Fig. 1.—Bicycle.

Bicycle Planning in the City of Portland:
Evaluation of the City's Bicycle Master Plan and
Statistical Analysis of the Relationship between the City's
Bicycle Network and Bicycle Commute

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I'd like to dedicate this to my love Anna, my parents Veronica, Sergio and Ted, my sister Griselle, as well as to my wonderful family the world over.

Abstract

Of the major cities in the United States, the city of Portland has consistently ranked among the most bicycle-friendly. This paper evaluates the efforts by the City of Portland in providing an environment conducive to bicycle use.

Five years since the *Bicycle Master Plan* was completed, this paper finds that the City has considerably increased the number of miles of bicycle lanes and boulevards, bicycle parking facilities, promotional and educational activities, among others. Overtime, the crash rate has decreased and surveys indicate that the number of bicyclists has steadily increased. The number of bicycle commuters increased by roughly 90 percent from 1990 to 2000. However, the City's five-year goal of a three-percent share of bicycle commuters citywide has not materialized.

This paper also finds a statistical relationship between the provision of bikeways and the percentage of bicycle commuters per census tract. Findings confirm previous studies which indicate that, other things equal, census tracts with more bikeways are associated with higher percentage of bicycle commuters.

I. Introduction

Consistently, the city of Portland has ranked among the most bicycle-friendly cities in the country. Twice in the last decade, in 1995 and in 1998, *Bicycling* magazine ranked Portland as the friendliest city in the United States, and in 2001 the magazine ranked it as the friendliest city in North America. This recognition is shared in the local press as well. According to *The Oregonian,* "few cities can top Portland when it comes to residents riding bikes to work…"

In my years as a cyclist and resident of Portland, I have learned that what made Portland a great place to bike was the collaboration of three important groups. One group is made of passionate and strong bicycle advocacy groups. Another is the City of Portland and its commitment to turn the bicycle into a valid mode of transportation. The third, and perhaps most important group, is the small army of cyclists who, defying bad weather and other factors, ride their bicycles on a regular basis. This collaboration, fueled by the City's participatory planning process, has resulted over the years in the creation of an effective bicycle system.

This paper analyzes city policies and accomplishments that have made Portland a great place to bike. Attention is given to the different aspects that create an effective bicycle system. Federal, state and regional policies are presented in relationship to the City's 1996 *Bicycle Master Plan*.

Finally, this paper uses regression analysis to find a statistical relationship between Portland's expanded bicycle network and increases in the percentage of bicycle commuters.

1.1 The Need for Bicycle Planning and Policies

Local and national polls have cited the lack of bikeways as the number one reason more people do not bicycle for daily trips. In 1994, 88 percent of those surveyed in Portland stated that lack of bikeways prevented more frequent cycling (City of Portland 1998). The survey also found that people in the region "increasingly support the expenditure of taxpayers' funds to install bikeways" (ibid.). The plan is explicit about the benefits of bikeways to both the cycling and non-cycling public, including better air and water quality, less noise, less congestion, and more efficient use of public dollars (by reducing road maintenance costs). Bikeways improve "safety for all users as bicyclists feel they have a safe space on the road and tend to be more law-abiding, while motorists are placed at greater ease knowing where bicyclists are apt to be. Bikeways also help motorists to be aware of bicyclists' presence and right to be on the road" (ibid., p. 21).

Similarly, several studies confirm bicyclists' preference for additional bikeways. One study found that both recreation and commuting cyclists ranked bike lanes highest in their preference for bicycle facilities. This preference held true despite different personal characteristics and levels of cycling experience. Bike paths are also highly ranked (Antonakos 1994, pp. 29-31).

Several surveys show more Americans are bicycling. Though stated preference surveys do not indicate (and usually overestimate) future use, the numbers are encouraging. A Harris poll showed that in 1991, 46 percent of adults aged 18 and older (or 82 million people) had ridden a bicycle in the previous year. Respondents stated that 46 percent would sometimes commute to work by bicycle if safe bike lanes were available. Also, fifty-three percent stated that they would commute to work if they had safe, separate designated paths on which to ride (U.S DOT 1992).

Pucher *et al* (1999), using data from the U.S. Department of Transportation, showed that bicycle modal share for the whole United States has increased slightly from 0.6 percent in 1977 to 0.9 percent in 1999. Other non-automotive modes experienced a decrease during the same period of time. Data from the 1990 and 1995 Nationwide Personal Transportation Survey, indicates that the number of bicycling trips increased by 89 percent (or 3 billion more bicycling trips), though the number of trips for all modes increased by more than 50 percent (U.S.DOT 1999).

Americans' increasing attraction to bicycling as an alternative form of transportation has been accelerated by concerns about the environment, improved health benefits and cheaper transportation costs (Williams and Larson 1996).

II. Mode Split in the City of Portland

Table 1 shows mode share for 1990, 1996, and 2000. The data was obtained from the U.S. Census for 1990 and 2000, and the U.S.Census 1996 American Community Survey. In the last two decades, there has been decrease in the percentage of auto commuters. In 1990 almost 82 percent of commuters relied on the automobile. In the 2000, the percentage decreased to 79.3 percent. This trend on auto commute is consistent with the City of Portland's *Transportation System Plan* goal of reducing drive alone and carpool commuters to work to a combined 75 percent by 2020 (City of Portland 2002, p. 5-38). Transit has seen a steady increase in mode share, from 10.8 percent in 1990 to 12.7 percent in 2000.

Table 1. Mode Split in the City of Portland 1990-2000

	1990	Mode Split	1996	Mode Split	2000	Mode Split
Car and carpool	192,714	81.8%	197,900	81.1%	209,940	79.3%
Public transportation	25,391	10.8%	29,147	11.9%	33,632	12.7%
Walked	12,573	5.3%	10,705	4.4%	14,218	5.4%
Bicycle	2,522	1.1%	4,264	1.7%	4,800	1.8%
Other	505	1.1%	52	0.8%	187	0.83%
Total	235,695	100%	244,064	100%	264,777	100%

*Data based on 1990, 2000 Census and 1996 American Community Survey. Respondents are asked on April 1 to name the "usual" means of transportation to work for the previous week.

Walking has remained stable at around 5.3 percent, and bicycle commute has experience an increase from 1.1 percent to 1.8 percent.

Table 2 compares the rate of growth in bicycle commuters and in the bicycle network. From 1990 to 2000, the number of bicycle commuters increased by 90.3 percent. During the same period of time, the bicycle network increased by 255.9 percent. The greatest gain in bicycle commuters occurred between 1990 and 1996, when bicycle commuters increased by 69.1 percent. The greatest increase in bicycle network occurred between 1996 and 2000, when the network expanded by 121.7 percent.

Table 2. Percentage Bicycle Commute and the City of Portland Bicycle Network

	1990	1996	2000	Change 1990-1996	Change 1996-2000	Change 1990-2000	Change 1990-1996	Change 1996-2000	Change 1990-2000
Total Cyclists	2,522	4,264	4,800	1,742	536	2,278	69.1%	12.6%	90.3%
Mode Share	1.1%	1.7%	1.8%						
Bicycle Network (miles)	44.98	72.2	160.1	27.22	87.90	115.12	60.5%	121.7%	255.9%

III. Literature Review

3.1. Bicycling and Bicycle Facilities

Portland is not alone in its attempts to improve its bicycle network. Many jurisdictions across the nation have incorporated similar policies. Some studies have begun to evaluate the effectiveness of bicycle facilities in increasing bicycle use.

Nelson and Allen (1997) compared eighteen different jurisdictions in the United States. They used a cross-sectional analysis, controlling for a variety of variables such as climate, terrain, percentage of college students, and mean high temperature. They estimated that each mile of bikeway per 100,000 residents increases bicycle commuting 0.069 percent, all else being equal. The R^2 was 0.825. The number of rain days and the percentage of college students were also shown to affect bicycle commute.

The 1992 *National Walking and Bicycle Study—Case No 1: Reasons Why Bicycling and Walking Are and Are Not Being Used More Extensively as Travel Modes* analyzed the relationship between bike facilities. Adjusting for cities other than university towns, the study found a "very slight relationship between a high ratio of bikeways to proportion of bicycle commuters." They also note that the highest group had a 1.7 percent bicycle commute rate whereas the bottom half had a 0.7 percent bicycle commute rate. The study also compared bike lanes. It found that, removing university towns, there are "three times more commuter cyclists in cities with higher proportions of bike lanes." They also indicated that "though bicycle commuting does not decline smoothly as arterial miles increase at the expense of bike lanes, a downward trend is nonetheless apparent."

The study found no relationship between separated paths and commuting, explaining that the reason "may simply be that bike paths follow scenic corridors and do not

necessarily lead to major destinations, but a high ratio of bike paths is also an indication that bicycling has not been incorporated into the transportation network and is limited to its recreational function" (U.S DOT 1992, pp. 40-46).

On the other hand, another study found that separated bike paths, though lengthening commutes, provide an important role in the transportation network by serving a slightly different market segment than the on-street facilities (Shafizadeh and Niemeier, 1997).

Although only about one percent of total U.S. trips are made by bicycle, several North American communities (including Palo Alto, Madison, Boulder, Eugene) have cycling rates five to ten times higher (Comsis 1993). High levels of bicycle travel in such geographically diverse communities, and lower levels in otherwise similar areas, indicate that transport policies and community attitudes are more important than geography or climate in determining non-motorized travel (ibid., U.S. DOT 1992, Pucher 1997).

The presence of a major university appears to have the strongest relationship to bicycle commute. The common explanation is that university towns have higher percentage of young, healthy people living within close proximity to campus and who do not have dress restrictions (U.S. DOT 1992).

John Pucher (1997) provides a case outside of North America, where a large city almost tripled bicycle use since 1976. Munich, Germany saw its bicycle modal split rise from 6 percent to 15 percent. He notes that the length of the bikeway network doubled during the same period.

Reid Ewing (1996) reports that skilled bicyclists prefer to travel on the street system along with automobiles, on bike lanes or extra-curb lanes. Between the two facilities, bike lanes appear to be both safer and more accepted.

Some studies are less optimistic of bicycle improvement's ability to increase bicycle modal split. John Forester (2001) concludes that bicycling in traffic is no more difficult than motoring in the same traffic. He also states that bikeways of practical, street-level design have not been shown to either reduce the accident rate at the same travel speed or to allow increased speed at the same accident rate, in comparison with cycling on the roadway, with the rights and duties of vehicles.

However, analyzing survey responses, Moritz (1997) finds that, adjusting for the share of commuting kilometers, streets with bicycle lanes or marked bicycle routes appeared to have less than half the risk of local streets, and 40 percent the risk of major streets.

Gordon and Richardson (1998) hypothesize that what leads people to bike is personal preferences and ideological principles, rather than bicycle network improvements or policies encouraging bicycling.

3.2. Other Factors

Obviously, commuting is only one of many ways to bike. In fact, most bicycle trips do not involve commuting. According to Pucher *et al* (1999), only nine percent of all bicycle trips are work commuting trips, compared to 12.7 for shopping trips, and 12.5 for personal business. U.S. data from the Bureau of Transportation Statistics indicate that 53.9 percent of respondents cited using bicycling for recreational purposes, with 31.2 percent riding for exercise (Dill and Carr 2002, p.2).

Other environmental variables seem to also affect the level of bicycling. Potential travel impacts seem to be greater if cycling is integrated with transit and with "smart growth" type of development practices (which the Portland region encourages) that are supposed to reduce travel requirements, for example, by locating schools and shops within residential neighborhoods (U.S DOT 1999).

