Prioritizing Bicycle Facility Improvement Projects Based on Low-Stress Network Connectivity

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Abstract

This thesis introduces a new method to prioritize bicycle facility improvement projects based on low-stress network connectivity. A bicycle network typically contains the following bicycle facilities: sharrows, bicycle boulevards, bike lanes, buffered bike lanes, and pathways. Using Moscow, Idaho as a case study, over 29 miles of bicycle facilities were analyzed to determine their impact on the bicycle network. The case study’s bicycle facilities are part of a proposed improvement plan, which breaks up the bicycle facilities into 37 projects. To determine the importance of each project, a new prioritization method used open-sourced Python code and geographic information systems (GIS) software to route every residential parcel to a defined “basket” of important destinations. (Routes were considered only if they were within a specified stress threshold.) The method produced a rank of each project’s importance to the bicycle network, which provides planners and engineers valuable insight when facing challenging transportation investment decisions.

Acknowledgments

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Preface

The Netherlands has the highest percent of trips taken by bicycle. In 2008, 26% of trips were taken by bicycle in the Netherlands, while only 0.5% of tips were taken by bicycle in the United States (Buehler et al., 2012). The Netherlands also ranks lowest in bicycle fatalities and injuries per kilometer. Between 2004 and 2009, the Netherlands had 1.1 cyclists killed per 100 million km, and the United States had 5.5 cyclists killed per 100 million km. During that time, 1.6 cyclists per 100 million km were injured in the Netherlands, and 33.5 cyclists per 100 million km were injured in the United States (Buehler et al., 2012). The Netherlands' impressive bicycle mode share and bicycle safety statistics are largely due to their substantial investments in low-stress bicycle facilities. According Mekuria et al. (2012, pg. 12), "intolerance for traffic stress also explains the enormous difference in bicycle use between the U.S. and European countries such as the Netherlands and Denmark, where separation from traffic is a fundamental principle of bicycle facility design."

I traveled to the Netherlands for my 2014 summer semester to study sustainable transportation, and I saw firsthand the importance of low-stress network connectivity. I do not speak Dutch, and I did not know my way around, but I traveled by bike with ease and little confusion. My experience abroad inspired me to investigate methods that qualitatively and quantitatively explain the value of low-stress bicycle facilities. I felt the Netherlands should be used as a model for bicycle planning, and this ultimately led me to constructing this thesis. My goal was to illuminate the importance of low-stress bicycle facilities. With the help of Dr. Michael Lowry and his novel prioritization idea, we were able to create a new method for prioritizing bicycle improvement projects. Our method can help engineers and planners make challenging transportation investment decisions.

Improving bicycle travel is a top priority for the United States Department of Transportation. In 2010, former United States Transportation Secretary Ray LaHood signed a policy statement to establish well-connected bicycle networks to create livable communities, improve bicycle safety, provide opportunities for active travel, and reduce vehicle emissions and fuel use (LaHood, 2010). More recently, on September 10, 2014, the current Transportation Secretary Anthony Foxx launched a new initiative to enhance bicycle safety that will include increased federal funding for bicycle improvement projects (USDOT, 2014).

Secretary Foxx called the new initiative “the most innovative, forward-leaning, biking-walking safety initiative ever” (Foxx, 2014). In my opinion, if the U.S. is serious about increasing bicycle safety, they should invest in low-stress bicycle facilities that are well-connected to important destinations. The new prioritization method we present in this thesis can help engineers and planners identify the best projects for improving low-stress connectivity.

Chapter 1. Introduction

Between 1979 and 1999, the number of bicycle trips in the United States doubled. There is enormous potential for continued growth because nearly half of all trips in American cities, regardless of mode, cover a distance less than three miles (Pucher et al., 1999). As bicycling increases, cities are aggressively devising Bicycle Master Plans, which enumerate a wish list of improvement projects. One common goal is to provide more low-stress bicycle facilities, i.e. facilities that minimize cyclist exposure to automobile traffic (SDOT, 2013). This can be accomplished through bicycle infrastructure, pavement markings, and signage. Improvement projects might include sharrows, bicycle boulevards, bike lanes, buffered bike lanes, pathways, bridges, and underpasses. Mekuria et al. (2012) suggest "(f)or a bicycling network to attract the widest possible segment of the population, its most fundamental attribute should be low-stress connectivity". Connectivity means a bicycle network has minimal gaps between bicycle facilities.

Implementing a Bicycle Master Plan requires difficult decisions about how to allocate limited funds. There are currently no quantitative methods that utilize low-stress connectivity principles with geographic information systems (GIS) software to prioritize bicycle facility improvement projects.

This thesis introduces a new method to prioritize bicycle facility improvement projects based on low-stress connectivity. The method is demonstrated for a case study with a proposed improvement plan consisting of 37 projects. The new method was coded for GIS software using open-source Python. The method produces a priority rank for each project.

The next chapter of this thesis provides background on project prioritization and past efforts to assess low-stress connectivity. This is followed by a chapter presenting the new method and how to use the GIS tools. Next, a chapter describes the case study data and then a chapter describes the analysis and results for Moscow, Idaho's proposed improvement plan. The final chapter draws conclusions and offers suggestions for future research.

Chapter 2. Background

Low-Stress Connectivity

Assessing low-stress bicycling can be accomplished through various *bicycle suitability assessment* methods. More than a dozen methods exist, and each calculates suitability ratings, i.e. a perceived level of stress, based on different roadway attributes (Callister and Lowry, 2013). A pioneering bicycle suitability assessment method was proposed by Sorton and Walsh (1994) called Bicycle Stress Level (BSL), which uses three roadway attributes, (1) width of outside lane, (2) vehicle traffic volume, and (3) vehicle speeds, to produce a rating consisting of five stress levels ranging from “Very Low Stress” to “Very High Stress”. The 2010 Highway Capacity Manual presents a bicycle suitability assessment method called Bicycle Level of Service (BLOS) based on 10 roadway attributes[1] and produces a letter grade rating from “A” through “F” (TRB, 2011). Mekuria et al. (2012) developed a method called Level of Traffic Stress (LTS) which produces four ratings (LTS 1 to LTS 4) based on eight input attributes: (1) street width, (2) bike lane width, (3) speed limit, (4) bike lane blockage (adjacent land use), (5) presence of parallel parking lane, (6) vehicle right turn lane length, (7) presence of traffic signal, and (8) number of vehicle lanes.

A person’s interpretation of suitability ratings depends on his or her experience and confidence with bicycling. Most bicycle suitability assessment methods were developed for a particular type of cyclist. Geller (2006) identifies four types of cyclists and asserts a proportion of the population associated with each type:

- *Strong and Fearless* (<1%): willing to ride under any conditions,
- *Enthused and Confident* (7%): willing to ride with minimal bicycle accommodations,
- *Interested but Concerned* (60%): uncomfortable riding with fast traffic, and
- *No Way No How* (33%): no interest in bicycling.

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[1] The Highway Capacity Manual also provides a method to calculate BLOS for trail segments based on 10 trail attributes. We know of no other bicycle suitability method for trails. Some methods do not even mention trails in their documentation, while others, such as LTS, simply give trail segments the best possible rating without requiring any calculation.

Mekuria et al. (2012) suggest their LTS ratings correspond to Geller's cyclist types as follows: "strong and fearless" can tolerate up to LTS 4 roadway segments, "enthused and confident" can tolerate up to LTS 3 roadway segments, and "interested but concerned" will only tolerate LTS 2 and LTS 1 roadway segments. Using San Jose, California as a case study, they calculated LTS for the entire street network and show that the community is well-connected when every possible street is considered, but when only LTS 1 and LTS 2 streets are considered, "islands" of poor connectivity emerge, separated by barriers of high-stress streets. They suggest that "interested and concerned" cyclists might tolerate a small amount of high-stress bicycling (perhaps one or two short street segments), but otherwise they will probably not choose to use their bicycle to get to their destination. Furthermore, they demonstrate how a few proposed bicycle facility improvements (i.e. stress reducing bicycle accommodations) would triple overall connectivity. They then argue, "For a bicycling network to attract the widest possible segment of the population, its most fundamental attribute should be low-stress connectivity" (Mekuria et al., 2012, Abstract).

In terms of utilitarian transportation, a demand for greater connectivity is more precisely a demand for greater *accessibility*, i.e. the ease of reaching important destinations[2]. Hansen (1959) developed a widely used method to evaluate accessibility where the accessibility of a particular location (origin) to a set of all possible destinations is equal to an *impedance relationship* between the origin and each destination times the *intensity* of the destination and summed across all destinations. The impedance relationship might be, for example, distance, travel time, cost or some functional form thereof. The intensity of the destination is a valuation of importance or attractiveness, such as number of employees or floor area.

A few researchers have attempted to modify Hansen's accessibility model for bicycle travel. Lowry et al. (2012) created a GIS tool to sum the BLOS values along the shortest path from each residential parcel (origin) in a community to all non-residential parcels (destinations) to quantify the "bikeability" for each origin. McNeil (2010) defined a list of essential destination types (e.g. restaurant, bank, etc.) and associated a point value to each type. He then calculated an accessibility score for residential parcels by summing the points within a 20-minute bike ride. The Walk Score® website uses a similar method to assess how

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[2] Technically speaking, it is possible that a network could be very well-connected, but does not exhibit any good reason besides recreation for traveling across the network.

good a location is for walking on a scale from 0 – 100 (Walk Score, 2014a). A user of the free website enters a street address and a map appears showing the location that was entered, nearby amenities, and an accessibility score for the location based on the diversity of amenities within walking distance. The creators of the website developed a more sophisticated method to calculate Bike Score™; however, the method is not available as an interactive web application. Instead, the website provides Bike Score™ summaries for over 100 cities (Herst, 2013). The proprietary Bike Score™ method involves proximity to bike lanes, nearby hills, and the local commuting mode share as derived from the most recent US Census (Walk Score, 2014b).

These methods are all effective at providing valuable information regarding the importance of low-stress bicycle facilities, but they do not incorporate systematic prioritization procedures. The rationale for developing our new method is to combine the low-stress connectivity principles with a systematic prioritization technique.

Project Prioritization

Capital investment decisions of any kind, not just bicycle improvement projects, usually involve two key steps: project appraisal and project prioritization. Project appraisal determines if there is economic justification for the project based on expected benefits and costs. One approach is to monetize expected impacts over a particular time period in terms of present-value dollars to confirm a benefit-cost ratio greater than one. It can be fairly easy to estimate costs; NCHRP Report 552 provides guidance to estimate construction and operating costs for bicycle improvement projects (Krizek et al., 2006)[3]. On the other hand, monetizing benefits can be very difficult. Most benefits from bicycle improvement projects are non-market benefits, meaning the dollar value is not readily apparent. They are also typically indirect or ancillary benefits, meaning the benefit is not directly due to the project, but rather due to incidental impacts from change in behavior. For example, if a community improves their bicycle network, more people might choose to ride their bike rather than drive, which in turn might improve health, reduce emissions, and decrease traffic congestion. Likewise, improvement projects might increase home values or increase community attractiveness. These benefits, as well as direct benefits like reduced bicycle crashes, are very difficult to

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[3] See Appendix A

quantify and monetize. Consequently, decision-makers often use professional judgment and the intensity of public request to justify bicycle facility improvement projects.

Once projects have been determined to be economically justified, the next step is to prioritize them for implementation. There are various techniques, and the information used during project appraisal can often be used for prioritization as well. For example, through a process called Incremental Analysis projects can be rank-ordered based on benefit-cost ratios. However, once again decision-makers face the challenge of monetizing non-market benefits. An alternative approach is to identify performance indicators (also called measures of effectiveness or project selection criteria) to evaluate how well a project is expected to perform with regard to specific goals and objectives[4]. For example, the Seattle Department of Transportation (SDOT) identified five goals and corresponding performance indicators to prioritize candidate bicycle improvement projects through public involvement activities, stakeholder focus groups, assessment of data availability, a review of the literature, and other activities. The goals are to increase (1) ridership, (2) safety, (3) connectivity, (4) equity, and (5) livability (SDOT, 2013). Prioritization can be achieved by rank-ordering a single performance indicator, a composite indicator, or through some deliberative process.

Preferably, the evaluation of performance indicators should involve quantitative analysis. The USDOT notes, “Quantitative information lends objectivity to a decision-making process which might otherwise be dominated by subjective judgment or political considerations.” (FHWA, 2011). Quantitative analysis is more likely to be repeatable and transparent. Nevertheless, as already discussed, the benefits associated with bicycle improvement projects are often very difficult to quantify, in which case, qualitative indicators may be the only viable alternative. Qualitative evaluation might consist entirely of narrative description. For example, the City of Portland’s bicycle implementation plan involves a series of yes/no and open-ended questions to evaluate seven performance indicators. A quasi-qualitative evaluation might involve subjectively assigning a “score” to some or all of the performance indicators on a scale of 1 to 10. SDOT’s bicycle master plan notes that project prioritization should use “a variety of qualitative and quantitative methods, recognizing that prioritizing bicycle projects is not a science but rather an art.” (SDOT, 2013, pg. 8).

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[4] Sometimes performance indicators can also be used for post-project evaluation to determine if goals are being met and inform future project development and implementation.

Chapter 3. Method

The method developed for this thesis routes residential parcels to business destinations. The analyst follows three steps and utilizes a GIS tool. The first step is to define impedance weights for routing the shorting paths. The second step is to calculate accessibility to important destinations. The third step is to rank projects based on centrality. The analysis is done for the existing conditions and for any proposed improvement scenarios. Comparing the output for the scenarios allows the analyst to rank bicycle facility projects. This chapter describes the three steps and GIS tool.

