (Chapter 5) should be the first priority for further research on the PCAM. This would lead to an application with a more accurate scoring system and more robust capabilities.

There are several other areas of further research that would help to improve the PCAM. One of these areas is with the mapping and data presentation. The current maps and presentation are sufficient but could certainly be enhanced. Improvements to the map results will provide more clarity to the end user. Providing additional data in an easy-to-access manner will also increase the usefulness.

Another possibility is to integrate the PCAM with traditional transportation planning analyses such as regional travel modeling. Regional travel models typically
lack the capability to adequately model walking and bicycling demand. The PCAM could provide data to the travel model on the walking and cycling demands throughout the region which in turn would influence the modeling of vehicular travel.
Appendix A: Illustration of the PCAM

The PCAM is an aggregation of three parts: residential accessibility, destination accessibility, and design. The following graphics illustrate the calculation of the PCAM.

Residential Accessibility – From the home, uses the proximity of eleven specific destination and two density measures to determine how accessible the residential end of a trip is for walking and cycling.

![Diagram of Residential Accessibility](image)

- School
- Grocery store
- Drugstore
- Post office
- Park
- Library
- Small food store
- Dry cleaner
- Beauty/barber shop
- Bank
- Home

Proximity
**Destination Accessibility** – From each of the eleven specific destinations, uses the proximity of the other ten specific destination and two density measures to determine how accessible the destination end of a trip is for walking and cycling. The below example is for a grocery store.
Design – For each origin to destination pair (from the home to destination or destination to destination), the path, presence of infrastructure, and volume of traffic are assessed to determine how easy it is to reach the destinations.
Appendix B: Details of the design measure

Three parts to the design analysis:

1. Network
2. Infrastructure
3. Traffic

Each square is 50 feet by 50 feet. The range for the analysis is 1 mile for walking (106 points under ideal conditions) and 3 miles for biking (318 points under ideal conditions). For each destination within the range, the distance is recorded in points. This is then converted back to the equivalent distance in miles before being used in the residential and destination accessibility equations.

Network

• Every square on the network = 1 point

Infrastructure

Pedestrian

• Every square w/ sidewalk = 0 points
• Every square w/o sidewalk = 1 point

Cycling

• Each square w/ bike lane = 0 points
• Each square w/o bike lane = 1 point

Traffic

Pedestrian

• Each square along major road with:
  o PRES_VPD / NUM LANES ≥ 360 = 1 point
  o 360 > PRES_VPD / NUM LANES ≥ 90 = .5 points
  o 90 > PRES_VPD / NUM LANES = 0 points

• One square crossing major road with:
  o PRES_VPD / NUM LANES ≥ 720 = 2640 points
  o 720 > PRES_VPD / NUM LANES ≥ 360 = 1320 points
  o 360 > PRES_VPD / NUM LANES ≥ 180 = 660 points
  o 180 > PRES_VPD / NUM LANES ≥ 90 = 330 points
  o 90 > PRES_VPD / NUM LANES = 0 points
  o NUM_LANES ≥ 6 = 5280 points

Cycling

• Each square along major road with:
  o PRES_VPD / NUM LANES ≥ 360 = 2 points
  o 360 > PRES_VPD / NUM LANES ≥ 90 = 1 points
  o 90 > PRES_VPD / NUM LANES = 0 points

• One square crossing major road with:
  o PRES_VPD / NUM LANES ≥ 720 = 2640 points
  o 720 > PRES_VPD / NUM LANES ≥ 360 = 1320 points
  o 360 > PRES_VPD / NUM LANES ≥ 180 = 660 points
  o 180 > PRES_VPD / NUM LANES ≥ 90 = 330 points
  o 90 > PRES_VPD / NUM LANES = 0 points
  o NUM_LANES ≥ 6 = 5280 points
Appendix C: SIC codes used in the PCAM

Table C.0.1 SIC codes used for each destination in Table 3.1.

<table>
<thead>
<tr>
<th>Destination</th>
<th>SIC codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drugstore</td>
<td>5912</td>
</tr>
<tr>
<td>Grocery store</td>
<td>541105</td>
</tr>
<tr>
<td>Library</td>
<td>8231</td>
</tr>
<tr>
<td>Post office</td>
<td>4311</td>
</tr>
<tr>
<td>Small food store</td>
<td>541101</td>
</tr>
<tr>
<td></td>
<td>541103</td>
</tr>
<tr>
<td></td>
<td>5421</td>
</tr>
<tr>
<td></td>
<td>5431</td>
</tr>
<tr>
<td></td>
<td>5461</td>
</tr>
<tr>
<td>Park</td>
<td>n/a</td>
</tr>
<tr>
<td>Bank</td>
<td>60</td>
</tr>
<tr>
<td>Dry cleaner</td>
<td>721201</td>
</tr>
<tr>
<td>Beauty/barber shop</td>
<td>7231</td>
</tr>
<tr>
<td></td>
<td>7241</td>
</tr>
<tr>
<td>School</td>
<td>8211</td>
</tr>
<tr>
<td>Friend's place</td>
<td>n/a</td>
</tr>
<tr>
<td>Restaurant</td>
<td>8512</td>
</tr>
<tr>
<td>Place of work</td>
<td>n/a</td>
</tr>
<tr>
<td>Jobs-housing balance</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Appendix D: Cycling accessibility maps

The results from the bike analysis are fairly similar to the pedestrian analysis but with a larger accessible area to account for the larger range of cyclists.

Figure D.1 A map showing the areas within cycling range of destinations.

Figure D.2 A map showing the areas within cycling range of a mixture of destinations.
Figure D.3 A cycling accessibility map showing the areas of highest potential for walking trips.

Figure D.4 A cycling accessibility map showing the areas with the best infrastructure to destinations.
Figure D.5  The final cycling accessibility map showing the aggregation of residential accessibility, destination accessibility, and design.
References