Residents in neighborhoods with suitable street environments tend to walk and bicycle more, ride transit more, and drive less than comparable households in other areas (PBQD, 2000). One study found that residents in a pedestrian friendly community walked, bicycled, or rode transit for 49% of work trips and 15% of their non-work trips, 18- and 11-percentage points more than residents of a comparable automobile oriented community (Cervero and Radisch, 1995). Safer bicycle facilities and designs can also substantially reduce accident rates (Pucher and Dijkstra 2000). Another study found that walking is three times more common in a community with pedestrian friendly streets than in otherwise comparable communities that are less conducive to foot travel (Moudon *et al* 1996).

Communities that improve non-motorized travel conditions often experience significant increases in non-motorized travel and related reductions in vehicle travel (PBQD, 2000). According to Reid Ewing, "the willingness to walk, bike, or ride transit increases with density" (Ewing 1996, p. 28). Likewise, a street network with high, web-like connectivity encourages non-automotive modes (ibid.).

IV. Bicycle Planning: Policy Framework

Several policies enacted since 1990 have begun to reshape the importance of bicycling as a mode of transportation. Legislation at the federal, state, regional, and local level has increasingly realized the need to recognize the once neglected role of bicycling in the general transportation system and the need for improved bicycle facilities. The following reflect policies with direct implications for bicycle policy, bicycle planning as well as for bicycle network improvements in the City of Portland.

4.1. Federal Level

Two pieces of legislation drastically changed the role of bicycling as a transportation alternative. The first one, the 1990 Clean Air Act, set the tone for evaluating

alternative, non-motorized modes of transportation that had previously been neglected. More importantly, the second, the 1991 *Intermodal Surface Transportation Efficiency Act* (ISTEA), resulted in "stricter standards for air quality and required regions to develop methods to reach compliance, including bicycling as a transportation alternative" (Williams and Larson, 1996).

The greatest boost to bicycle commute came in the form of this policy requirement and the significant increase in funds allocated to bicycle facilities (ibid.). ISTEA, and its reauthorization legislation, the 1998 *Transportation Equity for the 21st Century*, have resulted in $339.1 million in stand-alone bicycle and pedestrian projects (FHWA web page).

The U.S. Department of Transportation, in its 1992 *National Bicycling and Walking Study* set two overarching goals: to double the percentage of total trips by bicycling and walking from 7.9 percent to 15.8 percent of all travel trips, and to simultaneously reduce the number of bicyclists and pedestrians killed or injured in traffic crashes by 10 percent. Sixty action items were developed to reach these goals (U.S. DOT 1999).

4.2. State of Oregon

The state, through the Oregon Department of Transportation (ODOT)**,** has been a leader in providing bicycle infrastructure at the state level. In 1971 the State legislature required that "one percent of the State Highway Fund be spent on bicycle and pedestrian facilities to be built in conjunction with most roadway projects" (U.S. DOT 1992). The rule has resulted in millions of dollars allocated to bicycle facilities. ODOT administers the funds, handles bicycle and pedestrian planning, design and engineering, construction, and technical assistance to local government agencies. The state has a Bikeway Program Office with a full-time Bikeway/Pedestrian Program Manager and a full-time bikeway specialist. Together, they identify and prioritize bikeway projects and develop policies, among others (ibid.).

ODOT's Bicycle Plan (1992) sets forth guidelines for designing and implementing bicycle projects. The ODOT guidelines were used as the basis for the City of Portland's *City Bikeway Design and Engineering Guidelines* (City of Portland, 1998).

4.3. Metro

The Portland Metropolitan Region's regional government, *Metropolitan Services District*, or "Metro", has also taken an active role in including bicycling in its comprehensive transportation planning efforts. Metro's predecessor, the *Columbia Region Association of Governments*, published *A Bikeway Plan for the Columbia-Willamette Region* in 1974. Metro's *Regional Bicycle Plan* (1994) *and Regional Transportation Plan* (2000) provide an important legal framework for the 24 local jurisdictions within the metropolitan region. The region's bicycle system contains 512 miles of bike lanes (a 68-mile increase over a 3-year period) and 124 miles of multi-purpose paths (a 34-mile increase). Metro recently published its *Bike There!* map, a

large, water-proof, full-color map identifying bicycle facilities within the region and low-traffic neighborhood streets (Metro web page).

4.4. City of Portland

The City of Portland's *Comprehensive Plan* (1995) and the recently adopted *Transportation System Plan* (2002) contain a series of statements (goals, policies, objectives) that guide the way the City plans and implements improvements. Goal 6 of the City's comprehensive plan identifies the need for a "balanced, affordable and efficient transportation system" (City of Portland 1998, p.15). Goal 6.12 calls specifically for bicycle transportation to "make [traveling by] bicycle an integral part of daily life in Portland, particularly for trips of less than five miles, by implementing a bike network, providing for end-of-trip facilities, improving bicycle/transit integration, encouraging bicycle use, and making bicycling safer" (ibid., p 16). Goal 11B "Public Rights-of Way", Policy 11.13, "Bicycle Improvements", calls for the provision of "bicycle facilities appropriate to the street classification, traffic volume, and speed in design and construction of all new or reconstructed streets. Where the appropriate bikeway facility cannot be provided on the street, provide alternative access for bicycles on parallel streets. Bicycle safety should be the highest priority in the design of all bikeway facilities" (ibid., p 18). Goal 11B, Policy 11.14, "Public Bicycle Parking", asks for safe short term, and sheltered long-term parking in the City's properties and downtown and where needed (ibid.).

It is within this basic policy framework that the City of Portland worked with the community to create the *Bicycle Master Plan,* finalized in May of 1996 and updated in July of 1998. The plan is also consistent with numerous city, regional, and state plans such as the *Central City Transportation Management Plan*, Metro's *2040 Plan*, the Metro *Regional Bicycle Plan* and *Regional Transportation Plan*, ODOT's *Bicycle Plan*, and others.

V. Overview of the City of Portland *Bicycle Master Plan*

The City's first bicycle plan was developed in 1973 by a residents' task force, and led to the creation of the Portland Office of Transportation's Bicycle Program (one of the oldest in the nation) and the Bicycle Advisory Committee (BAC), made of a group of residents appointed by the City Council on matters related to bicycling.

5.1 Key Policy Recommendations, Action Items and Benchmarks

The master plan identified five key elements:
  A) *Policies and objectives that form part of Portland's Comprehensive Plan Transportation Element*. Some of the objectives included "[to] provide short- and long-term bicycle parking in commercial districts, along Main Streets, in employment centers and multifamily developments, at schools and colleges, industrial developments, special events, recreational areas, and transit facilities such as light rail stations and park-and-ride lots" (ibid., p.3). Another important

objective established criteria to "provide bikeway facilities that are appropriate to the street classifications, traffic volume, and speed on all rights-of-ways" (ibid.).

B) *Developing a recommended bikeway network.* The plan called for an increase in the bikeway network from 185 miles in 1998 to a full "630 mile network of preferred and appropriate convenient and attractive bikeways throughout Portland" (ibid.). The goal is that once completed the network should enable cyclists to find a bikeway within approximately one-quarter to one-half mile from every location in Portland.

C) *Providing end-of-trips facilities.* The plan called for a public-private partnership to install higher levels of bicycle parking; provide for long-term bicycle parking to serve commuters, students, and others needing longer-term bicycle storage; and provide other end-of trip services like showers, changing rooms, and clothing storage.

D) *Improving the bicycle-transit link.* Cyclists can use two types of transit services: buses and light rail. Tri-Met's bicycle permit in 1995 was purchases by 6,300 users, for a total of almost 80,000 bicycles-on-transit trips. The plan called for continuing support and promotion of Tri-Met's bicycle program, and assist the regional organization in providing and promoting long-term bicycle parking at the transit system to encourage bicycle use.

E) *Promoting bicycling through education and encouragement.* The proposed increased network, additional end-of-trip facilities, and better bicycle-transit links should encourage bicycle use. Bicycle education will help develop safe cycling skills in children, teaching adults cyclists their rights and responsibilities, and teaching motorists how to more effectively share the road with cyclists.

Each element was accompanied with objectives, action items, and five-, ten-, and twenty-year benchmarks to measure progress. Costs were included, where appropriate (ibid., p. 5).

5.2. Portland's Bicycle Network

The bikeway network is to provide a higher level of service for cyclists and encourage bicycle use (City of Portland 1998). When complete, the network (including planned and recommended bikeways) will include 630 miles of bikeway miles.

To date, Portland has a bicycle network that includes 142 miles of lanes, 26 miles of bike boulevards and 53 miles of paths. The combined total reaches 228 miles. There are differences in the treatment and purpose of a lane versus a boulevard or a path. They are explained below, according the city's *Bicycle Master Plan* (1998):

A) *Bicycle Lane*: "A bicycle lane is that portion of the roadway designated by eight-inch striping and bicycle pavement markings for the exclusive or preferential use of bicycles."

B) *Shoulder Bikeways*: "A shoulder bikeway is a street upon which the paved shoulder, separated by a four-inch stripe and no bicycle lane markings, is usable by

bicycles. Although the shoulder can be used by bicycles, auto parking can be allowed on a shoulder. Examples currently include parts of Marine Drive and Airport Way west of I-205.”

C) *Bicycle Boulevard:* “ A bicycle boulevard is a shared roadway (bicycles and motor vehicles share the space without marked bicycle lanes) where the through movement of bicycles is given priority over motor vehicle travel on a local street. Traffic calming devices are used to control traffic speeds and discourage through trips by motor vehicles. Traffic control devices are designed to limit conflicts between automobiles and bicycles and favor bicycle movement on the boulevard street.”

D) *Off-street path:* “An off-street path is a bikeway that is physically separated from motorized vehicular traffic by an open space or barrier and either within the roadway right-of-way or within an independent right-of-way. Off-street paths are intended to provide adequate and convenient routes for bicycling, walking and other non-motorized uses. Off street paths may be implemented in corridors not well served by the street system.”

5.3. Criteria for Selection of the Bicycle Network

The bicycle plan staff, with input from the Bicycle Master Plan Steering Committee and interested residents, selected four criteria for the development of the city’s bicycle network. The criteria area as follows:

A) Connect cyclists to desired destinations, such as employment centers, commercial districts, transit stations, universities, schools, and recreational destinations;
B) Provide continuity with the regional bikeway system proposed by Metro, thus providing connections with neighboring bikeways in Multnomah, Washington, and Clackamas Counties;
C) Provide the most direct routes possible; and
D) Provide a bikeway approximately every half-mile (City or Portland 1998).

Staff analyzed routes taking into considerations aspects such as street width, traffic volume, topographical problems, surface quality, availability of parking and parking usage, number of existing traffic lanes, presence/absence of curbs, stop sign presence at each intersection, and other relevant observations. When the most direct route contained considerable constraints, alternative, parallel routes were analyzed (ibid.).

5.4. Evaluation of the Plan to Date

The *Bicycle Master Plan* recommended 14 benchmarks. In October of 2001, Roger Geller, the Bicycle Coordinator for the City of Portland, presented the City Council with a five-year update of the *Bicycle Master Plan.* The document evaluated each of the benchmarks, and compared results with the 5-year targets stipulated in the plan. Below are some of the most important findings.