Routing Shortest Paths

Bicyclists traveling for utilitarian purposes choose routes that will minimize distance, slope, and other undesirable attributes such as vehicle traffic. This behavior can be modeled by assigning every link and node in the bicycle network a "weight" (also called impedance or generalized cost) and finding the "shortest" path between origin and destination that minimizes total weight. For a street and trail network composed of a set of links and a set of nodes, denoted E and V (in graph terminology links and nodes are called edges and vertices, respectively), we define the *natural weight* for every link $e \in E$ as:

$$W_e^* = L_e\left(1 + F_{slope,e}\right) \qquad \text{(Equation 1)}$$

where

W_e^* = natural weight for link e,

L_e = length of link e, and

$F_{slope,e}$ = slope factor for link e.

In Equation 1, the slope factor increases the perceived distance across a link by a certain percentage. Broach et al. (2012) placed GPS trackers on cyclists and used logistic regression to empirically identify slope factors. For example, they found that ascending a moderate slope is equivalent to increasing travel distance by 40%, and ascending an extremely steep slope is equivalent to increasing travel distance by 320%. In other words, a bicyclist is willing to go 320% farther to avoid a very steep slope.

We define the natural weight for passing through every node $v \in V$ as:

$$W_v^* = F_{turn,v} \qquad \text{(Equation 2)}$$

where $F_{turn,v}$ represents the perceived increase in distance due to turning (if a turning movement is to occur). For example, if L is measured in feet, then F_{turn} might be 150 feet for a left turn and 50 feet for a right turn. Thus a cyclist seeking to find the shortest "distance" to his or her destination will avoid turning, especially left turns.

The shortest path between origin *i* and destination *j* based on minimizing total W_e^* and W_v^* from *i* to *j* is an ordered set of links denoted $\sigma_{ij}^* \in E$, which we call the *natural path*. The natural path represents the path a bicyclist would choose based solely on distance, slope, and avoiding turns.

We define *stressed weight* for a link and node, respectively, as:

$$\widehat{W}_e = L_e\left(1 + F_{slope,e} + F_{stress,e}\right) \qquad \text{(Equation 3)}$$

$$\widehat{W}_v = F_{turn,v} + F_{stress,v} \qquad \text{(Equation 4)}$$

where the additional component F_{stress} represents a perceived increase in distance due to vehicle traffic stress. Stress factors can be determined empirically in the same manner as slope factors, i.e. using GPS tracking to exploit observed bicyclist routing behavior. The stress factors used in the case study are presented in the next chapter.

The shortest path between *i* and *j* based on minimizing total stressed weight is denoted $\hat{\sigma}_{ij} \in E$, which we call the *predicted path*. The predicted path represents the path a bicyclist would most likely choose to get from *i* to *j*.

The natural path and predicted path may or may not be the same. The natural path is what a bicyclist would choose if there were not any stress from vehicle traffic anywhere in the network. The length of the natural path will always be less than or equal to the length of the predicted path as long as F_{stress} is always non-negative[5].

Calculating Accessibility to Important Destinations

If the length between *i* and j is greater than some threshold, τ^*, then it is unlikely a bicyclist will travel for utilitarian purposes between *i* and j. For example, the 2009 National Household Survey suggests commuters typically do not bicycle beyond 5 miles (Santos et al., 2011). Furthermore, we assert that if the total stressed weight associated with $\hat{\sigma}_{ij}$ is greater than some amount, then a bicyclist will decide to forgo traveling from *i* to j. In other words, if the cumulative stress along a path exceeds a maximum acceptable stress threshold, $\hat{\tau}$, then the bicyclist will deem the trip too stressful and not complete the trip. The stress threshold $\hat{\tau}$ depends on the cyclist. Some cyclists are willing to tolerate more stress than others.

To calculate accessibility for a community, we define a set of destination types, $\tilde{B}$, to represent a “basket” of important and/or desirable types of destinations. For example, in the case study we defined $\tilde{B}$ to include the following: postal service, department store, grocery store, clothing store, restaurant, drinking place, pharmacy, sporting goods store, bank, barber/beauty salon, physical fitness facility, amusement and recreation, dentist, heath care provider, elementary or secondary school, university, library, child day care, religious organization, movie theatre, park, and bus stop.

The basket of destination types is analogous to the consumer price index which economists use to calculate the cost of purchasing a collection of essential items such as eggs, milk, and cereal. It is possible that some bicyclists would not need certain destinations in the basket, and it is also possible that different bicyclists would have unique preferences for particular destination types, e.g. preference for a particular restaurant. Nevertheless, like the consumer price index, the concept of a basket provides a means to calculate a meaningful metric with objectivity.

If B is the set of all possible destinations in a community, then $\hat{B}_i$ can be defined as the *predicted basket* for origin *i* representing the subset of destinations that can be reached

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[5] Because $\widehat{W}_e = W_e^* + L_e(F_{stress,e})$ and $\widehat{W}_v = W_v^* + F_{stress,v}$

through predicted paths $\hat{\sigma}_{ij}$ and within thresholds τ^* and $\hat{\tau}$. The percent of important destinations that can be reached from origin *i* is

$$\hat{R}_i = \frac{|\hat{B}_i|}{|\tilde{B}|} * 100\% \qquad \text{(Equation 5)}$$

where | | means the size of the set. This leads to a key metric introduced in this paper: *the percent of residents that can reach a majority of important destinations using low-stress bike routes*. The metric is denoted as $\hat{R}$ and is calculated as follows

$$\hat{R} = \frac{\sum_{i \in S} r(\hat{R}_i) * M_i}{\sum_{i \in S} M_i} \qquad \text{(Equation 6)}$$

where

S = set of all origins,

M_i = multiplier (population) for origin *i*, and

$$r(\hat{R}_i) = \begin{cases} 1, \text{ if } \hat{R}_i \text{ is} \geq 60\% \\ 0, \text{ otherwise} \end{cases}.$$

For the case study, the cutoff for “majority of important destinations” was 60%, but an analyst could use a different cutoff.

Assessing Connectivity based on Network Centrality

McDaniel et al. (2013) introduced a network connectivity metric called *centrality* to quantify the relative importance of a link in a network. Their formulation counted the number of times a link is used on the shortest path between every residential parcel (origins) and every non-residential parcel (destinations). We slightly modify their formula by only accounting for paths to the predicted basket, $\hat{B}_i$. Thus, our centrality metric for a link *e* is

$$C_e = \sum_{i \in S, j \in \hat{B}_i} \hat{\sigma}_{ij}(e)\, M_i M_j \qquad \text{(Equation 7)}$$

where

$$\hat{\sigma}_{ij}(e) = \begin{cases} 1, \text{ if link } e \text{ is used in predicted path } \hat{\sigma}_{ij} \\ 0, \text{ otherwise} \end{cases},$$

M_i = multiplier for origin i, and

M_j = multiplier for destination j.

The origin and destination multipliers represent a magnitude of trip potential. For origins, the multiplier is the population (or number of dwelling units), while the destination multiplier can be number of employees or square footage (see McDaniel et al. 2013 for more information).

Furthermore, we rescale the centrality values across the network to calculate an index between 0 and 100, as follows:

$$Network\ Centrality\ Index = NCI_e = \frac{C_e - \min_{e \in E} C_e}{\max_{e \in E} C_e - \min_{e \in E} C_e} * 100 \qquad \text{(Equation 8)}$$

NCI provides a means to evaluate the relative importance of links in the network. Next, for the links within a proposed improvement project, the Project Average NCI can be calculated by averaging the length-weighted NCI across the project. Formally this written as

$$Project\ Average\ NCI = \overline{NCI}_k = \frac{\sum_{e \in P_k}(NCI_e * L_e)}{\sum_{e \in P_k} L_e} \qquad \text{(Equation 9)}$$

where $e \in P_k$ are the links within improvement project k. The Project Average NCI provides a means to compare the importance of different projects in terms of network connectivity.

Conducting GIS Analysis

The calculations described above were coded for GIS using open-source Python code. The tool can prioritize candidate projects for a proposed improvement plan. The tool requires a street network, residential parcel data, destination points, and impedance tables as the input data[6]. The tool produces NCI and Project Average NCI values for the streets and shared-use paths polyline shapefile. The symbology representing these values utilizes graduated line thicknesses to characterize the relative importance of links and projects in the bicycle network. The tool also produces values for the percent of residents that can reach a majority of important destinations using low-stress bike routes. These values are located in the polygon shapefile of residential parcels. The symbology representing these values uses graduated shades of color to characterize the percent of basket destinations that can be reached. Finally, the tool outputs a csv file containing the Project Average NCI values for later analyses, and a help file was created so that users who are unfamiliar with the tool can easily navigate the GUI[7].

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[6] See Appendix E: Tool Organization and GUI

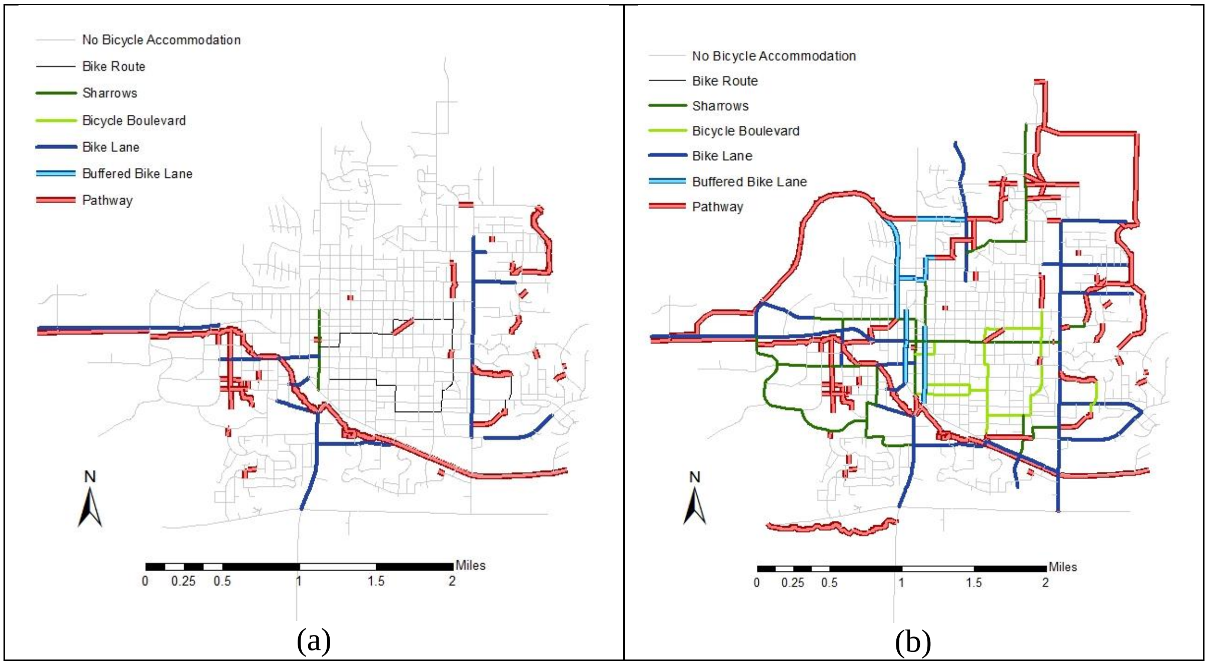
[7] See Appendix F: Help Documentation

Chapter 4. Case Study Data

Network Improvement Scenarios

Moscow, Idaho (population 25,000) is our case study. The community is home to the University of Idaho, which is the state's oldest public university. Washington State University in Pullman, Washington is located nine miles away, and it is connected by a shared-use path. The university students and employees contribute to a bicycle mode share higher than usual for a rural community of this size.

Figure 4.1 shows the case study's bicycle facilities for the existing conditions and proposed improvement plan. The proposed improvement plan consists of over 29 miles of various bicycle facilities, which are broken up into 37 projects. These projects include the implementation of sharrows, bicycle boulevards, bike lanes, buffered bike lanes, pathways, and grade separated crossings (underpasses). The total cost of the proposed improvement plan is $4,297,575. The individual projects have been deemed economically justified, but it is not financially feasible to implement the entire plan simultaneously. The projects therefore need to be prioritized.



(a) (b)

Figure 4.1: Case study bicycle facilities for (a) existing conditions and (b) proposed improvement plan.

Natural weight and stressed weight were calculated (see Chapter 3) for every link in the network under the existing conditions and proposed improvement plan. Slope factors were based on the findings of Broach et al. (2012). For links, stress factors were calculated as

$$F_{stress,e} = F_{facility,e} * \left(1 - F_{bikeaccom,e}\right) \qquad \text{(Equation 10)}$$

where

$F_{stress,e}$ = stress factor for link e,

$F_{facility,e}$ = roadway facility stress factor for link e, and

$F_{bikeaccom,e}$ = bicycle accommodation stress reduction factor for link e.

Equation 10 is essentially a new bicycle suitability assessment method that produces a value for perceived stress. Our intent with Equation 10 was to introduce a simple bicycle suitability method that uses minimal and commonly available roadway attribute data. The roadway facility factors increase stress while the bicycle accommodation factors reduce stress; both are percentages between 0 and 100%. Tables 4.1 and 4.2 show the factors used in the case study. The magnitude of increased stress is greater for facilities with presumably greater vehicle traffic intensities. Stress factors were devised using professional judgment and the findings of Broach et al. (2012) and Hood et al. (2001). For modeling in GIS, an additional stress of 400% of the length is added for wrong-way travel (Hood et al., 2001).

