ENVIRONMENTAL EFFECTS OF ROAD DESIGN: USING SPATIAL ANALYSIS TO TRACE DESIGN HISTORY

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A thesis submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

In partial fulfillment of the requirements

For the degree of

Master of Landscape Architecture

Graduate Program in Landscape Architecture

Written under the direction of

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New Brunswick, New Jersey

May 2016

ABSTRACT OF THE THESIS

Environmental Effects of Road Design: Using Spatial Analysis to Trace Design History

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This study investigates the relationship between road characteristics and the surrounding landscapes, using as a framework for analysis the history of construction methods and landscape architecture's once prominent role in road design. This research seeks to expand the scale of focus from the species-level, typical of much road ecology scholarship, to a regional, road network-scale analysis.

As roads were constructed in the United States in the early decades of the 20th century, design guidelines and safety regulations did not yet exist, resulting in demonstrably different shapes and forms of roads. Since then, many roads have been widened and straightened, but original alignments remain part of many of our federal and state highways. This research seeks to answer the question: Are the different construction methods preserved in the patterns and composition of the surrounding landscapes, and in the shapes of the roads themselves? Is the role of the landscape architect in road design visible in the road network patterns of the landscape? Can these differences be measured?

Using tools from the field of landscape ecology to study the Appalachian region of North Carolina, this study found that among five road categories—interstates, US highways, state highways, secondary routes, and federal parkways—measureable differences in land cover, terrain, and road form are present. A spatial regression in ArcGIS explored the strength of relationships between road characteristics such as sinuosity, elevation change, traffic count, road width, and other variables and land cover present within three different distances from the roads. A visual assessment of one road from each of the five categories was also conducted to test assumptions about road type and to compare to the road characteristics database.

ACKNOWLEDGEMENTS

I would first like to thank my thesis committee: Dr. Jean Marie Hartman, Dr. David Tulloch, and Dr. Marci Meixler, for their deep knowledge, insightful advice, and steady encouragement. I also want to thank Gail McKenzie for shepherding me and my classmates through this process (and many other processes) with grace and wisdom. To those classmates, thank you all for being the kind and supportive people that you are.

I am very grateful to my parents, Tony and Karen Oettinger, for their unwavering support and for fostering my sense of curiosity. (They are also excellent field work assistants.)

Last but not least, I would like to thank my husband, Christopher White, who gives me the latitude to explore, and packs me a sandwich for the trip.

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1. Introduction

From the 1910's through the 1950's, technology dramatically changed the way roads were constructed as roads were built at a rapid pace across the nation. The resulting straighter and wider roads allowed cars to travel faster and more safely through mountains instead of over and around them. The Southern Appalachians were home to some of the major roads built across the Eastern Continental Divide. Do the different highways in this region tell us different stories? Are the different construction technologies preserved in the patterns and composition of the surrounding landscapes, and in the shape of the roads themselves? Is the role of the landscape architect-as-road designer visible in the patterns of the landscape? Can these differences be measured? This research explores the land cover patterns correlated with these different systems of road alignment and construction and seeks to identify specific characteristics of road design and alignment that could explain these effects.

This research includes two major elements: 1) An illustrative history of highway and parkway design as related to construction technology and methods. As a subset, this review describes the role of landscape architects as road builders during the parkway-building era (1920's-50's); 2) A spatial analysis in ArcGIS 10.2.2 to examine road characteristics and surrounding landscape pattern and composition, using methods from the field of landscape ecology. The historical investigation is a survey of existing scholarship rather than original historical research. The results inform the design of the spatial analysis, especially the groupings of highways into the different design categories, which are: interstates, US highways, state highways, national parkways, and secondary routes. A visual assessment was also included to check available spatial data against actual conditions and to provide insight into the experiential aspects of traveling along different types of roads.

This study is really all about scale. Landscape architects are strict in their approach to scale. We are concerned about the human scale. What is the experience from the eye level of a person walking along an enclosed path? What is the experience at eye level of coming around a bend and seeing a new vista? Landscape architects designed roads in curvilinear fashion so they are beautiful at the human scale, to showcase the landscape.

Landscape ecologists are also concerned with scale. Scale is what differentiates the field of landscape ecology from traditional ecology. Just as we landscape architects know that scale choices can change the human experience of a place dramatically, research abounds proving the myriad ways in which choice of scale alters results in landscape ecology (Turner, Gardener, and O'Neill, 2001). Landscape ecologists often work at the regional scale instead of at the species scale like traditional ecologists, using the word "landscape" to denote this regional scale.[1] Studying in two-dimensions, from maps and remotely sensed data, landscape ecologists look at broad spatial patterns of the land.

This study investigates broad patterns of the land in this way, using humans as the study species, taking into account design features created for the travel experience at the human scale. Landscape architects designed curvilinear roads at the human scale. What does this mean at the regional scale, or as landscape ecologists say, at the landscape scale?

Curvilinear design for scenic effect is one of the ways that roads become measurably sinuous. A second and more common way was by necessity. These curvilinear roads were constructed in the vernacular tradition, and not by landscape architects. Road builders before the bulldozer had to wind around mountains instead of blasting through them (Figure 1.1). Aligning a road straight over a mountain was impractical for the design vehicle of the time: the horse-drawn wagon. A lot of our smaller highways are still sinuous for this reason. The old alignments have remained, though larger highways that carry heavy amounts of traffic have been widened and straightened.

Figure 1.1: Diagrams of Road Construction Technology and Road Alignment

(Davis, Croteau, and Marston, 2004)

[1] The ecological definition of the word "landscape" is "an area that is spatially heterogeneous in at least one factor of interest," and denotes this regional scale (Meixler, 2014). Note that this meaning is very different from the word "landscape" in the field of landscape architecture, which broadly refers to a human-scale view of land, but can take on a plethora of other meanings; landscape historian John Stilgoe recently published a book solely on this multitude of meanings.

The results of a large part of this study are quantified tables of statistics describing the form and shape of roads as well as characteristics of the land and terrain around them. The reader must keep in mind that numbers only go so far. As Norman Newton states in his foundational landscape architecture textbook *Design on the Land* from 1971 (p. 618):

> But geometric standards, including those inherited by the freeway from its cousin the parkway, are in the long run no more important than a certain quality that does not yet submit itself to mathematical analysis. This is the overall 'feel' of the freeway, the result of civilized attention to visual and psychological factors, and primarily what makes the best parkways a delight. It recognizes the humanity of humans, their functional difference from animals, their intuitive capacity to react—to sights and sounds, form and color and texture—in ways and to degrees that animals apparently do not. It rejects the purely mechanical solution as inadequate for humans. It postulates that the travel way of the future shall have the operational perfection of the most advanced freeway, coupled with the pleasantness and visual charm of the parkway. It is what occurs when the engineer and landscape architect merge their talents in genuine collaboration.

Four decades later, we know that Newton's statements on the "operational perfection" of future highways did not materialize. Still, this research seeks to capture some of these design characteristics and generalize the ungeneralizable—the experience of a drive (or bicycle ride) on a road aligned in harmony with the rises and falls of the surrounding landscape, absorbed, invisible as Emerson's transparent eyeball, observing nature (Emerson, 1836).

2. Background

This section is a brief history of road building in the US, with a focus on the East Coast. Section 2.1 sweeps through centuries of road and trail building beginning in colonial times. Section 2.2 discusses design standards and lack thereof that created different types of roads as seen today. Similarly, Section 2.3 reviews alignment methods in use during different points in history; this section is one of the most informative to this study for its discussion of road sinuosity. Section 2.4 describes technologies that affected road design and alignment. Section 2.5 summarizes the theoretical and cultural underpinnings of the renowned parkways and scenic roads in the US. Copious writings on this subject do more justice than this section can cover. The inclusion is demanded by the methods discussed later, but a thorough treatment of the intricacies that the subject necessitates would demand an entire thesis itself; indeed, some landscape history scholars such as Timothy Davis and Thomas Zeller have made this topic the main focus of their scholarship.

Section 2.6 is a departure from highways and describes the basic tenets of landscape ecology and its subdiscipline road ecology as these principles relate to this research design and analysis.

2.1. Road History

The Federal Highway Administration (FHWA) divides the history of roads in the US into four eras, from a highway design perspective:

1. 1900-1920 – “The Twilight of the Wagon Road” – This era consisted of the slow, then rapid, adoption of the automobile and the road designer’s struggle to accommodate new technology in mixed traffic on existing infrastructure.
2. 1920-1930 – “The Dawn of the Motor Highway” – This period was marked by new road proliferation, experimentation and haphazard, often dangerous, road designs as road builders realized the permanence of the automobile and its different demands on transportation infrastructure.

3. 1930-1940 – "Stabilization in Design Practices" – This decade finally brought federal standards to road design practices, with a continued rush to construct thousands of miles of new roads, taking advantage of the new technologies and cheap labor of the 1930's.
4. 1940-Present – "The Era of the Freeway" – The highway became the major feature of the American landscape when the pre-World War II idea of a national network of interstate highways became a reality.

This section generally follows these eras, with a specific focus on the design, alignment, and technology aspects of road history.

2.1.1. Mud, Wars, and Good Roads

The colonial road system was based on waterways, and most overland routes were merely trails that had been cleared for foot traffic (FHWA, 1976, p. 3). The first road over the Appalachians was the Wilderness Trail through Cumberland Gap at the borders of Tennessee, Kentucky, and Virginia, cleared in 1775 (FHWA, 1976, p. 6). A more organized postal service, led by Post Master Ben Franklin, improved postal roads in the colonies beginning in the mid-1700's (FHWA, 1976, p. 6). Entrepreneurs in the new nation built private turnpikes in the 1700's. With trade increasing after the Revolutionary War, road funds began flowing from the states, but the Founding Fathers maintained that the federal government could not fund roads (Lewis, 2013, p. 103). The federal government allowed one exception: the National Road stretching from Cumberland, Maryland, to Vandalia, Illinois, on which construction began in 1811.

As private property proliferated after the Revolutionary War, rights-of-way had to be acquired for road construction, though much of this was donated by property owners eager to improve their access to markets (FHWA, 1976, p. 356). The property owners also helped build and maintain the roads (FHWA, 1976, p. 356). This method, called "working the road tax" on "road drags" (Lewis, 2013, p. 109), was typically structured as a small crew providing maintenance work for a handful of days each year. Labor was required of everyone over 16—all "tithable" males—free, slave, or otherwise; many wealthy land owners paid others to work their road tax for them (FHWA, 1976, p. 6). Such intermittent and disorganized maintenance routines left the roads in a sad state of repair. The Federal-Aid Road Act of 1916 was revolutionary not only because it marked the beginning of a century of federal investment in roads, but also because it allowed the elimination of this hodge-podge of crews.[2] By the time the 20th century began, the nation had suffered nearly 50 years of road neglect since before the Civil War (FHWA, 1976, p. 381)

"King Mud" was considered the farmer's worst enemy at the turn of the century. Towns could be isolated for days after heavy rain due to impassable roads (FHWA, 1976, p. 366). Thomas MacDonald, the longtime head of the nation's Bureau of Public Roads and one of the primary forgers of our national road network, campaigned to be chief engineer for Iowa's roads department on the slogan, "Get Iowa out of the mud!" (FHWA, 1976; Lewis, 2013). Different paving methods had been used in urban areas for decades, but rural roads were too expensive to pave due to their length and varied terrain.

The Good Roads movement ushered in an era of better road surfacing, led by cyclists during the bicycle's huge wave of popularity in the 1880's. The League of American Wheelmen, a bicycle advocacy organization formed in 1880, advocated for smooth, surfaced roads of packed gravel instead of dirt or plank roads. Their efforts initiated road improvement programs and also served as legal precedents for automobiles when car owners were struggling to gain the right to drive on public roads (Longhurst, 2015).

The first American car arrived in 1893, and the bicycle's popularity waned in the late 1890's, (Longhurst, 2015, p. 82). The Good Roads movement faded with it but had helped leave a mark on federal policy. The Office of Road Inquiry was established in 1893 to address road conditions in the country. As a unit in the federal Department of Agriculture, its focus was more on rural routes to connect farmers to markets, but the conversation about roads had been elevated to the national stage by urban cycling enthusiasts (FHWA, 1976; Longhurst, 2015).

Following the Good Roads movement, World War I battered the nation's highways. Trucks carrying heavy equipment traversed the nation, and roads took the beating (Rose, 1976, p. 86). The heavy manufacturing and military transports required to keep the nation at war, combined with increasing use of

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[2] This first act relied on general funds; the first federal gas tax was not implemented until the Revenue Act of 1932, at $0.01 per gallon (Federal Highway Administration, 2016).

trucking by private companies for interstate deliveries instead of just local deliveries, reverted the nation's newly-improved roads to their former rutted, potholed, eroded state (Lewis, 2013, p. 11).

Automobile ownership skyrocketed in the 1910's and 1920's after the introduction of Ford's Model T in 1908. Following the destructive force of World War I on the nation's roads, public demand for road improvement reached fever pitch in the 1920's. The combination of public demand and the new federal funding, authorized in the Federal-Aid Road Act of 1916 and increased in the Federal-Aid Road Act of 1921, resulted in a road building craze in the 1920's. This period was marked by major experimentation and a panicked eagerness to keep up with the technological advances of the automobile industry, which kept raging forward until the early 1930's. The 1920's were "a period of trial and error" (FHWA, 1976, p. 385). Road designers had no precedents to work with. Noted in the FHWA history:

> While building upon these bases of knowledge, highway designers were often in a dilemma as to which features of wagon roads should be retained, modified, or rejected, which characteristics of railroad practice should be incorporated, and what new concepts were needed to satisfy the peculiar qualities of automobile traffic. Resolution of these matters was often the subject of heated debate with the answers frequently being dictated by economics. (p. 381)

The American Association of Highway Officials (AASHO) formed in 1914. Toward the end of the 1920's, AASHO and the Bureau of Public Roads, expanded from the Office of Road Inquiry, began reining in this haphazard design era with federal design standards, which they tied to federal funding of highways.

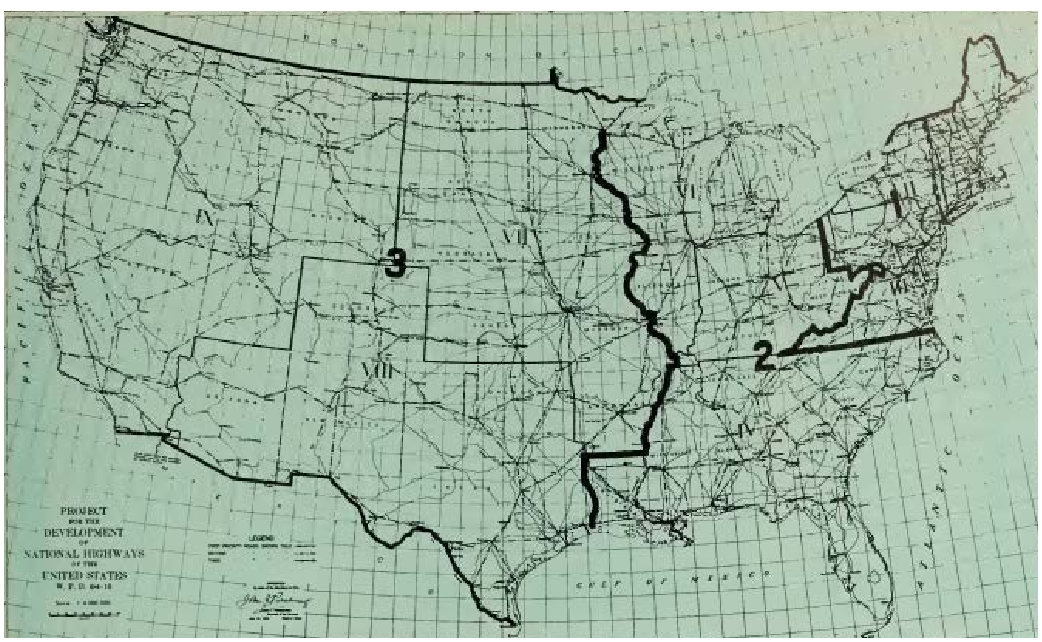
Federal policy makers had begun to think of the road network on a larger scale, as well. The federal system of numbered US highways was established in 1925 (Lewis, 2013, p. 18). This system was based on the idea that each county seat in the nation should be connected by an intercity highway, instead of roads being designed only for local travel to cities (Lewis, 2013, p. 19). Coordination among states was necessary to ensure that highways connected at borders and made sense to an interstate traveler; many highways previously named after presidents or local heroes were rebranded by a number (Lewis, 2013). The system began with US Highway 1 on the East Coast and numbering continued west.

The 1930's continued the important task of road design standardization, with new safety standards implemented more widely and consistently. Adding to the uniformity of roads built during this time was the huge investment in public works by the federal government to combat the Great Depression (FHWA, 1976, p. 370). Cheap labor and advances in construction technology made building roads cheaper and easier.

Along with federal aid to states, this era was also the formative decade for roads in national parks and for parkways. The designs now considered classic park and parkway designs, including use of local materials and hand-built details, were made possible by the unique economic conditions of the 1930’s and built on the decades of road construction experience garnered in the previous decades (FHWA, 1976, p. 370; Davis 2004, p. 219).

This heyday ground to a halt with the advent of World War II, which postponed all major highway investments that were not deemed critical to the war effort (FHWA, 1976, p. 456). The 1930’s were enough time, however, for the federal government to envision its highway future: ribbons of highway across the continent, wide enough to speedily transport military convoys and evacuate citizens from the vulnerable coasts. Bureau of Public Roads Chief Thomas MacDonald presented President Roosevelt with the publication *Toll Roads and Free Roads*, which first proposed this interstate system of highways, in 1939 (Lewis, 2013). In fact, MacDonald had already used his own and Army staff to draw a nation-wide highway network in 1922 for “routes across the country essential to military operations” (Figure 2.1); these general routes were used as the basis for the interstate system (Lewis, 2013, p. 16).

Figure 2.1: Pershing Map of 1922



(FHWA, 1976, p. 143)

World War II diverted attention from road building temporarily, but immediately following the war, the federal government acquired the rights-of-way for the interstate system, called "national defense highways" (FHWA, 1976, p. 354).

Prior to the interstates, road alignments had generally been constructed along existing trails and paths. "Surfaces were paved or repaved, lanes were widened or added, and curves or grades were smoothed … but generally the original alinement [sic] was preserved and little, if any, additional land was acquired" (FHWA, 1976, p. 369). Bureau Chief Thomas MacDonald had his qualms about building roads where no demand for traffic existed, along entirely new rights-of-way (Lewis, 2013, p. 139). But the Road-Builder in Chief was on his way out, having served Iowa and then the nation for 34 years, overseeing the nation's transition from a haphazard lacing of muddy trails to an intricate network of asphalt highways.

The National System of Interstate Highways was created by the Federal-Aid Road Act of 1944, signed by President Roosevelt, requiring federal design standards to be established by the Bureau of Public Roads, but this was not the Act that spurred the construction of the interstates, since it included no funding mechanism and no urban routes. In 1956, President Eisenhower signed a new Federal-Aid Road Act that created the Highway Trust Fund and authorized construction of the system designed over a decade earlier (Lewis, 2013, p. 121). Like the previous national system of highways, the US numbered routes, interstates received a numbering system; to avoid confusion with US highways, the numbers began on the West Coast and increased moving east.

Since 1956, about 47,000 miles of interstates have been constructed in our cities and across the country. Each mile consumes approximately 24 acres of land, including, among other uses, the road itself, shoulders, wide Clear Zones to keep free of trees and fixed objects, and interchanges (Lewis, 2013, p. 153). As Thomas MacDonald predicted, it was one of the greatest public works efforts of the 20th century (Lewis, 2013). Visible from space (Lewis, xiii), the system redefined the American landscape like nothing else in the last 250 years.

Safety and speed took precedence over scenic experiences along interstates. As a result, in the 1950's, highway engineers gradually became the lead road designers, and landscape architects only had a place in road design at the National Park Service. Mary Myers notes that this era marked the "breach" between civil engineers and landscape architects in road design and that landscape architects were “relegated to cosmetic landscape improvements” (2001, p. 1). Myers notes the “stultifying sameness” of highways that resulted (2001, p. 5).

2.1.2. Design

Most roads constructed before 1910, with notable exceptions like the National Road and some private turnpikes, were constructed for horses and horse-drawn wagons to use. “It is questionable whether rural roads in many of the States up to this time were actually designed” (FHWA, 1976, p. 384). Horses traveled about 4-5 mph and stagecoaches about 6-7 mph (Engle 2006, p. 63; FHWA, 1976, p. 381). Grades of 5% were maintained to accommodate the horses, which, according to the FHWA, “resulted in rather crooked locations carefully selected to avoid steep grades, closely fitted to the terrain, with small cuts and fills to save grading costs” (p. 382). Roads were typically 12’-15’ wide, made of stamped layers of gravel. Horizontal curves and straight tangents all had the same 6”-8” crown. As a wagon wound around the outside of a curve, this meant the wagon would tilt slightly downhill, down the mountain, instead of toward the inside of the curve, the safer option. For safety, traffic used the middle of the road, and road material migrated to the outside of the curves as a result (FHWA, 1976, p. 381).

Roads did not have vertical curves since traffic moved at such low speeds. Horizontal curves were tight, with 105 feet being a “generous radius” to allow a 50-foot horse team and wagon to turn within a 12-foot roadbed (FHWA, 1976, p. 382). Road builders continued constructing roads in this manner through the 1910’s. Cars were not yet very prominent outside of cities, and builders assumed that even with the higher speeds achievable by car, drivers could perceive these changes in the land and curves in the road in time to adjust their speed safely (FHWA, 1976, p. 382). It wasn’t until nearly 1930 that highway designers realized that the human eye cannot perceive the sharpness of a curve in the road at the higher speeds being driven (FHWA, 1976, p. 390; Vanderbilt, 2008).

A few changes came about in the 1920’s, however. Recognizing the increased horse power of automobiles, road designers straightened out highly tortuous curves and draped roads more directly over topography. This resulted in much steeper grades. A Bureau of Public Roads statement issued in 1929 reads, “If local conditions permit either a 7% grade with a sharp curve or a short 9% grade with a wider curve, the latter design is thought to be the better practice because it is safer for modern motor traffic” (FHWA, 1976, p. 394). The phenomenon of steep, straight hills is most plainly seen in the Midwest, where section lines from the Land Ordinance Act divided 30 states into square parcels with no consideration for topography (Figure 2.2). In 1866, these dividing lines were officially declared public rights of way, and many thus became roads (FHWA, 1976, pp. 356-6).

Figure 2.2: Missouri Road Straight Over Hill

Road widths were still arbitrarily decided and varied between nine feet and 20 feet, but averaged 14 feet, allowing for safer passage (FHWA, 1976, p. 385). Horizontal curve standards were adopted in the 1920’s. Much of the road construction undertaken in the 1910’s, 20’s, and 30’s skipped rigorous safety tests because of the rapidly increasing demand for new road mileage. As a result, the FHWA states, “Every section of newly paved highway seemed to have its ‘deadmans’ curve’” (p. 387).

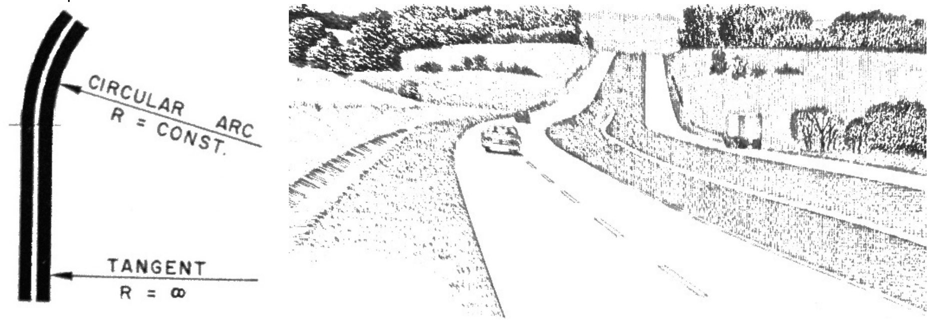
A landmark innovation in highway engineering came in 1921, when the first design speed was adopted. Designing a road specific to the speed of a design vehicle required more difficult upfront calculations but provided safer roads. In 1921, the standard design speed for roads was 25 mph; in 1928, it had risen to 35 mph. By 1944, the design speed for flat topography became 75 mph (FHWA, 1976, pp. 385 & 390).

Two additional major innovations came about in the late 1920's and worked in tandem to make curvature tighter and safer: superelevation and spiral curves. Superelevated curves are banked toward the inside of the curve, which counters centripetal force that pulls vehicles to the outside of the curve. Standards for superelevation were issued by AASHO in 1928, though it had been used in places, in a variety of haphazard forms, earlier in the decade (FHWA, 1976, p. 394). Superelevation had been discovered in 1910 but not deployed until after 1920 when funding for surfacing was available (FHWA, 1976, p. 381).

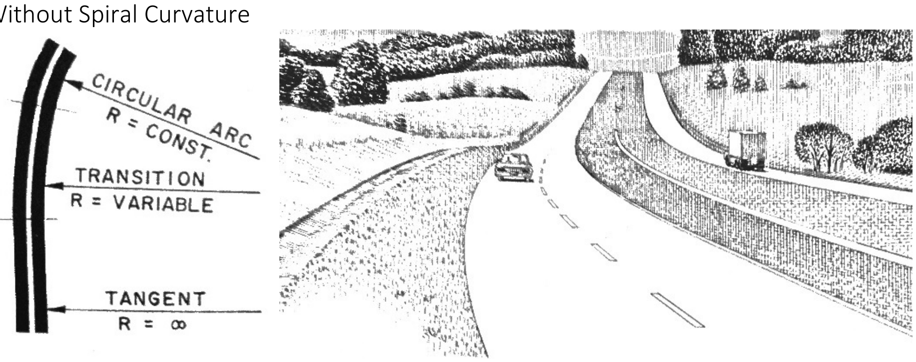
Spiral curves, also called transition curves, were invented in the late 1800's for railroads (Myers, 2001, p. 1). This type of curve (Figure 2.3) created a more seamless transition from the tangent of a straightaway into a curve, which was very jerky at high speeds. Spiral curves have a consistently changing radius, from a radius of infinity (straight tangent) to the radius of the curve they lead into, and are thus cumbersome to calculate and design. Prior to spiral curves, roads abruptly veered into curves; combined with the lack of superelevation, these flat, fast curves caused skidding to the outside (Myers, 2001, p. 2). The results were most dire for trains; four wheels per train car traveling at different speeds during a transition from a straight tangent to a curve caused derailments (Myers, 2001, p. 2).

