Environmental Audit Instruments:

Evaluation and analysis of two leading bikability Instruments

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Preface: This project is a follow up to work done by the author while employed with the Wasatch Front Regional Council. The project was created in response to the Master Degree requirements of the department of City and Metropolitan Planning.

Special Thanks to the Wasatch Front Regional Council for supporting much of this work, and my excellent graduate project review committee for guiding the project to success.

Table of Contents

Executive summary …… 4

Introduction …….. 5

Environmental Audit Instruments ……. 5

Model Selection …….. 7

Bicycle Level of Service……. 7

Bicycle Compatibility Index ……..…….. 10

Methodology ……..……..……..…… 12

Data ……..…… 12

Results ……..…… 13

Analysis ……..……..…… 13

Model Improvements ……..…… 16

Slope ……..…… 16

Intersection level of service ……..…… 17

Real-time user input …….…… 17

Conclusions/Recommendations ……..…… 19

Appendix …… 21

References …… 32

List of Tables

Table 1: Summary of Bicycle Environmental Audit Instruments …… 5

Table 2: Model Consistency ……..…… 13

Table 3: Model Score Comparison …… 13

List of Figures

Figure 1: BLOS and BCI Maps for Weber County …….. 12

Figure 2: Depiction of the score differences between BLOS and BCI Models ... 14

Executive Summary

The author, while employed at Wasatch Front Regional Council (WFRC), worked the equivalent of two full-time months on model development and the collection/input of data for execution of the Bicycle Level of Service and Bicycle Compatibility Index models onto the WFRC road network. In the completion of this effort both models were successfully executed for the WFRC road network found within Salt Lake, Davis and Weber Counties. The analysis exposed key differences in the two models, and oversights in both.

The findings show that the BLOS model scored a majority, 92%, of road segments more suitable for bicyclists than the BCI. In the BLOS results, the scores were more heavily weighted towards the positive end of the A-F grading range, whereas the BCI model had a more even distribution. Similarities were found amongst the road segments, which had the most contrasting scores from the two models. These similarities were, narrow road width and low traffic volumes. Road segments of this type scored very low according to the BCI model, due to a low tolerance for narrow road widths. Whereas, the BLOS model gives more leeway for road segments with low traffic volumes.

The analysis exposed several key problems that arise in the use of both of these models, and arrived at several key solutions to these issues. Elevation gain and loss are vital to the level of service a road segment possesses. Solutions for inclusion of elevation data are found. Intersection suitability is another important aspect; inclusion of an Intersection Level of service analysis would be an important inclusion of a thorough assessment of a road network. And finally, real-time user interaction and input was arrived upon as a potential solution to a myriad of issues that are involved in utilizing a bicycle environmental audit instrument.

Introduction

The Wasatch front region is unique in many ways. Geographically, socially and economically rich, the region, unsurprisingly, is expected to bring in a monumental population increase of between 50% and 100% within the next 30 to 40 years. Due to this glaring fact, our region no doubt faces extreme transportation challenges. One small, but growing, piece of the transportation sector is non-motorized automobile alternatives. Bicycling, while holding a relatively small share of trips made, less than 5% (Turner et al, 1997), is a legitimate and growing transportation mode and should be heard in our planning decisions.

Recognizing the regions pending growth and the difficulties it will bring, Wasatch Front Regional Council (WFRC) has begun a series of efforts to plan for this future. Amongst these efforts is an assessment of current bike facilities within their five county region. This assessment will do two things. First, it will provide information to facility users, to inform trip-making decisions and increase the usability of existing facilities, thereby encouraging usage. Second, the assessment will allow WFRC to make informed planning decisions in order to accommodate future need and nurture cycling in the future.

> "Currently, the largest of the application needs for a bicycle quality-of-service model is in assessing roads and streets as a criterion for setting bicycle-facility investment priorities and developing a bicycle-suitability network map." (Landis et al, 2007)

In carrying out this assessment, two models were implemented on WFRC's entire road network, consisting of 5,605 individual road segments, throughout Salt Lake, Davis and Weber counties. Both models were used in tandem as to allow for in depth comparison. The two models used that were used are Bicycle Level of Service (BLOS) and the Bicycle Compatibility Index (BCI).

Environmental Audit Instruments

Although this study looks at the comparison of two instruments, or models, in particular, it is important to understand the full breadth of tools available to carry out this type of assessment. There are a number of different types and techniques for this analysis, dating back to the mid 1980's. Research done in 2003 by Moudon and Lee outlined and evaluated extensively what they referred to "Environmental Audit Instruments". In the research, they found 31 of said instruments, 13 of which were specific to bicycling. These instruments are listed and described in Table 1. Their words best describe the concept behind environmental audit instruments:

> "A behavioral model of environments helps define and analyze environmental determinant of community walkability and bikability. This model rests on the general construct of interactive relationships between human behavior and human environments. In this construct, human environments are understood as 'bricks and mortar' or spatiophysical entities shaped by social systems. As such, environments are sociophysical entities, both shaped by and shaping behavior…. Yet spatiobehavioral and spatiopsychosocial aspects also need to enter the model because of the interactive nature of the relationship between the word of bricks and mortar and that of behavior" (Moudon and Lee, 2003)

Table 1: Summary of Bicycle Environmental Audit Instruments

Author	Instrument Name	Description
Botma	Bicycle path level of service	Ranking of bicycle paths and trails based on bicyclist and pedestrian behaviors. Method used to validate audit and ranking not explained
Anderson	Measuring environmental indicators	Inventory of elements of the environment on and along the roadway. Adapted from Pikora=SPACES
Dixon	Bicyclist performance measures	Ranking of road segments based on roadway characteristics and traffic conditions. Method used to validate audit and ranking not explained.
DOT	Bikeabillity checklist	Simple survey of neighborhood characteristics for lay communities
DOT	Bicycle Compatibility index	Ranking of road segments based on roadway characteristics and traffic conditions. Model tested on 200 subjects using concept of "comfort level." R2=0.89. Elaborate guide available to use method.
Eddy	Level of service for bicycle use	Simple formula to rank road segments based on roadway characteristics and traffic conditions. Method Used to validate audit and ranking not explained
Landis	Bicycle level of service	Ranking of roadway characteristics and traffic conditions. Model calibrated and tested on 150 subjects for levels of "perception" in real time
Landis	Bicycle interaction hazard score	Ranking of road segments based on roadway characteristics and traffic conditions. Model calibrated and tested via consensus groups and interviews
Landis	latent demand score	Latent demand for bicycle trips along corridors based on trip purpose and proximity of generator/attractors.
Mescher	Internet-based delphi technique with GIS	Method to define and weigh criteria to select bike routes. Applies in GIS to identify optimal bike routes
Pikora	Systematic pedestrian and cycling environmental scan	Inventory of elements of the environment on and along the roadway.
Sorton-Walsh	Bicycle Stress level	Bicycle compatibility roadway design. Preliminary analysis of roadway characteristics and traffic conditions for association with bicyclist "stress level" Tested on 61 subjects watching tapes of roadway segments.
Teichgraber	Latent bicycle traffic demand	Survey of cycling behavior correlated with access to bikeways. Minimal consideration and measurement of access to bikeways.

Source: Derived from Walking and Bicycling: An Evaluation of Environmental Audit Instruments, Table 1 "Summary of Environmental Audit Instruments Reviewed"

The spatiophysical factors, or "bricks and mortar," are the static and physical pieces of the environment captured in and environment instrument, such as bike lanes and road quality. The spatiobehavioral factors are those comprised of the types and intensity of human uses in the physical environment. For example, volumes of pedestrians, bicyclist and drivers, and the issues related to the

interactions and conflicts between these facility users. And lastly, the spatiopsychosocial elements are an individual's internal responses and reactions to interacting with both the spatiophysical and spatiobehavioral factors described above. Examples of spatiopsychosocial elements would be perceived comfort, attractiveness, and safety. Detailed lists of spatiophysical, spatiobehavioral, and spatiopsychosocial elements can be found in Appendix C.

The static and physical elements, or spatiophysical, are easily defined and measured for use in an environmental audit instrument. Pieces of the spatiobehavioral elements are also usually found easily, like traffic or pedestrian volumes. The hard piece is the spatiopsychosocial element, due to the variations of perceptions from person to person. Due to this difficulty many of the available audit instruments leave this piece out, but the more complete ones do their best to include this complex and hard to measure elements of the environmental audit instrument concept.