Table 4.1 Roadway Facility Stress Factors

Roadway Facility	**Stress Factor (%)**
Pathway	0%
Greenway	5%
Local	10%
Priority Local	20%
Collector	30%
Minor Arterial	50%
Primary Arterial	75%

Table 4.2 Bicycle Accommodation Stress Reduction Factors

Bicycle Accommodation	**Stress Reduction Factor (%)**
Signed Bike Route	10%
Bicycle Boulevard	20%
Sharrows	20%
Bike Lane	40%
Buffered Bike Lane	60%
Protected Bike Lane	70%

For the nodes of the network, the case study turn factors were 44 feet, 30 feet, and 15 feet for left turns, right turns, and through movements, respectively[8]. Node stress factors, $F_{stress,v}$, were determined based on the type of facility approaching the intersection and the cross-street facility type. Table 4.3 shows the cross street stress factors used in the case study. The rows represent approach facility types and the columns represent cross-street facility types. The units are in feet and represent an increase in perceived travel, such that more stressful street crossings are associated with greater perceived distance traveled. Although minor and primary arterials are typically stressful facilities, sometimes they can be attractive because they provide direct routes and have few interruptions.

A community could define their own set of factors and factor values, perhaps using a public involvement process, GPS tracker data, or some other bicycle suitability method, such as the Highway Capacity Manual's BLOS or the LTS method developed by Mekuria et al. (2012).

Table 4.3 Street Crossing Stress Factors

Facility Type Approach\Cross	**Pathway**	**Greenway**	**Local**	**Priority Local**	**Collector**	**Minor Arterial**	**Primary Arterial**
Pathway	0	10	20	30	50	75	125
Greenway	0	0	0	0	0	75	125
Local	0	20	20	30	50	75	125
Priority Local	0	20	10	30	50	75	125
Collector	0	0	0	0	50	75	125
Minor Arterial	0	0	0	0	50	75	125
Primary Arterial	0	0	0	0	30	50	125

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[8] These numbers were devised based on professional judgment to accurately model left turn movements in GIS. In order to accurately model left turn movements, the summation of right and through movement turn factors must be greater than the left turn factors.

Origins and Destinations

Parcel data for the case study was obtained from the City of Moscow Community Development Department. The residential parcels were used in the analysis as the origins. Hoovers business data were used as destinations. Hoovers Inc., a subsidiary of Dun & Bradstreet Inc., maintains a database of more than 80 million companies, with information about industry type, street address, number of employees, facility square footage, annual revenues, and other business information (Hoovers, N.D.). Hoovers business data can be purchased through a subscription service or directly through their website by choosing specific database filters, such as zip code and Standard Industrial Classification (SIC) code[9].

For the case study, Hoovers business data was obtained for companies within city limits and with SIC codes corresponding to these basket destination types: postal service, department store, grocery store, clothing store, restaurant, drinking place, pharmacy, sporting goods store, bank, barber/beauty salon, physical fitness facility, amusement and recreation, dentist, heath care provider, elementary or secondary school, university, library, child day care, religious organization, and movie theatre. The Hoovers business data was geocoded for GIS analysis. Figure 4.2 shows the case study residential parcels and Hoovers business data points. Public parks, bus stops, and movie theatres were added to the GIS file and included as basket destination types[10].

The following thresholds were used for the case study. The acceptable travel distance threshold, τ^*, was 5 miles. The acceptable stress threshold, $\hat{\tau}$, was 10%. A "majority" of important destinations was defined as 60% or more of basket destination types. (See Chapter 3. Method for more information about thresholds).

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[9] See Appendix B: Dun & Bradstreet Hoovers Data

[10] Public parks and bus stops had to be added to the GIS file because Hoovers business data does not contain this information. Movie theaters were also added because the case study's Hoovers business data wrongly categorized two movie theatres under different SIC codes. See Conclusion for Hoovers data limitations.

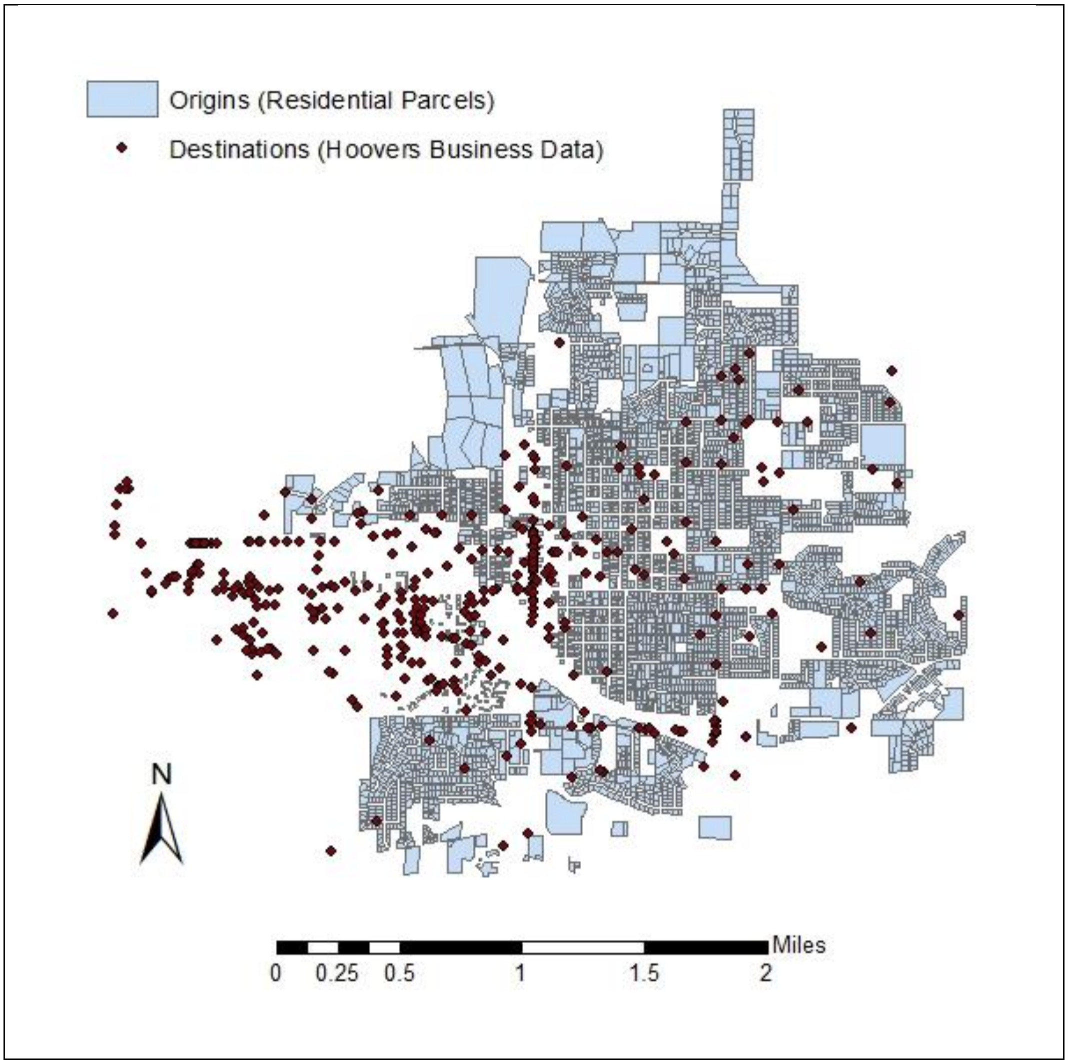


Figure 4.2: Origins and destinations.

Chapter 5. Analysis and Results

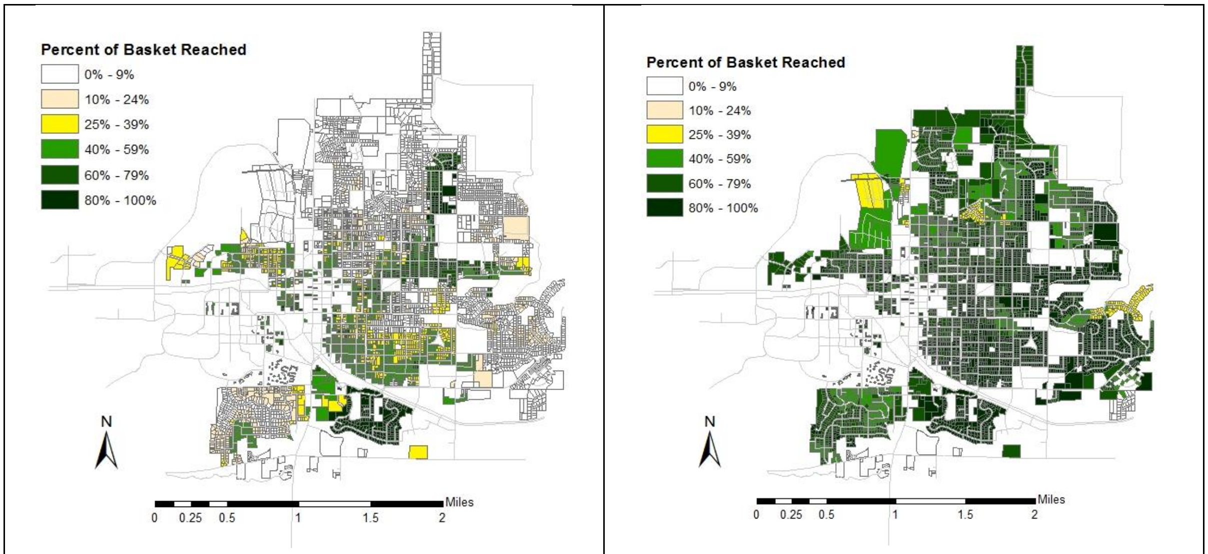
The analysis was conducted for two scenarios: the existing conditions and proposed improvement plan. The execution time on a standard, workstation-class laptop was about 7 minutes for each scenario (Lenovo w500 with 4 GB memory and Intel Core 2 Duo 3.06 GHz processor). This chapter describes the analysis and results.

Accessibility to Important Destinations

A key output from the analysis concerns the accessibility to important destinations. Figure 5.1 shows the percent of important destinations that can be reached using low-stress bike routes for each residential parcel. Many residential parcels exhibit poor accessibility to important destinations under the existing conditions (Figure 5.1a). In fact, most of the parcels cannot even reach 25% of the basket destination types. Accessibility is especially poor along the perimeter of the case study, with the exception of the south-east residential units that border the shared-use path. One neighborhood in the south-east exhibits excellent accessibility by bicycle because it can directly access a shared-use trail, comprises low-stress streets, and is in close proximity to a shopping center with a variety of destinations.

Figure 5.1b shows how low-stress bicycle improvements can increase the accessibility to important destinations. After implementing over 29 miles of various bicycle facilities, it can be seen that most of the residential parcels are able to access at least 60% of the basket destination types. This is because the proposed improvement plan consists of low-stress facilities that are conducive for utilitarian bicycle trips.

Across the community the proposed improvement plan would dramatically increase the percent of residents that can reach a majority of important destinations using low-stress bike routes from 12% to 78%. This drastic change would result from completing the entire proposed improvement plan, but other scenarios could be analyzed with more or fewer projects. Projects could even be analyzed one at a time, but the analysis would not take into account the interaction between projects. Analysts could use maps like these to visualize how improving low-stress connectivity might help various areas of the community and/or population segments.



12% of residents can reach a majority of important destinations using low-stress bike routes.

(a)

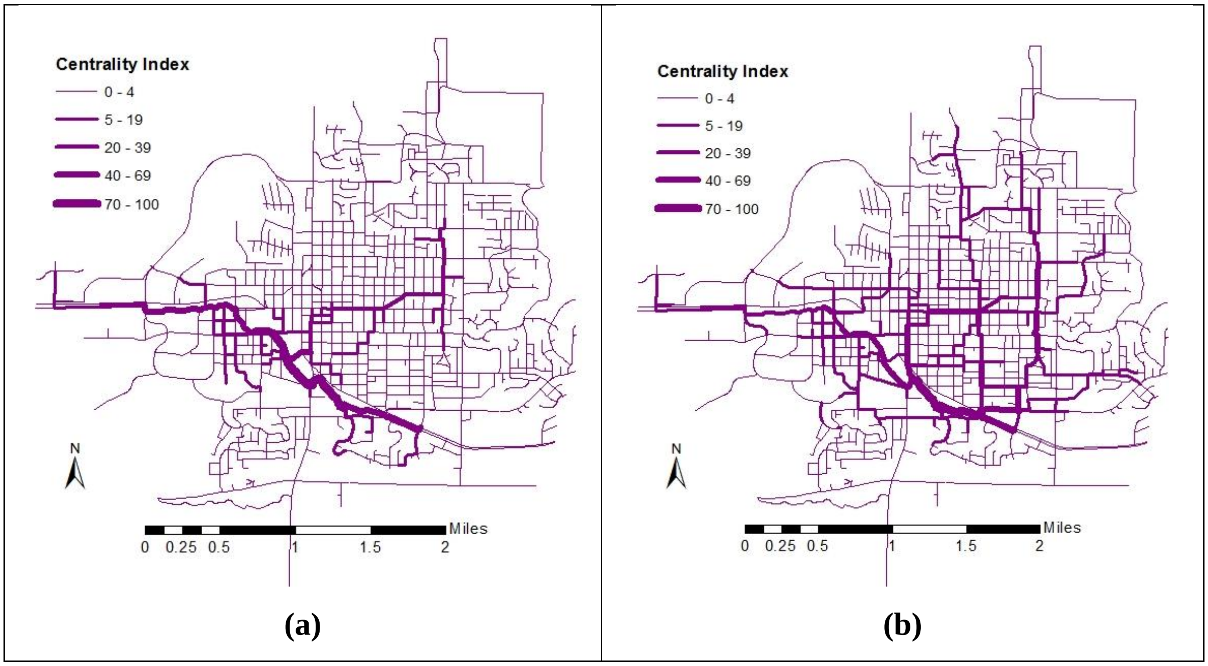
78% of residents can reach a majority of important destinations using low-stress bike routes.

