CLASSIFYING URBAN FEATURES AND LANDSCAPES TO IMPROVE SPATIAL KNOWLEDGE FOR VISUALLY IMPAIRED PEDESTRIAN TRAVELERS

by

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(Under the Direction of Xiaobai Yao)

ABSTRACT

For low vision travelers, independent mobility is almost essential to access basic services in urban environments. In the context of this study, independent mobility may be defined by its three basic components: the physical ability of the traveler, cognitive knowledge, and environmental conditions of the travel landscape. Each of these components is associated with specific potential problems that relate to, or can be represented by, geographic features. This research utilizes spatial data analysis and modeling techniques to rate urban environments in regards to individuals with visual impairments. A case study is conducted to illustrate the modeling procedures.

INDEX WORDS: Visually Impaired, Urban Landscapes, Glare, Orientation & Mobility, Travel Problems, Cognitive Knowledge, Remote Sensing, Route Knowledge, GIS

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1. INTRODUCTION

Current population trends indicate that United States urban regions are rapidly aging. In US urban centers about one out of eight individuals were over fifty-five years of age during the 1990's. That population is expected to increase to one out of six individuals by 2010 (Woodruff-Pak 1997, Pope and Tarlov 1991, Crews and Clark 1997). For people over fifty-five, age related vision illnesses such as macular degeneration, cataracts, and diabetic retinopathy (Eperjesi, Fowler and Evans 2002) gradually reduce vision acuity and field of view. When vision problems are experienced during the course of reading, writing, and general navigation, significant changes in an individual's "life-space" may occur (May, Nayak and Isaacs 1985). For example, difficulty reading the morning paper may also be indicative of trouble viewing traffic signs or reading specific bus routes posted. Bumping into furniture may transfer to tripping over guy wires or running into low branches. The ease and comfort of navigating in one's home is not nearly as challenging as walking to the local grocery store, bakery or deli. Other essential facilities such as churches, schools or medical facilities are typically in more complex commercial or industrial regions. Unfortunately, a substantial portion of US urban populations struggle in their attempt to access basic social services, and are more likely to require assistance from the public healthcare system, municipal transit systems, and community outreach services.

Overseas, the picture for urban centers is somewhat different. European countries have pedestrian networks in their urban communities which are designed to enable residents to achieve their basic needs without ever owning a personal vehicle. In addition to well designed public transportation systems, small towns are commonly linked via pedestrian and bicycle trails (Figure 1). Residents are frequently able to travel for miles along pathways without having to cross major vehicular traffic arteries due to an abundance of pedestrian overpasses. The basic configuration of Europe's cities is much different from American counterparts. For example, most residential neighborhoods are interspersed with local retail shops which provide goods and services to residents. Urban transit systems are widespread, efficient and inexpensive to ride. With such infrastructure in place, it is no wonder why so many European families are able to 'get by' with fewer automobiles and a weakened dependence upon motor vehicles for independent mobility.

Figure 1- German Bicycle Path between Villages
(http://www.hausmargarete-erden.de/Images/Loesnich.jpg)

Conversely, pedestrian travel in United States urban regions is not for the faint of heart. American sidewalks and access trails are designed to convey pedestrians only within isolated zones or regions (e.g. commercial, retail or residential) and were not built for navigation between zones. Residential districts frequently lack crosswalks, and in some cases sidewalks.

Commercial zones may have traffic islands or medians without clear markings. Industrial zones frequently have wider roads and higher speed limits to accommodate heavy vehicles. Pedestrian travel paths can be cluttered with hydrants, post boxes, access slopes, retail encroachments, and landscape trees (Figure 2). Many urban centers are undergoing constant reconstruction, and as a result, sidewalks are frequently closed for safety purposes. Crosswalk regulations are rarely enforced, and metropolitan transportation systems are typically overwhelmed due to urban sprawl, traffic congestion, and strained municipal budgets. Fortunately, with the assistance of government programs such as the Americans with Disabilities Act, many cities are eligible for federal grants to improve accessibility for the low vision community.

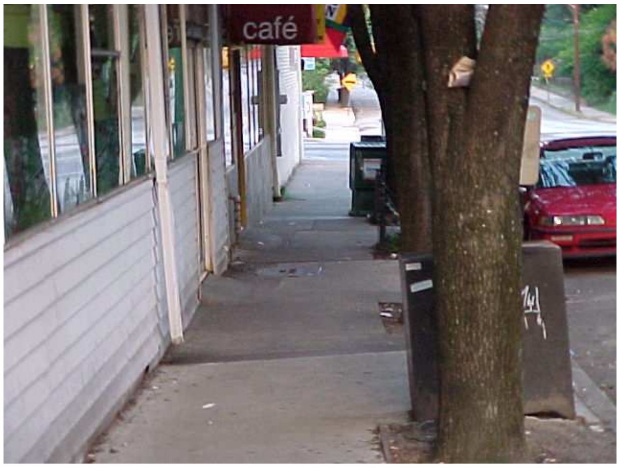

Figure 2 Sidewalk/Travel Paths On 10th Street Near Piedmont Park, Atlanta, Georgia.

Problem

Due to the complex relationship between pedestrians and urban travel environment, there are significant challenges in identifying factors that are indicative of hazards in the travel landscape. Up to 90% of our travel information comes from visual cues (Geruschat and Smith 1997). A large portion of one's travel landscape is cluttered with natural and man made structures which are designed to attract our attention. While these distractions are not as significant for persons with average vision, the sheer amount of data plays a considerable role in the ability of a visually impaired pedestrian to filter unnecessary information and make sound travel decisions in the dynamic urban landscape.

Independent mobility (as it pertains to a visually impaired person) is the ability to detect and avoid hazards, and successfully navigating to a destination (Bentzen 1997). It is dependent upon an accurate assessment of landscape features, and some level of knowledge about the travel environment. The objective of the low vision Orientation and Mobility (O&M) specialist is to empower the low vision traveler by providing tools or methods to improve those assessment, detection, and navigation skills (Guth and Rieser 1997). In an effort to best assess remote landscapes, O&M specialists frequently rely upon route map applications, ground observations, and available photography. Unfortunately, in most cases, street map data are generalized and not likely to provide information about sidewalk availability or other features that apply specifically towards pedestrians or visually impaired pedestrians. Street level photography may be a viable alternative, but in general it is limited in its ability to project the 'big picture' of the travel landscape. Furthermore, the availability of high resolution aerial photography cannot be guaranteed, while many urban regions are being flown for data collection, the process is still time consuming and cost prohibitive in many locations. Therefore, an alternative solution must be investigated to provide knowledge about remote environments for low vision travel problems. The solution must be able to assess, detect and navigate the traveler using information that is available in most urban regions.

Current accessibility maps for the visually impaired are, in general, insufficient for the needs of the low vision traveler. It is difficult to compress the wide range of surfaces, objects and details that occur in nature into a static map. As a result, most low vision maps describe only specific terrain features. For example, one type of accessibility map may focus upon curb cuts and terrain slope (Brouwer et al. 1984), whereas others maps may focus upon the orientation and layout of road features as they pertain to cognitive abilities of travelers (Golledge et al. 1993). Even current accessibility maps that are managed within Geographic Information Systems (GIS) applications have limitations due to data resolution, portability, and changing conditions (Sobek and Miller 2006). Because of the complex dynamic that occurs during pedestrian travel in urban landscapes, another approach is necessary to inform O&M trainers about route knowledge in urban landscapes.

Research Objective

Based upon quality of life studies, there is a strong correlation between the spatial distribution of vision related travel problems and probability of independent mobility (Stalvey et al. 1999). As a result, O&M instructors attempt to guide their clients through regions that have less risk and higher suitability for independent mobility. Independent mobility is based upon three factors: the physical abilities of the traveler (vision clarity, field), cognitive knowledge about travel routes (route knowledge, confidence) and environmental conditions through which the individual travels (road crossings, travel paths). Likewise, any model produced to evaluate travel landscapes would need to take those factors into consideration. To date, both physical abilities of low vision travelers and cognitive knowledge have extensive research histories; however the study of environmental conditions as they apply to low vision travelers is somewhat limited. To address these limitations, three objectives were achieved:

- Identify problems specific to environmental features or objects that decrease the probability of independent mobility for low vision travelers.

- Identify Geographic features that are spatially related to the environmental problems.
- Utilize Geographic features to provide suitability map of a potential travel regions.

A discussion of cognitive knowledge (specific to individuals with visual impairments) and physical abilities (acuity, field) as they relate to independent mobility will be utilized to identify common travel problems. This dialogue will include a review of current O&M technologies and research into cartographic products. Finally, a review of previous studies into travel problems will be examined to select problems that can best be associated with common environmental features. Environmental features will be identified and assigned risk factors based upon independent mobility surveys and problem questionnaires. The outcome product will be a summary of the risk factors of the environmental features, providing a graphic that identifies regions or routes that present less risk potential (or greater suitability) for low vision travelers.

2. LITERATURE REVIEW

Current research into the cartographic process (MacEachren 1991) suggests that vision and cognitive understanding are the primary tools designed to represent and transfer data for pedestrian travel. The emphasis upon visual understanding and fundamental cognitive principals of cartography represent some sort of informational understanding of an environment by the designer. One may posit that all landscapes require a given amount of information in order to assess, understand, and then safely traverse. The ability to travel is therefore a function of the individual's aptitude in collecting and in processing travel information both through learned and reflexive responses. For example, a manicured forest path may be easy to navigate in full daylight but could be hazardous under nighttime conditions. This situation is commonly experienced by individuals with severe vision impairments. In many cases low vision travelers navigate in the same physical environment as individuals without impairments (Golledge 1993b).

Golledge suggests that there is an inherent transformation of space that occurs due to visual impairments. Hazards which may seem harmless for individuals with a full field of view can be an unpleasant surprise for someone with limited vision fields. A number of cultural and physical barriers are imposed by social norms can impair freedom of mobility and in general, reduce the overall quality of life for the visually impaired traveler. For example, curb cuts reduce the vertical expression between the sidewalk and road surface to enable wheelchair access across roadways. Unfortunately, curb cuts also make detection more difficult for the cane based traveler to detect the sidewalk edge, increasing the possibility of the visually impaired traveler inadvertently to wander into traffic.

In order to utilize cartographic tools to define disabled space, O&M researchers must be cognizant of the travel landscape as well as the impairments that are being taken into consideration. The concept of spatial awareness should not be confused with vision, but should be considered as a form of perception which empowers the traveler. It is important to note that an individual's vision acuity (or clarity) and field of vision limitations must be understood to accurately transfer navigational information about unfamiliar landscapes. Spatial awareness has a number of key components (i.e. vision, mobility, cognitive understanding) which make it possible to interact with environmental features in a nearly effortless manner (Tuan 1974). To use Tuan's example, spatial awareness is similar to riding a bicycle, once learned, it (riding a bicycle) requires no intensive skill to understand, but is a complex array of forces interacting with each other (Tuan 1977). In a similar manner, spatial awareness can be transferred from O&M specialist to visually impaired traveler using models, simulations and mobile communication devices.

Cognitive knowledge of a given landscape is best exemplified by the rural traveler that attempts to navigate in an unfamiliar urban environment, regardless of impairments there is a level of physical and mental unease while navigating within unfamiliar surroundings. Physical unease in the sense of mobility, suggests that certain basic skills are required for successful travel in urban environments. The term mental unease implies a real or perceived threat to safe travel attributed to conditions in the urban landscape. The concept of landscape perception as a basis for environmental assessment is essential to empowering visually impaired travelers with the ability to utilize a modified form of object oriented travel. To address these skills, Bentzen (1997) provides O&M instructors with a range of training guidelines specific to urban environments. These guidelines include orientation techniques, discussions of route patterns and identifying key objects to aid in navigation. Each aspect of landscape perception is based upon physical and social attributes that can be detected through analysis of urban GIS data.

Existing Vision Classification Systems

Vision acuity loss is one of the more common age related problems and can be defined as a reduction of the ability to see details. Visual cues are essential for orientation, navigation, utilizing public transportation or accessing other municipal facilities. The total amount of information that can be perceived as objects can be expressed as a function of the contrast between the target object (and text) and the background. Travelers who walk at twilight or dawn frequently have difficulty because of low contrast and irregular lighting conditions. A common example of acuity problems occur when one attempts to read text in a dimly lit room (e.g. by candlelight or 20 watt bulb). Individuals who have trouble reading newsprint, street signs, bus route numbers, or other text based information are likely to have acuity problems when traveling in urban landscapes. Recent improvements to municipal transport systems have included identifying routes by bus color, therefore eliminating the need to read bus numbers from a distance.

In general, vision and visual based perception varies by traveler. The most common problems experienced outdoors are glare, visual field loss, scotoma (a region of reduced vision within a visual field), night blindness, light adaptation, refractive errors, nystagmus (a rapid flutter of the eye), fluctuating vision and depth perception(Geruschat and Smith 1997). Many researchers (Sauerburger 1989, Massof 2002b, Arditi and Rosenthal *1996*, Genensky 1970) have defined low vision (or visual impairments and aspects of visual disabilities) through an individual's physical potential to play an active role in society. The modern definition of low vision is composed of vision based upon acuity (vision impaired & legally blind), vision field (10 degrees, & 20 degrees respectively), and the presence of binocular contrast. Vision acuity is measured in terms of efficiency and expressed using ratios (20/70 vision sees at 20 feet what a person with normal vision could see at 70 feet).

By using classifications that are expressed as a function of an individual's visual acuity, or field of vision, O&M trainers are able to select devices or tools to reduce or to mitigate their impairments that best match the vision classifications. Common examples of these corrective devices are fisheye lenses, telescopes, canes, electronic sensing devices, and global positioning receivers (Farmer and Smith 1997). In an effort to improve accessibility for all individuals with vision problems, the expansion of the classification system to include standards ranging from 'Functionally Blind' (able to have some level of visual perception, but unable to navigate or to read even with optics or enhancement devices) to 'Functionally Sighted' (able to navigate or read with optics or enhancement devices)(Genensky 1970). Any classification systems should serve as a function of an individual's ability to acquire and to maintain employment (Arditi and

Rosenthal 1996). These vision classifications present a very strong argument for the relationship between an individual's ability to function in society and the acuity abilities of the traveler.

Most refractive problems can be classified as hyperopia (farsightedness), myopia (nearsightedness), or astigmatism (a result of irregular or uneven shapes of cornea, lens or both). These problems all relate to the bending of light and images. In many cases, one's vision can usually be improved via corrective lenses or laser based surgery. While refractive problems are a common problem for all ages, some issues are not as easily corrected. Other visual problems, such as cataracts (clouding in or around the lens), create a blurring of imagery as perceived by the individual. Another issue that may be associated with aging, presbyopia (loss of magnification capabilities) causes individual's problems when viewing things close-up. While this should not be confused with myopia, presbyopia, with age, is a condition in which the lens becomes more rigid and less capable of adjusting.

Field loss or tunnel vision is restrictive in which a well defined but limited field of vision exists (between 5 and 20 degrees). Furthermore, blind or blurred spots may occur anywhere within the visual field (i.e. normal central vision and poor vision at periphery, or poor central vision and normal vision at the periphery). Broad visual fields are key to the perception of large spatial target within a complex urban visual environment (Millar 1994). The identification of key targets are essential to maintaining depth perception, orientation and navigation in regions that have frequent terrain changes and an overwhelming number of visual landmarks (Geruschat and Smith 1997). In an effort to reduce the negative effects of field loss, persons with visual impairments are trained in using grid based tracking and targeting techniques with their residual vision capabilities.