Model Selection

The WFRC lead staff member of this project preselected the two models used for the purposes of this study. The selection of these two models was sound. Established model developer, Landis, states that the BLOS and BCI are "leading models." Both of these models have been calibrated and tested on groups of actual riders, meaning that they include and account for the spatiopsychosocial element, which many other models leave out. The challenge was to select which of the two would best suit the needs of the project. Rather than make the decision based solely on the finds on model development, it was determined that the best method would be to run both models in tandem, then use both the model development/history and the results to base the decision for model selection. The following sections summarize the two models.

Bicycle Level of Service

Level of service (LOS) is defined by the Department of Transportation as the "qualitative measures that characterize operational conditions within a traffic stream and their perception by motorists and passengers." (Highway Capacity Manual) For the application for automobiles, LOS is a standard measure of facility capacity. "For cars… LOS measures levels of congestion given posted speed limits and highway capacity" (Moudon, Lee, 2003). Applied directly for the use of non-motorized transportation, the concept does not translate correctly. Instead, LOS for these purposes focuses on levels of safety and comfort. Due to this departure, LOS model development for this purpose is complicated because of the qualitative nature of the perception of safety and comfort, or spatiopsychosocial elements.

In the development of the BLOS model, study participants were placed in real traffic and roadway scenarios to obtain feedback on real-time perceptions. The study was able to capture the feedback of nearly 150 participants. Landis et al believes that they have "represented a good cross section of age, gender, experience level, and geographic origin" (Landis et al, 2007). Each participant completed an urban-area course and then gave feedback on their perceived safety and comfort level. The course was approximately 17 miles long, including 30 road segments of varying traffic and roadway conditions.

Extensive data was collected from both the participants and the attributes of the course. "This study sought to mathematically express, for road or street links, the roadway and traffic conditions that affect bicyclists' perceptions of the quality of service, or level of accommodation." (Landis et al, 2007) The process for the development of the initial model is as follows:

1. Identify which variables are relevant
2. Test for the best configuration of established variables
3. Establish coefficients for each variable that result in the best-fit regression model

The BLOS model was first hypothesized as a function of a set of variables. A regression analysis method was used on an "extensive" selection of roadway and traffic variables to identify these relevant variables: per-lane traffic volume, traffic speed, traffic mix, cross-traffic generation, pavement surface condition, and available roadway width for bicycling. Then a regression analysis was conducted based on the approximately 4,300 observations from the study participants. They ultimately produced a model, which they felt could represent "the total population of bicyclists and roads and streets in US metropolitan areas." (Landis et al, 2007)

Since the original development of the BLOS model, widespread application has led to several refinements. It has been adopted by the Florida Department of Transportation as the recommended methodology for assessing bicycling conditions in Florida. The latest version of the model, version 2.0, was developed by Sprinkle Consultants in 2007. The equation for this model can be found in Appendix A. This latest version of the BLOS model includes numerous variables, including:

- Volume of directional traffic in a 15 minute period
- Number of Directional Through lanes
- Effective speed limit
- Percentage of heavy vehicles
- FHWA's five point pavement surface condition rating
- Average effective width of outside through lane
- Percentage of road segment with occupied on-street parking

Volume of directional traffic in a 15 minute time period, represented as Vol_{15} in the equation, is calculated from a number of sub variables, these include the average daily traffic, directional factor, peak to daily factor, and the peak hour factor. These sub variables were pulled from the WFRC's traffic demand model for each road segment. This is a very important variable because it represents the nature of the typical traffic conditions for each road segment, which represents the highest source of danger for any cyclist.

The total number of directional through lanes (L_n) is a simple, but also important variable. WFRC has this information catalogued in its traffic demand model. This is important because the number of lanes determines the nature of the amount of traffic. Two road segments with the same VOL_{15} values, but with a different number of directional through lanes will have a different concentration of traffic per lane, and so, will be perceived differently by a cyclist.

The effective speed limit (SP_t) is another simple, but important variable. The model uses the posted speed limit in a calibrated equation to get the value of the effective speed limit. Literature provided by Sprinkle Consultants on Version 2.0 gives no detailed description of the meaning of "effective" in "effective speed limit" and early versions of the model used only the posted speed limit.

Similar to that of the volume of directional traffic, percentage of heavy vehicles (HV) has a direct and strong connection to the perceived and actual safety of a road segment. These vehicles take up more road space than regular vehicles making this variable's relation to the number of directional through lanes important. The operators of these vehicles also have lessened visibility, especially concerning smaller objects, such as pedestrians and cyclists.

Another of the variables is the FHWA's five-point surface condition rating (PR_5). Surface conditions are a critical aspect of the bikability of a road segment. Poor road conditions make it hard for a cyclist to keep control, and so, increase not only the difficulty of a road segment, but also increase the danger. Collection of this level of detail requires a significant investment of time and resources. For the purposes of WFRC's assessment, this investment was not made, and so, an assumed constant value was used across all road segments.

Determination of the value of effective width of the outside through lane (We) required the most complicated set of rules and equations (see Appendix A). It requires a set of sub variables, which are: total width of outside lane (and shoulder) pavement, percentage of segment with occupied on-street parking, width of paving between the outside lane stripe and the edge of pavement, width of pavement striped for on-street parking, and the effective width (a function of total width of outside lane pavement and traffic volume).

The last variable is the percentage of road segment with occupied on-street parking (OSPA). This variable affects the level of service of a road segment for a couple of reasons. The first is that the more use on-street parking has, the more potential conflict there is with vehicles and cyclists. The second reason is that occupied on-street parking reduces the available space for cyclists to ride, pushing them closer toward traffic lanes.

Bicycle Compatibility Index

In the creation of the Bicycle Compatibility Index the objective was "to develop a methodology for deriving a bicycle compatibility index that could be used by bicycle coordinators, transportation planners, traffic engineers, and others to evaluate the compatibility of specific roadways to accommodate both motorists and bicyclists." (Harkey, 1998) This bicycle compatibility index (BCI) was developed for urban and suburban road segments.

Study participants viewed video tape of numerous road segments and were tasked to rate how comfortable they would be riding on the shown segments. The developers of BCI claim that the video-based method had the following advantages:

1. There were no risks to bicyclists. In other words, bicyclists did not need to ride in or be exposed to conditions that they would consider uncomfortable or unsafe. This fact allowed the inclusion of conditions, such as large trucks or buses on very narrow lanes that could not be safely evaluated using on-the-road bicyclists.
2. Specific variables could be presented to bicyclists in a controlled environment. For example, all subjects were exposed to the same number of vehicles (i.e., traffic volume) and to the same conditions (i.e., right-turning traffic or heavy vehicles). This form of variable control is virtually impossible by having bicyclists actually ride on the roadway. Bicyclists riding the same segment during two different time periods may be exposed to different levels of traffic volume, traffic composition, or other factors, and, thus, their ratings of the same segment of roadway would be based on different operating conditions.
3. The number of operational and geometric conditions to which subjects were exposed was much greater than could have been experienced in the field. For example, the participants in the pilot study described below rated the 13 sites in less than 15 minutes from the video, but it took almost 3 hours to drive to and rate all 13 locations in the field. If all geometric and operational conditions desired for the study are in several cities (as was the case in this effort), it is simply impractical to present all conditions to a group of bicyclists.

4. The same set of geometric and operational conditions were examined and rated by bicyclists in several municipalities. This advantage allowed the direct comparison of ratings between bicyclists in different regions of the country or communities that vary with respect to bicycling facilities or "bicycle friendliness."

Various sites were select for video survey collection, which represents a range of geographic conditions present in the United States. These locations included:

- Eugene and Corvallis, Oregon
- Cupertino, Palo Alto, Santa Clare, and San Jose, California
- Gainesville, Florida
- Madison, Wisconsin
- Raleigh and Durham, North Carolina.

Within these locations, 67 sites were selected, which included a wide range of geometric and operational characteristics. The sites were filmed for 15 minutes between 9:00am and 4:00pm to maximize the range of possible conditions at each site. Like the BLOS model relevant geometric and operational variables were selected for regression modeling.

The model used for this project was provided by WFRC and was sourced from the FHWA. The model rules and equations can be found in Appendix B. This Excel model required the following input variables:

- Number of directional through lanes
- Curb lane width
- Bicycle/paved shoulder lane width
- Presence of a residential development
- Speed limit
- 85th percentile speed (optional)
- Average daily traffic
- Large truck percentage
- Right turn percentage (optional)
- Presence of a parking lane
- Parking lane occupancy
- Parking time limit (optional)

The variables found in the BCI model that are the same or similar to those found in the BLOS model have identical reasoning and descriptions, and can be found in the previous section. The variables unique to this model are the presence of a residential district, and right turn percentage.