Figure 2.3: Roads with and without Spiral Curvature

With Spiral Curvature



Without Spiral Curvature



(Tunnard & Pushkarev, 1963, pp. 180 & 182)

In tandem, spiral curves and superelevation were major innovations that created a smoother and more enjoyable ride. Many of the nation's parkways, including the Blue Ridge Parkway and Skyline Drive, were designed with these curves (Myers, 2001, p. 3). An added bonus for road builders was lower construction costs. Spiral curves could be designed with higher safety standards within a smaller footprint since extra space did not have to be allocated to cars drifting toward the outside of the curve (Engle, 2006, p. 63). Other railroad design innovations became widely employed for roads in the 1930's: gentler horizontal curves (Figure 2.4) and long, flat vertical curves (Figure 2.5). Road builders had long known that these types of curves were safer for drivers, but prior to 1930, the cost of all of the earth moving this level of intense grading required was prohibitive (FHWA, 1976, p. 394).

Figure 2.4: Horizontal Curves: Undesigned and Designed

Undesigned Horizontal Curve Designed Horizontal Curve

(Tunnard & Pushkarev, 1963, p. 180)

Figure 2.5: Vertical Curves: Undesigned and Designed

Undesigned Vertical Curve Designed Vertical Curve

(Tunnard & Pushkarev, 1963, p. 193)

Road builders began to realize the impacts of some of these haphazard design methods in the late 1920’s and 1930’s. For instance, many of their highways were being used to transport goods in trucks, not just for a private individual in an automobile. Trucks slowed down traffic considerably on the 9% grades that were the typical design in the 1920’s (FHWA, 1976, p. 389). Grades were adjusted to 5% maximum in most terrain; in design standards issued for the interstate highways in the 1950’s, standard grades were reduced even further to a recommended 3% (Lewis, 2013, p. 140).

AASHO took action in 1928 by issuing general design standards for roads: 8-foot shoulders and 10-foot traffic lanes for safety (FHWA, 1976, p. 388). Interstates required 10-foot shoulders and 12-foot traffic lanes (Lewis, 2013, p. 140).

Three lane roads were constructed in the 1920’s as a way to improve sight lines and allow for cars to pass each other, but they were soon discovered to be extremely dangerous. Four lane roads came about to increase sight lines and create shorter passing distances. This design allowed for straighter alignments within the same right-of-way. Roads became wider and straighter since the width accommodated the safety need (FHWA, 1976, p. 396).

To further improve safety between oncoming lanes of traffic, dividers were erected between opposing lanes. Medians were designed into the road, widening over the years, until eventually splitting into two different roadbeds, separately aligned and designed to the landform. The innovation of divided highways reduced construction costs in rugged terrain, since a single cut and fill operation did not have to accommodate four lanes of traffic plus shoulders at the same elevation.

As it happens, Frederick Law Olmsted, the father of landscape architecture, was also the progenitor of another of these innovative highway design concepts. His grade-separated intersections for different modes of traffic in Central Park were adapted decades later for the automobile as safety improvements on highways. Highway engineers used grade-separated intersections to create safer conditions on highways and also speed traffic along. A sister concept, limited access, forbade any driveway or parking lot for businesses or residences from opening directly onto the highway.

In the 1960's, a third of all crashes were "single vehicle, run-off-the-pavement" types (FHWA, 1976). Fixed objects along the roadside caused a huge number of traffic fatalities. Advocates for "Clear Roadsides" demanded safer designs. Engineers developed the Clear Zone guidelines, standards for flatter, rounded shoulders free of fixed objects like trees and signage (FHWA, 1976, p. 403).

As the list of safety standards became longer and longer, the nation's highways did become much safer than in previous decades. With engineers dominating road design, however, scenic concerns were lost amidst priorities to make highways more efficient conduits of faster and faster traffic. "For many engineers the structure itself was the goal rather than the structure in relation to the land. Engineers were not alone, for many progressive planners regarded the highway, speed, and efficiency to be of primary importance" (Lewis, 2013, p. 170).

2.1.3. Alignment Methods

Prior to the 1930's, roads were aligned on foot by a "locator" who placed stakes for the centerline by looking at what he could see in front of him – no aerial views, no maps, nothing to help him see through the trees or over the hills. This is called the Direct Method of alignment (FHWA, 1976, p. 382). This method suited road builders for the first decades of the 20th century. The Direct Method is the fastest way to lay out a road, and the design impacts on the safety of auto travel were still not well understood.

The Topographic Method was used by railroad designers beginning in the early 1800’s. Instead of staking a route visually, a locator would first survey a route and create a topographic map of the corridor. Only then would he begin aligning a route along the map itself. “Instead of seeing only a hill in front of him he saw the country in a miniature far ahead” (FHWA, 1976, p. 382). The locator calculated cut and fill costs in line with railroad design standards and redid the process if the alignment was not satisfactory (FHWA, 1976, p. 382). For cost reasons, highway designers did not begin using the topographic method until the 1930’s (FHWA, 1976, p. 382). The method was much slower and therefore cost more. It also was not considered necessary for roads since so many alignments already existed from old roads and trails, though safety concerns were beginning to change that (FHWA, 1976, p. 389).

Commercially aerial photography began to be widely used for surveying in the 1920’s and made the topographic method much less involved (FHWA, 1976, p. 389). The aerials eliminated expensive survey work that had to be undertaken before the alignment work could start (FHWA, 1976, p. 389). The Federal-Aid Highway Act of 1956, the same act that authorized the Highway Trust Fund and thus spurred the construction of the interstates, officially authorized the use of “photogrammetric methods in mapping” (FHWA, 1976, p. 396). By 1960, builders so trusted calculations made from aerials that they based their cut and fill cost estimates on the photographs and not survey work (FHWA, 1976, p. 396).

2.1.4. Technology

The most influential technology affecting road design were the private vehicles operating on the roads. The first American car was invented in 1893. Between then and the 1910’s, brakes were bad, street lighting was bad, and horse-drawn vehicles were still in use. Traffic on the streets was a chaotic mess. Managing horse manure was a huge municipal expense and a public health concern. On top of all of those factors, the road design and alignments could be deadly (FHWA, 1976, p. 387). The benefits of cars, though, were obvious – cleaner streets, no manure, fewer flies, faster, cheaper, and more efficient.

Some paved roads built before 1900 were for the wealthy on the East Coast, the elite who owned automobiles for sport. Most of the country's roads remained in extremely poor shape until the 1920's. When Ford's Model T rolled out of Michigan in 1908, it was "designed … for the rough Midwestern American landscape" (Lewis, 2013, p. 32), and then, the American landscape was designed for the Model T.

All of the design innovations in roads after 1910 were built to accommodate cars, and road design has barely kept pace with auto technology since. These design innovations were made possible, by developments in construction machinery and, as the previous section illustrated, somewhat by alignment and surveying methods and aerial photography. For decades, designers had known that gentle curves and uniform grades were the safest designs for cars, but they were limited by funding and technology. Animal-drawn grading equipment, typically a flattened log pulled by a horse (aka "split-log drag") necessitated minimal cuts and fills. Alignments thus went to sidehill locations (FHWA 387). They did use black powder in rare circumstances (Davis, Croteau, and Marston, 2004, p. 3).

Beginning in the early 1930's, new construction machines were used (Haycroft, 2011). "Tractor-drawn self-loading scrapers with capacities of 12 cubic yards came upon the scene for the first time" (FHWA, 1976, p. 454). Diesel engine tractors and graders (Figure 2.6) became available in 1931 and were rapidly adopted; the powerful bulldozer followed crawling tractors and became available in the 1940's (FHWA, 1976, p. 452). A confluence of technology and changes in road design also made earth-moving machinery easier to use. The pneumatic tire enabled trucks to operate more easily on the loose fills of a mountainous construction site; dump trucks became equipped with pneumatic tires in 1924 and scrapers in 1932 (FHWA, 1976, p. 454). As wider lanes became mandated and two-lane roads took the place of narrow 10-foot roads, machines could maneuver within the roadbeds more easily (FHWA, 1976, p. 394).

Figure 2.6: Diesel-Powered Shovel

(FHWA 1976, p. 452)

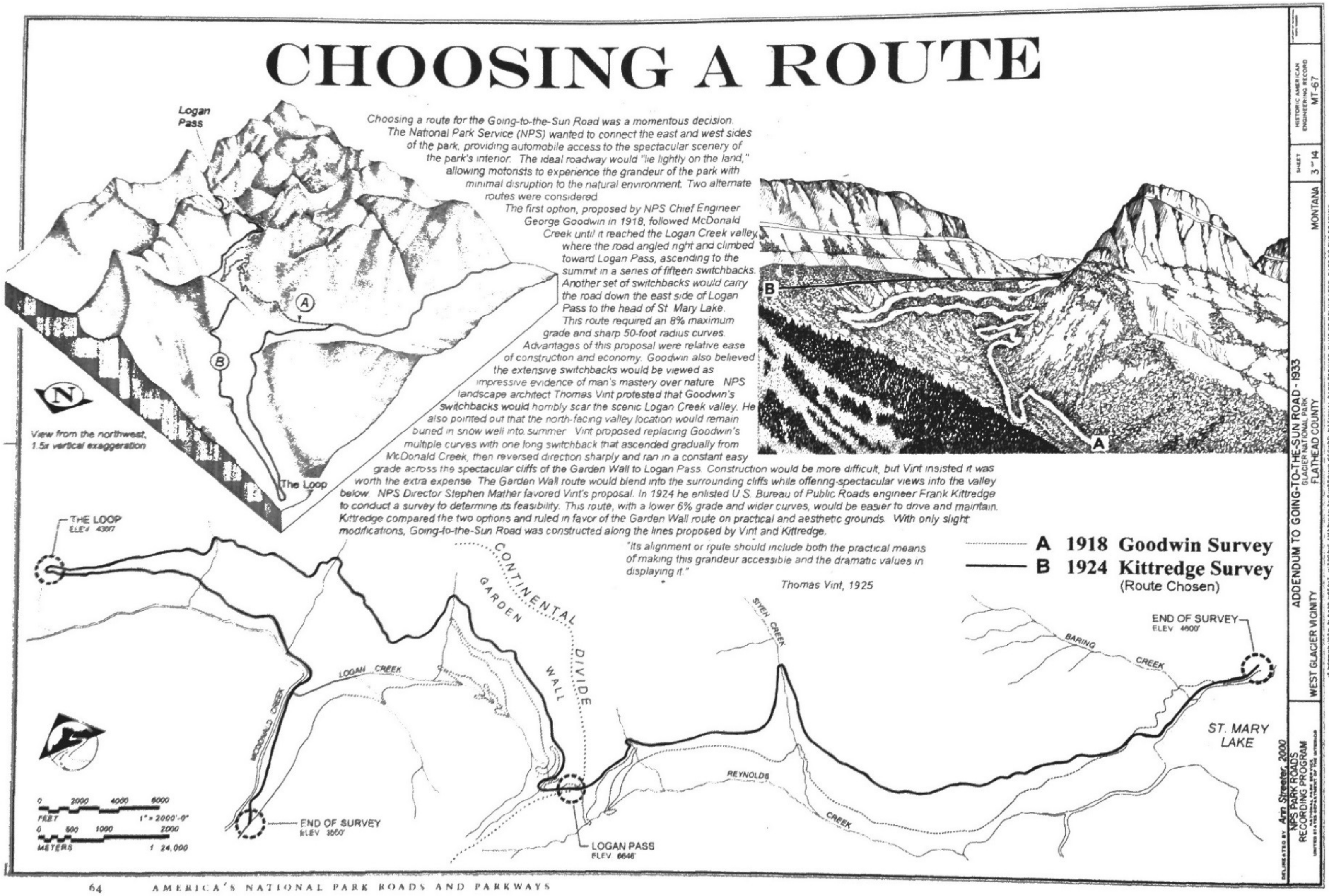
Steadily, earth moving became the “best bargain” of the entire road building process (FHWA, 1976, p. 395). Tim Davis notes that the invention of dynamite also greatly altered the abilities of road crews to blast and tunnel through topography instead of “zigzagging” around it. (2004, p. 11). The cost of moving a cubic yard of earth in 1922 was \$0.40, compared with \$0.21 in 1938 (Lewis, 2013, p. 18). This was no doubt in part due to the cheap labor afforded by the Great Depression, but savings are also attributable to technological advances.

A stunning example of new alignment methods enabled by technology is Going-to-the-Sun Road in Glacier National Park. Before the road opened in 1933, drivers had to ship their cars around the park in order to traverse the Logan Creek Valley (Davis, Croteau, and Marston, 2004, p.62). The head engineer at the National Park Service, George Goodwin, designed the road with 15 switchbacks in each direction up and down the pass, which would have been relatively easy to construct. A landscape architect for the Park Service, Thomas Vint, designed a different route that would intrude less on the scenic valley. Vint’s design included only one switch back, connecting two long, graceful curves, with a maximum grade of 6%, versus Goodwin’s 8% (Figure 2.7). The construction would be much more advanced, but NPS designers had learned to design to the technology of the time (Davis, Croteau, and Marston, 2004, p. 5). Vint’s design won out. The resulting Going-to-the-Sun Road is 51 miles long and is hailed as "one of the most scenic and technologically impressive mountain roads in the world" (Davis, Croteau, and Marston, 2004, p. 62).

Technology did enable more innovative design in some cases. In others, however, design was lost in the race to use the newest sleek technology. Perhaps the most extreme example was a proposed plan in 1963 to vaporize the Bristol Mountains in California with 22 atomic bombs to allow the Santa Fe railroad and I-40 to pass through. The plan was fortunately not approved because of the engineers' uncertainty about how long it would take the radiation to dissipate (Lewis, 2013, p. 170).

As Tom Lewis describes in his book about the interstates, "Forget following the contours of the natural landscape, just pound the road through. Should a mountain prove too high, just blast the top off or tunnel through. Should a ravine prove too deep, just fill it with stone and dirt" (Lewis, 2013, pp. 169-170). Aside from a few examples like Going-to-the-Sun Road and the Blue Ridge Parkway, most of the roads in US since the 1940's have been constructed with this ethos in mind. Table 2.1 summarizes the major road building design trends of the first half of the 20th century.

Figure 2.7: Going-to-the-Sun Road Alignment Proposals



(Davis, Croteau, and Marston, 2004, p. 6)

Table 2.1: Summary of Road Construction and Alignment Methods

FHWA Era	**Pre-1910** **"Twilight of the Wagon Road"**	**1910-1930** **"Dawn of the Motor Highway"**	**1930-1940** **"Stabilization of Design Practices"**	**1940-Present** **"Era of the Freeway"**
Design Vehicle	Horse-drawn wagon	Automobile	Automobile	Automobile
Alignment Method	Direct	Direct	Topographic	Photogrammetric (Aerial Photography)
Design Grade	5%	9%	5%	3%
Design Speed	5-8 mph	25 mph (1921) 35 mph (1928)		75 mph (flat)
Roadbed Width	8'-12'	9'-20' (14' avg) 18' min. rule (1921)	10' lanes	48' (24' each roadbed) 12' lanes
Superelevated (Banked) Curves	No superelevation Center crown, even on outside curves	Superelevated curves, no standards Horiz. curve standards	Superelevated curves with federal standards Vert.curve standards	
Construction Equipment	Split log drag Animal-powered	Power shovels	Crawling tractor Diesel engine tractors, graders Dump trucks Pneumatic tires on haulers	Bulldozer (early 1940's)
Funding	State Federal (began 1916)	State Federal (began 1916)	Federal State	Federal State
Resulting Roads	Narrow, curvy, high elevation change Secondary Rtes	Narrow, curvy (some straight), high elevation change Secondary, State Hwys	Slightly wider, straighter, gentler grades US, State Hwys	Wide, straight, very gentle grades Interstates, US Hwys

2.1.5. Landscape Architects, Parks, and Parkways

An entire network of American roads was constructed from a different cultural tradition and still serves a purpose wholly separate from roads built and maintained under AASHO and federal guidelines: these are the roads governed by the National Park Service. A 1968 National Park leaflet states, “Park roads are for leisurely driving only. If you are in a hurry, you might do well to take another route, and come back when you have more time” (Davis, Croteau, and Marston, 2004, p. 7).

Park roads received formal recognition as a distinct category in the Interbureau Partnership of 1926, signed by the National Park Service and the Bureau of Public Roads; this document codified the intent of park roads to “lie lightly on the land” (Davis, Croteau, and Marston, 2004, p. 5). This partnership still exists today and governs the design and construction of roads within national park land.

One of the very first pleasure drives in the nation was the approach road to Washington’s Mount Vernon, designed after the English tradition promoted by designer Batty Langley (Marriott, 2011, p. 7). The idea of pleasure drives came from the English Landscape School of the 18th century. Humphrey Repton (1752-1818) was one of the most influential and certainly most detailed in descriptions of pleasure drives, opining that mansion approach roads should adhere to a careful sequence of views and enclosure before arriving at the front of the house (Marriott, 2011, p. 8). Andrew Jackson Downing brought Repton’s ideas to the US, where they inspired Frederick Law Olmsted and Calvert Vaux’s Greensward Plan for Central Park (Marriott, 2011, p. 8). Olmsted and Vaux morphed these carriage roads into an entire network of paths in the park. The sequencing and pastoral quality of these paths, in turn, heavily influenced parkway designers 50 years later. Much like the meticulously planted views created for Central Park, our national parkways on the East Coast are built in this pastoral tradition, appearing to showcase the vernacular countryside of our humble, forgotten past.

The first parkways were a throw-back to English tradition, but eventually “embraced native forms and desires” (Davis, 2003, p. 228). Tim Davis argues that the parkway as a form combined the American vernacular – rustic, rural values – with European influences and that the influence of European traditions has been overplayed in much landscape history (p. 230). Olmsted and Vaux even “acknowledged” that country roads were preferable to designed parkways, if you could find them, but the team used parkways as a way to increase parkland in urban areas, addressing an acute need in American cities at the time (Davis, 2003, p. 231).

Landscape architects were the lead designers for a majority of the parkways built in the first half of the 20th century. The idea of a linear park specifically for driving came about in the 1910's, when the Bronx River Parkway was designed by Gilmore Clarke, who went on to lead most of the design teams for the parkways still famous today, including the Taconic Parkway and the Mount Vernon Memorial Parkway. His protégé Stanly Abbott was sent south to lead the design of the Blue Ridge Parkway. The 1920's saw huge investments in private parkway corporations and the 1930's brought the inexpensive labor and capital infusions required to design and construct intricate roads in the landscape through difficult terrain. The Blue Ridge Parkway's "impetus … was firmly rooted in the New Deal," Davis states (2004, p. 219). It was proposed as a public works project in 1933, with quotas for local hiring; construction began in 1935.

Norman Newton's *Design on the Land* states that "the parkway was not itself a road; it contained a roadway" (p. 597). The Blue Ridge Parkway is just that: an "elongated national park" (Davis, Croteau, and Marston, 2004, p. 219) that contains a roadway painstakingly designed to showcase the park itself.

In the Appalachians of North Carolina, many areas of the mountains were logged heavily between 1880's and 1920's. In fact, the idea to create a Great Smoky Mountains National Park was originally floated at a 1923 board meeting of the Knoxville Automobile Association, whose members were upset with the extensive logging in the region that was destroying their scenic driving experience (Davis, Croteau, and Marston, 2004, p. 74). Pleasure driving was formative to the notion of preserving scenic beauty in the region. At the time, the parkway was the longest road planned as a single feature in US, located away from cities and settlements, not a ridgeline route. "Designers provided the road with a high standard of grade and curvature so that motorists could safely devote their attention to the scenery" (Davis, Croteau, and Marston, 2004, p. 219). Scenery was preserved selectively; designers improved, created, and "invent[ed] an idealized Appalachian landscape that combined seemingly unspoiled naturalistic scenery with engaging vignettes of traditional mountain culture" (Davis, 2003, p. 237). The mountaintops were reforested in specific areas to frame views and restore naturalistic mountain scenery.

Vegetation was also used to hide newer barns or improved homesteads that did not fit with Stanly Abbott's conception of "pioneer mountain architecture." Some farmers were paid to remain within the scenic easement to showcase their practices; others were relocated. While local farmers envisioned a new road to access markets, they did not realize that commercial traffic, including, in some cases, their own vehicles, would be prohibited on the parkway. The reality of the parkway landscape was at odds with the grand vision (Davis, 2003, p. 238).

Still, the design innovations employed on the parkway mark an important era in road design. No white line demarcates the edge of the pavement, to make travelers feel more connected with the landscape (Myers, 2001, p. 3). Guard rails and bridges are faced with local stone or made in the traditional split-rail fashion. Distant, middle, and close views are patterned in a careful sequence to vary the experience of the Appalachian pastoral (Myers, 2001). Directional views facing the driver straight ahead on the road using the roadside trees as frames showcase distant peaks; panoramas to the side of the road at overlooks and openings in the vegetation offer sweeping views of the iconic layers of the Blue Ridge Mountains (Davis, Croteau, and Marston, 2004, p. 66). Instead of connecting tangents with curves, the road was designed as a single "continuous flowing curve" (Myers, 2001, p. 3).

Parkways are a singularly American road typology. Park roads are narrower than most other roads, usually under 22 feet, with no shoulders, and curbs only in developed areas (Davis, Croteau, and Marston, 2004, p. 5; Myers 2001, p. 3). Tunnels are used to frame views and reduce visual and environmental impacts on the landscape (Davis, Croteau, and Marston, 2004, p. 6). The National Park Service still uses designs formulated in the 1930's as inspiration for designs of today.

2.2. Ecology and Transportation

This study melds road construction history with contemporary road ecology research. This section provides an overview of landscape ecology principles and tools, a brief summary of the field of road ecology, and a state of the practice review of road ecology research as part of federal policy.

2.2.1. Landscape Ecology

Landscape Ecology is a branch of ecology that focuses on analysis of patterns and processes only visible at the "landscape," or regional, scale. The discipline includes studies of disturbance regimes, ecosystem processes, and quantification of landscape pattern. Landscape ecology changed the way ecologists conducted research, widening the focus from species-based, spatially constrained studies to broader patterns between ecosystems at a larger scale. Landscape ecologists seek to quantify patterns in the landscape as shaped by abiotic and biotic processes, by landform, by human land use, and by disturbance regimes such as flooding and fires. Three major innovations, beginning in the 1980's, allowed ecologists to look at phenomena at these larger scales: increased computing power, satellite technology, and sophisticated GIS software.

In practice, landscape ecology generally takes two shapes. The first, the European School, is an older school of thought focused on the built environment and is therefore represented more in planning and design disciplines. The second, the American School, came to prominence more recently, in the mid-1980's. The American School is concerned more with natural systems and, as a result, is usually represented in natural resources or biology departments. This branch of landscape ecology uses a specific set of tools and models to investigate regional patterns.

Analyzing patches in land cover is central to landscape ecology; a landscape can be described through statistics like average patch size and the ratio of patch perimeter to core. Other metrics include landscape composition, spatial configuration, fragmentation, diversity, and connectivity of the landscape. Software such as GIS, Fragstats, and R are typically used to compute these metrics. Geostatistics and spatial statistics are also used and do not require the definition of patches. Since this research is not specific to a species or type of habitat, a patch is not defined. This research uses a geostatistics approach to study vegetation patterns at a regional scale.

2.2.2. Road Ecology

Road ecology is a wide-ranging field that incorporates principles from a variety of disciplines as they intersect with the built environment of roads. Road ecology research spans chemistry, aquatic ecology, atmospheric science, wildlife ecology, transportation planning, plant ecology, and public policy.

The first study on the ecological effects of roads was published in 1925. Dayton Stoner documented 225 animals killed by cars in Iowa (van der Ree et al, 2011, p. 1). Incidentally, Iowa was then the state that had dedicated perhaps the most resources toward its road network, having had Thomas MacDonald at the helm of the state roads department for 20 years before his promotion as Chief of the nation's Bureau of Public Roads. It was the state with the highest vehicle ownership per capita in 1914 and boasted some of the best roads in the nation for the first few decades of the century (FHWA, 1976, p. 10).

Following decades of a few scattered studies, such as Frank Waugh's "Ecology of the Roadside" in 1931, the term "road ecology" itself was not coined until 1981, and in German (as cited in van der Ree et al, 2011). Richard Forman brought the term into English in the 1990's, publishing a seminal paper in 1998 with Lauren Alexander titled "Roads and Their Major Ecological Effects." He ultimately published a book with Dr. Daniel Sperling, an edited collection of research titled *Road Ecology* in 2003. Since then, the number of articles, books, and conferences on road ecology has been steadily growing (van der Ree et al, 2011, p. 1). Roads are the largest contributor to habitat fragmentation worldwide (Noss 1993 as cited in van der Ree et al, 2011, p. 2) and Forman called them the "sleeping giant of conservational biology" (as cited in van der Ree et al, 2011).

Road effects include (van der Ree et al, 2011, p. 2):

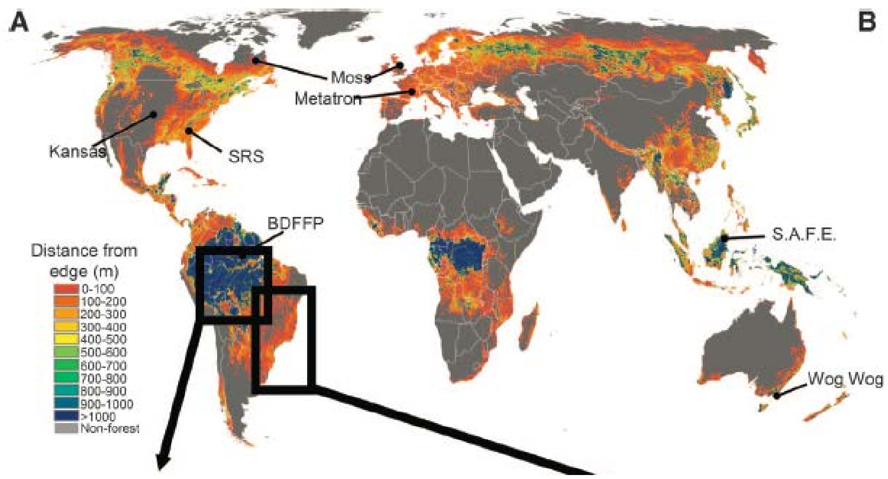
- Loss and fragmentation of habitat
- Increased rates of mortality due to vehicle collisions
- Changes in light, moisture, and wind regimes
- Light, noise, and chemical pollution from traffic
- Acceleration of the spread of invasives via vehicles

In their 1998 study, Forman and Alexander estimate 15-20% of the total land area of the US is affected by the road effect zone. The extent of the edge effect is different for different species. Most sensitive are birds, which can suffer effects from traffic noise up to 1,200 meters into their habitats (Forman & Sperling, 2003). Runoff, dust, and pollution from roads affects the soil up to 30 meters from the edge of the pavement; they can affect wetland processes up to 500 meters from the road (Shilling & Waetjen, 2012, p. 7). In general, the effects of roads on wildlife include: decreased habitat amount and quality; increased mortality from vehicle collisions; barring access to resources; and division of populations into smaller subpopulations. The factors that contribute to the type and magnitude of these four effects on a given species are: animal behavior, population sensitivity, road width, and traffic volume (Jaeger et al, 2005).