A) Bikeway network. According to the City of Portland, the “most noticeable, and arguably most significant, improvement to the City’s bicycling environment since 1990

has been the development of a comprehensive, connected bikeway network" (Bicycle Master Plan Five-Year Update). The City's built network has increased from 111 miles in 1995 to 228 miles of developed bicycle lanes, boulevards (local streets parallel to major arterials that enjoy low auto traffic and favorable signaling and infrastructure for bicycles), and off-street paths.

The five-year benchmark called for the network to be 40 percent completed in 2001. The rate in 2001 was 38 percent, though an additional 28 miles were funded, increasing the percentage to 42 percent by 2003.

B) Bicycle Parking. A City code rewrite in 1996 required more and better bicycle parking in a safer environment. Also important, the code divorced bicycle from land use's automobile parking that mandated that a bicycle parking space be provided for every 20 automobile spaces. In the old code there was nothing to distinguish commuter ("long-term") from visitor ("short term") parking.

The new code is a "great improvement on four accounts:

1. It generally calls for more bicycle parking than did the former code.
2. It requires buildings not in conformance with current bicycle parking requirements to come up to code.
3. It divorces bicycle parking from auto parking and instead determines the amount of required bicycle parking based on land use and building size.
4. It creates secure long-term bicycle parking for commuters" (ibid., p.4).

As of August 2001, the City owns and maintains more than 2,100 short-term bicycle parking racks throughout the City' commercial districts, and 350 bicycle lockers (for long-term parking) located in the Downtown and Lloyd District.

C) Bicycle Ridership. The report to Council explicitly states that Portland's steady investment in the bikeway network has "paid off" in steadily increasing bicycle ridership. In addition to cyclists using the network, a survey conducted in the summer of 2000 found that new riders are continuing to be attracted to the system (ibid., p.5). The survey found that fully one-third of 600 responding peak hour cyclists began using their bicycles for work within the past two years. One-fifth began within the last year. The document goes on to say that "this demonstrates that we are attracting new riders to the network for transportation-related, rather than recreational trips" (ibid.).

The five-year benchmark for bicycle ridership calls for a 5 percent mode split for commute trips in the inner city and a 3 percent mode split for commute trips citywide. The document acknowledges the difficulty in measuring mode split. The City estimates that the best available data at the time was either Metro's 1994 personal transportation survey or the U.S. Census Bureau. The City has conducted annual counts at same locations at the main bicycle bridges (Hawthorne, Burnside and Broadway) for years. The trend, comparing data from the mid 1990s to 2001 is towards greater bicycle traffic at these locations (with a growth of 143 percent from 1991 to 2001), far outpacing the City's growth in population. Mode split data for the City showed that bicycle

commuters were 1.8 percent of total commuters, according to the 2000 U.S. Census (which measures commute trips only at the time of year the census is conducted-March/April). This is short of the five-year benchmark of 3 percent. However, Portland ranked third best among large American cities (*The Oregonian*).

D) Safety. The document uses a proxy to estimate bicycle safety: Reported bicycle-motor-vehicle crashes. This type of collision has remained constant between 1987 and 1999, between 160 and 170 a year. However, the crash rate has gone down considerably as the number of bicycle riders has steadily increased. (The crash rate is calculated by dividing annual crashes by daily bridge riders multiplied by 10). The crash rate has gone from 0.91 in 1987 to 0.54 in 1995 to 0.29 in 1999. These numbers seem to be consistent with data in cities around the world where as motorists become more accustomed to driving near cyclists, expecting them to be on the road, in turn the crash rate is reduced. The 2001 survey conducted by the for the City found that approximately three-quarters of responding cyclists feel safe riding their bicycles on Portland's street, while approximately 9 percent reported feeling unsafe.

E) Education and encouragement. The City has produced maps and safety pamphlets and sponsored rides, races, and clinics. A full-time bikeway program manager has been on staff for several years.

According to the *National Bicycling and Walking Study* (1999), "Portland's bicyclists and pedestrian program has been successful in part because of the City's growth management initiative, transit development, and progressive efforts to link transit with bicycling and walking." Also, the Bicycle Transportation Alliance, an influential local bicycle advocacy group, in its *The Bicycle Friendly Communities Report Card 2001* rated Portland as the third best bicycle-friendly city, outpaced only by the college towns of Corvallis and Eugene (BTA, p.2). It cited Portland's main deficiencies in providing bicycle connections in West and Southwest Portland.

VI. Finishing First: Challenges Ahead

Despite the mostly positive evaluation of the impacts of Portland's policies on bicycling, of which the *Bicycle Master Plan* is the most important document, many challenges remain ahead.

The most serious challenge has to do with financing. First, the pace of construction has fallen off with many of the easier projects completed and the sharp decline in funding that has affected all programs in the Portland Office of Transportation (in addition to failed attempts to generate new sources of revenue). The 10-year benchmark of 60 percent completion of the bikeway network seems in this new reality as very difficult to accomplish. To achieve this end, an additional 106 miles would have to be constructed. According to Roger Geller, many of the new bikeways are in areas in the Southwest where infrastructure improvements demand widening the right-of-way and expensive sewage and storm water treatments that add up to millions of dollars. According to the *Bicycle Master Plan*, the project list for Priority 1 projects (1-5 years) includes 55

projects totaling about $16 million. Priority 2 projects (5-10 years) include 56 projects totaling about $22 million. On the other hand, Priority 3 projects (10-20 years), include 55 projects (most in Southwest Portland) for a total of $107 million.

The City has realized this new paradigm, dedicating its efforts toward identifying and filling "missing links" on the assumption that a "bikeway is only as good as its weakest link" (ibid., p.3). These areas are generally in poor shape in an otherwise good network. Fixing them would ensure better connectivity and consistency in the network.

The current financial situation will also continue to affect the amount of bicycle parking built in the City, where demand has consistently outpaced supply. Bicycle parking policy has encountered resistance as it has proved difficult in "getting developers to consider short-term bicycle parking as they design their buildings, [the] lack of knowledge about what constitutes good bicycle parking in the Office of Planning and Development Review (now the Bureau of Development Services), and loopholes in the parking code [which] have resulted in a dearth of short-term bicycle parking on newly-developed blocks" (ibid., p.4, Geller). This has occurred most prominently in the Downtown and River Districts, where developers and the Association for Portland Progress (now the Portland Business Alliance) have often advocated for space for the automobile over the bicycle's.

VI. Statistical Analysis of the Relationship between the City of Portland's Bicycle Network and Bicycle Commute to Work

In addition to evaluating the City's bicycle policies and benchmarks, this paper provides a statistical analysis of the relationship between bicycle commuting and the bicycle network. The City's five-year update explicitly claims that the investment towards increasing the bicycle network has resulted in increased bicycle ridership. This paper examines this claim as it applies to bicycle commuting.

6. 1. Methodology and Data

Ordinary least squares (OLS) regression is used to find a statistical relationship between the percentage or bicycle commuters and a number of socioeconomic and geographic variables, including the built bicycle network. Three times periods are used in this study: 1990, 1996, and 2000, plus one combining all years.

Socioeconomic variables are derived from the U.S. Census 1990 Summary Table 3, 2000 Summary Table 2, as well as the U.S. Census 1996 American Community Survey (ACS). The ACS is conducted every year, surveying a small a sample of the population. The survey is usually restricted to a few jurisdictions. In 1996 Multnomah County and the City of Portland were among a few jurisdictions selected for a special ACS that gathered data at the census tract and block levels.

Every ten years, the Census bureau surveys a sample of roughly 16 percent of households about employment, income, education, housing, etc. After identifying persons who are employed, the census form asks: "How did this person usually get to work last week?" The respondent must select the mode of transportation used for most of the distance. Respondents can select from items such as car, truck or van, bus or trolley, subway or elevated, railroad, ferry, taxi cab, motorcycle, bicycle, walked, worked at home, or other method (Williams and Larson, 1996). Decennial census information is gathered for April 1st. Some claim that the timing is not favorable in terms of weather to non-motorized transportation, yet several studies have not found climate to be a significant determinant of bicycle commutes (Pucher 1996, U.S. DOT 1992, Williams and Larson 1996). On the other hand, Nelson and Allen find the number of rain days to be significant (Nelson and Allen, 1997).

A number of variables were derived from geospatial data derived using Metro's Regional Land Information System (RLIS) and City of Portland shapefiles.
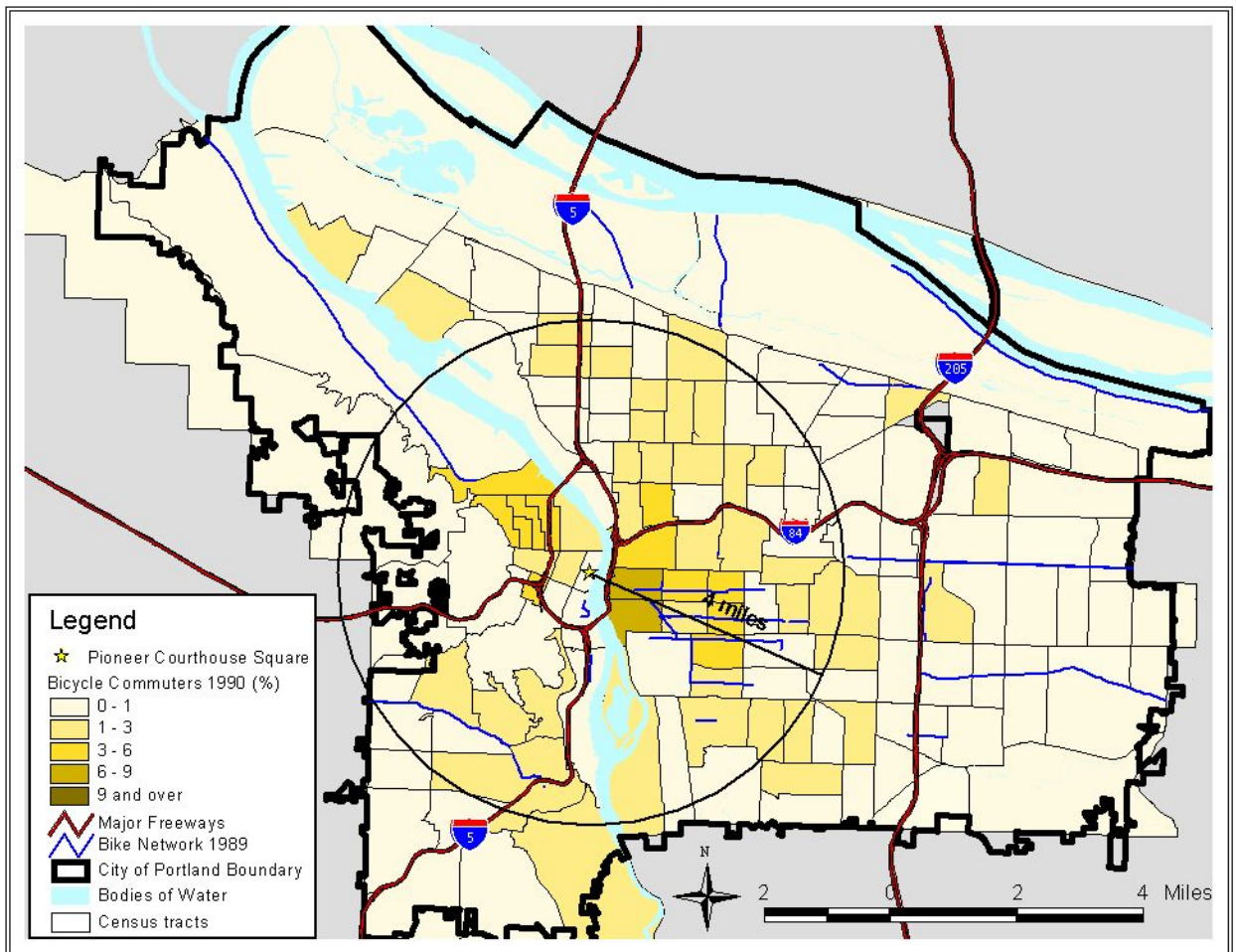
6.2. Variables

Between 141 and 145 census tracts, best approximating the boundary of the City of Portland, were used for this study using a geographic information system (GIS) software program, ArcView GIS 3.2. In the year 2000 four census tracts split, increasing the total number to 145.

