

USING GIS FOR SAFE BICYCLE ROUTING
IN MORRIS COUNTY, NEW JERSEY

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USING GIS FOR SAFE BICYCLE ROUTING

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Morris County, New Jersey

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Abstract

Through the course of the twentieth century, American has become increasingly dependent on the automobile, so much so that bicycling was referred to by some as the “forgotten mode of transportation.” Subsequently, in the past several years bicycle riding has regained some of its popularity due to new active lifestyle trends, fluctuations in gasoline prices, and environmental awareness. As a result of decades of urban sprawl and car-centric planning, bicycles are often not accommodated on roads shared with motorized vehicles. Standard computer navigation programs that are suitable for vehicles often yield dangerous routes for bicycles. Existing bicycle-specific routing programs are not specific to Morris County. They may carry incomplete datasets or have general algorithms that are not specifically suitable for the study area.

This research sought to create a GIS-based routing application that would route a bicyclist of any riding ability in the safest and most feasible way possible. The study first inventoried all bicycle facilities from a number of resources. Next, the road network was analyzed and classified to determine the degree of safe bicycle suitability of each road segment. Bicycle suitability factors have included road classes, zoning, traffic, and slope. The datasets were then combined and a cost analysis was performed to determine a score for each road segment in the resulting routing network. The cost also took into consideration a distance factor in order to avoid unreasonably long distances. ArcGIS

Network Analyst was configured to run the model so that when a user enters two or more points, the model yields turn-by-turn directions and a map. The results of the research were mixed. Although the model always yielded the safest routing option possible, the route was not necessarily perceived as safe for all bicyclists, especially young and novice riders. This is partly due to the nature of Morris County. In some cases, the only available routing option between two destinations is a busy thoroughfare with no available bicycle facilities. This issue can be used as a case in point when considering the accommodation of bicyclists in future circulation planning in Morris County. This model and the research should not be seen as final. It can be expanded upon with the availability of new and better data, it can be added to a website as an online tool, and it can be merged with other studies from neighboring counties to provide for regional seamless safe bicycle routing.

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List of Abbreviations

| | | |
|--------|---|--|
| AASHTO | - | American Association of State Highway and Transportation Officials |
| ADT | - | Average Daily Traffic |
| BCI | - | Bicycle Compatibility Index |
| BLOS | - | Bicycle Level of Service |
| CDC | - | Center for Disease Control and Prevention |
| DEMs | - | Digital Elevation Models |
| DOT | - | Department of Transportation |
| FHWA | - | Federal Highway Administration |
| GIS | - | Geographic Information Systems |
| LiDAR | - | Light Detection and Ranging |
| LOS | - | Level of Service |
| NHTSA | - | National Highway Traffic Safety Administration |
| NJDOT | - | New Jersey Department of Transportation |
| NJOIT | - | New Jersey Office of Information Technology |
| OGIS | - | Office of Geographic Information Systems |
| SRTS | - | Safe Routes to School |
| USDOT | - | U.S. Department of Transportation |

Chapter 1 - Introduction

Few of us who learned how to ride a two-wheeled bicycle will ever forget how it felt to ride a bike as a child. There was a certain magical feeling of freedom, of power to go faster than ever before, of seemingly endless possibilities. Having a parent let go of their hold and riding away on a bicycle could be viewed as a childhood rite of passage. In American culture, the novelty of the bicycle wears off around high school years. This is when teenagers experience another rite of passage, one that involves going through the process of getting a license, and getting behind a wheel of a car.

It is not surprising that American society is car-centric. Statistics for bicycle use as a mode of transportation in the United States have been low since the end of World War II when vigorous federal spending was dedicated to the rapid development of the high speed Interstate Highway system (Environmental Defense Fund 2010). The fast and efficient movement on highways along large distances promoted the development of single-family residential neighborhoods in areas further away from the traditional city centers resulting in vast suburban areas. The common single-tract American suburban design is often disjointed and has a poorly connected network of streets that rarely accommodate bicycle, pedestrian, or mass transit options (Girling & Kellett 2005). This urban sprawl resulted in increased car dependency while alternative modes of transportation such as walking, bicycling, and mass transit decreased (Environmental Defense Fund 2010). The United States had become so accustomed to traveling by automobile that by 1990 the United States Department of Transportation's (USDOT) Federal Highway Administration (FHWA) referred to bicycling and walking as the

“forgotten modes of transportation” (Federal Highway Administration 2004). A 2002 national survey by USDOT’s National Highway Traffic Safety Administration (NHTSA) reported that 72% of people over the age of 16 have never ridden a bicycle or have not ridden a bicycle for over 30 days (NHTSA 2003). These statistics are particularly low when compared to bicycle use in European countries. For example, according to a 2001 survey, residents of Netherlands, a country known to be bicycle friendly, have logged 24.7% of all their trips on a bike (Bax 2004).

Many indicators show that the practice of using a car for nearly all trips taken is simply not sustainable. Gridlock traffic has increased to all time highs, with the average American spending 24 minutes per day or over 100 hours annually commuting to work (U.S. Census Bureau 2009). Lack of proper exercise, partly due to increase in driving and decrease in walking and bicycling, contributed to historically high obesity rates. According to the Center for Disease Control (CDC) estimates, 26.7% of adults in America are obese (CDC 2010). More alarming are the increased obesity rates in children. A survey by CDC found obesity rates of 10.4%, 19.6%, and 18.1% among American children within age groups of 2-5, 6-11, and 11-19, respectively (Ogden & Carroll 2010). Heavy use of cars, especially for short trips, has several adverse environmental conditions that include poor air quality due to gasses emitted from exhausts, traffic noise pollution, and water pollution from pollutants leaking from cars and into waterways (U.S. Environmental Protection Agency 2000). Motorized vehicles emit carbon dioxide into the air, contributing to the process of global warming. Perhaps most tangibly, drivers have seen the cost of filling up their tank sky-rocket in recent years. In May 2008, crude oil hit \$135 per barrel, a 20% increase in one month and a

more than 100% increase in a year and half (Forbes 2008). Since the start of the economic recession that began in 2008, the price of oil has fluctuated from its record highs; however, this break in rising oil prices is seen as temporary. As global markets recover from the effects of the recession, demand for oil will undoubtedly rise again, especially in emerging economies, thus bringing up the price of crude oil to record highs once again (U.S. Energy Information Administration 2010).

These factors, among others, are reshaping Americans' attitude towards bicycling. Recent trends show that Americans are having a renewed interest in bicycling as a recreational activity as well as an alternative to driving short distances. There are plenty of reasons for governments at all levels to encourage this reignited interest. Bicycling improves overall well-being by providing healthy exercise. Traveling by bike reduces car trips thereby reducing road congestion, air pollution, and greenhouse gas emissions. It is an inexpensive mode of transportation, especially when compared with the cost of operating an automobile at times when the cost of gasoline trends higher. The combination of using human muscle to move bicycle chains and wheels provides for the most efficient way to transport mass over a distance (on average 0.15cal/g*km), beating cars, and even jets, and trains (Grava 2003). Communities that encourage bicycle use are characterized as more desirable, promoting businesses, working families, and tourism (Flusche 2009). Publications such as Money Magazine routinely use bicycle usage statistics as one criterion to rank most livable communities (Money Magazine 2008).

1.1 Research Background

The existence of bicycle facilities, lanes or paths that are designated for safe usage by bicyclists can greatly improve the real and conceived safety of riders and boost the rates of bicycle usage in a town. To any cyclist, a dedicated bicycle path that is segregated from motorized vehicles is a nicely inviting alternative to a narrow, congested vehicular road that lacks the sharing space between cars and bicycles. Many municipalities have been trying to accommodate more bicycle use by considering bicycle riders in their transportation master plans. There has also been an increase in newly built bicycle facilities. At the federal level, for example, the annual allowance for bicycle and pedestrian infrastructure projects has increased from \$2 million in 1990 to \$422 million in 2003 (Federal Highway Administration 2004). A number of cities have already taken dramatic steps in creating extensive bicycle facility networks. In Portland, Oregon, for instance, there are 280 miles of bicycle facilities while Boulder, Colorado boasts over 350 miles of bicycle facilities (Bower et al. 2007; Ferguson 2007).

The three most common types of bicycle facilities are multi-use off-road bicycle paths, assigned bicycle lanes, and paved shoulders. The most desirable facility option to a cyclist is the off-road bicycle paths which do not allow motorized vehicle access. Bicycle paths and paved shoulders are facilities that are integrated with motorized traffic. These facilities are more common as they are easier to integrate into existing and planned circulation networks and are easier to maintain.

Segregated bicycle paths, built away from motorized traffic, can be for the exclusive use of bicycles or can be multi-purpose with the shared use of pedestrians, equestrians, or other sports (sleds, cross-country skiing, etc.). The Rails-to-Trails paths

are an example of such multi-use facilities. These former railroad lines are rehabilitated into multi-use trails by the Rails-to-Trails Conservancy. The flat and straight characteristics of these former railroad tracks make them appealing for conversion into bicycle or multi-use paths. Railroad lines also tend to run in interconnected networks in the vicinity of urban areas. To date, there are 19,872 miles of rail-trails open in the U.S. (Rails-to-Trails Conservancy 2010).

Bicycle lanes are essentially an extra built-in lane of traffic that are designated for the exclusive or the preferential use of cyclists. These lanes are clearly marked with appropriate striping markings and signage. Bicycle lanes are popular in urban areas and are widely used in New York City.

Paved bicycle shoulders accommodate bicyclists by providing a width of space next to moving vehicular traffic. The shoulders vary in width but they are typically narrower than a bicycle lane. They may or may not allow parking. “Share the Road” signs are typically posted near these facilities.

For the average or novice cyclist, finding the safest route to get from point A to point B may be a daunting task. Information about the location of bicycle facilities in the area may be sparse, outdated, or not readily available. In addition, despite efforts to incorporate bicycling into transportation plans, the majority of Americans do not live in communities that maintain a vast network of bicycle facilities. As a result, most bicycle trips are taken at least partially on roads shared with cars. This can be an intimidating experience. Inexperienced bicyclists may think like motorists and pick the shortest route from their starting point to their destination. Most online mapping applications were built for car navigation purposes and tend to provide the fastest route for travel by car. In

reality, the shortest or fastest route suitable for a car is not necessarily the easiest or the safest route on a bicycle. High-speed roads with little room for bicycles can create hazardous riding conditions; some roads may have a steep grade that is not suitable for novice riders; other roads such as interstate highways, prohibit the use of bicycles all together.

1.2 Research Objectives

The objective of this research is to create an interactive Geographic Information Systems (GIS) application that provides safe feasible bicycle routing information when a starting location and an end destination are provided. The provided route should ultimately be safe enough for bicyclists of all riding experience. It should include road segments most suitable for enjoyable and safe bicycling with road characteristics such as flat surface, low traffic volumes and plenty of room for safe maneuvering.

1.3 Study Area

The study area chosen for this research is Morris County located in northern New Jersey (Figure 1.1). The County has a total area of 469 square miles. It is bordered by Somerset, Hunterdon, Warren, Sussex, Passaic, Essex, and Union Counties. Morristown is the County seat. The terrain in the study area is mostly flat in the eastern, more populated section of the County. Rolling hills turn into the New Jersey Highlands region in the western portion of the County.

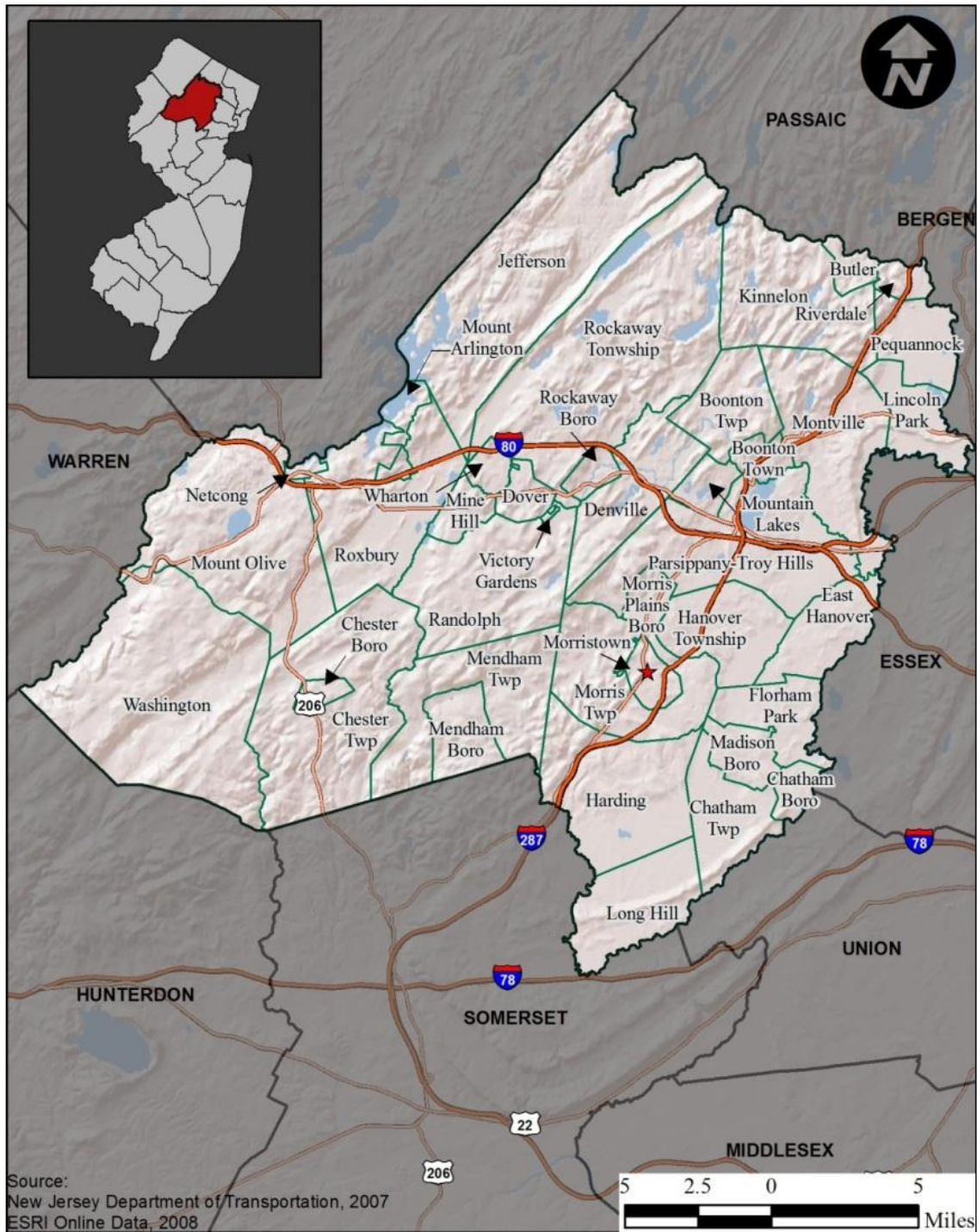


Figure 1.1 Study Area

In many ways, Morris County typifies transportation trends in the United States. New Jersey is the most densely populated state in the country mostly due to population expansions in the vicinity of two major neighboring metropolitan areas of New York City and Philadelphia. Morris County, approximately 30 miles northwest of New York City, has been affected by urban sprawl. Once an agricultural community, it is now considered to be part of the Greater New York Metropolitan area with many residents commuting daily to New York City. Two New Jersey Transit train lines run through the County and offer services to New York City; however, no other state destinations are offered and few other transportation options are available. Car usage in the County is, as expected, very heavy. According to the U.S. Census survey 2005-2009 5-year estimate, 87.50% of Morris County workers commute by car, and out of these, 79.8% drove alone (U.S. Census Bureau 2009). As expected from an area with vast urban sprawl, commute times are high with the average travel time to work standing at 29.3 minutes (U.S. Census Bureau 2009).

There are a number of current regional and local initiatives to encourage bicycling in Morris County. On the state level, the New Jersey Department of Transportation's (NJDOT) 1995 Statewide Bicycle and Pedestrian Master Plan kicked off a state-wide effort to identify and improve bicycle and pedestrian needs around the state. The state is encouraging local communities to include bicycle facilities within their circulation planning by conducting joint studies and by helping to make funding available. Citizens are voicing their desire to have better bicycle conditions with grassroots organizations. Critical Mass is a celebratory gathering of local bicyclists of all types for a monthly ride to promote bicycle road safety (Dahl 2009). Critical Mass in Morris County has been

active since August, 2007. Safe Routes to School (SRTS) is another community based effort, supported by federal and state funds, that encourages children to walk or bike to school. Wharton Borough, Netcong Borough, Mine Hill Township Parsippany, and Madison have all participated in some degree in the SRTS program (SRTS 2012).

To date, there hasn't been an organized effort to interactively map bicycle facilities and bicycle-compatible roads that focused specifically on Morris County. This research is designed to route local bicycle trips within the County in a safe, feasible, and fun manner.

Chapter 2- Literature Review

Special mapping for bicycle use is not a new concept. In 1899, the *New York Times* published a short feature about creating bicycle maps with such tips as "... the bicyclist, who is out for pleasures, by no means wishes to be tied to the nearest and most direct road from place to place. He desires to combine, as far as possible, the best roads with the finest scenery, and to have a choice even in that" (*New York Times* 1899). The following section discusses the history and developments of bicycle route mapping and how different approaches relate to this research.

2.1 History of Bicycle Road Mapping

The bicycle was thought to be invented as early as the 16th century; however, it wasn't until the 1890s when the Safety Bicycle was invented that bicycling became a social phenomenon. With similar-sized smaller wheels, a rear-wheel chain drive and lower center of gravity, this bicycle provided a safer, more efficient ride than its earlier counterparts. The Safety Bicycle was less expensive thanks to factory assembly line manufacturing, a change from its predecessors that were assembled in their entirety by a local craftsman, making the bicycle affordable to the masses, and quicker to fulfill high demands (McKernon 2007). The immense popularity of this version of the bicycle sparked the "bicycle craze", an important shift in bicycling history when cycling ceased to be a recreational sport serving a few daring men and became a mode of transportation for the masses. The Safety Bicycle was especially appealing to women with its safe, stable, and comfortable design (McKernon 2007). The Safety Bicycle became a symbol

of new mobility and freedom for women (Figure 2.1). Prominent feminist Susan B. Anthony said: "let me tell you what I think of bicycling. I think it has done more to emancipate women than anything else in the world. It gives women a feeling of freedom and self-reliance. I stand and rejoice every time I see a woman ride by on a wheel...the picture of free, untrammelled womanhood" (New York Sunday World 1896).

Prior to the time of the bicycle craze of the 1890s, only a small portion of roads were regularly maintained and few were adequately mapped. During this time, maintenance of roads was the responsibility of local government organizations (Akerman 2002). As a result, the only roads that were regularly maintained were almost entirely located in the densely populated cities of the Northeast. Less traveled roads such as ones in rural areas and those located between cities fell outside the jurisdiction of local governments and with the lack of proper funding, these roads were hardly traversable. Those who ventured out for a trip on one of these roads risked injury and damage to their equipment (Akerman 2002). Consequently, map publishing firms largely focused on marketing road maps for city streets and heavily traveled routes, ignoring rural roads and longer, less-traveled routes in between cities (Akerman 2002).

As the bicycle craze took hold, several bicycling groups began organizing across the country. One of the most notable groups was the American League of Wheelmen, formed by Colonel Albert Augustus Pope in 1880. Pope, the largest manufacturer of bicycles in the United States, under the brand name of Columbia, saw the need for more paved roads for bicycle use. He recognized that his bicycle manufacturing business would soar if bicyclists had decent paved road networks to ride on. Pope studied the European paved road systems that dated back to the days of Napoleon and with the help

of the League; Pope started the Good Roads Movement, a lobbying effort that argued that the government should be responsible for all roads in the nation and that every county seat should be linked by a paved path (Goddard 2000).