Much current road ecology research is focused on animal movement and wildlife-vehicle collisions and not on landscape function or ecosystem-level effects (van der Ree et al, 2011, p. 2-3). In a special issue of *Ecology and Society* in 2011, joint authors van der Ree et al state that in spite of a call for papers explicitly soliciting research at this scale, there is “a paucity of road ecology studies that explicitly examined higher order effects of roads” (p. 3). A majority of studies focus on behavior specific to a certain species, and some have developed planning or design recommendations for management and mitigation. Still, “many higher order effects remain unquantified, and must become the focus of future studies because the complexity and interactions among the effects of roads and traffic are large and potentially unexpected” (van der Ree et al, 2011, p. 1).

Some studies in recent years have broadened to wider scales. An examination of Sweden’s road network tested tools in GIS to quantify road effects at the national scale (Karlson & Mörtberg, 2015). Researchers in 2007 used GIS to quantify the volume of roadless space in the US (Watts, 2007). In 2015, an enormous study involving researchers from seven countries quantified the effects of roads on habitat fragmentation for the entire globe. Their research demonstrated that only two areas in the world are still far enough from roads to have seen little effect: a large region of the Amazon rainforest and the Congo River basin (Figure 2.8).

Figure 2.8: Global Map of Distances from Roads



Van der Ree and his colleagues point out that “the extent to which the results from the numerous local studies can be extrapolated to larger spatial and temporal scales is unknown. Therefore, an important next step is to evaluate how the density and configuration of entire road networks affect the functional relationships within and among ecosystems at the landscape scale” (van der Ree et al, 2011, p. 2).

2.2.3. Planning and Policy

The Highway Act of 1944 stated that the “adverse impacts of highways upon the environment were, of course, minimal in rural or undeveloped areas” (FHWA, 1976, p. 370). In this context, the writers of the Act likely meant “environment” to connote areas where humans lived, not the “environment” as we think of it since Rachel Carson’s book *Silent Spring* was published in 1961. The FHWA history publication from 1976 manifests a more contemporary idea of ecological concern: “The ecology of the areas traversed may have been affected, but it has only been in recent years, with the general recognition of the interdependent nature of the biosphere, that there has been serious recognition of this possibility” (p. 370). Later, the publication continues, “Highway construction inevitably left scars upon the landscape. These were not particularly objectionable until the era of heavy cuts and fills and relatively wide roadbeds that accompanied the design concepts of the 1930’s” (FHWA, 1976, p. 395).

Unless a road traverses an area containing an endangered species or wetlands, no federal legislation requires that its ecological effects be studied. The Endangered Species Act of 1973 requires this study as part of an Environmental Impact Assessment. As a rule, no larger effects of roads are quantified, let alone the effects of an entire network of roads within a region. Since no research exists to prove that there are effects, no one will incorporate studies into their planning process (van der Ree et al, 2011, p. 6). Van der Ree et al point out that many of these large transportation agencies and other governmental institutions involved in highway planning have sustainability as a goal, but employees are not authorized to spend time on these types of studies (van der Ree et al, 2011, p. 6).

However, van der Ree et al see these agencies as “a promising avenue to further develop the field of road ecology” through collaboration. Especially since, as the authors point out, such long term, large scale studies are not conducive to the format and timelines of masters and doctoral research or outside funding sources available to the scientific community (van der Ree et al, 2011, p. 6).

Fraser Shilling, Co-Director of the Road Ecology Center at the University of California at Davis, makes a similar point: “Road effects from the existence and use of infrastructure are pervasive throughout developed landscapes, but seldom measured, modeled, visualized and/or used in planning and transportation decision-making” (Shilling & Waetjen, 2012, p. 5). Shilling and Waetjen offer that this circumstance is changing, though. States and regions are becoming more interested in considering potential impacts of highway planning at the regional, corridor, and project scale (Shilling & Waetjen, 2012, p. 5). The federal level, as well, shows signs of increasing awareness and sensitivity to road ecology issues in federal transportation bills like ISTEA, SAFETEA-LU, and the new FAST Act (Shilling & Waetjen, 2012, p. 5). In fact, the FAST Act, passed in December 2015, includes provisions for the implementation of integrated vegetation management to encourage pollinator habitat along roadsides receiving federal funding.

Over the past two decades, more and more conferences, journals, and books focus on road ecology issues (van der Ree et al, 2011, p. 2). The International Conference on Ecology and Transportation (ICOET) held in the US and the Infra Eco Network Europe (IENE) hold conferences that attract researchers from all parts of the globe. Between conferences, the Transportation Research Board’s Ecology and Transportation committee works to pull together these two disparate sides of research.

Road ecology research is having an impact on construction and road design. Government agencies such as state DOTs, the US Forest Service, and the National Parks have begun building transportation infrastructure that facilitates wildlife movement across roads. Many of these features are upgraded underpasses or culverts, which can be retrofitted or redesigned during a corridor reconstruction project to better foster wildlife crossings. Other agencies have built the more attention-grabbing wildlife overpasses tailored to the behaviors of specific species in the region that are known to be sensitive to the presence of roads. The most famous of these are the bridges in Banff National Park in Alberta. The Western Transportation Institute has catalogued wildlife movement across these bridges and underpasses for 15 years. Their collection of research over this number of years may be the only type in the world thus far (Clevenger, 2012).

These designs take their inspiration from available road technology and from specific animal behavior. As such, they are designed on a corridor-by-corridor basis and are almost exclusively retrofits of existing roadways. Researching roadway alignment and shape at a road network scale to discover effects on not only wildlife but also on landscape pattern and habitat may inform the transportation planning process even without the presence of an endangered species or habitat.

3. Literature Review

3.1. History

The first and most important source of the history of roads in America is the Federal Highway Administration, whose self-appointed historians have chronicled the agency's activities for over a century. Beginning with Albert Rose, a road builder at the turn of the 20^{th} century, to the agency's present-day historian Richard F. Weingroff, the policies, designs, and methods used as well as a dizzying collection of statistics are available through publications on FHWA's website. The long form publication celebrating the American Bicentennial titled "America's Highways: 1776-1976" provided most of the historical detail referenced in this paper. Mary Myers' writings published in *Public Roads*, the magazine of the FHWA, are written with landscape architects in mind and cover the design implications of road history and construction and design techniques. Also helpful were the speeches of longtime Bureau of Public Roads chief Thomas MacDonald and the transportation-related observations of Alexis de Toqueville.

Tim Davis is a historian at the National Park Service whose book *America's National Park Roads and Parkways* (2004) is a treasure trove of stunning drawings and short histories describing the construction of this niche road network. Davis delves more deeply into the impetus for the design and creation of parkways in his essay "A Pleasant Illusion of Unspoiled Countryside: The American Parkway and the Problematics of an Institutionalized Vernacular" (2003), which may forever spoil parkways for the reader but is essential for placing these singularly American creations in their proper context.

Additional cultural context explaining the American parkway typology is provided by Paul Daniel Marriott in a two-part essay titled "Roads Designed for Pleasure: A Brief History of the Origins of Scenic Driving and Automobile Touring in the United States" (2011).

Janike Kampevold Larsen examines our interaction with geologic time through the materiality of road cuts in her essay "Imagining the Geologic," part of the book *Making the Geologic Now* (2012).

Other historical overviews were given in Reed Engle's *Skyline Drive* and Cornell's *Highway Design for Motor Vehicles: A Historical Review: Part 8 The Evolution of Highway Standards.* William Haycroft gives an account of the history of construction equipment in his 2011 essay of the same title.

An updated look at the history of American road building, and specifically the interstate system, is detailed in Tom Lewis' *Divided Highways: Building the Interstate Highways, Transforming American Life* (2013). Another contemporary look at our relationship with transportation, especially the capacity of our brains to manage the task of driving and our powers of perception to process the speeding world around us is Tom Vanderbilt's *Traffic: Why We Drive the Way We Do (And What It Says About Us)* from 2008.

Bike Battles by James Longhurst (2015) is a new history of the bicycle and bicycle policy in the US, and provides helpful insight into the Good Roads movement.

An old textbook by Christopher Tunnard and Boris Pushkarev, *Manmade America: Chaos or Control* helps explain in text and diagrams road design concepts no longer taught in detail in landscape architecture classrooms, including vertical and horizontal alignment and curvature, sight lines, and superelevation (1963). Another old textbook, Norman Newton's *Design on the Land* is helpful for establishing the cultural context of highway designers and landscape architects in the 1960's and 70's.

3.2. Road Ecology

Richard Forman and Daniel Sperling's *Road Ecology* (2003) provides the foundation for road ecology studies in a dense edited volume, encompassing the full range of science that falls under the road ecology umbrella and building on Richard Forman and Lauren Alexander's 1998 article "Roads and Their Major Ecological Effects." Forman and Sperling followed up on their book with design proposals and a brief update of research in their 2011 paper "The Future of Roads: No Driving, No Emissions, Nature Reconnected."

Other recent research is available in the biannual proceedings of the International Conference on Ecology and Transportation (ICOET), a full compendium of which is available free online at icoet.net for odd-numbered years. Specific ICOET papers referenced in this research include Charry and Jones' 2009 study "Traffic Volume as a Primary Road Characteristic Impacting Wildlife: a Tool for Land Use and Transportation Planning" and Tony Clevenger's "15 Years of Banff Research: What We've Learned and Why It's Important to Transportation Managers Beyond the Park Boundary."

Jochen Jaeger and his team published an important paper "Predicting when Animal Populations are at Risk from Roads: An Interactive Model of Road Avoidance Behavior" in 2005, which describes four detrimental effects of roads and the factors that contribute to these effects.

Researchers at UC Davis' Road Ecology Center compiled research on the effects of roads to create a tool in ArcGIS called the Road Effect Zone. The paper describing the tool, developed by Fraser Shilling and David Waetjen, cites numerous sources detailing the effects on different categories of wildlife, wetlands, and soil.

In their introduction to a 2011 special issue of *Ecology and Society*, four leading road ecology researchers, Rodney Van Der Ree, Jochen Jaeger, Edgar Van Der Grift, and Tony Clevenger, discuss the state of the field. Their essay "Effects of Roads and Traffic on Wildlife Populations and Landscape Function: Road Ecology is Moving toward Larger Scales" states that most road ecology studies are focused on species movement, and thus only encompass the scale of that species' range. Many papers published since have proven their prediction that the discipline is moving toward larger scales is correct: Haddad et al analyzed global habitat fragmentation in 2015, publishing "Habitat Fragmentation and its Lasting Impact on Earth's Ecosystems" in *Science Advances*; Karlson and Mörtberg studied the entire country of Sweden in "A Spatial Ecological Assessment of Fragmentation and Disturbance Effects of the Swedish Road Network" in *Landscape and Urban Planning* in 2014.

3.3. Landscape Ecology

Monica Turner, Robert Gardener, and Robert O'Neill's *Landscape Ecology in Theory and Practice: Pattern and Process* (2001) is an essential guidebook for navigating the field of landscape ecology.

To inform the GIS operations of measuring sinuosity, two geography papers were informative: José Luis García Balboa and Francisco Javier Ariza López' "Sinuosity Pattern Recognition of Road Features for Segmentation Purposes in Cartographic Generalization" (2009); and Guillaume Touya's "A Road Network Selection Process Based on Data Enrichment and Structure Detection" (2010). Most papers on the subject of sinuosity measurements deal with segmenting sinuous lines, typically roads, at vertices that will preserve the road's shape while simplifying the number of vertices needed to define the line as the map viewer zooms out. The topic is of major importance to online map makers.

GIS tools and techniques are primarily derived from lectures and labs created by Dr. Marcia Meixler at Rutgers University's Department of Ecology, Evolution, and Natural Resources.

3.4. Other

Dr. Tim Mulrooney of North Carolina Central University scrutinized the NCDOT Roads Database in 2014. His detailed look at the quality of the data available in the database is confirmed by research conducted for this paper.

4. Rationale

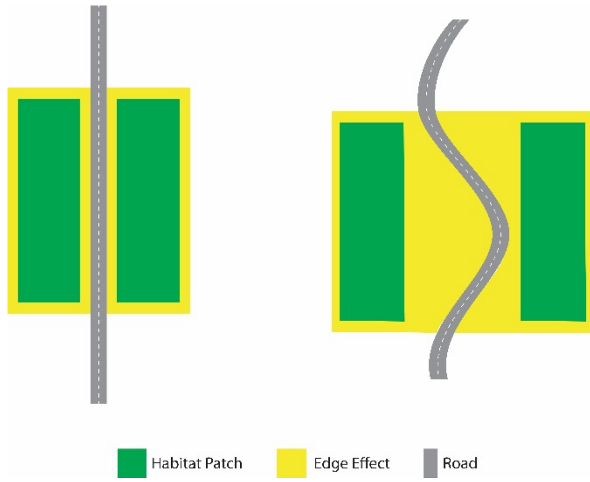
The premise of this paper is to investigate the differences in the landscapes surrounding roads constructed around mountains, with high sinuosity and steep changes in elevation, and roads constructed through mountains, along more direct alignments.

The National Park Service states that its roads "lie lightly on the land," meaning that their roads are narrow and curve gently through parkland and over terrain, providing visitors with a sense of enclosure – being surrounded by "nature." Implicit in this idea is the notion that other roads do not "lie lightly," but barrel through pristine nature through dynamited cuts, with wide, clear shoulders that convey no sense of place. Tim Davis puts these ideas in context: "Sinuous curves were thought to be more attractive. Curvilinear alignments also allowed road builders to follow the contours of the land more closely, significantly reducing the need for expensive, visually unappealing, and environmentally disruptive excavations" (2004, p. 5). As this paper illustrates in the Background chapter, sinuosity in roads arose not only by design, but more often by necessity. Do these roads, too, "lie lightly on the land" because of their alignment, which is similar to park roads, though was arrived at completely by accident?

For any landscape architect or landscape observer, this notion of a beautiful, narrow, winding road being less disruptive to the environment feels inherently true. However, we have no ecological basis to believe that it is true.

For landscape ecologists, studying the shapes and patterns of patches, corridors, and matrices on the landscape, a curvy road is merely a sinuous corridor, or even more basically, a patch edge that increases the edge to core ratio of a habitat patch as the sinuosity increases. A more sinuous patch edge creates a wider edge effect into the surrounding habitat patches. Therefore, it follows that a more sinuous road may in fact be more of an ecological disturbance than a straight road (Figure 4.1). Complicating this idea is the fact that some roads do not function as patch edges at all, but may remain a completely neutral piece of the habitat patch for some species. For instance, canopy dwellers like gliding squirrels may experience little disturbance if the road is narrow enough to allow the canopy to remain connected across the road; they can still move through the canopy (van der Ree et al, 2010). Another dimension is the differentiation between the effects from the physical presence of the road itself and the traffic traveling along the road causing disturbance.

Figure 4.1: Edge Effect Diagram for Straight and Sinuous Roads



This paper seeks to distill the illusive ecological truth from our deep-seated assumptions. The results are intended to inform future road alignments and road improvement projects, and to shed more light on the ramifications of our nation's road-building history.

5. Methods

This study utilizes spatial analysis tools in ArcGIS 10.2.2 and the statistics program SAS 9.4. This chapter details the steps taken to conduct a spatial analysis, including data acquisition and use of tools and software. First, the approach and study design are described (5.1). Next are descriptions of the study area (5.2), database of roads studied (5.3), and environmental characteristics (5.4). The spatial analysis process is described in 5.5. Finally, visual assessments undertaken during field work are discussed in 5.6.

5.1. Approach and Study Design

When considering approach, two different research methods were investigated: a time series study and a regression analysis.

A time series is the ideal method for comparing the effects of different road characteristics in the landscape over time. Looking at conditions before and after the roads were constructed would be the best way to capture, to the extent possible, the whole picture. However, a time series study could only look back to the 1970’s when Landsat began collecting land cover data, or would require digitizing aerial photographs, where available, from the 1930’s or 1940’s. Since many of these road were constructed prior to the advent of aerial photography, a time series could not capture the before and after conditions.

The second method that was ultimately chosen is a regression model covering a large region, including an independent variable describing the percentage of forest cover and explanatory variables describing other landscape characteristics, the road network, and selected road characteristics. This was deemed the best first step to approach the larger question of the interactions of road shape on environmental characteristics. The primary difficulty of this approach is making a best fit model; most models are based on prior research proving some type of link between the parameters being studied. In this case, past studies point to width of road and traffic volume (as a proxy for noise) as factors in animal behavior and mortality (Jaeger et al, 2005; Charry & Jones, 2009). But road shape has not been studied at this scale, and aside from a few studies of effects on roadside soil and wetland vegetation, not much research exists yet linking road characteristics with effects on vegetation at the regional scale.

Neither of these approaches, however, eliminates the perennial question among transportation researchers about the complex, mutually impactful effects of transportation and land use on each other. Extracting causal relationships between transportation networks and the land through which they pass is difficult to accomplish at any level but the narrative, corridor scale. With this major limitation in mind, a spatial regression was selected as a simple, broad method for seeking patterns in different types of roads and their surroundings, to see if there are, in fact, any generalizable patterns. The flexibility of the Exploratory Regression and Ordinary Least Squares tools in ArcGIS allow for the inclusion of a wide range of variables and different combinations of variables to rapidly explore these potential patterns.

Further, the study was constructed to mitigate several additional concerns related to the interactions of transportation and land use and to the non-spatial elements of policy and regulations. Below are two potential concerns of this type of study and attempts to address them in this study.

The first concern: Urbanization and the presence of developed areas, which increase fragmentation but whose existence and spatial characteristics are influenced by so much more than the presence of a road, present a difficult complicating factor to the hypothesis of roads influencing their surroundings. Fragmentation would appear magnitudes worse in these areas, due not only to the roads, but also to subdivision construction trends or local planning regulations. In this study, proximity to urbanized areas and population density were included as independent variables to account for this presence and influence. Moreover, since local roads were excluded from analysis by their absence in the NCDOT database, roads in these urbanized conditions were minimized.

A second concern: Roads built in national parks and wilderness areas are not simply constructed and left alone. The surrounding areas are constructed “wilderness” or managed forests, and in some cases were literally put there. An example in the study area is the Blue Ridge Parkway, in which bald mountaintops pillaged by the logging industry were re-forested as part of the construction of the parkway. The presence of the parkways would *improve* the surrounding landscape, not because they are more contextually and ecologically sensitive, but because they were constructed as access roads to a synthetic wilderness. Further, roads in designated parks or wilderness areas are less likely to have been altered over the years for realignment or widening. The National Park Service has different design guidelines and standards for construction, which also alters the conditions of these roads. In this study, parkways (of which there is only one in the study area) were analyzed as a separate category of roads but were left a part of the larger dataset. Removing the Blue Ridge Parkway entirely was considered, but would result in a change in the thesis from being about landscape architects as road designers to simply vernacular road construction techniques, a sacrifice that was not acceptable. The model includes a variable to represent protected land, whether federal or state park or wilderness areas, to account for these different conditions.

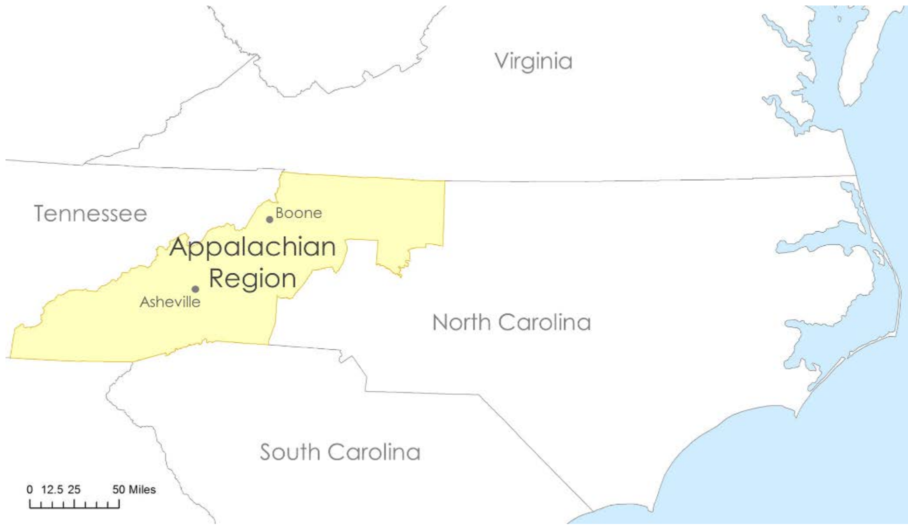
5.2. Study Area Selection

Mountainous terrain produces the most variety of road shapes and alignment, as well as the most dramatic viewsheds along a transportation corridor. North Carolina was chosen for the age of its roads, its mountainous terrain, and the quality of its road data.

North Carolina and Tennessee are home to the highest mountains in the Appalachians. Six mountain ranges in these two states have, together, more than 40 peaks over 6,000 feet. Of those, the Great Smoky Mountains contain the most. Mt. Mitchell in North Carolina, in the Black Mountain range, is the highest peak east of the Mississippi River, at 6,684 feet (Gaddy, 2010). The Appalachian Mountains are older than the mountains in the western part of the country; they also have harder bedrock, with deep rivulets, and are marked by gullies. They required “tremendous cuts and fills” according to J. Ross Eakin, the first supervisor of the Great Smoky Mountains National Park (Davis, Croteau, and Marston, 2004, p. 77). Road builders used more tunnels, bridges, and retaining and revetment walls as a result. In the late 18th century, as colonists gradually began moving farther west, they largely followed old Native American trails, but cut new wagon roads through these hard, serrated mountains. Some of the oldest trail alignments still evident across the Appalachians are in North Carolina, and the state is home to the Eastern Continental Divide.

For this preliminary exploration, a single state was determined to be the best starting point. Since an extensive database of roads characteristics was available for free download online, North Carolina was chosen as the area of study for this exploratory research. A 29-county area was extracted from the mountain region, based on the regional boundary set by the Appalachian Regional Commission (Figure 5.1).

Figure 5.1: Study Area



5.3. NCDOT Roads Database

The NCDOT GIS unit created a database of road arcs that includes all roads and segments in the state's maintenance roster, including federal roads for which the state receives federal funding to maintain. Local municipally-maintained roads are not part of the database. This absence of urban streets is preferable for this study since the origins and context of urban roads are so different from regional and rural roads. County-maintained roads are also absent; this leaves out some very interesting back roads in the study area, but the state database includes over 10,000 miles of secondary routes in the 29-county study area that capture many of the same road characteristics, such as narrow surface width, high sinuosity, and steep elevation changes.

The NC DOT Roads Database was downloaded in July 2015, prior to the agency's transition to Rome, a new roads data management system (Koschatzky, 2016). A July download means that the database contained first quarter 2015 (Q1 2015) road data. Since road characteristics, especially rights-of-way, change frequently, the download date may explain any differences between this data and newer or older datasets.

Table 5.1 lists the fields of interest given with the database and their corresponding characteristics. Selected field descriptions from the metadata are included in Appendix B.

Table 5.1: NCDOT Database Fields Utilized

Field Title	Name	Description
RTE_X_CLSS_CD	Route Class Code	NCDOT route classification (not federal or functional class)
STREET_NAM	Name	NCDOT route name (not local name)
ADTN_DT	Addition Date	Year of construction OR date road added to state roster
FC_TYP_CD	Functional Class	Fed. Hwy Admin. class determining federal aid eligibility
PPLTN_GRP_TYP_CD	Population Group	8 classes of municipal population size
RW_WID	Right-of-Way Width	Width in feet of generalized right-of-way
SPD_LMT_TYP_CD	Speed Limit	Speed limit as stated in traffic ordinances (not posted)
SRFC_WID	Surface Width	Paved width in feet (or ditch-to-ditch width if unpaved)
DS_NBR	Design Speed	Speed that determined design and geometry of segment
AADT_EST_CNT	AADT	Average Annual Daily Traffic in vehicles per day
MP_LENGTH	Milepost Length	Segment length based on 3D LIDAR data

Using a single database from a single source was important for this project. The sinuosity of linear features is scale-dependent (Meixler, 2014). Therefore, digitization at the same scale is critical to ensure comparison of this index across features. The NCDOT database was digitized at 1:400 scale, essentially, “along the paint line” of the road, resulting in very detailed data (Koschatzky, 2016).

The NCDOT database originated from a linear referencing system. The referenced segments are not of uniform length. In fact, 53% are less than 0.1 mile in length. The NCDOT GIS unit confirmed that the multitude of very short slivers of road results from the snapping settings in ArcGIS being set to default in earlier digitization efforts (Koschatzky, 2016). A primary goal of this study is to compare sinuosity between different road types, a characteristic that must be computed using segments of the same length. For instance, when sinuosity was calculated for the entire roads database prior to dissolving and segmenting into one-mile segments, the mean sinuosity was 0.962, describing fairly straight roads. Since so many road segments were so short, they were measured as having a sinuosity of 1, skewing the mean sinuosity toward the straight end of the sinuosity index. To make proper comparisons, the DOT data was dissolved by road name and divided into one-mile segments. After the roads were dissolved and segmented into one-mile lengths, the average sinuosity of the total database was 0.870.

Following segmentation, the data was then stratified into five categories of road type, based on the Route Class field. The resulting categories of roads were: Federal parkways (Blue Ridge Parkway – BRP), Interstates (I), US Highways (US), State Highways (NC), and Secondary Routes (SR). Categories that were not part of the study and were not retained for the regression were planned/projected routes (PRJ), access ramps (RMP), state park roads (SP), local roads (LOC), and rest areas (RST). Fewer than 30 miles each of state park and local roads are present in the Appalachian region. All roads with a total length of less than one mile were not retained for the analysis since the comparison is based on one-mile segments. Table 5.2 displays the mileage in each road category after the segmentation code ran.

These five road categories represent transportation policies of vastly different intent, governed by different sets of regulations. The US has supported road construction with federal funding since 1916. Many of the roads designated as US highways or state highways existed before this date; many US highways have seen their alignments significantly altered since then. Below are brief summaries of each road category as justification for this stratification. More detail can be found in the Background section (Chapter 2).