Presence of a residential district is an important variable that is incorporated into the BCI model. Its importance has much more to do with perceived comfort than

actual safety. The nature of the road manners and traffic conditions tend to be more favorable to cyclists in residential districts than in others, but these factors are accounted for in the other variables found in the model. Two identical roadways, all other variables constant, one is found in a residential district and the other is industrial will have identical safety risks for a cyclist. But the one found in the residential district will have a much better and friendlier cyclist environment for reasons hard to describe quantitatively.

Right turn percentage is another very important variable. This is due to the fact that road shoulders and bicycle lanes are nearly always outside the lane with vehicles turning right in intersections, requiring vehicles to pass through the cyclists riding space. The higher this percentage is, the more potential conflict there is between cyclists and vehicles.

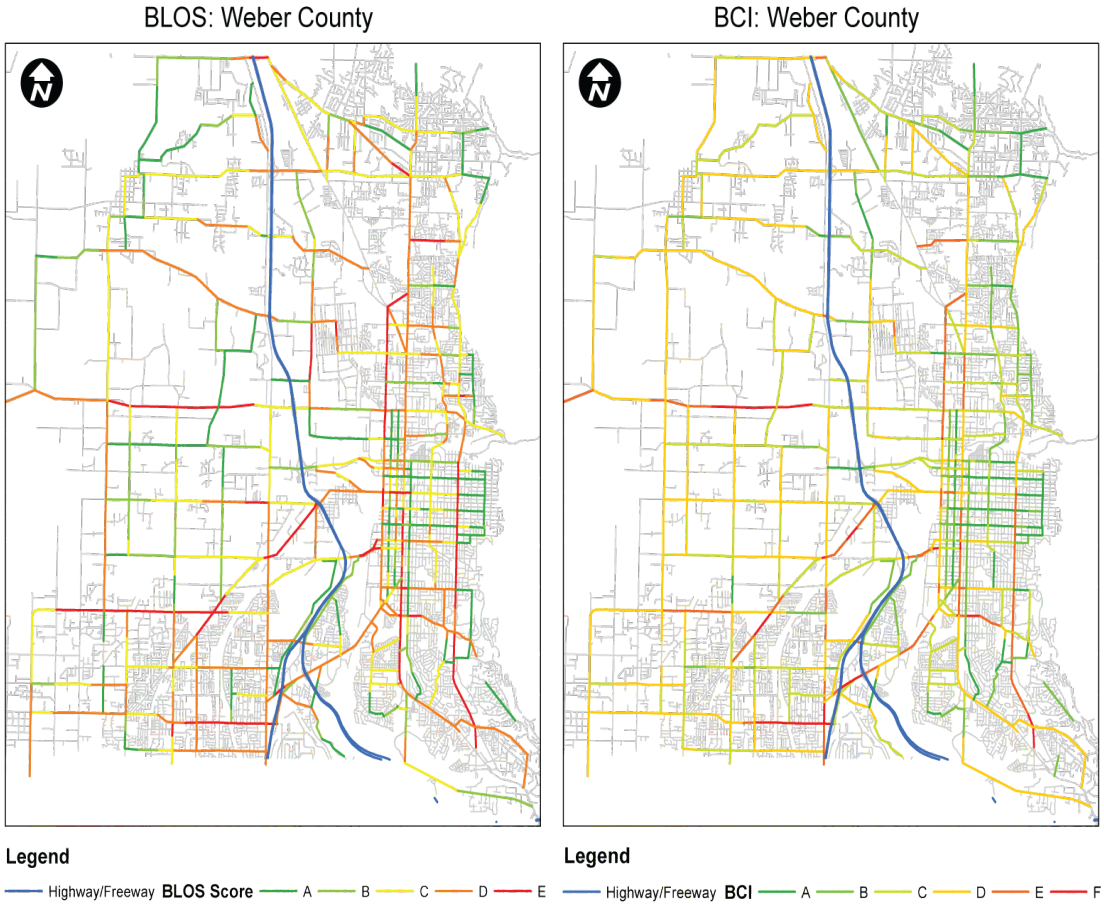
Methodology

In order to make an in depth comparison of the two models, the author administered them to the WFRC road network in tandem. This was done using Microsoft Excel software. A data entry page was created, which fed the required data into both the BLOS and BCI models. These two models were housed within the same Excel file on separate pages. The author created the BLOS model from the equations found in the publicly available Bicycle Level of Service Model For Segments from Sprinkle Consulting. A previously built version of the BCI model was provided by WFRC. Once the necessary data was entered for each road segment, the resulting score was sent to a final page of the model where a unique identifier for each road segment was assigned two scores, one from each model. This was done three times, once for each county in WFRC's road network, Weber, Davis, and Salt Lake. Once the scores for a county were calculated, they were joined to the GIS road network. The results from the models were graphically represented with each letter grade receiving a different color.

Data

The data needed for the model was acquired from several different sources by the author. Average Daily Traffic (ADT) of the road segments was pulled from the WFRC's own traffic model. Large tuck volume was pulled from the Utah Department of Transportation. Dimensional data for each road segment was measured using Google Earth over the course of several months. Of the data that was unavailable or unreasonable to obtain, assumptions provided by each model developer were used.

Figure 1: BLOS and BCI Maps for Weber County



Results

The tandem environmental audit instrument, which produced scores according to both the BLOS and BCI models, was designed by the author in such a way that a table was produced containing a row for every road segment and a column for each score, as well as a unique identifier for each road segment. This product allowed the scores to be easily joined to GIS model of the WFRC road network. Then, using ESRI GIS software, the author was able to represent the score of each road segment graphically, with assigned colors for each letter score. The ultimate result is two maps for each country, one for the BLOS and BCI models. Figure 1 shows an example for Weber County (See Appendix D for all resulting Maps). These maps allow for more efficient absorption of the data produced from the models. They can be used by cyclists, or by planners to inform decisions regarding bicycle infrastructure.

Analysis

To measure the consistency between the two models, the author assigned numerical values to each letter score: A-1, B-2, C-3 and so on, for each segment in Salt Lake County. The difference in these values between the two models was then calculated to gain a measurable indicator of their difference. Of the 3,577 road segments measured in Salt Lake County 27.5% of the scores were consistent between the two models and 49.3% of the scores were within one letter grade (Table 2). This means that 76.8% of the scores were fairly consistent, within one letter grade.

Table 2: Model Consistency		
Difference	Occurrence	% of total
0	984	27.5%
1	1763	49.3%
2	772	21.6%
3	59	1.6%

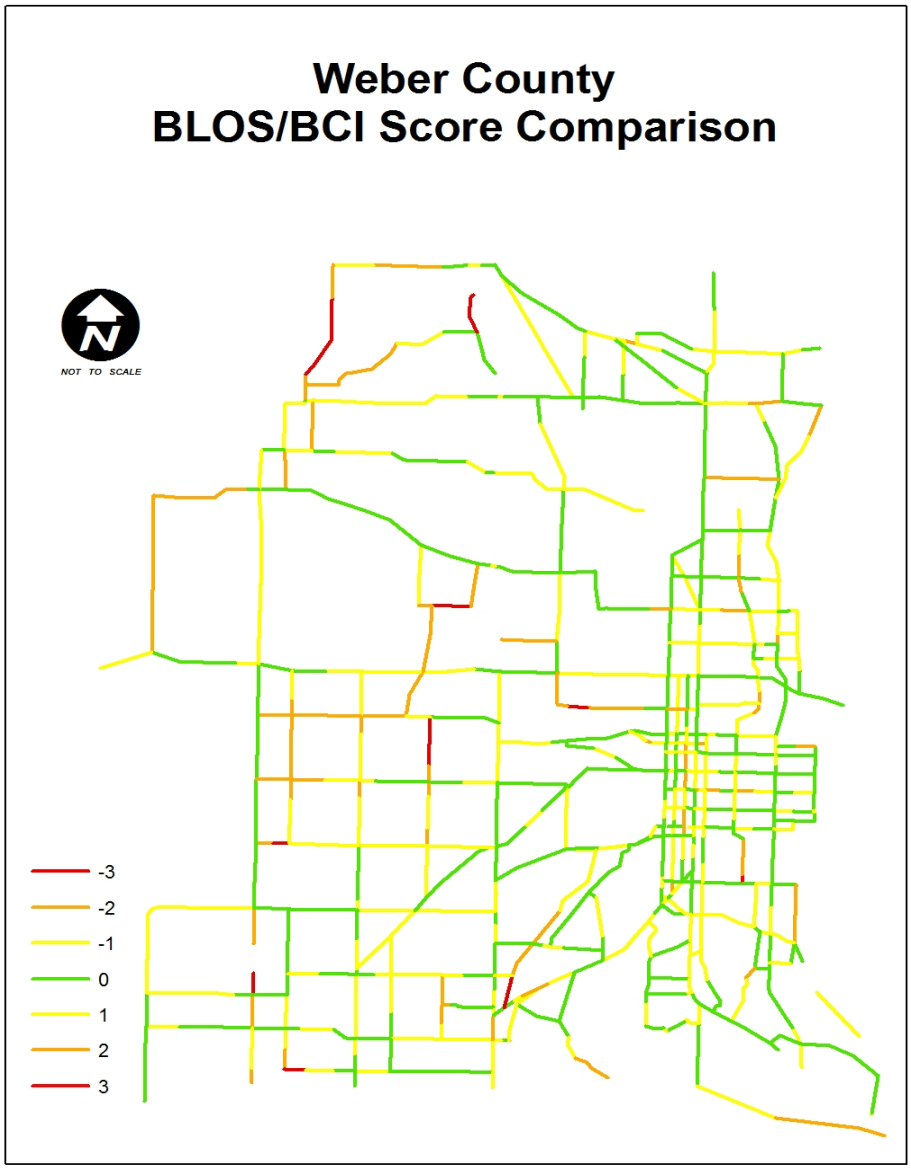
Of the 2,593 scores, which were not completely consistent, 92% had scores that were more positive according to the BLOS model. Meaning that in most of the differing scores, the BLOS score was more positive, pointing to the fact that the BLOS model has looser standards than the BCI. According to the BCI model, only 91 segments, or 2.5%, of the road segments received an “A” score, compared to the 506 “A” scores given by the BLOS model. This is over 5 times as many road segments considered having an “extremely high” compatibility to bicycle travel. Similarly, the BCI model designated 476 road segments as having and “extremely low” compatibility rating, or an “F”; whereas the BLOS model gave out no scores lower than an E, determining that there are no road segments within the WFRC Salt Lake County road network with an “extremely low” compatibility rating. This difference in the results can be expected due to the differing nature of the two models, each with different coefficients and variables. Despite the more critical nature of the BCI model, it has a more even distribution of scores, as compared to the BLOS model (Table 3).