As road projects started around the country, bicyclists from the League of American Wheelmen and other cycling organizations sent a new breed of adventure seeking trailblazers on bicycles with the objective to map all roads, new and old. These young volunteers collected field information about road conditions, distances, grades, and bicycle suitability (Akerman 2002). This information was then processed and published as small pocket-sized atlases, with each map generally scaled to show segments of about 100 miles. Roads were ranked based on cyclists' reviews and were symbolized accordingly. The atlases served as one of the first detailed road mapping efforts in the country. The first official roadmap for New Jersey was published in 1894 by the New Jersey Division of the League of American Wheelmen (Figure 2.2). The *New York Times* described this roadmap atlas as a collection of eight maps dividing the State, each "shows clearly all the roads in that part of the State, together with all points of interest and also tells of exactly what material the roads in different localities are built" (*New York Times* 1894).



MISS LONDONDERRY.

Figure 2.1 – Journal Illustration of Safety Bicycle (Bearings 1894)

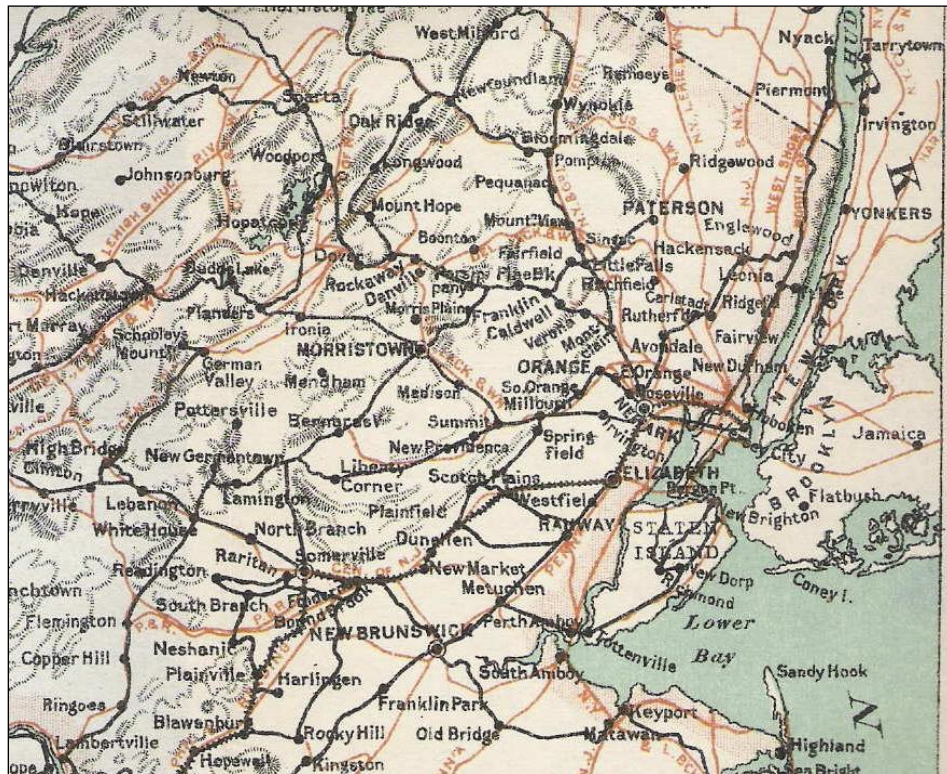


Figure 2.2 – Part of 1894 Index Map for New Jersey American Wheelman Atlas

By the 1920s the bicycle craze ebbed and the shift from the bicycle to the automobile in the United States was in full swing. Henry Ford came out with the Model-T car in 1908 and by end of production in 1927, 15,000,000 cars were sold, earning its reputation as “the car that put America on wheels" (Franks 2008). Even American bicycle pioneer Colonel Albert Augustus Pope ended his bicycle manufacturing empire in order to promote his new electric vehicle business – the Columbia Automobile Company (Flink 1988). As the American population started its love affair with motorized vehicles, road making and subsequent mapping efforts began catering to the driver rather than accommodating bicyclists.

Following decades of apathy towards bicycling, a gradual shift in attitude started occurring in the 1990s. With more awareness towards the health, economic, and environmental benefits of cycling, many Americans began dusting off their bicycles and getting on the road. While this change was not the sweeping culture transformation that happened in the 1890s, more and more people turned their interest to bicycling both as a sport activity and as a mean of transportation. The federal government has been encouraging municipalities to include bicycle accommodations in their municipal circulation plans by providing various aid programs to local governments; however, the actual implementation of bicycle facilities has been a slow on-going process that is taking place in discontinuous patchy regions of the country. It is not uncommon to see dedicated bicycle lanes that end abruptly at a municipal boundary. It is then not surprising that there is no one uniform method to map bicycle facilities.

2.2 The Traditional Paper Map

In 2002, the Morris County Department of Transportation published its Bicycle and Pedestrian User Guide, complete with a map showing all bicycle and pedestrian facilities in the County. This map is made available to the public by downloading a digital file of the pamphlet from the department's website. A pamphlet map, such as this, is still the most common way that municipalities provide information about bicycle facilities to their constituents. The production of this type of pamphlet requires relatively little resources or time investment. This option may seem attractive for municipalities that face limited funding.

The disadvantages of the paper map are numerous. The full format print of the Morris County Bicycle and Pedestrian User Guide map is not readily available to the average citizen. Out of four popular bicycle and outdoor sports shops contacted, only one shop had a copy of the map and since it was the store's copy, it was not available for distribution. A search of the local libraries shows that copies of the map are available as part of the bicycle element in county's circulation plan document; however, since these documents are considered reference material, they cannot be removed from the libraries. The digital copy that is available for download is set to be printed at a large format poster size that would require access to a plotter. Printed on a smaller page size, the map would have a distorted scale and much of the detail would be practically illegible. Static paper format maps such as the Morris County Bicycle and Pedestrian User Guide are not easy to update on a regular basis. The most current Morris County Bicycle and Pedestrian User Guide was last updated in 2002. In talks with representatives from Morris County Department of Planning in 2009, it was discussed that the County considers the Morris

County Bicycle and Pedestrian User Guide outdated and intends on creating a new edition in the near term; however, as of date, there has not been a newly published Guide. Even after a new Guide is revised and published, the maps need to be reproduced and redistributed, a potentially significant investment and effort.

Despite the disadvantages, the Morris County Bicycle and Pedestrian User Guide has been useful to this research. The Guide is the official bicycle map for Morris County. It was used as a reference for inventorying existing bicycle facilities and for quality assurance purposes in order to ensure that the data presented in this research is consistent with what is shown in the Guide.

2.3 The Digital/Static Hybrid Map – NJBIKEMAP and Bikely

The New Jersey Bike Map (www.njbikemap.com) and Bikely (www.bikely.com) are two examples of more technologically advanced bicycle mapping for Morris County. Both mapping services are served on the internet, reaching a much wider section of the population than a regular static paper map. Both have limited search capacity with no generating capacity and therefore they can be considered as a hybrid between a stand-alone static paper map and a fully interactive digital mapping service.

Developed by Dustin J Farnum Jr., the New Jersey Bike Map is a website that contains a collection of New Jersey maps with roads rated for bicycle suitability. Other features such as parks, paths, and points of interested are also illustrated. Farnum, an avid bicyclist has been touring New Jersey roads for over 30 years, covering about 85% of the state (New Jersey Bike Map 2010). Road information and bicycle-suitability ratings are collected through these personal rides. The maps are compiled using

AutoCAD software and USGS 1:100,000 scale maps. The maps are arranged by county and are downloadable as a PDF file on 8.5x11 paper format, a size that is suitable to use as a bicycle cue sheet. Since these roads are rated based on Farnum's personal experience, it is likely that the rating method used is highly subjective. In addition, Farnum states that he does not rate local level municipal roads, leaving many roads unmapped (New Jersey Bike Map 2010). Farnum's maps were used as a resource in this research to compile an existing bicycle facility inventory. There are a number of paths that are marked in Farnum's maps as dedicated bicycle facilities that are not marked in other resources. In this case, a facility that was not mapped elsewhere was deemed applicable because it was field-verified by an experienced bicyclist.

Bikely is another bicycle service created by bicyclists. Bikely is a Google Maps based application in which users can upload their favorite bicycle routes, hiking and running trails, and motorcycle roads. Each route provides turn-by-turn directions formatted to a cue-sheet, an elevation profile, and observations and tips by the user who uploaded the route. A route may be rated based on the user's bicycling ability and experience, and whether the purpose of the route is for commuting, recreation, or for vigorous training, etc. As of November 2008, there were 66 user-created routes traversing through Morris County. As with the New Jersey Bike Map, these routes are subjective in nature. In addition, only a small portion of the County is rated through this website.

2.4 Google Maps Biking Directions

Google Maps has long been a heavy-weight player in the realm of digital directions for automobiles. In March 2010, Google Maps added its bicycle direction option to its main map interface as a beta test program. The bicycling direction mapping service works just like the normal vehicle directions program. Bicycle-specific turn-by-turn directions are given when a start and an end point are entered by the user. When this option is utilized, highways are grayed out, bicycle facilities are given first priority, and recommended routes that are comprised of roads with flat surfaces and low traffic counts are given second priority (Google 2010). There is a user option to report a problem, such as dead end streets.

Google Maps is progressively updating its bicycling model and data with input received from bicyclists and so bigger metropolitan areas with larger populations of bicyclists may benefit more from the Google service than smaller bedroom communities like Morris County with significantly less bicyclists. Google Maps application seems to have incomplete data for Morris County. None of the bicycle paths are shown in the maps and there are no recommended routes for the area. When mapping bicycle directions in Google Maps around the County, cyclists are sometimes directed to use main roads, and often no consideration is given to bicycle paths or steep elevations.

2.5 Digital Bicycle Routing Applications

There were only a handful of destination-to-destination bicycle routing web applications that existed before the bicycle directions were made available on Google. These applications serve specific locations and are developed in a way that addresses

local challenges and conditions unique to the study area. The following discussion describes two examples: New York City's Ride the City (www.ridethecity.com) and Boulder, Colorado's Go! Bike Boulder (www.gobikeboulder.net).

New York City has been encouraging bicycling as an alternative mean of transportation since it established the Bicycle Network Development Program in 1994 (New York City 2011). The Bicycle Master Plan, issued as part of this program, identified 900 miles of potential bicycle network throughout the city's five boroughs (New York City 2011). In 2007, Mayor Michael Bloomberg introduced aggressive initiatives to promote environmental sustainability in a program called plaNYC. According to the 2008 progress report of the plaNYC, there are currently 420 miles of bicycle facilities in the city, and a new plan will be calling for a total of 1,800 miles of bicycle facilities to be completed by 2030 (City of New York 2008).

The Ride the City website helps bicyclists navigate the city's notoriously congested streets and avenues by providing turn-by-turn directions when a start and end points are provided. The GIS model behind the website considers two variables when generating a route: the shortest distance between the start and end destination, and the location of existing bicycle facilities in the vicinity of the route. There are three options available to choosing a resulting route: most direct route, safe route, and safest route. The most direct route calculates routes based on the shortest legal turn distance between the two destinations. In the safest route calculation, the resulting route utilizes as many existing bicycle facilities as feasible. This may result in a longer route. The safe route option is the compromise between the two previously mentioned options, the distance between destinations as well as utilization of bicycle facilities are both weighted.

Known as an outdoor sports destination, the City of Boulder boasts a massive 350-mile bicycle facility network and has a rate of 14% for trips taken by bike (Ferguson 2007). In June 2007, the City of Boulder, Colorado launched Go! Bike Boulder, an interactive website that provides bicycle trip routing within city limits (Ferguson 2007). The website provides turn by turn directions when points of interest, such as libraries and bike shops, are selected or when start and end addresses are entered in. The user can specify whether they want to be routed on streets or via one of the many multi-use segregated paths and trails that are free of motorized vehicles. The resulting route can be printed on bicycle cue sheets. Options are available to show change in grade along the route in an elevation profile. Also, various calculations are available for each route such as calorie calculator, carbon emissions savings and cost savings calculator.

This research strives to arrive at a similar destination-to-destination route generating format that these two websites offer. The main difference lays in the nature of each study area. Both Boulder, Colorado and New York City have vast bicycle facility networks on which their models heavily rely upon to generate routes. Morris County, on the other hand, is larger in area than both Boulder and New York City and has far fewer bicycle facilities. The Boulder model uses a more complex calculation to generate its routes by including roads that do not have bicycle facilities. These roads are assigned values based on various criteria including steep grade, driveway frequency, posted speed, vehicle volume, on-street parking, etc. (Ferguson 2007). The Morris County model similarly has to rank roads that do not have existing facilities in order to have a complete network for route generating analysis. The Boulder model utilized data analysis made by a traffic consultant to determine street bicycle suitability ranking and no specific ranking

algorithms were published. It is safe to assume that since Boulder and Morris County areas differ so widely, the same algorithm wouldn't suit both study areas.

2.6 Bicycle Suitability Ranking

As seen in the Boulder model, roads without bicycle facilities can be incorporated into a routing model by ranking them based on how compatible they are for shared use by motorists and bicyclists. The section below describes three popular bicycle suitability methods: Bicycle Stress Test, Bicycle Compatibility Index, and Bicycle Level of Service.

2.6.1 Bicycle Stress Test

One of the first research studies on road compatibility for bicyclists was performed by the Australian Geelong Bikeplan Team in 1978. The study concluded that bicyclists naturally seek to reduce physical effort; however, the reduction of mental stress caused by navigating congested roads is equally important (Jones & Carlson 2002). Based upon their collective experience, the bicyclists on the Bikeplan Team determined that the three top road factors with potential to cause most stress to the bicyclists were curb lane width, motor vehicle speed, and traffic volume (Jones & Carlson 2002).

Work from the Geelong Bikeplan Team was expanded upon in research by Sorton and Walsh (1994). In their Madison, Wisconsin study, participants with various riding experience were asked to view videotapes of 24 road segments that differ in the three variables that were originally examined by the Geelong Bikeplan Team: curb lane width, posted speed, and traffic volume. For each segment shown on the videotape, the

participants ranked each of the three road variables from a scale of 1 to 5. The final score for each segment was derived by averaging the three scores.

The bicycle stress tests take a very straight-forward approach in rating roads for bicycle friendliness. The two bicycle stress studies described above, for instance, observed only three road factors in their scope of study. These makes for easy recreation of the study, computation of data and communication of results to technical as well as non-technical audiences. However, because of the limited number of road factors and the heavy reliance of surveyed participants, these results can also be seen as too simplistic and somewhat subjective.

2.6.2 Bicycle Compatibility Index and Level of Service

The Bicycle Compatibility Index (BCI) was first developed for the Federal Highway Administration in 1998. The index looks at numerous road variables and rates suburban and urban roads based on a bicyclist's degree of comfort in riding these roads under different road conditions (Harkey et al. 1998). The participants in a number of cities were asked to view video clips of roadway segments with different variables (such as on-street parking, presence or absence of a shoulder, driveways, etc.). The participants then rated these segments based on how comfortable they would feel riding a bicycle along these roads. Comfort levels were compared for each road variable and were found to be similar among the majority of participants, whether they were novice or experienced bicyclists and whether they were city dwellers or lived in more suburban or rural setting (Harkey et al. 1998). The study established the BCI model formula (Equation 2.1) with adjustment factors (Table 2.1):

$$BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.022SPD + 0.506PKG - 0.264AREA + AF$$

Equation 2.1

where:

BCI = Bicycle Compatibility Index

BL = presence of a bicycle lane or paved shoulder greater than 0.9 meter

No = 0 *Yes* = 1

BLW = bicycle lane (or paved shoulder) width, meter (to the nearest tenth)

CLW = curb lane width, meter (to the nearest tenth)

CLV = curb lane volume, vehicles per hour (v/hr) in one direction

SPD = 85th percentile traffic speed, *km/h*

PKG = presence of a parking lane with more than 30 percent occupancy

No = 0 *Yes* = 1

AREA = type of roadside development

Residential = 1 *Other type* = 0

AF = adjustment factors

$AF = f_t + f_p + f_{rt}$

where:

f_t = adjustment factor for truck volumes (see Table 2.1)

f_p = adjustment factor for parking turnover (see Table 2.1)

f_{rt} = adjustment factor for right-turn volumes (see Table 2.1)

Table 2.1 – BCI Model Adjustment Factors (Harkey et al. 1998)

| Hourly Curb Lane Large Truck Volume (Vehicles with six or more tires) | t | Parking Time Limit (minutes (min)) | p | Hourly Right- Turn Volume (total number of right turns into driveways or minor intersections along a road segment) | rt |
|---|------|---|------|---|------|
| ≥ 120 | 00.5 | ≤ 15 | 00.6 | | |
| 60–119 | 0.4 | 16–30 | 0.5 | | |
| 30–59 | 0.3 | 31–60 | 0.4 | ≥ 270 | 00.1 |
| 20–29 | 0.2 | 61–120 | 0.3 | < 270 | 0.0 |
| 10–19 | 0.1 | 121–240 | 0.2 | | |
| < 10 | 0.0 | 241–480 | 0.1 | | |
| | | > 480 | 0.0 | | |

The Level of Service (LOS) concept was developed by the Transportation Research Board to rate roadways and highways for their flow effectiveness based on a motorized vehicle operator’s perception (National Research Council 2000). Factors affecting the LOS score of a road segment include travel time, traffic flow disruptions, convenience and ease of navigation (Harkey et al. 1998). The rating system ranges from A to F with A as the highest rating signifying free flow and F as the lowest ranking. The BCI model expanded on this concept by offering a bicycle-specific LOS rated using the BCI score as shown in Table 2.2, with lower scores ranking higher on the LOS scale. The BCI/LOS model is a widely accepted method in evaluating existing bicycle facilities and roads for their bicycle compatibility. It is the only method used on a federal level.

Table 2.2 – Bicycle Level of Service with Bicycle Compatibility Index Ranges (Harkey et al. 1998)

| LOS | BCI Range | Compatibility Level |
|-----|-------------|---------------------|
| A | ≤ 1.50 | Extremely High |
| B | 1.51 – 2.30 | Very High |
| C | 2.31 – 3.40 | Moderately High |
| D | 3.41 – 4.40 | Moderately Low |
| E | 4.41 – 5.30 | Very Low |
| F | > 5.30 | Extremely Low |

Critics of the BCI model claim that the study is flawed in a number of ways. Pein (2007) claimed that having the survey participants view recordings of road segments rather than actually riding these roads provides inaccurate representation of real world conditions. Specifically, the camera positioning may vary between road segments with shoulders or dedicated bicycle paths and roads without a bicycle facility, potentially skewing the perception of the film viewer. Pein (2007) also stated that many important factors such as bicyclist’s maneuverability, bicyclist speed and delay were left out of the BCI model.

In the critique of the BCI model, Allen (2003) reiterated the idea that the BCI is flawed by not considering bicyclist mobility, an important factor in determining the level of service in other modes of transportation. Other flaws in the BCI methodology include not incorporating instances when a bicyclist must take over the lane to the left, specifically when cars park in dedicated bicycle lanes, the skewed perception of bicyclist travel speed with the stationary video camera, and not accounting for vehicle-bicycle interactions at crossroads and intersections (Allen 2003).

2.6.3 The Bicycle Level of Service

Landis et al. (1997) proposed a bicycle level of service (BLOS) that is different from the BCI-associated LOS as discussed in the previous section. Similarly to the BCI model, the BLOS model was developed using bicyclist ratings of various road conditions. The roads were rated based on the perceived comfort and safety as participants rode through a prescribed course that included various road conditions. Experiences were reported in real time. There were a total of 150 bicyclists of varying age groups and riding experience. The looped course traversed through road conditions that are most likely to be found in U.S. urban setting. The results were analyzed and a BLOS model was formulated (Equation 2.2). The resulting BLOS model took into consideration more road variables than its BCI counterpart, and reported more detailed results. The level of service criteria were established as shown in Table 2.3.