- Secondary Routes are maintained by the state at the request of local jurisdictions. These routes are important to local traffic but are not part of the state highway system. An important caveat about Secondary Routes is that they may have the same given number in different counties. Since many counties use the same road name for secondary routes, such as SR 1100, county number was first concatenated with road name for secondary routes. A few Secondary Routes continue across county lines, but these route names were concatenated with the county number and treated as individual routes. In this instance, the lost information about alignments was minimal.
- NC Highways are state-designed and state-constructed highways. These highways are governed by federal design guidelines, and the state receives federal funding to maintain them. They are largely based on old pre-automobile alignments, but have many reconstructed segments.
- US Highways were part of the first effort to connect “every county seat in the nation” from the 1920’s (Lewis, 2013, p. 19). These routes were constructed and are maintained according to federal guidelines, though at the time of construction, technology and safety research had not created the stringent design regulations used today. The original routes of US highways were generally based on old alignments, but there has been significant reconstruction, realignment, and widening since.

- Interstates were constructed between the 1950's and 1980's and have their genesis as a national defense strategy. Inspired by the German Autobahn network built in the 1930's, the primary goal of the interstate system was to allow for rapid evacuation of the coasts and safe, rapid transportation across the country. These routes were constructed along new alignments where no roads had previously existed. Safety standards and construction technology had evolved such that gentle grades and gradually sloping roadsides clear of fixed objects were required.
- The Blue Ridge Parkway is an entity apart from the roads governed by the Federal Highway Administration. The Parkway was constructed in a specific design tradition, as an antecedent of English garden carriage roads infused with American values of the pastoral and nostalgia for its recent farming past. An Interbureau Agreement between the National Park Service and the Bureau of Public Roads, signed in 1926, determined design standards and the design process for the parkway; thus, the parkway was influenced by existing highway practices of the period, but had specific scenic intents not present in a typical highway.

These road types roughly correspond to the history detailed in the Background chapter in the following ways:

1. Vernacular construction (pre-1910), winding around hills to accommodate wagons and horse traffic that could not climb steep grades. Include copious switchbacks. Secondary routes and some segments of state highways (NC highways) are still configured along these alignments; US highways may still have short segments from this period.
2. Local, uncoordinated construction methods for the car (1910-1920), built straight up and over hills in response to the heftier horsepower of automobiles. Include sharp curves and steep grades. Secondary routes and some segments of state highways (NC highways) are still configured along these alignments; US highways may still have short segments from this period.
3. Alignments for safety (1930-1940), period of standardization regarding curvature, incorporating gentler curves and grades. Include superelevated curves, straighter alignments, and shallower grades.

Segments of US highways and state highways were reconstructed during this period to be straightened and widened for safety.

4. Freeways (1940's on), built for safety and speed, conquering topography in order to maintain even grades and straight alignments. Include maximum grades of 5% (7% in mountainous regions), extremely gentle curvature, wide clear zones free of objects, and wide rights-of-way. Interstates were constructed as the freeway era reached full maturity; segments of US highways and some NC highways to a lesser extent adopted some of these design standards, but not the alignment or widths available to the interstates' entirely new rights-of-way.

Table 5.2: Mileage in Region by Road Category: Before and After Segmentation Code

Category	Total Mileage	Mileage after Processing
Interstates	607	582
US Highways	1,570	1,452
State Highways	1,867	1,648
Secondary Routes	11,517	9,588
Blue Ridge Parkway	252	249
Total	15,813	13,519

A Python script run in IDLE was used to segment the roads and compute sinuosity, elevation change, and adherence to contours (See Appendix C for code). The Sinuosity tool computes an index comparing the Euclidean distance between the two segment termini to the actual length of the given polyline. The sinuosity tool is widely used for measuring the nature of polylines of all kinds in ArcGIS. The Calculate Sinuosity tool creates a new field and populates the field with values between 0 and 1, 0 for a perfectly circular route, 1 for straight (Esri, 2011).

Fractal dimension is a typical metric used to describe geographic and manmade features. Fractal dimension was calculated in the Field Calculator using the formula: log(n)/[log(n)+log(d/L)]. Where n is the number of segments, d is the straight line distance, and L is the length of the line. The sinuosity field was used as d/L since this difference had already been measured when calculating sinuosity. The Fractal Dimension figures resulted in less differentiation among the types of roads. Since fractal dimension captured a similar characteristic as sinuosity, the latter metric was retained for its simpler computation and more intuitive readability as an index between 0 and 1.

The elevation change code computes the difference between the minimum and maximum elevation along each one-mile segment, measured with points at 0.1-mile increments. The adherence to contours code counts the number of times the segment crosses 50-foot contour lines. These two elevation measurements—elevation change and adherence to contours—were created to capture the relative steepness of a road and the nature of the alignment to existing topography, both of which are indicators of road alignment techniques from different methods of construction. LIDAR downloaded from the NCDOT website provided the elevation data for these tools.

The resulting roads database contained the following fields:

- Road name
- Total road length
- Unique segment ID ("seg_no")
- Sinuosity
- Elevation change
- Adherence to contours

One field in the original NCDOT database (MP_LENGTH) contains the road segment length as measured milepost to milepost, resulting in a 3D segment length that accounts for slope when measuring distance instead of using 2D length, which would be shorter. The segmentation code written must use 2D length in order for the series of tools called in the code to work. This discrepancy had the potential to be a big deficiency. To check the magnitude of the discrepancy, when the data was segmented, the segment 3D length (MP_LENGTH) was summed. This field was then compared to the newly calculated 2D length field. For each road in the entire segmented roads set, the mean difference between the 2D lengths and 3D lengths was 0.006 miles (31 feet), and the sum of the difference for all 13,519 one-mile segments was 28.1 miles. The largest difference was 0.4 mile, on a road with a total length of 264 miles (US Highway 19). The difference between 2D and 3D lengths was determined to be not large enough to skew the results.

Once the segmentation code ran, the results were joined to data from the original NCDOT roads database using the Spatial Join tool in ArcGIS. In order to aggregate data from all of the short segments to the one-mile segments without losing data, the setting Join One to Many was used, with field mapping as shown in Table 5.3.

Table 5.3: NCDOT Fields and Field Mapping

Field	Field Mapping
AADT	Maximum
Functional class	Mode
Nearby population category	Mode
ROW width	Maximum
Surface width	Maximum
Speed limit	Maximum
Design speed	Maximum
Year of construction/addition	Mean

Each field had a significant number of null values, so the maximum value for each field was taken. A few of these characteristics vary considerably within a one-mile stretch, especially in the Interstate and US highways categories, where ROW width and AADT is highly variable. Using the maximum value captures the maximum potential effect of that particular characteristic. Mode was used for field mapping where the field was a code representing a classification and not a continuous numerical value.

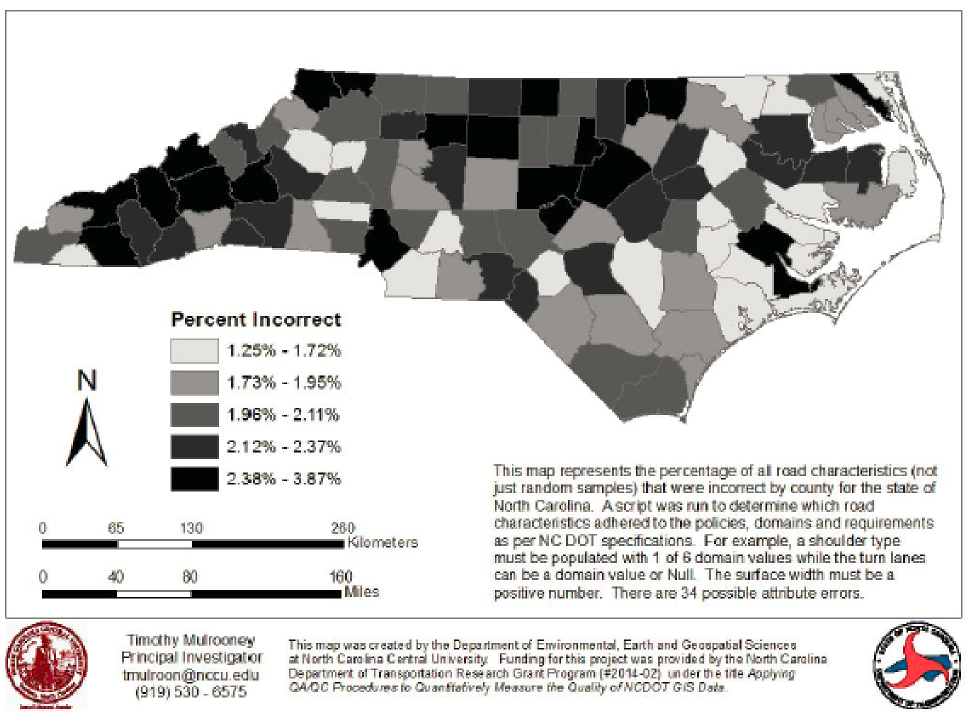
Year of construction was a critical data point to this study. Linking sinuosity to a year could confirm that different practices resulted in different alignments. However, the data for the year of construction in the NCDOT database was missing or inaccurate in nearly 40% of the data, and 98% of some road categories. Moreover, the year 1901 was used as a substitute for "No Data" in many counties; some interstate segments and on/off ramps show a construction/addition date of 1901, which is impossible. However, 1901 also indicates the date that some old roads were added to the state roster, so eliminating the 1901 date altogether skews the data in some categories. For instance, when all 1901 entries are removed from the NC highways category, the average year of construction becomes 1978, which is incorrect. Because of the inaccuracy of even the available data that only showed newer years of construction, the year of construction attribute was not used in this study. Table 5.4 represents the total mileage of missing or null year of construction data by road type.

Table 5.4: Missing or Null Year of Construction Data by Road Type

Name	Length with Inaccurate or Null Designation (Miles)	Length with Accurate Year Designation (Miles)	Total Miles in DOT Database	% of Total for Analysis
Interstate	24.4	582.7	607.1	96.0%
Blue Ridge Pkwy	249.0	4.1	253.2	1.6%
US Route	1,411.5	460.1	1,871.7	14.6%
NC Route	1,376.7	194.1	1,570.7	12.4%
Secondary Route	4,527.0	11,179.0	15,706.0	71.2%
Total	7,588.6	12,420.0	20,008.6	62.1%

Year of construction was not the only data missing. Dr. Tim Mulrooney conducted a review of the NCDOT database in 2015. His research showed that attribute accuracy ranged from 72% to 95% by county, overall a high percentage considering the vast geography and the number of jurisdictions contributing to the database (p. 16). In Figure 5.2, it is visible that the counties within the study area have a higher percentage of missing or erroneous data than other parts of the state. Table 5.5 shows the percentage of missing data by field in the study area.

Figure 5.2: Total Attribute Completeness by County



(Mulrooney 2015, p. 40)

Table 5.5: NCDOT Fields and Missing Data

Field	Percent (%) Missing Data (Varies by road type)
AADT	10%-70%
Functional class	0%
Nearby population category	1%-75%
ROW width	30%-87%
Surface width	27%-76%
Speed limit	27%-79%
Design speed	33%-95%
Year of construction/addition	4%-98%

The end result was a road database for the 29-county area representing 13,519 miles of state-maintained roads, divided into one-mile segments, with the following fields populated for each segment:

- Road name
- Unique segment ID
- Sinuosity
- Elevation change
- Adherence to contours
- Functional class
- Size of nearby population
- Right-of-way width
- Surface width
- Speed limit
- Design speed
- AADT

5.4. Environmental Characteristics

Several types of data were used to summarize the environment surrounding road segments in the region. Data describing terrain, land cover, protected status, and human development were gathered and included in the analysis.

5.4.1. Terrain Statistics

LIDAR data provided online by NCDOT was downloaded for each of the 29 Appalachian counties. The data was captured at 20’ resolution and derived from flights commissioned in 2011. Rasters for both elevation and slope are available for each county in the state on the NCDOT website. The elevation raster was then used to compute hilliness (the standard deviation of elevation) and to create contours used in the adherence to contours measurement.

5.4.2. Land Cover

The National Land Cover Database (NLCD) was used to determine land cover in the study area. The most recent NLCD data available is from 2011. The database uses a modification of Anderson's Land Cover Classification System categories to describe national land cover and is derived from the Landsat satellite at 30-meter resolution.

There are 16 categories of land cover present in North Carolina:

- Open Water
- Developed Land: Open Space
- Developed Land: Low Intensity
- Developed Land: Medium Intensity
- Developed Land: High Intensity
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Herbaceous
- Shrub/Scrub
- Hay Pasture
- Cultivated Crops
- Woody Wetlands
- Emergent Herbaceous Wetland
- Grassland
- Barren Land

5.4.3. Protected Land

State parks, federal lands, and managed lands vector data were acquired from the North Carolina One Map Geospatial Data Portal. The vector data was converted into a binary raster ("0" for not protected, "1" for protected).

5.4.4. Human Population

Two population statistics from the US Census were used to estimate the effects of human presence in the one-mile segment buffers. Average population density was calculated from the 2014 5-Year American Community Survey data. The Urban Areas vector data was used to create a proximity to urban areas raster, in order to estimate the effects of nearby populations if none existed within the buffered areas themselves.

5.5. Capturing Environmental Data with Buffers

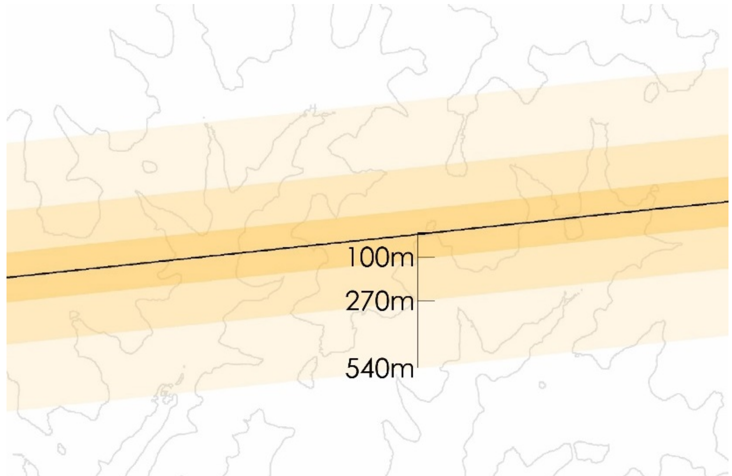
Model Builder was used to create buffers around each one-mile road segment. Buffers of three different sizes were used to test different scales. A 270-meter buffer was created based on the average vegetation effects documented by Schilling and Waetjen in their Road Effect Zone tool shown in Figure 5.3 (2012).

Figure 5.3: Table of Road Effect Zone Distances

Road Effect	Effect Distance (m)	Citation
Amphibians	1000	Eigenbrod et al., 2009
Sensitive birds	1200	Forman et al., 2002
Large mammals	600	Gagnon et a., 2007
Soil contamination	30	Backstrom et al., 2003
Wetlands processes	500	Findlayand Houlahan, 1996
Human health	400	Raaschou-Nielsen, 2011; Spira-Cohen et al., 2011

The average of soil contamination and wetlands processes is 235 m. One additional cell (30 m) was added to achieve nine cells on either side of the road. Coincidentally, this distance also approximates the Federal land surrounding the Blue Ridge Parkway, a 300-meter buffer of land that is maintained by the National Park Service. A 100-meter buffer was created to test results at a narrower range, and the 270-meter buffer was doubled to a 540-meter buffer to test at a wider range (Figure 5.4). To achieve regular, smooth-edge geometry, round-end buffers were used.

Figure 5.4: Distance from Road Segments



Using the Tabulate Area and Zonal Statistics as Table tools, environmental characteristics within each buffer were compiled. These tools create a raster from the input buffers and collect data from the intersecting rasters, in this case, the environmental characteristics. Since a raster is created from the buffer vectors, the buffers that overlap are converted into non-overlapping raster values. This means that double counting a cell in the intersecting raster is not possible. However, this does result in buffers of unequal size. Thus, weighted averages were computed in the summary statistics.

Table 5.6 displays the environmental characteristics captured within each size buffer for each one-mile road segment.

Table 5.6: Data Tabulated from Buffers

Characteristic	Statistic	Source
Slope	Mean	20’ LIDAR
Elevation	Mean	20’LIDAR
Hilliness	Standard Dev. of Elevation	20’ LIDAR
Protected Status	% of Protected Land in Buffer	NC One Map
Forest Cover	% Forest of All Types (Mixed, Decid., Evergreen)	LULC
Population Density	Mean	ACS 2014 5-Year
Proximity to Urban Area	Mean	Census Urban Area

The data tabulated in each buffer were joined by the segment number field (“seg_no”) to the segmented roads table.

5.6. Regression Analysis

The spatial regression was conducted using a combination of Model Builder in ArcGIS and IDLE (Python GUI) to explore the hypothesis that the sinuosity and other characteristics of a road are influencing factors in the type of cover surrounding the road. In this case, forest cover was used as an initial test. A second model tested the hypothesis that land cover characteristics may influence the sinuosity of a road segment.

First, the Exploratory Regression tool was used to determine which characteristics were the most influential and should be included in the Ordinary Least Squares regression. The Exploratory Regression tool also determines multicollinearity of variables showing which variables overlap and explain the same phenomenon in the model. The Ordinary Least Squares regression tool was then used to determine the fit of the model and the level of influence of each of the independent variables.

The dependent variables tested were percent forest cover and sinuosity. Since these values were indices between 0 and 1, the Field Calculator was used to logarithmically transform the values prior to running the tools. Table 5.7 displays the independent variables.

Table 5.7: Regression Independent Variables

Road Characteristics	Terrain Characteristics	Development Characteristics
Right of Way (ROW) width	Sinuosity*	Population density
Surface width	Adherence to contours	Proximity to urban areas
Speed limit	Elevation change	Percent protected land
Design speed	Mean elevation	Percent forest cover*
AADT (traffic count)	Mean slope	Percent developed cover (low, med., high)**
	Hilliness	Percent developed open space**
		Percent hay pasture**

*Excluded as an independent variable when being tested as the dependent variable.
**Only included in the sinuosity regression.

Many of the independent variables included in the model contained a significant percentage of null values. These were assumed to be No Data, since so much data was missing, and since, in all cases except traffic counts, a 0 value is impossible for the given spatial or dimensional characteristic, such as road width.

Statistical Analysis Software (SAS) version 9.4 was also used to test the variables without including the spatial element in the ArcGIS tools. The proc reg command was used to call the linear regression function; two models were tested, one using the percentage of forest cover as the independent variable and the other the sinuosity field. The same independent variables were used as in the OLS model. The significance level (ALPHA command) was left at the default of 0.05, resulting in confidence intervals of 95%.

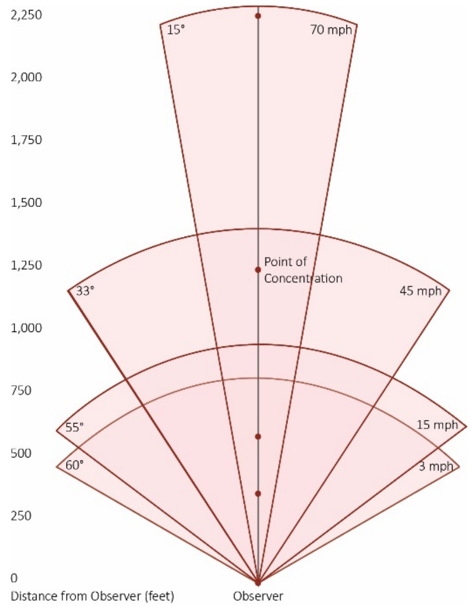
5.7. Field Work

Field work, in the form of a visual assessment, was undertaken over a four-day period in February 2016 to check the characteristics recorded in the NCDOT database against measurements in the field. The season allowed for more open view corridors along the roads and of the scenery. The field work was structured to allow for examination of single corridors within the larger database, for a more detailed investigation of context and land use patterns in the corridor.

The visual assessment consisted of several layers of data collection:

- A stretch of approximately 20 miles was driven along each corridor. Segments were chosen primarily for their representation of typical conditions of each category. Diversity of terrain was also considered, since a variety of experiences are available in the Appalachians.
- The road was driven in a car at the speed limit of the road, or at the safest speed possible in the circumstances. Two of the roads required a much slower speed.
- A GoPro video camera documented the visual experience, recording with the wide-angle setting. This wide angle setting is wider than the field of vision measured for drivers driving above 15 mph (Figure 5.5), but accounts for the scenic experience of the driver as the cone of vision moves. The camera's wide angle cannot capture the full scenic experience of any passengers, however, since their field of vision is much wider than the driver's and they may turn their heads, theoretically, to any possible angle within a 360 degree view.

Figure 5.5: Cone of Vision at Speed of Travel

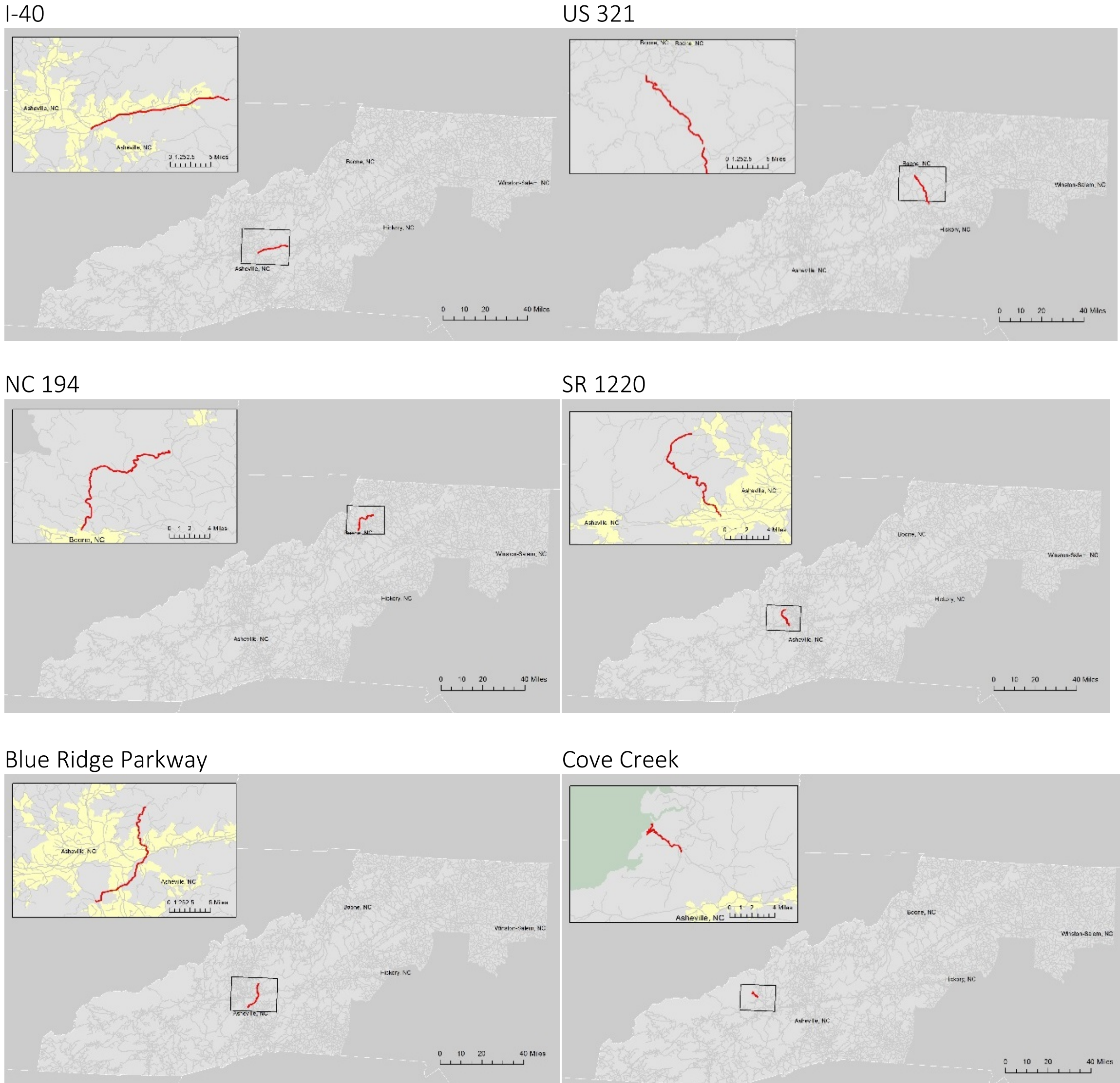


(Goldfinger, 1941; Tunnard & Pushkarev, 1963)

- Photographs were made of a select group of road conditions and treatments in order to document typical conditions in each type of road category.
- Historical maps from USGS Historic Topographical Map Explorer were downloaded for the earliest date available. In this case, the road building eras of interest would designate road alignments present on maps prior to 1910, between 1910 and 1930, between 1930 and 1940, and post-1940 as the eras of interest. As detailed by Mulrooney and revealed by the database statistics, the year of construction data was unavailable for nearly 40% of the total mileage in the Appalachian region; for some road categories, data availability was as low as 1.6%. While this project did not allow for digitizing historical maps for the entire region, which could have revealed historical alignments for roads where the data is missing, finding historical alignment and construction data for the segments of five corridors included in field work was a manageable addition to the project.
- A GPS logger (Amod Pro) recorded the car's location along each road for the duration of the driving. This documentation serves as a check to the alignments drawn by NCDOT.

One road from each of the five categories was selected in order to gather typical treatments for each type (Figure 5.6).

Figure 5.6: Maps of Road Segments in Visual Assessment



A sixth road was selected for field work since its well-documented history showed it to be very close to the alignment of a Cherokee Trail that had been used in the region for centuries. This road, Cove Creek Road, is the approach to Cataloochee Valley in the Great Smoky Mountains National Park. The road leads to the beautiful Cataloochee Valley, where elk have been reintroduced and where many original wagon roads and Native American trails have been preserved within park boundaries. Cove Creek becomes Cataloochee Valley Road at the NPS border, and this alignment is essentially the same route as a Cherokee trail called the Cataloochee Trail that cut across the range centuries before. White settlers first widened the

Cataloochee Trail into a wagon road in the 1820's and 1830's (Davis, Croteau, and Marston, 2004, p. 76). In the field work, this was the only road with switchbacks, with a 5 mph speed limit.

NC 194 is also a North Carolina Scenic Byway (not a Federal Scenic Byway, of which there are only two in the region); the road segment was selected for its characteristics and not for its scenic byway designation, but this added another layer to the visual assessment. There are 59 North Carolina Scenic Byways, a designation that denotes a road of scenic, historic, or cultural significance. A road is named a scenic byway after it is constructed, so the designation does not affect alignment or design.

The elements documented along each corridor are listed below. The check sheet for conditions documented is included in Appendix E.

- Surface width
- Lane width
- Shoulder width
- Embankment profile
  - Uphill width and slope
  - Downhill width and slope
- Horizontal curvature
- Vertical curvature
- Horizontal-vertical alignment
- Crossings, intersections, interchanges
- Roadside treatments
  - Managed/unmanaged vegetation
  - Selectively thinned vegetation
  - Stormwater management
  - Wildflower program
  - Enclosure
  - Clear Zone
  - Signage
- Overlooks and turnouts
- Viewsheds

6. Results

This chapter describes summary statistics of road characteristics (6.1), terrain (6.2), land cover (6.3), and human population (6.4). Section 6.5 discusses the regression analysis results. Section 6.6 describes results from the visual assessment and field work.