Table 3: Model Score Comparison				
	BCI		BLOS	
A	91	2.5%	506	14.1%
B	540	15.1%	566	15.8%
C	1043	29.2%	1449	40.5%
D	936	26.2%	976	27.3%
E	491	13.7%	80	2.2%
F	476	13.3%	0	0.0%

Looking into characteristics of the road segments that scored most dissimilarly between the two models, the differing natures of the two models becomes apparent. Of the road segments with scores differing by at least 3 grades, nearly all of them have similar

characteristics. They all were relatively narrow and had low ADTs. This is shown in Figure 2, a map displaying the consistency between the two models. The color of the road segments represents the difference between the two models, with red showing segments that have dramatically different scores and green showing segments with consistent scores. It is clear that the majority of the roads with higher inconsistency are of those on the periphery of the county. This means that the BLOS model determines narrow road segments as bicycle compatible, as long as there is low ADT. Conversely the BCI model finds narrow road widths to be unsuitable to bicycle travel regardless of traffic conditions.

Figure 2: Depiction of the score differences between BLOS and BCI Models



MODEL IMPROVEMENTS

Although the best models available are calibrated based on real human perceptions, these calibrations only reflect a small grouping of individuals, 202 for BCI and 150 for BLOS. It is impossible that these small groups of individuals' perceptions were reflective of the entire population. Also the models do their best to reflect, in their outputs, the perceptions of the grouping of individuals as a whole. Meaning that the scores produced would be consistent with an average cyclist. However, it is possible, by nature of the sport, types of users are grouped together in such a way that creating a score of an average user would miss these grouping all together. This fact along with what may be pivotal oversights in "relevant" variables and components of the street environment, may leave these two model and others, inadequate. The following subsections address these issues.

Slope

One glaring deficit found in both models is the absence of elevation data. In a deceivingly hilly landscape such as the Wasatch Front, this information is highly important and can truly effect appropriate route selection. Various roads, such as many along the foothills, have scored well according to both models, but these roads, due to slope variations could prove to be too difficult for many riders. For a bicycle level of service model to be effective, this data must be included. In both these models, where the physical characteristics of the street environment were held to such great importance, neither mention slope as a possible "relevant" variable for model inclusion. The omission may have been an oversight, as is likely in the case of the BCI model where participants in the study did not actually ride in real conditions, or may have been avoidance due to the potential complexity of adequate data collection.

Inclusion of slope or elevation change could be accomplished utilizing GIS software. In this process, the elevation at each end point of a road segment would be determined, then using simple math the slope could be determined (see equation below).

(Elevation 1 – Elevation 2)/segment length = segment slope

This information could then be included in the model score, segments with relatively steep slopes achieving lower scores. This information could also be represented graphically. In order for slope information to truly be utilized, its direction must also be known. Arrows along a road segment pointing up-slope

could accomplish this task. The color of these arrows could also be used to indicate steepness. This way the slope information could be displayed separately, but alongside the model score, enabling the facility users to make to most informed route decisions. One user could select a route with the highest quality facilities, while another could find the easiest, with the least elevation gain.

The main issue with this approach is that variations of slope within a road segment would not be captured. This is because the slope is only being calculated from the difference in elevation at each end of a segment. It is possible and likely that this will not entirely capture the nature of the slope for each road segment. This problem will be exasperated with longer road segments, due to the greater possibility for longer segments to contain variations of elevation within them. To combat this issue, again using GIS software, it would be possible to use elevation data to slice road segments at instances where elevation gains and losses end and begin. Road segments with relatively consistent slope would remain intact, where as those with slope variation would be broken up into smaller segments, each represented accurately with a slope calculation.

Intersection level of service

Intersections are another pivotal oversight of the models reviewed. Intersections are an important part of a bicycle journey, and in most cases have their own sub-environments, with differing conditions than the road segments abutting them. An A scoring roadway, with beautiful and commodious bike lanes, could be intersected by and E or F, which would likely have resulting characteristics of some mixture of each of them. Because of this, it cannot be assumed that the quality of an intersection reflects completely the characteristics of either roadway of which it is comprised. To account for this, an effective network assessment would model the quality of its intersections, independent of the roadways. Landis et al, in conjunction with the Florida Department of Transportation developed such a model. This model should be utilized and subsequent data incorporated.

Incorporation of this additional data would best be utilized in a similar fashion to the intersection scores. GIS point data of each intersection within the WFRC road network would need to be created. Then once the analysis was completed the resulting score for each intersection would be joined to the GIS point data. The varying scores of each intersection could then be visualized using a color range, green for high scores, down through red for low ones. This could then be superimposed upon the existing road segment maps, providing a complete picture of the nature of the road network's segments and their connections.

Real-time facility user input

> "In the closely related and rapidly growing area of bicycle suitability mapping, the current practice in many areas of the United States is subjectively to evaluate roads to determine their compatibility for bicycle travel. However, consistent evaluation of the roads among the map updates is not possible without involving the same people in every update year. As a result, either inconsistency or inaccuracy results. A statistically calibrated, mathematically based model is thus needed." (Landis et al. 2002)

No doubt the greatest drawback to using a model to measure the 'bikability" of a roadway is the variability of current conditions and user interpretation. One way to combat this would be to allow for real-time user input to the model. The model could be housed publicly where users of the facilities could log in and report actual impressions on the road segment. Information on the user could be used to inform how their inputs are processed. For example there could be several different versions of the road score map housed online. Each version would be tailored to a specific type of cyclist, perhaps one for beginner, intermediate and expert. Only those users who fall within a certain category could inform that map, so that only like users are informing each other's maps.

The user input would also be used to inform facility maintenance. One could log-in and share information on debris on a certain segment or instances of puncture weed. Maintainers of this online flexible system could also upload useful information, such as construction sites, and schedules.

Another issue, which could be solved with this type of system, is the varying nature of differing people's riding type. Bike riders with different riding styles will have different perspectives on what classifies an A graded road segment or an F graded one. It is likely that more aggressive riders will consider a larger percentage of any given road network to be more suitable for cycling than a more passive or novice one. To combat this, users of the system could be required to take a short survey when first logging into it. This survey would determine the rider type of the user. The network map accessible to the user would then be automatically calibrated to the type of rider he/she tested as.

A study done by the City of Portland established that there are four types of transportation cyclists. The "Strong and Fearless" type consists of individuals who are generally undeterred by roadway conditions. "Enthused and Confident" riders do not mind sharing the road with automobile traffic, but prefer to have specific bicycle facilities. The "Interested but Concerned" bicyclists are those who like riding, but are scared to do so amongst automobiles. And the fourth type of transportation cyclists is the "No Way No How" type, which are those who are "currently not interested in bicycling at all." (City of Portland) Clearly there are different types of cyclists and effective facility maps should be calibrated to

account for this. Skill level and confidence are key in cycling safely within a city, and because of this, a suitable roadway for one person may be dangerous and frightening to another. Having a system where the road network map calibrates to the type of rider could help avoid riders getting out of their depths, and may reduce bicycle related accidents.