While the BLOS model is quite data intensive and may be costly to reproduce with little funding, it is a popular method of ranking roads for their bicycle suitability. This model has been applied in government and planning agencies across the nation including many state master plans.

$$\text{BLOS} = a_1 \ln(\text{Vol}_{15}/L) + a_2 \ln[\text{SPD}_p(1 + \%HV)] + a_3 \ln(\text{COM15} * \text{NCA}) + a_4 (\text{PC}_5)^{-2} + a_5 (W_e)^2 + C$$

Equation 2.2

where:

BLOS = Bicycle Level of Service/perceived hazard of the shared-roadway environment

Vol₁₅ = volume of directional traffic in 15-minute time period

L = total number of through lanes

SPD_p = posted speed limit

%HV = percentage of heavy vehicles

COM15 = trip generator intensity of the land use adjoining the road segment (stratified to a commercial trip generation of 15, multiplied by the percentage of the segment with adjoining commercial land development)

NCA = effective frequency per mile of noncontrolled vehicular access (driveways and on-street parking spaces)

PC₅ = FHWA's 5-point pavement surface condition rating

W_e = average effective width of outside through lane

a₁ : 0.507

a₂ : 0.199

a₃ : 7.066

a₄ : -0.005

C : 0.760

where:

(a₁-a₄) = coefficients established by multivariate regression analysis

Table 2.3 – Bicycle Level of Service (Landis et al. 1997)

| LOS | BLOS Score |
|-----|-----------------------|
| A | ≤ 1.5 |
| B | >1.5 and ≤ 2.5 |
| C | >2.5 and ≤ 3.5 |
| D | >3.5 and ≤ 4.5 |
| E | >4.5 and ≤ 5.5 |
| F | > 5.5 |

2.6.4 Bicycle Suitability – State of Practice

Government entities on the state and local levels as well as other planning organizations around the U.S. use a variety of methodologies to evaluate their roads for bicycle suitability (Day 2003; NJDOT 2004; Turner et al. 1997). As shown in this section, some entities choose methods that are a deviation of the widely accepted BCI and BLOS methods while other organizations opt for customized solutions (Arizona Department of Transportation 2003; Turner et al. 1997; Barsotti & Kilgore 2001; NJDOT 2004; Somerset County, NJ 2007).

The Arizona Department of Transportation considered the following parameters to evaluate state roads for bicycle suitability: right shoulder width, traffic volume to capacity ratio, percent trucks to cars, and speed limit (Arizona Department of Transportation 2003). Each variable was broken down to four classes and each class was assigned a score. Right shoulder width and traffic volume variables were weighted twice as much as percent trucks and speed limit. Scores for all road segments were tallied to derive final assessments (Arizona Department of Transportation 2003).

For their state-wide bicycle maps, the Colorado Department of Transportation considered two variables to determine bicycle suitability: average daily traffic (ADT) and outside lane width (Turner et al. 1997). The traffic volume data was broken down to 4 classes with ranges that included roads with less than 1,000 vehicles per day as most suitable and roads with more than 5,000 vehicles per day as least suitable. The outside lane width was broken down to two classes: less than or greater than 4 feet in width. In order to encourage bicycle tourism, the Colorado Department of Transportation also considered additional road suitability criteria such as elevation change, scenery and available amenities (Turner et al. 1997). These customized criteria were based on recommendations from a panel of bicyclists. Specific tourism routes were developed based on the panelists' suggestions.

The Illinois Department of Transportation used the following criteria to evaluate bicycle suitability, listed here in order of importance: traffic volumes (for roads with and without truck traffic), lane widths, width of paved shoulders, and road surface conditions (Barsotti & Kilgore 2001). Each category was broken down to three classes, with each class having a score. The breakdown of the classes and the associated scores were derived using a consensus of a panel of bicyclists. The final result was a series of bicycle maps spanning the State with roads classified in the following three categories:

- most suitable for the average/experienced cyclist,
- Cautionary for cycling, but may be suitable for more experienced cyclists who are comfortable with riding in traffic conditions
- Should be avoided by cyclists

In the Phase II of the New Jersey Department of Transportation (NJDOT) Statewide Bicycle and Pedestrian Master Plan, a modified version of the BCI model was used in order to calculate bicycle suitability on all state routes and certain county routes (NJDOT 2004). Specifically, the NJDOT model included traffic from other lanes into the model by adding the following into the BCI equation (Equation 2.1): $+ 0.0004$ (*Other Lane Volume*). The NJDOT also adjusted the resulting BCI scores so that they are ranked in the range of 0 to 100 with 100 representing the most suitable roads (NJDOT 2004). The LOS criteria were changed accordingly to reflect the BCI score range, as shown in Table 2.4.

In 1996, eight years prior to the publication of the Phase II report for the New Jersey Statewide Bicycle and Pedestrian Master Plan, the NJDOT published the *Bicycle Compatible Roadways Planning and Design Guidelines* report. In addition to bicycle facility design guidelines, the report provides a true/false model to identify specific road segments where minimum improvements need to be made in order to make it compatible for bicycle use (NJDOT 1996). The model, shown in Table 2.5, was compiled based on local transportation experts as well as on report by FHWA's (NJDOT 1996).

In the State of New Jersey, several counties and planning entities used the 1996 NJDOT model to evaluate bicycle compatibility. In 2000, Cumberland County analyzed 200 miles of roads using this model in order to determine where there are missing links of bicycle compatible roads within the County's roadway system (NJDOT 2004). Franklin Township used this model to prioritize bicycle facility improvements projects (NJDOT 2004). Somerset County produced a county-wide bicycle map showing roads classified as suitable for biking, roads where caution needs to be taken, and roads with difficult

biking conditions (Somerset County, NJ 1997). Classifications were derived using the NJDOT Bicycle Compatible Roadway Pavement Widths model, as well as other parameters including shoulder conditions, sight distance, traffic entering and exiting the roadway, and other potential hazards for bicyclists (Somerset County, NJ 1997; NJDOT 2004).

Table 2.4 – NJDOT Bicycle Level of Service (NJDOT 2004)

| LOS | BCI Range |
|-----|----------------|
| A | 89 - 100 |
| B | 82 - 88 |
| C | 75 - 81 |
| D | 69 - 74 |
| E | 61 - 68 |
| F | < 60 |
| L | Limited Access |

Table 2.5 – NJDOT Bicycle Compatible Roadway Pavement Widths (NJDOT 1996)

| Traffic Speed (mph) | Urban with Parking | Urban without Parking | Rural |
|--|--------------------|-----------------------|-----------------|
| Condition I – Average Daily Traffic 1,200-2,000 Vehicles | | | |
| <30 | Shared lane 12' | Shared lane 11' | Shared lane 10' |
| 31 – 40 | Shared lane 14' | Shared lane 14' | Shared lane 12' |
| 41 – 50 | Shared lane 15' | Shared lane 15' | Shoulder 3' |
| >50 | N/A | Shoulder 4' | Shoulder 4' |
| Condition II – Average Daily Traffic 2,000-10,000 Vehicles | | | |
| <30 | Shared lane 14' | Shared lane 12' | Shared lane 12' |
| 31 – 40 | Shared lane 14' | Shared lane 14' | Shoulder 3' |
| 41 – 50 | Shared lane 15' | Shared lane 15' | Shoulder 4' |
| >50 | N/A | Shoulder 6' | Shoulder 6' |
| Condition III – Average Daily Traffic >10,000 Vehicles or Trucks over 5% | | | |
| <30 | Shared lane 14' | Shared lane 14' | Shared lane 14' |
| 31 – 40 | Shared lane 14' | Shoulder 4' | Shoulder 4' |
| 41 – 50 | Shared lane 15' | Shoulder 6' | Shoulder 6' |
| >50 | N/A | Shoulder 6' | Shoulder 6' |

Chapter 3 - Conceptual Framework and Methodology

The scope of this research was to build a GIS routing application, designed for safe routing of bicyclists in Morris County, New Jersey. The beginning and end points of each route are entered by the user and the route is picked based on the location of bicycle facilities and streets that are deemed most suitable for bicyclists. To create this model, an inventory of bicycle facilities was compiled and street data was analyzed with available data parameters in order to determine bicycle suitability. This chapter discusses the technical aspects of the research in detail including data used and steps taken to build the model.

3.1 Morris County

Morris County, with its bedroom communities, historic downtowns, open spaces and farmlands, does not fit the stereotypical rough and tough New Jersey stereotype that is often portrayed in popular American entertainment media. Morris County, established in 1739, can be generally described as middle to upper class suburban area. Located in northwestern New Jersey, it is approximately 25 miles due west of New York City and is considered to be part of the New York Metropolitan Area. Morris County is comprised of 481 square miles (Morris County Planning Board 2007). It has 39 municipalities with Morristown serving as the County Seat and Parsippany as the largest and most populous municipality. When traveling from east to west, one will encounter flat, more densely populated suburban communities rising to rolling hills and higher peaks with more rural and agricultural communities.

The area in and around Morris County is rich with historical resources. It was originally inhabited by the native Lenni-Lenape tribes. Colonized as part of the Dutch New Netherland Colony, it was first settled by Europeans the early 18th century when it was part of the Province of New Jersey. Morris County is named after Lewis Morris, the governor of the province at that time. During the Revolutionary War, Morris County was an important strategic location for George Washington and the Continental Army. The Morristown National Historic Park includes two of Washington's army winter encampment sites as well as a site on a hill that served as a fire signal point. Numerous historic sites and places of interest dating from the Revolutionary War are scattered throughout the County.

About 22% of the land in the County, about 105 square miles, is designated as park, open space or wildlife management areas in the County (Morris County Planning Board 2007). Two major federal parks are located within the County, the Morristown National Historic Park, and the Great Swamp National Wildlife Refuge. Preserved and active farmland constitutes 10% of the County's land area (Morris County Planning Board 2007). Recent open space initiatives, land acquisitions, and continuous voter support for open space all contribute to the high percentage of farm and open space in New Jersey and in Morris County. Almost the entire County is designated to be within the Highlands Region area. This large swath of ecologically important land stretches across seven counties in northwestern New Jersey and contains critical drinking water resources that serve over 5 million people within the New York Metropolitan Area (Highlands Water Protection and Planning Council 2008). A large swath within the Highlands jurisdiction, called the Highlands Preservation Area, has special planning and

development restrictions in order to preserve natural areas, protect water sources, and discourage urban sprawl. 188 square miles or 39% of Morris County total land area is included within the Highlands Preservation Area (Morris County Planning Board 2007).

Employment in Morris County trends heavily on white collar executive and research jobs. Numerous Fortune 500 companies and research facilities have their headquarters or major operations in Morris County. Some of these companies include Novartis, Kraft, Honeywell, Pfizer, Johnson and Johnson, Cadbury, etc. Morris County residents are most likely to be employed in the management, professional and technical occupations (Morris County Planning Board 2007). According to the 2007 U.S. Census data, median household income in Morris County topped \$92,000, ranking second highest in New Jersey and fifth highest nation-wide (Morris County Economic Development Corporation 2009).

The high wages are often offset by the high cost of living in Morris County and especially the high cost of housing. Available land for development is becoming scarce. Development restrictions due to open space and preserved farmland deeds, as well as Highlands Preservation laws, have significantly reduced the remaining available land for housing. As of 2005, 81% of the County's land was considered developed (Morris County Planning Board 2007). Where development has occurred, the trend has been to build large single family luxury type dwellings on large lots. As a result, new residential construction has been limited. According to real estate website Zillow that tracks home values, the median home price in Morris County as of April 2011 was \$371,300, as compared to \$268,400 state-wide and \$170,100 nation-wide (Zillow 2011). New Jersey is also notoriously known for its high property taxes. The average property tax paid by a

homeowner in Morris County in 2009 was \$7,904, the eighth highest amount in the nation (Tax Foundation 2011).

A cheaper alternative to new development is the redevelopment of existing housing in the downtown areas of the County's municipalities. In recent years, redevelopment projects largely consisting of higher density multi-family type units have been proposed or implemented in Morristown, Dover, Netcong, and Butler (Morris County Planning Board 2007). Some downtown redevelopment projects, such as the ones located in Morristown, are built around the "Transit Village" concept, developing residential areas within walking distance to shopping and services as well as to mass transit options such as bus stops and train stations (Morris County Planning Board 2007). This concept encourages the development of much needed housing options and at the same time discourages the heavy dependency on personal vehicles. These downtown redevelopment projects are located near already existing bicycle facilities or in municipalities that are studying implementation of additional facilities to their circulation plans.

3.2 Data Sources

The primary data in any GIS network model is the linear data on which the routing is based on. In this research this data was based on the road network data for Morris County and a compilation of bicycle facility data, which included bicycle lanes, designated paths and paved shoulders.

The road data was received from Morris County's Department of Planning, Development & Technology, GIS Section in 2008. This street data contains linear

features for all streets and highways in the County. The associated attribute table includes street names, municipalities, and other associated data that can be used to determine location by address. One-way streets are designated accordingly the table. The traffic direction is marked by having the sequence of vertices from first to last in the direction of traffic. Other fields for data such as posted speed and curb width were present in the attribute table but at the time of research these fields were not yet populated.

Bicycle facility data was gathered from a variety of sources. The Second Phase of the New Jersey Bicycle and Pedestrian Master Plan included a task to create a spatial inventory of existing and proposed bicycle facilities throughout the State. This data, received from NJDOT included data sets for each county of New Jersey. These data sets were compiled by NJDOT using any available data from individual counties as well as from planning organizations, bicycling groups, and environmental organizations (NJDOT 2004). The associated attributes to the bicycle facility data include the status of the facility (existing, proposed, or funded but not yet built) and whether the facility is on- or off-road. NJDOT originally received most of this data in paper map format that was then digitized into a geodatabase. When brought in to the GIS environment, the bicycle facility datasets didn't appear to be spatially accurate and did not align properly to the street data or aerial imagery, and additional manipulation of this data was needed in order to make it ready to be used in the model. Details of these processes are included in the methodology description in the next section.

In addition to the State's facilities data, a number of other sources were utilized to compile facilities data for the model. The Morris County Bicycle and Pedestrian User

Guide was another major source of bicycle facility data. Data from this source was digitized from a scanned version of this map that is only available as a paper format. PDF files of bicycle facilities compiled from Franum's NJBikemap website were used in the model. These maps, originally done in AutoCAD but only available digitally as PDF files, were also georeferenced and digitized into a geodatabase. Municipal bicycle facility information was available for Madison and Randolph. Madison's data, compiled by the city engineer, was originally created in AutoCAD but was only available in scanned paper version. Randolph data was shown as part of a larger trail paper map. Both data sets were compiled by using heads-up digitization. Lastly, the NJDOT's County Road and Sidewalk Inventory was used in the model. This data, available in GIS formats that include shapefiles and geodatabases, was queried to show any bicycle path and bicycle lane data in Morris County. This feature data did not spatially align with the Morris County street data and additional manipulation was needed to incorporate this information. Details of this are provided in the following methodology section.

Aerial imagery was used as a reference throughout the model generation process. It was used for checking spatial accuracy of line features, for georeferencing scanned maps, and to digitize designated bicycle facilities paths as seen in the imagery. The aerial imagery available for this research is the 2007 New Jersey High Resolution Orthoimagery, published by the New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS) 2008. The imagery was captured from March to May in 2007 and was produced at a scale of 1" = 200' with a 1-foot pixel resolution. The imagery is comprised of 5,000-foot by 5,000-foot tiles.

The degree of traffic, a parameter used in the bicycle suitability modeling, was determined from traffic count data, obtained from the Morris County Department of Transportation. Traffic counts are conducted on a selection of streets every spring and fall. Traffic data utilized in this report were from 1992 through 2008. The following methodology section describes the way in which the traffic data, originally in a tabular form, was manipulated to be included in the GIS model.

Zoning data was utilized to differentiate residential streets from non-residential streets, another parameter used in the bicycle suitability model. Zoning data was received from Morris County's Department of Planning, Development & Technology, GIS Section in 2008.

Terrain data was used to analyze slopes, another suitability model parameter. Light Detection and Ranging (LiDAR) data from the New Jersey Highlands Council was used for this task. This high resolution elevation data was collected in 2007 and spanned the entire area of the Highlands Region and surrounding areas. The entire area of Morris County was covered in this effort. The Highlands Council provided the native LiDAR data as LAS files as well as additional derived data. One of these products included a large series of Digital Elevation Models (DEMs) created by post-processing bare earth LiDAR data elevation points into raster databases with a resolution of 5'x5'. These high resolution DEMs were used to calculate slopes for the model.

3.3 Building the Model

The general steps that were taken to build the network model are illustrated in the work flow chart (Figure 3.1). The following section will describe in more details the outlined steps.

3.3.1 Compiling the Road and Facility Features

The first step was to prepare the current street data for use in the model. As mentioned above, the street data used was received from Morris County. It spatially aligns up to aerial imagery and it seems to be a largely complete set of roads and highways in the County. There were two topological tasks that were performed on the dataset. The first topology rule used was the Must Not Overlap rule. This is to ensure that only one road segment is considered by the model for any road portion. The rule also checks for overlap in data. The second topology rule that was established was the Must Not Have Dangles. This rule was set so that the network has continuity and that segments are not erroneously cut off. While checking this rule, there were a great number of exceptions that had to be set for all the dead-end roads and cul-de-sac streets in the County. The next action was to break the road segments at their vertices in order to get more street segments in the network. Breaking a road segments into smaller sections allows for multiple ranking of that road. Thus, the model can have more choices when routing a bicyclist.

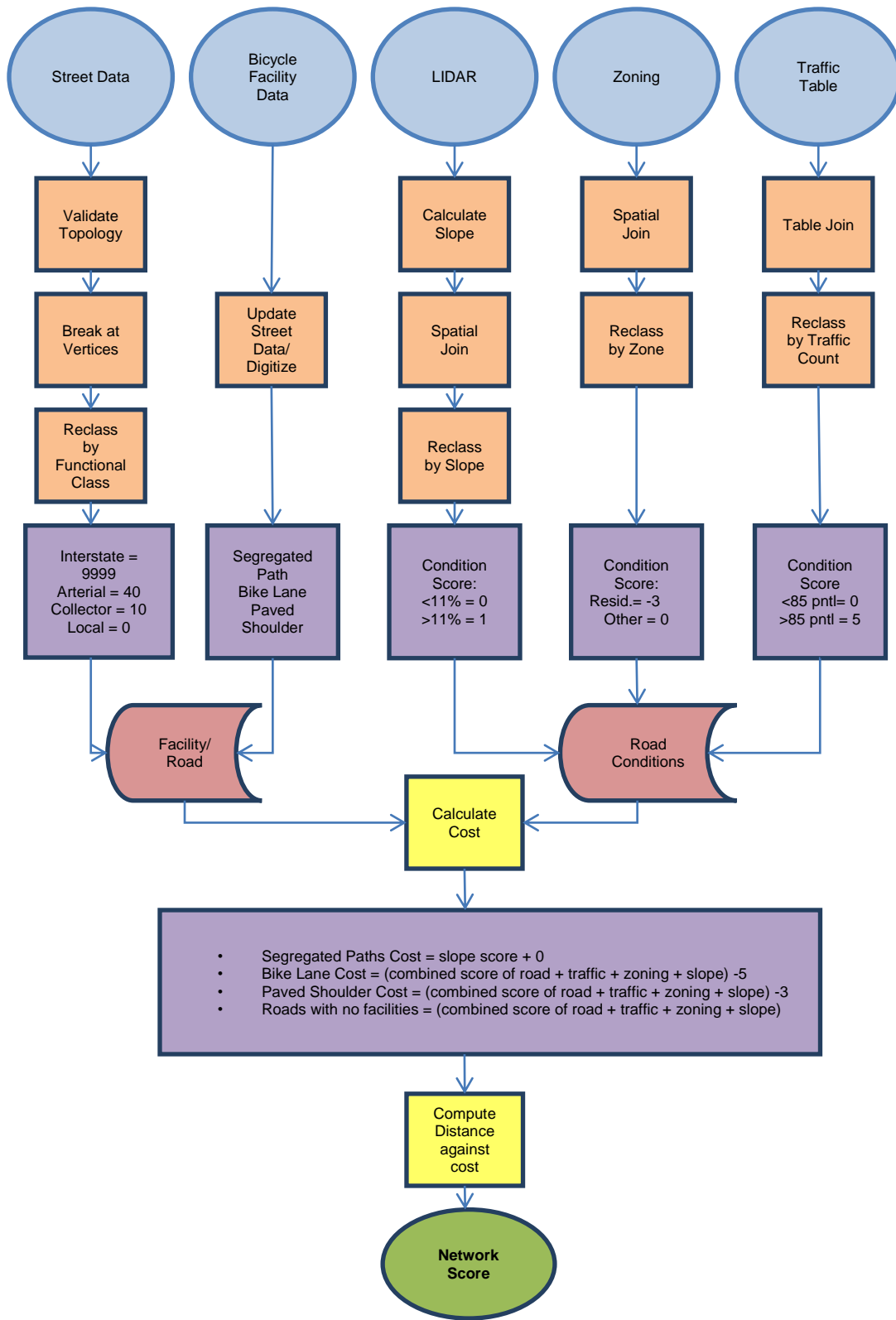


Figure 3.1 – Model Flow Chart

As stated in the previous section, the bicycle facility inventory for this research came from a number of sources in various types of formats. Spatial data sets received from NJDOT included the New Jersey Bicycle and Pedestrian Master Plan as well as the County Road and Sidewalk Inventory. These data sets were not spatially accurate and did not properly align with the street data or aerial imagery. In order to incorporate them into the database, each line feature had to be manually examined. Bicycle facilities on roads were matched appropriately based on the streets attributes. For example, Main Street in Madison, having a designation of a bicycle lane, was matched accordingly. Designated bicycle facilities that do not follow roads, such as the non-motorized rail-to-trails paths were digitized and spatially corrected using the general location of the bicycle facility from the shapefile and aerial imagery. Digital images of bicycle maps from Morris County Bicycle and Pedestrian User Guide, NJBikemap, and municipal maps were all georeferenced to aerial imagery. The network dataset was built up to contain all street and bicycle facility features. Figure 3.2 shows the bicycle facility network in the study area.