Current O&M Technologies

Traditionally, O&M, as an instructional system, is based on a series of skills assumed to be progressively linear in complexity and demand across environments. Advances such as actuated (pressure sensitive) traffic signals (time signals can better be predicted and more comfortable for low vision travelers to utilize) and reduced automobile noise have combined with complex urban travel features such as traffic circles to make pedestrian wayfinding more hazardous (Geruschat and Smith 1997) for the traveler in unfamiliar landscapes. To assist the visually impaired wayfarer, recent breakthroughs such as the Robocane™ (Blasch, De l'Aune and Blasch 1994) and the Sonicguide (Farmer and Smith 1997) have been suggested as reliable technological devices to provide supplemental travel information. One of the biggest advances since 1990 has been the development of Global Positioning System devices which are utilized in conjunction with travel diaries and other tracking systems to analyze travel patterns (Golledge 1998) and assist in remote location finding for individuals navigating in unknown environments. The objective of these diaries are to associate travel patterns with learned skill sets and determine if travel patterns change after specific skills training. In addition to technology, O&M instructors play a key role in planning travel and providing spatial information about the travel environment (Bentzen 1997). The job of the O&M instructor is to provide supplemental information to the traveler and therefore replace information that is unable to be gathered on site due to the traveler’s visual impairments.

The remote rehabilitation process utilized by the medical community is an effective tool for health care providers to transmit remote-diagnosis information to rural locations (Tran, Buckley and Prandoni 2001). Advances in distance learning technologies have begun to support rehabilitation training techniques which have, in turn, provided low vision patients access to a wide range of solutions to allow the visually impaired traveler greater freedom of independent movement. In a similar manner, O&M researchers envision a parallel method of transferring travel data both to trainers and travelers. The inherent complexity of both travel abilities and the dynamics of urban landscape environments make modeling systems convoluted and difficult to implement. Basic environmental and navigational descriptions of travel space are by nature, unique to the individual, complex to communicate, and changes rapidly due to social or cultural events. As a result, any data collected in a given environment relies heavily upon human perception to determine how the information is best utilized.

O&M and Geographic Methods

Route knowledge can be defined as the understanding of common environmental features as identifying key landmarks which enable pedestrians to determine metrics specific to the desired route (Golledge et al. 1993). Individuals with vision impairments tend to travel through the use of landmark recognition, spatial orientation, and pattern identification that in many cases were learned prior to vision loss (Golledge and Stimson 1997). Because all these factors are important in a mobility sense, they also become significant when examining travel problems. One component of route assessment is identifying the orientation of pedestrian travel spaces. Landscapes that are developed in grid patterns tend to be easier to navigate as opposed to older cities with curvilinear roads and unconventional crossings (road crossings with traffic islands, at oblique angles, or five way intersections). The O&M trainer attempts to understand both vehicular traffic patterns and pedestrian density over the landscape routes. Road crossings are planned based upon the presence of crosswalks, traffic islands and traffic regulators (e.g. stop signs, traffic lights). Individual objects and hazards are among the most difficult to predict or plan for (landscape trees, postboxes, advertisements) and have been reported to cause severe problems for low vision travelers. In an effort to reduce onsite evaluation requirements, high resolution air photographs can be utilized to acquire a number of travel features through heads-up digitization methods.

Feature classification methods using remotely collected data have been well documented since the 1976 research proposing a standardized land use and cover system (Anderson et al. 1976). At this time, feature classification, remote sensing techniques and GIS models can be observed in vegetation management (Hagishima and Tanimoto 2004), land use analysis (La Barra 2003, Thanapura et al. 2007), and a number of population growth representations (Besussi and Chin 2003). Orientation and Mobility researchers have also utilized GIS applications to transfer knowledge about travel landscapes (Jacobson and Kitchin 1997, Golledge 1991, Buliung and Kanaroglou 2004). In some cases, travel diaries have been utilized to analyze travel patterns (Buliung and Kanaroglou 2004, Badland, Schofield and Garrett 2008), while others are cartographic representations of routes or regions with details specific to low vision travelers (Golledge 1991). Early efforts to utilize cartographic products for travel knowledge included the use of tactile maps to define curb cuts and terrain slope along specific routes (Brouwer et al. 1984). Other maps focused upon the orientation and layout of road features as they pertain to cognitive abilities of travellers (Golledge 1993a). Unfortunately, at this time there is no standard set of variables to represent features specific to low vision problems.

Identifying Low Vision Problems

The many processes by which we as geographers translate environmental observations into usable data for determining travel routes are usually convoluted and imprecise depending upon the observer and specific conditions (Stern and Portugali 1999). As such, our approach to understanding the relationship between perception and landscape has become more complex as research fields of psychology and geography have matured as disciplines of science (Welsh 1997). Route knowledge by nature is extremely subjective and varies widely by traveler and location. Current measurements of route knowledge assessment include outcome evaluations, travel diaries, GIS models; data based support systems, activity scales and questionnaires (Blasch and Williams 2002, Buliung and Kanaroglou 2004, Sobek and Miller 2006, Røe 2000, Genensky et al. 1979). These methods generally involve information about specific routes (Golledge et al. 1993, Espinosa et al. 1998) or methods to communicate map data via tactile or audio based techniques (Jacobson 1998, Jacobson and Bradley 1997, Jacobson and Kitchin 1997). The route knowledge assessment for this study will be based upon observations from the landmark Genensky survey (Genensky et al. 1979). The Genensky group of researchers identified common problems that are experienced by people with low or partial vision, and identify methods that would better utilize residual vision.

The Genensky survey consisted of 491 questions with yes-sometimes-no, or big problem-small problem-almost no problem, as the responses. Over 45% of participants were over the age of fifty and were evenly split between male and female respondents. A large majority of individuals surveyed had serious visual problems for over five years with 81% being considered legally blind but retaining some functional vision. This landmark research achieved several goals: it defined blindness in terms of remaining residual vision, it measured the aptitude of visually impaired adults to assess terrain features, and established the need for rehabilitation techniques to take advantage of residual vision capabilities (Genensky et al. 1979). The intent of the survey was to identify problems which could be mitigated using residual vision via training and low vision aids. This was especially important at the time because a majority of visual aids were oriented towards indoor or other near activities. Since the Genensky study, a number of aids for distance viewing (binocular, monocular, and other telescopic spectacles) have been utilized by O&M trainers. A number of devices were also developed for the use of detecting changes in surfaces, elevation, and other obstacles (Dykes 1992). More importantly, a number of travel techniques and methods used to improve upon residual vision capabilities were developed from the findings of the Genensky study.

In his research, Genensky (1979) noted that key mobility variables for the partially sighted are far more complex then those for the functionally blind (vision reduced to illumination detection or worst). For the low vision traveler, the basic element of travel problems can be directly related to information (or the lack of it) about the environment. It has been suggested that route decisions (that a person makes) are a function of an individual's ability to navigate that path (Sobek and Miller 2006). Others attempt to rate travel independence by utilizing self reporting visual functions or comfort levels (Massof 2002a), analyzing existing travel patterns (Buliung and Kanaroglou 2004) or even modifying existing rating systems found on ski slopes or golf courses to best predict travel conditions (Blasch, La Grow and Penrod 2004). Regardless of method, the most common metrics of travel independence are the use of acuity and field of vision. Common vision acuity benchmarks are 20/70 corrected for impaired vision and 20/200 corrected for legally blind. Vision field loss is assessed as nominal (between 5% and 20% loss) or significant (greater then 20% loss).

Problem factors are cognitive or environmental features that may result in complications for the low vision traveler when navigating in an urban environment. Many factors would be indicative of problems for any individual attempting to navigate or wayfind in an unfamiliar environment. Others are specific to low vision travelers and can be assessed with varying weights depending upon the assigned Vision Class. Many problem factors can be spatially represented using open source GIS data; others will be dependent upon the individual and not utilized in this case study. Current estimates indicate that vision accounts for over 75% of information required for independent mobility (Geruschat and Smith 1997). In addition to visual acuity and good field of vision; cognitive information, audible cues, and environmental conditions all play key roles in empowering pedestrians with travel knowledge in urban environments.

Previous research into route knowledge demonstrated how the understanding of common environmental features is the best method of identifying key landmarks, and obtaining route metrics (Golledge et al. 1993). In most cases, environmental features are learned by common travel experiences. A pedestrian gains knowledge about a pothole by tripping, or seeing it. The low vision traveler must use the long cane with a much shorter sensory range. Early research in cognitive knowledge (Downs and Stea 1973) suggests that perceived representations of the travel landscape have a significant impact upon the individual's ability to navigate independently. Just as landscape perceptions are important, other factors play a key role in travel independence. Individuals with vision impairments tend to travel through the use of landmark recognition, spatial orientation, and pattern identification that in many cases were learned prior to vision loss (Golledge and Stimson 1997). Because all these factors are important in a mobility sense, they also become significant when examining travel problems (Figure 3).

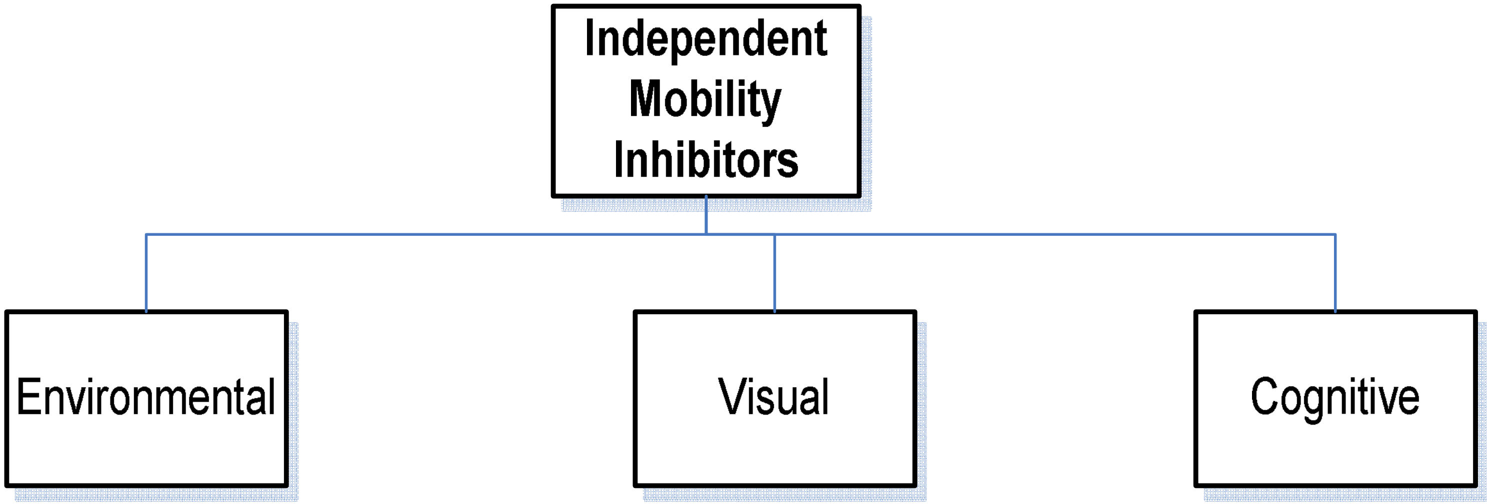

Figure 3 Independent Mobility Problem Types

Current methods of understanding the relationship between perception and landscape have become more complex as modern research fields of psychology and geography have matured as disciplines of science (Welsh 1997). Route knowledge by nature is extremely subjective and varies widely by traveler and location. Current measurements of route knowledge assessment include outcome evaluations, travel diaries, GIS models; data based support systems, activity scales and questionnaires (Blasch and Williams 2002, Buliung and Kanaroglou 2004, Sobek and Miller 2006, Røe 2000, Genensky et al. 1979). These methods generally involve information about specific routes (Golledge et al. 1993, Espinosa et al. 1998) or methods to communicate map data via tactile or audio based techniques (Jacobson 1998, Jacobson and Bradley 1997, Jacobson and Kitchin 1997). Of the Genensky findings, 95% of respondents reported that they navigate outdoors alone. Of those that responded that they did walk around outdoors, most were uncomfortable navigating in unfamiliar areas. Problems in unknown environments include objects (e.g. skates, bikes, or carriages) such as those found near parks; landscape trees such as those found in municipal regions; and signage near retail facilities. Other problems may occur in parking lots, near streets with heavy traffic and construction zones. The O&M trainer identifies a travelers strengths and weaknesses (such as Table 1 and Table 2) then utilizes that knowledge to best select vehicular traffic patterns and pedestrian density over the landscape routes that provide routes with the highest probability of success. Road crossings are planned based upon the presence of crosswalks, traffic islands and traffic regulators (e.g. stop signs, traffic lights). Individual objects and hazards are among the most difficult to predict or plan for (landscape trees, postboxes, advertisements) and have been reported to cause severe problems for low vision pedestrians. Each of these features can be identified either by using manual classification methods or by association with GIS feature classes.

The process of cognitive understanding as a functional element of navigation has been defined as a construct (or schema) that represents the personal understanding of one's surroundings (Golledge and Rushton 1984). Hence, cognitive mapping (or mental maps) can be defined as the process in which individuals gain understanding about their travel environment through data collection, interpretation, and response. By exploring the process of gathering, understanding and reacting to environmental stimuli, these researchers are proposing that spatial awareness (or the lack thereof) has a specific role in our ability to navigate successfully. Travelers who are able to be aware of their surroundings (in a cognitive sense) would be better prepared to make decisions about potential obstacles they may face. While some of this information is already well known (i.e. roads are more hazardous to cross in commercial zones as opposed to residential zones), a number of additional associations have been drawn from examining the environment in a cognitive sense.

Since the Genensky study was conducted (Genensky et al. 1979), the community of researchers, therapists and O&M technicians have explored cognitive methods to identify best methods of assessing travel landscapes. In 1985 a life space study focused upon familiar landscapes as a reliable predictor factor for independent mobility (May et al. 1985). This research reaffirmed the comfort findings by the Genensky study (see Tables 1 & 2 below). Familiarity, as a factor of independent mobility, is among the most subjective and challenging to represent (geospatially) for a large demographic of users. For an individual client, the distance from one's home-space would be inversely related with the ability for the client to navigate successfully (Buliung and Kanaroglou 2004). Comfort levels are also strongly influenced by demographics and socio-economic conditions within the travel area.

Table 1 Question 153 from Genensky et al. 1979 p.38

Circumstances in which Comfortable

Variable	Number of Respondents or Responses
Familiar streets and blocks	29
Familiar areas	19
Own yard	10
Daytime or sunlight	10
Paths or hiking trails	6
Parks or gardens	6
Dim day	3
In company of fully sighted person	3
Woodsy, rocky areas	2
Using white cane	2
Uncrowded area	2
Others	13

Table 2 Question 154 from Genensky et al. 1979 p.38

Circumstances in which Uncomfortable

Variable	Number of Respondents or Responses
Unfamiliar areas	21
Night	17
Unfamiliar streets and blocks	9
Woodsy areas	6
Paths or hiking trails	6
Parks or gardens	6
Rain	5
Areas with construction	5
Areas with steps	4
Paths or hiking trails	4
Dim cloudy day	3
Isolated area	2
Others	8

The visual acuity of a traveler is just as important as the cognitive knowledge an individual possesses. By learning information about a low vision traveler's acuity limitations, the O&M trainer has a better understanding of potential hazards to the client. Acuity plays a big part in detection of approaching traffic, reading navigation signs, and scanning for hazards such as tree branches or toys on the travel path. Each traveler has specific awareness capabilities and has a sense of their most comfortable viewing distances (Geruschat and Smith 1997). Acuity based environmental assessments are utilized by both client and trainer to get a sense for environmental nuances that enable the traveler to make good wayfinding decisions and improve independent mobility.