In a similar vein, the type of trip may impact the type of score a road segment should receive. There are two main purposes for a bicycle trip, transportation and recreation. Recreational cycling could also be broken into two types, exercise oriented and scenery oriented. Depending on which category a bicycle trip falls into will alter the way the rider will perceive the quality of a road segment. For destination based trip, or one for the purposes of transportation, a rider will most likely hold less scrutiny on the environment, and more on the length and ease of any particular road segment. Designation of the type of trip could be required of the cyclist each time the network map is accessed, allowing for the network to be more effectively calibrated.

RECOMMENDATIONS/CONCLUSION

In order for these instruments to truly be effective, the improvements previously discussed would need to be developed and explored. The potential cost to invest the man hours needed for this may or may not be great, but in either case how would this upfront cost compare to the ongoing social, environmental and economic cost benefits these improvements would have on the Wasatch Front region? A cost benefit analysis would need to be conducted, but the ongoing cost benefits of this work, will likely outweigh the upfront cost burden, especially when all positive externalities associated with the healthier transportation mode split, that this work will ultimately produce, are taken into account.

The first prudent step in taking this further would be to determine a smaller test geography. This would make development of a more comprehensive prototype model more manageable. An ideal location for this geography would be within an area with a good variation of roads with deferring compositions, and measurable amounts of bicycle traffic. With a test geography established, the model recommendations could be explored and tuned to ultimately be deployed onto any road network.

For the use of this model for network users, it would be beneficial to re-calibrate the model selected for established rider types within the test geography. Network maps could then be available in a variety of forms for the user to choose based on their own preferences. This task could be accomplished very simply by adjusting the coefficients in the model based on existing research done on different cyclist types. With the appropriate resources, this could also be accomplished in a more thorough fashion, by recalibrating the models based on participants which fall within differing cyclist types.

Incorporating the Intersection LOS into the model would be very beneficial to network users. As established previously, the street environment can change dramatically within an intersection, and to effectively assess the quality of streets for bicycle use, this information needs to be incorporated into a facility map. Collection of the data needed to run the Intersection LOS will most certainly take much time and effort, but compared to the collection efforts associated with the BCI and BLOS model it will be considerably less. This is because the data needed for this analysis will be concentrated at the intersections, rather than spread out along the streets. It will also be less time intensive because there will be significantly fewer intersections than road segments. One intersection will not be broken down into hundreds of segments, which need to be measured separately.

The elevation data necessary to explore incorporation of slope is available publicly on the Utah GIS Portal website. This component of the model improvements would be a very unique and interesting GIS project. Once the proper workflow was established, the software could be used to automate the process making it easy and quick to apply to any road network.

Continuation of this work is truly important if the results of these models are to be useful and representative of actual conditions. Fortunately at the moment the climate in the Salt Lake valley is ideal for this type of work. There is an air of urgency to help prepare our urban infrastructure in order to accommodate the mass influx of people we will likely see in the coming years. What better time than now to take back the streets from their current state of complete automobile domination? Work such as this helps provide crucial information in order to properly inform this effort. Although much has been done, this is just the tip of the iceberg. As previously stated, the currently available instruments are inadequate to properly assess our streets. We need to step forward to pioneer and develop adequate measurement instruments. What better place than here? What better time than now?

Appendix A: BLOS model equation

Bicycle LOS = $a_1 \ln (Vol_{15}/L_n) + a_2 SP_t(1+10.38HV)_2 + a_3(1/PR_5)_2 + a_4 (W_e)_2 + C$

Vol_{15} = Volume of directional traffic in 15 minute time period
$Vol_{15} = (ADT \times D \times K_d) / (4 \times PHF)$
Where:
ADT = Average Daily Traffic on the segment or link
D = Directional Factor
K_d
= Peak to Daily Factor
PHF = Peak Hour Factor
L_n = Total number of directional through lanes
SP_t = Effective speed limit
$SP_t = 1.1199 \ln(SP_p - 20) + 0.8103$
where:
SP_p = Posted speed limit (a surrogate for average running speed)
HV = percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual)
PR_5 = FHWA's five point pavement surface condition rating
W_e = Average effective width of outside through lane:

where:
$W_e = W_v - (10 \text{ ft} \times \% \text{ OSPA})$ and $W_l = 0$
$W_e = W_v + W_l (1 - 2 \times \% \text{ OSPA})$ and $W_l > 0$ & $W_{ps} = 0$
$W_e = W_v + W_l - 2 (10 \times \% \text{ OSPA})$ and $W_l > 0$ & $W_{ps} > 0$ and
a bikelane exists
where:
W_t = total width of outside lane (and shoulder) pavement
OSPA = percentage of segment with occupied on-street parking
W_l = width of paving between the outside lane stripe and the edge of pavement
W_{ps}= width of pavement striped for on-street parking
W_v = Effective width as a function of traffic volume
and:
$W_v = W_t$ if ADT > 4,000veh/day
$W_v = W_t(2-0.00025 \times ADT)$ if ADT ≤ 4,000veh/day,
and if the street/
road is undivided
and unstriped
a_1: 0.507 a_2: 0.199 a_3: 7.066 a_4: - 0.005 C: 0.760
(a_1 - a_4) are coefficients established by multi-variate regression analysis.

Source: Sprinkle Consulting Inc. "Bicycle Level of Service, Applied Model" Tampa, FL 2007.

Appendix B: BCI Model Equation

$$BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF$$

where:

BL = presence of a bicycle lane or paved shoulder ≥ 0.9 m
no = 0
yes = 1

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

CLW = curb lane width
meters (to the nearest tenth)

CLV = curb lane volume
vehicles per hour in one direction

OLV = other lane(s) volume - same direction
vehicles per hour

SPD = 85th percentile speed of traffic
km/h

PKG = presence of a parking lane with more than 30 percent occupancy
no = 0
yes = 1

AREA = type of roadside development
residential = 1
other type = 0

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

where:

f_t = adjustment factor for truck volumes (*see below*)

f_p = adjustment factor for parking turnover (*see below*)

f_{rt} = adjustment factor for right turn volumes (*see below*)

Adjustment Factors

Hourly Curb Lane Large Truck Volume[1]	f_t
≥ 120	0.5
60 - 119	0.4
30-59	0.3
20-29	0.2
10-19	0.1
< 10	0.0

Parking Time Limit (min)	f_p
≤ 15	0.6
16 - 30	0.5
31 - 60	0.4
61 - 120	0.3
121 - 240	0.2
241- 480	0.1
> 480	0.0

Hourly Right Turn Volume[2]	f_{rt}
≥ 270	0.1
< 270	0.0

Source: David L. Harky, Donald W. Reinfurt, and Matthew Knuiman, "Development of the Bicycle Compatibility Index," Transportation Research Record 1636 (1998) Paper no. 98-1073

Appendix C:

Variables in the Spatiophysical, Spatiobehavioral and Spatiopsychosocial Aspects of Bicycling	
Spatiophysical	Condition of road; typical section attributes; intersection geometry
	Road width; roadway alignment
	Roadway character, improvements, and environment
	Visibility
	Length of segment under consideration for improvement
	Number of links in grade-separated system
	Intersection; midblock
	Midblock
	Number of lanes; total number of through lanes; center tum lane
	Presence and width of shoulder or bike lane
	Number of turn lanes; direction(s) of traffic flow
	Outside lane width
	Usable width of outside through lane
	Presence of bicycle lane/paved shoulder
	Width of bicycle lane/paved shoulder
	Off-street parking spaces with unrestricted access per household
	Parking lane; presence of on-street parking
	Path type
	Path width
	Uncontrolled vehicular access, such as driveways or on-street parking spaces
	Curb cuts, ramp, type, and lane width (same as outside lane)
	Driveways or curb cuts; driveway and side streets
	Sloping terrain; intersection
	Presence of barrier-free facility; obstructions
	Presence of barriers within the buffer area (usually trees)
	Frequency of signalization
	Signal phase; stop sign frequency; traffic control devices
	Path condition, smoothness and material
	Pavement factor
	Street surface
	Surface condition, quality, and type
	Architecture (local)
	Building features and frontage
	Roadside development; garden maintenance
	Lighting
	Lighting (street)
	Lighting (pedestrian scale)
	Maintenance; litter
	Parking for bicycles
	Benches; furniture (street)
	Trees (shade tree)
	Trees (street tree)
	Connectivity; continuity