3.3.2 Gathering the Road Conditions

The next step was to add road conditions to the network database. As discussed earlier in Chapter 2, when reviewing the literature on the state of practice in determining road bicycle suitability around the nation, it was found that studies used various numbers and types of road conditions to rank suitability. The Colorado DOT, for instance, used only average traffic volume and outside lane width (Turner et al. 1997) while other organizations used the BLOS method that utilizes eight different road conditions and

other parameters. The level of detail in creating each model stemmed from data and resources that were available to the organization running the bicycle suitability model. In addition to the road and bicycle specific information, this research utilized three additional available data parameters to evaluate bicycle suitability: zoning, traffic and slopes. The study took a customized approach to rate suitability based on these data parameters.

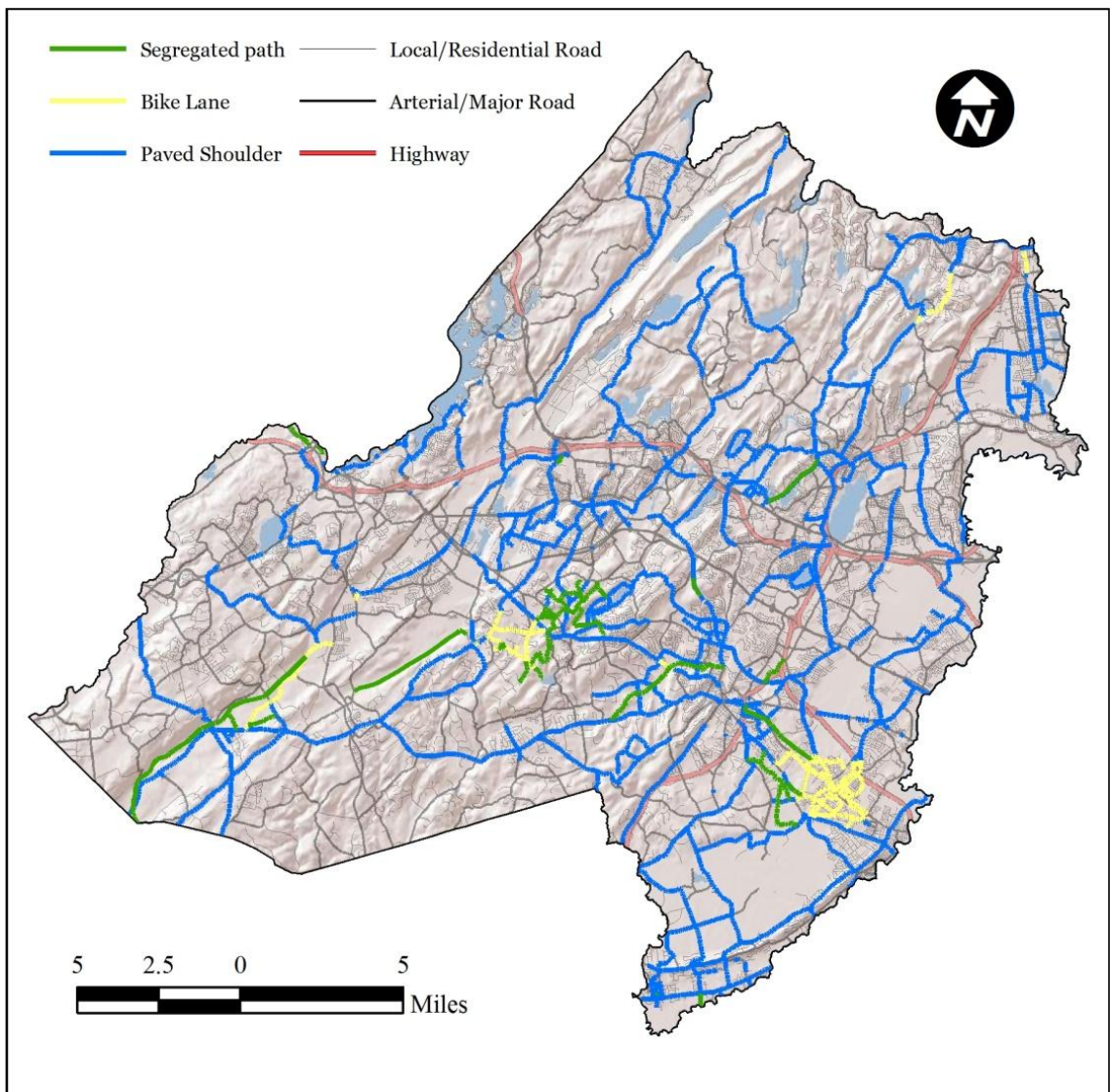


Figure 3.2 - Bicycle Facility Network in Study Area

The type of land use in the area in which a road segment runs through is a criteria used in the widely used and detailed BLOS model. In addition, the type of land use also inadvertently determines posted speed limits. New Jersey residentially Residentially zoned neighborhoods typically have lower posted speed limits and less traffic than commercial and industrial zoned areas and thus are more suitable for bicycle riding. Land use zoning was taken from zoning datasets received from Morris County. The road and facility network dataset was spatially joined to the zoning polygon dataset to get zoning information for each line segment. Line segments were classified to be in a residential zone or in other designated zoning. If a road segment had residential on one side of the line and another designation on its second side, the other designation was favored.

Vehicular traffic was used as a road condition parameter in a many bicycle suitability models. Traffic counts were not available for most roads in Morris County; however traffic counts for some roads were compiled in the Traffic tables from Morris County DOT. The data from the traffic tables was joined by a table join to the road and facility network database.

Slope was used as a minor road condition parameter in this research. While not widely used in many suitability models, it is still a good criteria for a bicycle routing model. A bicyclist will most often favor a level road over a hilly slope. It can be daunting to cycle up a steep hill and dangerous to descend down a steep slope in high speeds, especially for novice riders that do not have the experience to navigate or stop a speeding bicycle in a shared road. Grade is a factor in the Boulder, Colorado routing model (Ferguson 2007). Similarly to Boulder, Morris County has some steep roads,

especially towards the western boundary that bicyclists should avoid, given an alternative. Slope for this research was derived from the Highlands LIDAR-derived DEMs. The resulting slope coverage was a raster dataset. The linear road and facility network was buffered a short distance of 5 feet to create a polygon dataset. Zonal statistics of the average slope were derived using the polygon dataset as the designated zones. The zones were then incorporated back to the linear network dataset by creating a table join using the unique values that matched those of the polygon buffer dataset.

3.3.3 Reclassifying the Road Parameters and Calculating Road Costs

The bicycle routing model is in essence a cost analysis of bicycle facilities and roads with road conditions as parameters. As an analogy, each adverse condition such as busy roads, no bicycle facility or steep grade can be seen as a weight added to a bicyclist's backpack. A cyclist would naturally choose the route that has the least amount of weight, or adverse conditions. In order to calculate these road costs, each parameter was reclassified to a numerical value. Next, all road conditions costs for each segment were added up to derive a numerical cost.

Roads were reclassified based on their functional class to three categories: local/residential, major/arterial and highway. Due to the highly residential nature of Morris County, the vast majority of the roads, 81% of total road miles, are designated as local or municipal (Morris County Planning Board 2007). Since drivers prefer the easier navigation of regional arterial roads, these roads tend to have high traffic counts, congestion, and high posted speed limits. Navigating these busy arterial roads can be daunting. Most intersections at state and county roads ban left turns forcing drivers to

look for the infamous jug-handle turns. These turns, located at a back of an intersection, take a driver around a loop circle, emulating a handle of a jug, before straightening out across and over an intersection (Figure 3.3). These take the places of left turns at an intersection. While bicycling is not completely banned on state and county roads, it is highly not advisable to use these busy roads on a bicycle route when given an alternative, especially for novice riders. As a result when determining an appropriate road condition score, regional arteries were assigned a score of 10 while local and municipal roads were assigned a score of 0. The remaining highway functional classed roads ban bicycle use altogether. These roads were assigned the very large score of 9999 in order to have the model not consider them as an option for routing. Figure 3.4 shows the road network in the study area as classified by these three classes.



Figure 3.3 – Jug Handle Turn Example (Bing Maps 2012)

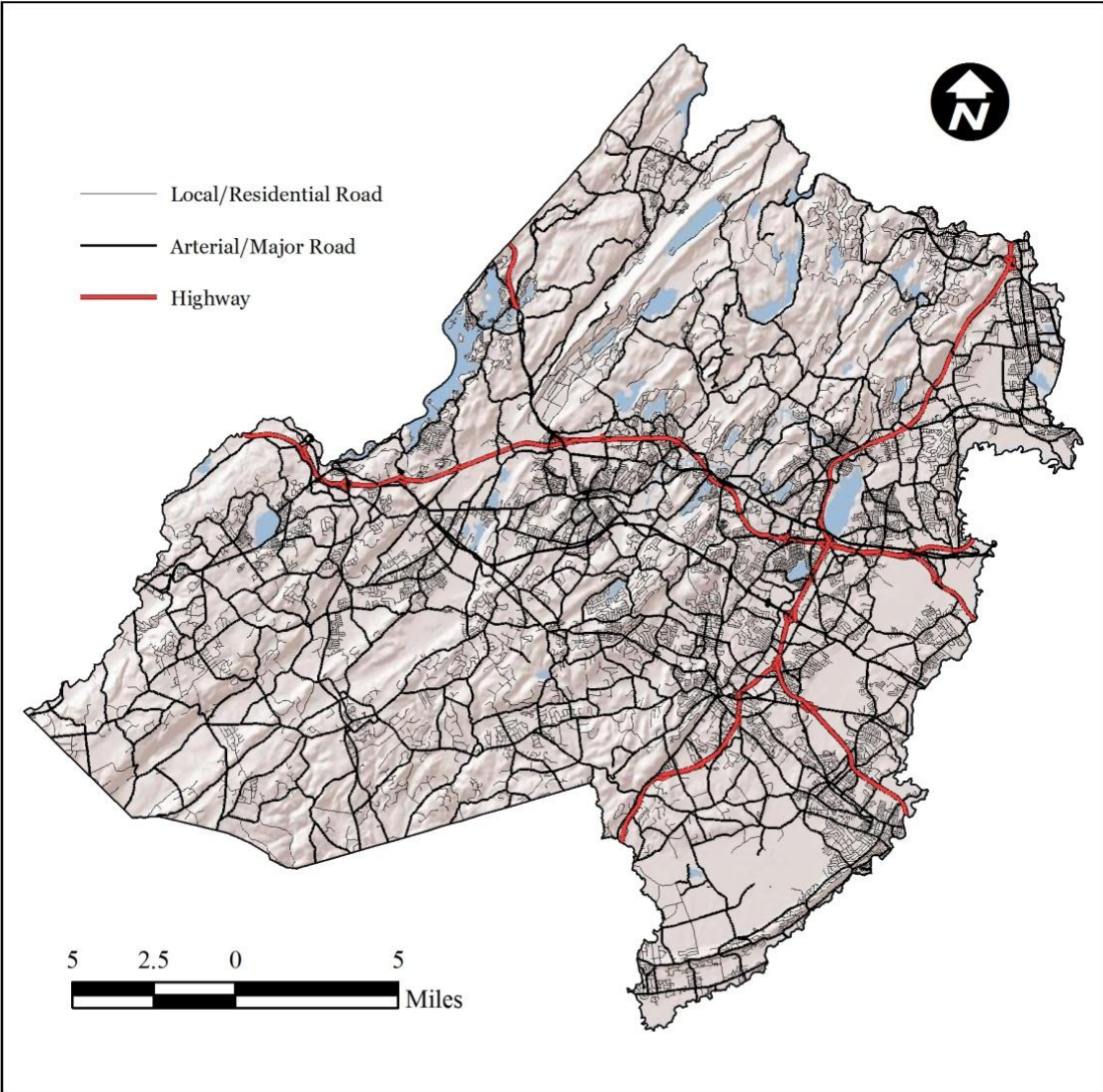


Figure 3.4 - Road Network in Study Area

As described in the previous section, zoning was classified as residential or other. For this study, a bicyclist is better off riding in a residential zone than a zone designated as industrial or commercial due to heavier vehicle traffic counts, the presence of curb-side parking, and the number of trucks in the vicinity of businesses. Some commercially zoned properties have a mix of multi-unit housing, such as the case in downtown Morristown. In other cases schools, libraries and other points of interest may be located at zones that are not designated as residential. For these reasons, a non-residential zone was assigned the score of 0 and the residentially zoned road segments were assigned a score of -3. The reasoning behind this score assignment is not to add a weight to the road segment, should it fall within a land use zoning that is not residential, but to reduce the cost of those road segments that fall within residential streets thus favoring them in the model. Figure 3.5 shows the two zoning classifications in the study area.

The traffic count parameter was considered only for the very highly congested streets. One reason for this is that only a small number of roads were sampled in the traffic count tables, thus possibly skewing the data. Another reason for this is that road conditions can vary greatly in the arterial roads, and some roads that have a medium count some days may have lighter traffic on other days. It can be said with some confidence that the streets with the highest traffic counts tend to be congested on most days and in most conditions. Roads that were in the highest 85th percentile for traffic counts were given a cost score of 5 while all others were given a cost of 0. Figure 3.6 shows the location of these road segments.

When considering the road grade parameter, the research looked to the 1999 *Guide for Development of Bicycle Facilities* by the American Association of Highway

and Transportation Officials (AASHTO). According to this widely used guide, a slope over 11% is not recommended for bicycle use in segments that are longer than 50 feet (AASHTO 1999). Based on this statement, segments with slopes over 11% were reclassified with a cost of 1. All other roads were given a score of 0. The low cost of slope meant to reflect that road grade is not necessarily a highly important factor when determining road suitability. Figure 3.7 shows the location of these steep slope road segments.