(b)

Figure 5.1: Accessibility to important destinations for (a) existing conditions and (b) proposed improvement plan.

Network Centrality Index

NCI was calculated for every link in the network for the existing conditions and proposed improvement plan. The calculation of NCI can be thought of conceptually as gauging the *essential flow* from every residential parcel in a community to the closet nearby important destinations. Figure 5.2 shows the NCI for the existing conditions and proposed improvement plan. Figure 5.2a shows most of the NCI or essential flow runs east-west along the southern shared use trail. Figure 5.2b shows a dramatic change in essential flow throughout the community. High NCI values are concentrated along the various proposed bicycle facilities. Across the community the proposed improvement plan would change the location and amount of essential flow through the network.



(a) **(b)**

Figure 5.2: Network Centrality Index for (a) existing conditions and (b) proposed improvement plan.

To determine which proposed improvement project would have the greatest impact on improving network connectivity, values for Project Average NCI were calculated using Equation 9 and compared for the existing conditions and proposed improvement plan. The projects with the greatest change are considered the most important to the overall network. Figure 5.3 shows the change in Project Average NCI between the existing conditions and the proposed improvement plan. Six projects exhibit significant change in Project Average NCI. These projects provide better access to important destinations, and they provide better access to the southern shared-use path, which is a crucial bicycle facility for utilitarian trips. The projects that showed minor change are either bike paths that are more practical for recreational purposes, or bike facilities that do not provide access to a large number of destinations. There was one project that showed adverse change in Project Average NCI, meaning there was a *decrease* in essential flow after the proposed improvement plan was implemented. This is probably because the other surrounding bicycle improvement projects are more conducive for utilitarian bicycle travel and therefore would attract more of the essential flow.

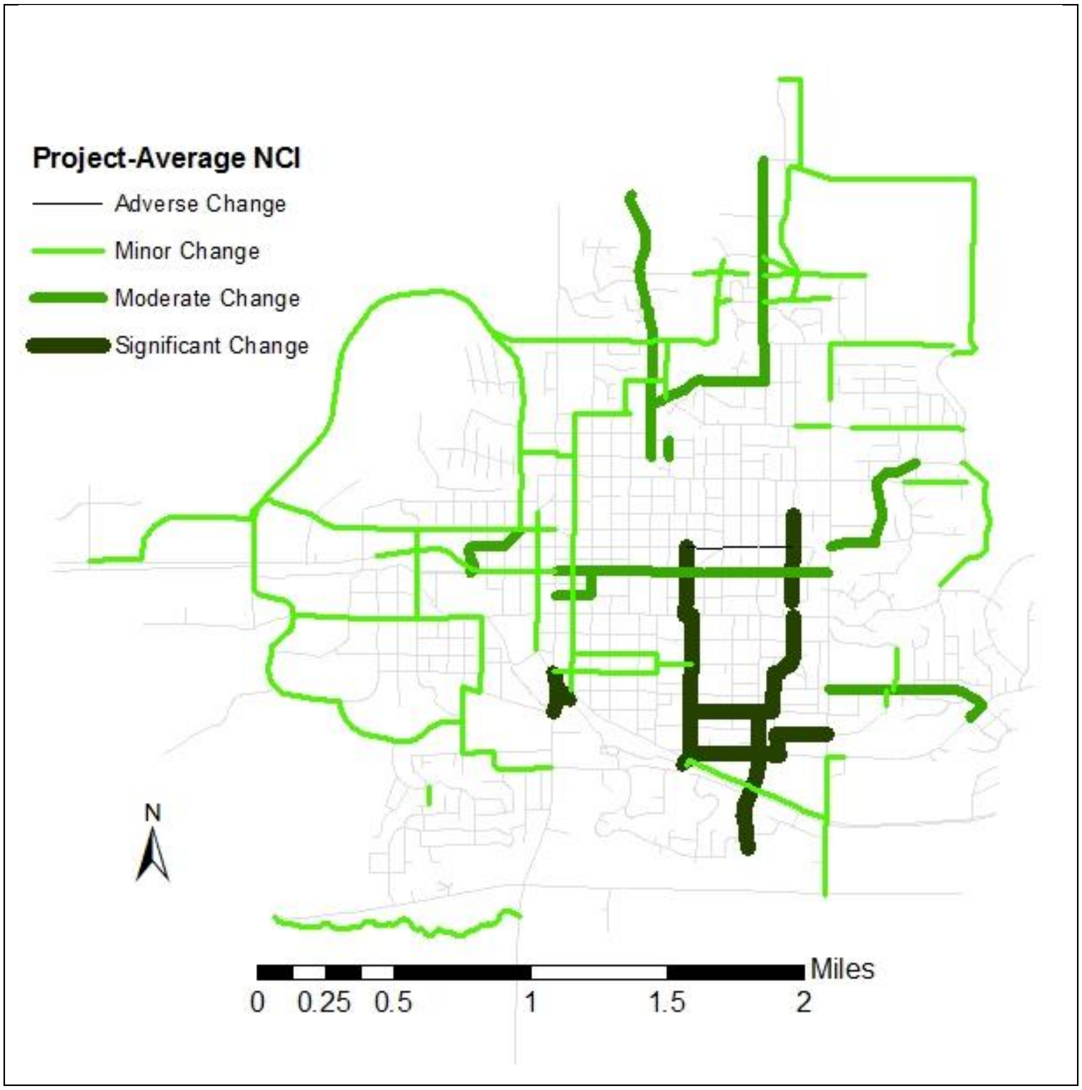


Figure 5.3: Change in Project Average NCI between the existing conditions and proposed improvement plan.

Table 5.1 lists all 37 projects ranked by change in Project Average NCI. The greater the change between the existing conditions and proposed improvement plan equates to a higher rank of *connectivity importance*. The highest ranked project is a bike path underpass of a primary arterial. This project provides a critical connection between the southern shared-use path and the bicycle boulevards to the north. Two of the top five projects are bike path underpasses that connect the southern shared-use path to surrounding low-stress bicycle facilities. The remaining three projects ranked in the top five are bicycle boulevards that directly feed into the southern bike path via the underpass of the highest ranked project.

Some projects involve constructing completely new trails, in which case the Project Average NCI is zero for the existing conditions. Sometimes new trails exhibit significant change in Project Average NCI because the essential flow goes from zero under existing conditions to a large number under the proposed improvement plan (e.g. the 3rd ranked project). On the other hand, for a few new trails the Project Average NCI under the proposed improvement plan is very low and is reflected in the rank ordering (e.g. the 25th to 28th ranked projects). These projects rank poorly because the method of prioritizing bicycle facility improvements is based on routing utilitarian trips instead of recreational travel. Whereas utilitarian trips have distinct origins and destinations, recreational travel typically does not. Riding one's bicycle for the purpose of exercise is an example of recreational travel, and often there is no well-defined destination.

Table 5.1 also presents estimated project costs[11]. A community could choose to fund projects according to the rank order of change in Project Average NCI until all available funding is exhausted. For example, if the case study community were to have a budget of $2 million, then the top nine projects could be funded. Another approach might be to select projects so as to fund as many as possible while maximizing total change in Project Average NCI. Table 5.1 shows that some projects are low cost yet exhibit significant change in Project Average NCI (e.g. the 2nd ranked project). On the other hand, some projects are very costly and exhibit very poor change in Project Average NCI. The 23rd ranked project, for example, would cost nearly half a million dollars but only exhibits a small change in NCI.

How ever a community chooses to select projects, it is important to note that the analysis is for the full scenario and not individual projects. In the case study, the proposed improvement plan is a "full build-out" of all projects, which means projects and their respective ranks are interdependent. For example, the bicycle boulevard projects ranked 2nd, 4th, and 5th are all desirable due to their low cost and substantial change in Project Average NCI. Their substantial change in Project Average NCI, however, is largely dependent on the implementation of the 1st ranked pathway underpass project because the bicycle boulevards directly feed into the pathway underpass. If funding is limited, the case study community may wish to implement these bicycle boulevard projects, but without the implementation of the 1st ranked pathway underpass, they should expect lower changes in Project Average NCI.

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[11] See Appendix A: Estimating Costs for Bicycle Improvement Projects

Planners and engineers may choose to remove costly projects from consideration and rerun the analysis to determine new projects ranks for affordable bicycle facilities. These new ranks would be more representative of Project Average NCI changes in the short term but quite possibly less representative of Project Average NCI changes in the long term. If projects are disregarded for one analysis, but then are later implemented, then the entire bicycle network would function differently, and the change in Project Average NCI might be different.

Table 5.1 Priority Ranking for Proposed Improvement Projects

Rank	**Description**	**Miles**	**Project Average NCI[a]**			**Cost**
			EC	**PIP**	**Change**	
1	Pathway underpass of primary arterial	0.66	1.00	36.70	35.70	$928,006
2	Bicycle boulevard on local	0.76	2.42	35.82	33.40	$37,640
3	Pathway underpass of primary arterial	0.20	0.00	27.37	27.37	$445,922
4	Bicycle boulevard on local	0.30	3.82	28.28	24.45	$14,234
5	Bicycle boulevard on local	0.71	11.38	35.50	24.11	$33,347
6	Sharrows and bike lanes on collector	0.50	4.50	22.53	18.03	$2,870
7	Sharrows on collector, bicycle boulevard on local	1.23	13.19	26.50	13.32	$6,370
8	Pathway connecting N Howard St at E Homestead Pl	0.06	0.00	11.00	11.00	$16,163
9	Bike lanes on collector	0.65	1.00	11.42	10.42	$4,587
10	Pathway underpass of primary arterial	0.38	0.00	8.56	8.56	$903,676
11	Bike lanes on collector	0.98	1.02	9.23	8.21	$6,923
12	Sharrows on local, pathway connecting Eisenhower St to N Mountain View Rd	0.57	1.47	9.64	8.17	$88,332
13	Sharrows on collector	1.25	1.00	9.01	8.01	$5,063
14	Bicycle boulevard on priority local	0.88	4.69	11.94	7.25	$43,121
15	Sharrows and bike lanes on collector, bike lane on minor arterial	1.33	1.94	7.72	5.78	$7,736
16	Sharrows on collector	0.97	2.37	7.84	5.48	$3,989
17	Pathway connecting Rodeo Dr to nearby neighborhoods	1.01	0.00	4.25	4.25	$189,516
18	Bicycle boulevard on local	0.22	1.00	5.09	4.09	$10,351
19	Pathway connecting Shetland Ct to Ridge Rd	0.07	0.00	4.08	4.08	$16,231
20	Bike lanes and sharrows on collector	0.33	2.81	6.22	3.41	$2,250
21	Buffered bike lanes on collector	0.78	1.00	3.52	2.52	$23,904
22	Sharrows on collector	1.38	2.55	4.98	2.44	$5,524
23	Long pathway from Palouse Mall to N Main St, buffered bike lanes on collector	2.72	1.00	3.41	2.41	$464,383
24	Bike lanes on primary arterial	0.68	1.00	2.34	1.34	$4,768
25	Sharrows on collector	0.69	15.63	16.86	1.23	$2,762
26	Pathway connecting neighborhoods to Orchard Ave	1.31	0.00	1.08	1.08	$243,769
27	Pathway running along W Palouse River Dr to Hwy 95	1.01	0.00	1.00	1.00	$186,362
28	Pathway connecting Mountain View Park and Arborcrest Rd	1.76	0.00	1.00	1.00	$319,422
29	Pathway connecting E 6th St to NE Paradise Loop pathway	0.58	0.00	1.00	1.00	$109,249
30	Bike lanes on minor arterial	0.23	1.00	1.86	0.86	$1,609
31	Buffered bike lanes on primary arterial	1.36	1.20	2.05	0.85	$42,977
32	Bike lanes on minor arterial	0.57	1.62	2.47	0.85	$3,998
33	Bike lanes on primary arterial	0.56	1.03	1.73	0.70	$3,962
34	Buffered bike lanes and a trail connecting N Almon St to N Polk St	0.85	1.00	1.58	0.58	$91,694
35	Bike lanes on collector	0.54	1.00	1.53	0.53	$3,802
36	Bike lanes on minor arterial	0.65	1.00	1.09	0.09	$4,587
37	Bicycle boulevard on priority local	0.39	20.38	14.27	-6.11	$18,476

[a] NCI = Network Centrality Index, EC = Existing conditions, PIP = Proposed improvement plan

Chapter 6. Conclusion

This thesis introduced a new method for prioritizing bicycle facility improvement projects based on low-stress network connectivity. Using Moscow, Idaho as a case study, over 29 miles of bicycle facilities were analyzed to determine their impact on the bicycle network. The case study's bicycle facilities are part of a proposed improvement plan, which breaks up the bicycle facilities into 37 projects. To determine the importance of each project, a new prioritization method used open-sourced Python code and GIS software to route every residential parcel to a defined "basket" of important destinations. The method produced a rank of each project's importance to the bicycle network, which provides planners and engineers valuable insight when facing challenging transportation investment decisions.