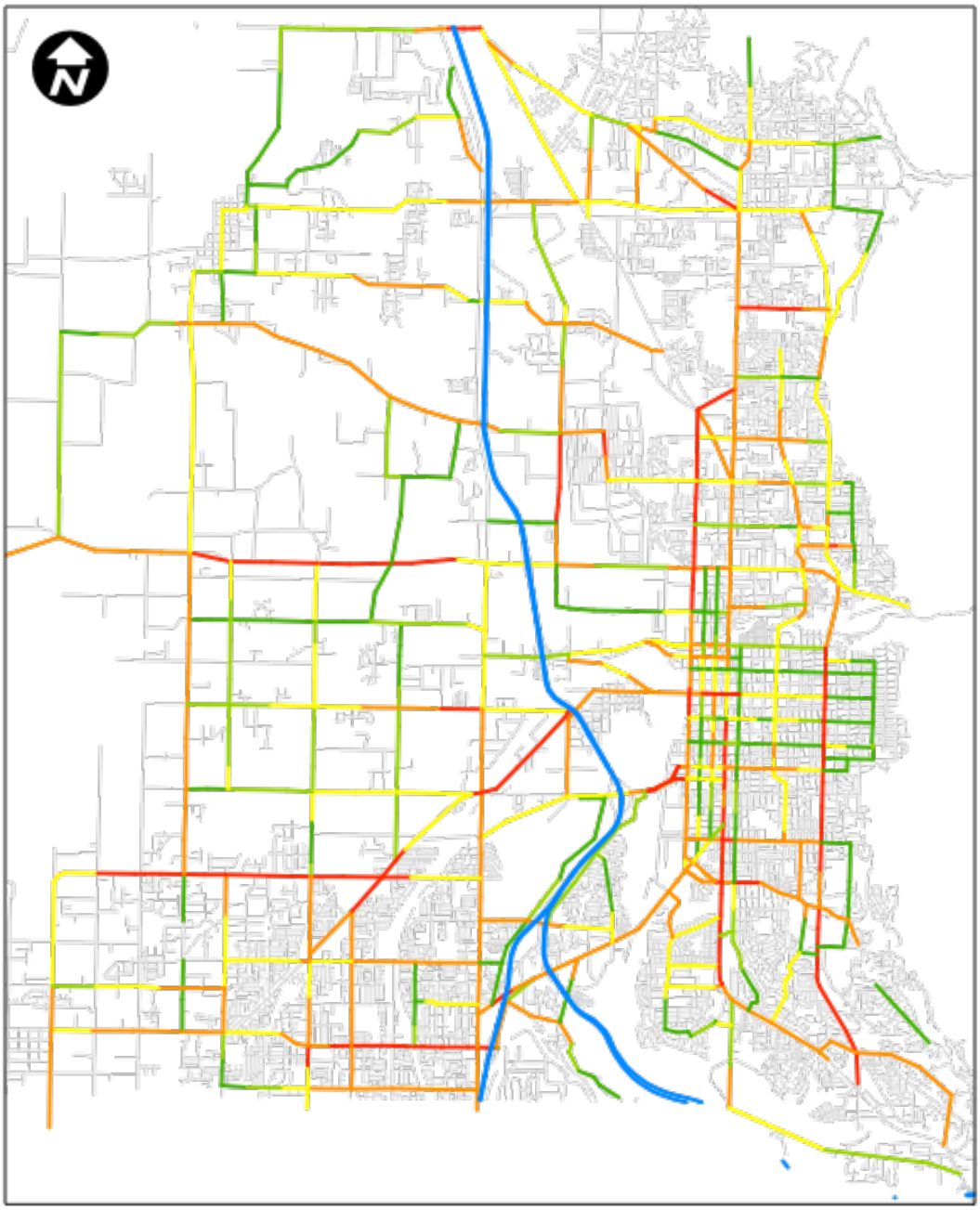
	Other routes available; parallel alternative facility
	Extent of sidewalk network; sidewalk continuity
	Fineness of grid, distance between intersections
	Street intersection density
	Access to bicycle facility
	Actual development on the ground; development, streets, freeways, rivers
	Floor area of specific land use at destination
	Housing density, employment, and population density
	Intensity of adjacent land uses
	Absolute number of residents or employees within a walkable area
	Connective tissue
	Destinations; land use types
	Zoning categories and related capacity
	Functional complementarity of land uses
	Specific land uses that are linked by pedestrian travel
	Proximity of residential and nonresidential land uses
	Spatial complementarity of land uses
	Block size
	Average parcel size
Spatiobehavioral	Average bicycle speed
	Speed differential (car and bicycle)
	Peak-pph (persons per hour) intersection and sidewalk midblock use
	Pedestrian volume
	Bicycle trip purpose (e.g., work, personal/business, recreation, school)
	Source of pedestrian trips: estimate car/walk, walk/bike-only, transit/walk
	Potential cross-traffic
	Potential for vehicle-pedestrian conflict
	Reduced turn conflict implementation
	85th percentile speed
	Posted speed limit
	Vehicle speed
	Speed (driving)
	Motor vehicle mix
	Presence of heavy truck traffic
	Presence of heavy vehicles
	Vehicle type (passenger equivalent)
	Average daily traffic (ADT)
	Curb lane vehicle traffic volume
	Directional split
	Non-curb lane vehicle traffic volume
	Number of commuters
	Transit ridership
	Vehicle traffic volume
	Auto level of service (LOS)
	Vehicle LOS levels, combined with number of lanes
	Volume/capacity ratio
	Frequency and severity of problems

	Automobile-pedestrian crash factor
	History of collisions by location
Spatiopsychosocial	Variables in the Spatiopsychosocial Aspects of Bicycling
	Attractiveness for cycling
	Bicyclist experience level
	Bicyclist characteristic (skill levels)
	Difficulty for cycling
	Driver behavior
	Ease of biking
	Safe places to bike
	Roadway share with motor vehicles
	Safety of bicycling
	Surface quality
	Street intersection condition
	Unrestricted sight distance
	Visibility from nearby buildings
	Easiness of following safety rules
	Ease of street crossing
	Number of neighborhood "places of significance" named by average respondent

Source: Derived from Walking and Bicycling: An Evaluation of Environmental Audit Instruments, Tables 3, 4 and 5