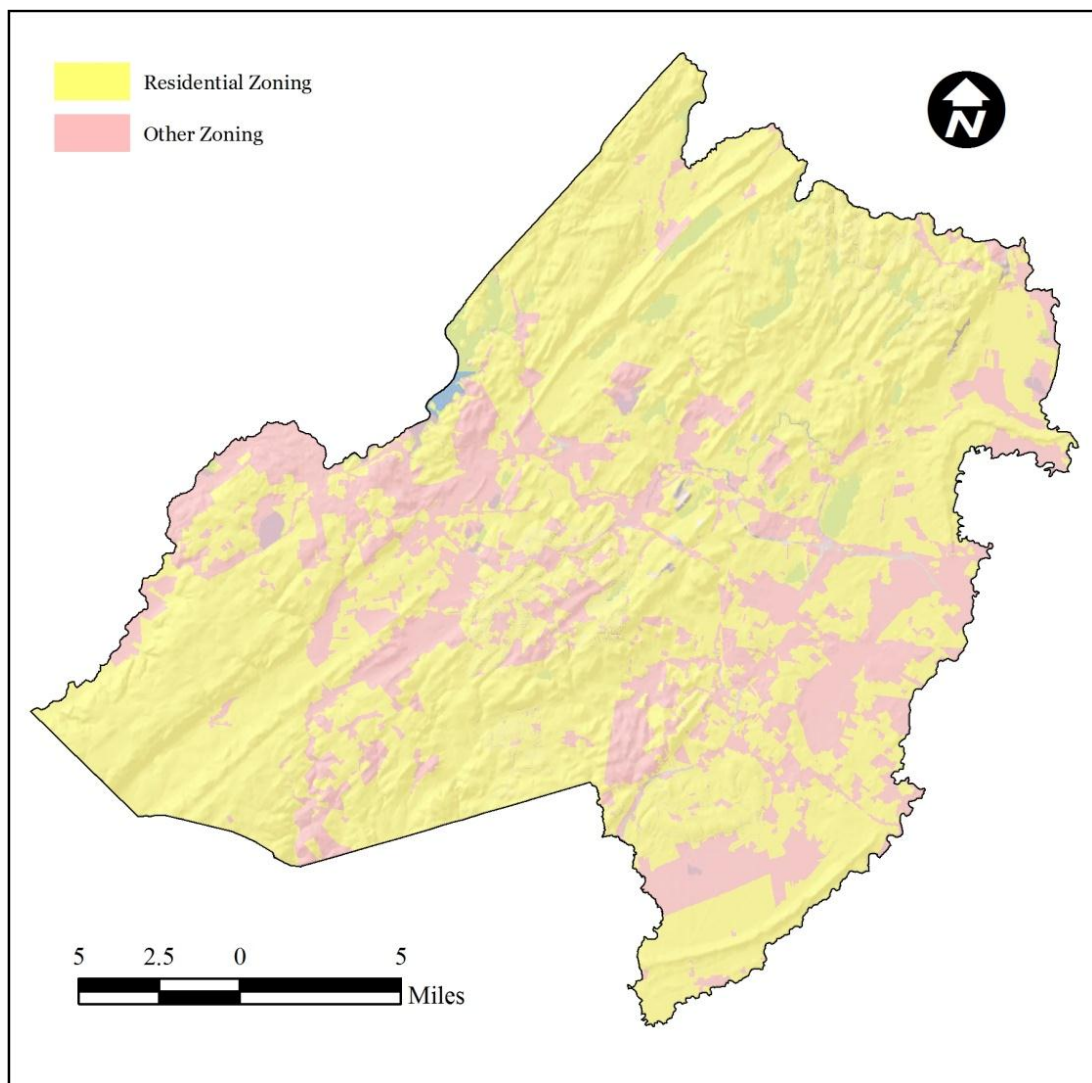


Figure 3.5 - Zoning in Study Area

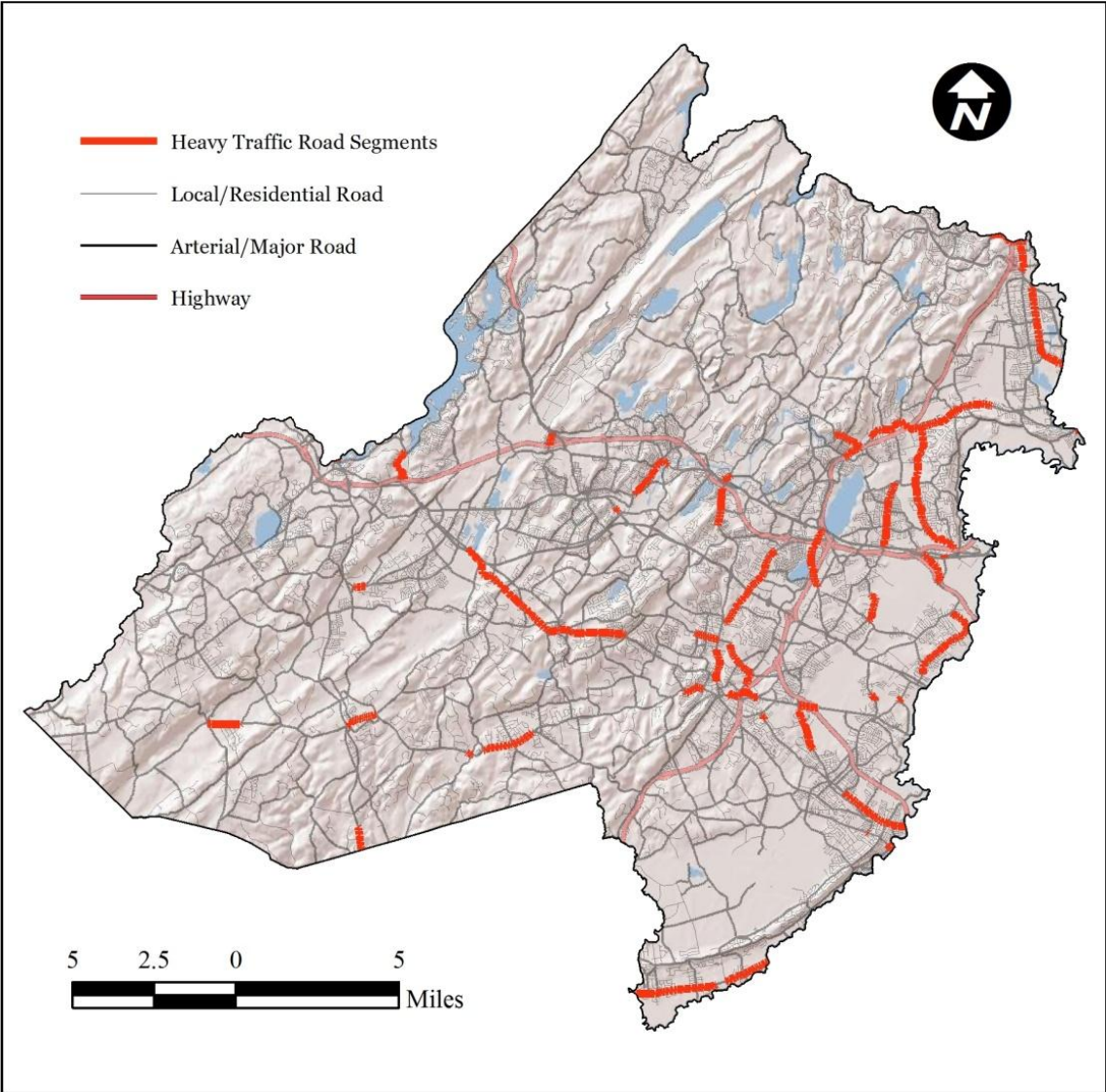


Figure 3.6 - High Traffic Road Segments

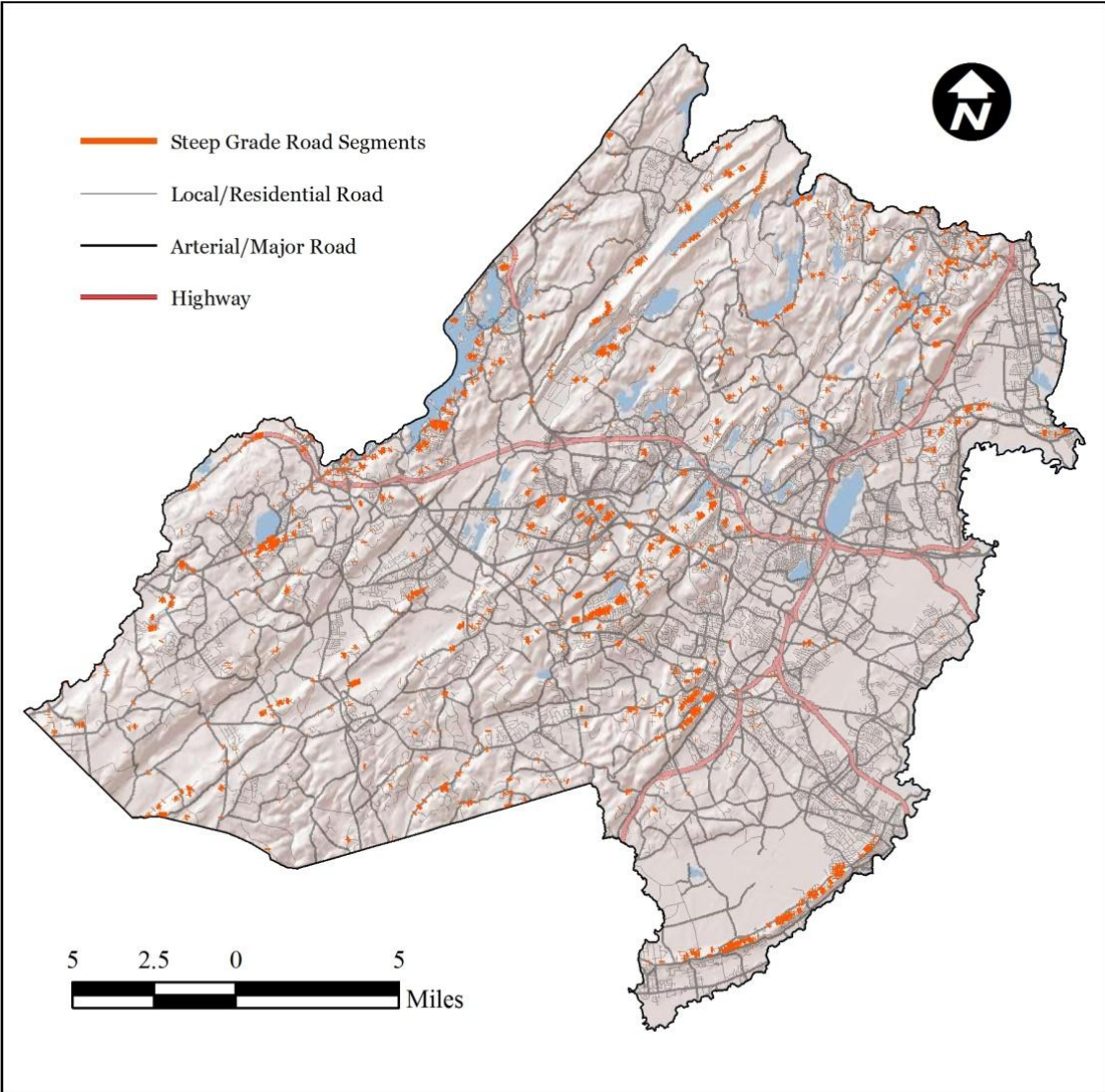


Figure 3.7 - Steep Grade Road Segments

When determining the total cost of each road segment, all of the parameters above were added and combined with bicycle facility type as shown in Equation 3.1.

$$\text{Segregated Bicycle Path Cost} = \text{slope} + 0$$

$$\begin{aligned} \text{Road Segment with Bicycle Lane Cost} \\ = (\text{combined score of road} + \text{traffic} + \text{zoning} + \text{slope}) - 5 \end{aligned}$$

$$\begin{aligned} \text{Road Segment with Paved Shoulder Cost} \\ = (\text{combined score of road} + \text{traffic} + \text{zoning} + \text{slope}) - 3 \end{aligned}$$

$$\begin{aligned} \text{Road Segments with no Facility Cost} \\ = (\text{combined score of road} + \text{traffic} + \text{zoning} + \text{slope}) \end{aligned}$$

Equation 3.1

For segregated bicycle paths with no vehicular traffic, there are no road conditions to consider; therefore the model only needs to factor in slope in order to calculate cost. For all other conditions, the cost parameters have to be added. The presence of a bicycle lanes and paved shoulders are favored by reducing the cost by 5 and 3, respectively. All other roads with no bicycle facilities do not get any other deductions.

One immediate observation when using this equation is that a road segment with a paved shoulder or a bicycle lane could have lower cost than a segregated bicycle path. For example, a local road with low traffic that is zoned residentially and has a paved shoulder facility could have a score of -6 while a neighboring segregated bicycle path would have a score of 0. This means that the model may choose the road segment with a paved shoulder over using the segregated bicycle path. Making the segregated bicycle facilities the lowest possible scored segments would have meant that the model would have made it a priority to direct the cyclist to the path at some point of the route, even if

that meant making the rest of the trip more dangerous by going through streets with no facilities and busier arterial roads. With the algorithm set up the way it is, the model considers the entire route and chooses the segregated path only if the rest of the route is safe for riding. Only roads with other facilities, those with dedicated lane or paved shoulders, can be chosen over a segregated path. There are only a handful of segregated bicycle paths in the study area. Most of them are surrounded by arterial roads or roads without facilities. Here, the model favors the segregated paths. The segregated paths in Randolph Township and the Traction Line path that runs near Morristown and Madison are two areas where segregated paths are located near residential, local roads that have bicycle paths and paved shoulders. In these two areas, the model may pick a road segment with a paved shoulder or bicycle lane over the segregated path, depending on the overall route.

In the next step of the model database creation, the cost analysis factored in the length of each road segment. Without factoring in the distance element, the model would route a cyclist through the least cost weighted road segments between the two entered points. As a result, a 6 mile bicycle trip could potentially turn into a 20 mile trip. The distance consideration makes the model more practical while favoring the safety. The distance-weighted score, the numerical score used by the network model, was calculated by using Equation 3.2.

$$\text{Network Road Segment Score} = \text{segment length} + (\text{segment length} * (\text{road cost}/10))$$

Equation 3.2

In this equation, the road cost is divided by 10. When testing the model, it was found that leaving the road cost unchanged yielded large numbers that skewed the results by favoring segments too much and thus affecting the connectivity around them. In addition, some road costs with large negative values created negative network road segment scores. This program required the use of positive values. When further testing the model, division values greater than 10, such as 50 and 100, yielded results with little impacts, meaning that a road segment with a bicycle facility was only very slightly favored over a segment with no other facilities. The division by 10 seemed to strike the right balance of network favorability between segments that have facilities and those that do not. In addition, none of the road segments came back with negative values.

As the last step, the actual network was created using Esri's ArcCatalog 9.3 and Network Analyst Extension. The network road segment score, derived from the formula above, and distance were used as cost attributes in the model. One way streets were used as restrictions, so that bicyclists are not routed to go in the wrong illegal direction on those streets. The global directions option was turned on and turn-by-turn settings were made appropriate for bicycle cue sheet use.

Chapter 4 - Analysis, Results and Conclusions

The data compilation and the various calculations that were described in the previous sections yielded a bicycle-routing model with results as described in this chapter. As intended, the model yields a graphical representation of the most bicycle-suitable route as well as turn-by-turn directions when two points are entered by clicking the physical location in the interface or by entering the address of each point. The model can calculate a route with any number of stops.

4.1 Routing Example - Morristown

In this first example, a bicycle route was calculated in Morristown. This area typifies the more densely populated areas of the County that are located mostly in the flatter eastern side of the study area. The town serves as the county seat and has a vibrant downtown with some of the oldest neighborhoods in the state.

The route was calculated between Thomas Jefferson Elementary School and Morristown High School located across town. The route is shown in Figure 4.1. The generated cue sheet with a smaller map is shown in Figure 4.2. The model directs the bicyclist through quieter, more residential streets through most of the model, keeping off arterial streets with high vehicular volumes. According to 2010 accident data from the NJDOT, there were 7 motor vehicle accidents that involved a bicyclist within Morristown municipal limits with 3 of these accidents occurring on Route U.S. 202 (NJDOT 2011). The calculated bicycle route completely avoids this busy and potentially dangerous road. One-way street rules are honored by the model as shown by the route going around the

correct configuration around the main square in the center of town, called the Green, at the intersection of Washington and South Streets.

The two points of interest are located across town from each other and in order to get from one point to the other, one must go through the center of town where the central business district is located. Due to the street layout of the town and its hilly topography there is no other easy and feasible way to navigate around the center of Morristown. This can be seen in Figure 4.3. Segments 7, 8, and 10 that direct the bicyclist to ride on South Street, going around the Green, and on Spring Street are typical busy center of town streets, especially at rush hour.

In comparison, Google Map bicycle routing between the same two points is as shown in Figure 4.4. The Google model uses proprietary data and the algorithms used by the application have not been published, so it is not surprising that the routing information is somewhat different than the results shown in this research. However, the basic elements of the route are the same in this example. Most of the route is directed to go on smaller, less travelled residential streets with the exception of the segments nearing the center of town. Google Map routes the bicyclist through Bank Street, an extension of U.S. Route 202, and Washington Street, an arterial road, both busy major streets in Morristown.