Dependent Variable

Percentage Commute by Bicycle: The dependent variable is the percentage of bicycle commuters of all commutes within a census tract. Data obtained from U.S. Census STF2 and STF3 for 1990, 2000, and the Census' 1996 American Community Survey. Maps 1, 2, and 3 show the percentage bicycle commuters for 2000, 1996, and 1990.

Map 1. 1990 Percentage Bicycle Commuters by Census Tract

Independent Variables

Bike Network: The City's Bicycle Coordinator, Roger Geller, put the city's bicycle network into digital form. The network is divided into several categories, including bike lanes, paths, and boulevards. It also contains information about the year that a certain facility was constructed. For this study, the built network used is that for the year previous to the year of the census. Thus, the networks selected are those

completed in the years 1989, 1995 and 1999. ArcView GIS 3.2 was used to select the networks and allocate bicycle lanes to the appropriate census tracts. Map 4 shows the bicycle network in 1989 and the additions to the network in 1995 and 1999.

Map 2. 1996 Percentage Bicycle Commuters by Census Tract
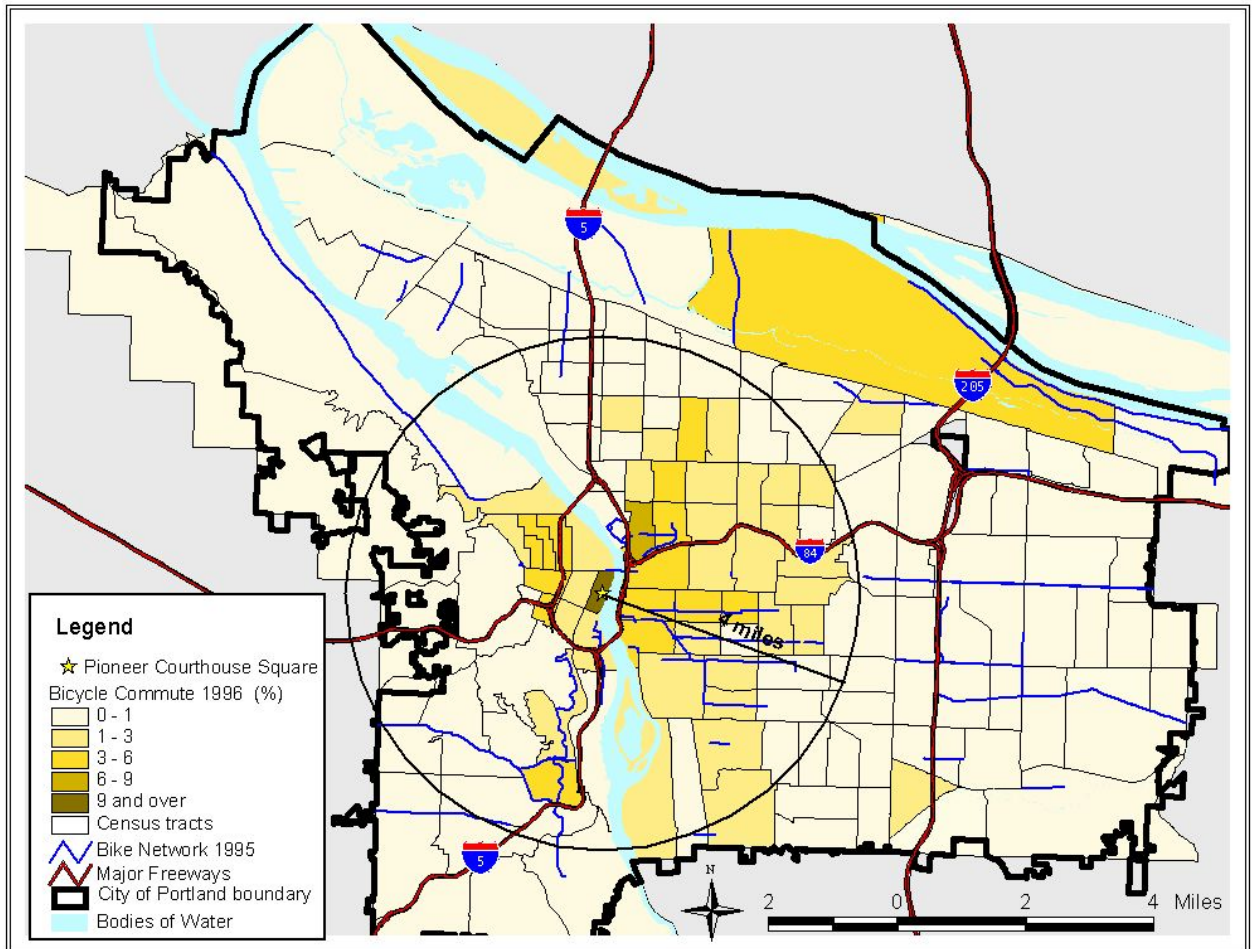
The way the bicycle network has been digitized, it is not possible to differentiate levels of quality in the network. For purposes of this study, all facilities are assumed to have the same level of quality. In reality, some parts of the network may be in better condition than others.

To accurately capture the relative importance of bicycle facilities on a census tract, the network was normalized by dividing the bikeways within a tract (in feet) by the area of a census tract (in square miles). This way, the ratio of bikeways to area in a census tract can be compared to another census tract.

We expect that there is a positive relationship between the level of bicycle facilities and bicycle commute in a census tract, as seen in Nelson and Allen (1997), Pucher (1997), U.S. DOT (1992), and Dill and Carr (2002).

Map 3. 2000 Percentage Bicycle Commuters per Census Tract
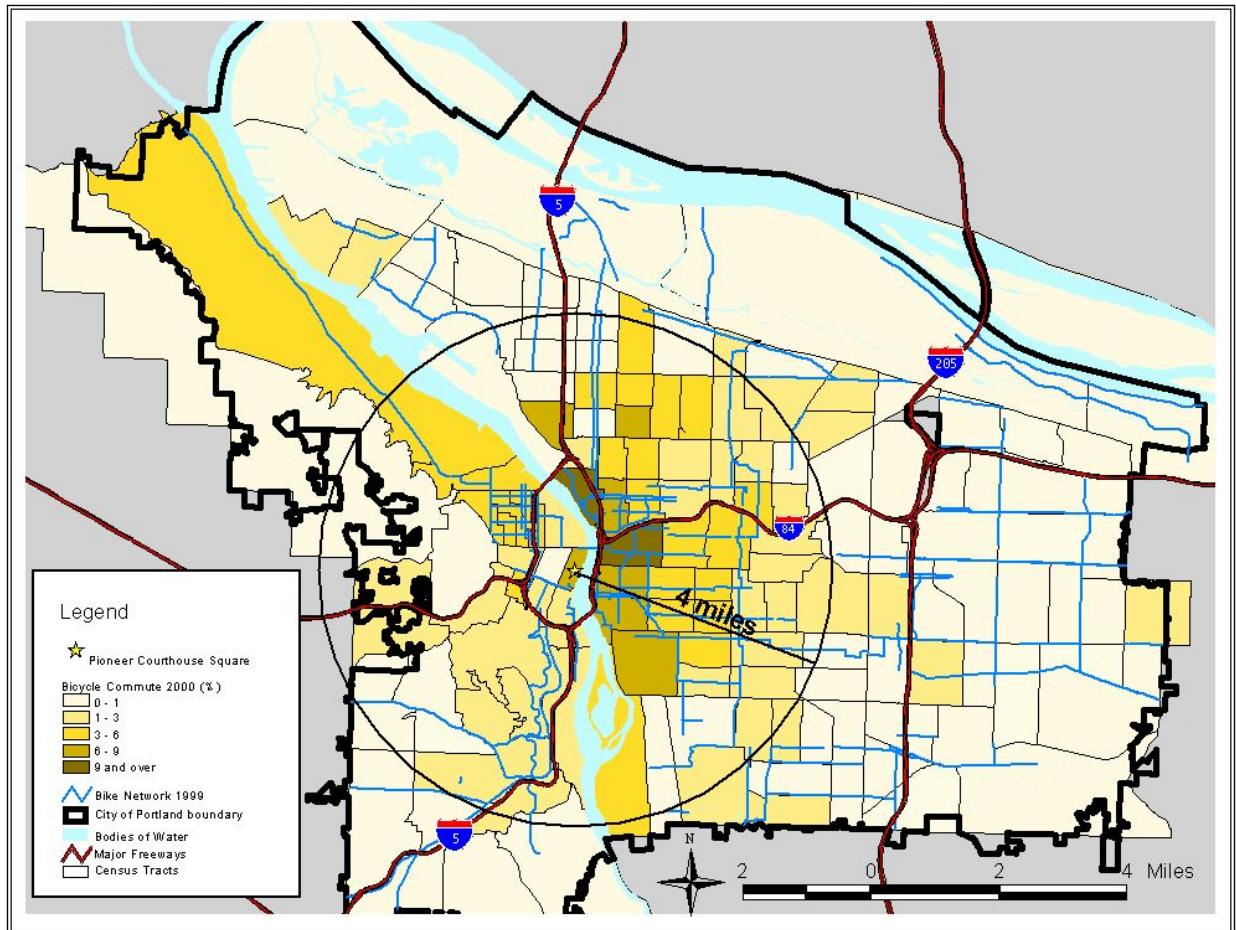
Distance to the Central Business District (CBD): We expect that, as downtown Portland contains a large share of the City's employment, recreation, shopping, and services, as well as extensive bicycle facilities, the farther away the census tract is to the CBD, the less the percentage of bicycle commuters. Several studies indicate that distance is a key variable determining whether workers commute by bicycle (U.S. DOT 1992, U.S. DOT 1994, Williams and Larson 1996).

This variable was created by using an ArcView extension (X-tools) that produced a centroid for each census tract. Another extension and script was used to calculate the distance from the census tracts' centroids to Pioneer Courthouse Square in downtown Portland. Maps 1, 2, 3, 5, and 6 show a four-mile radius around downtown.

Distance to Employment areas: The 1989 Nationwide Personal Transportation Survey found that 27 percent of all travel trips (not just commute trips) are one mile or less, 40 percent are two miles or less, and 49 percent are three miles or less (Williams and Larson 1996). Trips to work are slightly lower (U.S. DOT 1994). According to a

survey by Moritz (1997), the average bicycle commute distance was 12 km (7.5 miles), median 10 km (6.2 miles).