Appendix D: BLOS and BCI Maps for Weber, Davis and Salt Lake Counties

BLOS: Weber County

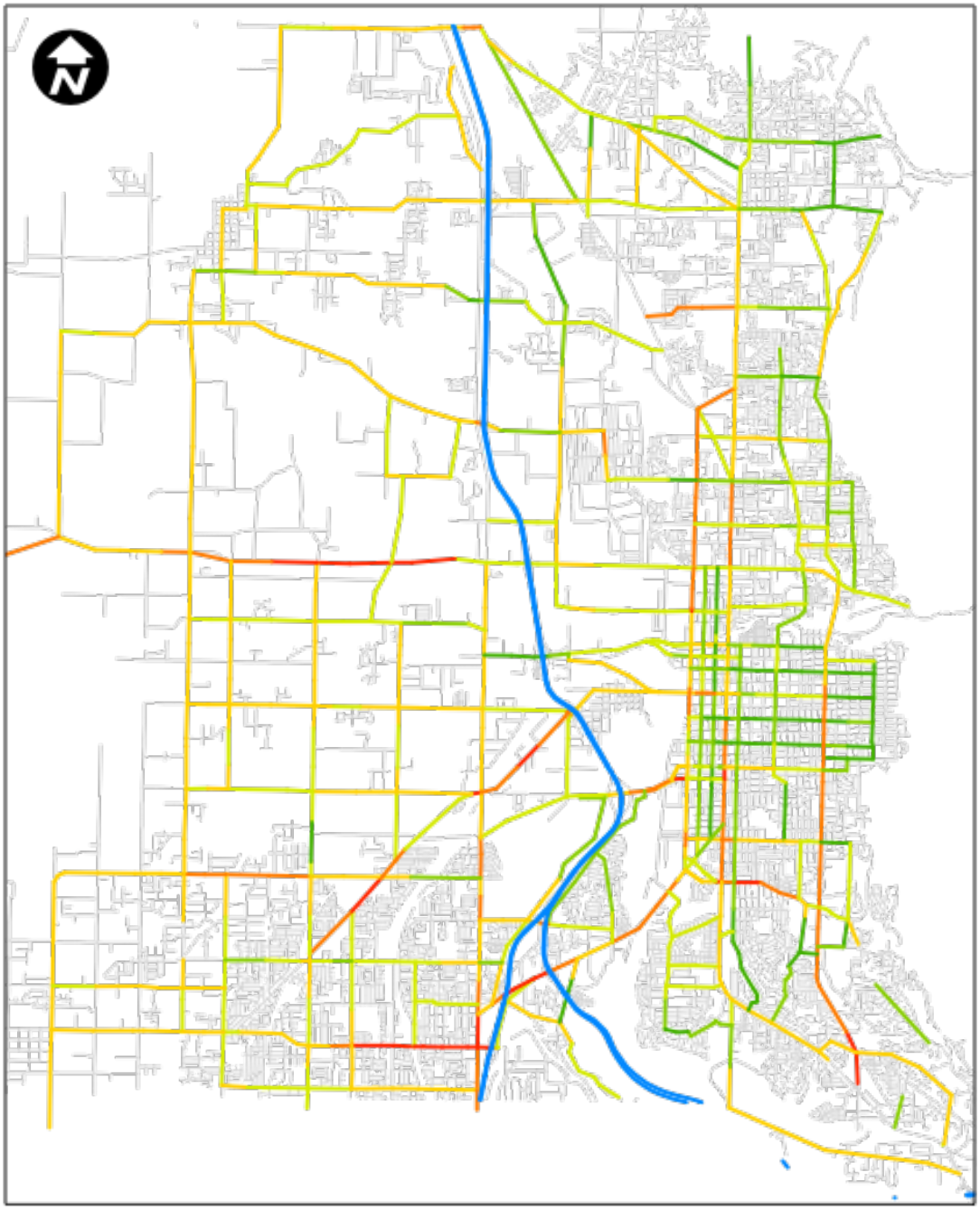


Legend

Highway/Freeway **BLOS Score** A B C D E

Created by: Kai Tohinaka

BCI: Weber County

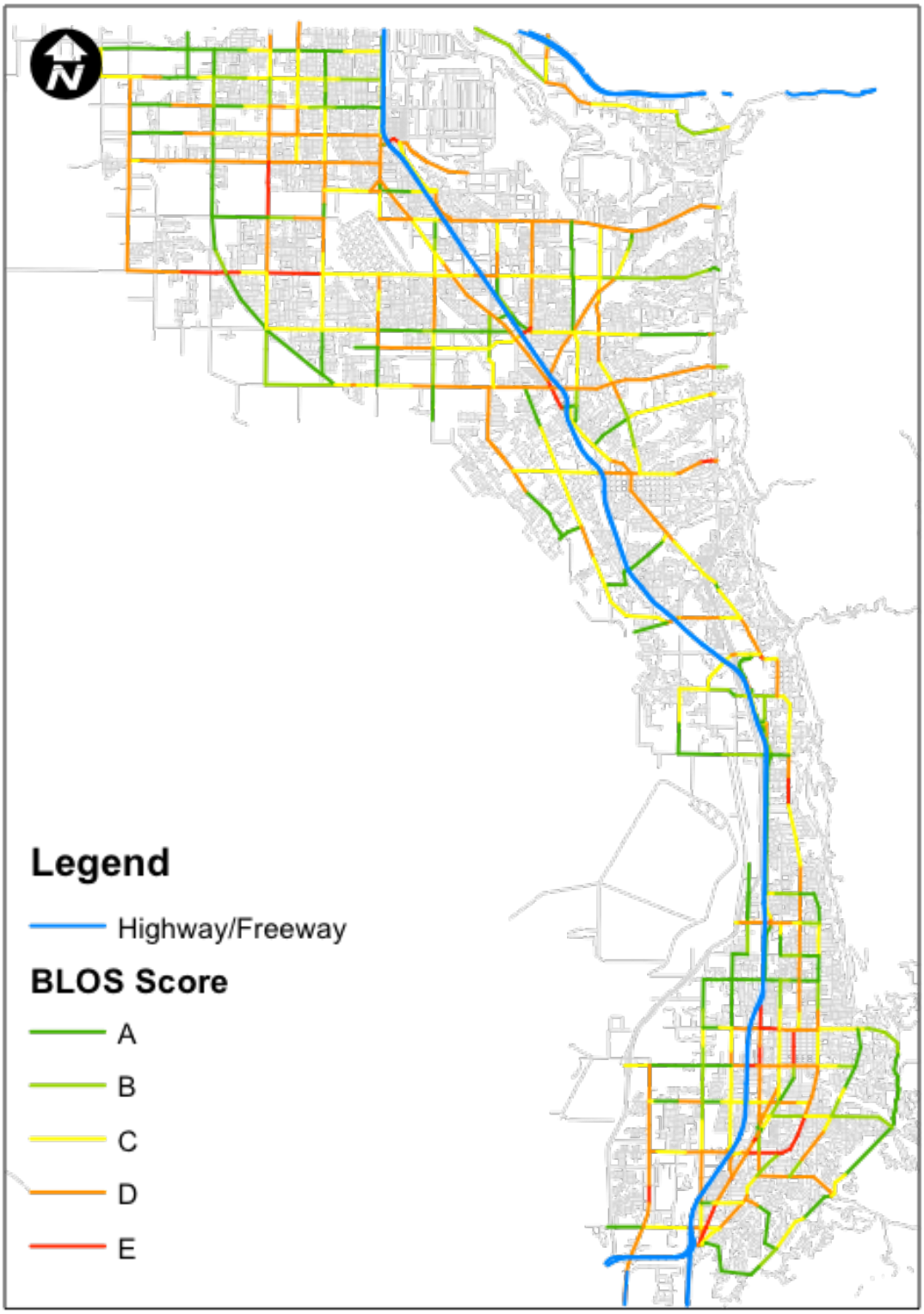


Legend

Highway/Freeway **BCI** A B C D E F

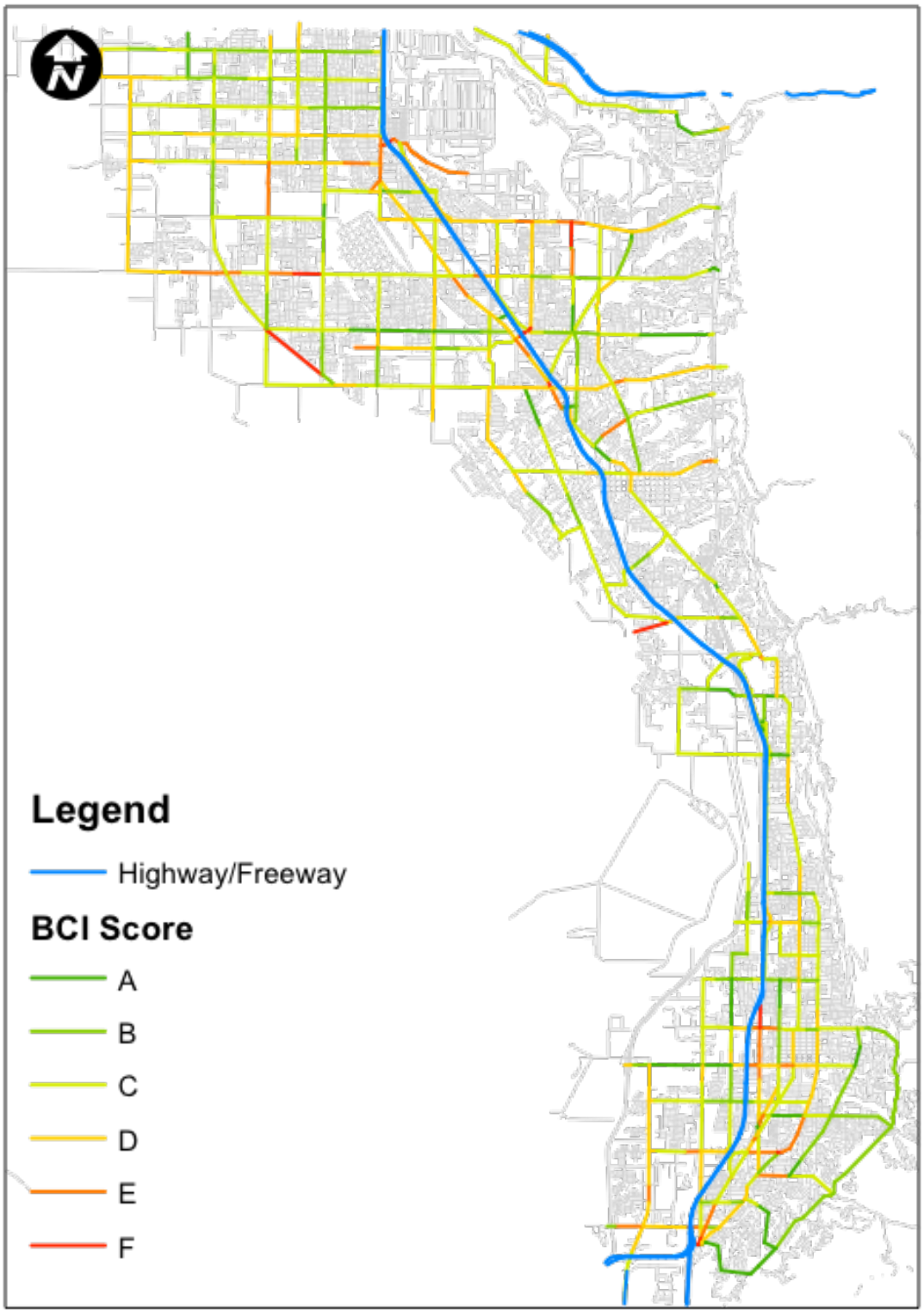
Created by: Kai Tohinaka

BLOS: Davis County