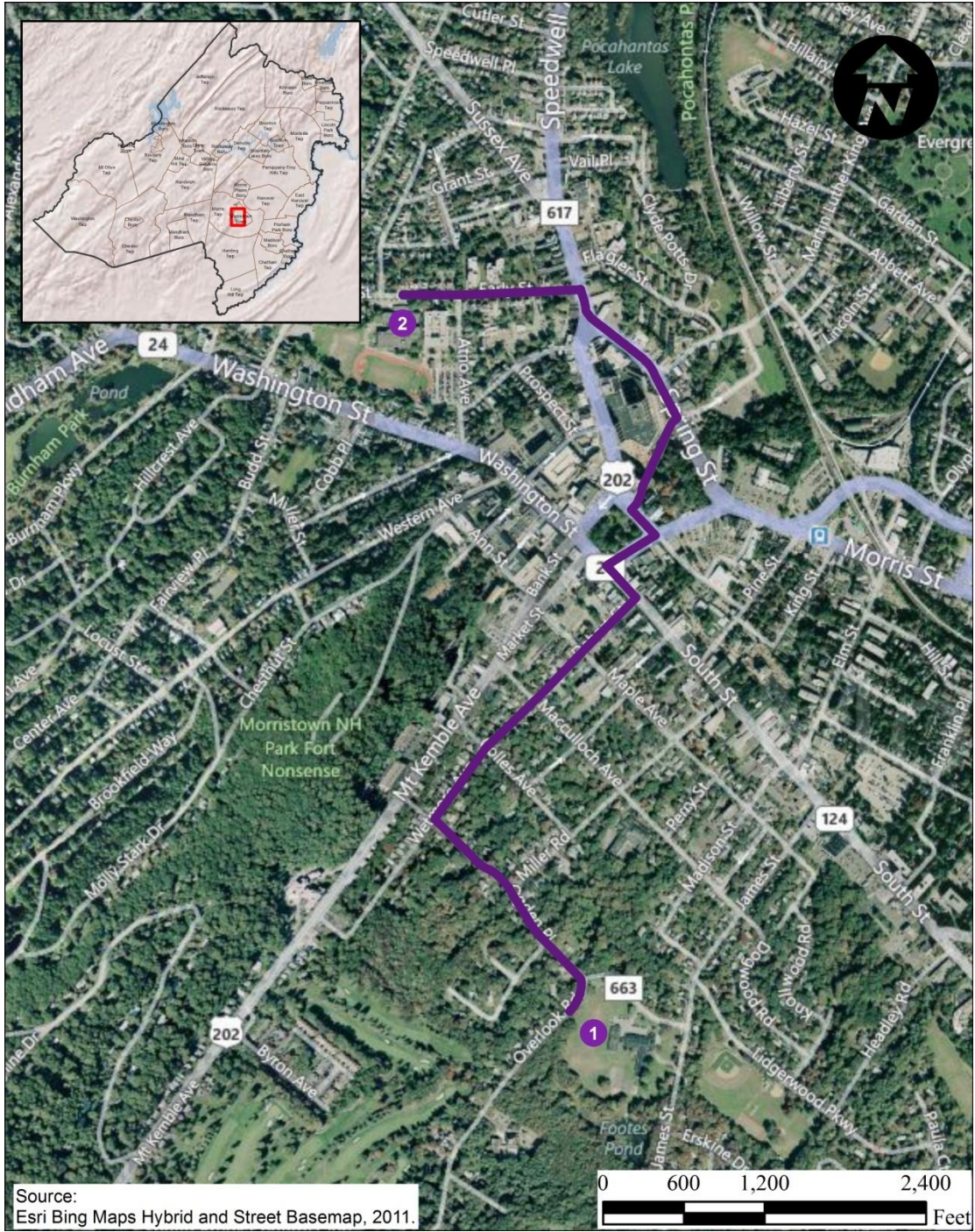


Figure 4.1 - Morrissett Route Map

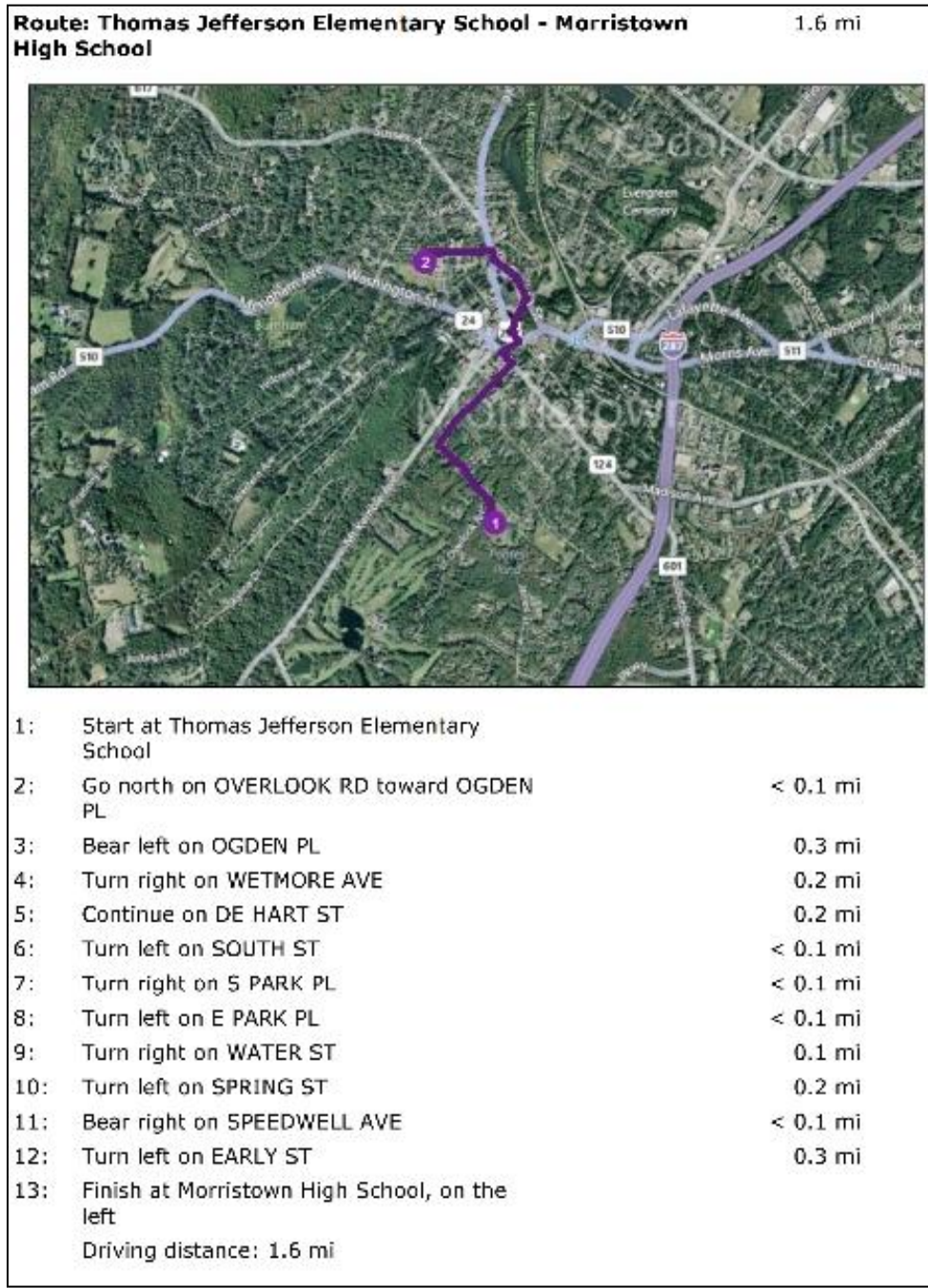


Figure 4.2 - Morristown Route Cue Sheet

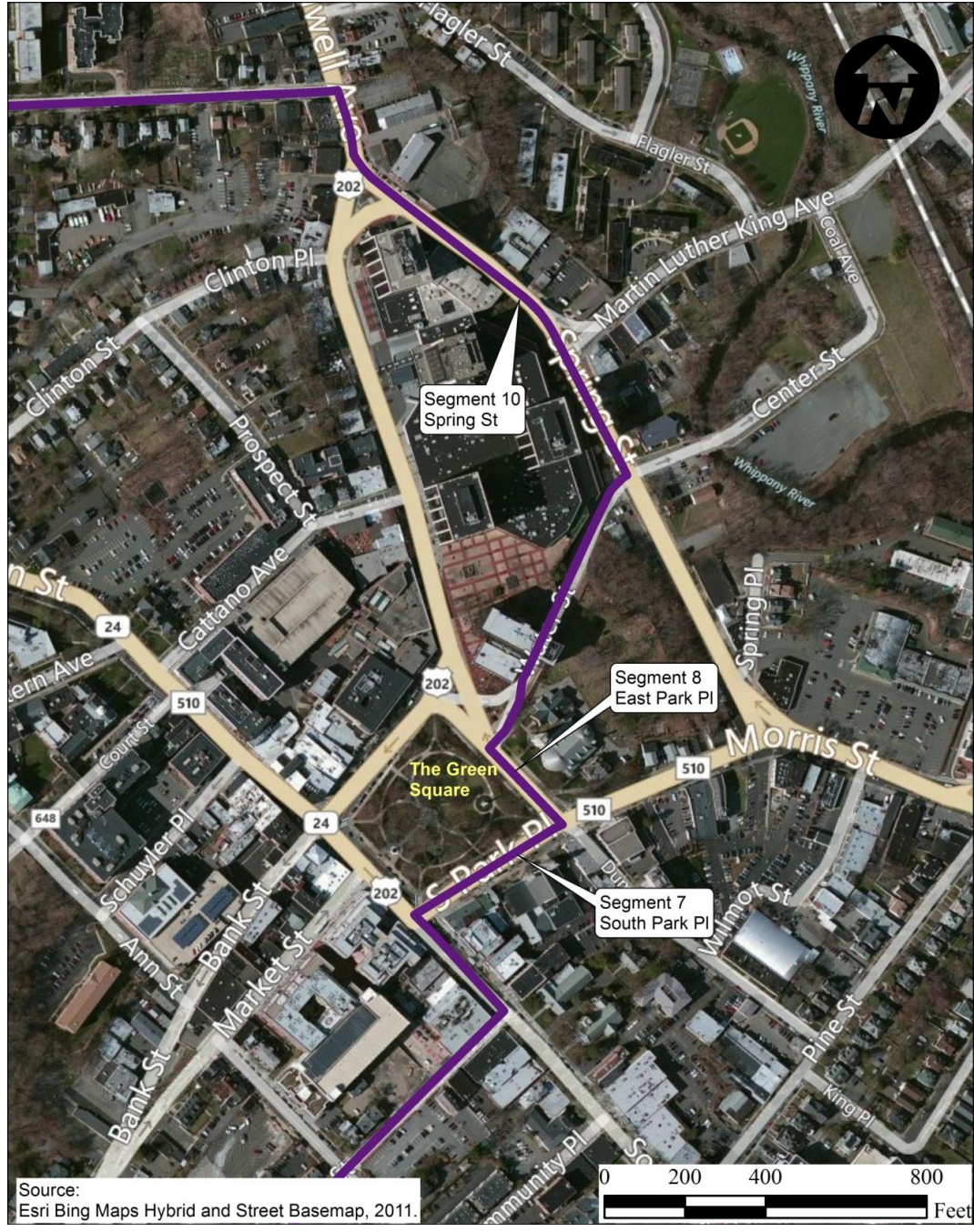


Figure 4.3 – Morristown Route around Morristown Green

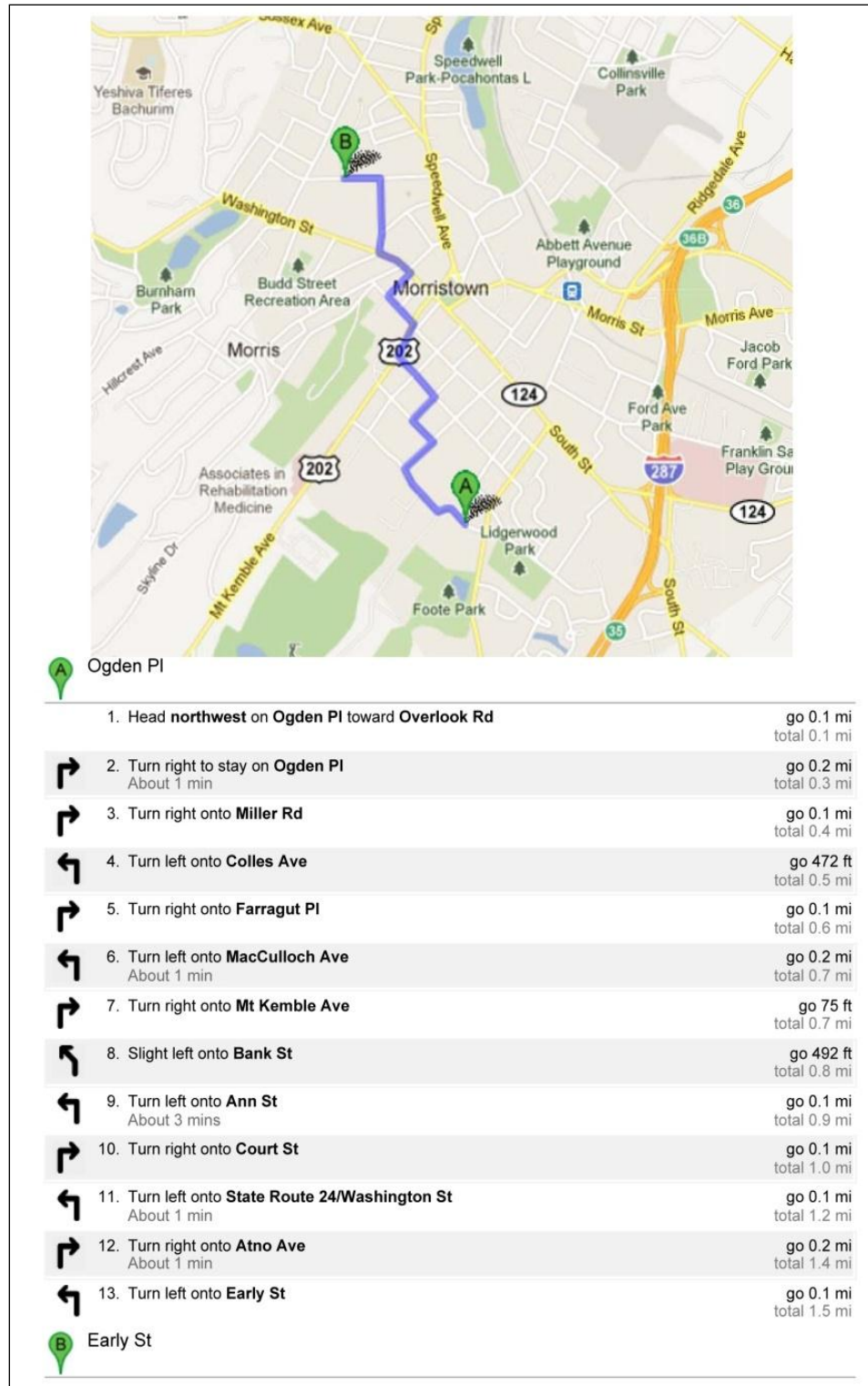


Fig 4.4 - Morristown Google Route (Google 2011a)

4.2 Routing Example – Denville

The second routing example shows a route going through Denville Township. Located in the center of the County, Denville is an affluent community with a small, thriving downtown and sprawling residential streets bordered by vast open spaces and scenic glacial lakes. The route entered starts at Morris Knolls High School at the southern end of the Township and goes to Riverview Elementary School, near the center of town.

The routing model completely avoids Route 46, a busy arterial street going through the heart of the Township (Figure 4.5 and 4.6). According to the NJDOT 2010 accident database, there were 5 vehicular accidents involving a bicyclist in the Township with 2 of these occurring on Route 46. For half of the calculated route, the bicyclist is directed via Franklin Avenue and Franklin Road. Neither street is ideal for bicycle use. The shoulders are not very wide and the streets are often flanked by some grading, not leaving much room for maneuvering. The only other alternate route between these two destinations would have put the bicyclist on dangerous Route 46. As soon as Franklin Road is intersected with residential areas, the bicyclist is promptly routed through quieter, residential streets, finishing out the route in more bicycle-suitable roads.

In comparison, the Google Maps alternative (Figure 4.7) chooses routes the bicyclist on Franklin Road until the last 0.3 miles of the trip. The Google Maps route is more direct, and has fewer turns, cutting the overall length of the trip by over a mile. However, this route takes place on some of the busier roads in the Township, requiring a higher level of skill and riding confidence. At one point the Google Maps model directs

the bicyclist to walk their bicycle as they are turning right on Savage Road at a particularly busy intersection.

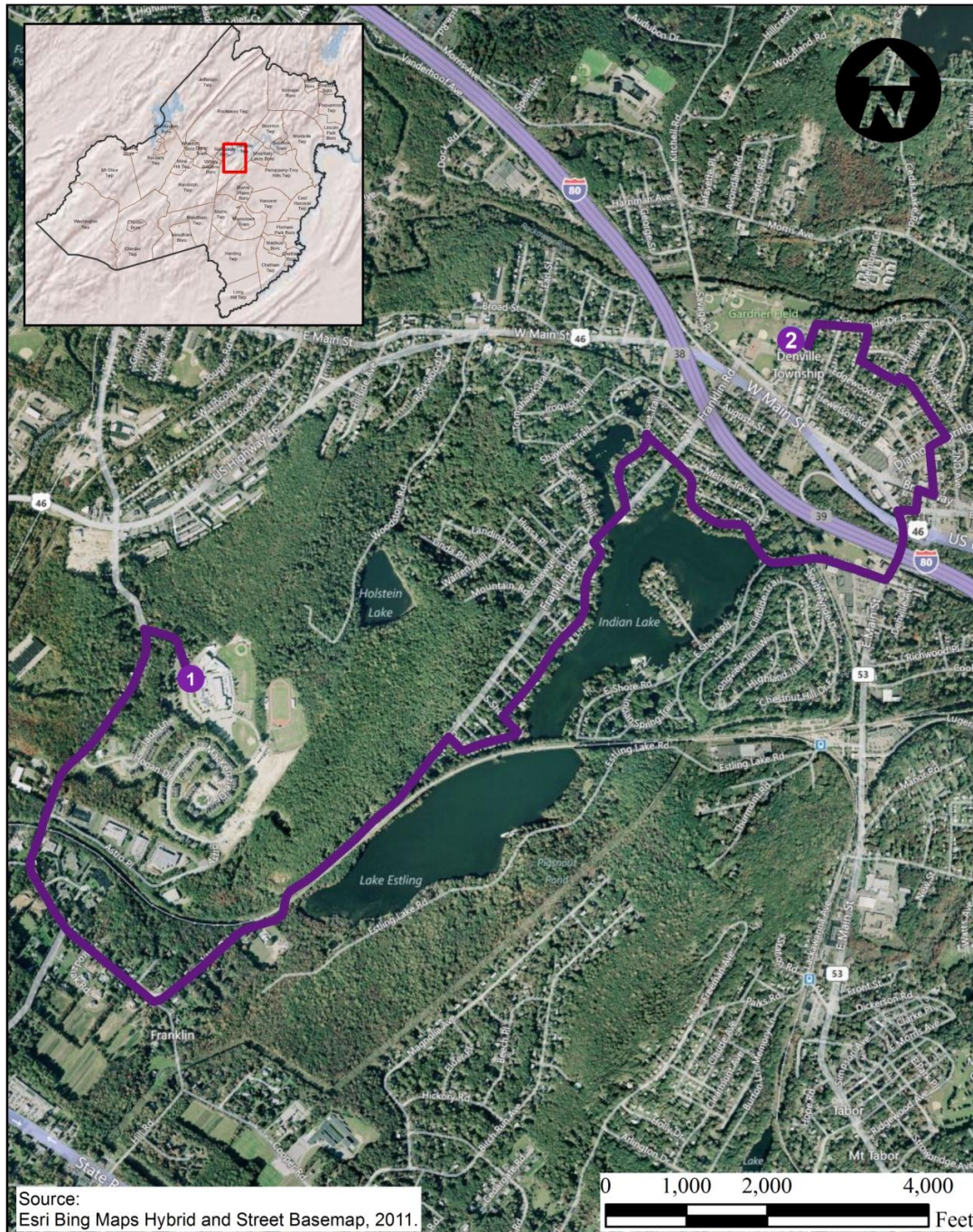


Fig 4.5 - Denville Route Map

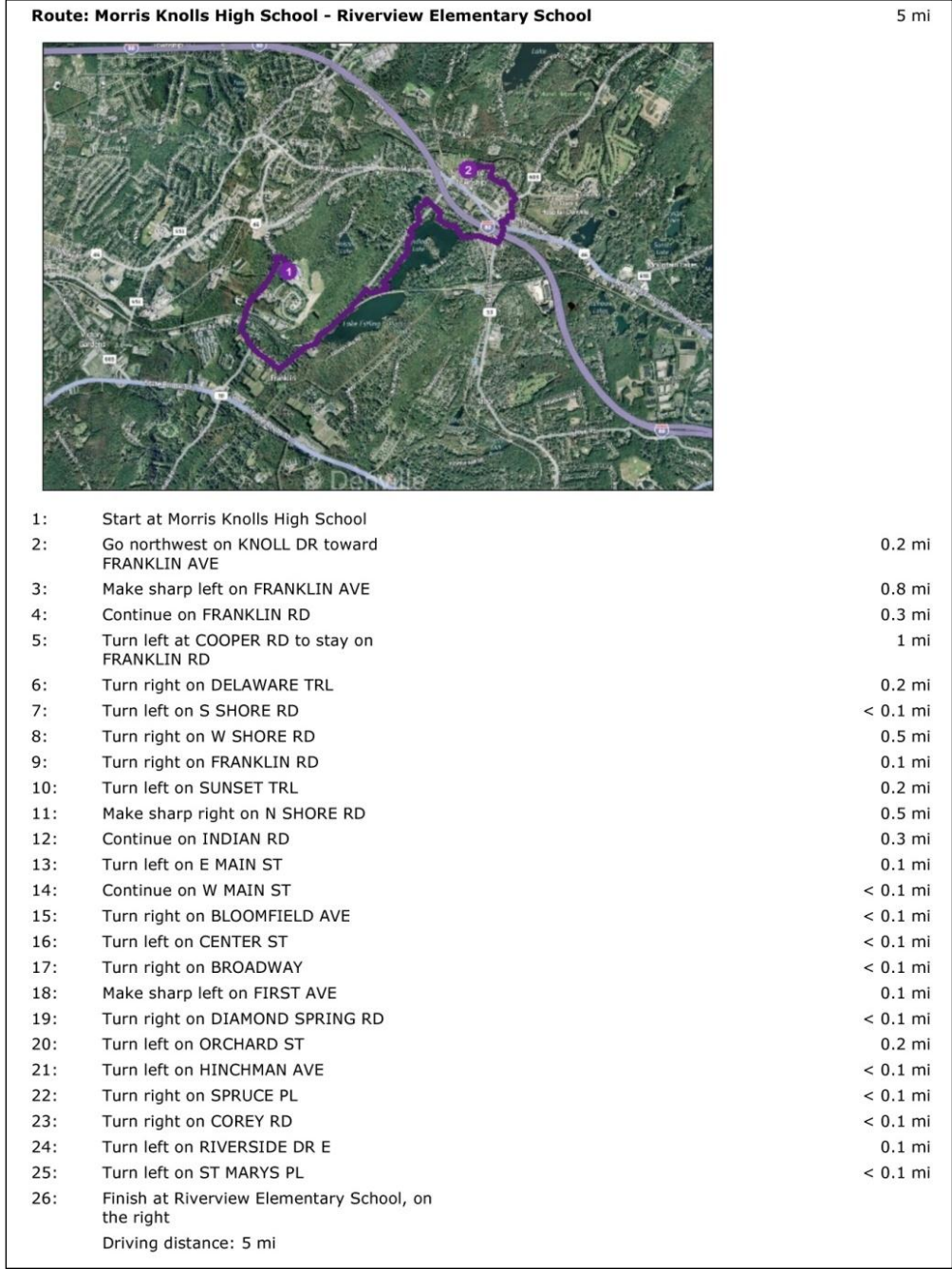


Figure 4.6 - Denville Route Cue Sheet

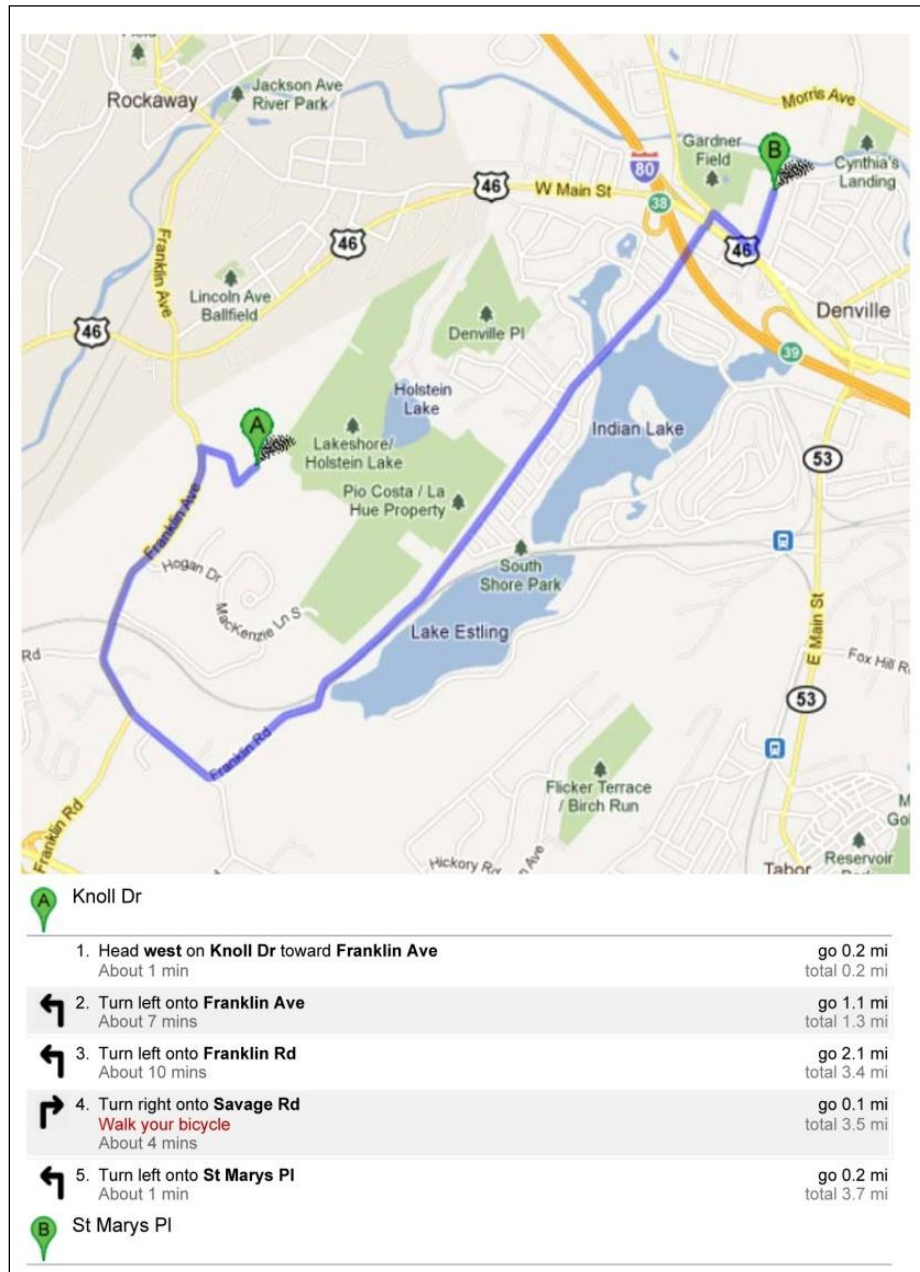


Figure 4.7 - Denville Google Route (Google 2011b)

4.3 Routing Example – Washington Township

The third routing example goes through the Long Valley section of Washington Township on the southwest side of the County. This picturesque area can be described as rural with vast open spaces, farms, and sprawling estates. This route originated at West Morris High School and ended at Long Valley Middle School. Both destinations are located on busy main arterial streets. This typifies the Long Valley area where there is little connectivity between business and services locations and bisecting residential streets that terminate in dead ends or cul-de-sacs.