Map 4. Bicycle Network in 1989, 1995 and 1999
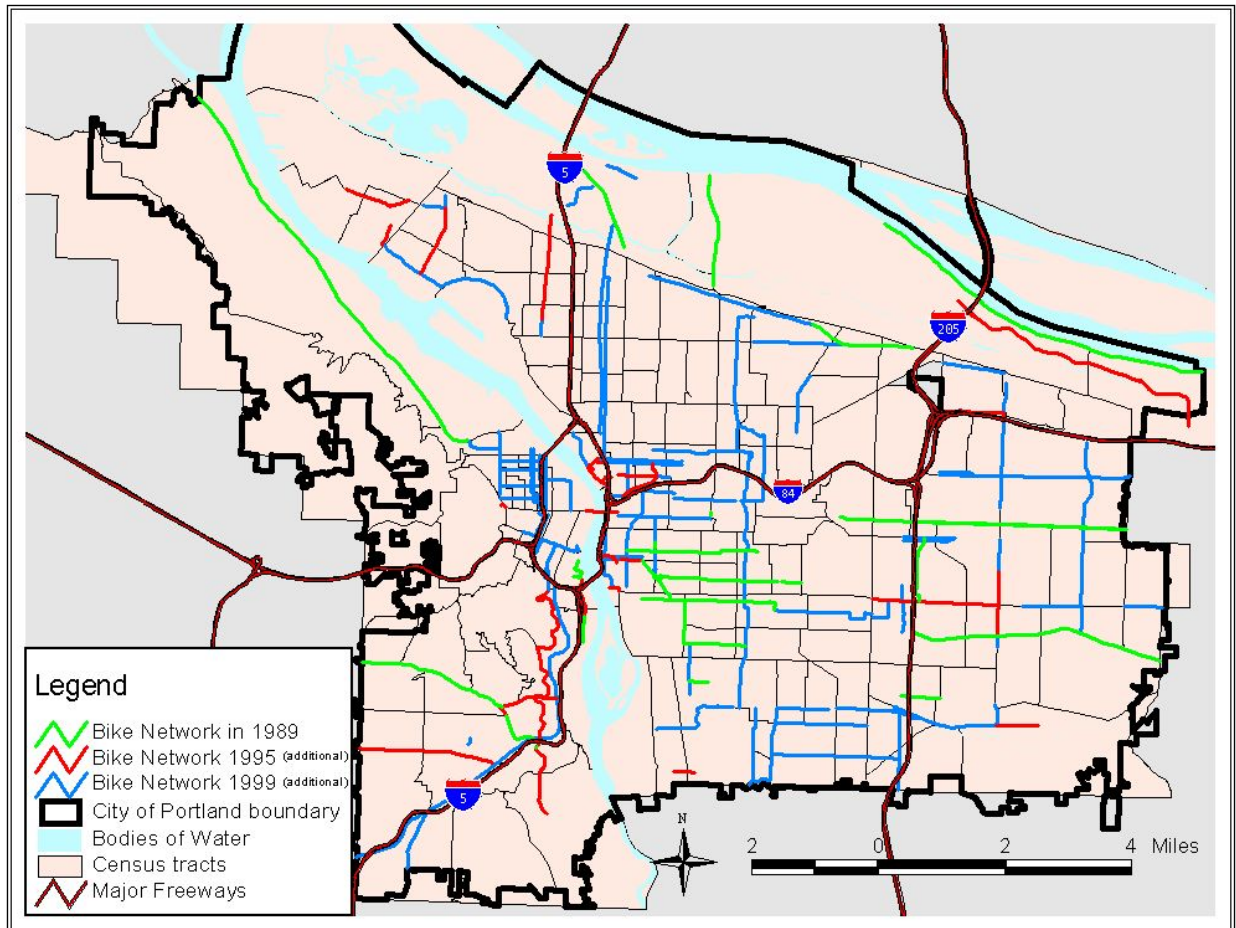
Distance from workplace to residence must be short enough to allow reasonable commuting time. Bicycle commuters report a shorter travel time than other workers. On average, bike commuters arrived at work about 16 minutes after they left home, compared to 22 minutes for persons using other means (Williams and Larson, 1996, p 70). Close to 80 percent of trip miles are 5 miles or shorter (1995 National Personal Transportation Survey).

This variable includes employment figures within a five-mile radius (as the crow flies) from the centroid of a census tract, using employment data by traffic analysis zone (TAZ) from Metro's RLIS. Numbers were derived in ArcView GIS 3.2 by creating a 5-mile buffer around a census tracts and measuring the TAZs within the buffer and adding the total number of employees for 1994, 1995, and 1996.

Map 5. 1990 Population Density by Census Tract
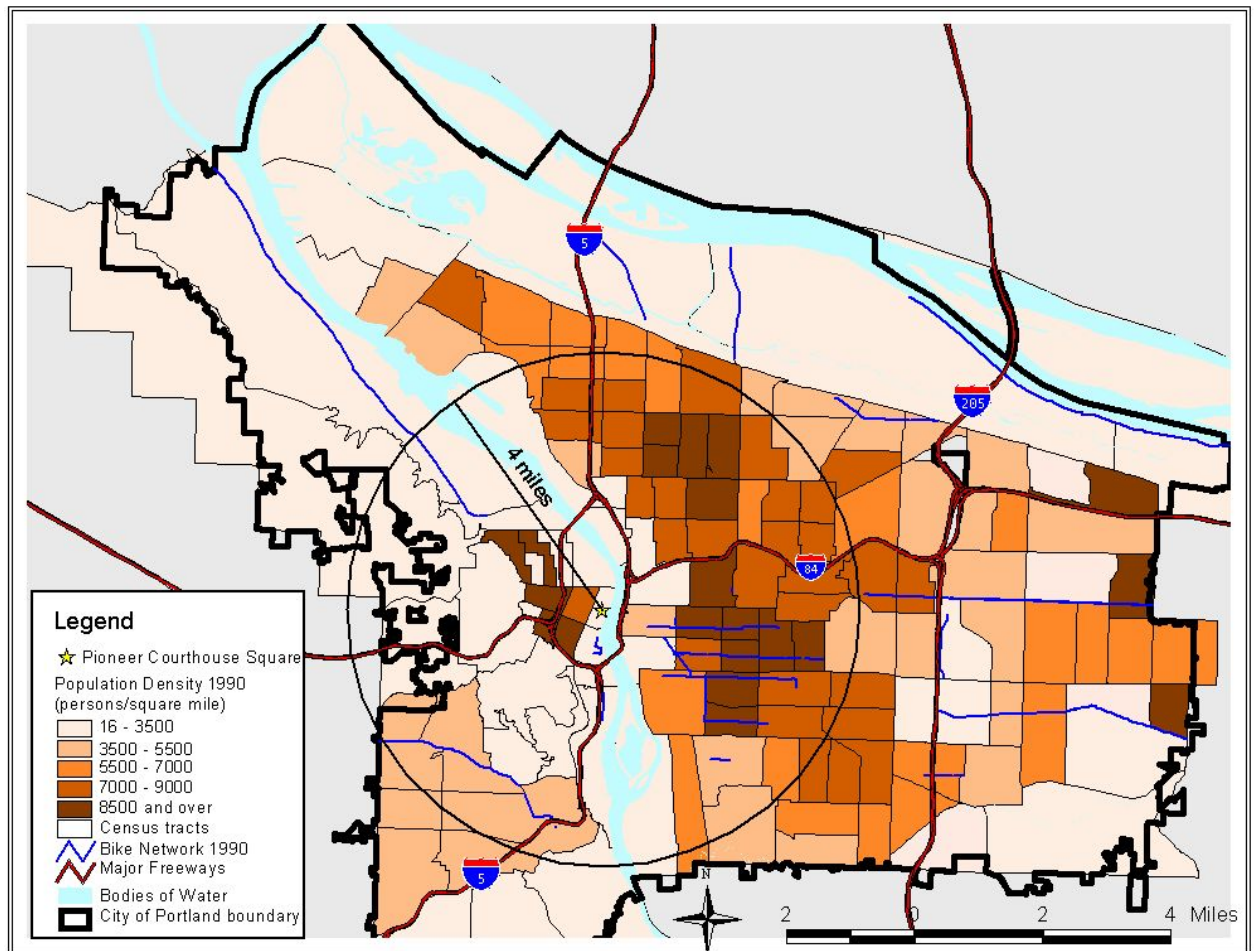
Population Density: Some claim that population density (persons per square mile) leads people to more easily use non-automotive modes of transportation (Ewing 1996). Others, however, claim that density is not enough encouragement, citing low levels of bicycle use in historically dense cities such as New York and Boston in the United States and some cities in Europe (Pucher *et al* 1999, 1997; U.S.DOT 1992). Maps 5 and 6 show density per census tracts for 1990 and 2000.

Percentage College Students: The presence of college students appear to have some of the greatest impacts on bicycle commuting. College students have strong incentives to commute by bicycle, such as living in close proximity to campuses, low income, youth and health, and the way many campuses are laid out (Pucher 1997, Nelson 1997, U.S.DOT 1992). A positive relationship is expected between this variable and the dependent variable.

Map 6. 2000 Population Density by Census Tract
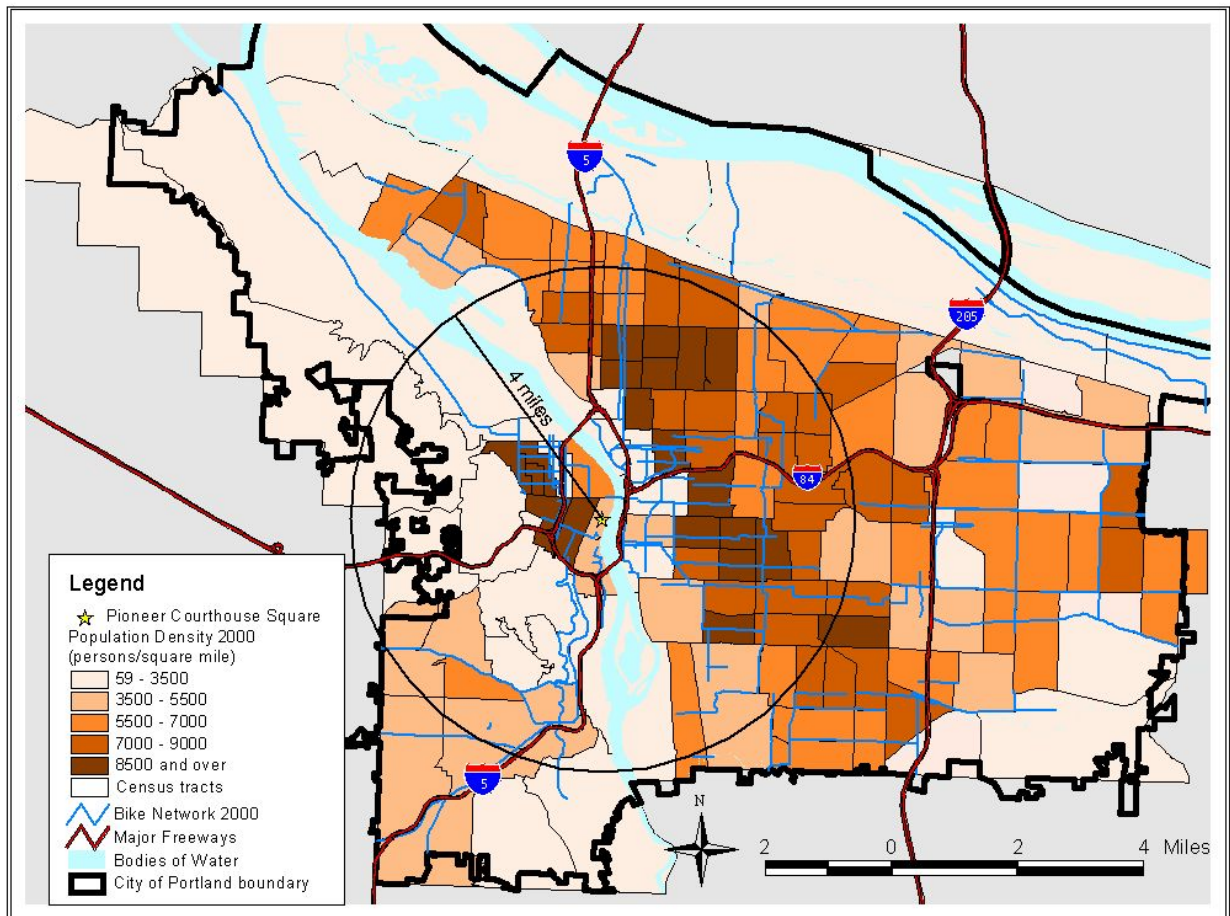
Elevation and slope: These variables will test whether topography has an effect on bicycle commute. The variables were created using ArcView GIS 3.2, RLIS 2002 and City of Portland Corporate GIS shapefiles. Average elevation was derived by adding 10-foot contour lines within a census tract and calculating the mean. Percent slope includes the percentage grade at the tracts' centroid. Maps 7 and 8 show terrain and elevation contours.