6.1. Road Summary Statistics

Summary characteristics were computed for each category of road, drawing data from the NCDOT database and from the statistics derived in ArcGIS (Table 6.1).

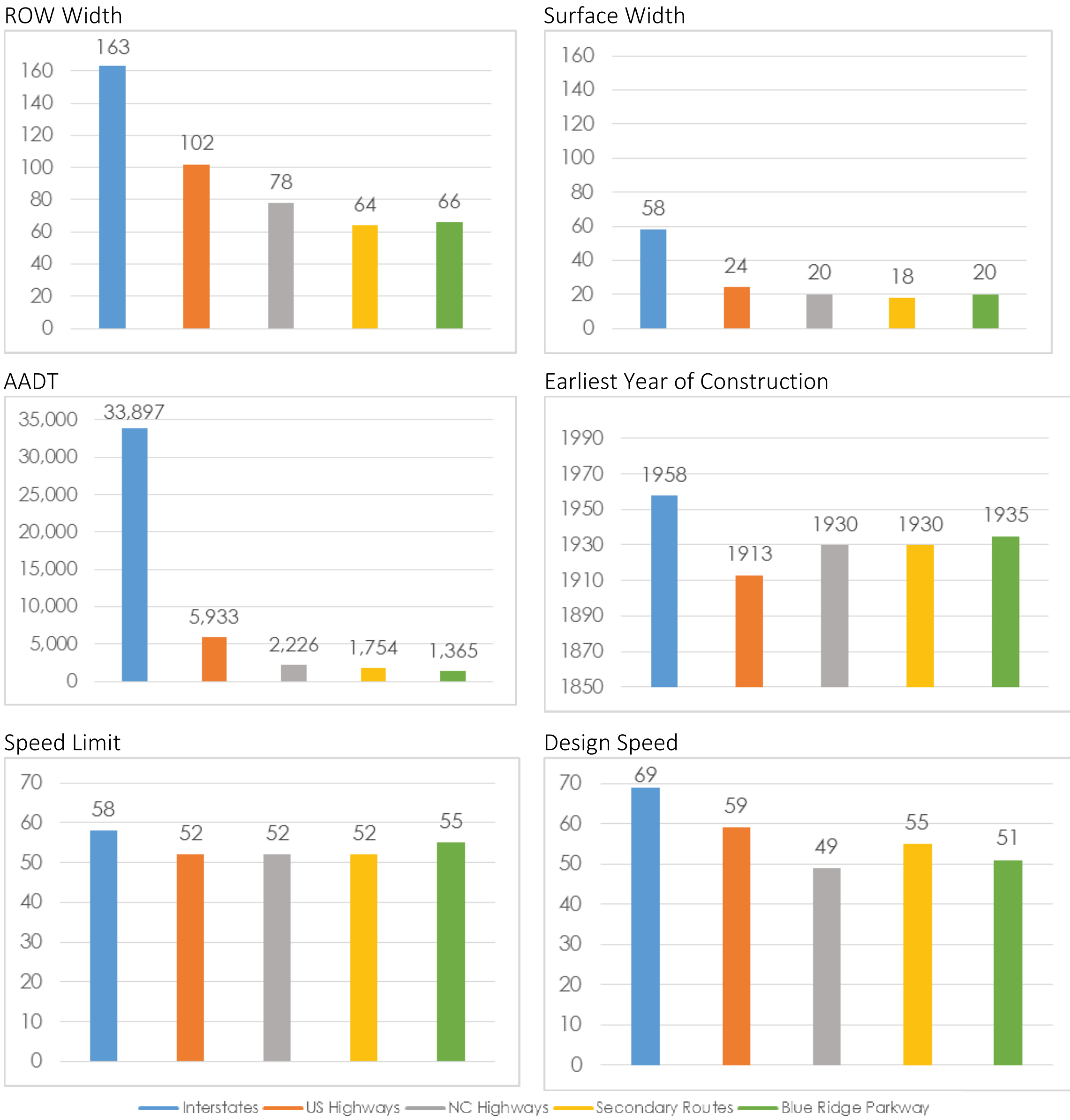
Table 6.1: NCDOT Database Characteristics - Averages by Road Category

Road Category	ROW Width (Feet)	Surface Width (Feet)	AADT (Daily Traffic)	Speed Limit (mph)	Design Speed (mph)
Interstates	163	58	33,897	58	69
US Highways	102	24	5,933	52	59
NC Highways	78	20	2,226	52	49
Secondary Rtes	64	18	1,754	52	55
Blue Ridge Pkwy	66	20	1,365	55	51

The data summary illustrates differences in these basic road characteristics. Interstates, unsurprisingly, have the widest rights-of-way (ROW) and surface widths (Figure 6.1).

The widths of the ROW for each category reflect the policies of the time. Older highways like the state and secondary highways were carved out of private property early on, with their width most likely resulting from the same 66’ survey chain that created the roads from section lines in the Midwest and West. The wider ROWs of the US highways and interstates illustrate two characteristics of these roads, one based on design and one on safety. Since both types of highways used gentler grades that required blasting through hills, more gently sloped roadside embankments were used to prevent erosion and soften the visual experience. More gradual slopes on embankments required more ROW space. The second ROW concern involved guidelines developed for the Clear Zone in 1966, which require fixed objects to be set back from the roadway a minimum number of feet based on design speed and embankment slope. The Clear Zone requires more space beyond the edge of the pavement for vegetation management, especially trees.

Figure 6.1: Computed Road Characteristics – Averages by Road Type



US Highways received the same treatment as interstates as they were straightened and widened in the second half of the 20th century. Some segments of state highways were also upgraded, which explains the slightly wider ROW results. These treatments were retrofits, however, and as such, can only change the road conditions to an extent.

The surface widths of interstates are the widest, with 58-foot surface widths. This reflects a four-lane road, likely of 10-12-foot lanes and two 5-9-foot shoulders, in many areas divided into two separate roadways of two lanes each.

Widths for the other types of road reflect the standards under which they were built: 12-foot lanes for US highways, 10-foot lanes for the typically older and/or less updated state highways, and narrow 9-foot lanes for secondary routes. The Blue Ridge Parkway was designed uniformly with 10-foot lanes and 20-foot surface width.

Important to note is the fact that these characteristics would not hold true in other types of terrain. The average interstate surface width in this mountainous terrain is 58 feet, four 12-foot lanes with minimal paved shoulder, especially on divided roadways. In other terrain, interstates have more generous shoulder surfaces.

Traffic counts (Average Annual Daily Traffic or AADT) appear consistent with the general understanding of road functionality: interstates carry heavy long-distance interstate, intercity, and some local traffic; US highways carry heavy intercity and some local traffic; state highways carry some intercity and local traffic; and secondary routes carry generally local traffic. The Blue Ridge Parkway carries almost exclusively tourist traffic, with the exception of a section east of Asheville, NC, which is considered part of the regional commuting corridor (National Park Service, 2016). Interstates comprise 1% of national road mileage but carry 20%-30% of total traffic (Lewis, 2013, p. 260).

Year of construction data is missing for about 40% of the database. The chart reflects that the year 1930 is the first year the counties in North Carolina were required by state legislation to produce transportation maps. These maps form the basis of the NCDOT roads database. Many segments attributed to 1930 stem from these maps, but are not indicative of the actual year of construction; therefore, for the road types of state highways and secondary routes, 1930 is the earliest year recorded in the database, though a majority of roads in these categories were present decades before this date.

Interesting differences arise in the average speed limits and design speeds among the different roads. The speed limit for all of the categories hovers in between 50 and 60 mph, with interstates having the highest average speed (58 mph). This is perhaps due to the data being based on traffic ordinances and not posted speed limits. The typical traffic ordinance states that speed limits in rural areas is 55 mph and urban areas 35 mph. The Blue Ridge Parkway has a strict maximum posted speed limit of 45 mph and is often 35 mph or 25 mph, so the 55 mph average listed in the database is incorrect. Recording speed limit data by ordinance is a much more efficient method of data capture, but in this case, the data does not reflect reality.

The average design speed for each type of road differs by 20 mph. Design speeds are typically higher than posted speeds for safety reasons; also, segments that are designed for lower speeds often have warning signs posted for the driver to proceed at a lower speed. This signage is not reflected in the available data. Table 6.2, Figure 6.2, Figure 6.3, and Figure 6.4 display the computed road characteristics using averages by road category. The second set of summary statistics documents alignment characteristics for each type of road, as computed in ArcGIS with the segmentation code provided in Appendix C. As noted in the Methods chapter, each characteristic is computed by mile.

Table 6.2: Computed Road Characteristics - Averages by Road Category

Road Category	Sinuosity		Adherence to Contours		Elevation Change	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Interstates	0.974	0.048	2.25	1.91	46.1	66.0
US Highways	0.937	0.095	2.32	1.65	58.2	73.5
NC Highways	0.878	0.135	2.63	1.99	74.9	92.8
Secondary Rtes	0.852	0.126	2.98	2.07	91.3	100.8
Blue Ridge Pkwy	0.838	0.114	4.55	2.13	150.4	96.8

Figure 6.2: Sinuosity by Road Type

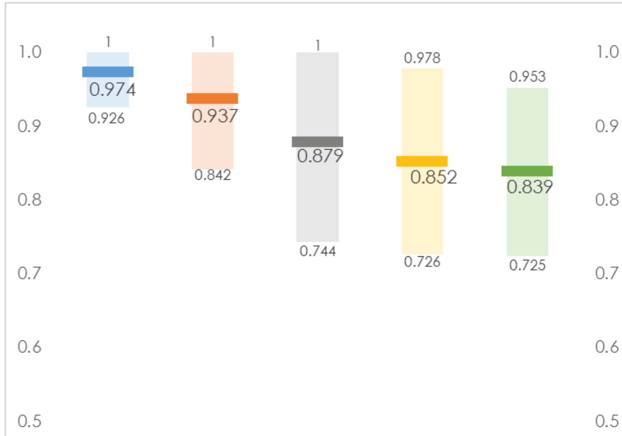


Figure 6.3: Elevation Change by Road Type

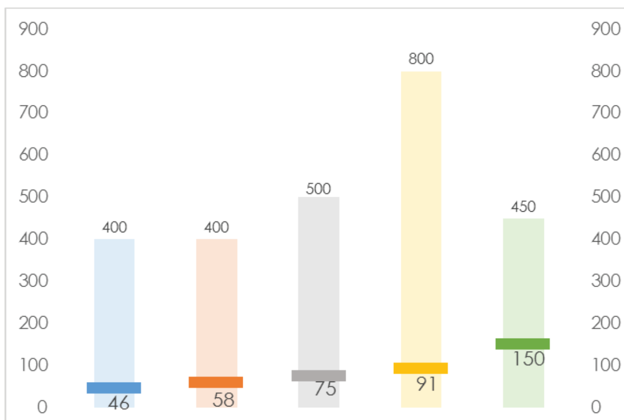
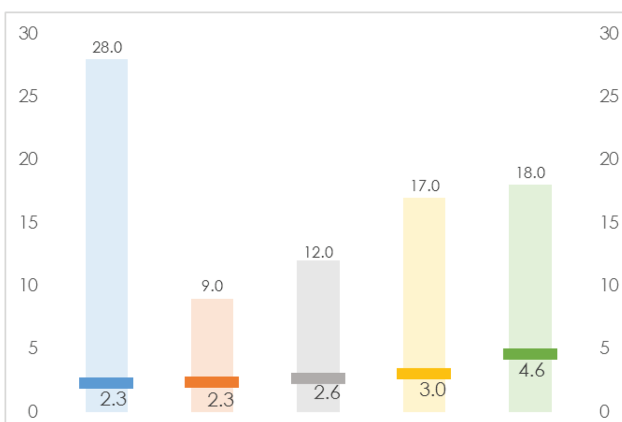
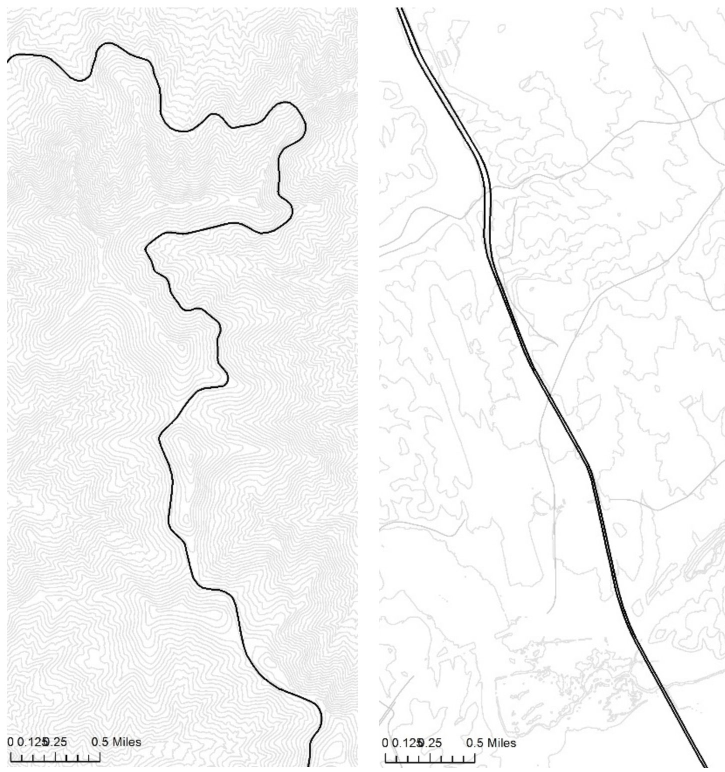


Figure 6.4: Adherence to Contours by Road Type



The sinuosity numerical index (where 1 is straight) does not appear to show dramatic differences between roads, but even a difference of 0.01 indicates a large difference in the shape of the road. For instance, Figure 6.5 shows the Blue Ridge Parkway and Interstate 26 at the same scale. The Blue Ridge Parkway has an average sinuosity of 0.839 and the interstates 0.974, yet the alignments are very different in plan view.

Figure 6.5: Sinuosity of Blue Ridge Parkway and I-26



The statistics make historical construction trends easy to spot. Interstates are straighter with less elevation change, reflecting the gentler design grades of 3-5% and much longer horizontal curvature resulting from large cuts in topography.

US highways are slightly curvier with slightly more elevation change, showing their higher federal design standards but general alignment that was laid out before technological advances and standardized alignment methods. State highways are curvier and steeper still, showing their general origin as old road alignments with less updating in later decades. Finally, the secondary routes have high average sinuosity and high average elevation change, revealing that there has been little intervention since their original alignment and construction. The Blue Ridge Parkway is, expectedly, the most sinuous with the highest elevation change. The Blue Ridge Parkway also has the highest number of intersections with 50’ contours; the interstates have the least on average.

Most striking in this set of numbers is the difference in elevation change of the Blue Ridge Parkway with the other roads. While the spread of average elevation change between the other four road categories is only 45 feet, average elevation change on the Parkway (150 feet) is nearly 60 feet greater than the next closest category, Secondary Routes (91 feet). This illustrates the singular intentionality of the road designers. “Rather than follow a ridgeline for miles,” Tim Davis notes, “a park road or parking drive might drop down to a hillside location for a while or wind back and forth across the crest to provide views in both directions” (Davis, Croteau, and Marston, 2004, p. 5). The other roads mark the most direct routes possible to build at the time.

6.2. Terrain Statistics within 100 m, 270 m, and 540 m Buffers

Three buffer distances were used to measure terrain characteristics around the road corridors. The three distances from the road were 100 m, 270 m, and 540 m, measured on each side of the road.

Using 20’ LIDAR data, average slope, average elevation, and average hilliness were computed for each buffer distance. The resulting statistics in Table 6.3 describe how each type of road is situated within the landscape (Figure 6.6, Figure 6.7, Figure 6.8).

Table 6.3: Terrain Statistics within 100 m, 270 m, 540 m from Road – Averages by Road Category

Road Category		Slope		Elevation (Feet)		Hilliness (Std. Dev. Elev.)	
	Buffer Distance	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Interstates	100 m	8.9	5.9	1,572	658	39	26
	270 m	9.1	6.5	1,586	665	51	40
	540 m	9.2	6.3	1,607	683	63	56
US Highways	100 m	9.7	5.7	1,817	843	43	26
	270 m	10.6	6.2	1,835	853	60	42
	540 m	11.5	6.5	1,859	869	82	64
NC Highways	100 m	11.2	6.2	2,007	980	50	32
	270 m	12.2	6.4	2,025	988	71	49
	540 m	13.1	6.6	2,050	1,003	95	69
Secondary Rtes	100 m	9.9	5.5	1,820	849	50	43
	270 m	11.1	5.8	1,834	864	65	43
	540 m	12.1	6.1	1,855	886	86	62
Blue Ridge Pkwy	100 m	18.6	6.6	3,808	938	87	33
	270 m	18.8	7.9	3,784	925	145	62
	540 m	19.1	5.9	3,730	905	203	91

Figure 6.6: Elevation by Road Type

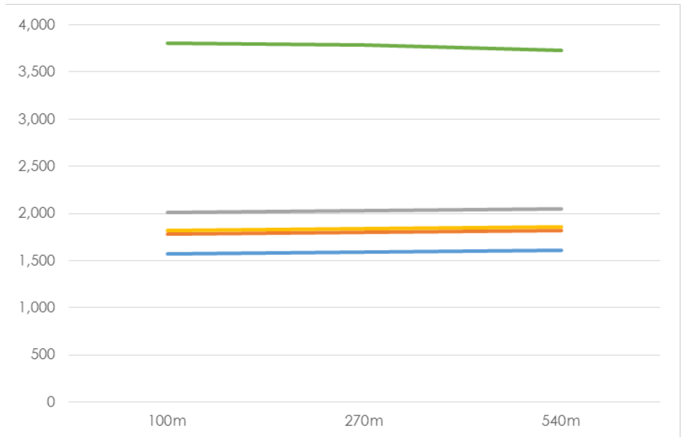


Figure 6.7: Hilliness by Road Type

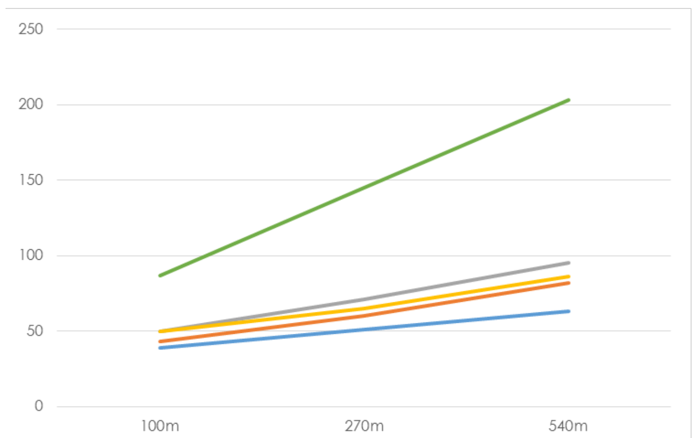
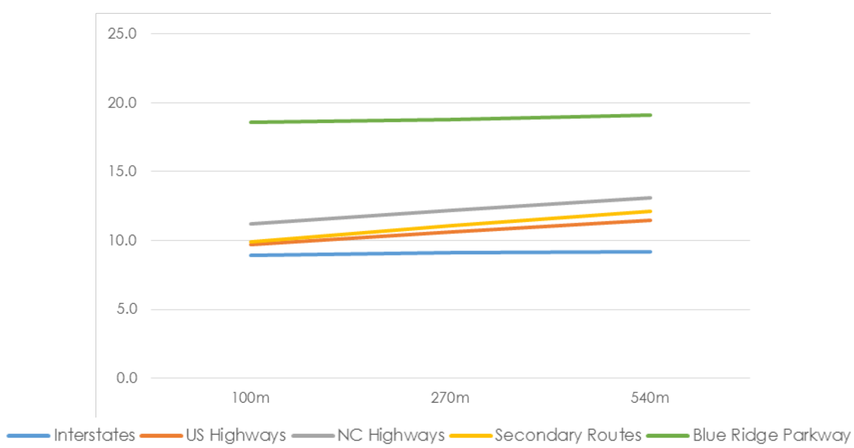


Figure 6.8: Slope by Road Type



The Blue Ridge Parkway is constructed in the highest, steepest, hilliest locations of all of the types of roads. This makes sense in light of the intentions of the road builders: crossing the ridgeline of mountains, skirting the top, providing the best views of the surrounding interesting topography. The average slope of the surrounding terrain increases by only 0.5 percentage points as distance from the road increases from 100 m to 540 m. Hilliness more than doubles as distance increases, proving that the road builders selected the best alignment through highly varied terrain. Average elevation decreases by 2%, reiterating the ridgeline position of most of the route.

On the opposite end of the spectrum are the interstates, where elevation *increases* as distance from the road increases, though by only 2%, proving that the interstates were constructed at the lowest, easiest passages through rough terrain. Hilliness increased by 50% as distance increased. Slope increased by only 0.3 percentage points, reiterating the valley positioning of the interstates.

In comparing the other categories, secondary routes and US highways seem to traverse the same types of terrain – both have very similar characteristics in each category, with the primary difference being that the slope increases slightly faster for secondary routes as distance from the road increases. Secondary routes have much higher sinuosity and elevation change on the roads themselves, however, illustrating that while these two types operate in very similar terrain, the roads were aligned according to different design standards.

NC highways traverse slightly higher areas on average than the other types of roads, reflecting perhaps the notion of secondary routes being more prevalent overall, and thus in lower and less hilly terrain.

6.3. Land Cover Summary Statistics within 100 m, 270 m, 540 m Buffers

Land categories with less than 5% within road category buffers were excluded from the table and charts below (Table 6.4, Figure 6.9). Figure 6.9 displays the percentage of different land cover categories by road type within the three buffer sizes.

Table 6.4: Land Cover Statistics within Distance from Road – Averages by Road Category

Road Category	Buffer Distance	Everg. Forest	Decid. Forest	Mixed Forest	Dev. Hi. Int.	Dev. Med. Int.	Dev. Low Int.	Dev. Open	Hay Pasture
Interstates	100 m	1.7%	16.5%	0.6%	1.0%	8.1%	25.7%	35.3%	7.2%
	270 m	3.1%	28.2%	1.2%	1.8%	6.0%	14.7%	25.7%	13.5%
	540 m	3.7%	33.1%	1.5%	1.8%	4.9%	11.1%	21.8%	15.9%
US Highways	100 m	2.1%	18.7%	0.7%	1.9%	6.7%	15.9%	42.8%	7.9%
	270 m	4.1%	33.6%	1.5%	1.7%	4.6%	9.6%	26.3%	13.2%
	540 m	4.7%	40.7%	1.8%	1.3%	3.3%	7.2%	20.9%	14.1%
NC Highways	100 m	3.8%	31.2%	1.5%	0.7%	2.7%	7.4%	30.1%	17.2%
	270 m	5.5%	42.6%	2.1%	0.7%	1.9%	4.5%	17.8%	18.6%
	540 m	6.1%	48.8%	2.3%	0.5%	1.4%	3.4%	13.6%	17.3%
Secondary Rtes	100 m	4.7%	32.9%	1.9%	0.2%	0.9%	4.2%	23.1%	25.7%
	270 m	6.2%	43.0%	2.4%	0.3%	0.8%	2.8%	14.1%	23.5%
	540 m	6.6%	49.3%	2.6%	0.3%	0.7%	2.3%	11.0%	20.2%
Blue Ridge Pkwy	100 m	4.9%	47.9%	1.2%	0.0%	0.1%	1.7%	41.9%	1.6%
	270 m	7.5%	64.9%	2.1%	0.0%	0.1%	0.9%	18.6%	4.1%
	540 m	6.9%	70.4%	2.2%	0.0%	0.2%	0.8%	12.07%	5.2%

Figure 6.9: Land Cover within Distance of Roads by Road Type

Note that these charts are intended to compare rates and direction of change. Thus, for clarity, they have different Y-axes values.

Developed open space shows one of the most interesting patterns. The developed open space category includes areas that have been developed but contain less than 20% impervious surface; primarily, the category consists of parkland, golf courses, and other vegetation planted in developed settings. The Blue Ridge Parkway has a large amount of developed open space within the 100 m buffer, but this amount drops sharply as the distance from the road increases. For other road types, the amount of developed open space also decreases, but at a much slower rate. This trend shows that the Blue Ridge Parkway is a highly managed landscape, selectively cleared for viewsheds from the road; developed open space approaches a more normal trend as the distance from the road moves beyond the NPS boundary.

Percentage of developed high, medium, and low intensity land generally decreases as distance from the road increases. The interstates and US highways both have the highest percentages of development in the 100 m buffer, but this percentage drops more sharply for these two categories than for the others. The exception is high intensity development, which increases for interstates as distance increases (Note that the percentage is still very low: 2%).

Percentage of forest cover generally increases for all road types in all three categories of forest as distance from the road increases. This makes sense, since developed land decreases moving away from the road and is generally replaced by forested land. Both commercial and residential development follows transportation infrastructure closely.

A prominent difference between secondary routes and other roads is that Hay Pasture *decreases* as distance from the road increases. In all other categories, Hay Pasture *increases* as distance from the road increases. Secondary routes travel through farmland and the least amount of protected land. Much of the area was heavily logged before the early 1900's, but the national park and forests, the Parkway, and many state parks were intentionally reforested. This explains the absence of forest cover in this least protected road category of Secondary Routes.

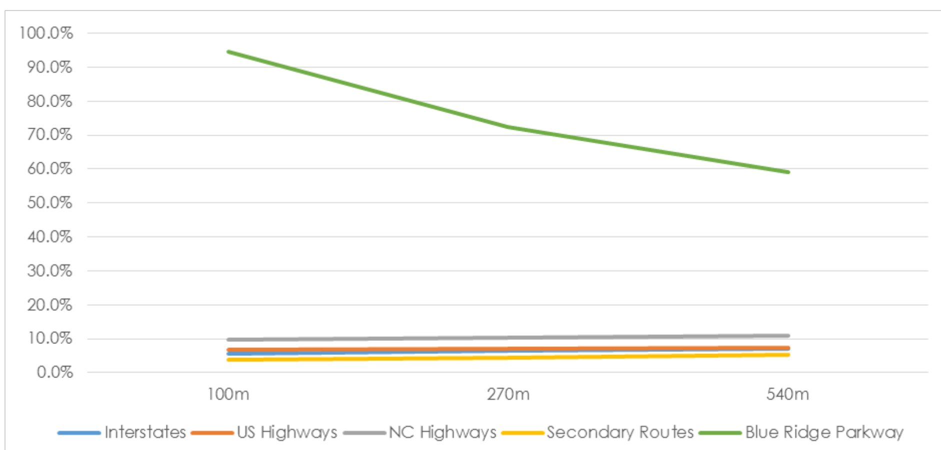
Secondary routes stand out as having the most diversity of land cover surrounding them, which makes sense because these routes are the most prevalent in the set (over 9,500 miles of secondary routes out of a total of 13,519 miles of road) and thus pass through a wider range of types of land cover.