While there are few on-road bicycle facilities such as bicycle paths or shared road opportunities, the model does take advantage of an off-road multi-use segregated path called the Columbia Trail (Figures 4.8 and 4.9). This motorized vehicle free Rail-to-Trail is flat, scenic and quite ideal for bicycle riding. The model utilizes the trail for over 2.5 miles of the route. The other portions wind through relatively less busy sections of road. As with the first example in Morristown, at least 1 mile of the journey still takes place on busy thoroughfares of Bartley and West Mill Road simply because of lack of any other alternative.

For the same route the Google Maps alternative directs the bicyclist through Bartley and West Mill Road (Figure 4.10). Google Maps show the Columbia Trail starting past Long Valley Middle School and so it does not take the off-road facility into consideration in its routing. This alternative also ignores any side streets, opting for the most direct route. This shortens the total route by 3 miles, a significant reduction from a 6.9 mile trip. The route also has only one turn as opposed to 10. However, the drawback

to this direct route is that it takes place entirely on busy arterial roads, which may be suitable only for experienced bicyclists.

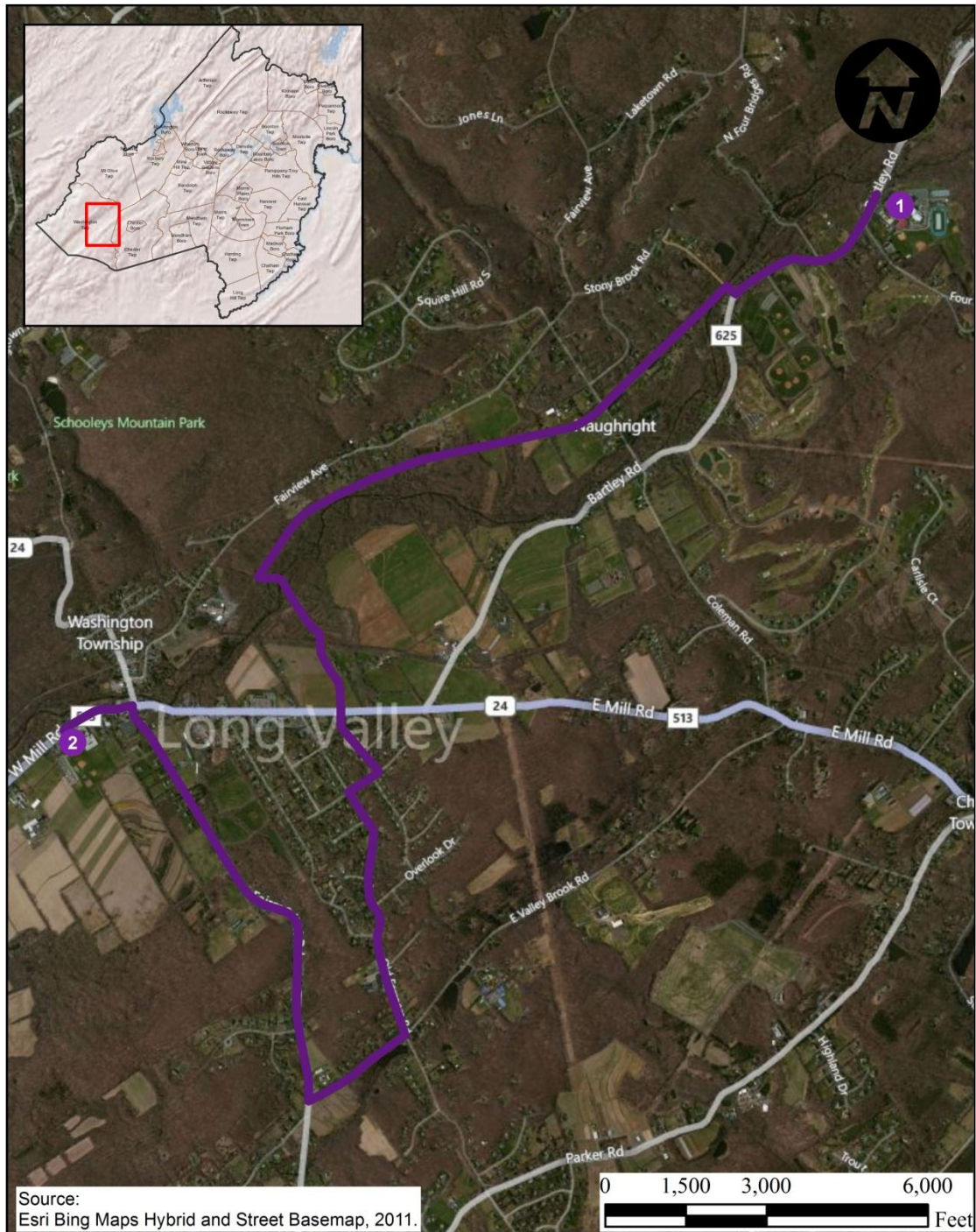
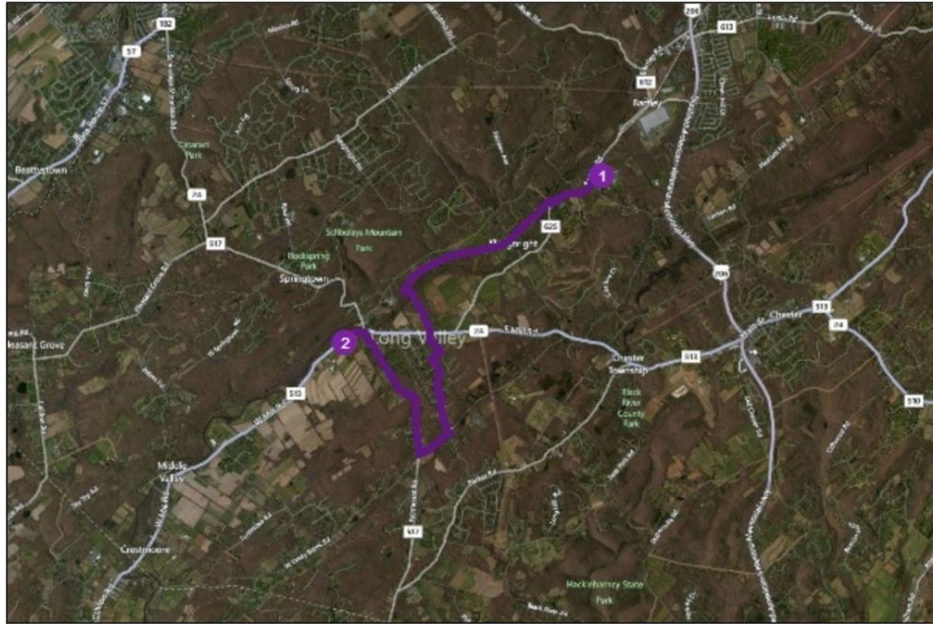


Figure 4.8 - Washington Route Map

Route: West Morris High School - Long Valley Middle School

6.9 mi



- | | | |
|-----|---|----------|
| 1: | Start at West Morris High School | |
| 2: | Go southwest on BARTLEY RD toward S FOUR BRIDGES RD | 0.7 mi |
| 3: | Turn right on ELIZABETH LA | < 0.1 mi |
| 4: | Turn left on COLUMBIA TRAIL | 2 mi |
| 5: | Make sharp left on MORRIS COUNTY MULTI-USE PATH | 0.6 mi |
| 6: | Continue on N WASHINGTON VALLEY RD | 0.3 mi |
| 7: | Turn right on LONG VALLEY BLVD | 0.1 mi |
| 8: | Turn left on OLD FARMERS RD | 0.9 mi |
| 9: | Turn right on E VALLEY BROOK RD | 0.4 mi |
| 10: | Make sharp right on FAIRMOUNT RD | 1.6 mi |
| 11: | Turn left on W MILL RD | 0.3 mi |
| 12: | Finish at Long Valley Middle School, on the left | |
| | Driving distance: 6.9 mi | |

Figure 4.9 - Washington Route Cue Sheet

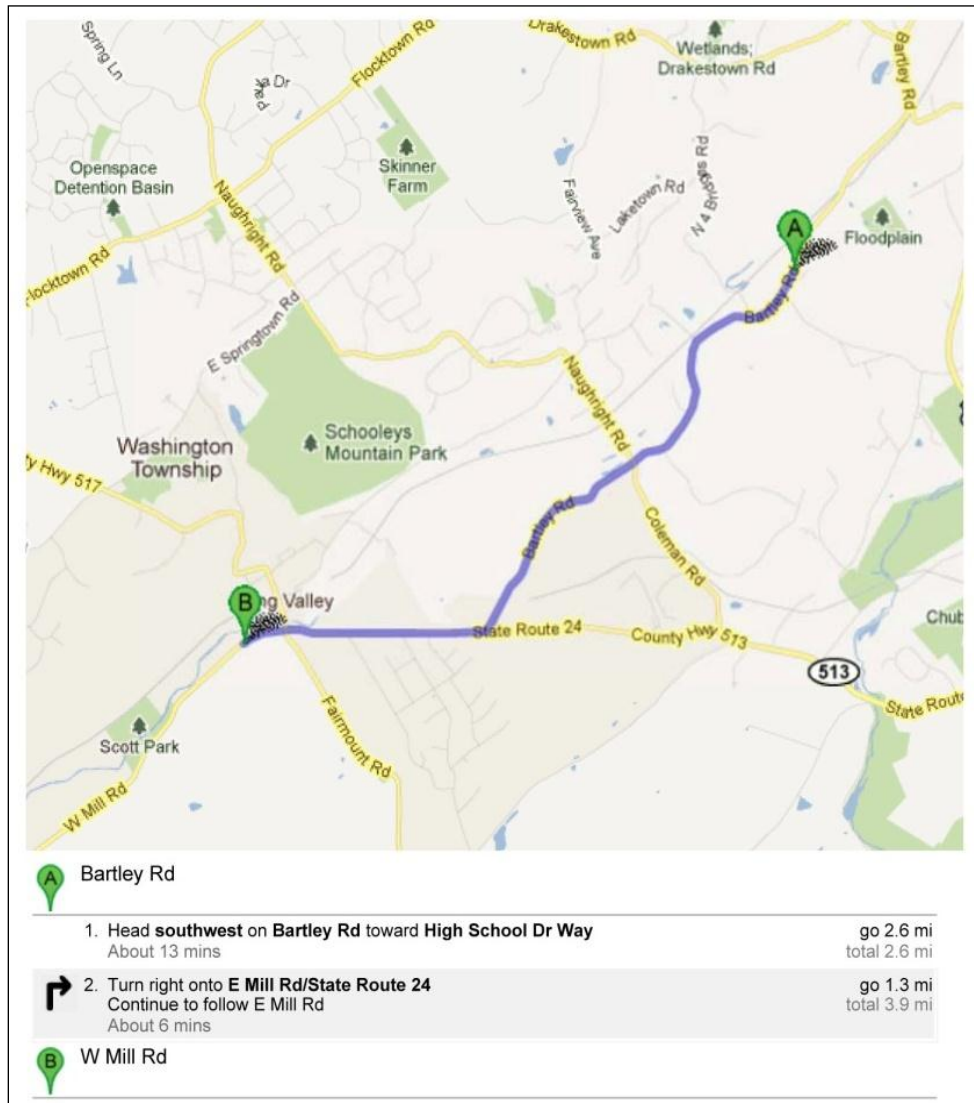


Figure 4.10 - Washington Google Route (Google 2011c)

4.4 Routing Example – Kinnelon Borough

The fourth and last example traverses through Kinnelon Borough. This area is characterized by middle-upper class suburban households, low density housing, moderate elevation changes, park lands and reservoirs. The bicycle route in this example originated at Kinnelon High School and ended at Stoneybrook Elementary School. Kinnelon High School is located at Kinnelon Road, a local street. Stoneybrook Elementary is located across town on Boonton Avenue, a county road that has a bicycle lane.

The routing model and the Google Maps model direct the bicyclist through the same turns (Figures 4.11, 4.12, and 4.13). The Kinnelon area has favorable conditions for bicycle riding. There are many quiet residential areas that connect with each other and thus, a bicyclist can easily avoid busy routes. The only segment of the road that is not a local street is Boonton Avenue. This county road is mainly residential with some scattered set-back businesses. This residential quality coupled with the presence of a bicycle path made this segment of the trip better suited than the longer residential streets in the vicinity of Boonton Avenue. Google Maps does not indicate the presence of a bicycle facility on Boonton Avenue. The Google Maps model, while it does not have published algorithms, may have chosen this segment of the road for its residential quality and for making the route as short and direct as possible.

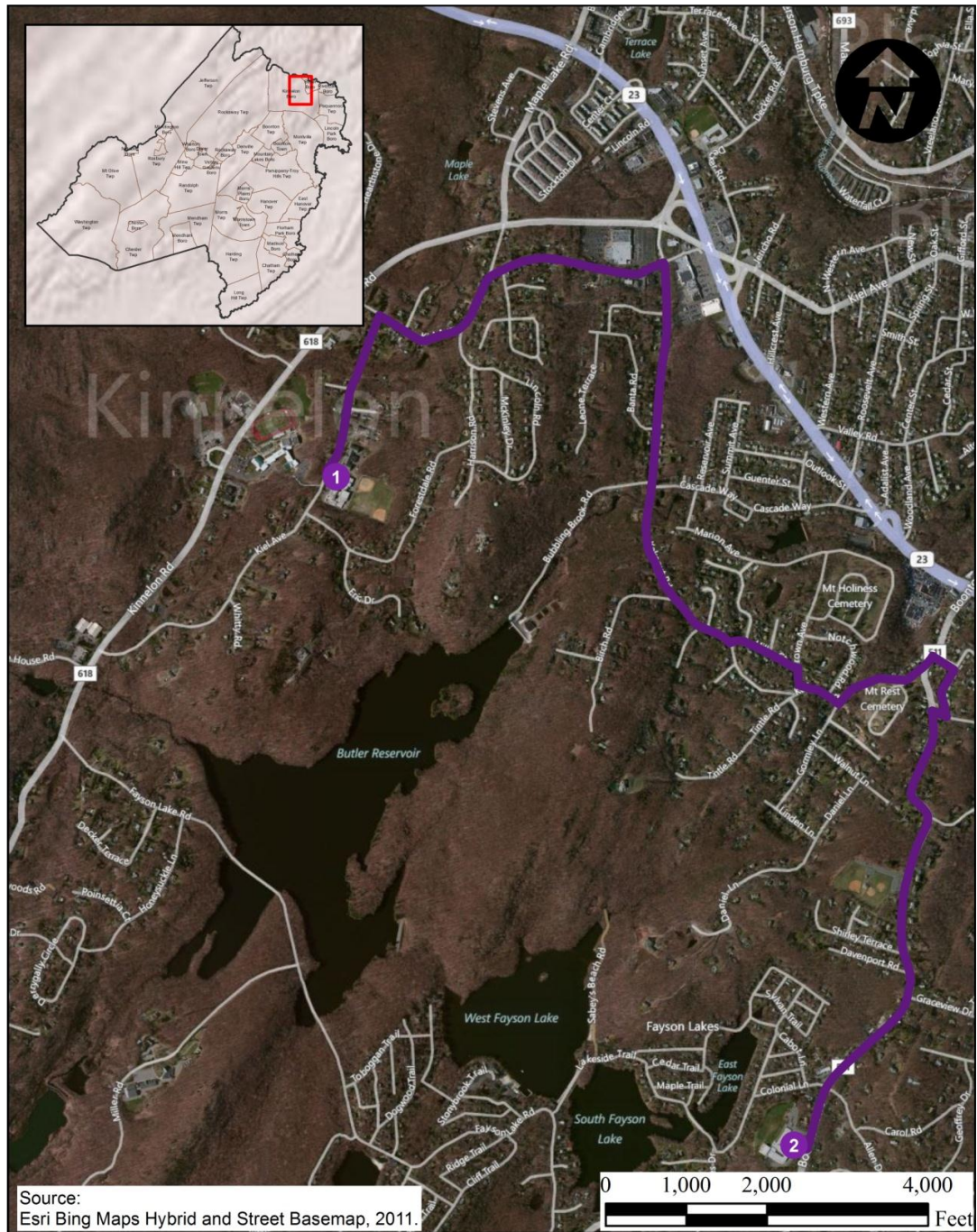


Figure 4.11 - Kinnelon Route Map

Route: Kinnelon High School - Stoneybrook Elementary School

4.1 mi



- | | | |
|-----|---|----------|
| 1: | Start at Kinnelon High School | |
| 2: | Go north on KIEL AVE toward ROCKWALL TER | 0.4 mi |
| 3: | Turn right to stay on KIEL AVE | 0.8 mi |
| 4: | Turn right on KAKEOUT RD | 1 mi |
| 5: | Turn left on HILLER CT | 0.2 mi |
| 6: | Turn right on BROWN AVE | < 0.1 mi |
| 7: | Turn left to stay on BROWN AVE | < 0.1 mi |
| 8: | Continue on KAKEOUT RD | < 0.1 mi |
| 9: | Turn left at GORMLEY LA to stay on KAKEOUT RD | 0.2 mi |
| 10: | Continue on BOONTON AVE | < 0.1 mi |
| 11: | Turn right on DEAN AVE | < 0.1 mi |
| 12: | Turn right on SIEK RD | 0.1 mi |
| 13: | Make sharp right on CUTLASS RD | < 0.1 mi |
| 14: | Make sharp left on BOONTON AVE | 1.1 mi |
| 15: | Finish at Stoneybrook Elementary School, on the right | |
| | Driving distance: 4.1 mi | |

Figure 4.12 - Kinnelon Route Cue Sheet

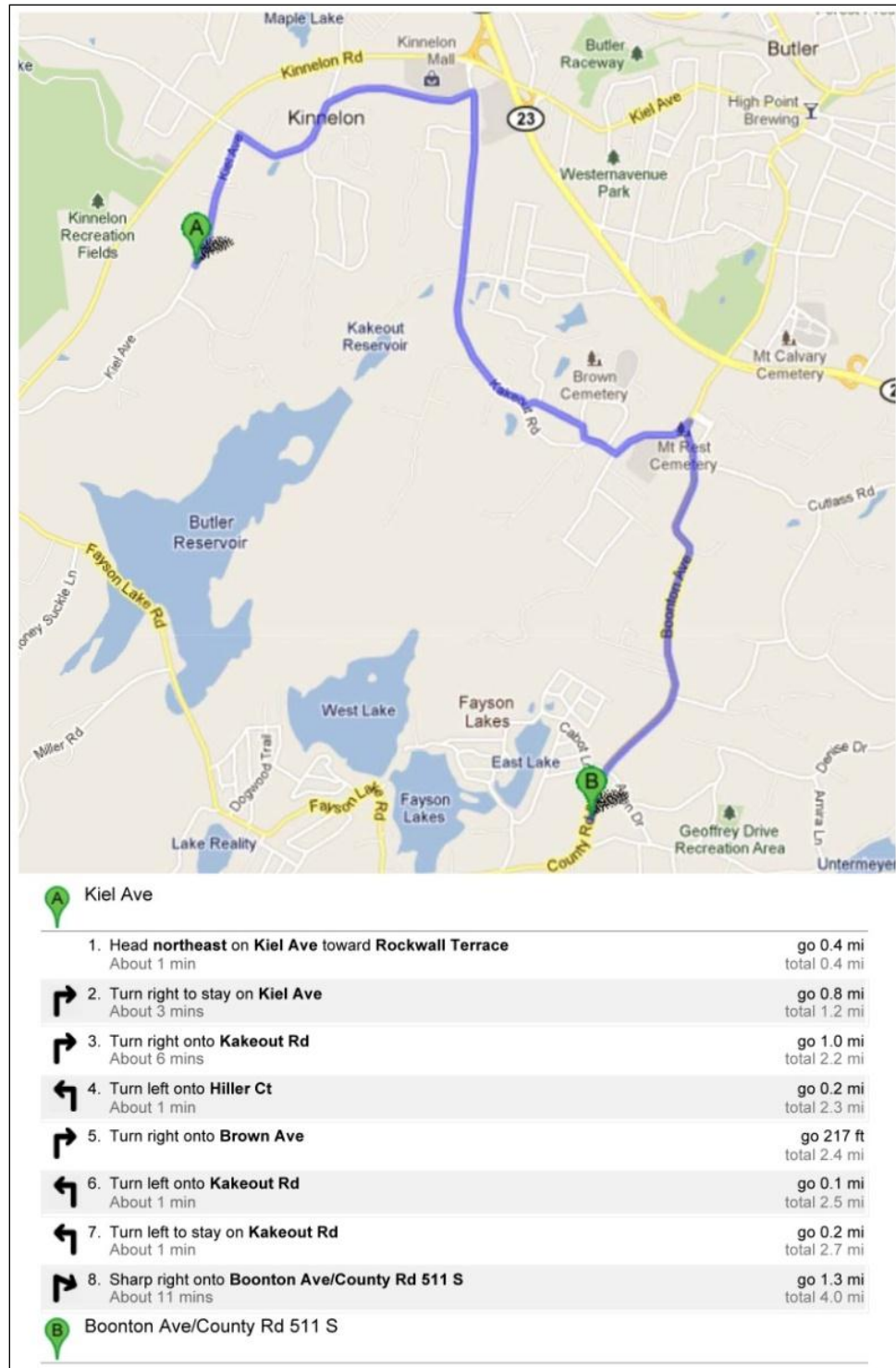


Figure 4.13 - Kinnelon Google Route (Google 2011d)

4.5 Discussion of Results

The most glaring issue observed in the results of the model is that with most routes, at least some of the route directs the bicyclist through a busier arterial road with no bicycle facility present. The reason for this issue is due to the suburban and car-centric nature of Morris County. With its many cul-de-sacs and dead end residential streets, network connectivity tends to be poor in many areas. It is a major setback to the model's objective since it was intended to be used by all bicyclists, including novice riders. By including these busy thoroughfares, some riders may be turned off by these conditions that may seem too dangerous and with the lack of a practical alternative, may abandon the effort to ride the route on a bicycle all-together.