This prioritization method does not aim to be an all-in-one solution for every bicycle investment tradeoff. Instead, it is meant to provide critical information that can help guide the decision-making process for bicycle facility investments. Engineers and planners can use this method in a variety of ways. For example, a planner can choose to analyze a single project to see its impact on the percent of residents that can reach a majority of important destinations using low-stress bike routes. A planner could also analyze an entire proposed improvement plan and rank projects based on the change in Project Average NCI (as was illustrated in this thesis with the case study). Projects and their respective ranks are interdependent.

A few limitations should be noted. First, the method ranks projects based on existing origins and destinations. The implementation of future projects may not have the expected impact on accessibility because future origins and destinations are not considered. Second, the destinations (basket items) were selected by judgment decisions, and it is possible that the basket items are not all-inclusive. Third, the Hoovers business data are not perfect; it is possible for businesses to be categorized by incorrect SIC codes. Finally, impedance factors were not all based on previous research; some impedance factors were based on professional judgment.

Other limitations include recreational travel and the interdependencies of bicycle facility improvement projects. Recreational travel was not considered for the case study, and there is the potential for higher essential flows if recreational travel is included in the analysis. The interdependencies of bicycle facility improvement projects makes it difficult to quantify incremental improvements to a bicycle network, but there was no evident approach to mitigate this limitation.

One final limitation involves facility and bicycle accommodation simplifications. Facility and bicycle accommodation stress factors are aggregate representations of traffic and infrastructure characteristics. For example, the stress factor associated with local roadway facilities represents low vehicle speeds, low traffic volumes, and single-lane roadways. Conversely, the stress factor associated with primary arterial roadway facilities represents high vehicle speeds, high traffic volumes, and multi-lane roadways. Roadway facilities, however, can have a range of vehicle speeds, traffic volumes, and number of lanes, and still be classified under a single facility type. Facilities and bicycle accommodations were used instead of traffic and infrastructure characteristics because the data is easier to obtain. Although the data are easier to obtain, it is possibly less accurate than traffic and infrastructure characteristics.

This method can be improved by addressing some of the limitations previously mentioned. First, the origin-destination limitation can be addressed by acquiring new origin parcels and destination points in the future so that additional analyses can be conducted using the most up-to-date data. Second, future research should be done to determine the best possible basket destinations. It may be discovered that destinations will vary among cities due to differences in their Bicycle Master Plan goals. Third, analysts should review the Hoovers business data to ensure there are not any businesses incorrectly categorized by SIC codes. Fourth, recreational travel might want to be considered in future studies to determine the impact on essential flows of a bicycle network. Fifth, the interdependencies of bicycle facility improvement projects should be investigated to see if individual projects and their respective impacts on a bicycle network can be effectively isolated. Finally, additional research should be done to increase the accuracy of the impedance factors. For example, future analysts should investigate the accuracy of facility and bicycle accommodation stress factors by using individual traffic and infrastructure characteristics as opposed to our more aggregated approach.

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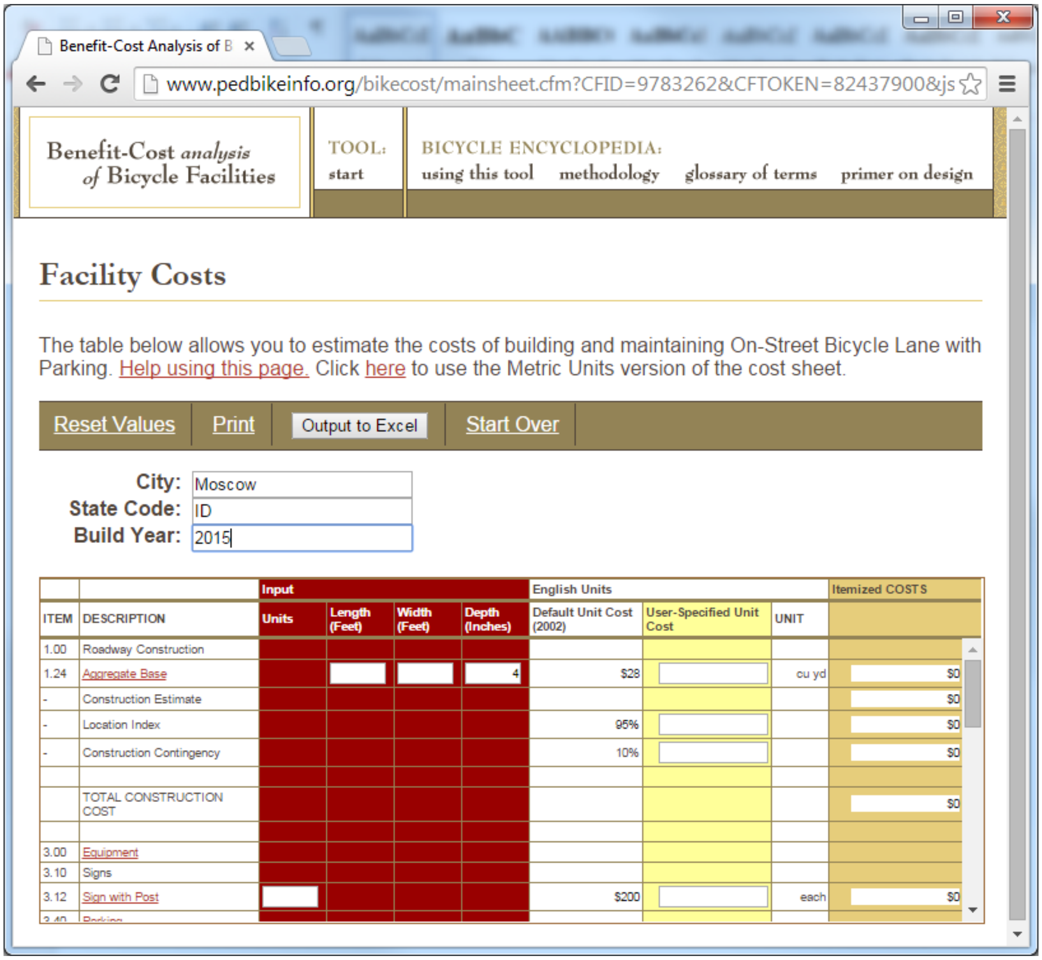
Appendix A: Estimating Costs for Bicycle Improvement Projects

Figure A.1 is a screenshot of the NCHRP 552 web-based guidelines for benefit-cost analyses of bicycle facilities. This webpage was used to estimate the case study's project costs, which can be seen in Appendix D, Table D.1. To estimate the cost of a project, a user inputs a build location and year, along with bicycle facility attributes. The web-based cost sheet results can be outputted as an excel file; Table A.1 is an excel file output example for Project 1. The web-based default unit costs were used for every bicycle facility attribute, except for the underpass attribute. A user-specified unit cost of $2,000 was used because the case study already has an existing facility at the Project 1 site, but there is currently no pathway under the primary arterial. The total estimated cost of Project 1 is $928,006.



Facility Costs

The table below allows you to estimate the costs of building and maintaining On-Street Bicycle Lane with Parking. Help using this page. Click here to use the Metric Units version of the cost sheet.

City: Moscow
State Code: ID
Build Year: 2015

		Input				English Units			Itemized COSTS
ITEM	DESCRIPTION	Units	Length (Feet)	Width (Feet)	Depth (Inches)	Default Unit Cost (2002)	User-Specified Unit Cost	UNIT	
1.00	Roadway Construction								
1.24	Aggregate Base				4	$28		cu yd	$0
-	Construction Estimate								$0
-	Location Index					95%			$0
-	Construction Contingency					10%			$0
	TOTAL CONSTRUCTION COST								$0
3.00	Equipment								
3.10	Signs								
3.12	Sign with Post					$200		each	$0

Figure A.1: Webpage for NCHRP 552 benefit-cost analysis of bicycle facilities.

Table A.1 Example Bicycle Facility Costs

		Input	**Itemized COSTS**						
ITEM	**DESCRIPTION**	**Units**	**Length (Feet)**	**Width (Feet)**	**Depth (Inches)**	**Default Unit Cost (2002)**	**User-Specified Unit Cost**	**UNIT**	**Itemized Cost**
	City	Boise							
	State Code	ID							
	Build Year	2016							
1	Roadway Construction								
1.1	Earthwork								
1.11	Clearing and Grubbing					$1,703		acre	$0
1.12	Excavation		1800	8	6	$15		cu yd	$4,000
1.13	Grading		1800	8		$2,555		mile	$697
1.14	Pavement Removal		1800	8		$14		cu yd	$0
1.15	Curb/Gutter Removal					$4		l ft	$0
-	Earthwork Contingency					10%			$470
1.2	Pavement								
1.21	Portland Cement Concrete Pavement				5	$142		cu yd	$0
1.22	Bituminous Concrete Pavement		1800	8	3	$135		cu yd	$18,000
1.23	Crushed Stone Surface				3	$37		cu yd	$0
1.24	Aggregate Base		1800	8	4	$28		cu yd	$4,978
1.25	Curbing		0			$22		l ft	$0
1.26	Curb Ramps	3				$1,068		each	$3,203
1.3	Drainage								
1.31	Storm Drains		2			$113		l ft	$226
1.4	Pavement Markings								
1.41	Bicycle Arrow					$53		each	$0
1.42	Bicycle Symbol					$71		each	$226
1.43	Bicycle Box (colored pavement)		8	5		$9		sqft	$0
1.44	Lane Striping					$3,266		mile	$0
1.45	Shared Lane Marking (sharrow)	8				$71		each	$569
1.5	Landscaping								
1.51	Landscaping - Grass					$1,363		acre	$0
1.52	Landscaping - Trail					$27,188		mile	$0
1.53	Root Dams					$11		l ft	$0
2	Structures								
2.1	Bridge								
2.12	Bridge Deck (concrete or steel)	1	100	16		$91		sqft	$145,455

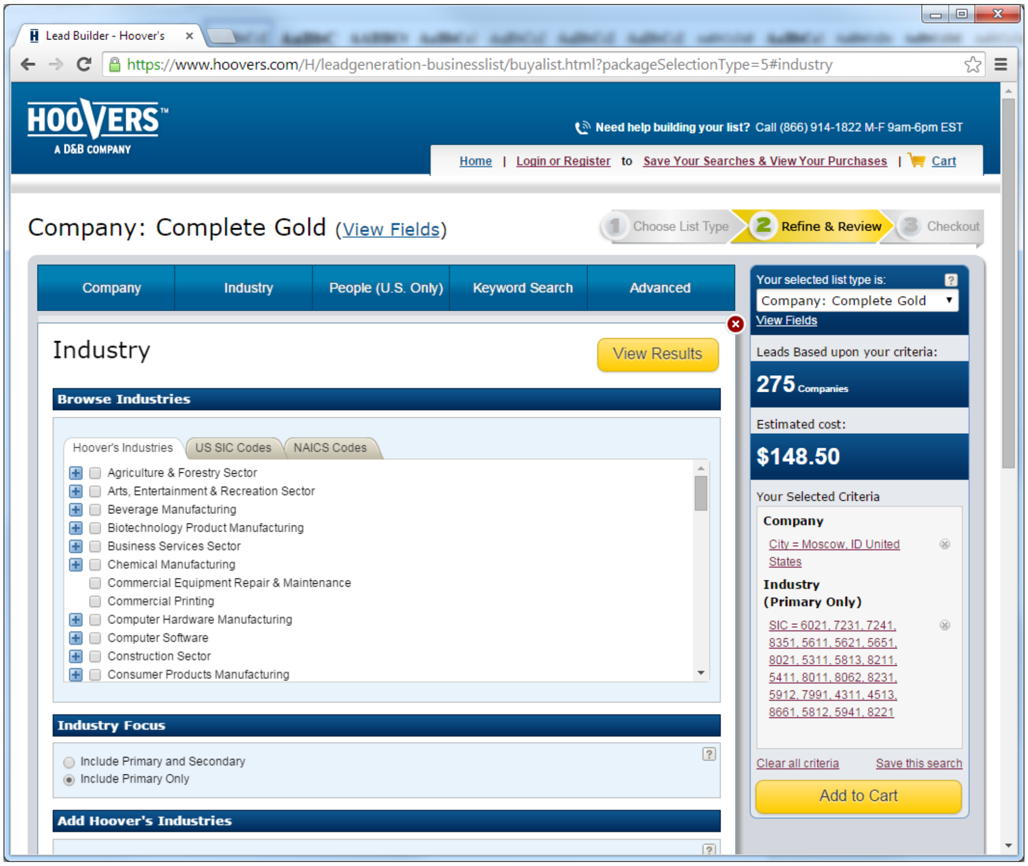
2.13	Abutments	2				$17,273		each	$34,545
-	Bridge Contingency					10%			$18,000
2.2	Underpass								
2.21	Underpass		100			$3,840	2,000	l ft	$200,000
-	Construction Estimate								$430,143
-	Location Index					95%			($21,507)
-	Construction Contingency					10%			$40,864
	TOTAL CONSTRUCTION COST								$449,499
3	Equipment								
3.1	Signs								
3.12	Sign with Post	2				$200		each	$400
3.2	Traffic Signals								
3.21	Bicycle Signal					$10,000		each	$0
3.22	Pedestrian Signal Activation - 4 Way					$3,900		each	$0
3.23	Pedestrian Signal Activation - 2 Way					$1,900		each	$0
3.24	Loop Detector					$1,500		each	$0
3.3	Barriers								
3.31	Trail Gates					$1,500		each	$0
3.32	Trail Bollards					$130		each	$0
3.33	Fencing					$13		l ft	$0
3.4	Parking								
3.41	Bicycle Rack (Inverted U, 2 bicycles)					$190		each	$0
3.42	Bicycle Rack (Ribbon or similar, 6 bicycles)					$65		per bike	$0
3.43	Bicycle Locker (2 bicycles)					$1,000		each	$0
3.44	Bike Station					$200,000		each	$0
3.5	Conveyance								
3.51	Bus Rack					$570		each	$0
3.52	Interior Train Rack					$0		each	$0
3.6	Lighting								
3.61	Street Lights					$3,640		each	$0
3.7	Security								
3.71	Emergency Call Boxes					$5,590		each	$0
3.72	Security Cameras					$7,500		each	$0