The percentage of protected land is highest in the 100 m buffer of the Blue Ridge Parkway, reflecting the national park that surrounds the road (Table 6.5). The percentage of protected land drops sharply as distance from the parkway increases. For all four other types of road, the amount of protected land increases as distance from the road increases; in tandem with the statistics about development patterns, this explains that development follows roads (Figure 6.10).

Table 6.5: Protected Land Status within 100 m, 270 m, and 540 m of Roads by Road Type

	Interstates	US Highways	NC Highways	Secondary Rtes	Blue Ridge Parkway
100 m	5.5%	6.8%	9.7%	3.9%	94.5%
270 m	6.5%	7.1%	10.3%	4.4%	72.3%
540 m	7.0%	7.4%	11.0%	5.3%	59.1%

Figure 6.10: Protected Land Status within 100 m, 270 m, and 540 m of Roads by Road Type



6.4. Human Population Summary Statistics within 100 m, 270 m, 540 m Buffers

Neither population density nor proximity to urban areas change much for any of the road categories as distance from the road increases (Table 6.6, Figure 6.11, Figure 6.12). Interstates and US highways showed a similar trend to development intensity in the land cover category: population density rose slightly as distance from interstates increased, like the high intensity development, while the opposite occurred around US highways. All other categories remained virtually the same.

Table 6.6: Population Density and Proximity to Urban Areas by Road Type

Road Category	Buffer Distance	Population Density (Persons/Sq. Mile)	Proximity to Urban Areas (Miles)
Interstates	100 m	495	1.91
	270 m	509	1.92
	540 m	510	1.93
US Highways	100 m	319	5.03
	270 m	313	5.04
	540 m	308	5.02
NC Highways	100 m	188	6.32
	270 m	188	6.33
	540 m	187	6.34
Secondary Rtes	100 m	177	5.42
	270 m	177	5.43
	540 m	178	5.44
Blue Ridge Pkwy	100 m	114	5.65
	270 m	115	5.65
	540 m	116	5.65

Figure 6.11: Population Density

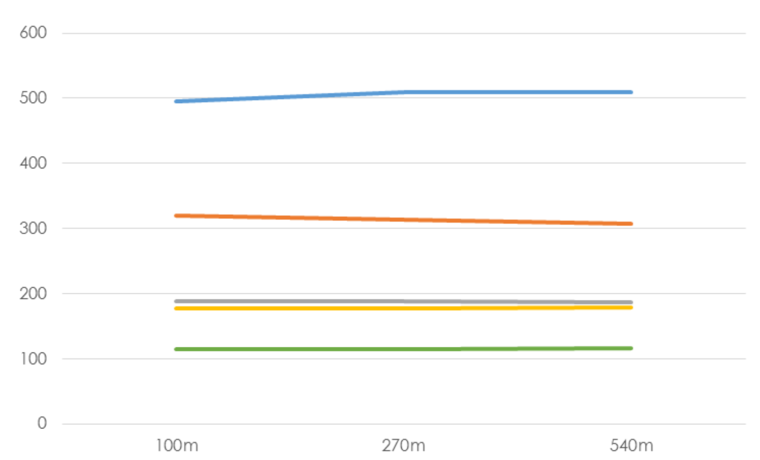
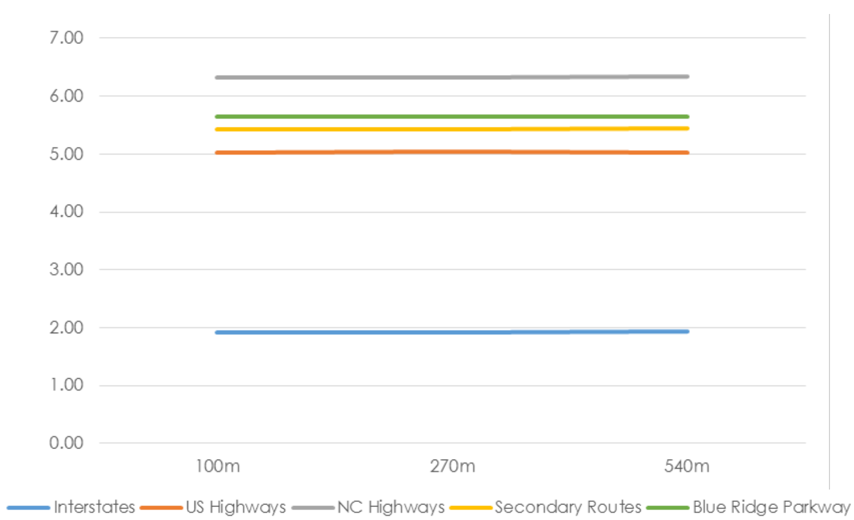


Figure 6.12: Proximity to Urban Areas



6.5. Regression Analysis

The OLS regression in ArcGIS indicated that the model was potentially biased; the regression in SAS was used to check against the OLS results.

In the ArcGIS OLS tool, six checks are used to determine model fitness in the OLS tool output:

- Adjusted R^2 value – shows the percentage of the dependent variable that is explained by the independent variables; includes adjustments that reflect model complexity (number of variables)
- Variable metrics:
  - Coefficient – displays the direction and magnitude of the explanatory variable's influence on the dependent variable.
  - T-test and p-value – measures the statistical significance of the explanatory variables. The closer the associated p-value (probability) is to 0, the more likely the associated variable's coefficient is *not* 0. The Robust p-value must be used when the Koenker statistic is statistically significant.
  - Variance Inflation Factor (VIF) – represents the overlap of variables; if a variable has a VIF value over 7.5, it is redundant.
- Joint F and Joint Wald Statistic – display the overall model significance. Joint Wald is used instead of Joint F when the Koenker statistic is statistically significant. At 95% confidence level, the Joint F and Joint Wald statistic should be below 0.05 for model statistical significance.
- Koenker BP Statistic – indicates the viability of the model across geography and data differences, testing stationarity of the model. If the Koenker test is statistically significant, the model is truer in certain geographic areas or in certain scenarios than in others.
- Jarque-Bera test – assesses whether the model residuals are normally distributed. A statistically significant Jarque-Bera could indicate four scenarios: 1) the model may be

misspecified; 2) the modeled relationship is non-linear; 3) the data includes influential outliers; or, 4) the disparity between model fitness for different scenarios is large.

- Spatial Autocorrelation – A separate test, Global Moran's I, should be run on the residual of the OLS results to determine spatial autocorrelation

6.5.1. Dependent Variable: Percent Forest Cover

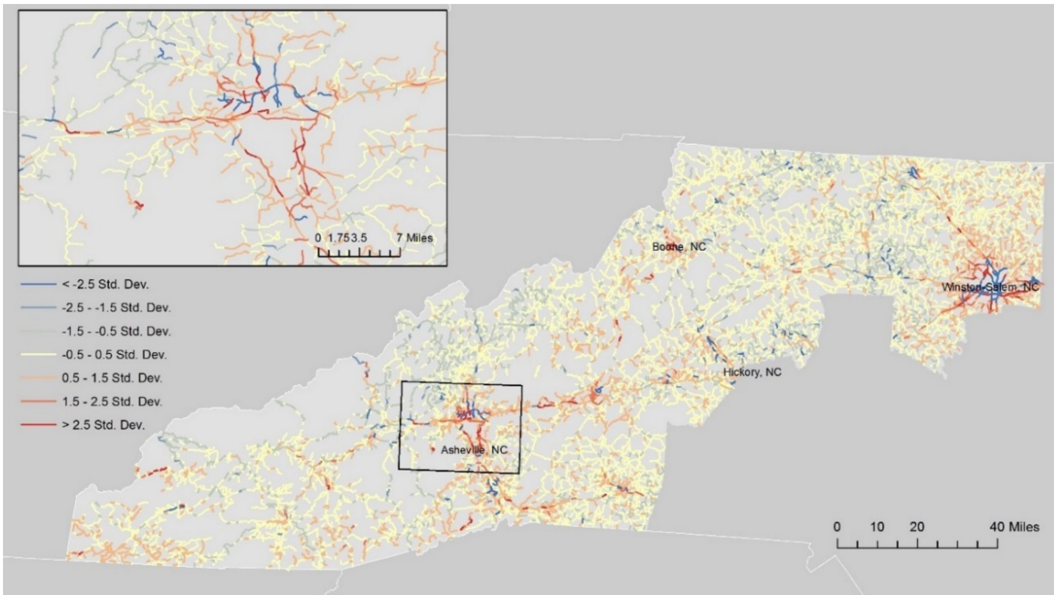
For the independent variable representing percentage of forest cover, the regression analyses run in ArcMap with the Ordinary Least Squares tool and with proc reg in SAS both showed an adjusted R^2 value in a similar range: 46.3% in ArcMap and 41.4% in SAS (Table 6.7). The variables with the highest coefficient values were also consistent between SAS and ArcMap, though the estimated coefficient varied.

Table 6.7: Summary of OLS Model Results – Dependent Variable: Percent Forest Cover

Test	Value / Significance
Adjusted R^2	0.463
Joint F	Statistically Significant
Joint Wald	Statistically Significant
Koenker (BP)	Statistically Significant
Jarque-Bera	Statistically Significant

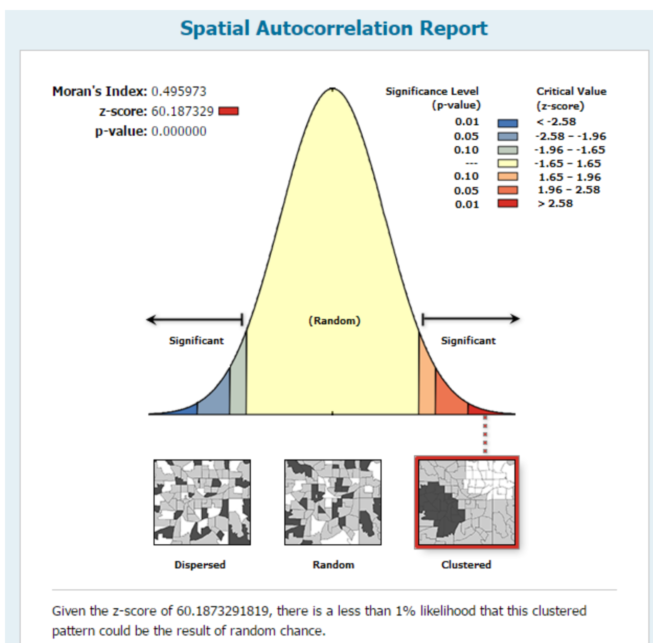
The Jarque-Bera test in the ArcMap OLS results was statistically significant, indicating that the model as designed is not fit to the data. The map of the standard deviation of the residual after running OLS in ArcMap shows geographic clustering, indicating that there may be a spatial element to the missing data (Figure 6.13). The model has the least fit in the cities of Asheville and Winston-Salem. However, no discernible pattern within the cities is visible to help reveal what is missing from the model.

Figure 6.13: Standard Deviation of Residual after OLS – Dependent Variable: Percent Forest Cover



Indeed, the output from Global Moran's I, a tool used to measure residual clustering, showed significant clustering (Figure 6.14).

Figure 6.14: Spatial Autocorrelation Report – Dependent Variable: Percent Forest Cover

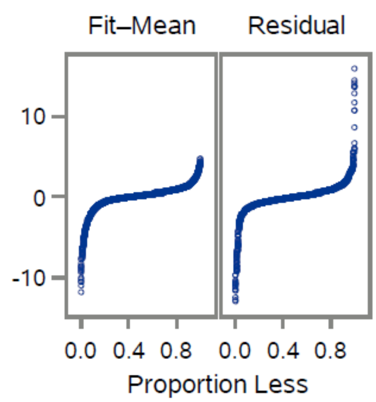


The most influential variable was percentage of protected land, with a coefficient of 0.95 (1.46 in SAS). Sinuosity was next, with -0.677 (-0.41 in SAS). The sinuosity coefficient showed a negative relationship, which makes sense given that as the sinuosity index increases, the road becomes straighter. Slope was somewhat influential, with a coefficient of only 0.104 (0.098 in SAS).

Three variables had VIFs larger than 7.5, meaning that they were redundant: adherence to contours, elevation change along the road, and mean elevation of the surrounding landscape. The ROW width variable showed a higher than accepted p-value for the null hypothesis of the value being 0, meaning that it is less certain that the variable has influence over the dependent variable.

One of the charts produced by the SAS proc reg report also indicates that a large amount of explanatory data is missing from the model, as indicated by the long tail in the residual graph on the right that is absent from the fit of the model graphed on the left (Figure 6.15).

Figure 6.15: Mean Fit of Model versus Residual Plot (SAS) –Percent Forest Cover



6.5.2. Dependent Variable: Sinuosity

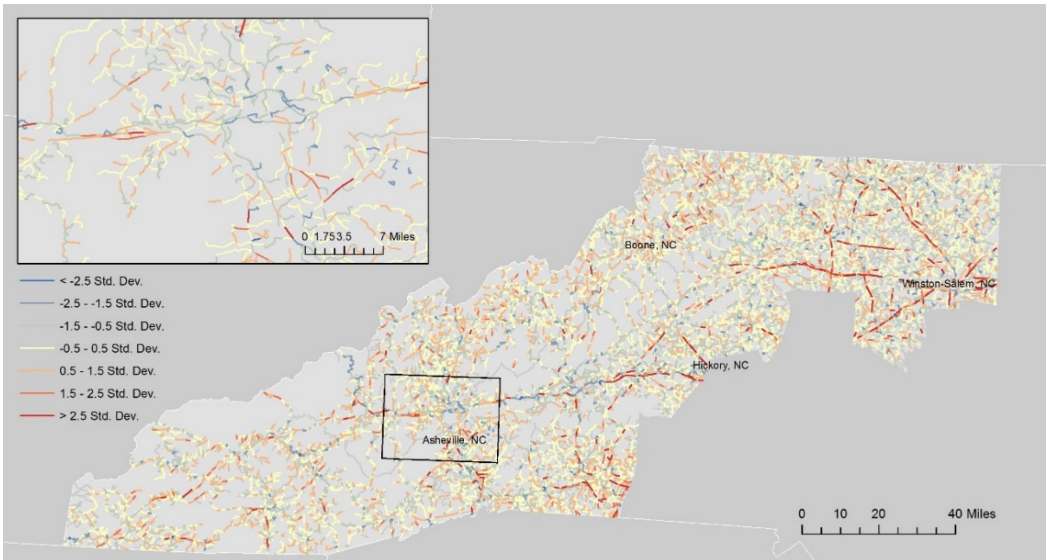
For the independent variable representing sinuosity, the regression analyses run in ArcMap with the Ordinary Least Squares tool and with proc reg in SAS also showed an adjusted R^2 value in a similar range: 38.9% in ArcMap and 44.7% in SAS (Table 6.8). The variable with the highest coefficient value was also consistent between SAS and ArcMap, though the estimated coefficient varied.

Table 6.8: Summary of OLS Model Results – Dependent Variable: Sinuosity

Test	Value / Significance
Adjusted R^2	0.389
Joint F	Statistically Significant
Joint Wald	Statistically Significant
Koenker (BP)	Statistically Significant
Jarque-Bera	Statistically Significant

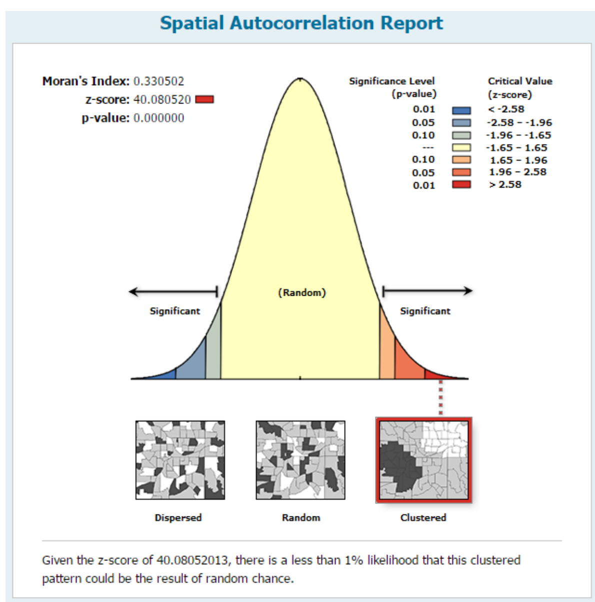
As with the other OLS results, the Jarque-Bera test in the ArcMap OLS results was statistically significant, indicating that the model as designed is not fit to the data. The map of the standard deviation of the residual after running OLS in ArcMap does not show much visible geographic clustering (Figure 6.16).

Figure 6.16: Standard Deviation of Residual after OLS – Dependent Variable: Sinuosity



Though the map shows no obvious pattern, the output from Global Moran's I, a tool used to measure residual clustering, showed significant clustering (Figure 6.17).

Figure 6.17: Spatial Autocorrelation Report – Dependent Variable: Sinuosity



The only variable with a notable coefficient that had a statistically significant probability was functional class, with a coefficient of -0.467 (-0.537 in SAS). Since roads in functional classes with lower numbers are interstates and US highways, this makes sense that as functional class decreases, the sinuosity index rises, indicating a straighter road.

Other variables in the sinuosity model showed mixed results. Adherence to contours, elevation change, and hilliness again had VIFs larger than 7.5, meaning that they overlapped. The land cover variables forest cover, urban cover, and hay pasture did, as well. A long list of variables had higher than acceptable probabilities, meaning that it is less certain that the variable has any influence over the dependent variable. These included surface width, design speed, traffic count, protected status, and all of the land cover variables (forest, urban, open, and hay pasture).

The sinuosity model, overall, was less conclusive than the forest cover model. This may be due to the high variability in the largest category of roads, the secondary routes. These are the most sinuous roads, and their contexts are highly diverse across terrain and land cover.

6.6. Field Work

Field work was intended to determine the validity of the roads database and to provide insight into the experiential aspects of roads that cannot be quantified using current tools. As with any attempt to make large generalizations and identify phenomena at a regional scale, the work served as an important reminder of the enormous variety of road conditions on the ground and their causes, ranging from policies to the quirks of local decision-makers to geology. Field work to document road conditions in detail along a corridor would take weeks, even for the short stretches driven along each of the selected routes, which totaled less than 1% of the total road database used in this study.

6.6.1. Route Summaries

The variety of experiences and road treatments within same corridor was most drastic along US 321, which is, in parts, a lovely two-lane highway curving around the side of a cliff, with beautiful vistas west across the valley, and in other parts, a four- or five-lane highway with 8-foot shoulders, a 30-foot median, and metal guardrails hemming in the cars.

I-40 typifies the interstate experience, but one portion of the section driven traverses more constrained conditions than most interstates; the road is narrower and more sinuous as a result.

NC 194 was a surprisingly beautiful drive, as a state scenic byway. Secondary Route 1220 near Asheville was a thrilling mix of unpaved road, steep climbs and sharp vertical angles over the crests of hills, evidence that it was built before vertical curvature designs were standardized in the 1930's.

Most exciting, by far, was Cove Creek Road, an old Cherokee trail stitched into the sides of hills leading into the Cataloochee Valley in the Great Smoky Mountain National Forest. According to Tim Davis, the road follows the same alignment as it did in the pre-colonial days (2004). The map of 1893 confirms that it was at least in place over 120 years ago.

The alignments of NC 194, SR 1220, and Cove Creek Road ensured that the travel speed remained low, as low as 5 mph around some bends. US 321 and I-40 enabled high speeds, and truck traffic was much more prevalent along these stretches.

6.6.2. Cuts, Embankments, and Roadside Treatments

The Appalachians are old mountains and are highly rutted, with long rivulets running vertically down from peaks. This formation is obvious when riding the roads; some roads, like the Blue Ridge Parkway, balance winding around the sides with minimal cut and fill, resulting in the relatively regular sight of a gently banked, planted cut every few hundred feet (Figure 6.18).

Figure 6.18: Blue Ridge Parkway Sloped Embankment

Conversely, cuts along the interstates and US highways are much more dramatic, with drilled holes for dynamite still visible in the rock (Figure 6.19). National Park road builders often avoided leaving raw banks from excavation. The banks are sloped back gently and rounded to appear as natural topography (Davis 2004 6). Old methods of creating this aesthetic may not still appeal to wider audiences; many people, including this author, love the geologic appearance of raw excavation, especially after tiny plants have laid anchor or elegant drips of ice adorn it. Other authors, like Janike Kampevold Larsen, extoll these cuts as some of the only spaces through which humans can see into deep time. “To enjoy road cuts however, one must not only have a sense of geologic presence, but for the ordinary, for repetition of views, and not the least for that which we pass at great speeds” (Larsen, 2012, p. 5).

Figure 6.19: Vertical Dynamite Drill Lines along I-40

The following images compare typical conditions along each type of road, though, as discussed, the variability along each road, especially US 321, was high and conditions changed frequently (Figure 6.20).

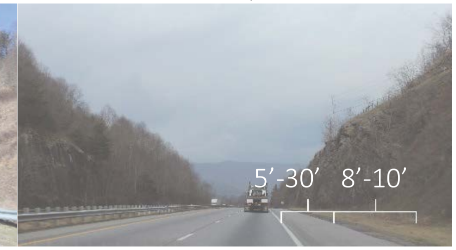
Figure 6.20: Shoulders and the Clear Zone, Lane Width and Roadbed Division, and Cuts along Routes

SR 1220
0’-<1’ Unpaved Shoulder

NC 194
3’-5’ Unpaved Shoulder

US 321
5’-8’ Paved Shoulder

I-40
8’-10’ Paved Shoulder, 5’-30’ Clear Zone

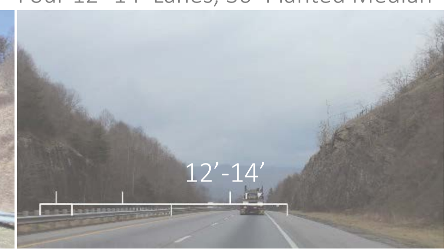


SR 1220
Two 9’-10’ Lanes

NC 194
Two 10’-11’ Lanes

US 321
Four 10’-12’ Lanes

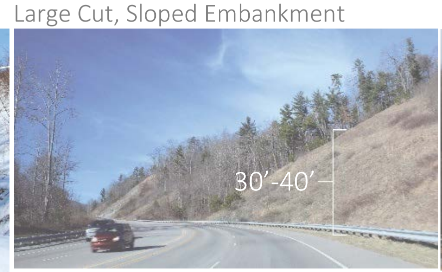
I-40
Four 12’-14’ Lanes, 30’ Planted Median



SR 1220
Shallow, Sidehill Cut

NC 194
Sidehill, Sloped Embankment

US 321
Large Cut, Sloped Embankment



I-40
Large Cut, Sloped Embankment

6.6.3. Scenic Experience: Designed Vernacular and Working Landscapes

David Nye states in his essay about the American sublime, “Every form of transportation, no matter how utilitarian it may seem, is implicitly part of an idealized landscape. It is not enough to look only at the vehicle and the pathway. Rather, each form of transportation has been used to define and construct a landscape, to embody a certain gaze” (p. 99). This is true along the highways and secondary routes in the region, but especially along the Blue Ridge Parkway, where the road itself is hundreds of miles of carefully planned view sequences specific to the motoring tourist of the mid-20th century. The road varies in topography and enclosure, tied seamlessly together with unified curvature and local, rustic materials (Figure 6.21).

Figure 6.21: Selected Scenic Details from Blue Ridge Parkway Design

The parkway is similar in some ways to the scenic byways and other beautiful drives in the region, though is more meticulously planned and provides a place apart from any reference to contemporary culture or in fact real residents dwelling on the land. The visual assessment work made plain two seemingly paradoxical truths about the Blue Ridge Parkway: its very presence reveals the technical and aesthetic mastery that had been reached by American landscape architects by the mid-20th century, and, in designing an artificial American ideal, this technical mastery had simultaneously divided the designer from the beauty the design was meant to showcase. About parkways and their influence beginning in the 1910's, Tim Davis states, "Allusively, at first, but with an increasing literalness that eventually verged on caricature, they evolved into idealized simulations of classic country roads" (Davis, 2003, p. 228).

Despite countless experiences on the Blue Ridge Parkway while growing up in the state, visiting the road after reading for the first time about its history and place in a long sequence of cultural influences greatly altered this visitor's experience, to the point where the other roads part of field work seemed to encapsulate a truer vernacular than the parkway. Several scenes of old barns, barns with iconic quilt paintings on the sides, and even an old waterwheel, evoked scenes typified by the Blue Ridge Parkway iconography, but were found on the other roads and not along the parkway itself.

A notable example is the sight of a wooden waterwheel in a cow pasture beside NC 194 near Boone (Figure 6.22). A similar, and staged, example exists at Milepost 176 in Virginia along the Blue Ridge Parkway at Mabry Mill. Designers restored the waterwheel, installed a stream and pond, and moved an old barn from miles away to create a perfect scene of an old mill (Davis, 2003; Marriott, 2011). This mill scene has become an icon, not only for the Blue Ridge Parkway, but for nostalgic Americana itself, appearing even as product logos (Hill, 2015).

Figure 6.22: Comparison of Cultural "Artifacts"

Waterwheel at Mabry Mill along Blue Ridge Parkway

Photo: Fulmer (2014), Creative Commons license

Waterwheel and Stream along NC 194

Photo: Author

These observations may seem tangential, but the intent of the designers of the Blue Ridge Parkway sets the parkway apart from other roads in the region in a quantifiable way. The previous section illustrates this difference through the parkway's patterns on the land surrounding it and the shape of the parkway itself.

6.6.4. Historic Road Alignments and Current Conditions

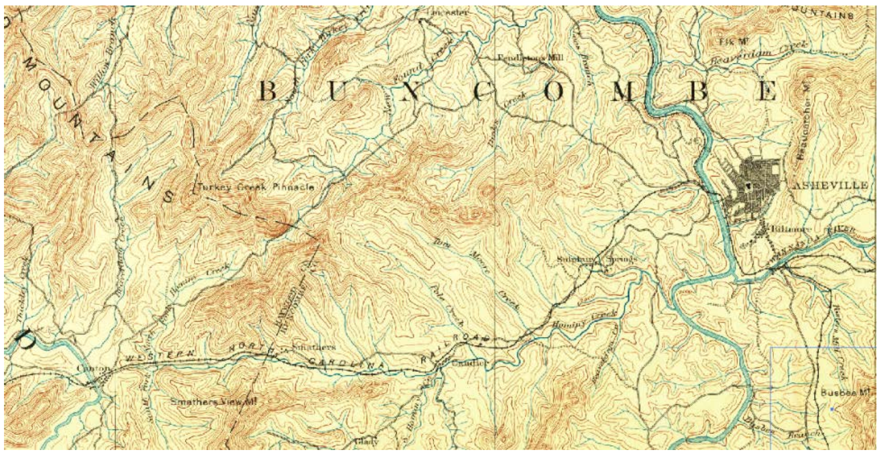
In the absence of data on year of construction for the roads, the historical alignments of the six roads were researched using US Geological Survey Historical Topographic Maps.