Travel environments are every bit as influential for independent mobility as cognitive knowledge and vision acuity. A pedestrian friendly environment can provide a safe environment for a wide range of travelers; whereas hazardous environments frequently require a higher level of expertise (either using advanced cognitive knowledge or vision acuity). Handrails for stairs frequently put the traveler on notice that there is about to be an elevation change (either positive or negative); crosswalks and sidewalk curbs better define road surfaces and crossings; and signs with large clear text provide necessary details about navigating in urban landscapes (Bentzen 1997). Elevated pedestrian crossings for major interstates allow low vision travelers to access a wider range of services and facilities. Busses allow low vision travelers to navigate safely far beyond their home space (May et al. 1985), enabling them to independently take care of essential and recreational needs. Newer traffic controllers have audible aids to assist at crosswalks and notify oncoming traffic of high use pedestrian crossings. Other environmental features such as raised surface mats or stripes have also been used at crossings with some success (Bentzen 1997).

To date, cognitive studies in low vision travel have typically examined local features (Tellevick 1992, Jacobson 1998, Golledge 1999, Gärling and Golledge 2000). By utilizing feature classification for route suitability, O&M trainers can now get a big picture view with small scale mapping features. Associating travel problems with geographic attributes can remind urban planners of the significance of including disabled populations in new design requirements, and serve as a reminder to municipal decision makers when accessibility features are debated. Transportation factors are far more objective then comfort level factors, but still represent a complex network of hazards. Streets and road surfaces represent one of the most significant hazards to low vision travelers, conversely, sidewalks represent safe travel lanes. Years ago, navigating across a road was an easy task. Vehicles were louder, road crossings were conventional and stop signs were more prevalent (Sauerburger 1989). Modern vehicles are difficult to detect for severely impaired travelers due to quieter engines. Traffic islands and right turn on red light laws cause significant problems for low vision travelers (Barlow et al. 2001). Actuated traffic lights prevent low vision travelers from timing the red light cycles (Sauerburger 1995). Traffic circles or curvilinear intersections can cause significant problems for individuals dependent upon straight line travel with a clear and well defined path (Bentzen 1997). Engineers are challenged to provide accessibility crossing signals (Figure 4) to provide audible cues to aid low vision travelers when crossing multiple lanes of traffic (Sauerburger 1995). Travel paths vary greatly dependent upon local features, demographics and the significance of the adjacent road network.

Figure 4 Improved Pedestrian Signals in Savannah GA

3. METHODOLOGY

In order to append risk to environmental factors the physical abilities of low vision travelers are taken into consideration. To provide 'best fit' suitability outcomes, four classifications have been established to adjust for physical limitations. For each classification, a risk index is used to represent how the environmental factors impact the overall suitability of the landscape. Additionally, weights are applied to the risk index based upon dynamics that occur in urban landscapes. The intent of weighting the risk index is to more accurately model conditions and features that influence independent mobility suitability. Environmental factors that are considered have been classified based upon their relationship to an individual's travel ability in the specific environment. Theses factors include transportation features, land use regions, illumination data, and temporal features. Each of these factors will be discussed in detail below.

Vision Classifications

To assess geographic features, acuity and field loss have been utilized to apply weights of each factor that may cause travel problems. Four classifications are utilized to allow O&M instructors to adjust the outcomes of this project for specific clients. Vision Classification 1 (VC1) covers individuals who have acuity problems (greater then 20/70 corrected but less then 20/200) with nominal or better field of vision (less then 20 % loss). People in VC1 typically have some trouble reading text or street signs in high glare or low light situations, but are generally able to detect large objects, road crossings or other hazards. Vision Classification 2 (VC2) covers individuals who have acuity problems (greater then 20/70 corrected but less then 20/200) with poor field of vision (greater then 20% field loss). People in VC2 have trouble detecting large objects, road crossings or other hazards in high glare or low illumination levels, but can navigate without the use of a long cane during hours of good illumination. Vision Classification 3 (VC3) covers individuals who have severe acuity problems (greater then 20/200) with nominal or better field of vision (less then 20% loss). People in VC3 may have significant problems reading street signs, identifying safe travel paths and detecting hazards even in good illumination. Long canes may be utilized at all times, and significant O&M training is helpful to maintain independent mobility. Vision Classification 4 (VC4) covers individuals who have severe acuity problems (greater then 20/200) with poor field of vision (greater then 20% loss). People in VC4 require the use of a guide dog or long cane to navigate most of the time and depend a great deal upon existing cognitive knowledge of travel routes.

Environmental Classifications

In this study, road networks are classified in three tiers based upon their highway speed, and number of lanes (described as significance above). Road Class 1 (RC1) roads are limited access roads (and most difficult to cross). These roads are most likely to be interstates or high volume roads (such as bypasses or other form of expressway). They are characterized by having higher speed limits (generally greater then 50 miles per hour) and few traffic regulators (e.g. stop signs, red lights, traffic circles). Pedestrian crossings are typically limited to overpasses or pedestrian bridges. As a result, RC1 roads may act as a barrier for many low vision travelers. Road Class 2 (RC2) roads are designed to transfer traffic flow from limited access roads to local access roads. They frequently have midrange speed limits (from 30 miles per hour to 50 miles per hour), may have two to four lanes of traffic, and have a large array of traffic regulators (e.g. stop signs, signals, or traffic circles). Additionally, many intersections of RC2 roads have crosswalks to provide safe crossing lanes and improve visibility for vehicle operators. Road Class 3 (RC3) roads are local access roads. These typically have low speed limits (under 30 miles per hour), and traffic is usually regulated using stop signs (although some traffic lights may be utilized). Additionally, RC3 roads typically have only two lanes of traffic to cross.

Travel paths will be grouped together in a single classification. Sidewalks are the most frequently utilized travel path and can be frequently observed near RC2 and RC3 roads. They are typically 3 to 6 feet wide and may be bounded by the road curb on the road side. In city parks or other open spaces, travel path surfaces may be dirt or gravel, but typical sidewalks are composed of concrete. Unfortunately, in many commercial areas, the sidewalk areas may be cluttered with signage or other obstructions. Other transportation factors will be collected in separate feature classes. Crosswalks represent safe crossing zones for pedestrians and are designed to remind vehicle operators to be aware of possible pedestrians crossing in these zones. Conversely, traffic islands represent significant hazards to the low vision traveler. These medians typically do not have crosswalk markings and encourage motor vehicle operators to continue traffic flow without slowing for the intersection. Public transportation routes enable low vision travelers to cross very hazardous intersections. Additionally, many modern busses and trains have audible cues to alert the passenger of upcoming stops. Public transportation empowers the low vision traveler to access distant services and goods.

Land use data is a general indicator of travel conditions. For this study, land use data will comprise of three primary feature classes: commercial, industrial, and residential. City parks, urban forests and vacant lots are difficult areas to assess. While they can provide safe travel zones in urban environments, low vision travelers may have trouble identifying clear travel paths, locating key waypoints or hazards. Dependent upon terrain and surface features, these landscapes may be of great benefit or great hazard to the low vision traveler (Geruschat and Smith 1997). As a result, parks, urban forests and vacant lots will not be assessed as a land use feature class. Two additional subclasses will be utilized: parking lots, and construction zones. Residential land use zones typically have local access roads (RC3) with lower speed limits and more frequent stop signs. Industrial and commercial zones are both more likely to have RC2 type roads with higher speeds and wider lanes. Commercial zones also have large parking lots that may cause problems for individuals with field of view problems. Construction areas may be in either industrial or commercial zones.

Illumination is very important for the low vision traveler when navigating outdoors (Table 3). Glare, contrast and Ultraviolet (UV) radiation present significant problems for urban pedestrians with visual impairments. To identify regions with high glare potential, the Restrahlen effect (backscatter illumination is composed of primary illumination minus absorbed illumination) will be utilized to identify natural (vegetation) surfaces from man made surfaces based upon significant changes in pixel values (Elachi and van Zyl 2006).

Table 3 Question 166 from Genensky, Berry et al. 1979 p. 42

Do you walk alone Outdoors?	Number of Respondents		
	Yes	Sometimes	No
In bright sunlight	79	4	6
On a cloudy day	82	4	3
At twilight	61	14	14
At night on brightly lit streets	42	13	34
At night on dimly lit streets or in moonlight	31	10	48
At night when it is very dark	30	6	53

It is proposed that given discomfort glare constants from previous research (Kim and Koga 2005), glare, contrast and UV radiation can be remotely predicted by examining the contrast between natural and man made reflective surfaces in urban landscapes. This problem is significant because parking lots are commonly situated near office buildings with high illumination backscatter. Other buildings (such as those found in multi-family dwellings, hotels, or other similar establishments) tend to have filtered glass or other devices that absorb and reduce backscatter. Natural surfaces and vegetation tend to have the least amount of reflective surfaces and the greatest absorption of radiation of all bandwidths, but most importantly in the upper visible and UV frequencies. These metrics can be utilized to predict changes in backscatter illumination due to environmental (natural or manmade) conditions.

Most temporal features are either event based; such as traffic congestion near schools, or commercial districts; or illumination based; such as regions of high glare or low illumination. Because temporal features are dynamic, any influences upon low vision travel are directly related. Geographic features will be utilized to represent temporal events. Some geographic features have a significant impact upon vehicular traffic. Specific locations such as school zones can have a significant impact upon vehicular traffic over wide areas (Saibel et al. 1999). In addition to local school zones, bussing systems have a significant impact upon traffic flow during these peak times. Traffic delays frequently result in a higher number of drivers who take on greater risks then those who drive during hours of lower traffic density.

Integration & Weighting of Factors

The definition of an individuals impairment has been described in terms of visual efficiency (Massof 2002a). For this study, visual efficiency will be represented by two variables acuity and field of vision. As discussed previously, those two variables will be expressed as four separate classes. The problem factors all have conditions that influence low vision travelers differently (table 4). To quantify this risk, a rating scale from 1 to 5 (very low risk to very severe risk) will be utilized to assess each problem factor in terms of the net effect upon a low vision traveler. The outcome of this table illustrates the net effect of field of vision loss on an individual. The values of each field were obtained from previous studies (Massof 2002a, Genensky et al. 1979, Sauerburger 1989, Sauerburger 1995, Barlow et al. 2001, May et al. 1985, Geruschat and Smith 1997). Each factor will also fall into one of three classifications in order of their influence upon the Vision Classes. Some factors, such as travel paths, roadways, and crosswalks represent tangible objects (or routes) that can be measured and have a very significant influence upon independent mobility. These features will be assigned a weight of 1. Other factors, such as illumination, have less significant influence, but at times have a very significant influence will be assigned a weight of .75. The third group of factors are land use features. These features provide generalized knowledge about landscapes without specific details. As a result, their weight will be .5 or one half the significance of travel paths, roadways and crosswalks.

To determine the assessments for the familiar areas grouping of problem factors, the Genensky study (1979) and the Life-Space assessment (May et al. 1985) were utilized to define those fields. Most travelers appear to be more comfortable navigating in their immediate neighborhood and to frequently used bus stops, but had slightly more problems accessing local services and places of worship because of increased pedestrian traffic in both locations. Additionally, because familiar locations are more likely to be utilized, they are typically utilized for comprehensive assessments and training by O&M specialists. Unfortunately, any metrics of familiar areas are extremely subjective and difficult to accurately assess.

Table 4 Problem Factor Assessment

Problem Factors			Weight	VC1	VC2	VC3	VC4
Familiar Areas	Home Space		0.5	1	1	1	1
	Neighborhood		0.5	1	1	1	1
	Local Bus Stops		1	1	1	1	1
	Local Parks		1	1	1	1	1
	Local Church		0.75	2	2	2	2
	Local Services		0.5	2	2	2	2
Transportation	Roads	RC1	1	5	5	5	5
		RC2	1	3	4	4	5
		RC3	1	3	4	3	4
	Travel Paths		1	1	2	1	2
	Crosswalks		1	2	2	3	3
	Public Trans Rt		1	1	1	1	1
	Traffic Islands		1	4	5	4	5
Land Use	Residential		0.5	2	2	2	2
	Commercial		0.5	3	3	3	3
	Industrial		0.5	4	4	4	4
	Parking Lots		1	3	4	4	5
	Construction		1	4	5	5	5
Illumination	Glare		0.75	4	4	4	4
Temporal	Schools		0.75	3	4	3	4
	Churches		0.75	3	4	3	4

Transportation features on the other hand are well documented. To be specific, Sauerberger and others have written at length about the complexities of road crossings and navigating in urban environments (Sauerburger 1989, Sauerburger 1995, Barlow et al. 2001, Bentzen 1997). Major interstates and limited access roads (RC1) are hazardous to traverse even for individuals with complete visual efficiency. However, RC2 and RC3 type roads have a wide variety of traffic controls and crossing types which can prove to be challenging for individuals with poor fields of vision. Lane widths are very significant when it comes to road crossings (Barlow et al. 2001). When faced with multiple lanes of traffic, people with severe acuity problems can have difficulty viewing crossing indicators. To assist, many pedestrian signals also have audible cues to assist crossings. Unfortunately, relying upon pedestrian signals are not enough to safely guide low vision travelers (Sauerburger 1995). Advanced skills are currently taught to assist travelers in judging distance and vehicular speed, by classifying roads based upon speed limit and lanes of traffic, O&M trainers would have more information for best route selection.

Across the urban environment, sidewalks rank as one of the best guides for navigation and wayfinding (Golledge et al. 1993). Most urban sidewalks have good contrasting surface textures and colors and in general follow straight paths along side roads. Lately, engineers have been installing warning surfaces (also known as blistered pavement) to indicate upcoming traffic intersections (Bentzen 1997). Street curbs provide good vertical displacement for long cane users to indentify road surfaces. Crosswalks act as safe zones when crossing busy intersections and provides significant benefit for low vision pedestrians (Genensky et al. 1979). They act as a visible guide for locating the far end of the intersection for travelers with poor field of vision or severe acuity problems. Traffic islands are quite the opposite (Bentzen 1997). They present significant problems for the visually impaired because frequently: they do not have crosswalks to assist travelers, they allow oncoming traffic to yield into oncoming traffic, and they do not require vehicles to come to a stop (and see any pedestrians).

Public transportation provides low vision pedestrians with significant opportunity (Genensky et al. 1979). In the Genensky survey, over 80% of respondents use public transportation, with detecting upcoming stops being the most frequent problem reported. Of late, many municipal transit systems have added audible cues to assist the traveler in identifying their desired stops. Furthermore, many stops have tactile maps to assist in route orientation and timetable recognition.

Land use features provide the O&M trainer with good generalized information about a specific region or environment. Some O&M researchers advocate the use of land use data to assist in building route knowledge (Buliung and Kanaroglou 2004). This study focuses upon three major land use classifications and two geographic features. Residential land use classes typically have RC3 roads with a high frequency of stop signs in lieu of traffic signals (Anderson et al. 1976). Commercial and industrial have a higher frequency of RC2 roads, with increased vehicular traffic and a large number of parking lots. Parking lots provide unique problems for low vision travelers (Bentzen 1997, Geruschat and Smith 1997). This becomes especially true where there is little contrast between the road surface, sidewalk and parking lots. To mitigate orientation problems, retailers are encouraged to use high contrast paint and parking bumpers. Construction zones are hazardous for individuals with full vision capacity. Closed sidewalks and uneven travel paths make construction zones areas to be avoided.

Temporal regions are areas which at certain periods of time provide significant problems for the low vision traveler. The two features discussed in this study (schools and churches) both have significant periods of high vehicular and pedestrian activity (Genensky et al. 1979). As a result, many temporal problems can be mitigated by adjusting travel routes or times to avoid peak periods. Additionally, because both feature types have very limited footprints, their area of influence is limited in scope.