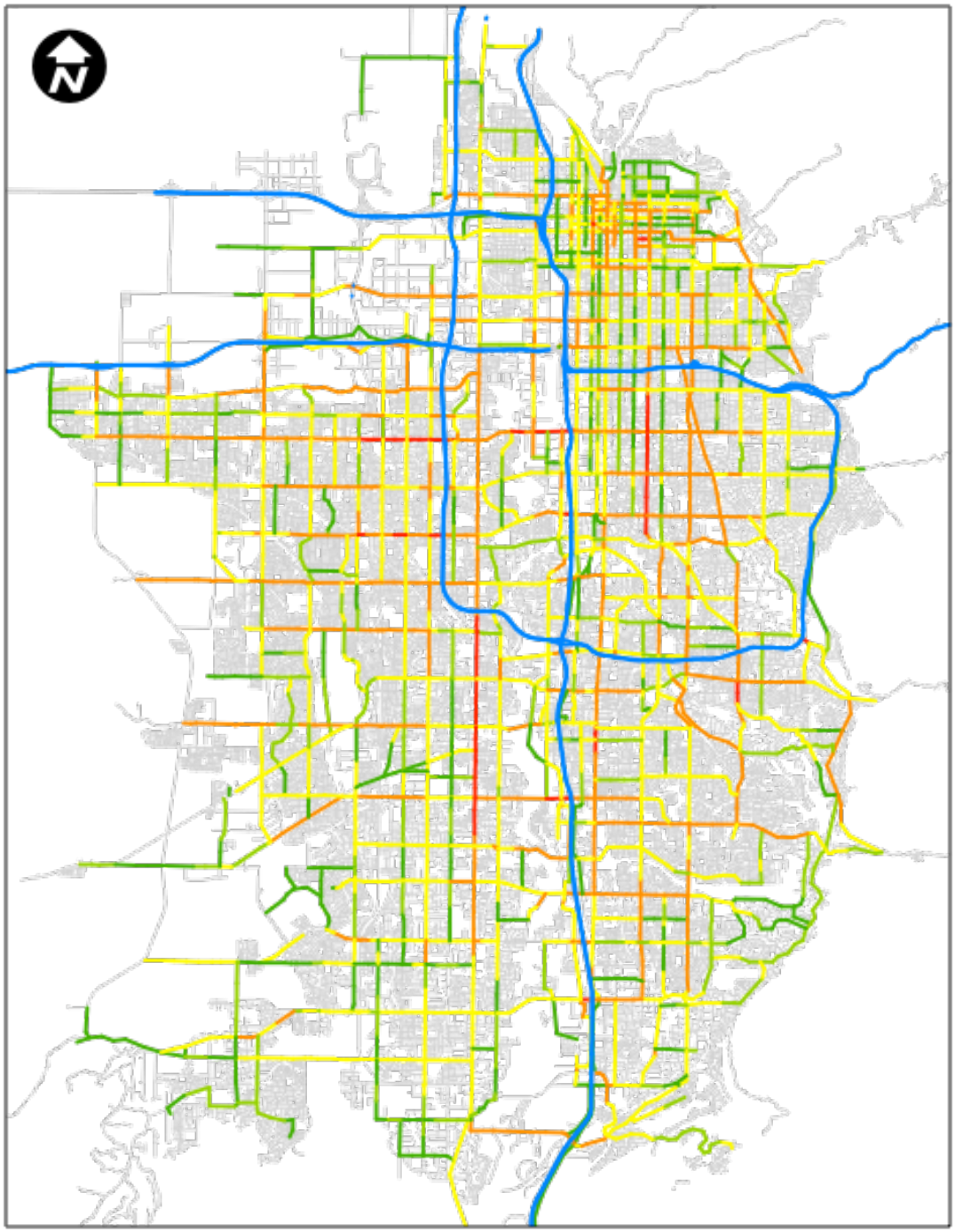
Created by: Kai Tohinaka

BCI: Davis County



Created by: Kai Tohinaka

BLOS: Salt Lake County

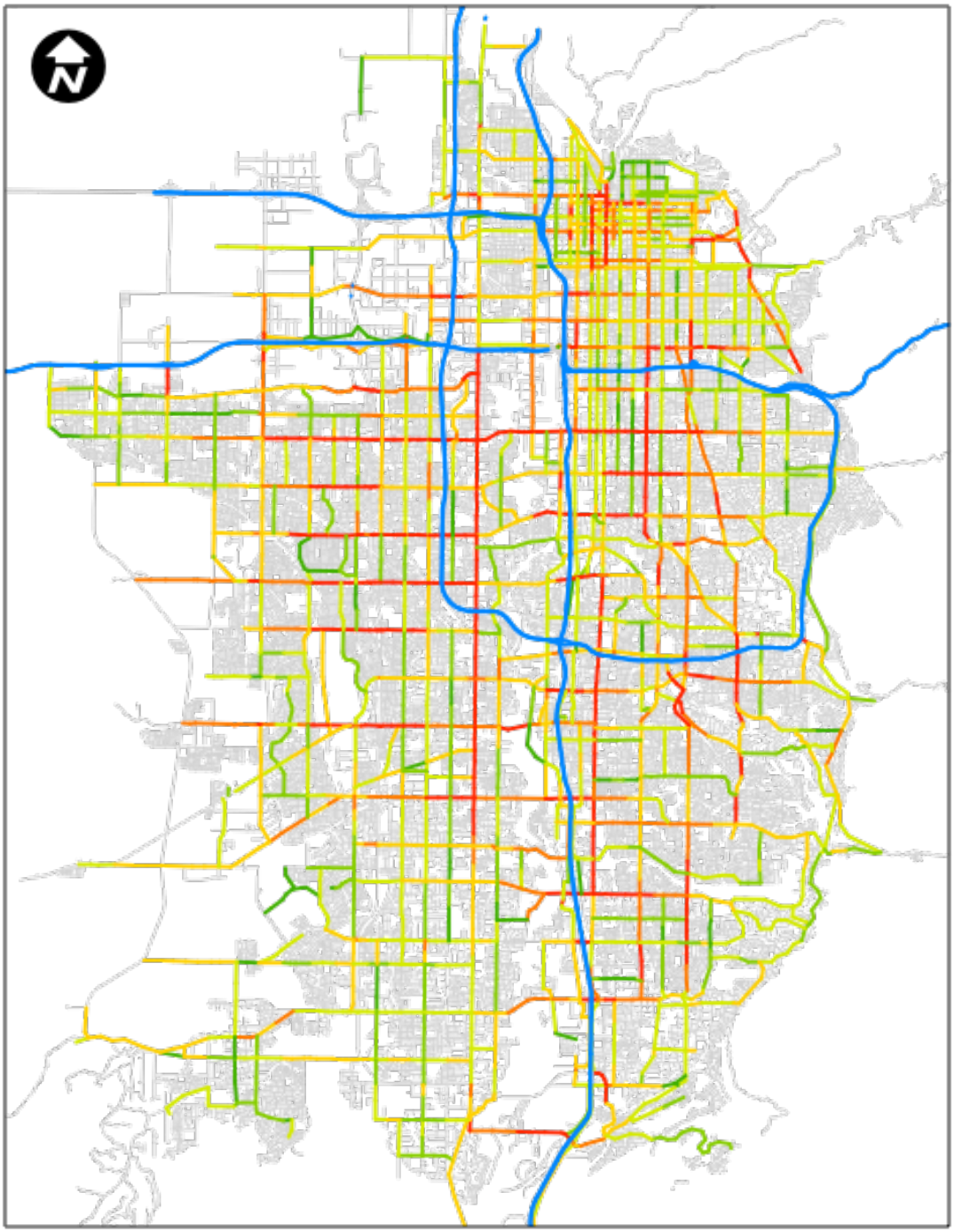


Legend

Highway/Freeway **BLOS Score** A B C D E

Created by: Kai Tohinaka

BCI: Salt Lake County



Legend

Highway/Freeway **BCI** A B C D E F

Created by: Kai Tohinaka

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