The histories of two roads, the Blue Ridge Parkway and I-40, were already known, so the historical maps were no surprise. One road, Cove Creek, which had been chosen for its history, was also assumed to have been present for centuries, but this was not confirmed with maps. NC 194, US 321, and SR 1220 were mysteries.

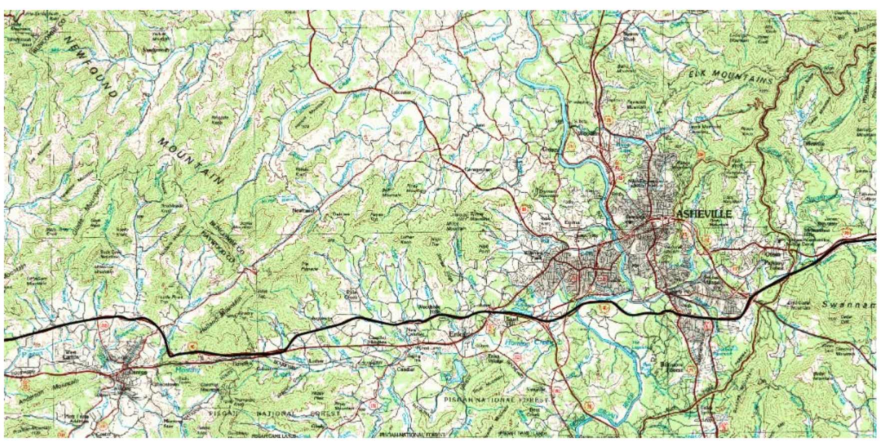
Interstate 40

Interstate 40 is visible in the 1985 map, in some places sharing an alignment with the railroad, what was called the Western North Carolina Railroad in the 1894 map (Figure 6.23). Also noteworthy in these maps is the degree to which Asheville sprawled west across the Broad River, as well as north and south along it, over the century. Figure 6.24 shows conditions along I-40.

Figure 6.23: I-40 Alignment



1894



1985

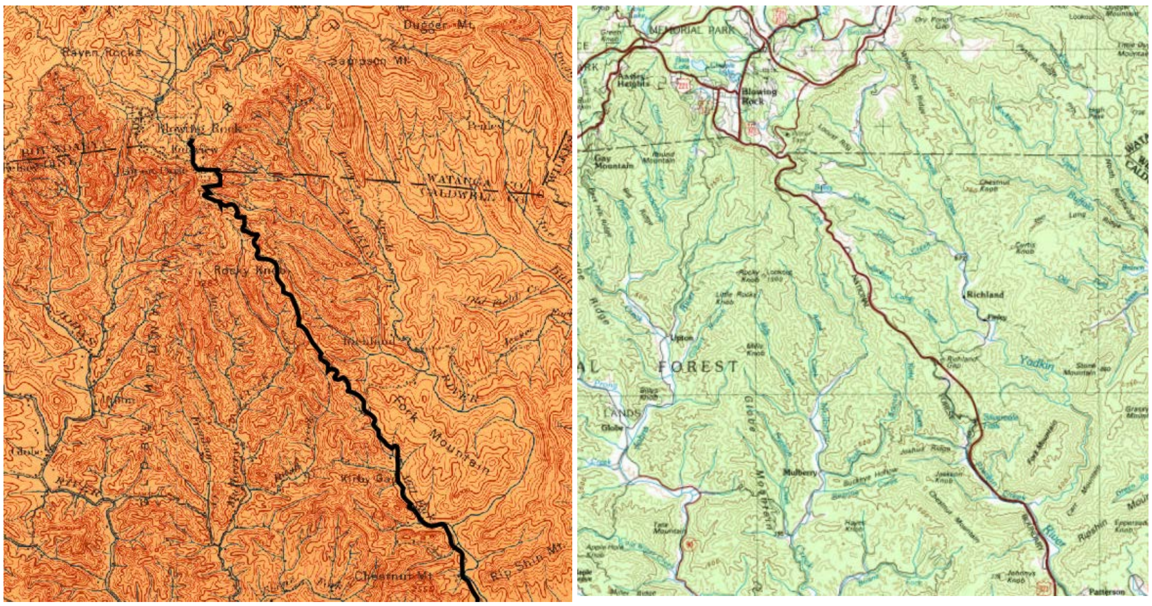
Source: USGS Topographical Map Viewer
US Geological Survey, Asheville [map], 1:125,000, Topographic Quadrangle Map, Reston, VA, 1894
US Geological Survey, Asheville [map], 1:100,000, Topographic Quadrangle Map, Reston, VA, 1985

Figure 6.24: I-40 Conditions

<u>US 321 between Blowing Rock and Lenoir</u>

US 321 is a major highway in the mountains. Here, a road along a similar alignment is in a 1902 map of the area. The 1985 map shows that the road has been visibly straightened and realigned in some places. Parts of the old alignment remain as separate roads, as can be seen directly south of Richland (Figure 6.25). US 321 is also called Blowing Rock Boulevard. Figure 6.26 shows conditions along US 321.

Figure 6.25: US 321 Alignment



1902 1985

Source: USGS Topographical Map Viewer
US Geological Survey, Cranberry [map], 1:125,000, Topographic Quadrangle Map, Reston, VA, 1893
US Geological Survey, Boone [map], 1:100,000, Topographic Quadrangle Map, Reston, VA, 1986

Figure 6.26: US 321 Conditions

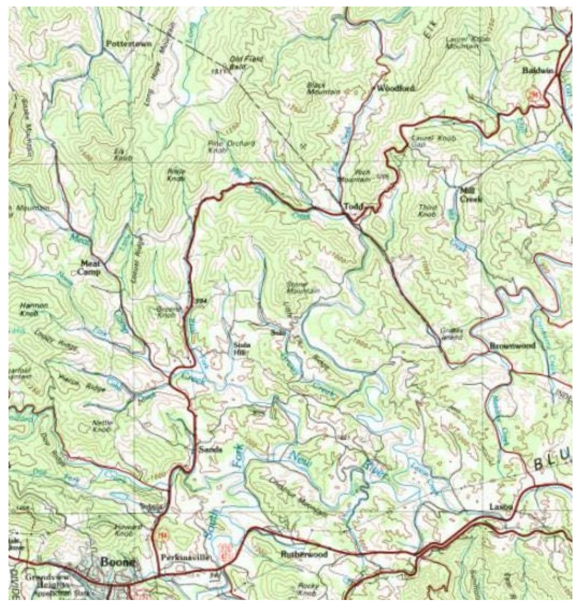
<u>NC 194 between Boone and Baldwin (New River Valley Byway)</u>

NC 194 is visible on the map of the region from 1893, except for one connecting segment east of Meat Camp. The road appears to have been straightened and curves made longer and gentler. The 1893 map uses a slightly smaller scale; although there is less detail, the older map still shows more variation in alignment, indicating that the road was improved later (Figure 6.27). The NCDOT field office for the region is located along NC 194. Figure 6.28 shows conditions along NC 194.

NC 194 was designated a North Carolina Scenic Byway and renamed New River Valley Byway.

Figure 6.27: NC 194 Alignment

1893



1985

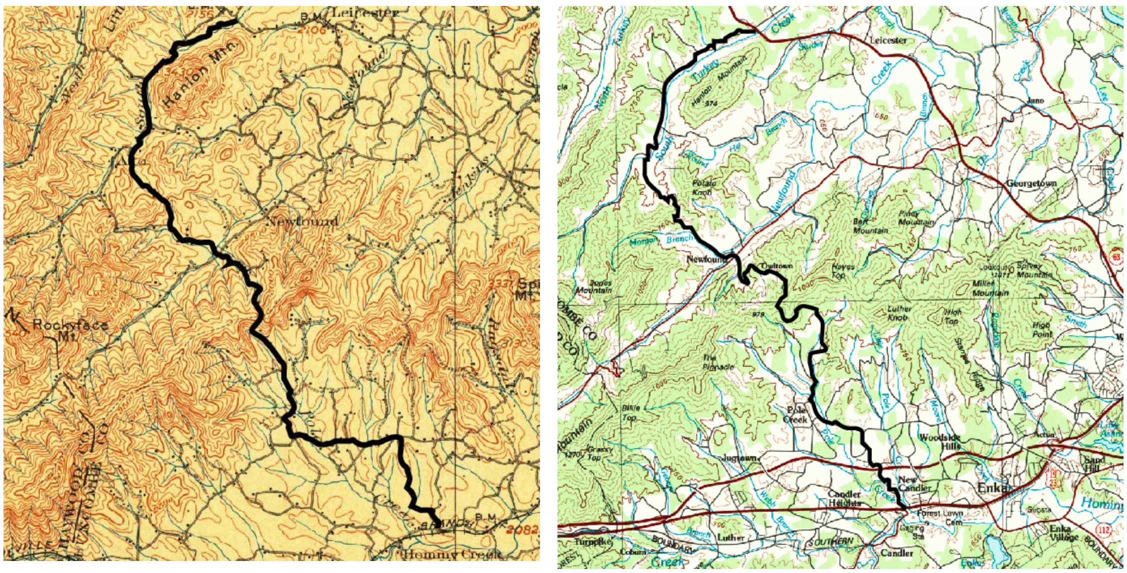
Source: USGS Topographical Map Viewer
US Geological Survey, Cranberry [map], 1:125,000, Topographic Quadrangle Map, Reston, VA, 1893
US Geological Survey, Boone [map], 1:100,000, Topographic Quadrangle Map, Reston, VA, 1986

Figure 6.28: NC 194 Conditions

<u>Secondary Route 1220 between Enka and Leicester</u>

Secondary Route 1220 appears to have remained largely along the same alignment between 1901 and 1985, though with two wide sweeps around topography south of Newfound on the 1985 map that may have been realigned (Figure 6.29). Figure 6.30 shows conditions along SR 1220. This stretch of SR 1220 is also called Dogwood Road, Hookers Gap Road, Potato Branch Road, Morgan Branch Road, and South Turkey Creek Road.

Figure 6.29: SR 1220 Alignment



1901 1985

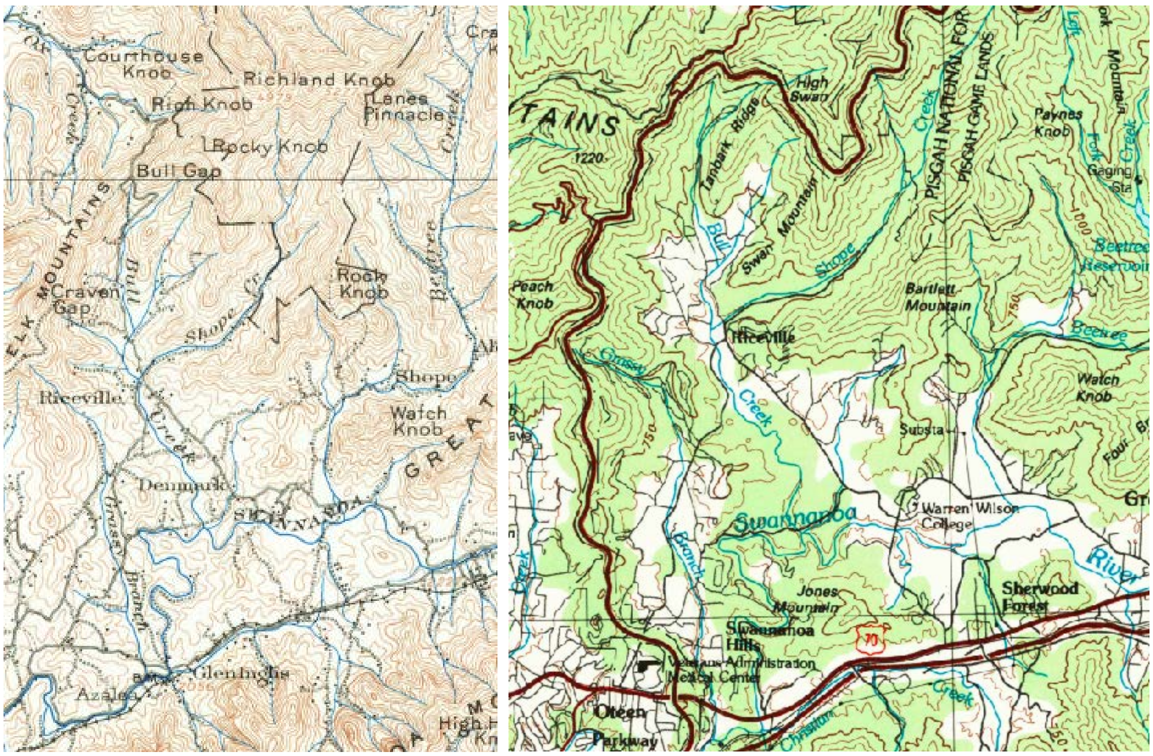
Source: USGS Topographical Map Viewer
US Geological Survey, Asheville [map], 1:125,000, Topographic Quadrangle Map, Reston, VA, 1901
US Geological Survey, Asheville [map], 1:100,000, Topographic Quadrangle Map, Reston, VA, 1985

Figure 6.30: SR 1220 Conditions

Blue Ridge Parkway between Mileposts 375.6 and 395

The Blue Ridge Parkway was built on new right-of-way, as is visible on these maps of the segment east of Asheville. Note Bull Creek running north-south on the left-center of both maps and Watch Knob in the central right of both maps for orientation (Figure 6.31). Figure 6.32 shows conditions along the Blue Ridge Parkway.

Figure 6.31: Blue Ridge Parkway Alignment



1900 1985

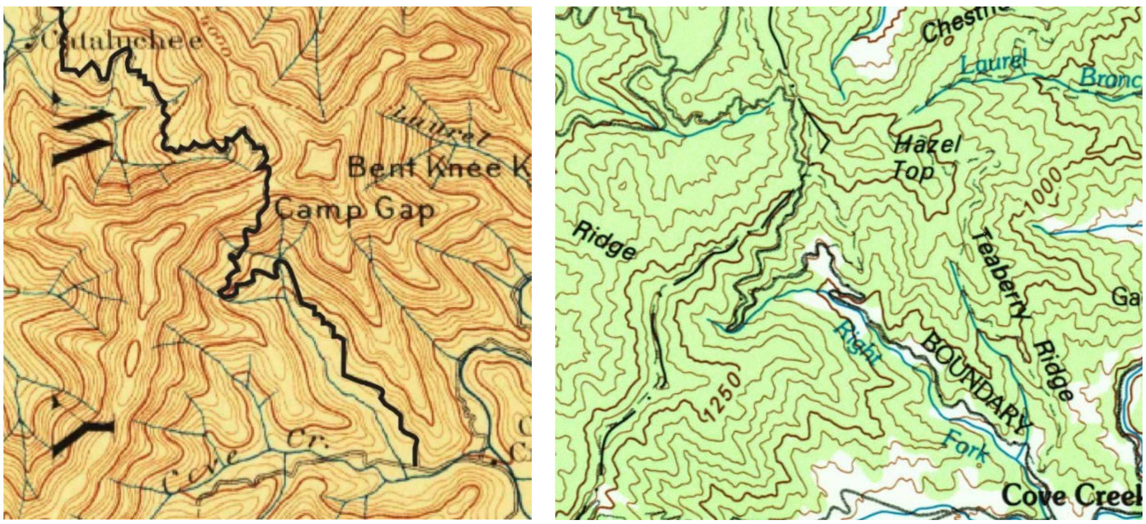
Source: USGS Topographical Map Viewer
US Geological Survey, Mt. Mitchell [map], 1:125,000, Topographic Quadrangle Map, Reston, VA, 1966
US Geological Survey, Asheville [map], 1:100,000, Topographic Quadrangle Map, Reston, VA, 1985

Figure 6.32: Blue Ridge Parkway Conditions

<u>Cove Creek Road near Waynesville and Great Smoky Mountain National Forest</u>

Cove Creek Road was a Cherokee Trail until white settlers began moving to the area in the late 1700's. The trail was widened to accommodate wagons in the 1820's and 30's (Davis, Croteau, and Marston, 2004). These two maps compare the alignment between an 1893 map of the Mt. Guyot area and a 1997 map of Cove Creek Gap, which is largely the same (Figure 6.33). Some difference may be attributed to map scale; the 1893 map covers more area and thus is less detailed. The presence of I-40 in the 1997 map is also a notable difference. Figure 6.34 shows conditions along Cove Creek Road.

Figure 6.33: Cove Creek Alignment



1893 1997

Source: USGS Topographical Map Viewer
US Geological Survey, Mt. Guyot [map], 1:125,000, Topographic Quadrangle Map, Reston, VA, 1893
US Geological Survey, Cove Creek Gap [map], 1:24,000, Topographic Quadrangle Map, Reston, VA, 2001

Figure 6.34: Cove Creek Road Conditions

7. Discussion

The goal of this research was to investigate the landscape characteristics of a road network, examining road ecology phenomena at a regional scale. Though the regression model results were not definitive, summary statistics show major differences in land cover around different road types. This research is a first step toward understanding the effects of road networks, and the design standards and policies that shape them, on the environment.

7.1. Results

Transportation agencies categorize roads according to a few standardized methods classifying the roads based on the type of traffic the route is expected to carry and the type of maintenance funding for which the route is eligible. Transportation agencies already know the major differences between these categories of roads: differing right-of-way and surface width, speed limit, design speed, and traffic volume, to only name a few.

This study moved beyond the characteristics of the road itself and demonstrated that the landscapes and terrain surrounding the roads, though not governed by transportation regulations like the roads themselves, are also different based on the adjacent road type.

The five road types studied are differentiated in three measureable ways:

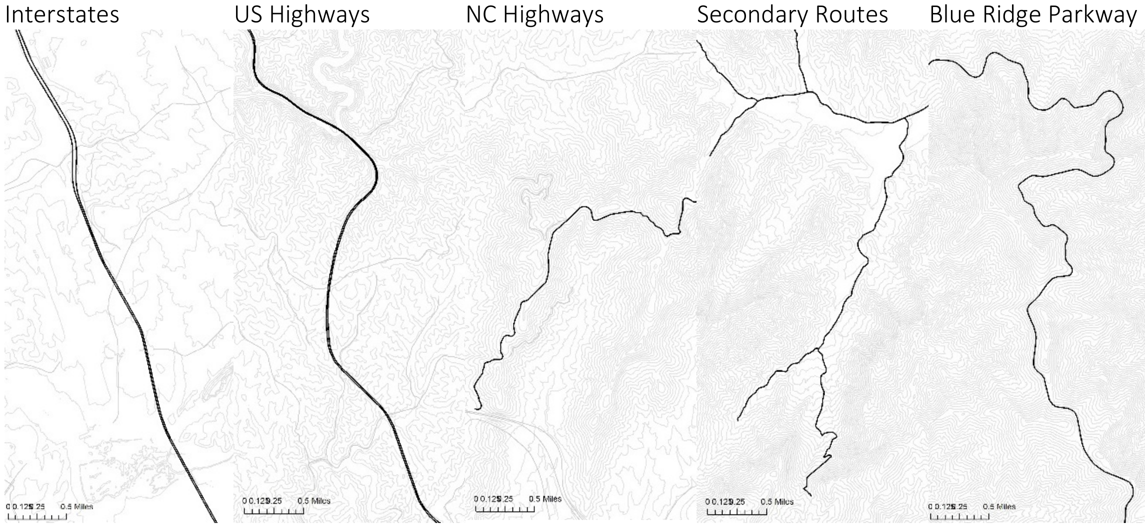
1. The surrounding terrain ranges from steep mountain passes to easy grades along the valley floor according to road type. This finding quantifies through geospatial statistical tools what was understood to be true about the policies and intentions governing the construction of the different road categories. The results show that: Interstates are indeed situated at the lowest elevations possible within the terrain and are straight, wide, and gently graded, a finding that confirms what is known about how they were designed. The Blue Ridge Parkway is perched atop the mountains and winds up and down the ridges, a finding that also confirms the history of its design. Secondary routes are steeper, curvier, and traverse hilly terrain and a diverse range of land covers, a result that is in sync with history about their pre-automobile

alignments. US and state highways are hybrids of interstate and old alignment patterns, as was hypothesized from the historical background.

2. Land cover and population of the surrounding landscapes are different according to category and change at different rates as distance from the road increases, a result supporting the concept that scaling is not hierarchical. These results confirm that the road categories are situated in measurably different landscape contexts, whether by design, as a result of existing land uses, or as a cause of the surrounding land cover.
3. The way each category traverses the terrain is measurably different by category and creates different patterns on the land. Larger highways appear as straight lines, or "ribbons," which is how they were described upon conception (Lewis, 2013). Lower functional classes like state highways and secondary routes appear as snaking lines, and they climb up and over ridges in measurably different ways than the higher functional classes (Figure 7.1).

Figure 7.1: Patterns in Plan, by Road Category

Interstates | US Highways | NC Highways | Secondary Routes | Blue Ridge Parkway



This study also demonstrated that research using spatial analysis at the road network scale is possible and is a promising area for future research. This study took very basic steps of categorizing and measuring known characteristics of roads; the possibilities using variations on this theme alone are vast. Other types of road classes, such as functional class or federal-aid class, might yield different insights. Using a wider variety of variables to analyze environmental factors is another way to expand this same method of categorizing and measuring within the categories. Additional future research is outlined in Chapter 8.

7.2. Methods

The mutual influence of land use and transportation infrastructure on each other is evident in the regression results. Field work reinforced the fact that factors contributing to road shape and alignment are manifold and reducing them to explanatory variables in a model is a challenge. As revealed in a conversation with local NCDOT officials at the field office along NC 194 during field work, piecing together the story of even that single corridor was a demanding task for the staff, requiring intensive archival research, policy research, and assumptions about missing data (Greer, 2016).

This relates to another challenge: generalizing characteristics of roads to the corridor level or to the network level is difficult. Especially along US and state highways, road widths, the number of lanes, roadside treatments, and a host of other road characteristics can change dramatically even within a short distance. Yet, generalizing the details within each corridor in order to draw broader conclusions about the road network is essential to learning about their effects. Determining the level of accuracy necessary to capture conditions while simultaneously maintaining the manageability of the data poses a dilemma that must be dealt with on a project-by-project basis.

7.3. Efficacy of Tools and Data Limitations

Year of construction data at the road network scale is likely to remain a difficult variable to integrate in regional analyses. Some states, such as Virginia, have made digitization and preservation of historic maps a priority and have robust documentation of road construction history. Even with the extensive work done by the NCDOT to log historic maps, their oldest state-wide documentations of road presence are the 1930 maps required of the counties by state legislation. While the historic map comparison for the six roads examined in the field work was illuminating, such an examination for a regional analysis would be too resource-intensive for many projects. The hope is that at least a few states are able to conduct historic research and update their records, and such data may be used to develop a model indicating year of construction based on road shape, terrain, elevation change, and other factors. Until such a model is constructed, these characteristics cannot be used to definitively determine the age of a road.

Other road characteristics attribute fields may lend themselves to improvement more easily. For instance, speed limit data in the NCDOT database is taken from traffic ordinances, which is a coarse metric for one-mile segments. More accurate speed limit data by road segment is available from sources like commercial databases and could be incorporated. Other fields such as design speed would be more resource-intensive to digitize since the main sources for this data are project design documents for the individual corridors.

Maintaining current and accurate records is a huge challenge for state DOTs. The innumerable data points for over 60,000 miles of road in North Carolina mean that errors are likely. NCDOT has a large GIS staff who keep its database in good standing, despite its inaccuracies. Staff have methods in place to streamline updates from other departments and consistently seek to improve these data and methods. Databases maintained by government agencies are vital resources for researchers, and states should prioritize investment in maintaining quality data.

Another limitation of available data is the spatial resolution of vegetation data. While geospatial tools are improving rapidly, and this study may not have been possible even a decade or two ago, finer scale examination of roadside vegetation treatment might give even more insight into the environmental ramifications of federal transportation policy. Roadside vegetation is governed by fewer regulations than road shape, but several important pieces of federal legislation affect what state DOTs plant and how they manage their roadsides. The Highway Beautification Act of 1965 fostered a decades-long movement to plant wildflowers along roadsides, and many states, including North Carolina, still have robust programs. The most recent federal transportation act passed in December 2015, titled Fixing America's Surface Transportation Act, or FAST Act, includes provisions for states to manage roadsides for pollinator habitat. North Carolina invests in detailed LIDAR data fairly regularly; if vegetation data, currently available at 30 m, were available on the scale of the state's LIDAR—20'—more detailed investigation of these and other roadside treatments may be possible.

Finally, a reiteration of Norman Newton's sentiment from the Introduction is in order. Quantifying the experiential aspects of travel along a roadway is not currently possible and may not be quantifiable. Carl Steinitz' work in Acadia National Park with visual assessments along the Loop Road and other visual preference studies begin to shed light on how we perceive transportation landscapes. Tom Vanderbilt's book *Traffic* details how our brains perceive the world while driving. At a network scale, a survey of opinions or perceptions would certainly be prohibitively resource-intensive. Devising some method of using landscape ecology tools to identify road characteristics that capture the elusive quality of pleasant driving would have exciting implications for ways to shape the transportation landscape of the future.

8. Future Research

8.1. Informing Future Alignments and Policies

Road networks and traffic volume are still increasing significantly in other countries, especially in China, India, and Latin America (van der Ree et al, 2011, p. 1). For instance, a South American project called IIRSA, Initiative for the Integration of the Regional Infrastructure of South America, is a joint project between the Inter-American Development Bank and the World Bank that is creating a network of new transportation corridors through sensitive ecosystems across the continent, including the Amazon Basin. These networks are being created with scant data on regional environmental effects of road alignment and shape. As these countries struggle to balance the promise of economic development benefits that are assumed to come from transportation access and their sometimes globally-significant ecosystems, further research on road alignment and shape could inform designs in order to mitigate negative ecological effects.

8.2. Incorporating Additional Tools and Data

The software Fragstats is a raster-based software for analyzing regional environmental patterns using landscape ecology tools. Fragstats allows researchers to compute statistics relating to patch characteristics, connectivity, diversity, fragmentation, and a range of other landscape pattern indicators. Fragstats could be especially helpful in demonstrating potentially different fragmentation patterns or spatial configuration of the landscape surrounding different road types.