Travel landscapes with high contrast ratios and locations with a large number of reflective surfaces (windows, roads, lakes, etc) present the greatest challenge in regards to travelers having to struggle with lighting effects(Geruschat and Smith 1997). Kim & Koga, (2005) quantify the physical impact of glare, regardless of type, as a function of the luminance of the source divided by the luminance of the background in a manner similar to the contrast ratio $C_r = \frac{x_{\max}}{x_{\min}}$ frequently utilized by remote sensing specialists (Sabins 1978). Unfortunately, in the context of this research project, providing contrast ratio information alone is not enough. Both Genensky, (Genensky et al. 1979), and Geruschat, (Geruschat and Smith 1997) posit the need to highlight regions of high brightness and point locations where a traveler may navigate between regions of high to low glare potential. As a result, area with high reflectivity will be identified as somewhat hazardous. These values may be extracted from orthophotographs using the ESRI Spatial Analysis extension. The brightness value of each pixel will be clustered and converted into vector format (polyline) using the contour object. This technique is similar to those utilized in estimating subsurface volumes in other applications (Price 2002). Each polyline represents a value interval of 10 units. Once calculated, the outliers (outer 25%) of the polyline set are identified and extracted from the main set of polylines. This set of outliers represents the brightest and darkest pixel regions of the orthophotographs. These regions are then assigned their appropriate problem factor value based upon the relative distance from the brightness mean value (see Figure 5).

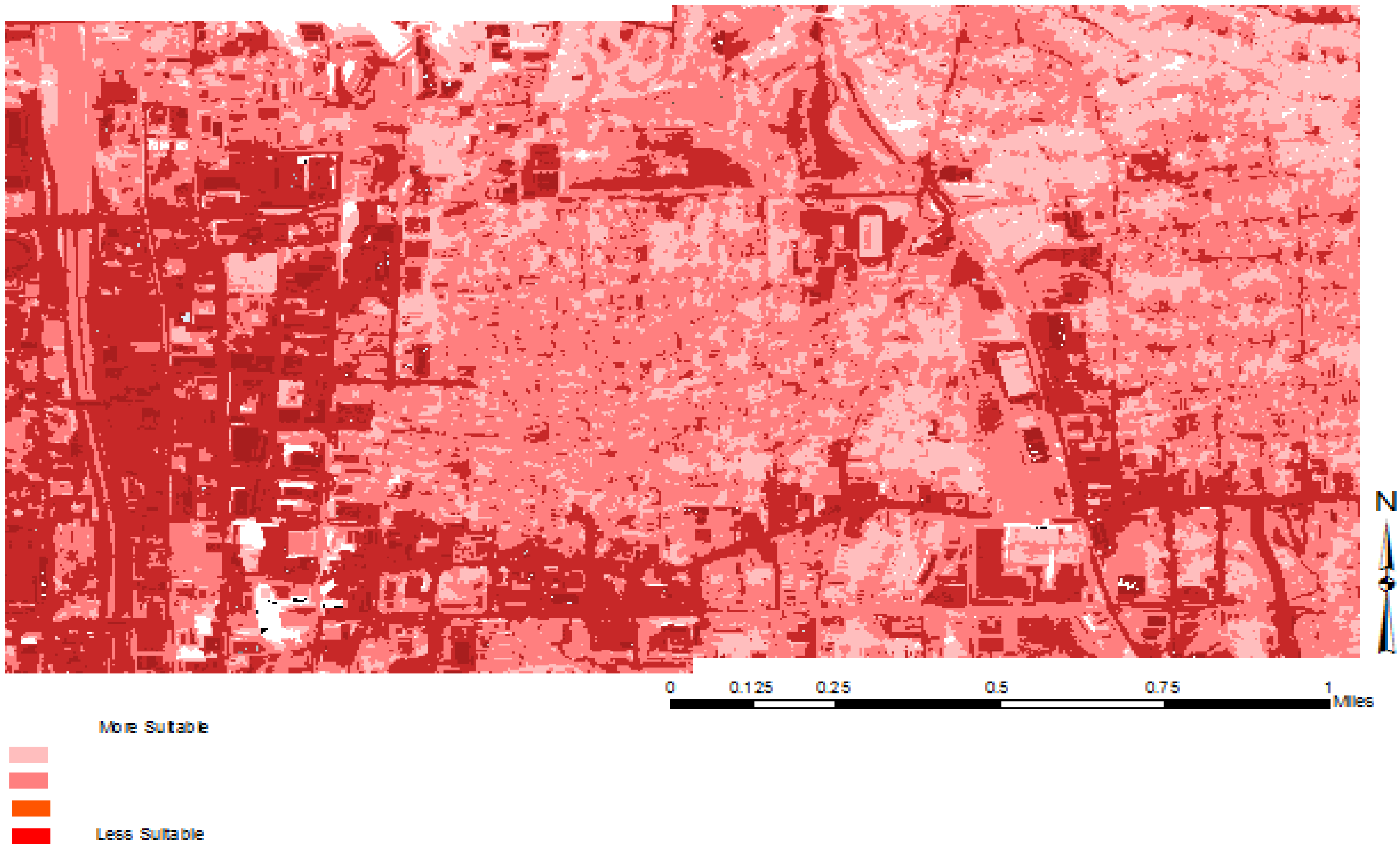

Figure 5 Illumination/Glare Data in Midtown Atlanta

Implementation in GIS

Each problem factor is represented by geospatial feature classes. Road feature classes are can be obtained from a number of sources. In this case study, road centerlines were exported from the ESRI Data and Maps set (ESRI ©2002), along with church and school locations utilized in the temporal feature dataset. Land use feature classes and bus routes were exported from the Atlanta Regional Information System dataset (ARIS 2002). Illumination, travel paths, crosswalks, parking lots, construction zones and traffic islands were all extracted from the National Map orthophotograph (USGS 2008).

Figure 6 (below) illustrates the process of converting the feature classes (that were selected as problem factors) into a composite raster to represent the overall travel suitability. In the first process, a two meter grid was created using the fishnet Arc object; then converted to polygon using the intersect Arc object in the ESRI toolbox. In order to prevent memory resource problems, the outcome grid should be no greater then 150,000 features. If the area is larger (the case study area contains approximately 1.4 million polygons) breaking the coverage into smaller feature classes is recommended. Linear feature classes have buffers

(Step 2) appended to them to represent the spatial footprint (point features also have calculated buffers based upon their area of influence, such as schools are buffered to school zones). The width of the buffer depends upon the feature class. In the case of RC1 (interstates or limited access roads) these buffers may be up to thirty meters wide based upon measurements extracted from the orthophotographs utilized. Travel paths are typically buffered 1-2 meters depending upon the average values obtained from the overhead photograph. Next, for each feature class, an intersect was calculated to fracture the created buffers into the two meter grids

(Step 3). New fields were built for the influence values and problem factor values (step 4-5). Each feature class was calculated with the problem factor values in Table 4 (step 6-7). After the fields are calculated, each problem factor dataset is aggregated into the main problem factor data classes (transportation, land use, illumination, and temporal); then into a composite feature class to be converted to raster. The polygon to raster Arc object is used to blend the Vision Class outcome values for each feature dataset and weigh the values by the influence attribute field while converting the data into the raster format (step 8).

Illumination data is calculated from available projected aerial photographs using pixel values that represent contrast. The photographs are converted to a polyline dataset using the Spatial Analysis ArcGIS extension with the pixel brightness value utilized as the predominate value. The variance of the polyline brightness values are calculated to isolate those regions that represent the brightest and darkest regions of the photographs. The outlier regions (upper and lower 12.5%) are then selected and exported. The exported contours are converted to raster; then converted back to polygon. The polygons are loaded into the aforementioned summary polygon features then converted to raster by vision classification groups. Color ramps will be utilized to express favorability in descending order using the finalized raster data.

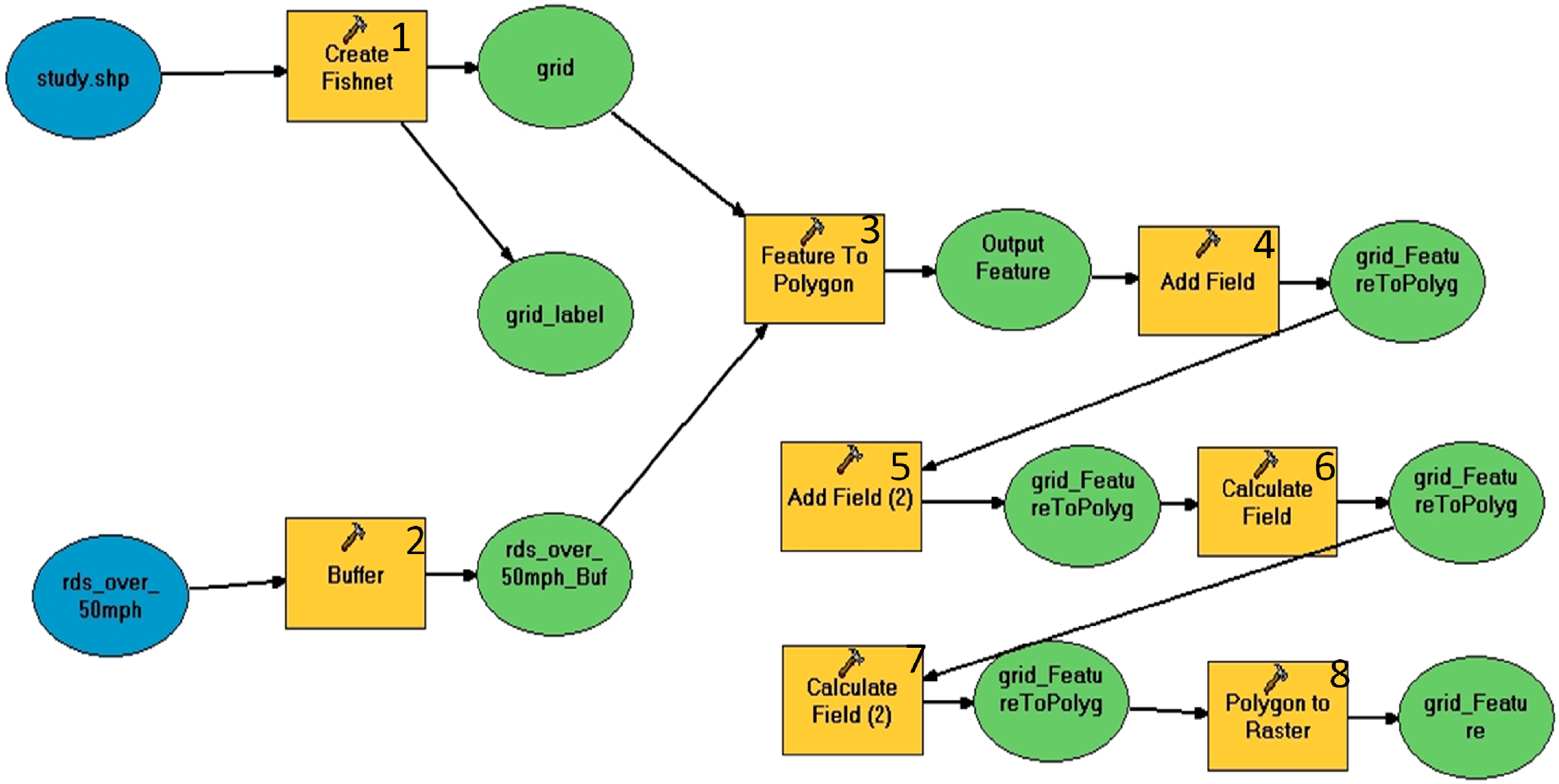

Figure 6 Feature Classification Data Mode

4. CASE STUDY

The area of Atlanta Georgia known as Midtown was selected as the case study area because of its wide range of geographic features. In particular the region extends from 13^{th} street (northern edge) to North Avenue (southern edge), and is bounded by Georgia Tech and Interstate 75/85 (western edge) to the Virginia Highlands neighborhood (eastern edge). The western part of the study area is mostly commercial and industrial while the eastern portion is mostly residential. Two major roads (10^{th} street and Ponce de Leon/Highway 75) are major east–west corridors for vehicular traffic and Piedmont park is well known for its many festivals and celebrations. There are a number of historic homes to include the Margaret Mitchell House, tourist attractions and restaurants that make Midtown Atlanta a complex urban landscape (Figure7).

Like other remote sensing feature classification systems, this study utilizes high resolution aerial photography from public sources such as the National Map (USGS 2006), Google Earth (Google 2006) and the Terraserver (Microsoft 2008). Because the identification of potential urban pedestrian routes is essential to the classification system; the use of imagery with a resolution of one meter or better is advised (Figure 8). Additionally, because the imagery will be used in conjunction with GIS data so rectification to a standard projection will be required also. The data in this research study utilized the North American Datum 1983, Universal Transverse Mercator zone 16 North with the unit of measurement set to meters. The imagery in this study was downloaded from the National Map (USGS 2006).

The density of available travel paths is positively related to independent mobility. For this study, a travel path is designated as a path wide enough for a single pedestrian to pass

Figure 7 Case Study Region in Midtown Atlanta

without hindrance and has a clear demarcation between the path and possible hazards. Examples of appropriate boundaries may include street curbs (vertical expression) surface textures (vegetation or soils) or other physical structure (fences, buildings or parking bumpers). Gaps between travel paths may be a result of roads, curb cuts, railroad crossings or open parking lots. It should be noted that there are some regions with fewer travel paths, this may be related to the block size or may be due to worn or overgrown travel paths. The land use dataset used in this case study was obtained from the Atlanta Regional Information System (ARIS 2002). To examine the land use distribution of travel paths in the case study area, the land use feature class was aggregated using the dissolve Arc object(Figure 10). The travel path raster dataset was merged with the land use feature class to adjust for the influence that features in each land use type has upon the goodness of the travel path segment. The travel paths were then aggregated based upon the land use attribute and calculated. In this case study, it appears travel paths account for approximately 4% of total surface areas with 41% of the travel paths in residential regions followed by 40% in commercial land use regions.

Metadata posted with the data indicated that the imagery was flown in 2002 by Photo Science Inc for the United States Geologic Service and was orthorectified using the national elevation dataset (see appendix A). In lieu of panchromatic imagery, three band color imagery was used to get a better sense of contrast with a pixel resolution of 0.3 meters. The first step of examining significant travel paths was the acquisition of sidewalks and travel paths via heads up digitization methods (Figure 9). Centerlines were drawn were sidewalks were apparent in the case study area. In areas where it appears that sidewalks continued but visibility was blocked were interpolated and verified via other data sources (e.g. http://maps.live.com/). In parks and public spaces, the centerlines of visibly distinct travel paths were traced and recorded. In separate feature classes, crosswalks were drawn as polyline features, along with traffic islands as polygons. Road networks and bus routes were extracted from the ESRI Streetmap dataset and clipped to the extent of the study area. Each feature class was converted into two meter raster grids and combined into the Transportation raster dataset.

Road networks separate regions in terms of economic or cultural features and frequently represent significant environmental changes or barriers. Specific attributes such as road width and speed limits play a significant role in determining how effective those boundaries can be. Other traffic control regulators such as stop signs, timed traffic lights, actuated traffic lights or traffic circles, are designed to enable pedestrians to cross busy city streets. The O&M community has put forth a series of training programs to assist visually impaired travelers to best understand how traffic control devices regulate pedestrian flow. In addition to improved knowledge about urban pedestrian landscape, the O&M community works closely with governmental agencies in order to enact legislation to improve pedestrian accessibility.

The road layers in this study area were collected from the Environmental Systems Research Institute street map dataset (ESRI ©2002). For pedestrian travel paths, the significance of each road crossing is dependent upon several variables. Two of the most significant variables include the width of the road (number of lanes) and the posted speed limit of the vehicular traffic on the road. In the extreme, road crossings may prove to be a barrier for the low vision traveler. Similar to travel paths, road networks have a distinct pattern based upon posted speed limits. In urban environments roads with posted speed limits over 50 miles per hour are in general multi-lane (6-12 lanes in the study area) with very limited access. Roads with speeds between 30 and 50 miles per hour can be seen as network roads that connect local access roadways to major access roads. There appears to be a positive relationship between posted speed limits and the number of traffic lanes in the data studied in the case study. But an overall negative relationship exists between travel lanes, traffic speed, and independent mobility (table 5).