Demographic variables: A number of studies have explored the relationship between demographic and economic variables and bicycle use (U.S. DOT 1992, Williams and Larson 1996). Age and gender, marital status, presence of children, race and ethnicity, employment, income and education are all variables that may affect travel behavior. There seems to be an inverse relationship between age and commute by bicycle. Most bicycle commuters tend to be male. Single households tend to bike to work more than married persons and married couples with children. According to Williams and Larson, "blacks are the least likely commute by bicycle, followed by whites, Asians, American Indians, and Hispanics" (ibid., p. 70).

Map 7. Topography of the City of Portland
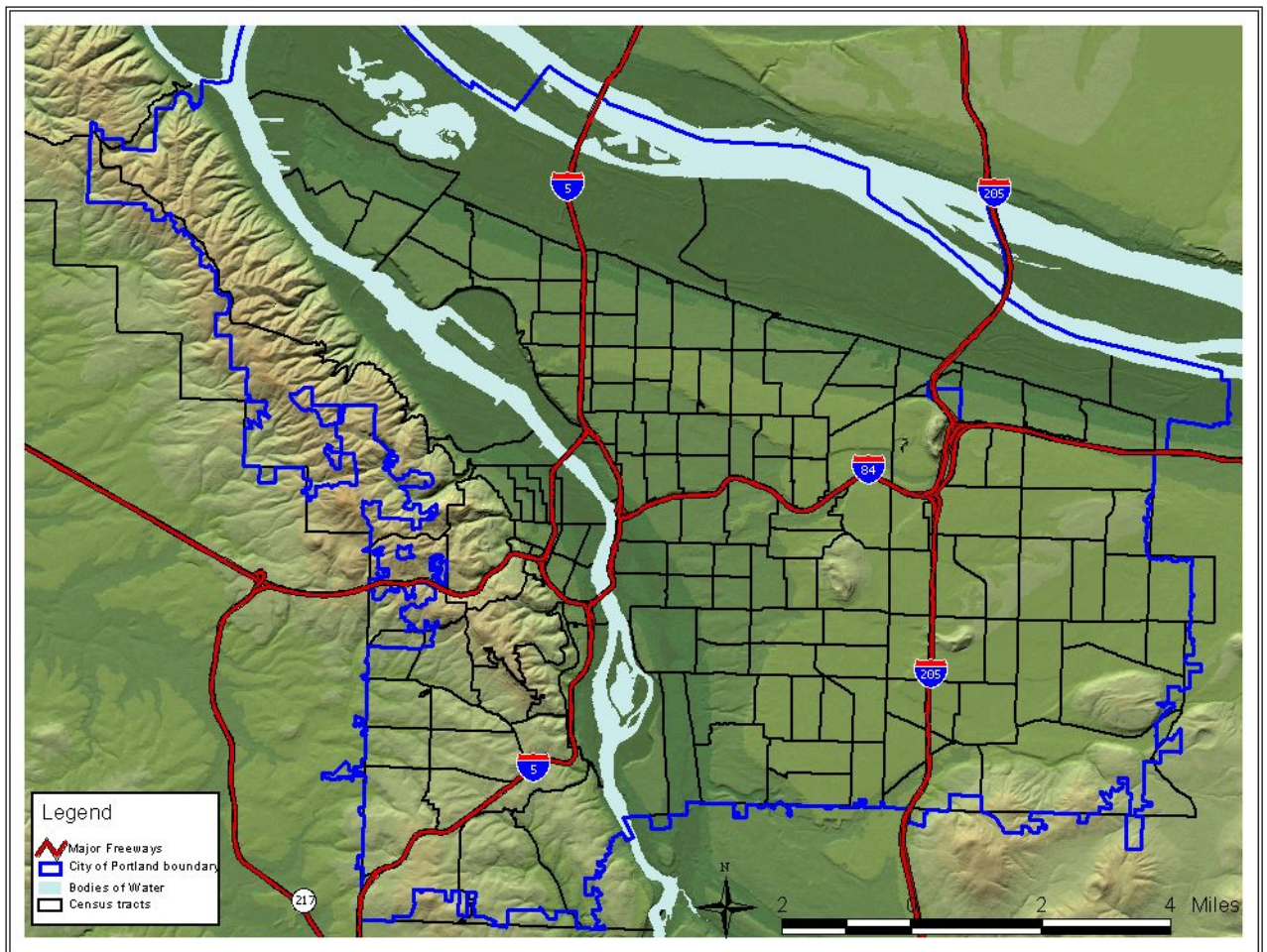
Bicycle commuters tend to earn less money than other workers. The average income for all bicycle commuters was $23,840 in 1996, compared to $28,876 for all commuters (Williams and Larson 1996). There seems to be a link between age and income, with younger and therefore less affluent workers commuting more by bicycle. For the age groups 45 to 54 and 55 and over, Williams and Larson found that they had an average income higher than the average for all workers. The higher mean income seem to suggest a different motive for riding to work. Personal health or environmental benefits may be other possible reasons. Greater flexibility and independence, often associated with higher incomes, may provide for more transportation options (ibid.).

Map 8. Elevation Contour Lines for the City of Portland (each line implies a 10 foot elevation gain)

Legend

Elevation (in feet)
- 6 - 100
- 101 - 220
- 221 - 340
- 341 - 470
- 471 - 590
- 591 - 710
- 711 - 820
- 821 - 940
- 941 - 1060
- 1061 - 1270
- Major Freeways
- City of Portland boundary
- Bodies of Water
- Census tracts
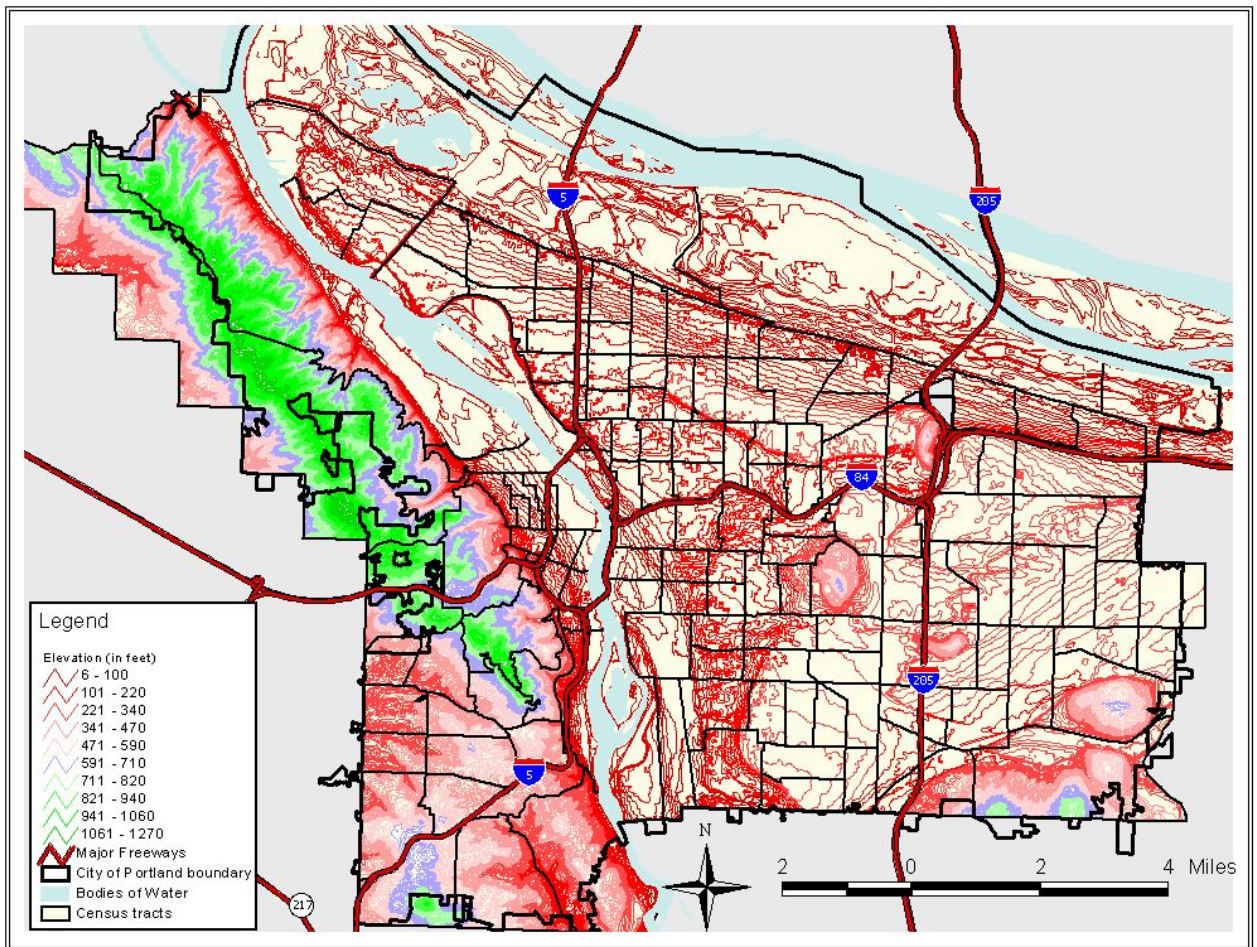
The following table provides descriptive statistics for the variables used. Some variables were not available in the 1996 American Community Survey. There were 145 census tracts in 2000 and 141 in 1996 and 1990.