	TOTAL EQUIPMENT COST								$400
4	Real Estate								
4.01	Rural/Undeveloped					$1,270		acre	$0
4.02	Suburban/Single Family Residential					$37,669		acre	$0
4.03	Urban/High Density Residential					$17		sqft	$0
4.04	Urban CBD					$28		sqft	$0
-	Real Estate Contingency					20%			$0
	TOTAL REAL ESTATE COST								$0
-	Administration (Construction)					6%			$26,994
-	Planning (Construction)					2%			$8,998
-	Design/Engineering					10%			$44,990
-	Field Inspection					2%			$8,998
	SUBTOTAL PROJECT COST								$539,879
-	Project Contingency					30%			$161,964
	TOTAL BASE YEAR CAPITAL COST					1		2002	$701,843
	TOTAL BUILD YEAR CAPITAL COST					0		0	$928,006
5	Operations and Maintenance								
5.1	Maintenance					$6,500		mile/yr	$0
	TOTAL OPERATIONS AND MAINTENANCE								$0

Appendix B: Dun & Bradstreet Hoovers Data

Figure B.1 is a screenshot of Dun & Bradstreet's Hoovers Lead Builder. A user specifies a location for business data, and the Lead Builder outputs the number of companies and estimated cost of acquiring the data. Inputting SIC codes specifies the types of companies to be outputted, which can substantially reduce the cost of acquiring data. Figure B.2 shows the different Lead Builder packages, which have varying amounts of data that can be acquired. The "Expanded Company Information" ($0.54 per lead) data package was used to determine the number of businesses located in the case study, and it was also used to estimate the cost of obtaining the Hoovers business data.

Table B.1 presents basket destinations and their respective SIC codes. Table B.2 summarizes the case study results and the results for 12 different locations. Figures B.3 and B.4 respectively show Seattle and Moscow Hoovers Business Data for all and basket-only destinations.



https://www.hoovers.com/H/leadgeneration-businesslist/buyalist.html?packageSelectionType=5#industry

Company: Complete Gold (View Fields)

Industry

☐ Agriculture & Forestry Sector
☐ Arts, Entertainment & Recreation Sector
☐ Beverage Manufacturing
☐ Biotechnology Product Manufacturing
☐ Business Services Sector
☐ Chemical Manufacturing
☐ Commercial Equipment Repair & Maintenance
☐ Commercial Printing
☐ Computer Hardware Manufacturing
☐ Computer Software
☐ Construction Sector
☐ Consumer Products Manufacturing

○ Include Primary and Secondary
● Include Primary Only

Your selected list type is: Company: Complete Gold

Leads Based upon your criteria: 275 Companies

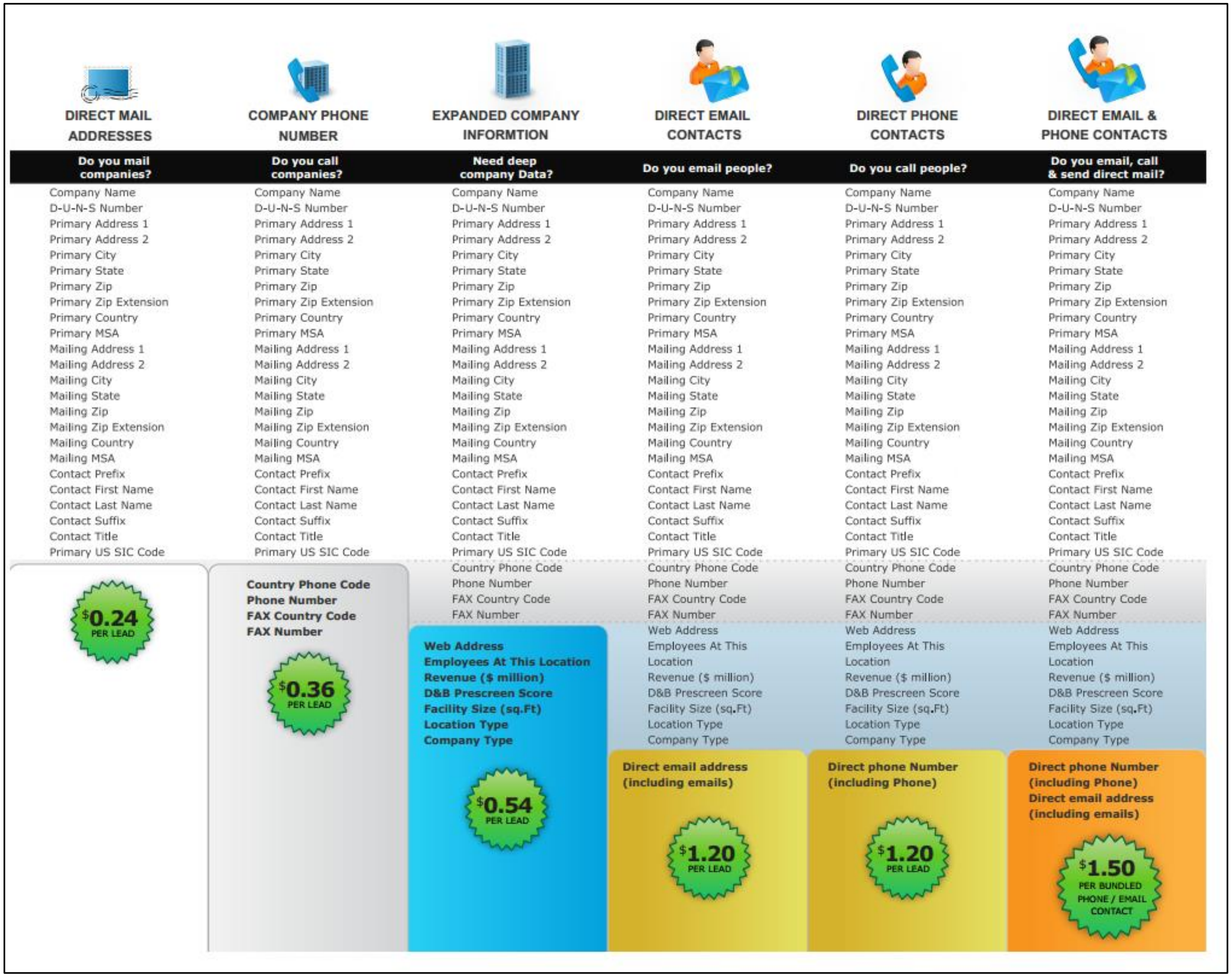
Estimated cost: $148.50

Your Selected Criteria

Company
City = Moscow, ID United States

Industry (Primary Only)
SIC = 6021, 7231, 7241, 8351, 5611, 5621, 5651, 8021, 5311, 5813, 8211, 5411, 8011, 8062, 8231, 5912, 7991, 4311, 4513, 8661, 5812, 5941, 8221

Figure B.1: Dun & Bradstreet Hoovers data list building webpage.



DIRECT MAIL ADDRESSES	COMPANY PHONE NUMBER	EXPANDED COMPANY INFORMTION	DIRECT EMAIL CONTACTS	DIRECT PHONE CONTACTS	DIRECT EMAIL & PHONE CONTACTS
Do you mail companies?	**Do you call companies?**	**Need deep company Data?**	**Do you email people?**	**Do you call people?**	**Do you email, call & send direct mail?**
Company Name	Company Name	Company Name	Company Name	Company Name	Company Name
D-U-N-S Number	D-U-N-S Number	D-U-N-S Number	D-U-N-S Number	D-U-N-S Number	D-U-N-S Number
Primary Address 1	Primary Address 1	Primary Address 1	Primary Address 1	Primary Address 1	Primary Address 1
Primary Address 2	Primary Address 2	Primary Address 2	Primary Address 2	Primary Address 2	Primary Address 2
Primary City	Primary City	Primary City	Primary City	Primary City	Primary City
Primary State	Primary State	Primary State	Primary State	Primary State	Primary State
Primary Zip	Primary Zip	Primary Zip	Primary Zip	Primary Zip	Primary Zip
Primary Zip Extension	Primary Zip Extension	Primary Zip Extension	Primary Zip Extension	Primary Zip Extension	Primary Zip Extension
Primary Country	Primary Country	Primary Country	Primary Country	Primary Country	Primary Country
Primary MSA	Primary MSA	Primary MSA	Primary MSA	Primary MSA	Primary MSA
Mailing Address 1	Mailing Address 1	Mailing Address 1	Mailing Address 1	Mailing Address 1	Mailing Address 1
Mailing Address 2	Mailing Address 2	Mailing Address 2	Mailing Address 2	Mailing Address 2	Mailing Address 2
Mailing City	Mailing City	Mailing City	Mailing City	Mailing City	Mailing City
Mailing State	Mailing State	Mailing State	Mailing State	Mailing State	Mailing State
Mailing Zip	Mailing Zip	Mailing Zip	Mailing Zip	Mailing Zip	Mailing Zip
Mailing Zip Extension	Mailing Zip Extension	Mailing Zip Extension	Mailing Zip Extension	Mailing Zip Extension	Mailing Zip Extension
Mailing Country	Mailing Country	Mailing Country	Mailing Country	Mailing Country	Mailing Country
Mailing MSA	Mailing MSA	Mailing MSA	Mailing MSA	Mailing MSA	Mailing MSA
Contact Prefix	Contact Prefix	Contact Prefix	Contact Prefix	Contact Prefix	Contact Prefix
Contact First Name	Contact First Name	Contact First Name	Contact First Name	Contact First Name	Contact First Name
Contact Last Name	Contact Last Name	Contact Last Name	Contact Last Name	Contact Last Name	Contact Last Name
Contact Suffix	Contact Suffix	Contact Suffix	Contact Suffix	Contact Suffix	Contact Suffix
Contact Title	Contact Title	Contact Title	Contact Title	Contact Title	Contact Title
Primary US SIC Code	Primary US SIC Code	Primary US SIC Code	Primary US SIC Code	Primary US SIC Code	Primary US SIC Code
	Country Phone Code	Country Phone Code	Country Phone Code	Country Phone Code	Country Phone Code
	Phone Number	Phone Number	Phone Number	Phone Number	Phone Number
	FAX Country Code	FAX Country Code	FAX Country Code	FAX Country Code	FAX Country Code
	FAX Number	FAX Number	FAX Number	FAX Number	FAX Number
		Web Address	Web Address	Web Address	Web Address
		Employees At This Location	Employees At This Location	Employees At This Location	Employees At This Location
		Revenue ($ million)	Revenue ($ million)	Revenue ($ million)	Revenue ($ million)
		D&B Prescreen Score	D&B Prescreen Score	D&B Prescreen Score	D&B Prescreen Score
		Facility Size (sq.Ft)	Facility Size (sq.Ft)	Facility Size (sq.Ft)	Facility Size (sq.Ft)
		Location Type	Location Type	Location Type	Location Type
		Company Type	Company Type	Company Type	Company Type
			Direct email address (including emails)	**Direct phone Number (including Phone)**	**Direct phone Number (including Phone)** **Direct email address (including emails)**
$0.24 PER LEAD	$0.36 PER LEAD	$0.54 PER LEAD	$1.20 PER LEAD	$1.20 PER LEAD	$1.50 PER BUNDLED PHONE / EMAIL CONTACT