Both speed and lane number attributes have a negative relationship upon independent mobility. The table above indicates that a majority of roads in the study area have posted speed limits of 30 miles per hour (mph) or greater and are located in mostly commercial regions. An evaluation of multilane roads indicate that most roads with speed limits under 30 mph are two lane roads. As speed limits increase over 30 mph, the likelihood of a multilane road increases with all limited access highways having speed limits over 50 mph (Figure 11).

As roads lanes increase and speed limits increase, the need for crosswalks increase. Crosswalks have a strong positive relationship with independent mobility (Table 6). Crosswalks have been defined as an extension of a pedestrian travel path designed to aid in safe crossings of road intersections (Zegeer et al. 2005). In the study area, there are just over 100 crosswalks that were collected using heads up digitization methods throughout most land use regions. While there are additional attributes (contrast, reflectivity, style) that may influence the effectiveness of crosswalks in urban landscapes, this study will not take them into consideration. Of greater importance is the distribution of crosswalks by land use classification and by the speed limits of the intersecting roads. Once again, commercial districts have the largest percentages of crosswalks, accounting for almost 75% of intersections with crosswalks (Table 7). Additionally, roads with higher speeds appear to be more likely to have marked intersections (Figure 12).

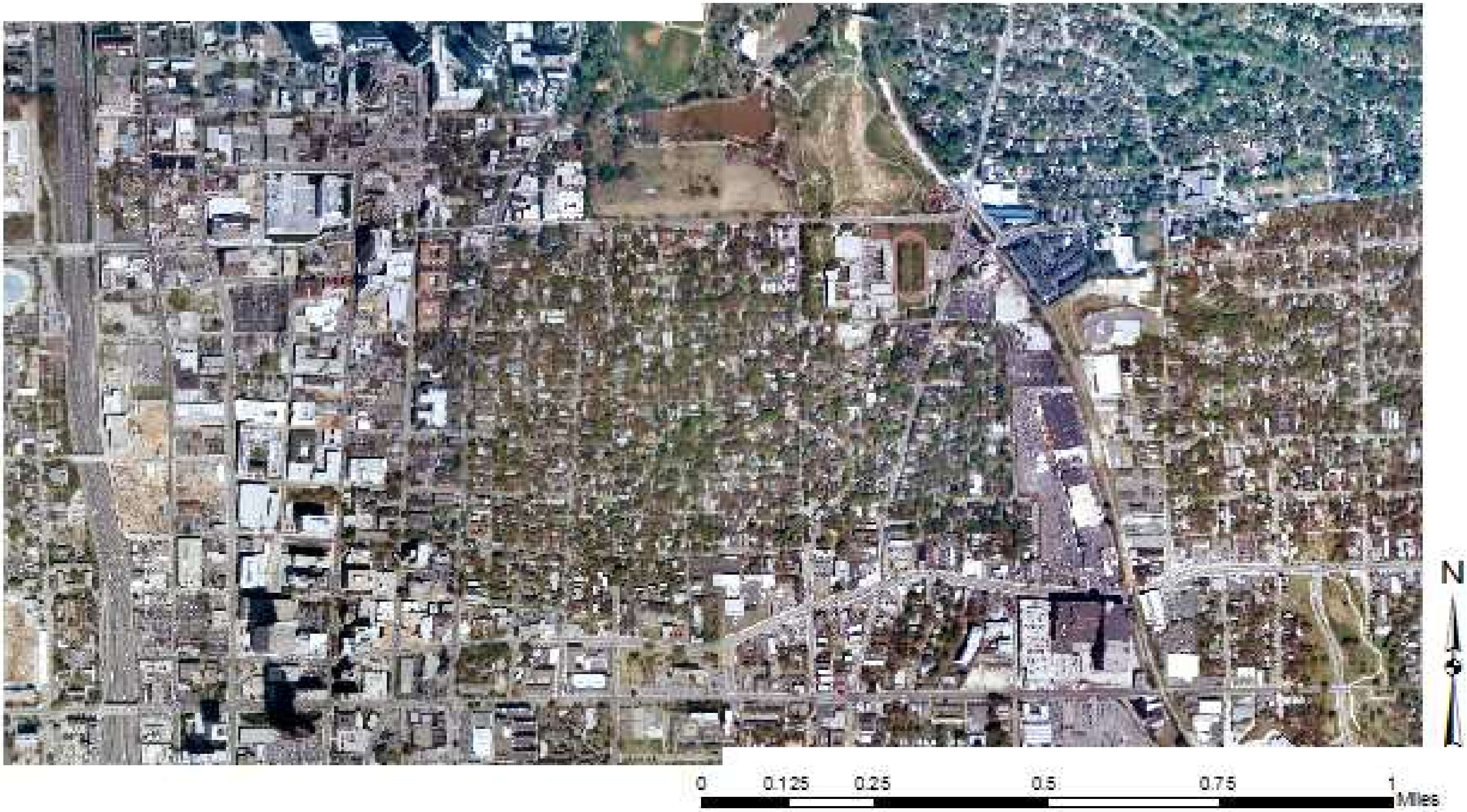

Figure 8 Aerial Photograph Mosaic of Midtown Atlanta

Figure 9 Travel Paths in Midtown Atlanta

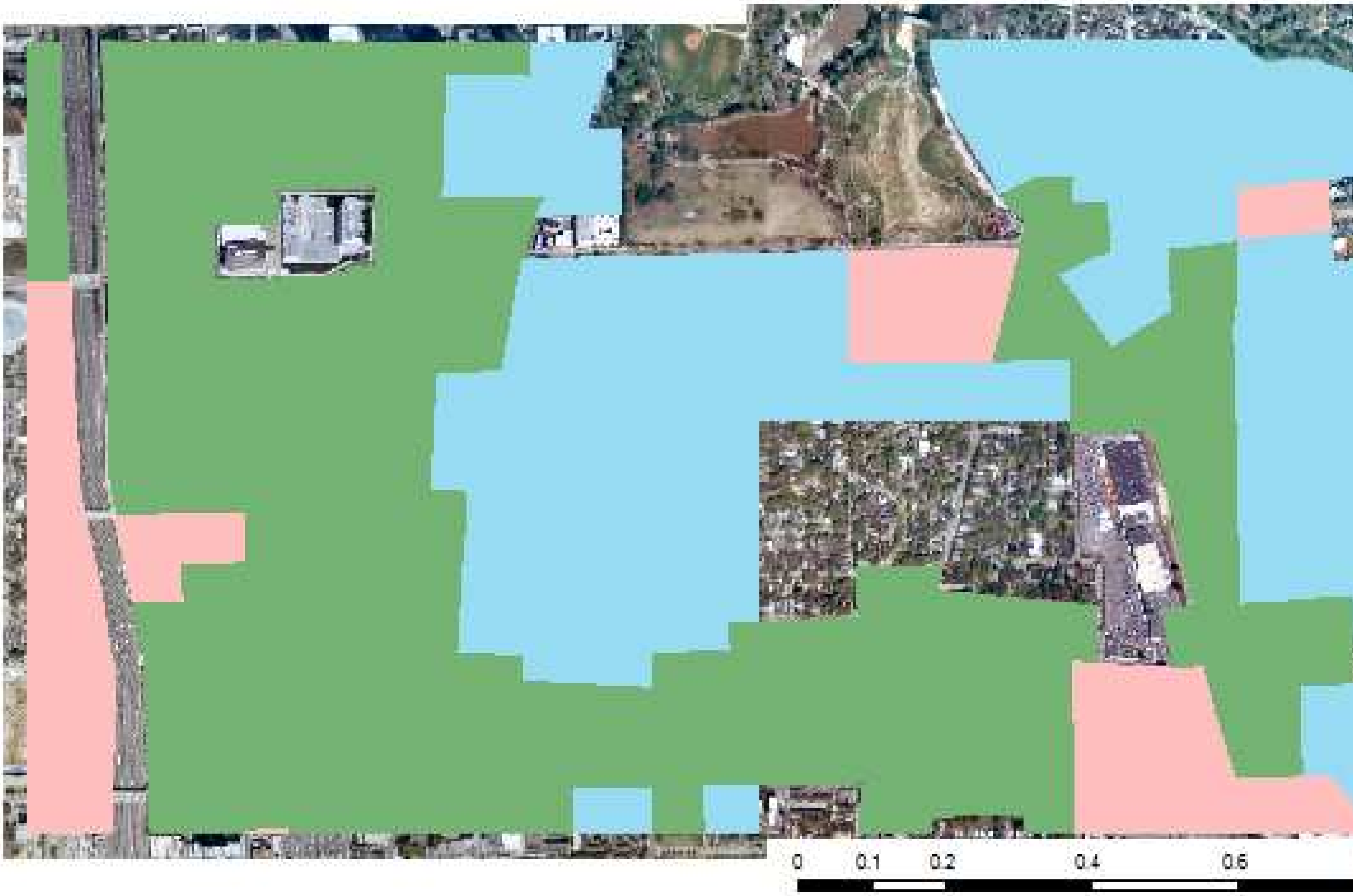

Figure 10 Land Use Classifications in Midtown Atlanta (Blue-Residential, Green Commercial, Pink-Industrial)

Table 5 Road Speed Limits (Percent of Total Length) in Land Use Classification Regions (as a Total Percentage by Miles Per Hour)

Sum of percentage	Column Labels						
Row Labels	10	25	30	35	50	65	Grand Total
COMMERCIAL	0.41%	29.54%		12.06%	4.95%		46.97%
FOREST		0.09%					0.09%
IND/COM				0.86%			0.86%
INST_INTENSIVE		2.56%	0.17%	1.11%	0.29%		4.12%
LTD_ACCESS		1.73%	0.47%		0.07%	2.68%	4.95%
PARK_LANDS		0.71%		2.12%			2.83%
RES_HIGH		24.71%		3.39%			28.10%
RES_MED		0.10%		0.21%			0.31%
RES_MULTI	0.47%	4.26%		1.07%			5.80%
TRANSITIONAL		1.61%		0.71%			2.32%
URBAN_OTHER		2.59%		0.33%	0.74%		3.66%
Grand Total	**0.89%**	**67.91%**	**0.63%**	**21.85%**	**6.05%**	**2.68%**	**100.00%**

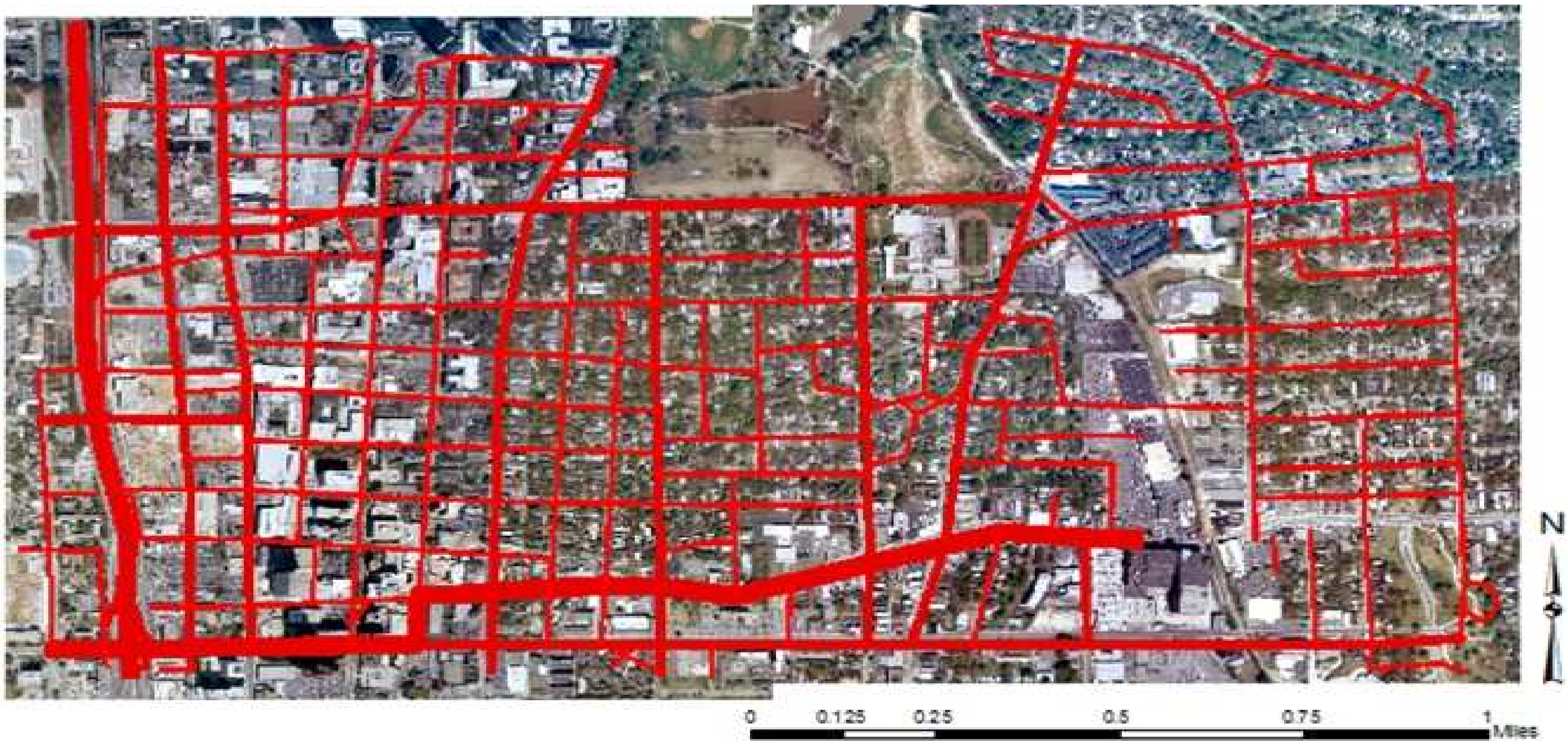

Figure 11 Roads and Expressways in Midtown Atlanta

Table 6 Question 169 from Genensky, Berry et al. 1979 p. 43

How do you cross the street in daytime with any aids that you use (Q169)	Number of Responses
I use traffic signals and crosswalks	23
I cross when other people cross	22
I use cars as an indicator	21
I note when cars are in motion or at rest	21
I listen to the sound of traffic	20
I am able to see traffic signals	11
I am unable to see traffic signals	10
I view the adjacent signal	6
I use my white cane to indicate to drivers that I have trouble seeing	5
I use the crosswalks	3
I listen for traffic	3
I don’t cross streets alone	3
I listen to clicks in the traffic signal	1

Table 7 Crosswalks with Land Use Classification Regions and Speed Limits
(as a Total Percentage by Miles Per Hour)

Sum of Percentage	Column Labels				
Row Labels	25	35	50	65	Grand Total
COMMERCIAL	44.63%	27.54%	2.10%	0.64%	74.90%
INST_INTENSIVE	4.76%	1.11%			5.87%
LTD_ACCESS	1.50%			0.33%	1.83%
PARK_LANDS		2.30%			2.30%
RES_HIGH	5.78%	3.29%			9.06%
RES_MED	0.52%				0.52%
RES_MULTI	0.98%		1.67%		2.65%
TRANSITIONAL	0.58%		0.32%		0.90%
URBAN_OTHER	0.66%		1.30%		1.96%
Grand Total	**59.41%**	**34.24%**	**5.38%**	**0.97%**	**100.00%**