Table 3. Descriptive Statistics

Variables	1990			1996			2000		
	Mean	Median	Std. Deviation	Mean	Median	Std. Deviation	Mean	Median	Std. Deviation
Bikeways (feet) per Square Mile	2,295	0	4,411	3,841	814	5,536	11,078	8,445	11,324
Distance to CBD (miles)	4.1	3.9	2.3	4.1	3.9	2.3	4.2	3.9	2.3
Average elevation (feet)	219	219	146	219	195	146	221	200	146
% Slope at Tract's Centroid	7.5	5.0	6.2	7.4	5.0	6.0	7.5	5.0	6.1
Population	3,539	3,369	1,590	3,620	3,292	1,686	3,734	3,667	1,513
% Male Population	49.0	48.2	4.7	49.2	48.8	4.7	49.7	48.8	4.1
Families	862	789	455	856	787	469	848	802	419
Families with Children <18	86	76	59	N/A	N/A	N/A	274	257	164
Families with no Children	566	533	322	N/A	N/A	N/A	349	331	182
Female Headed Household with Children <18	56	55	38	N/A	N/A	N/A	95	86	67
Female Headed Household with No Children	103	82	77	N/A	N/A	N/A	68	66	41
Age under 6	294	297	177	286	257	194	268	251	162
Age 6 -17	497	490	308	525	484	338	520	489	317
Age 18-24	350	294	231	310	274	185	377	334	247
Age 25-44	1,291	1,270	568	1,263	1,237	573	1,296	1,257	518
Age 45-64	603	564	302	741	694	366	839	799	352
Age 65 and over	505	472	263	496	452	302	434	382	264
% Population Non White	17.6	12.1	15.7	17.0	12.6	14.4	24.5	21.3	14.2
% College Students	8.4	6.9	6.2	7.3	6.5	4.5	15.6	15.7	8.5
% Population with Bachelor Degree	11.6	10.1	7.4	14.1	12.0	8.2	15.6	15.7	8.5
Population Density (population per square mile)	6,037	5,547	3,606	6,076	5,753	3,588	6,251	6,288	3,568
Median Household Income (1999 $)	34,805	32,723	13,971	37,167	34,835	15,863	42,771	39,950	16,193
% Persons in Poverty	14.8	12.5	10.6	15.4	14.1	9.0	13.0	11.3	8.0
% Persons Over 18 in Poverty	13.6	11.2	10.1	14.0	12.2	8.5	12.3	11.3	7.7
% Households with No Vehicle	16.4	11.9	15.4	14.2	10.5	13.8	14.2	10.8	13.7
Persons Who Worked in City of Portland	1,172	1,158	610	1,202	1,242	619	1,378	1,398	574
Persosn Who Worked Outside City of Portland	509	358	531	N/A	N/A	N/A	513	466	315
Persons Who Worked in Central City	1,282	1,247	565	N/A	N/A	N/A	1,400	1,407	586
Total Jobs Within 5-mile Radius *	317,572	370,311	99,667	328,449	383,395	103,987	339,060	406,643	118,402
% Bicycle Commuters	1.1	0.7	1.28	2.1	1.3	2.7	2.1	1.1	2.8
% Commute by Walking	1.1	0.7	1.28	5.4	2.7	9.1	6.2	2.7	9.6
% Transit Commuters	6.2	3.1	8.91	12.4	11.3	6.5	13.0	12.0	6.8
Time to Work (minutes) per Commuter	12.0	10.5	7.7	20.9	21.1	2.8	22.9	22.8	3.1
Number of Vehicles per Commuter	1.3	1.4	0.3	N/A	N/A	N/A	1.3	1.3	0.3

* Note: Jobs for 1990, 1996 and 2000 were best approximated by using RLIS data for 1994, 1995, and 1996 respectively

6.3. Equation

Four OLS regression models are presented in this study: One for 1990, one for 1996, one for 2000. The fourth includes the observations from all years to examine the stability of the coefficients over time. The structure of an OLS regression is as follows:

$$x_0 = a + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n + e,$$

where
a is the constant,
x_0 is the dependent variable,
x_1 to x_n are the independent variables,
b_1 to b_n are parameters of the independent variables, and
e is the error term.

VII. Results of Statistical Analysis

7.1. Correlation Issues

Table 4 shows the correlation between the dependent and independent variables. A Pearson's correlation coefficient of "one" indicates perfect correlation. Distance to CBD has the strongest negative correlation with percentage bicycle commuters. The number of vehicles per commuter also has a strong negative correlation with the dependent variable. The number of families, families with and without children, and some of the age brackets also are negatively correlated with the dependent variable.

Table 4. Correlation between the Dependent and Independent Variables

Variable	1990	1996	2000
Bikeways per Square Mile	0.130	0.125 *	0.329 *
Distance to CBD	-0.513 *	-0.478 *	-0.505 *
Average Elevation	-0.251 *	-0.284 *	-0.278 *
% Slope Tract's Centroid	-0.152	-0.119	-0.100
Population	-0.224 *	-0.371 *	-0.365 *
% Male Population	0.187 *	-0.010	-0.356 *
Families	-0.356 *	-0.440 *	-0.434 *
Families with Children < 18	-0.322 *	N/A	-0.429 *
Familes with no Children	-0.360 *	N/A *	-0.423 *
Female Household with Children < 18	-0.194 *	N/A	-0.226 *
Female Household with no Children	-0.176 *	N/A	-0.250 *
Age under 6	-0.315 *	-0.401 *	-0.377 *
Age 6-17	-0.329 *	-0.457 *	0.406 *
Age 18-24	-0.001	-0.137 *	-0.170 *
Age 25-44	-0.147	-0.128 *	-0.132 *
Age 45-64	-0.325 *	-0.364 *	-0.395 *
Age 65 and over	-0.236 *	-0.311 *	-0.363 *
% Population Non White	0.043	0.050	0.125
% College Students	0.243 *	0.267 *	0.295 *
% Population with Bachelor Degree	0.237 *	0.337 *	0.295 *
Population Density	0.342 *	0.087	0.073
Median Household Income	-0.241 *	-0.222 *	-0.269 *
% Persons in Poverty	0.250 *	0.156	0.342 *
% Persons Over 18 in Poverty	-0.254 *	0.182 *	0.385 *
% Households with No Vehicle	0.325 *	0.374 *	0.410 *
Persons Who Worked City of Portland	0.112	-0.046 *	-0.167 *
Persons Who Worked Outside City of Portland	-0.254 *	N/A	-0.166 *
Persons Who Worked in the Central City	-0.014 *	N/A	-0.167 *
Total Jobs within 5-mile Radius	0.417 *	0.347 *	0.383 *
% Commute by Walking	0.333 *	0.250 *	0.242 *
% Transit Commuters	0.249 *	0.248 *	0.473 *
Time to Work per Commuter	-0.211 *	-0.347 *	-0.129 *
Number of Vehicles per Commuter	-0.479 *	N/A *	-0.489 *

Variables significant at a two-tailed 95 percent confidence level

Total number of jobs is the variable with the strongest positive correlation with the dependent variable. Other variables positively correlated with the dependent variable include percentage walking commuters and percentage transit commuters.

Some of the variables used in the regression models do not appear to be significantly correlated with the dependent variable. They include percentage bikeways per square mile, slope at centroid, and population density.

Several independent variables are correlated (R = 0.6 or higher) in all years. This explains why most of the variables that show a significant correlation with the dependent variable did not perform well in the regression models. The age categories are correlated among themselves. Percent slope and average elevation are also correlated. Percentage persons in poverty is correlated with percentage households with no vehicle. Median household income is correlated with percent of the population with a Bachelor degree. Correlated variables were removed from the model, leaving only the ones with most explanatory power.

7.1. Regression Results

Table 5 shows the regression results for the different years 1990, 1996, and 2000. The table results also show a model labeled "All Periods." This model uses observations from the three years and serves as a way to check for stability in the variables over time. Coefficients that deviate considerably from the results of the different models tend to be unstable, with larger standard errors.

Most variables used in the models did not prove to have a statistically significant relationship with the dependent variable. We estimated a series of regression models with various combinations of independent variables. The models presented are based on model and variable significance. Several variables show a statistically significant relationship with the dependent variable in all years, others in two years. In some instances, substituting variables that were highly correlated (i.e. substituting percentage persons in poverty for percentage households with no vehicles) resulted in models whose variables performed well but had less explanatory power.

1990 Model

The adjusted R^2 was 0.321. The model explains roughly 32 percent of the variation of the dependent variable. Several variables are significant and with the expected sign. The variable bikeways per square mile (shown in 100 feet per square mile) is significant at the 90 percent confidence level (p-value of 0.093). An additional 1,000 feet of bikeways is associated with a 0.035 percent increase in bicycle mode share, other things being equal.

Table 5. Regression Results

Variables	1990 Model Estimated Coefficient	Standard Error	1996 Model Estimated Coefficient	Standard Error	2000 Model Estimated Coefficient	Standard Error	All Periods Estimated Coefficient	Standard Error
Constant	1.9744	0.435	4.5274	0.912	5.227	0.935	2.6439	0.425
	(4.540)*		(4.962)*		(5.591)*		(6.222)*	
100 Feet of Bikeways per square mile	0.003512	0.002	0.005984	0.004	0.003712	0.002	0.005995	0.001
	(1.691)*		(1.698)*		(2.009)*		(5.758)*	
100 Persons per square mile	0.005726	0.003	-0.005573	0.006	-0.018801	0.006	-0.00642	0.003
	(2.018)*		(-0.945)		(-2.009)*		(-2.291)*	
Distance to CBD (miles)	-0.26560	0.048	-0.531421	0.107	-0.541501	0.100	-0.319731	0.047
	(-5.568)*		(-4.964)*		(-5.416)*		(-6.840)*	
% Slope at Census Tract Centroid	-0.026706	0.017	-0.071136	0.036	-0.078787	0.036	-0.039586	0.017
	(-1.591)		(-1.988)*		(-2.202)*		(-2.375)*	
% Households with No Vehicles	0.002423	0.007	0.025518	0.017	0.03687	0.017	0.036505	0.007
	(0.333)		(1.485)		(2.162)*		(4.875)*	
R^2	0.345		0.291		0.357		0.328	
Adjusted R^2	0.321		0.265		0.333		0.320	
N	141		141		145		427	

Notes: T-values are in parenthesis
* Statistically significant at 90 percent confidence level

Population density (shown in 100 persons per square mile) is significantly related with the dependent variable. Higher population density is associated with a higher percentage of bicycle commuters. Distance to the CBD also is significant with the dependent variable, with the expected sign. An extra mile from downtown to a census tract is associated with a 0.26 percent decrease in the percentage of bicycle commuters.

Percent slope is not significant though it shows an inverse relationship with the dependent variable. Substituting average elevation for percentage slope does not improve the model or make the variable significant, though the sign remains as expected. The coefficient of the variable percentage of households without a vehicle has the expected sign but is not significant.

1996 Model

The adjusted R^2 was 0.265. The model explains roughly 26 percent of the variation of the dependent variable.

Bikeways per square mile (shown in 100 feet per square mile) is significant at the 90 percent confidence level (p-value of 0.092) and its sign shows a positive relationship with the dependent variable. The coefficient was 0.00598, the highest for the three years. The coefficient indicates that, other things equal, an additional 1,000 feet of bikeways is associated with a 0.060 percent increase in the percentage of bicycle commuters.

Distance to CBD is significant and has an inverse relationship with the dependent variable. The coefficient indicates that census tracts closer to downtown Portland have higher percentage of bicycle commuters. Percentage slope at the centroid of a census tract is also significant, with an inverse relationship with the dependent variable. A steeper grade is associated with a smaller percentage of bicycle commuters.

Population density (shown in 100 persons per square mile) did not prove significant and its sign indicated an inverse relationship with the dependent variable. Percent households with no vehicle is not significant though it has the expected sign. The same variables that were correlated in the 1990 are correlated in 1996. Correlated variables were removed from the model, only leaving the one with the most explanatory power.