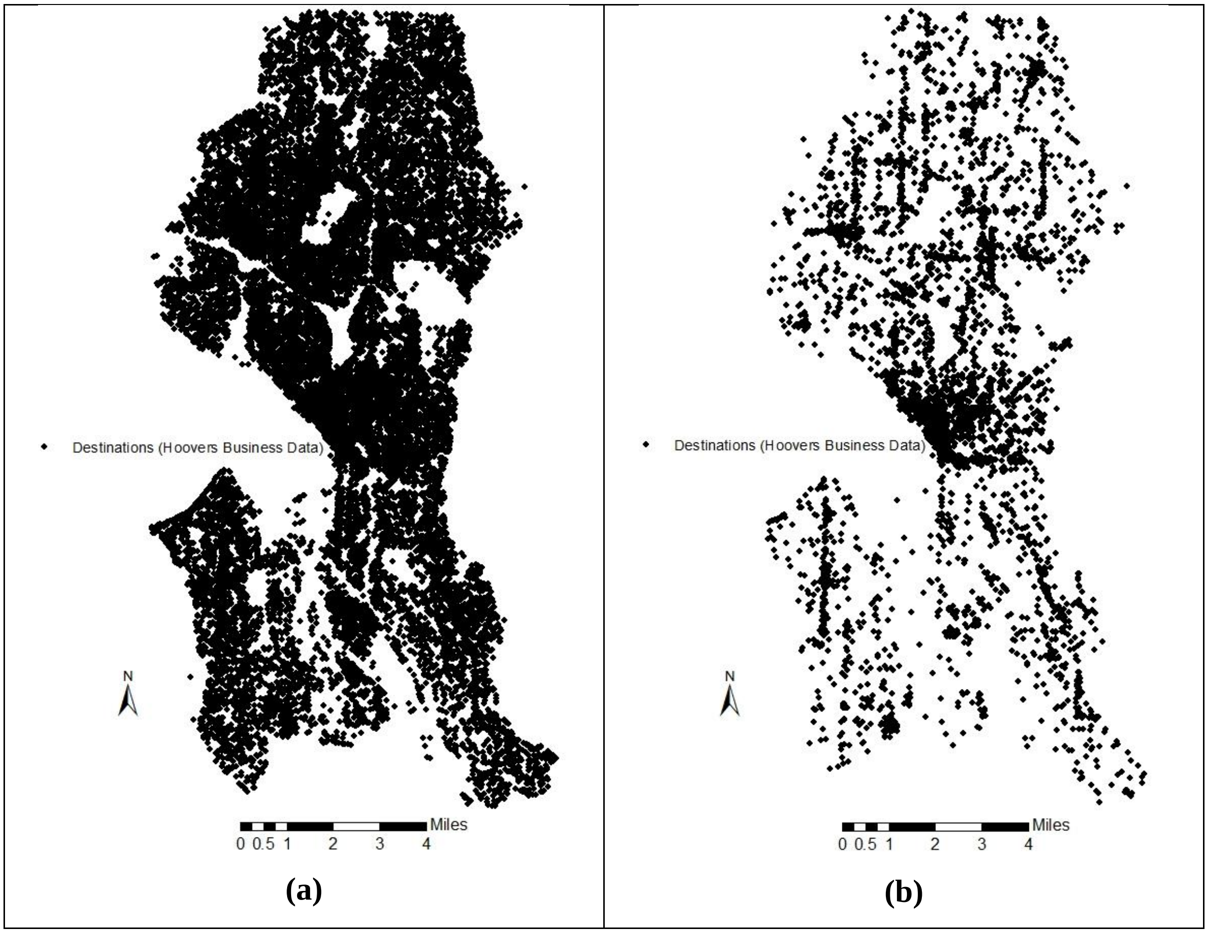
Figure B.2: Dun & Bradstreet Hoovers Lead Builder data field options.

Table B.1 Case Study Basket Destinations

Basket Destination	Basket SIC Codes	Moscow	Seattle
Bank	6021	6	82
Beauty Salon, Barber, Etc.	7231, 7241	17	650
Child Day Care	8351	14	369
Clothing Store	5611, 5621, 5651	8	363
Dentist	8021	8	559
Department Store	5311	4	19
Drinking Place	5813	3	296
Elementary or Secondary School	8211	12	165
Grocery Store	5411	9	502
Health Care Provider	8011, 8062	26	1130
Library	8231	4	43
Movie Theatre	7832, 7833	2	13
Pharmacy	5912	6	123
Physical Fitness Facility	7991	5	222
Postal Service	4311, 4513	2	20
Religious Organization	8661	34	446
Restaurant	5812	64	1349
Sporting Goods Store	5941	6	106
University	8221	37	87

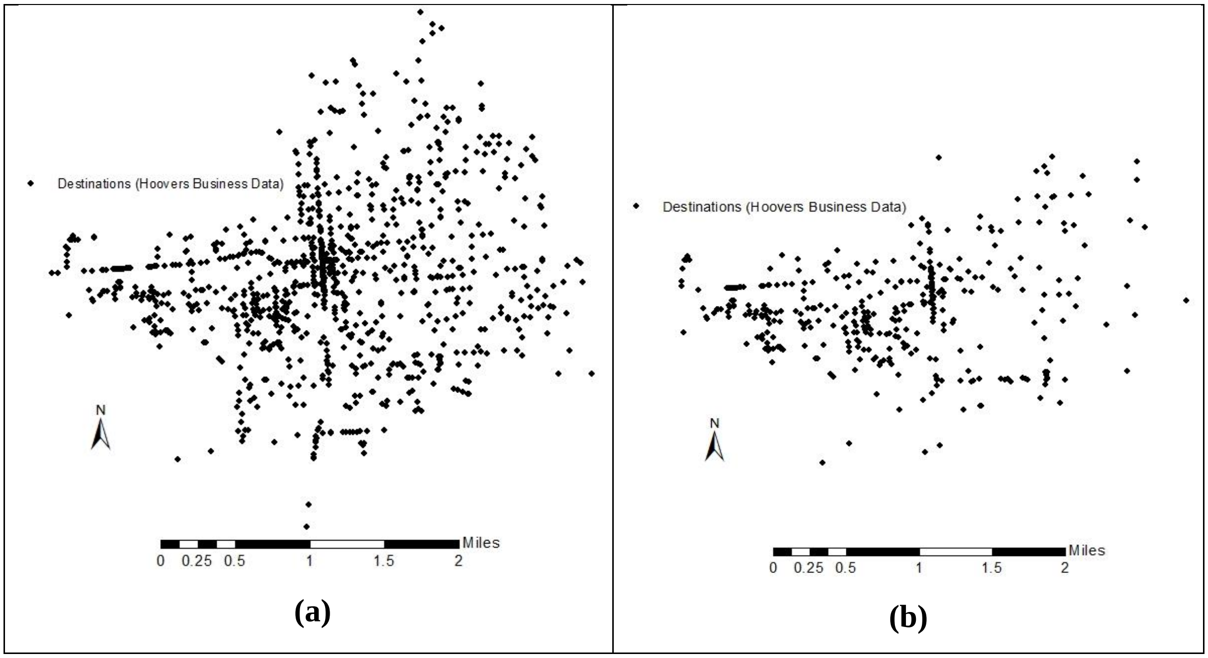
Table B.2 Dun & Bradstreet Price Comparisons

		All Destinations		Basket-Only Destinations		
City	**State**	**Number**	**Cost**	**Number**	**Cost**	**Cost Reduction**
Albuquerque	NM	36,471	$19,694	5,405	$2,919	85%
Arlington	VA	13,115	$7,082	1,849	$998	86%
Billings	MT	9,518	$5,140	1,273	$687	87%
Colorado Springs	CO	33,947	$18,331	4,895	$2,643	86%
Fort Worth	TX	45,131	$24,371	7,502	$4,051	83%
Indianapolis	IN	48,784	$26,343	8,762	$4,731	82%
Miami	FL	112,815	$60,920	15,613	$8,431	86%
Minneapolis	MN	55,428	$29,931	8,567	$4,626	85%
Moscow	ID	1,353	$731	275	$149	80%
New Orleans	LA	23,125	$12,488	4,458	$2,407	81%
Portland	ME	7,699	$4,157	1,350	$729	82%
San Diego	CA	82,303	$44,444	12,332	$6,659	85%
Seattle	WA	57,150	$30,861	8,986	$4,852	84%



(a) **(b)**

Figure B.3: Seattle Hoovers business data geocoded for (a) all and (b) basket-only destinations.



(a) **(b)**

Figure B.4: Moscow Hoovers business data geocoded for (a) all and (b) basket-only destinations.

Appendix C: Impedance Tables

In order to utilize the equations for stressed weight, distance and stress factors must be identified. Tables C.1, C.5, and C.6 contain the distance factors that are respectfully defined by slope, turning movements, and street crossings. Tables C.2, C.3, and C.4 contain the stress factors that are respectfully defined by facility type, bicycle accommodation type, and wrong-way travel. These distance and stress factors are inputs for Equations C1 – C3, and they affect an individual's bicycle route choice.

$$\widehat{W}_e = L_e\left(1 + F_{slope,e} + F_{stress,e}\right) \qquad \text{(Equation C1)}$$

where

$\widehat{W}_e$ = stressed weight for link *e*

L_e = length of link *e*

$F_{slope,e}$ = slope factor for link *e*

$F_{stress,e}$ = stress factor for link *e*

$$F_{stress,e} = F_{facility,e} * \left(1 - F_{bikeaccom,e}\right) \qquad \text{(Equation C2)}$$

where

$F_{stress,e}$ = stress factor for link *e*,

$F_{facility,e}$ = roadway facility stress factor for link *e*, and

$F_{bikeaccom,e}$ = bicycle accommodation stress reduction factor for link *e*.

$$\widehat{W}_v = F_{turn,v} + F_{stress,v} \qquad \text{(Equation C3)}$$

where

$\widehat{W}_v$ = stressed weight for node *v*

$F_{turn,v}$ = turn factor for node *v*

$F_{stress,v}$ = stress factor for node *v*

Table C.1 Slope Weight Increase Factors

Slope (Upper Cutoff %)	Distance Increase Factor (%)
2	0%
4	37%
6	120%
100	324%

Table C.2 Roadway Facility Stress Factors

Roadway Facility	Stress Factor (%)
Pathway	0%
Greenway	5%
Local	10%
Priority Local	20%
Collector	30%
Minor Arterial	50%
Primary Arterial	75%

Table C.3 Bicycle Accommodation Stress Reduction Factors

Bicycle Accommodation	Stress Reduction Factor (%)
Pathway	0%
None	0%
Bike Route	10%
Bicycle Boulevard	20%
Sharrows	20%
Bike Lane	40%
Buffered Bike Lane	60%
Protected Bike Lane	70%

Table C.4 Wrong-Way Stress Factor

Wrong-Way	Wrong-Way Stress Factor (%)
Wrong-Way	400%

Table C.5 Turn Stress Factors

Turn	Stress Factor (feet)
Left	44
Right	30
Through	15

Table C.6 Street Crossing Stress Factors

Traveling Street\Cross Street (feet)	**Pathway**	**Greenway**	**Local**	**Priority Local**	**Collector**	**Minor Arterial**	**Primary Arterial**
Pathway	0	10	20	30	50	75	125
Greenway	0	0	0	0	0	75	125
Local	0	20	20	30	50	75	125
Priority Local	0	20	10	30	50	75	125
Collector	0	0	0	0	50	75	125
Minor Arterial	0	0	0	0	50	75	125
Primary Arterial	0	0	0	0	30	50	125

Appendix D: Proposed Projects and Results

The case study's proposed improvement plan consists of over 29 miles of various bicycle facilities, which are broken up into 37 projects. These projects include the implementation of sharrows, bicycle boulevards, bike lanes, buffered bike lanes, pathways, and grade separated crossings (underpasses). The total cost of the proposed improvement plan is $4,297,575. Figure D.1 shows the case study's proposed improvement plan projects. Table D.1 presents the differences in project type, length, cost, and NCI change.

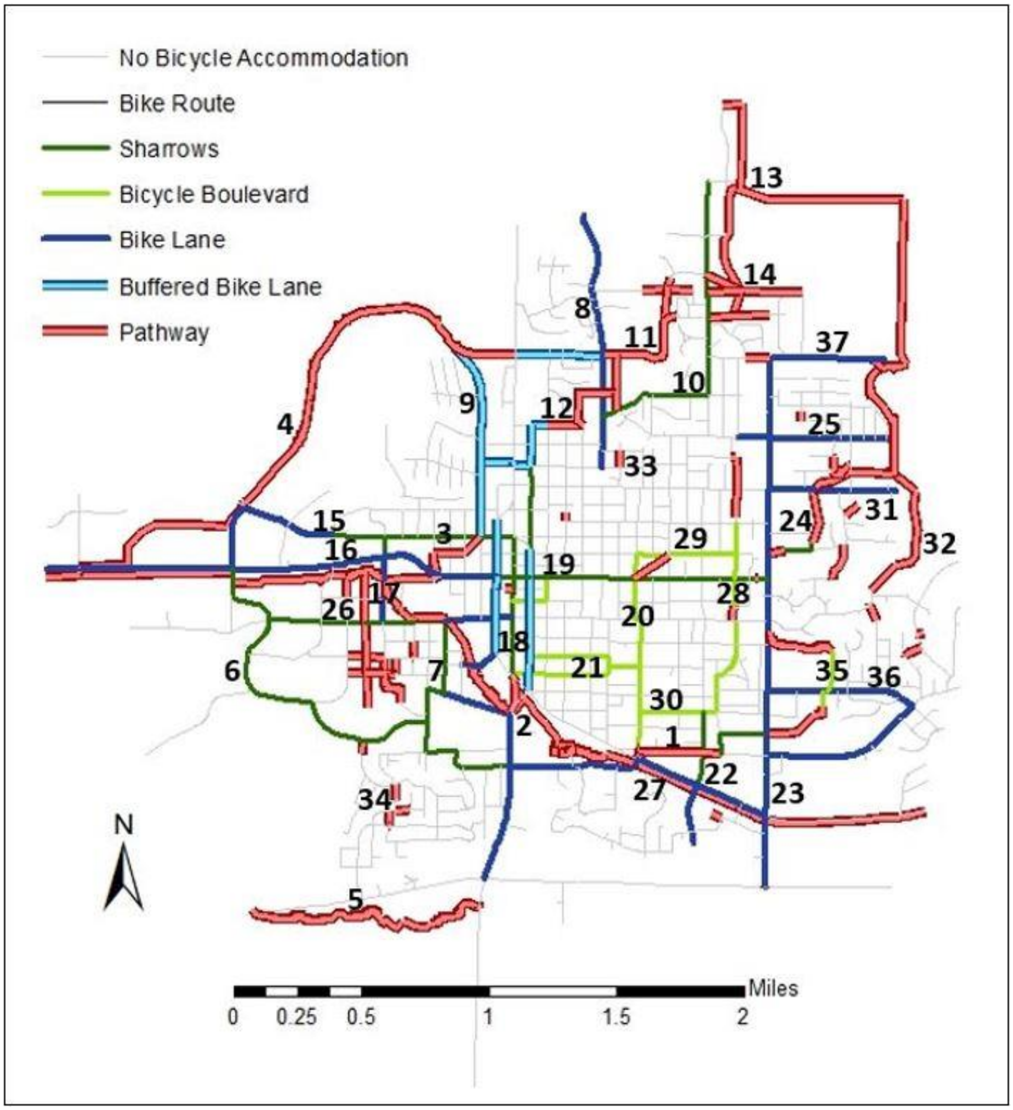


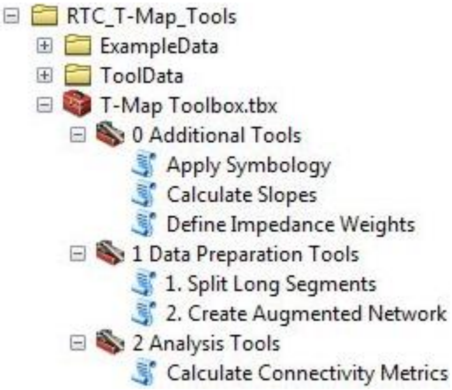
Figure D.1: Case study proposed improvement projects.