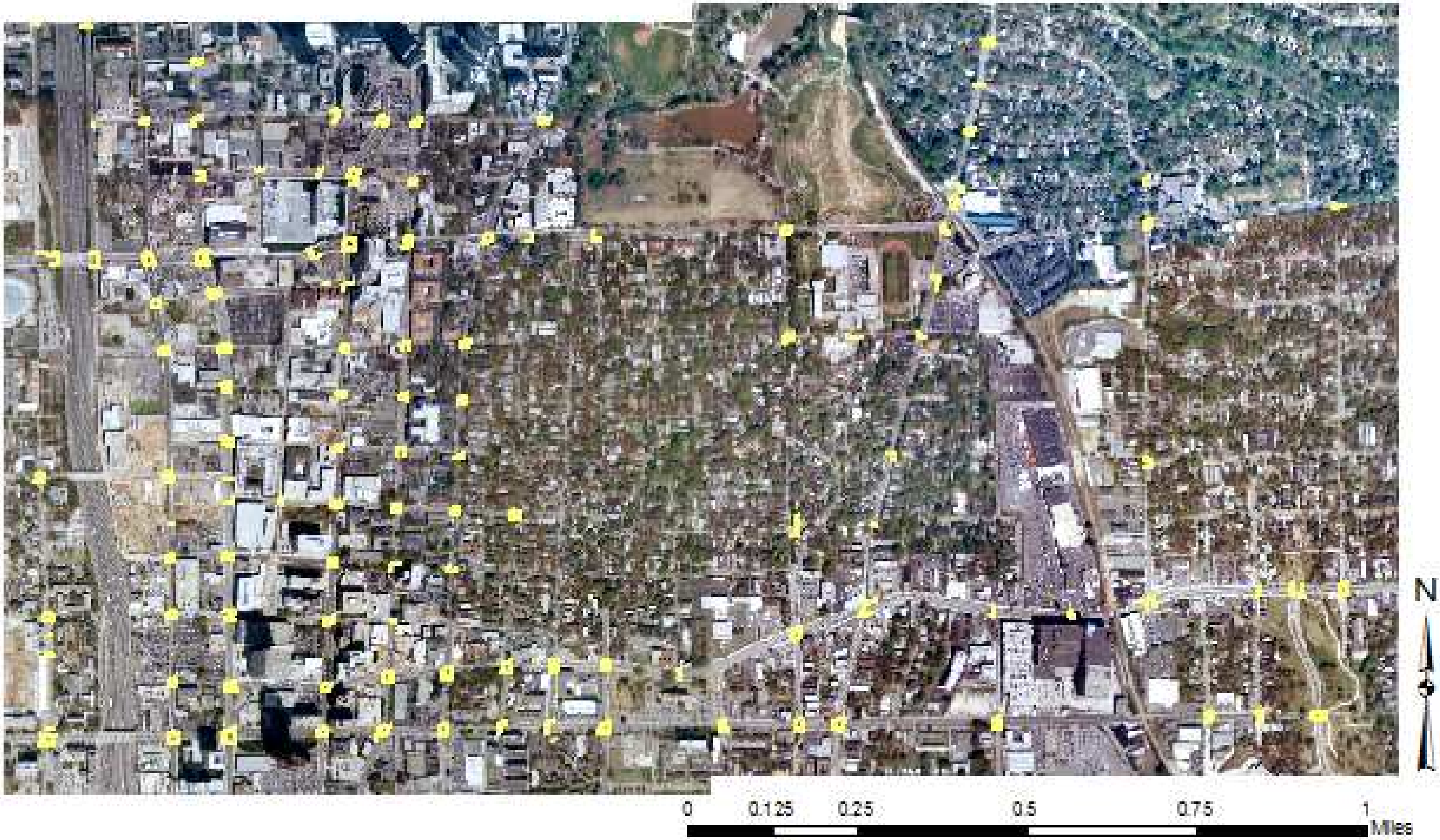

Figure 12 Crosswalks in Midtown Atlanta

Just as paths can be intersected by roads, parking lots can cause significant problems. If parking lots are not marked with bright parking bumpers or asphalt markings, low vision travelers may have trouble differentiating the sidewalk path from adjacent parking lots. Changes in surface color, texture, and elevation have a significant impact upon low vision travelers. Low vision travelers frequently report problems where there are extensive paved surfaces (Figure 13), such as parking lots, shadows, and stairwells (Geruschat and Smith 1997, Bentzen 1997). Long cane users frequently utilize the vertical expression between sidewalk and road surface as guides to assist orientation. In addition to parking bumpers, curb cuts for vehicular access to parking lots can be difficult to identify unless there is a distinct color difference between the parking lot and sidewalk surface (e.g. asphalt parking lot next to concrete sidewalk). Similar to parking lots, playgrounds or

Traffic islands and circles are medians or raised surfaces at intersections or in divided roads that are intended to provide pedestrians a safe haven when crossing large streets or to provide a traffic regulator at busy intersections. The most frequent style of traffic island in the case study tends to lie between a right hand turn lane and traffic lanes intended for crossing the road. They typically do not have crosswalks although the main intersection may have them. In Figure 14 (below) this object is especially hazardous because there is no crosswalk to indicate the optimal path to the island nor is there any traffic regulator to slow or warn the traffic in lieu of a pedestrian crossing. These locations were identified by utilizing heads up digitization methods with the aerial photographs discussed previously (USGS 2008) (Figure 8). Figure 15 below shows the location of several traffic islands (marked red against green travel paths) that pose significant hazards for low vision travelers.

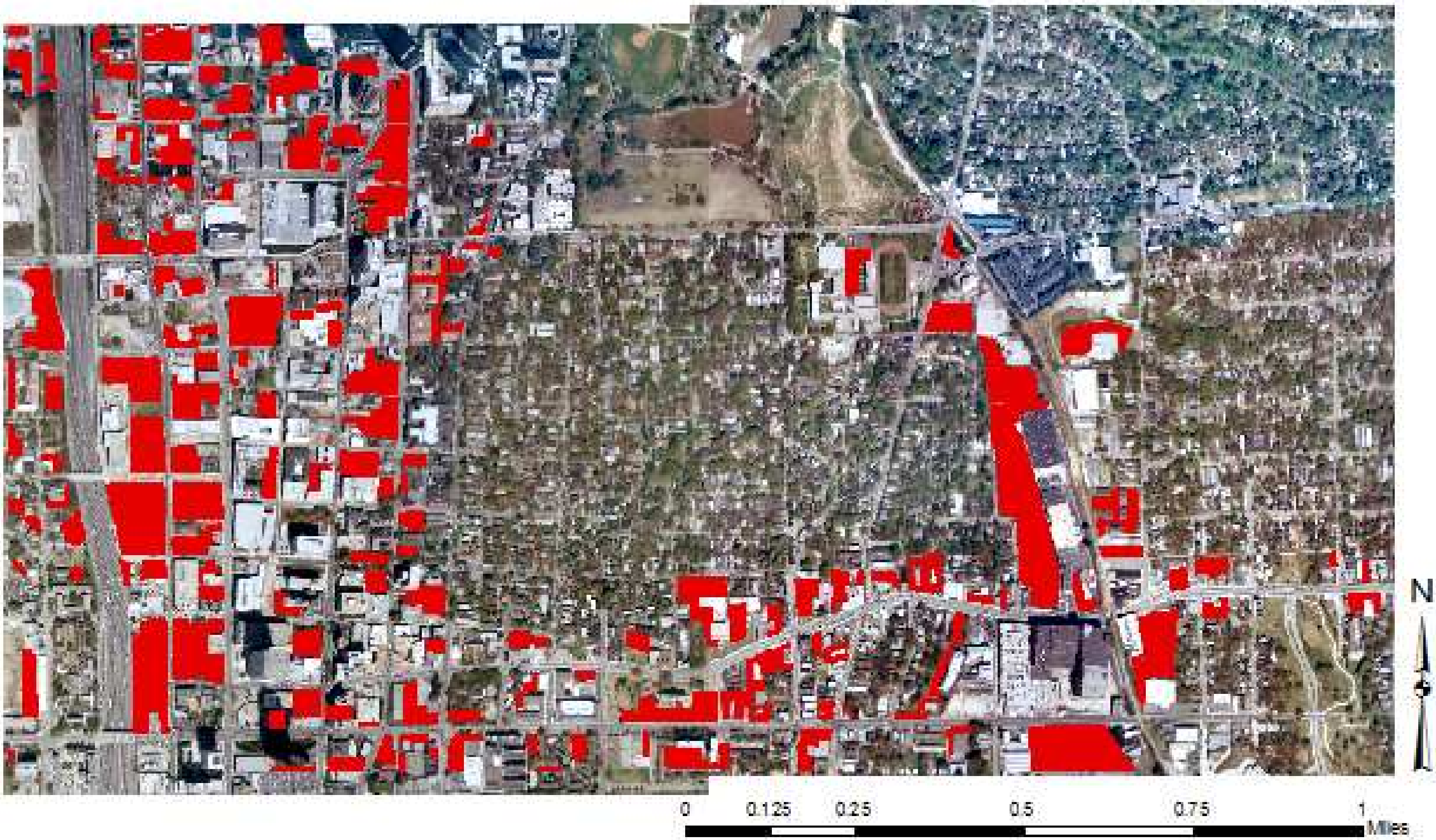

Figure 13 Parking Lots in Midtown Atlanta

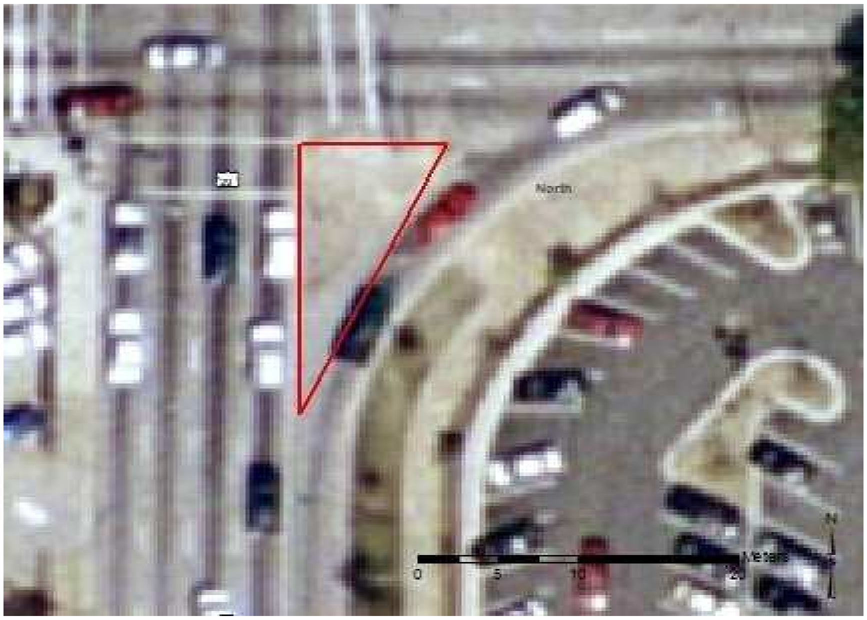

Figure 14 Traffic Island at Intersection in Midtown Atlanta

Bus route data for this study was obtained from the Atlanta Regional Information System dataset (ARIS 2002). The ability to utilize public transportation enables a low vision traveler to expand their travel space significantly. An individual that can utilize municipal transit systems with some level of confidence can greatly impact their freedom of mobility. It is a mixed blessing that bus routes are typically located along roads that are very difficult to cross. The savvy pedestrian may even ride the bus route to cross an especially hazardous crossing or travel to an easier intersection for crossing (Figure 14). The Genensky study indicated that a large number of respondents take advantage of bus travel (Table 8). While some travelers have difficulty in identifying unfamiliar stops and routes, the low vision travelers surveyed by the Genensky group appear to be able to overcome problems. Based upon the findings from Genensky, it can be assumed that public transportation routes are beneficial for improving independent mobility (Figure 16).

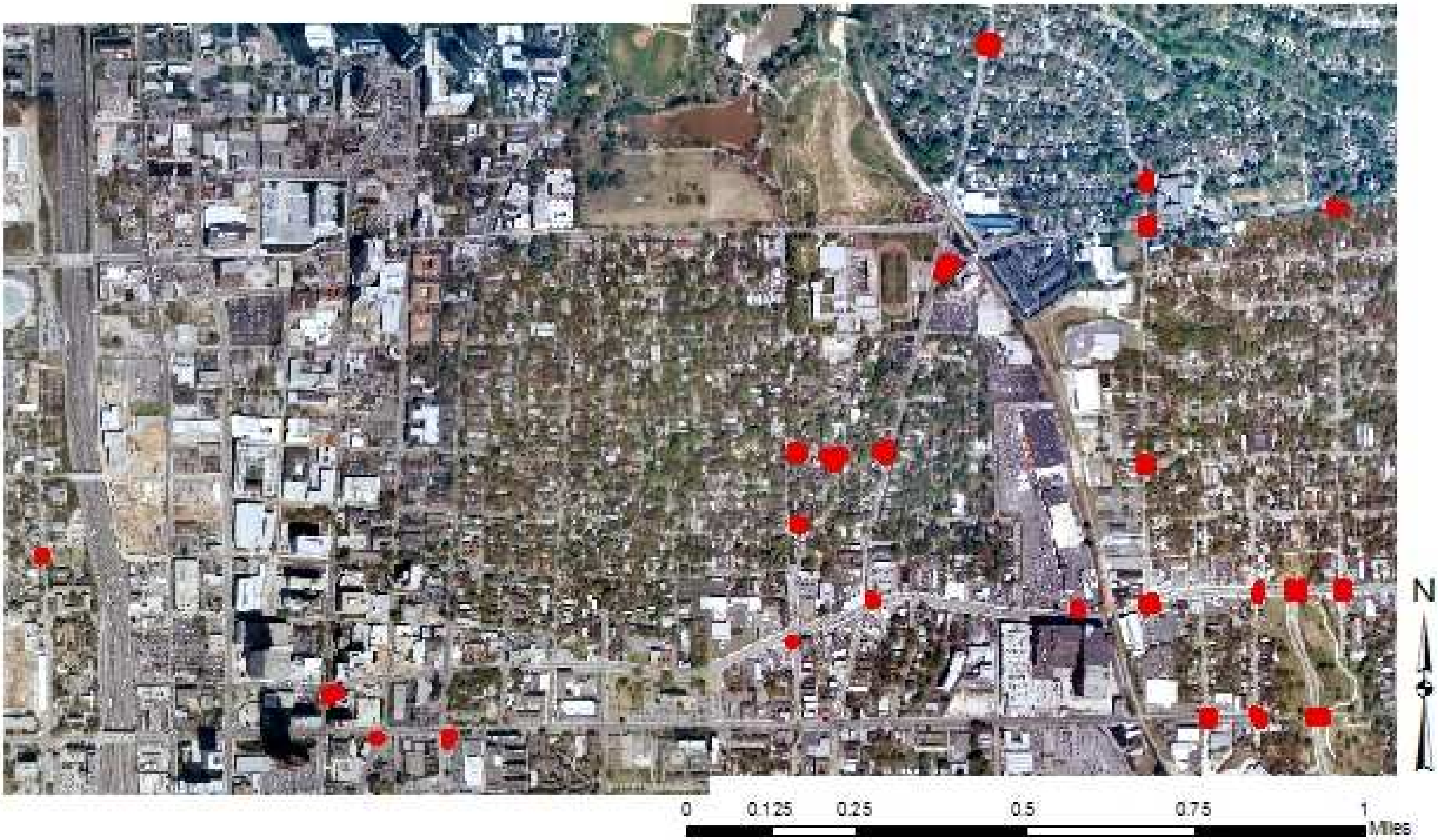

Figure 15 Traffic Islands in Midtown Atlanta

Table 8 Questions 176, 178 from Genensky, Berry et al. 1979 p. 42

Bus Travel Alone

	Number of Respondents or Responses	Percentage
(Q176) Bus-Taking	n=89	
Yes		88%
No		12%
(Q178) How Frequently?	n=78	
Frequently		67%
Occasionally		19%
Rarely		14%

Figure 16 Public Bus and Subway Routes in Midtown Atlanta

The classifications used in this research have a number of features, objects and subclasses that provide some level of influence into wayfinding and navigation for the low vision traveler. Independent travel can be examined as a metric by summarizing the net effect of each feature previously discussed. Some of these features have more influence or weight then others. This influence is a metric of two things, the severity of the problem for the traveler and the distribution & density of the feature occurring with in the case study area. Because this study was designed for a GIS platform, each feature class was assigned an attribute to represent its influence upon independent mobility in terms of acuity and field of vision. While field of vision is utilized in this study in a secondary role, it is still extremely significant in some environments. Because independent mobility is the net outcome of all of these positive or negative variables, it can be expressed as the sum effect of each variable (both severity and distribution of the variable). While GIS data provides a good summation of feature classes as potential travel paths, the objective of this research is to combine the 'goodness' factors of each layer utilizing to assess the overall travel environment in the urban setting.