Another dataset that could be analyzed as the dependent variable in the model is the Normalized Difference Vegetation Index (NDVI). The NDVI is remotely sensed data showing greenness levels, an indicator of ecological health. Instead of demonstrating land cover differences among road types, NDVI would demonstrate overall forest health. NDVI data is available at 250 meter resolution; since the maximum buffer distance in this study is 540 meters from each side of the road, this spatial resolution would likely not be adequate. Some researchers have successfully combined NDVI data with Landsat data to up sample and achieve a finer grain of spatial resolution. Rao et al demonstrated this method in the 2015 paper "An Improved Method for Producing High Spatial-Resolution NDVI Time Series Datasets with Multi-Temporal MODIS NDVI Data and Landsat TM/ETM+ Images." The process is still fairly intensive and may not be easily incorporated into smaller studies, but the paper proves that NDVI data may be used at higher resolutions.

For estimating distances and the potential shape of the road effect zone using purely geographic tools instead of linking these shapes to environmental characteristics, another potentially useful method would be using Hull rectangles. Hull rectangles are polygons drawn around irregular objects (such as the irregular road buffers bounding sinuous roads) that can measure maximum width and length statistics. This would allow for systematically measuring the width of road buffers in order to relate to the road characteristics, instead of measuring buffer width manually.

8.3. Future Vehicle Technology and Roads

The US is on the cusp of a dramatic change in our transportation infrastructure landscapes. Connected and autonomous vehicles (CAVs) promise to reshape our nation's roads more drastically than any technology since the Ford Model T in 1908. CAVs dominate discussions in the tech and transportation engineering worlds, but no one has created tools or even diagrams to explore their effects on the built environment.

Landscape architects can have an impact larger than our last involvements in major federal highway policy, the Highway Beautification Act of 1965 and our 2015 victory of pollinator habitat provisions in the FAST Act. As CAV regulations take effect, the potential for major streetscape and roadside transformations is enormous. Just as much of the nation's road network was built in a few short decades in the 1910's and 1920's, the transportation landscape will be completely restructured as CAV technology becomes more of a reality. Adoption of completely autonomous vehicles is still several decades away (Litman, 2015), but a mandate for vehicle-to-vehicle communication technology, which will be more revolutionary from a built environment perspective, is anticipated to be adopted by 2020 (USDOT, 2014).

With sensors and vehicle-to-vehicle technology making driving safer, safety regulations that have constrained roadside designs may be relaxed, allowing for a new wave of discussion of the roadside not seen in over 50 years. Sensor technology may lift long-standing regulations like the Clear Zone, since sensors will be able to "see" trees along the roadside and thus avoid collisions. Physical signage may become obsolete, as traffic controls become digital in a connected network. The scenic experience will again gain traction as an important function of roads, as drivers are freer to experience the landscapes through which they pass. Vehicle-to-vehicle technology would enable lanes to narrow, since cars would know exactly how far away nearby vehicles were. This leaves more publicly-owned space in the rights-of-way for landscape architects to design.

Before the wave of connected and autonomous vehicles strikes, the transportation and design communities must understand what road design policies of the past have wrought on the environments through which they pass. Continuing to examine road networks at the regional scale will help foster this understanding and provide important underpinnings to future discussions of US road design policy.

APPENDICES

Appendix A: All Summary Statistics by Road Type

100m (328 ft) buffer										
Category	**Blue Ridge Parkway**		**Interstates**		**NC Highways**		**US Highways**		**Secondary Routes**	
Summary		before		before		before		before		before
Total Miles	249	252	582	607	1,452	1,570	1,648	1,867	9,588	11,517
Number of Unique Roads	1	1	6	6	68	68	26	26		4,273
Average Road Length	249	252	97.0	101.2	21.4	23.1	63.4	71.8		2.70
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Alignment Metrics										
Sinuosity per Mile	0.8388	0.1141	0.974	0.048	0.8788	0.1352	0.9371	0.0951	0.8524	0.126
50' Contour Intersections per Mile	4.55	2.13	2.25	1.91	2.63	1.99	2.32	1.65	2.98	2.07
Elevation Change per Mile	150.4	96.8	46.1	66.0	74.9	92.8	58.2	73.5	91.3	100.8
Geographic Metrics										
Slope	18.6	6.6	8.9	5.9	11.2	6.2	9.7	5.7	9.9	5.5
Elevation	3,808	938	1,572	658	2,007	980	1,817	843	1,820	849
Hilliness†	87	33	39	26	50	32	43	26	50	43
NCDOT Database		n= miles		n= miles		n= miles		n= miles		n=miles
ROW Width (feet)	66	33	163	349	78	1,023	102	909	64	2,959
Surface Width (feet) *	20	59	58	360	20	1,065	24	931	18	6,964
AADT	1,365	225	33,897	168	2,226	1,023	5,933	798	1,754	3,233
Speed Limit (mph)	55	53	58	360	52	1,064	52	930	52	6,961
Design Speed (mph)	51	18	69	348	49	977	59	879	55	518
Avg. Year of Construction	~	~	~	~	1909	1,070	1921	944	1924	6,958
Earliest Yr of Constr. (no 1901)	1930		1958		1930		1913		1930	
Year of Construction (no 1901)	1945	59.3	1973	350	1978	118	1980	240	1936	4,795
% Protected Land	94.5%	7.3%	5.5%	18.6%	9.7%	24.6%	6.8%	21.6%	3.9%	14.6%
Population Density (per mile)	114	221	495	698	188	379	319	537	177	294
Proximity to Urban Area (miles)	5.6	3.6	1.9	3.1	6.3	5.9	5.0	6.9	5.4	5.9
Land Cover										
% Forest Cover	53.95%		18.78%		36.5%		21.5%		39.6%	
% Evergreen	4.86%		1.71%		3.8%		2.1%		4.7%	
% Deciduous	47.85%		16.47%		31.2%		18.7%		32.9%	
% Mixed Forest	1.23%		0.59%		1.5%		0.7%		1.9%	
% Urban/Developed	43.75%		70.11%		40.9%		67.4%		28.5%	
% High Intensity	0.00%		1.01%		0.7%		1.9%		0.2%	
% Medium Intensity	0.10%		8.11%		2.7%		6.7%		0.9%	
% Low Intensity	1.66%		25.71%		7.4%		15.9%		4.2%	
% Open Space	41.98%		35.28%		30.1%		42.8%		23.1%	
% Shrub	0.53%		0.78%		1.4%		0.8%		1.8%	
% Herbaceous	0.14%		2.12%		2.7%		1.7%		3.6%	
% Hay Pasture	1.56%		7.23%		17.2%		7.9%		25.7%	
% Cultivated Crops	0.03%		0.13%		0.3%		0.2%		0.3%	
% Open Water	0.02%		0.27%		0.7%		0.2%		0.2%	
% Woody Wetlands	0.03%		0.40%		0.2%		0.2%		0.2%	
% Emergent Herbaceous Wetlands	0.00%		0.04%		0.0%		0.0%		0.0%	
% Barren Land	0.00%		0.15%		0.1%		0.1%		0.1%	

* Interstates are divided roadways; pavement width includes both roadways

270m (885 ft) buffer										
Category	**Blue Ridge Parkway**		**Interstates**		**NC Highways**		**US Highways**		**Secondary Routes**	
Summary		before		before		before		before		before
Total Miles	249	252	582	607	1,452	1,570	1,648	1,867	9,588	11,517
Number of Unique Roads	1	1	6	6	68	68	26	26		4,273
Average Road Length	249	252	97.0	101.2	21.4	23.1	63.4	71.8		2.70
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Alignment Metrics										
Sinuosity per Mile	0.8388	0.1141	0.974	0.048	0.8788	0.1352	0.9371	0.0951	0.8524	0.126
50' Contour Intersections per Mile	4.55	2.13	2.25	1.91	2.63	1.99	2.32	1.65	2.98	2.07
Elevation Change per Mile	150.4	96.8	46.1	66.0	74.9	92.8	58.2	73.5	91.3	100.8
Geographic Metrics										
Slope	18.8	7.9	9.1	6.5	12.2	6.4	10.6	6.2	11.1	5.8
Elevation	3,784	925	1,586	665	2,025	988	1,835	853	1,834	864
Hilliness†	145	62	51	40	71	49	60	42	65	43
NCDOT Database		n= miles		n= miles		n= miles		n= miles		n=miles
ROW Width (feet)	66	33	163	349	78	1,023	102	909	64	2,959
Surface Width (feet) *	20	59	58	360	20	1,065	24	931	18	6,964
AADT	1,365	225	33,897	168	2,226	1,023	5,933	798	1,754	3,233
Speed Limit (mph)	55	53	58	360	52	1,064	52	930	52	6,961
Design Speed (mph)	51	18	69	348	49	977	59	879	55	518
Avg. Year of Construction	~	~	~	~	1909	1,070	1921	944	1924	6,958
Earliest Yr of Constr. (no 1901)	1930		1958		1930		1913		1930	
Year of Construction (no 1901)	1945	59.3	1973	350	1978	118	1980	240	1936	4,795
% Protected Land	72.3%	22.1%	6.5%	20.5%	10.3%	24.5%	7.1%	21.5%	4.4%	14.9%
Population Density (per mile)	115	225	509	693	188	391	313	516	177	295
Proximity to Urban Area (miles)	5.65	3.62	1.92	3.08	6.33	5.91	5.04	6.89	5.43	5.89
Land Cover										
% Forest Cover	74.50%		32.55%		50.22%		39.20%		51.60%	
% Evergreen	7.47%		3.11%		5.50%		4.05%		6.19%	
% Deciduous	64.97%		28.21%		42.64%		33.62%		43.03%	
% Mixed Forest	2.06%		1.23%		2.09%		1.53%		2.39%	
% Urban/Developed	19.63%		48.21%		24.81%		42.19%		18.03%	
% High Intensity	0.02%		1.75%		0.66%		1.69%		0.27%	
% Medium Intensity	0.12%		6.02%		1.87%		4.56%		0.80%	
% Low Intensity	0.93%		14.74%		4.53%		9.63%		2.83%	
% Open Space	18.57%		25.69%		17.75%		26.31%		14.13%	
% Shrub	1.29%		1.41%		1.90%		1.45%		2.27%	
% Herbaceous	0.34%		2.77%		2.99%		2.65%		3.57%	
% Hay Pasture	4.05%		13.48%		18.62%		13.15%		23.45%	
% Cultivated Crops	0.03%		0.39%		0.41%		0.39%		0.39%	
% Open Water	0.08%		0.49%		0.71%		0.40%		0.30%	
% Woody Wetlands	0.06%		0.51%		0.23%		0.38%		0.23%	
% Emergent Herbaceous Wetlands	0.00%		0.03%		0.01%		0.03%		0.01%	
% Barren Land	0.02%		0.16%		0.10%		0.16%		0.14%	

* Interstates are divided roadways; surface width includes both roadways

540m (1,771 ft) buffer										
Category	**Blue Ridge Parkway**		**Interstates**		**NC Highways**		**US Highways**		**Secondary Routes**	
Summary		before		before		before		before		before
Total Miles	249	252	582	607	1,452	1,570	1,648	1,867	9,588	11,517
Number of Unique Roads	1	1	6	6	68	68	26	26		4,273
Average Road Length	249	252	97.0	101.2	21.4	23.1	63.4	71.8		2.70
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Alignment Metrics										
Sinuosity per Mile	0.8388	0.1141	0.974	0.048	0.8788	0.1352	0.9371	0.0951	0.8524	0.126
50' Contour Intersections per Mile	4.55	2.13	2.25	1.91	2.63	1.99	2.32	1.65	2.98	2.07
Elevation Change per Mile	150.4	96.8	46.1	66.0	74.9	92.8	58.2	73.5	91.3	100.8
Geographic Metrics										
Slope	19.1	5.9	9.2	6.3	13.1	6.6	11.5	6.5	12.1	6.1
Elevation	3,730	905	1,607	683	2,050	1,003	1,859	869	1,855	886
Hilliness†	203	91	63	56	95	69	82	64	86	62
NCDOT Database		n= miles		n= miles		n= miles		n= miles		n=miles
ROW Width (feet)	66	33	163	349	78	1,023	102	909	64	2,959
Surface Width (feet) *	20	59	58	360	20	1,065	24	931	18	6,964
AADT	1,365	225	33,897	168	2,226	1,023	5,933	798	1,754	3,233
Speed Limit (mph)	55	53	58	360	52	1,064	52	930	52	6,961
Design Speed (mph)	51	18	69	348	49	977	59	879	55	518
Avg. Year of Construction	~	~	~	~	1909	1,070	1921	944	1924	6,958
Earliest Yr of Constr. (no 1901)	1930		1958		1930		1913		1930	
Year of Construction (no 1901)	1945	59.3	1973	350	1978	118	1980	240	1936	4,795
% Protected Land	59.1%	30.6%	7.0%	21.3%	11.0%	24.5%	7.4%	21.3%	5.3%	15.9%
Population Density (per mile)	116	230	510	683	187	397	308	501	178	298
Proximity to Urban Area (miles)	5.65	3.62	1.93	3.09	6.34	5.90	5.02	6.84	5.44	5.88
Land Cover										
% Forest Cover	79.54%		38.28%		57.29%		47.14%		58.47%	
% Evergreen	6.86%		3.68%		6.13%		4.68%		6.57%	
% Deciduous	70.43%		33.13%		48.83%		40.67%		49.33%	
% Mixed Forest	2.24%		1.46%		2.33%		1.79%		2.57%	
% Urban/Developed	13.09%		39.71%		19.00%		32.63%		14.30%	
% High Intensity	0.02%		1.84%		0.53%		1.28%		0.26%	
% Medium Intensity	0.17%		4.99%		1.42%		3.28%		0.71%	
% Low Intensity	0.83%		11.12%		3.44%		7.20%		2.33%	
% Open Space	12.07%		21.75%		13.61%		20.88%		11.00%	
% Shrub	1.43%		1.62%		2.08%		1.73%		2.45%	
% Herbaceous	0.50%		2.87%		2.87%		2.90%		3.40%	
% Hay Pasture	5.21%		15.93%		17.32%		14.14%		20.18%	
% Cultivated Crops	0.02%		0.46%		0.38%		0.41%		0.37%	
% Open Water	0.11%		0.44%		0.71%		0.49%		0.42%	
% Woody Wetlands	0.06%		0.50%		0.22%		0.37%		0.26%	
% Emergent Herbaceous Wetlands	0.00%		0.04%		0.01%		0.03%		0.01%	
% Barren Land	0.04%		0.16%		0.12%		0.17%		0.15%	

* Interstates are divided roadways; pavement width includes both roadways

Appendix B: NCDOT Database Selected Field Descriptions

From NCDOT routes metadata document "Road_Characteristics_Field_Descriptions"

Selected field descriptions:

6. RTE_X_CLSS_CD Common Name	Route Class
Definition	The NCDOT route class code
Data Owner	GIS Unit
Extent	Every segment except for gap segments
Values	Coded domain
Notes	Route Class drives the 1st digit of the Route ID or 8-Digit Route Number.

Value	Description	Notes
I	Interstate	State-maintained (exceptions noted in the Ownership field)
US	US Route	State-maintained (exceptions noted in the Ownership field)
NC	NC Route	State-maintained (exceptions noted in the Ownership field)
SR	Secondary Route	State-maintained (exceptions noted in the Ownership field)
RMP	Ramp	Typically state-maintained but not counted towards state-maintained mileage
RST	Rest Area	State-maintained but not counted towards state-maintained mileage
PRJ	Projected	Generalized locations of major facilities that have not yet been built
LOC	5-Local	Federal-aid roads maintained by municipalities
SP	6-State Parks	Federal-aid roads maintained by other state agencies
FED	7-Federal	Federal-aid roads maintained by federal agencies
NA	NA	Indicates no co-route present (used for route classes 2 -6)

18. STREET_NAME Common Name	Street Name
Definition	The NCDOT name of the route
Data Owner	GIS Unit
Extent	Every segment
Values	Text
Notes	This field is a concatenation of the route class, route number and sometimes route qualifier. It can be used to label. It is not the street name, as in "Main Street" but the NCDOT name as in

23. LOC_1_CNTY_CD Common Name	Location County
Definition	The county that the segment is physically located in
Data Owner	GIS Unit
Extent	Every segment
Values	Coded domain – see the metadata or contact the GIS Unit for a full list of codes

37. ADTN_DT Addition Date

Common Name

Definition The date that the section of road the road was constructed, or the date that the road was added to the state maintenance system, if it was already built

Data Owner MSAU

Extent State-maintained roads, where available

Values Dates

Notes The date 12/31/1901 indicates that the date is unknown. Typically December 31st is used when the year was known but the day and month were not.

41. FC_TYP_CD Functional Classification

Common Name

Definition A classification system of roads based on the character of traffic service that they are intended to provide. Approval of changes is done by the Federal Highway Administration and is managed by the Program Development Branch at NCDOT.

Data Owner GIS Unit

Extent Every segment

Values Coded domain

Notes Functional Classification along with National Highway System and Urban Identification determine federal-aid eligibility. All roads on the National Highway System are eligible for federal-aid. In addition, all routes functionally classified Interstate through Major Collector, plus urban Minor Collectors are federal-aid eligible. Ramps are given the highest Functional Classification value of the routes that they serve, but ramps are not eligible for federal-aid.

Value	Description	Notes
1	INTERSTATE	
2	PRIN_ARTERIAL_OTHER_FWY	Principal Arterial – Other Freeways and Expressways
3	PRIN_ARTERIAL_OTHER	Principal Arterial – Other
4	MINOR_ARTERIAL	
5	MAJOR_COLLECTOR	
6	MINOR_COLLECTOR	
7	LOCAL	

51. PPLTN_GRP_TYP_CD Population Group

Common Name

Definition Population categories based on the municipality that the segment is located within

Data Owner GIS Unit

Extent Segments that are located within the Municipal Boundaries

Values Coded domain

Notes No data indicates that the segment is not with in any city or town limits.

Value	Description	Notes
1	UNDER_1000_POPULATION	Municipality population is under 1,000
2	1000_TO_2499	Municipality population is between 1,000 and 2,500
3	2500_TO_4999	Municipality population is between 2,500 and 5,000
4	5000_TO_9999	Municipality population is between 5,000 and 10,000
5	10000_TO_24999	Municipality population is between 10,000 and 25,000
6	25000_TO_49999	Municipality population is between 25,000 and 50,000
7	50000_TO_99999	Municipality population is between 50,000 and 100,000
8	100000_AND_OVER	Municipality population is over 10,000

54. RW_WID	Right of Way
Common Name	
Definition	The width of the right of way of the road in feet
Data Owner	MSAU
Extent	Where available
Values	Positive numbers
Note	Right of Way can vary continuously along the road. The data has been generalized in areas of widely varying Right of Way to represent significant changes.

64. SPD_LMT_TYP_CD	Speed Limit
Common Name	
Definition	The posted speed limit in miles per hour
Data Owner	Traffic Safety Unit
Extent	State-maintained roads
Values	Positive numbers (in a text field)
Notes	This data comes from traffic ordinances governing speed limit; where there is no ordinance, the speed limit is 35 within municipalities and 55 outside.

67. SRFC_WID	Surface Width
Common Name	
Definition	The paved surface width in feet, or the road width from ditch to ditch on unpaved roads
Data Owner	MSAU
Extent	State-maintained roads
Values	Positive numbers
Notes	The Surface Width does not include the median width. On divided roads, it is the paved width on that side of the median. On paved roads, the Surface Width is edge of pavement to edge of pavement (includes paved shoulders).

73. DS_NBR	Design Speed
Common Name	
Definition	A selected speed used to determine the various geometric features of the roadway, in miles per hour
Data Owner	MSAU
Extent	Where available
Values	Positive numbers

87. AADT_EST_CNT	AADT
Common Name	
Definition	Annual average daily traffic volume estimate for the AADT year in vehicles per day
Data Owner	Traffic Survey Group
Extent	Where available (federal-aid roads and some additional Secondary Roads)
Values	Positive numbers
Notes	AADT is reported on the inventory direction of divided roads but represents total traffic for both directions.

97. MP_LENGTH	Milepost Length
Common Name	
Definition	The length of the segment in miles, calculated by the ending milepost minus the beginning milepost. The milepost values are based on 3D measures generated from LIDAR data.
Data Owner	GIS Unit
Extent	Every segment
Values	Positive numbers; six decimal places

Appendix C: Segmentation Code

```
import arcpy
import os
from arcpy import env
arcpy.CheckOutExtension("spatial")
arcpy.env.overwriteOutput = True

# set inputs, outputs, and environment
env.workspace = "E:\\Mapping\\Thesis\\Jan26_SRe"

#import custom toolboxes CreatePointsLines and CalculateSinuosity
arcpy.ImportToolbox("E:\\Mapping\\Tools\\CreatePointsLines.tbx")
arcpy.ImportToolbox("E:\\Mapping\\Tools\\Sinuosity.pyt")

# Local variables:
table = "E:\\Mapping\\Thesis\\table"
table2 = "E:\\Mapping\\Thesis\\table2"
table3 = "E:\\Mapping\\Thesis\\table3"
distance = 5280
fc = "E:\\Mapping\\Thesis\\Jan26_SRe.shp"
cntrs = "E:\\Mapping\\Thesis\\NC_region.gdb\\Fifty_ft"

# loop - select each road in dissolved shapefile
cursor = arcpy.SearchCursor(fc)
for row in cursor:
    road = row.getValue("NAME")

    rd = str(road) + ".shp"
    SQL = "NAME = '%s'" %(road)
    arcpy.Select_analysis(fc, rd, SQL)

    # Process: Create Points on Lines
    pts = "Pts_" + str(road) + ".shp"
    arcpy.CreatePointsLines_CreatePointsLines(rd, "BEGINNING", "INTERVAL", "NO", "", distance, "NO", pts)

    # Process: Split Line at Point
    split = "Spl_" + str(road) + ".shp"
    arcpy.SplitLineAtPoint_management(rd, pts, split, "5 Feet")

    # Process: Add Geometry Attributes
    arcpy.AddGeometryAttributes_management(split, "LENGTH", "FEET_US", "", "")

    #Delete rows that are less than designated distance. Should just be one.
    with arcpy.da.UpdateCursor(split,"LENGTH") as tooshort:
        for piece in tooshort:
            if round(piece[0]) < distance:
                tooshort.deleteRow()

    # Add segment number for each segment in road
    arcpy.AddField_management(split, "seg_no", "TEXT", "", "", "35", "", "NULLABLE", "NON_REQUIRED", "")
    arcpy.CalculateField_management(split, "seg_no", "\"%s_%s\" %( !NAME!, !FID!)", "PYTHON", "")
```

```
# Process: Calculate Sinuosity
arcpy.CalculateSinuosity_sample(split, "sinuosity")

# Process: Add Field
arcpy.AddField_management(split, "IntContrs", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculate adherence to contours defined as intersections with each mile-long segment
segments = arcpy.SearchCursor(split)
for part in segments:
    segment = part.getValue("seg_no")

    sg = "xxx" + str(segment) + ".shp"
    SQL = "seg_no = '%s'" %(segment)
    arcpy.Select_analysis(split, sg, SQL)

    out = "int" + str(segment) + ".shp"
    # Process: Intersect
    arcpy.Intersect_analysis([sg,cntrs], out, "ALL", "", "POINT")

    count = arcpy.GetCount_management(out)
    # Process: Calculate Field
    arcpy.CalculateField_management(sg, "IntContrs", count, "", "")

    # Add Field for elevation change
    arcpy.AddField_management(sg, "Elev_cha", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

    # Process Calculate min and max            elevation
    cntrs_list = []
    group = arcpy.SearchCursor(out)
    for item in group:
        cntrs_list.append(item.getValue("CONTOUR"))
    del group
    # Get min and max
    cntrs_list.sort()
    if len(cntrs_list) > 0:
        min = cntrs_list[0]
        max = cntrs_list[-1]
        change = max - min
        # Process: Calculate Field
        arcpy.CalculateField_management(sg, "Elev_cha", change, "", "")
    else:
        arcpy.CalculateField_management(sg,"Elev_cha", "0", "", "")

# merge all of the split shapefiles back into one segmented road
z = []
y = arcpy.ListFeatureClasses()
out2 = "z" + str(road) + ".shp"
for x in y:
    if "xxx%s" %(str(road)) in x:
        z.append(x)
if len(z) > 0:
    arcpy.Merge_management(z, out2)
```

```
    # set inputs, outputs, and environment
    workspace = r"E:\\Mapping\\Thesis\\Jan26_SRe"

    # Delete extra shapefiles
    file_mgmt = os.listdir(workspace)

    for name in file_mgmt:
        file = workspace + "\\" + str(name)
        if "lock" not in name:
            if "Spl" in name:
                os.remove(file)
            elif "Pts" in name:
                os.remove(file)
            elif "int" in name:
                os.remove(file)
            elif "xxx" in name:
                os.remove(file)

# merge all of the string shapefiles
split_list = []
output = arcpy.ListFeatureClasses()
out3 = "MergRds.shp"
for name in output:
    if "z" in name:
        split_list.append(name)
arcpy.Merge_management(split_list, out3)
```

Appendix D: Models of Road Segments

8” x 8” models, representing 2 mi x 2 mi
1” = 0.25 mi
1/8” hardboard, representing 100’ contours

Blue Ridge Parkway southwest of Mt. Mitchell
Center: 35°41’40” N, 82°23’32” W

I-40 near Clyde, NC
Center: 35°42’58” N, 83°01’59” W

Secondary Route 1220 between Enka and Leicester
Center: 35°35’33” N, 82°43’12” W

Appendix E: Visual Assessment Elements Checklist

Measure & Photograph

- Surface width
- Lane width
- Shoulder width
- Embankment profile
    - uphill width and slope
    - downhill width and slope

Photograph

- Horizontal curvature
- Vertical curvature
- Horizontal-vertical alignment
- Crossings, intersections, interchanges
- Roadside treatment
    - Managed/unmanaged vegetation
    - Selectively thinned vegetation
    - Stormwater management
    - Wildflower program
    - Enclosure
    - Clear Zone
    - Signage
- Overlooks and turnouts
- Viewsheds

ArcCollector – Point Data fields

- Surface width
- Lane width
- Shoulder width
- Roadside – text
- Viewsheds - text

Video

Windshield or bumper GoPro running continuously (2-3 hrs battery life)

GPS

Amon GPS log running continuously (2-3 days battery life)

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8k8ChU-8k5quz-8k5oi2-8k8BF5-3oTnmE-96aj2n-8k5r7r-4Lpe2W-4Lpe1y-4Lpeej-6672Rx-4Lpe4q-4Lpegm-4oLeGp-4oLeHP-66aJLd-4Lpe95-4Lpecb-4Lpe7Q-4LpeaE. Creative Commons License.

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