Table D.1 Case Study Proposed Improvement Projects

Project	Name	Description	Miles	Cost	ΔNCI
1	Troy Hwy Underpass	Pathway underpass of primary arterial	0.66	$928,006	35.70
2	Hwy 95 Underpass	Pathway underpass of primary arterial	0.20	$445,922	27.37
3	Pullman Rd Underpass	Pathway underpass of primary arterial	0.38	$903,676	8.56
4	Sheep Center Trail	Long pathway from Palouse Mall to N Main St, buffered bike lanes on collector	2.72	$464,383	2.41
5	Palouse River Dr Trail	Pathway running along W Palouse River Dr to Hwy 95	1.01	$186,362	1.00
6	Perimeter Dr Sharrows	Sharrows on collector	1.38	$5,524	2.44
7	East Campus Sharrows	Sharrows on collector	0.97	$3,989	5.48
8	N Polk St Bike Lanes	Bike lanes on collector	0.98	$6,923	8.21
9	N Almon St Buffered Bike Lanes	Buffered bike lanes on collector	0.78	$23,904	2.52
10	Orchard Ave Sharrows	Sharrows on collector	1.25	$5,063	8.01
11	Rodeo Dr Connection Trail	Pathway connecting Rodeo Dr to nearby neighborhoods	1.01	$189,516	4.25
12	Almon St and Polk St Connection	Buffered bike lanes and a trail connecting N Almon St to N Polk St	0.85	$91,694	0.58
13	Mountain View Park Trail	Pathway connecting Mountain View Park and Arborcrest Rd	1.76	$319,422	1.00
14	Orchard Ave Access Trail	Pathway connecting neighborhoods to Orchard Ave	1.31	$243,769	1.08
15	A St Bike Lanes and Sharrows	Sharrows and bike lanes on collector, bike lane on minor arterial	1.33	$7,736	5.78
16	W Pullman Rd Bike Lanes	Bike lanes on primary arterial	0.68	$4,768	1.34
17	Line St Bike Lanes	Bike lanes and sharrows on collector	0.33	$2,250	3.41
18	Downtown Buffered Bike Lanes	Buffered bike lanes on primary arterial	1.36	$42,977	0.85
19	Third St Sharrows	Sharrows on collector, bicycle boulevard on local	1.23	$6,370	13.32
20	S Lynn St Bicycle Boulevard	Bicycle boulevard on local	0.76	$37,640	33.40
21	Gritman Bicycle Boulevard	Bicycle boulevard on priority local	0.88	$43,121	7.25
22	S Blaine St Improvements	Sharrows and bike lanes on collector	0.50	$2,870	18.03
23	S Mountain View Rd Bike Lanes	Bike lanes on minor arterial	0.57	$3,998	0.85
24	Neighborhood Snake Trail	Sharrows on local, pathway connecting Eisenhower St to N Mountain View Rd	0.57	$88,332	8.17
25	E F St Bike Lanes	Bike lanes on collector	0.54	$3,802	0.53
26	W 6th St Sharrows	Sharrows on collector	0.69	$2,762	1.23
27	Troy Hwy Bike Lanes	Bike lanes on primary arterial	0.56	$3,962	0.70
28	Lena Whitmore Bicycle Boulevard	Bicycle boulevard on local	0.71	$33,347	24.11
29	E 1st St Bicycle Boulevard	Bicycle boulevard on priority local	0.39	$18,476	-6.11
30	Harold St Bicycle Boulevard	Bicycle boulevard on local	0.30	$14,234	24.45
31	E D St Bike Lanes	Bike lanes on minor arterial	0.23	$1,609	0.86
32	E 6th St Extension Trail	Pathway connecting E 6th St to NE Paradise Loop pathway	0.58	$109,249	1.00
33	N Howard St Connecton Trail	Pathway connecting N Howard St at E Homestead Pl	0.06	$16,163	11.00
34	Shetland Ct Trail	Pathway connecting Shetland Ct to Ridge Rd	0.07	$16,231	4.08
35	S Meadow St Sharrows	Sharrows on local	0.22	$10,351	4.09
36	Joseph St Bike Lanes	Bike lanes on collector	0.65	$4,587	10.42
37	N Mountain View Rd Bike Lanes	Bike lanes on minor arterial	0.65	$4,587	0.09

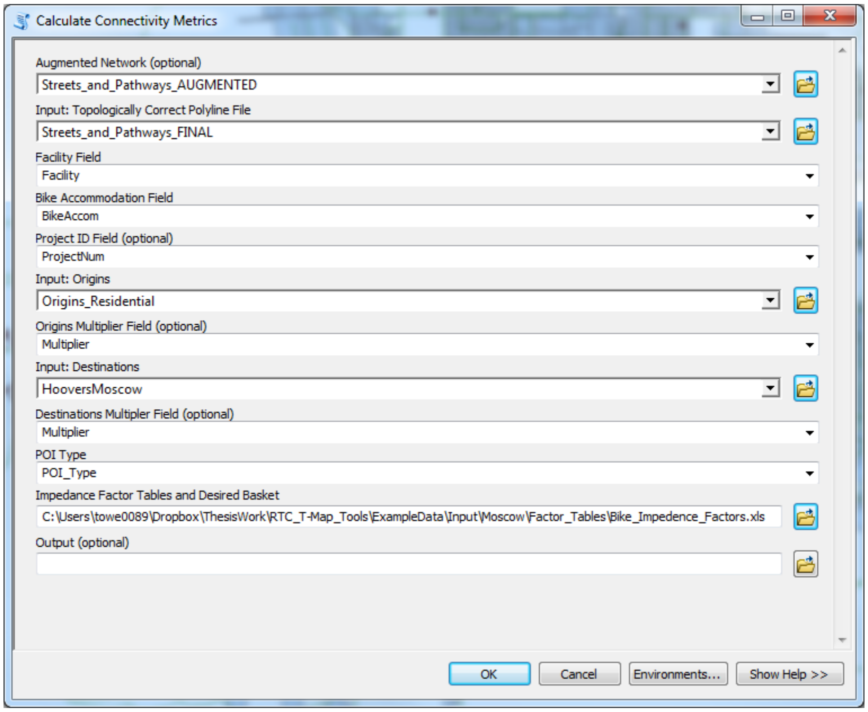
Appendix E: Tool Organization and GUI

The new GIS tool uses open-source Python code to prioritize candidate projects for a proposed improvement plan. The tool requires a street network, residential parcel data, destination points, and impedance tables as the input data. Figure E.1 shows how various tools are organized in ArcGIS; there are five tools used to prepare input data before running the final Calculate Connectivity Metrics tool. Figure E.2 presents the GUI for the Calculate Connectivity Metrics tool.



- RTC_T-Map_Tools
  - ExampleData
  - ToolData
  - T-Map Toolbox.tbx
    - 0 Additional Tools
      - Apply Symbology
      - Calculate Slopes
      - Define Impedance Weights
    - 1 Data Preparation Tools
      - 1. Split Long Segments
      - 2. Create Augmented Network
    - 2 Analysis Tools
      - Calculate Connectivity Metrics

Figure E.1: ArcGIS tools organization.



Augmented Network (optional): Streets_and_Pathways_AUGMENTED

Input: Topologically Correct Polyline File: Streets_and_Pathways_FINAL

Facility Field: Facility

Bike Accommodation Field: BikeAccom

Project ID Field (optional): ProjectNum

Input: Origins: Origins_Residential

Origins Multiplier Field (optional): Multiplier

Input: Destinations: HooversMoscow

Destinations Multipler Field (optional): Multiplier

POI Type: POI_Type

Impedance Factor Tables and Desired Basket: C:\Users\towe0089\Dropbox\ThesisWork\RTC_T-Map_Tools\ExampleData\Input\Moscow\Factor_Tables\Bike_Impedence_Factors.xls

Output (optional):

Figure E.2: Calculate Connectivity Metrics GUI.

Appendix F: Help Documentation

Below is the help documentation for the Calculate Connectivity Metrics tool, which provides a detailed explanation for users who are not familiar with the tool.

Calculate Connectivity Metrics

Title Calculate Connectivity Metrics

Summary

This tool is used to prioritize bicycle facility improvement projects based on low-stress network connectivity. The tool routes every residential parcel to a defined “basket” of important destinations. (Routes are considered only if they are within a specified stress threshold.) Essential flow values are calculated and averaged across bicycle improvement projects (Project Average NCI). The greater the change in Project Average NCI between the existing conditions and proposed improvement plan equates to a higher rank of *connectivity importance*.

Syntax

CalculateConnectivityMetrics ({Augmented_Network}, Input__Topologically_Correct_Polyline_File, Facility_Field, Bike_Accommodation_Field, Trail_Name_Field, Input__Origins, {Origins_Multiplier_Field}, Input__Destinations, {Destinations_Multipler_Field}, POI_Type, Impedance_Factor_Tables_and_Desired_Basket, Output)

Parameter	**Explanation**	**Data Type**
Augmented_Network (Optional)	This input is an augmented bicycle network feature layer, which is a polyline shapefile of the streets and shared-use paths that permit bicycle travel. These streets and shared-use paths, however, have additional information: slope, turn angle, movement, and wrong-way travel.	Feature Layer
Input__Topologically_Correct_Polyline_File	This input is a bicycle network feature layer, which is a polyline shapefile of the streets and shared-use paths that permit bicycle travel.	Feature Layer
Facility_Field	This field should provide the facility type for every link. Facility types include greenways, pathways, proposed pathways, locals, priority locals, collectors, minor arterials, and primary arterials.	Field

Bike_Accommodation_Field	This field should provide the bike accommodation type for every link. Bike accommodation types include pathways, buffered bike lanes, bike lanes, bicycle boulevards, sharrows, and none.	Field
Project_ID_Field (Optional)	This field should provide the unique project numbers. Project numbers should be unique, and a project number of zero should be used if a link is not part of a proposed improvement.	Field
Input__Origins	This input is a feature layer represented by a polygon shapefile, which must contain origin parcels. These origin parcels must include area values or the number dwelling units per parcel.	Feature Layer
Origins_Multiplier_Field (Optional)	This field should provide the weight for all origins. Weights are proportional to the number of dwelling units, the square footage, or the trip production rate.	Field
Input__Destinations	This input is a feature layer represented by a polygon shapefile, which must contain destination points. These destination points must include area values or the number of employees.	Feature Layer
Destinations_Multipler_Field (Optional)	This field should provide the weight for all destinations. Weights are proportional to the number of employees, the square footage, or the trip attraction rate.	Field
POI_Type	This field should provide the type of destination from the basket of important destinations. The types of destinations from the basket of important destinations include: postal service, department store, grocery store, clothing store, restaurant, drinking place, pharmacy, sporting goods store, bank, barber/beauty salon, physical fitness facility, amusement and recreation, dentist, heath care provider, elementary or secondary school, university, library, child day care, religious organization, movie theatre, park, and bus stop	Field
Impedance_Factor_Tables_and_Desired_Basket	This input includes factor tables that are arranged in multiple sheets of one excel file. There are distance factors and stress factors. The distance factors are defined by slope, turning movements, and street crossings. The stress factors are defined by facility type, bicycle accommodation type, and wrong-way travel. These distance and stress factors affect an individual’s bicycle route choice.	Disk Connection
Output (Optional)	This output provides a CSV file that includes the values for AvgProjNCI. The AvgProjNCI values can be used to determine the change in AvgProjNCI between existing conditions and proposed improvement plans, which ultimately allows an analyst to rank bicycle improvement projects.	File