Examining the outcome graphic, it is immediately apparent that there are a large number of hazardous regions. In particular, a number of construction zones located along the western quarter of the map have closed nearby sidewalks and travel paths. Several trends are apparent in the map outcome. First, the appearances of sidewalks and crosswalks occur more frequently in commercial areas then in residential. Illustrating this point is the residential zone in the center of the map, while most roads have sidewalks adjacent; there are very few crosswalks in that neighborhood. Second, there appears to be no clear relationship between land use classes and traffic islands, in fact; traffic islands appear to be distributed equally between commercial and residential districts. Third, there appears to be some relationship between a road's speed limit and the number of lanes of traffic on that road. This relationship resulted in the road speed classification (with 30 mph and 50 mph as the class breaks) utilized in this study.

Features that have been observed as part of the visual class include crosswalks, roads and traffic islands. Both traffic islands and roads are very hazardous travel paths with negative relationships towards independent mobility; whereas crosswalks serve as travel guides across road surfaces and have a very strong positive relationship with independent mobility. Visual classification features also have a strong relationship with land use classifications (cognitive). Both road speed limits and number of lanes are related to land use classes, and crosswalks appear more frequently in commercial zones then others.

Environmental features such as parking lots, construction zones have a strong negative relationship with independent mobility. City parks and open spaces are harder to evaluate. When city parks have good pedestrian trails and paths, the overall significance is diminished when compared to parks that have large open spaces without marked travel paths. These spaces have similar on visually impaired travelers as large parking lots. Parking lots (especially those without clear marking) can provide serious problems from an orientation sense. Construction zones are also hazardous because of heavy equipment, pits and closed sidewalks.

Interpreting the Outcomes

The final outcome product is a summary of transportation features (roads, bus routes, travel paths, crosswalks, and traffic islands), land use features (residential, commercial, industrial, parking lots, and construction zones), temporal features (schools and churches) and glare data extracted from the image brightness values. Each layer was assigned a value to represent the hazard potential for each feature (at a two meter resolution). Because each factor has differing levels of influence upon the outcome, a variable was added to indicate the level of influence each feature has upon the final outcome and weighted into the final outcome raster. A summary of the final outcome data indicates that 45% of the problem factor data was weighted at a .5 influence value. This indicates that a majority of the case study surface area evaluated were represented using land use feature classes. Of the study area 30% was represented by roads, travel paths or other objects weighted at a 1.00 influence value. The remaining 25% of the surface consisted of temporal features or glare hot spots that were weighted at a .75 value.

The first outcome map examined (VC1) is mostly suitable for independent mobility with few areas representing significant hazards (Figure 17). The average risk factor for VC1 travelers over the case study area is 2.6 (indicating some risk of travel). Of the analyzed surface area 38% of the region is represented having a low risk problem factor (value of 1-2). Travel paths and public transit routes, account for 8% of the total surface area and have full influence weighting (1), play a key role in the low risk outcomes. Additionally, 53% of the surface area outcome is represented as having a moderate risk factor (value of 3). Road surfaces and commercial land use districts are the most significant feature classes (just over 30% surface area) with moderate risk factors. Interstates (RC1) are the only surfaces (3% surface area) rated as very severe in the VC1 outcome and are mostly counterbalanced by the extensive public transit network.

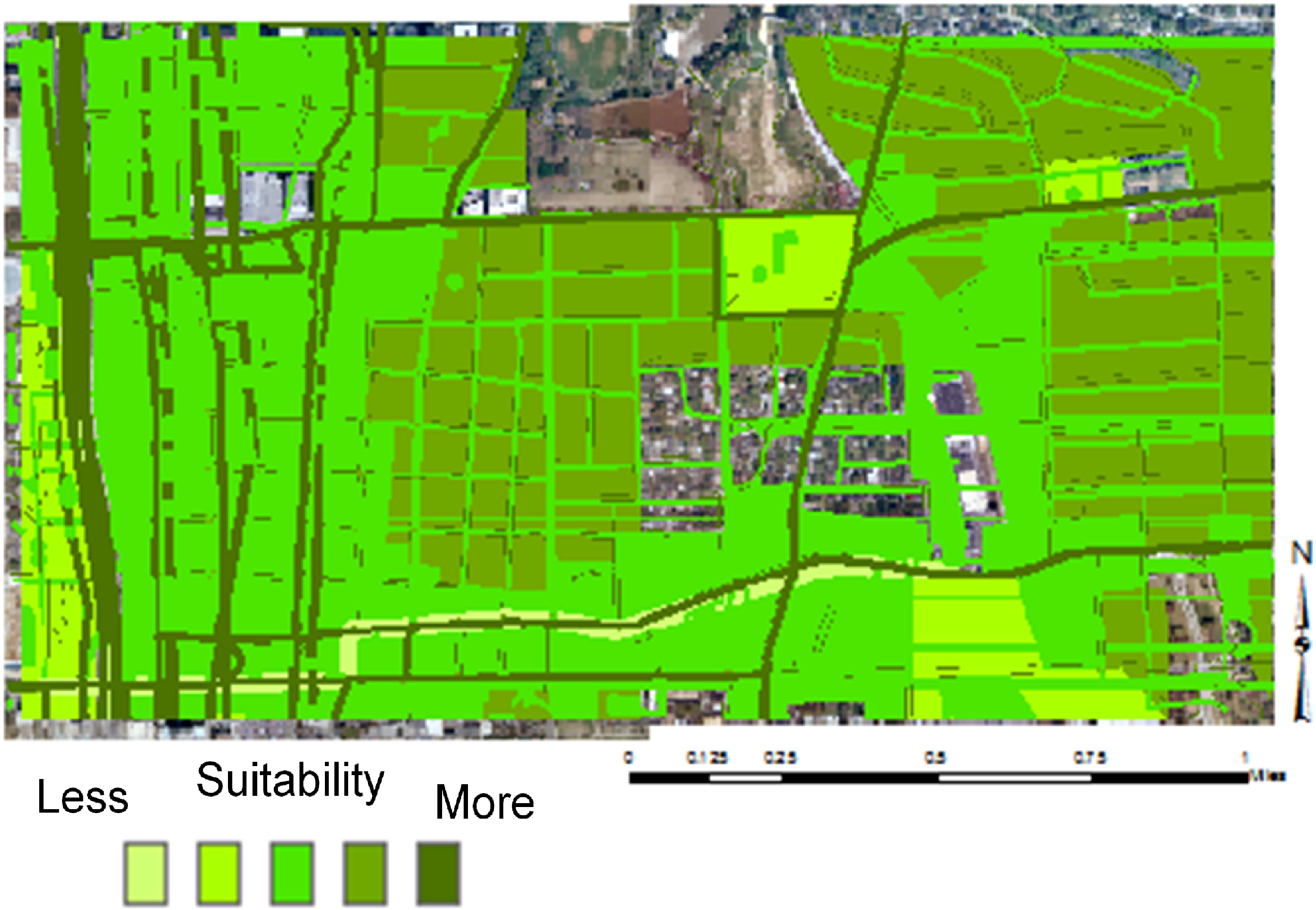

Figure 17 GIS Assessment of Travel in Midtown Atlanta (VC1)

The map representing VC2 (Figure 18) demonstrates the essential role of field of vision for wayfinding in urban landscapes. The average risk assessment is increased somewhat to 2.8 and a larger percentage of surface area is calculated as greater then moderate risk. This increase is over 23% gain of surfaces with risk assessments of 4 and 5. Much of this increase can be accounted for due to increase ratings for both RC2 and RC3 features. Additionally, there is a 3% decrease of risk category 1 surfaces which is almost totally accounted for by travel paths. Due to field of vision restrictions, Roads and parking lots become more difficult to navigate across and represent significant hazards for the VC2 traveler.

The VC3 outcome map is similar to the VC2 results (Figure 19). In fact there is no significant difference in the average risk factor outcome (2.8) between a landscape modeled for VC2 travelers and VC3 travelers. Distinct travel paths become visible as contrasted against hazardous road surfaces. RC3 features and commercial land use districts account for a great deal of the 37% of surface features that are predicted to be moderate risk. Parking lots and construction zones become more significant hazards as well as industrial land use classes for individuals with very poor acuity (VC3).

In the VC4 outcome (Figure 20) very low risk travel regions are widely dispersed and frequently intersected by more hazardous regions. The overall risk assessment for VC4 travelers is significantly higher the VC2 and VC3 with a rating of 3.1. This is mostly explained by the increased hazard assessment of parking lots, traffic islands, schools and churches accounting for approximately 12% of the total surface area. Significant increase of risk assessment values increase for travel paths (increase from 1 to 2) and RC3 features (from 3 to 4) covering another 10% of the total surface area also plays a key role into the increased overall assessment. While the overall risk assessment changes less then one full factor of goodness in this model, there are

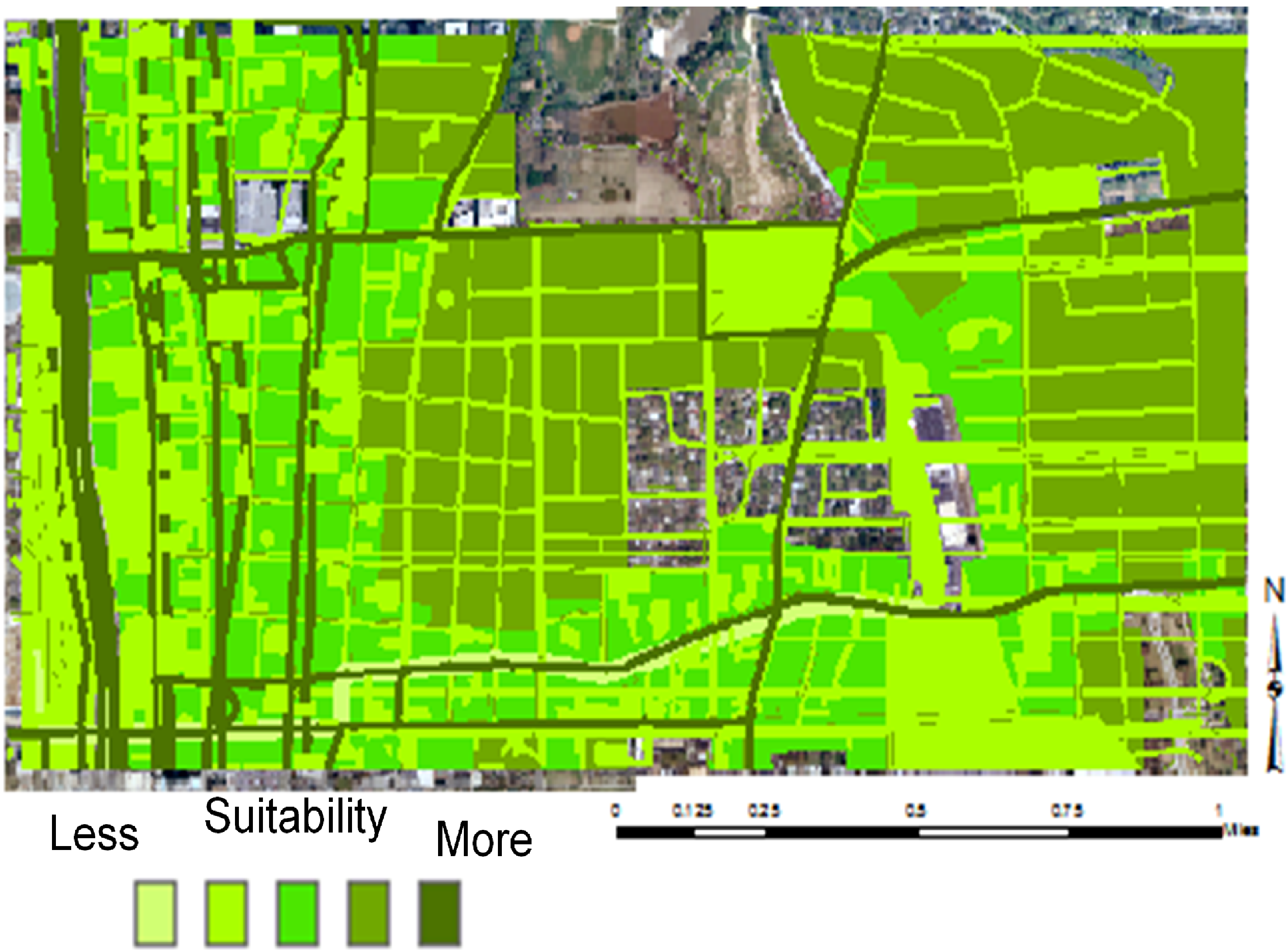

Figure 18 GIS Assessment of Travel in Midtown Atlanta (VC2)

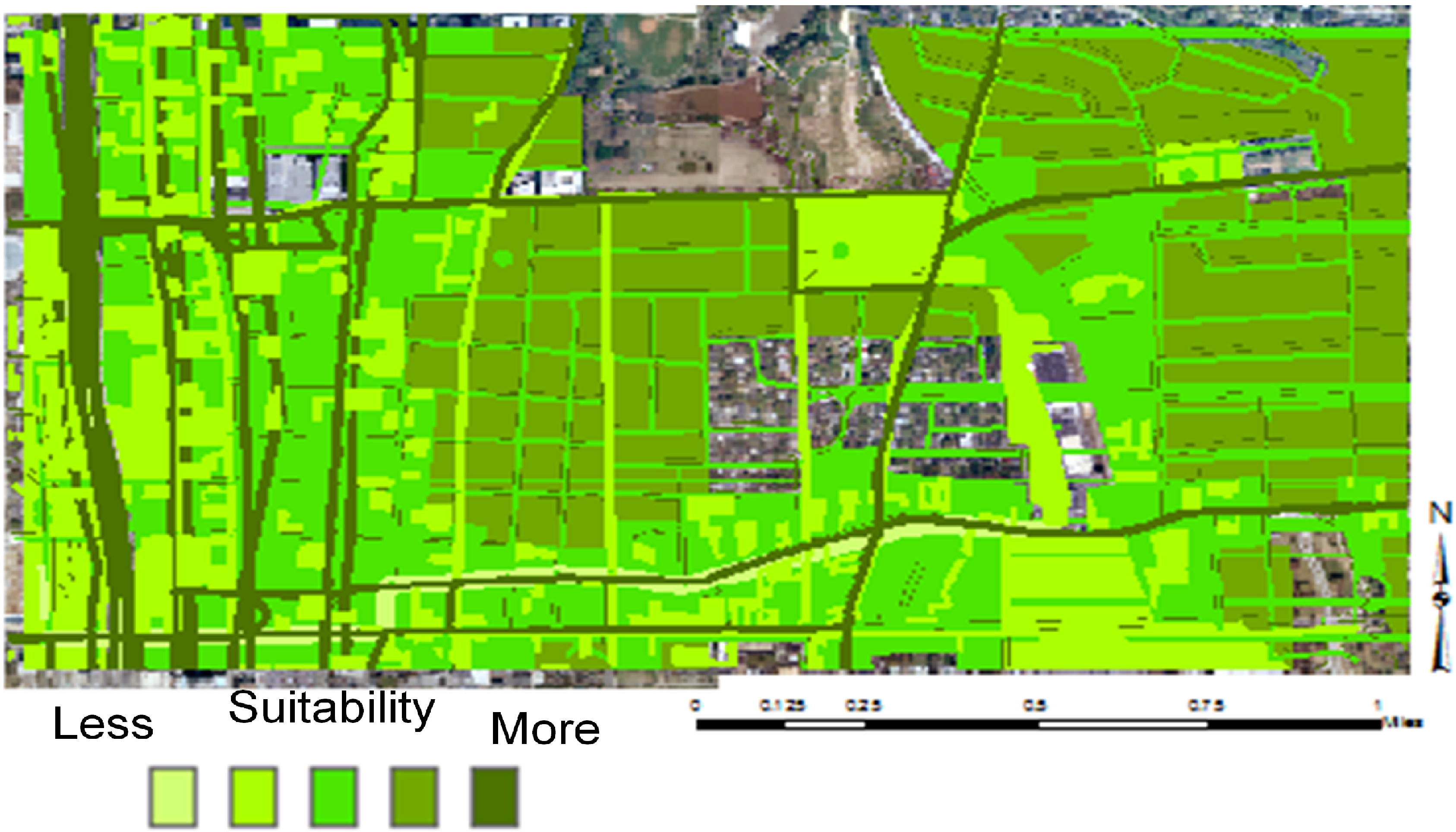

Figure 19 GIS Assessment of Travel in Midtown Atlanta (VC3)

significant outcomes that are observable and can be measured by associating low vision factors and survey data with off the shelf GIS data.