2000 Model

The adjusted R^2 is 0.333. The model predicts about a third of the variation on the dependent variable. All variables are significant at a 90 percent confidence level.

The number of feet of bicycle facilities (shown in 100 feet of bikeways per square mile) has a positive relationship with the percentage bicycle commuters (p-value of 0.046). According to the model, an additional 1,000 feet of bicycle network per square mile is associated with a 0.037 percent increase in bicycle mode share, other things being equal.

As distance from downtown Portland to a particular census tract increases, the percentage of bicycle commuters decreases. An additional mile from downtown Portland is associated with a decrease in the percentage of bicycle commuters by 0.54 percent. A negative relationship is also found for the variable percent slope at the centroid of a census tract: the steeper the slope, the less the percentage of bicycle commuters.

As the percentage of households with no vehicle increases, so does the percentage of bicycle commuters. Two explanations are possible, based on previous research. One is that in census tracts with higher poverty rates and higher percentage of households with no vehicle bicycling becomes a preferred way to commute due to its relative low cost. Also, workers who earn less tend to value the cost of travel time to a lesser degree than workers with higher incomes. An additional explanation is that neighborhoods with historically high poverty rates and high percentage of bicycle commutes (such as in NE Portland) have attracted an influx of young, affluent residents who use the bicycle to commute to nearby downtown Portland. Even though newcomers aren't technically poor, by living in poor areas and commuting by bicycle it boosts the importance of poverty rates and rates of households with no vehicle in the model, especially in 2000.

The results of the variable population density (shown in 100 persons per square mile) indicate that increases in population density are related to decreases in the percentage of bicycle commuters. This goes against research by Ewing (1996). Pucher *et al* (1999) offers an explanation. In his analysis of New York, he indicates that despite the high

density of the central city, flat terrain, and close proximity to jobs and amenities, only 0.30 percent of work trips were by bicycle (0.65 percent in Manhattan). He attributes the low mode share to a "legion of obstacles", including torn and "treacherous" pavement, substandard bike paths on bridges, car and truck exhaust, common bicycle theft, and worst of all, heavy traffic that forces cyclists to "constantly battle for a place on the road" (Pucher *et al* 1999, p. 637). It must be noted that the conditions of New York are very different from even the densest areas of Portland.

Another explanation is that higher population density will not shorten commuting distances if land uses and zoning regulation are not conducive to creating the right mix of jobs and housing.

Percent slope is significant, with the expected sign. A one percent increase in the slope at the centroid of a census tract is associated with a decrease of 0.078 percent in the percent of bicycle commuters, other things equal. Average elevation also proved significant.

All Periods

The adjusted R^2 is 0.320. The model explains roughly 32 percent of the variation in the dependent variable. The coefficients validate the results from the models described above. Over time, the different variables seem to have a stable, significant relationship with the dependent variable. All variables are significantly associated with the dependent variable.

It is interesting to note that in this model bikeways per square mile has a stronger relationship with the dependent variable than in 1990 and 2000. Its coefficient is very close to the 1996 model. It states that, other things equal, an increase of 1,000 feet in bikeways per square mile is associated with a 0.060 increase in bicycle commute.

7.3. Summary of Regression Results

Below is a summary of the different models used for the three data sets.

A) Variable "bike lane feet per square mile" is significant in all years (at the 90 percent confidence level, 95 percent confidence level in 2000). The signs are as expected. The models for 2000 and 1990 suggest that an additional 1,000 feet of bikeways is associated with roughly a 0.035 to 0.037 percent increase in bicycle mode share, other things being equal. The 1996 and "all periods" model suggest that the same increase in bikeways is associated with a 0.060 percent in the percentage of bicycle commutes.

B) "Distance to CBD" also is significantly related to the dependent variable in all years.

C) Variables that proved significant (with a 90 percent confidence level or better) are:

- Bikeways (in feet) per square mile
- Distance to CBD (in miles)
- Percent slope of tract at centroid (not significant in 1990)
- Percentage households with no car (not significant in 1990)
- Persons per square mile

D) Significant variables not included in the models due to correlation with other independent variables include:
- Average elevation (in feet, not significant in 1990)
- Percentage people in poverty (not significant in 1990)

E) Many variables (including statistically significant variables) were found to be correlated (r= 0.6 or higher). The variables were correlated in all years. Only the variable with the greatest explanatory power was used in the regression models.

F) Population density is significant in all years but its influence on the dependent variable is not clear. In 1996 and in 2000 it is inversely related to the dependent variable, whereas in 1990 it has a positive relationship with the dependent variable.

G) The "All Periods" model validates the stability of the independent variables over time. All variables presented in the different models are significant in this model.

VIII. Limitations of the Data and Models

A statistical analysis can be only as good as the quality of the data. Ideally, each variable used in an OLS-type regression would have a normally distributed set of observations, resembling the shape of a bell, with an equal number of observations on either side of the mean. In reality, however, perfectly distributed observations are not always common. Often, it is necessary to transform variables to meet the assumptions of a model.

8.1 Bicycle Network and Bicycle Commute to Work

Some of the most important variables used in this study, percentage commute by bicycle and bikeways per square mile, seem to deviate from a normal distribution, both skewing toward zero. The reason is that there is an important number of census tracts with no bikeways and zero percentage bicycle commuters. Furthermore, the further one goes back in time, the more census tracts with no bikeways and with zero percentage bicycle commuters.

What may be contributing to the high number of zeros in the data is the way the Census Bureau asks respondents how they usually get to work (Strathman). By asking respondents for the "usual" way to commute, perhaps an important number of respondents who ride a bicycle to work but use other modes more frequently do not get captured in the data set, leading to an underreporting of bicycle commutes. By asking the question differently, those bicycle commuters would get captured in the data. Additionally, some have suggested that the time of year and weather conditions when the question is asked (around April 1st) influence how respondents answer the question. Others state that weather does not play a role in bicycle commuting (Pucher 1997, Dill and Carr 2002).

One way of dealing with the number of zeros in the data set is to assign bikeways within a specified distance of a census tract rather than just within a tract. Doing this may result in lesser numbers of tracts with zero feet of bikeways. It also may be more realistic in capturing cyclist behavior, since a considerable number of tracts do not have bikeways in them but do have them nearby. Cyclists need only ride a short while to access them.

Alternative regression techniques could be used to explore the nature of the data. As part of this study, the natural log was computed for relevant variables. Squared variables and dummy variables were also used. The results were mixed, improving performance in some instances and variables but not in others. The natural log improves the distribution of the percentage of bicycle commuters but its effect on the distribution of bikeways per square mile is negligible. However, when both log-converted variables are used, bikeways per square mile proved statistically significant. Bikeways per square mile is positively associated with percentage bicycle commuters.

8.2 Simultaneity Issues

It is common to think of simultaneity as the case of what came first, the chicken or the egg. Often, planners will develop infrastructure in areas where they expect the greatest utilization to occur or in areas where use is already high . This poses challenges to a researcher. In the case of this study, it may be worthwhile to check for simultaneity in the data. As stated in the *Bicycle Master Plan*, some of the criteria for creating the bicycle network included connecting cyclists to desired destinations, such as employment centers, commercial districts, etc. Since the downtown is the main center of employment and services, it is possible that the variable distance to CBD may be capturing some of the effect of the bike network (the network is densest near the downtown) and viceversa. Additionally, the bicycle network was designed to connect with the regional bikeway system proposed by Metro. By connecting to the regional bikeway system, the network may be expanded in areas where bicycle use is already high.

8.3 Geographic Variables

The variables percentage slope at the centroid of a census tract and average elevation only consider the conditions within census tracts. Even though the variables proved significant in two of the three years, perhaps their performance would improve if the terrain conditions for areas near the tracts were also included, since many trips go beyond the boundaries of a tract. Finally, the methodology used here can be used to explore data at the block group level, which would increase the sample size.

IX. Implications for Planners

The results of the statistical analysis have implications for communities and planners attempting to increase bicycle ridership by creating or extending the bicycle network.

Below are the major conclusions for planners that can be extracted from the statistical analysis and the evaluation of the Portland's *Bicycle Master Plan*.

A) In general, adding bikeways in an area is associated with higher percentages of bicycle commuters. Nelson and Allen (1997) and Dill and Carr (2002) support this finding.

B) Other things equal, bicyclists prefer flat terrain to steep grade. Elevation difference can be seen in Map 8. Map 4 shows the bicycle network in different years and Maps 1 through 3 show bicycle use by census tract. Map 7 shows the topography in and around the city of Portland.

C) Proximity to places of employment and attractions is also a determinant of bicycle commute. Bicyclists who live closer to downtown Portland tend to commute more by bicycle. Maps 1, 2, 3, 5, and 6 show bicycle use and population density, with a four-mile radius around Pioneer Courthouse square in downtown Portland. As the

regression models show, one can see that bicycle commute decreases the farther away the tract is from downtown. The City's commitment to a healthy, active downtown (City of Portland 2001) seems to have an important influence on bicycle commute.

D) When planning for a network, attention must be guided towards expanding the network to include areas with higher percentages of persons in poverty and with higher percentage of households with no vehicles. This was not part of the criteria for the City of Portland's *Bicycle Master Plan*.

E) Population density may have an association with bicycle commute, but its exact relationship may depend on other factors. As the FHWA states in its report *Reasons Why Bicycling and Walking Are and Are Not Being Used More Extensively as Travel Modes*, "land use favoring compact development can shrink trip distances and thereby make bicycling a viable option. However, higher density can also mean greater traffic congestion on streets, making road space scarce for cyclists. Thus high density without a network of safe bicycling facilities may fail to stimulate bicycle trips" (FHWA 1992, p.2). Pucher *et al* (1999) states that some of the densest cities, including New York City and many European cities, do not have a high percentage of bicycle users. At the same time, however, other European cities with high density do have a high percentage of bicycle users. The difference in bicycle use seems to be related to a jurisdiction's efforts in promoting bicycle use and in providing an effective bicycle network.

F) Apart from the possible lessons derived from regression analysis and previous literature, it is important to follow sound planning practices and methodology, much like Portland's *Bicycle Master Plan*. An effective planning process must involve key stakeholders as well as the public at large. In addition, there must be sufficient time, resources and common will among participants to analyze existing conditions, set goals and objectives, listen to one another, develop alternatives and analyze the impacts of each, and reach consensus around a final preferred plan.

X. Conclusion

Since the adoption of the *Bicycle Master Plan* in 1996, the network of bikeways has improved considerably. Along with these improvements has come an increase in bicycle ridership. This paper finds that there is a positive statistical relationship between the bicycle network and bicycle commute to work.

The findings support current national empirical research that state that as a better bicycle infrastructure is built and it becomes more convenient and safe to travel by bike, more residents find that using the bicycle as a means of transportation fits their lifestyle.

This paper finds that there are other factors that affect bicycle commute. Policymakers and planners should pay close attention to them when planning for the provision of bikeways.

It is important to note that bicycle trips to work are a small percentage of total bicycle trips, and that the bicycle network can be used for a variety of trip purposes, not just for going to work. In addition, an effective bicycle transportation system must also include adequate parking facilities and signage, be safe, and have institutional and staff support from the city or county.

All of these issues are successfully addressed in the *Bicycle Master Plan*. This paper rates very positively the efforts by the City of Portland to promote bicycle use. New financial and political realities (less funds, more expensive and contested projects) will demand even greater focus and energy to complete building the network at the pace experienced in the 1990s.

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