Chapter 5 - Conclusion

The objective of this thesis research was to create a GIS routing model that provided for safe bicycle routing in Morris County when start and end points are entered. The model's algorithm was designed to direct the bicyclist through a route that utilizes the most bicycle facilities. In absence of any bicycle facilities, the model calculated routes through a cost-weight analysis that considered road segment characteristics favorable for bicycling such as flat segments, roads going through residential zones, roads with local classifications, and road segments that do not pass through intersections designated as high-volume points.

In theory, the model achieved the desired objective of finding the most bicycle-appropriate route available when two points are entered. In practice, however, the route often included segments that included busy thoroughfares and roads that may be intimidating to some bicyclists, especially novice ones that are not accustomed to sharing roadways with motorized traffic. The main reason for this unfavorable outcome is due to the nature of the study area. The road network of Morris County has few bicycle facilities and residential, non-collector roads are not well connected to each other, often terminating in a dead-end. Therefore, the model when routing the rider from one point to another had no other alternative but to yield directions that may not be deemed to be as safe as possible from a bicyclist's point of view.

5.1 Limitations of Study

There is a saying in science that the outcome is only as good as the data. That holds true in this case. There were a number of very detailed algorithms that the research review found to compute bicycle suitability. Some of these contain a large number of variables such as shoulder width, average number of motorized vehicles per intersection, posted speed limit, etc. This type of specific data was not available for the study area at the time of this research; therefore a more generalized approach was used when building the model, as detailed in Chapter 3.

The algorithm set in the model is set up in a way so that a segregated bicycle path is chosen only if getting to that path is feasibly safe. That means that at times, the model may choose motorized vehicle road segments with bicycle lanes or paved shoulders. This happens particularly near the Randolph Township paths and near the Traction Line path where the segregated paths are located in the vicinity of other bicycle facilities. An additional data limitation is the extent of the study area. The model only covered the area of Morris County. When entering a destination outside of Morris County, the resulting route would abruptly end at the County boundary. This can be particularly problematic for routes in the more heavily populated southeastern portion of the County where the administrative boundary in this area may be arbitrary for a bicyclist looking to ride to a nearby point of interest. Even in instances where both start and end destinations were within the study area, there may be segments of the route outside of the County that may be more suitable. The model did not consider any roads outside of the study area.

As seen in the results in Chapter 4, the derived safest route produced by the model did not at times seem as suitable for novice or young riders. The model has not been

configured to warn a user in such cases when parts or the entire route should be used by experienced bicyclists only. This could be an issue when an inexperienced rider sets out to go through the route without knowing too much about the potential challenging conditions along the way.

5.2 Future Improvements and Research

As previously discussed, with the nature of the road network and the existence of few bicycle facilities, it is naturally challenging to find a safe bicycle route for every situation in the study area, and so better data may not solve this routing problem. However, the model can certainly benefit with more detailed data and algorithms, and both can serve as a point for further research on this topic.

Similarly, extra custom parameters can be used to further expand the model. As discussed in Chapter 2, the Colorado DOT model utilizes parameters such as scenery and available amenities in its modeling (Turner et al. 1997). Morris County boasts many beautiful scenic areas such as bucolic farmlands, historic spots and nature preserves, which can be added as preferred routes in the model. Additional possible amenities to include are bicycle shops, bicycle racks, and bicycle lockers such as the ones recently installed at train stations. One benefit of using GIS is that extra parameters can be added relatively easily to an existing model.

Another feature that can be added in future research is an algorithm that warns bicyclists, based on their experience, whether a segment may be inappropriate for their level of comfort. A classification system, such as the one used by the Illinois DOT, could

be used to rank the route as suitable for all riders, for riders with average experience, and for experienced riders only.

Future research should merge routing algorithms in the surrounding areas outside of Morris County so that a bicyclist could seamlessly transverse between counties. Some neighboring counties are much more densely populated than Morris County and others are more rural with a higher elevation differences, and so the algorithms employed in Morris County may not be suitable for other counties. Once the appropriate algorithms are established, the resulting data may be combined to provide for uninterrupted regional routing.

The model, with its imperfections, can be used in several ways to achieve safer bicycling conditions in Morris County. In the immediate term, bicyclists can determine for themselves the most suitable route they have available to them between two given points. A parent, for instance, may find that a route through sleepy residential streets may be suitable for their child to ride to their school. Of course, this may not always be the case. And so, in the longer term, municipal governments, public agencies, and bicycle advocates may use the model to see where there is a need for additional accommodation for bicycles in a local circulation plan. As described in the Morristown case in Chapter 4, this may be just a short road segment that bridges two sections of the town. A short road segment such as this can be made better simply with appropriate signage and lowering the posted speed limit. Lastly, the more the model can be used to prove that safe bicycling can exist in the area, the more riders will be encouraged to take to the road and that will lead to more willingness on part of the local governments to invest in making the whole area more bicycle friendly.

An important improvement to the research would be to publish the model online in an easily accessible website. This format could reach a large number of bicyclists and provide an easy routing tool. The website could provide additional data such as road conditions, tips on safe bicycle riding, and any other information pertinent to bicycle riding in Morris County.

This model was not meant to be an all-inclusive research into bicycling in Morris County. Rather, it should be treated as a starting point for further research and utilization. As discussed, the model can be fine-tuned and customized to accommodate better data and custom parameters. The model can also be posted online, as part of an online mapping application to reach a much wider audience. Types of these models in Boulder, Portland, and New York City were described in Chapter 2. This could be part of a wider campaign to encourage bicycling, to educate riders about safety elements, such as wearing helmets, and potentially to have a real impact on safe bicycling in Morris County which is ultimately the goal of this research.

References

- Akerman, J.R., 2002. American promotional road mapping in the twentieth century. *Cartography and Geographic Information Science*, 29(3): 175-92.
- Allen, J., 2003. *The "Bicycle Compatibility Index" - Critique Of Implementation Manual and Workbook* [online]. Available at: <http://www.bikexpert.com/research/bci/bcirvw.htm> [Accessed 24 May 2009].
- American Association of Highway and Transportation Officials (AASHTO), 1999. *Guide for the Development of Bicycle Facilities*. Washington, D.C: AASHTO.
- Arizona Department of Transportation, 2003. *Statewide Bicycle and Pedestrian Plan*. Arizona Department of Transportation, Transportation Planning Division. Phoenix: Kimley-Horn and Associates.
- Barsotti, E. and Kilgore, G, 2001. *The Road Network is the Bicycle Network: Bicycle Suitability Measures for Roadways and Sidepaths* [online]. League of Illinois Bicyclists. Available from: <http://www.bikelib.org/wp-content/uploads/2009/09/TransChi2001.pdf> [Accessed 25 May 2009].
- Bax, F.M.W., 2004. *Bicycle Use in the Netherlands versus the United States*. Chapel Hill: University of North Carolina.
- Bearings, 1894. Miss Londonderry ready to start [online]. *Cycling Authority of America*. Available from: <http://archive.org/details/bearings818931894cycl> [Accessed 18 July 2011].
- Bing Maps, 2012. *Bird's Eye View of Route 10 and Algonquin Rd in East Hanover, NJ* [online]. Bing Maps. Available from: <http://www.bing.com/maps/?v=2&cp=qt2dvk8szxpd&lvl=17&dir=180&sty=b&w here1=State%20Route%2010%20%26%20Algonquin%20Pkwy%2C%20Whippa ny%2C%20NJ%2007981&form=LMLTCC> [Accessed 12 February 2012].
- Bower, D., Geller, R., Ginenthal, L., Igarra, D., Lear, M., and Waltz, J., 2007. *Existing Conditions for Bicycling Report 2007*. Portland, Oregon: Portland Bureau of Transportation.
- Center for Disease Control and Prevention (CDC), 2010. Vital Signs: State-Specific Obesity Prevalence Among Adults – United States, 2009. *Morbidity and Mortality Weekly Report*, [online], 59. Available from: http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5930a4.htm?s_cid=mm5930a4_w [Accessed 3 August 2010].

- City of New York, 2008. *plaNYC Progress Report 2008*. New York: City of New York.
- Dahl, G.T., 2009. *Empowerment of Cyclist Collective Identity in the Social, Safe, and Celebratory Spaces of Critical Mass*. Thesis (Master of Arts). College of Arts and Sciences of Ohio University.
- Day, J., 2003. *State-By-State Comparison of Bicycle Accommodation in the State Department of Transportation and Brief Review of Existing Literature*. Albany, NY: State University at Albany, NY.
- Environmental Defense Fund, 2010. *Bicycle Commuting, Returning to an Old Tradition Could Ease Traffic, Cut Pollution and Curb Global Warming*. [online]. Available from: <http://www.edf.org/article.cfm?contentID=5483> [Accessed 2 February 2011].
- Federal Highway Administration, 2004. *National Bicycling and Walking Study: Ten Year Status Report*. Washington: Federal Highway Administration.
- Ferguson, L., 2007. Go Bike Boulder: ArcIMS interactive bicycle routing website. In: *Esri User Conference*, June, 2007, San Diego, CA. pp. 1-7.
- Flink, J., 1988. *The Automobile Age*. Cambridge, MA: The MIT Press.
- Flusche, D., 2009. *The Economic Benefits of Bicycle Infrastructure Investments* [online]. Washington, DC: League of American Bicyclists. Available from: http://www.bikeleague.org/resources/reports/pdfs/economic_benefits_bicycle_infrastructure_report.pdf [Accessed 5 February 2011].
- Forbes, 2008. *Oil Soars To Record High Above \$135 A Barrel In New York and London*. [online]. Available from: <http://www.forbes.com/afxnewslimited/feeds/afx/2008/05/22/afx5038506.html> [Accessed 1 June 2008].
- Franks, B., 2008. *America on Wheels* [online]. The Times Daily. Available from: <http://www.timesdaily.com/apps/pbcs.dll/article?AID=/20081005/A> [Accessed 19 February 2011].
- Girling, C.L. and Kellett, R., 2005. *Skinny Streets and Green Neighborhoods: Design for Environment And Community*. Washington, DC: Island Press.
- Goddard, S., 2000. *Colonel Albert Pope and His American Dream Machines: The Life and Times of a Bicycle Tycoon Turned Automotive Pioneer*. Jefferson, North Carolina: McFarland & Company, Inc., Publishers.

- Google, 2010. *Biking Directions Added to Google Maps* [online]. Google Official Blog. Available from: <http://googleblog.blogspot.com/2010/03/biking-directions-added-to-google-maps.html> [Accessed 2 October 2010].
- Google, 2011a. *Biking Directions from Jefferson Elementary School to Morristown High School, Morristown, NJ* [online]. Google Maps. Available from: <http://g.co/maps/d2uwm> [Accessed 11 November 2011].
- Google, 2011b. *Biking Directions from Norris Knolls High School to Riverview Elementary School, Denville, NJ* [online]. Google Maps. Available from: <http://g.co/maps/7d397> [Accessed 11 November 2011].
- Google, 2011c. *Biking Directions from West Morris High School to Long Valley Middle School, Washington Township, NJ* [online]. Google Maps. Available from: <http://g.co/maps/29cgh> [Accessed 11 November 2011].
- Google, 2011d. *Biking Directions from Kinnelon High School to Stoneybrook Elementary School, Kinnelon, NJ* [online]. Google Maps. Available from: <http://g.co/maps/ezeau> [Accessed 11 November 2011].
- Grava, S., 2003. *Urban Transportation Systems: Choices for Communities*. New York: McGraw-Hill Prof Med/Tech.
- Harkey, D.L., Reinfurt, D.W., and Sorton, A., 1998. *The Bicycle Compatibility Index a Level of Service Concept : Implementation Manual*. McLean, VA: U.S. Dept. of Transportation, Federal Highway Administration, Research and Development, Turner-Fairbank Highway Research Center.
- Highlands Water Protection and Planning Council, 2008. *Highlands Regional Master Plan*. Chester, NJ: Highlands Water Protection and Planning Council.
- Jones, E. and Carlson, T., 2002. Development of a Bicycle Compatibility Index for Rural Roads in Nebraska. *Transportation Research Record* 1828.1, 124-132.
- Landis, B., Vattikuti, V., and Brannick, M., 1997. Real-time human perceptions: toward a bicycle level of service. *Transportation Research Record*, 1578, 119-126.
- McKernon, S., 2007. *Design of Change in Cycle Commuting, Meeting Auckland's Regional Cycle Commuting Aims for 2016*. Thesis (Masters of Design Management). Unitec Institute of Technology, Auckland, New Zealand.
- Money Magazine, 2008. *Best Places to Live 2008, FAQ and Sources, How We Picked the Best Places to Live* [online]. Available from: <http://money.cnn.com/magazines/moneymag/bplive/2008/faq/> [Accessed 12 February 2011].

- Morris County Economic Development Corporation, 2009. *2007 Median Household Income*, [online]. Available from <http://www.morriscountyedc.org/document.asp?id=55> [Accessed 17 November 2009].
- Morris County Planning Board, 2007. *State of the County Report, 2007*. Morristown, NJ: Morris County.
- National Highway Traffic Safety Administration (NHTSA), 2003. *National Survey of Pedestrian & Bicyclist Attitudes and Behaviors Highlights Report*. Chapel Hill, NC: Pedestrian and Bicycle Information Center.
- National Research Council, 2000. *Highway Capacity Manual*. Washington, DC: Transportation Research Board.
- New Jersey Bike Map, 2010. *About the Map* [online]. New Jersey Bike Map. Available from: http://njbikemap.com/njmap/about_the_map/about_the_map.html [Accessed 2 October 2010].
- New Jersey Department of Transportation (NJDOT), 1996. *Bicycle Compatible Roadways and Bikeways: Planning and Design Guidelines*. Trenton, NJ: New Jersey Department of Transportation.
- New Jersey Department of Transportation (NJDOT), 2004. *New Jersey Statewide Bicycle and Pedestrian Master Plan – Phase 2*. Trenton, NJ: RBA.
- New Jersey Department of Transportation (NJDOT), 2011. *Crash Records* [online]. Available from: <http://www.nj.gov/transportation/refdata/accident/rawdata01-03.shtm> [Accessed 11 November 2011].
- New York City, 2008. *New York City Bicycle and Trail Inventory*. New York City, Department of City Planning, Transportation Division.
- New York City, 2011. *Bicycle Network Development* [online]. New York City, Department of City Planning. Available from: <http://www.nyc.gov/html/dcp/html/bike/home.shtml> [Accessed 26 February 2011]
- New York Sunday World, 1896. *Champion of Her Sex*. February 1896, 10.

- New York Times, 1894. *A New Road Map, The New-Jersey Division Has Issued a Valuable Work for Roadsters* [online]. Available from: <http://query.nytimes.com/gst/abstract.html?res=9804E1DD1531E033A25752C0A96E9C94659ED7CF#> [Accessed 26 July 2008].
- New York Times, 1899. *The World of Sports; the Columbia* [online]. Available from: <http://query.nytimes.com/gst/abstract.html?res=9F05E3D91430E132A25756C2A9609C94689ED7CF> [Accessed 30 August 2008].
- Ogden, C., and Carroll, M., 2010. *Prevalence of Obesity Among Children and Adolescents: United States, Trends 1963–1965 Through 2007–2008*. National Center for Health Statistics, Health E-Stats. Atlanta: Center for Disease Control and Prevention.
- Pein, W., 2007. *Critique of the Bicycle Compatibility Index* [online]. NC Bike Ed. Available from: http://humantransport.org/bicycledriving/library/critique_BCI.pdf [Accessed 24 May 2009].
- Rails-to-Trails Conservancy, 2010. *Rail-Trail Statistics* [online]. Available from: <http://www.railstotrails.org/ourWork/trailBasics/trailStats.html> [Accessed 13 February 2011].
- Safe Routes to Schools (SRTS), 2012. *National SRTS State Project List* [online]. Available from: http://apps.saferoutesinfo.org/project_list/index.cfm [Accessed 6 March 2012].
- Somerset County, NJ, 1997. *Road Suitability Ranking Map, 1" = 0.5 miles*. Raritan, NJ: RideWise.
- Sorton, A., and Walsh, T., 1994. Bicycle Stress Level as a Tool to Evaluate Urban and Suburban Bicycle Compatibility. *Transportation Research Record* 1438, 17-34.
- Tax Foundation, 2011. *Property Tax by County* [online]. Available from: <http://interactive.taxfoundation.org/propertytax/> [Accessed 24 April 2011].
- Turner, S.M., Shafer, C.S., and Stewart, W.P., 1997. *Bicycle Suitability Criteria: Literature Review and State-of-the-Practice Survey*. College Station, TX: Texas Transportation Institute, Texas A&M University System, 3988-1.
- U.S. Census Bureau, 2009. *Morris County, New Jersey - Selected Economic Characteristics: 2005-2009* [online]. American Community Survey, 2005-2009 American Community Survey 5-Year Estimates. Available from: http://factfinder2.census.gov/legacy/aff_sunset.html?_bm=y&-geo_id [Accessed 13 February 2011].

U.S. Energy Information Administration, 2010. *International Energy Outlook 2010*. Washington: National Energy Information Center, IEO2010 [online]. Available from: <http://www.eia.gov/forecasts/ieo/index.cfm> [Accessed 5 February 2011].

U.S. Environmental Protection Agency, 2000. *Our Built and Natural Environments: A Technical Review of the Interactions between Land Use, Transportation, and Environmental Quality*. Washington, DC: U.S. Environmental Protection Agency, Development, Community, and Environment Division.

Zillow, 2011. *Zillow Real Estate Market Reports* [online]. Available from: <http://www.zillow.com/local-info/> [Accessed 1 April 2011].