Overall the case study results seem intuitive with no unexpected outcomes. Areas with wider roads that have higher speed limits represent higher risks for low vision travelers then other regions. Regions with urban forest canopies have less glare potential then areas without urban forests. However, there were several results that were unexpected. While the outcome maps vary across the vision classes, there is little change in average risk between the models. Several factors may account for this. First, variables with the largest surface areas (land use), for the most part were assigned in the lowest weight class (.5); variables with lowest surface areas (roads, travel paths) were assigned to the highest weight class (1). Next, glare as a geographic variable did not shift risk value based upon vision class, instead the risk value shift was dependent upon glare potential. It is apparent that additional work is necessary to fine tune the association between travel problems and geographic variables.

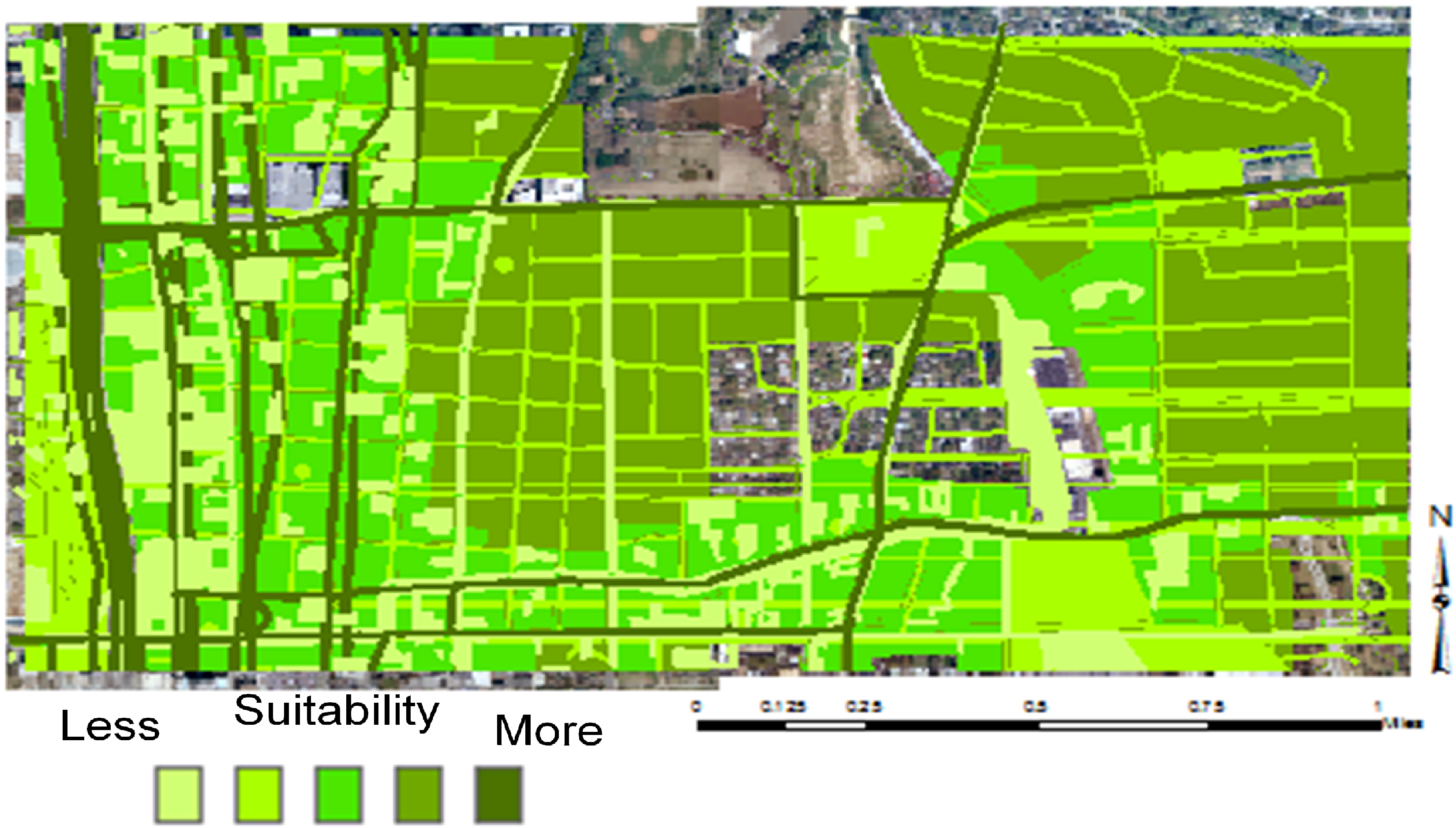

Figure 20 GIS Assessment of Travel in Midtown Atlanta (VC4)

5. SUMMARY

This research project utilized current literature and a benchmark survey to define common problems (e.g. street crossings, parking lots, and glare) that are experienced by low vision travelers in urban landscapes. These problems were evaluated and associated with geographic variables (e.g. roads, crosswalks, parking lots, and illumination feedback from orthophotographs) that are commonly utilized by many urban geographers. Based upon the severity of the problem, weights (in terms of significance) and risk factors were assigned to the associated geographic features. The geographic features were combined into a single feature dataset then converted into a raster outcome with risk values blended and weighed by the significance of each feature classification. The outcome raster would be utilized by O&M trainers to assess route suitability for their low vision clients.

The intent of using both the Genensky survey and current research to identify travel problems was to standardize both the problems and the geographic variables for O&M researchers. This standardize approach should give O&M specialists a common metric to which a greater number of individuals with vision impairments can utilize. Likewise, common GIS feature classes were utilized to enable O&M researcher to replicate these outcomes in other metropolitan regions. There are a number of complex variables that come into play when assessing risk for the low vision traveler. The process of identify problems that are common to low vision travelers in urban landscapes is very subjective in nature. Many O&M specialists rely upon individual surveys and assessments to gain insight into the requirements of their low vision client. In lieu of interviews, I chose to rely upon landmark surveys and research to identify the problem variable used in this research. In the future I think that fuzzy controllers could be utilized to more accurately represent the relationship between problem and geographic feature, in lieu of the weighting procedures utilized in this study.

While the outcomes of this study support suggests that geographic variables may be good predictors of risk; additional variables are necessary to improve the reliability and resolution of the risk assessment maps. Unfortunately, value laden features such as traffic regulators (stop signs, signals), and curb cuts are difficult to acquire without substantial ground surveys. One possible solution is to establish an internet based network O&M specialists to build a depository for data collected specific to low vision clients. Interpretation of the case study suggests that regardless of traveler capability, public transportation systems give low vision pedestrians a wide range of mobility options. Additionally, based upon the case study data, there seems to be a strong association between glare and commercial land use areas. This data is most likely to the greater surface area of impermeable surfaces and reflective surfaces that result from commercial facilities and buildings.

Geographic scale is another problem that will need to be addressed in future research. Urban landscapes are growing larger each year due to sprawl and expanding transportation networks. By limiting risk assessments to individual routes or local neighborhoods, geographers reduce the utility of their products. Conversely, by creating study areas too large, we gamble with the resolution and amount of details to provide a valuable outcome. Arguments can be made for projects at larger and smaller scales then the one utilized in this case study. The geographic features used in future suitability will be a significant determinant in the scale utilized.

This research project did achieve several goals. While urban landscapes have changed significantly since the travel problem surveys utilized in this study, problems defined in the surveys still exist. By utilizing previous research, O&M specialists should be familiar with the problem variables utilized in this research. That familiarity translates to a better understanding of the outcomes product and the problems that defined the outcomes. Additionally, this research demonstrated that travel problems can be associated with key geographic variables and modeled in complex urban landscapes.

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APPENDIX A

Python Script For Feature Classification

```
# Import system modules
import sys, string, os, arcgisscripting
# Create the Geoprocessor object
gp = arcgisscripting.create()
# Set the necessary product code
gp.SetProduct("ArcInfo")
# Load required toolboxes...
gp.AddToolbox("Z:/Arcgis/ArcToolbox/Toolboxes/Conversion Tools.tbx")
gp.AddToolbox("Z:/Arcgis/ArcToolbox/Toolboxes/Data Management Tools.tbx")
gp.AddToolbox("Z:/Arcgis/ArcToolbox/Toolboxes/Analysis Tools.tbx")
# Local variables...
study_shp = "F:\\airphotos\\thesis\\study.shp"
grid = "F:\\airphotos\\nets.gdb\\grid"
grid_label = "F:\\airphotos\\nets.gdb\\grid_label"
rds_over_50mph = "F:\\airphotos\\NewClassifications.gdb\\Transportation\\rds_over_50mph"
rds_over_50mph_Buffer = "F:\\airphotos\\NewClassifications.gdb\\Transportation\\rds_over_50mph_Buffer"
Output_Feature_Class = "F:\\airphotos\\nets.gdb\\grid_FeatureToPolygon"
grid_FeatureToPolygon = "F:\\airphotos\\nets.gdb\\grid_FeatureToPolygon"
grid_FeatureToPolygon__2_ = "F:\\airphotos\\nets.gdb\\grid_FeatureToPolygon"
grid_FeatureToPolygon__3_ = "F:\\airphotos\\nets.gdb\\grid_FeatureToPolygon"
grid_FeatureToPolygon__4_ = "F:\\airphotos\\nets.gdb\\grid_FeatureToPolygon"
grid_Feature = "F:\\airphotos\\nets.gdb\\grid_Feature"
#  This data is projected in NAD83, GRS80, UTM 16N-Meters with .01 meter tolerance
#  The Grid will be created by using the Fishnet ARC Object at 2 meter Accuracy
# Process: Create Fishnet...
gp.CreateFishnet_management(grid, "741456.8188 3739742.8475", "741456.8188 3739752.8475", "2", "2", "910",
"1620", "", "LABELS", study_shp)
#  The Buffer values were obtained by measuring road widths with Orthophotos
# Process: Buffer...
gp.Buffer_analysis(rds_over_50mph, rds_over_50mph_Buffer, "16 Meters", "FULL", "ROUND", "ALL", "")
# Process: Feature To Polygon...
gp.FeatureToPolygon_management("F:\\airphotos\\nets.gdb\\grid;F:\\airphotos\\NewClassifications.gdb\\Transporta
tion\\rds_over_50mph_Buffer", Output_Feature_Class, "", "ATTRIBUTES", "")
# Process: Add Field...
gp.AddField_management(Output_Feature_Class, "Influence", "DOUBLE", "", "", "", "", "NULLABLE",
"NON_REQUIRED", "")
# Process: Add Field (2)...
gp.AddField_management(grid_FeatureToPolygon, "VC1", "DOUBLE", "", "", "", "", "NULLABLE",
"NON_REQUIRED", "")
# Process: Calculate Field...
gp.CalculateField_management(grid_FeatureToPolygon__2_, "Influence", "1", "VB", "")
# Process: Calculate Field (2)...
gp.CalculateField_management(grid_FeatureToPolygon__3_, "VC1", "5", "VB", "")
# Process: Polygon to Raster...
gp.PolygonToRaster_conversion(grid_FeatureToPolygon__4_, "VC1", grid_Feature, "CELL_CENTER",
"Influence", "7.1")
```

APPENDIX B

Metadata for the Atlanta Digital Orthophoto Quarter Quadrangle Imagery

http://extract.cr.usgs.gov/distmeta/servlet/gov.usgs.edc.MetaBuilder?TYPE=HTML&DATASET=UA_222_01

Source_Contribution:
Horizontal and vertical control used to establish positions and elevations for reference and correlation purposes and as input to the aerotriangulation process. Control consists of both Airborne GPS to provide camera station positions and photoidentifiable surveyed ground control for ground reference.
Process_Description:
"The aerial platform used during the photo acquisition for this project was a Rockwell Turbo Commander turbine-powered aircraft capable of cruise speeds of around 215 knots. This capability is very important for good production on a very large photo acquisition project such as this one. A Jena LMK 2000 lens high-precision photo-grammetric camera was used as the photographic instrument. This camera has a nominal 6-inch focal length with Forward Motion Compensation (FMC,) gyro-stabilized mount, airborne GPS (ABGPS,) and Inertial Measurement Unit (IMU). Dual-frequency GPS observation data was collected on-board the aircraft at a one second epoch. Additionally, inertial data was collected during all periods of flight and is collected at a rate of 0.005 seconds. The midpoint of each photo exposure was precisely captured as an 'event' by the GPS receiver. All ABGPS and Inertial data was then post-processed to provide accurate positional and rotation data of the camera for each exposure. Effectively, the three dimensional position (x, y, and z) of each exposure was determined from the ABGPS data while the three-dimensional rotation (omega, phi, and kappa) of each exposure was determined from the inertial data. The IMU data (which includes adjusted position and orientation of the camera at time of exposure) were orthorectified using the relevant USGS Digital Elevation Models. These were processed using Z/I's OrthoPro package. The orthorecitifed images were then mosaicked (if necessary, to reduce the effects of micro-relief on the final product). Product tiles were then extracted from the orthorecitifed images or mosaic and converted to GeoTIFF format. Product RMS accuracy was determined by measuring the metric displacement of common features in adjacent tiles or measuring the ground control that was collected. Metadata files were then created and populated to reflect the relevant tile and project data. Product tiles and metadata were then written to DVD for delivery to USGS."

Metadata for the ARIS data used in this study

All of the GIS datasets are provided in a Geographic coordinate system (NAD83 datum) using latitude and longitude (decimal degree) units of measurement. This "projection" is used for three different formats of the data: Coverages or “Themes,” Arc/Info export files (E00s), and ArcView Shapefiles. For specific information about Themes, such as source and date, refer to the various paragraphs which describe each dataset in greater detail. Within these paragraphs, please note that "Scale" refers to the relative level of detail at which the data were compiled, as indicated by the ratio of map units to actual units of measurement. For example, 1:12,000 scale Themes have the greatest spatial resolution with features within 33.3 feet of their true location, according to the U.S. National Map Accuracy Standards. 1:250,000 scale Themes have the lowest spatial resolution with features within 416.7 feet of their true location.